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Future of Fishing for a Vulnerable Atoll: Trends in Catch and Catch-Per-Unit-Effort in Tokelau's Domestic Marine Fisheries 1950–2016

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Tokelau is among the most vulnerable countries to climate change from both an environmental and economic perspective, whilst being highly dependent on marine resources for dietary nutrition. Industrial as well as small-scale fisheries are present in Tokelau's waters, with Tokelau itself only participating in small-scale fisheries. Industrial fisheries consist exclusively of foreign distant-water tuna fleets. This study aims to reconstruct and investigate the trends in the domestic small-scale marine fisheries catches, fishing effort, and catch-per-unit-effort (CPUE) from 1950 to 2016. We used kWdays as our metric of fishing effort or fishing capacity, estimated using length, motorization and type of fishing vessels. Total fishing effort was approximately 11,900 kWdays in 1950 and increased rapidly after the 1980s with the introduction of larger motorized vessels. Despite evolving fishing effort, catches taken in subsistence fisheries have been relatively consistent at approximately 370 $t{\cdot}year^{-1}$, resulting in a reduction of subsistence CPUE from 32.4 $kg{\cdot}kWdays^{-1}$ in 1950 to 2.6 $kg{\cdot}kWdays^{-1}$ in 2016. This trend is opposite to that of the artisanal fishery, where CPUE increased since the start of this fishery in 2003, from 1.7 $kg{\cdot}kWdays^{-1}$ to 2.6 $kg{\cdot}kWdays^{-1}$ in 2016. Tokelau's domestic catch is greatly underreported, with reconstructed domestic catch since 2010 being nearly four times larger than the data reported by the Food and Agriculture Organization (FAO) of the United Nations on behalf of Tokelau. The abundance of reef fishes are predicted to decrease while the abundance of pelagic fishes is expected to increase within Tokelau's waters due to climate change, likely further altering future fishing practices. The present CPUE analysis, combined with the forecasted effects of climate change, suggests that the domestic fisheries in Tokelau may be on an unsustainable path, highlighting food security concerns, despite the potential for growth in offshore fisheries.

Keywords: catch reconstruction, small-scale fisheries, Pacific Islands, climate change, CPUE (catch-per-unit-effort)

INTRODUCTION

The Pacific Island countries and territories (PICTs) are considered some of the most vulnerable countries to the projected impacts of climatic change (Cheung et al., 2013; Valmonte-Santos et al., 2016). Concurrently, PICTs are among the most marine resource dependent countries on earth (Bell et al., 2013). PICTs are generally characterized by small, relatively isolated island groups, with challenging topographies and largely infertile soils (Valmonte-Santos et al., 2016). Despite human dietary shifts, with a progression from traditional local food sources to imported and processed food (Charlton et al., 2016), local fisheries continue to play a vital role in PICT tradition and food security (Bell et al., 2009; Zeller et al., 2015; Valmonte-Santos et al., 2016). Among the PICT countries, atoll states that are characterized by low-lying islands are thought to be the most susceptible to changing climates (Woodroffe, 2008), with limited arable land, water supplies and space for habitation (Storlazzi et al., 2015). Both sea level rise and increasingly severe storm surges driven by climate change are predicted to reduce atoll island land area, therefore reducing the space for land-based food production and possible habitation (Storlazzi et al., 2015, 2018). Due to the reliance on marine resources in PICTs, there is a high potential for a resource crisis in the near future as climate change increasingly alters marine ecosystems.

The Pacific Island region includes Melanesian, Polynesian, and Micronesian island countries and territories (Charlton et al., 2016). Polynesian islands are volcanic areas or low-lying coral atolls resulting in resource poor land, and Tokelau, an overseas territory of New Zealand, is the smallest in the South Pacific (Chand et al., 2003; Barnett, 2010; Charlton et al., 2016). Tokelau consists entirely out of low-lying atolls and has the smallest population of the PICTs, with just 1500 inhabitants in 2016 (Barnett, 2010; Statistics New Zealand, 2016). The small inhabitable land mass of atolls limits their capacity to support a growing population, and the emigration of a portion of each family is these days recognized as a cultural norm (Hooper and Huntsman, 1973).

Unsurprisingly, Tokelau has a high traditional dependence on local fisheries (Toloa et al., 1991). A survey by Chapman et al. (2005) revealed almost all Tokelauan households participate in fishing, indicating the socio-economic value and importance of domestic fisheries to Tokelauan society. Despite this, Gillett (2009, 2016) noted that Tokelau's per capita consumption of fish is expected to be much lower than that of its neighbor states' Kiribati and Tuvalu. This is largely due to Tokelau's comparative affluence when compared to its neighboring states, with considerable financial support from New Zealand enabling islanders to import an estimated 99.4 $kg \cdot person^{-1} \cdot year^{-1}$ of alternative protein/food sources. Nonetheless, local demersal fisheries are expected to decrease in Tokelau under various climate change scenarios, although it's coral reefs are still expected to supply ~410 $kg \cdot person^{-1} \cdot year^{-1}$ of fish until 2020 (Bell et al., 2011b, 2015). Although Tokelau has relatively high food imports compared to other nearby islands, local reef fishes remain a vital component in the diet and tradition (Gillett, 2016).

Unlike demersal reef fishes, tunas and nearshore pelagic fishes are projected to increase in biomass within Tokelau's waters under modeled climate change scenarios (Bell et al., 2013; Dueri et al., 2016). Currently, the Exclusive Economic Zones (EEZ) of PICTs provide over 30% of the world's tuna catches (Chand et al., 2003). License fees for foreign distant-water fishing vessels have seen an increase of 400% in recent years, creating considerable economic gains for these countries (Bell et al., 2015). However, prospective gains are limited considering Tokelau's low human development index (HDI) of 0.75 and ongoing reliance upon industrial fisheries access fees for national income (Lam et al., 2016). Tokelau is a non-self-governing territory and relies heavily upon New Zealand for financial support (Carpenter, 2015). With a remote location and small land area, Tokelau has limited capacity to expand its economic base, including fish processing plants or fish sales, with its primary asset being foreign industrial fishing access fees within the EEZ (Carpenter, 2015). In the 2014/15 financial year, revenue from industrial fishing access agreements was just over 50% of government revenue (Gillett, 2016). Given Tokelau's current dependence on foreign aid and its desire for increased self-governance (Carpenter, 2015), understanding Tokelau's dependence on fisheries for economic and subsistence purposes is particularly important. Therefore, the present study reconstructed and investigated the trends in the domestic small-scale marine fisheries catches, fishing effort, and catch-per-unit-effort (CPUE) in Tokelau from 1950 to 2016. Our work is part of a publically available global fishing database[1] and builds on and updates a previous technical catch data reconstruction for Tokelau by Zylich et al. (2011).

MATERIALS AND METHODS

Exclusive Economic Zone (EEZ)

Tokelau is comprised of three atolls (Fakaofo, Nukunonu, and Atafu) separated by relatively shallow oceanic waters (van Pel, 1958), located between 8°–10° S and 171°–173° W (**Figure 1**). Nukunonu has approximately 5.5 km^2 land area and 109 km^2 lagoon coverage, making it the largest of the three atolls. Fakaofo is located to the southeast and is the second largest, with 3 km^2 of land area and 59 km^2 of lagoon coverage (Ono and Addison, 2009), followed by Atafu to the northwest with 2.5 km^2 of land and 19 km^2 of lagoon. The small population of Tokelau is split fairly evenly between the three atolls, and mainly concentrated in one area on each atoll (van Pel, 1958). The EEZ was declared in 1980, and according to the *Sea Around Us* spatial database (Pauly and Zeller, 2015) has a total area of slightly over 319,000 km^2 with a shelf area (to 200 m depth) and an Inshore Fishing Area (Chuenpagdee et al., 2006) of 279 km^2. According to the 2006 Millennium Coral Reef Mapping Project (Andréfouët et al., 2006), Tokelau has a total coral reef area of 204 km^2 and supports a coastal fish production of 610 $t \cdot year^{-1}$ (Bell et al., 2015).

[1] www.seaaroundus.org

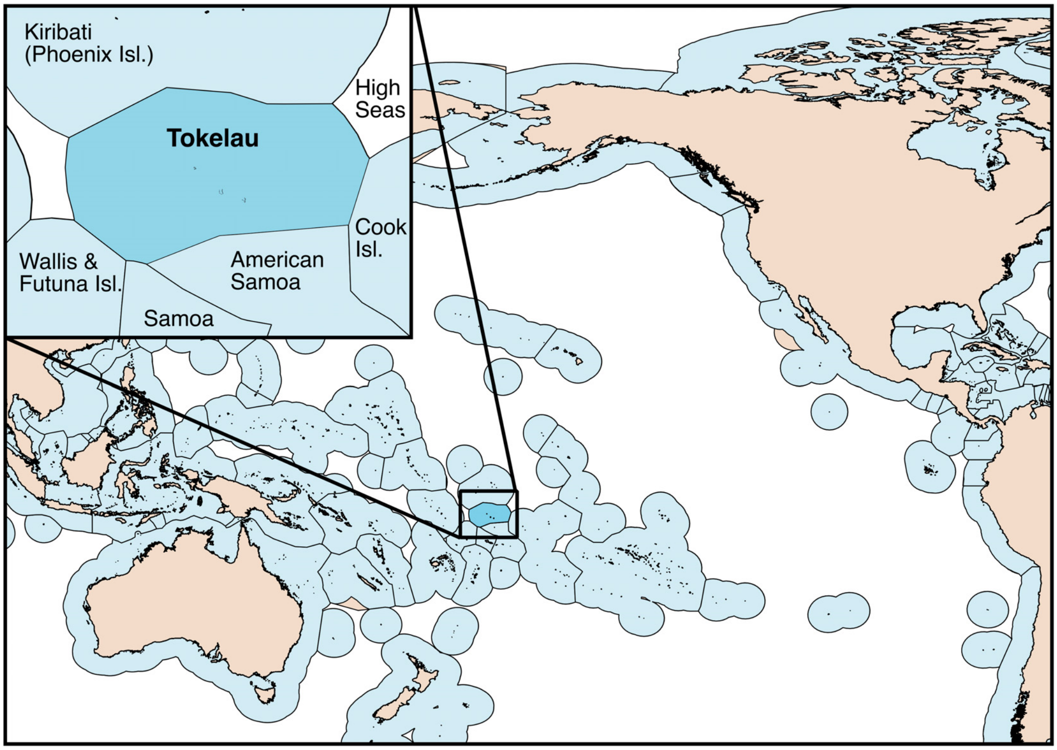

FIGURE 1 | The Exclusive Economic Zone (EEZ) of Tokelau, an overseas territory of New Zealand, and the neighboring EEZs of Kiribati (Phoenix Islands), Wallis and Futuna Islands (French overseas territory), Samoa, American Samoa (United States overseas territory), and the Cook Islands.

Catch Reconstruction

We estimated total domestic catch for Tokelau using a variety of sources and known catch amounts. For years where the estimated total catch was greater than the amount reported by the Food and Agriculture Organization of the United Nations (FAO) on behalf of Tokelau (FAO, 2018), we considered this portion as unreported catch. Several reports point to the historical absence of commercial fisheries operating domestically in Tokelau. Therefore, we assumed all domestic fishing in Tokelau in the early years was small-scale subsistence fishing, i.e., for self- and family-consumption, barter or community use (Zeller et al., 2016). Subsistence catches in Tokelau include fish and invertebrates that are landed for personal/family consumption, as gifts to send overseas, and for trade/sharing within the community. Zylich et al. (2011) derived a taxonomic breakdown for domestic catches based on van Pel (1958), Gillett and Toloa (1987), and Passfield (1998). Primary species caught domestically include flyingfish (*Cypselurus* spp.), parrotfish (Scaridae), jacks/trevallies (Carangidae), and Bigeye scad (*Selar crumenophthalmus*).

Artisanal fishing is defined as small-scale commercial fishing, and includes fish caught for sale at local markets or export (Zeller et al., 2016). As there are strong societal obligations to fulfill family and community subsistence needs before selling catch, no fishers are operating solely for commercial benefit (Vunisea, 2004). The first profit from fishing was reported in the 2006 census, where 7 households (2% of households) reported that they had made income from selling excess catch (Statistics New Zealand, 2007). In the previous census in 2001, no profits from fishing were reported (Statistics New Zealand, 2002). Based on these data, we assumed artisanal fishing began in 2003. By 2014, an estimated 10% of small-scale fishers' catch was sold for profit (Gillett, 2016). No discards are estimated for either subsistence or artisanal fisheries, as they are conservatively considered to produce minimal waste, assuming all catch is utilized for a purpose such as consumption or as bait. Baitfish was calculated by the amount of bait required for small-scale catch of near-shore tuna and other pelagic species (*Thunnus* spp., *Istiophorus platypterus*, *Sphyraena barracuda*, etc.) and Requiem sharks (Carcharhinidae) (Zylich et al., 2011). Since Tokelauan fishing primarily uses traditional methods utilizing less bait, a 32:1 ratio by Gillett (2011) was modified to 50% bait usage (64:1) and applied to the total small-scale tuna/pelagic target catch each year. Baitfish consists of an even proportion of species including but not limited to flying fish and bigeye scad throughout the entire time period.

As subsistence fishing is driven by dietary demand, we estimated yearly demand using a population time series and per capita consumption rates. For the early time period (1950–1980s), one trading ship brought Tokelau basic items such as flour, sugar, rice, kerosene, and tobacco three to four times per year (van Pel, 1958). It is assumed due to Tokelau's remote location that they were not receiving canned meats or fish at this time (Passfield, 1998). The preliminary catch reconstruction by Zylich et al. (2011) estimated a per capita seafood consumption rate of 255 kg·person^{-1}·year^{-1} based on the assumption that total animal protein was supplied by fresh seafood. Gillett (2009) estimated the 2007 total catch for Tokelau to be 250 tonnes based on estimates from several independent studies completed between 1977 and 1998, including Hooper (1985) and Passfield (1998). Using Gillett's estimate of 250 tonnes in 2007 and updated population data, we estimate a fresh seafood consumption/catch rate of 171.8 kg·person^{-1}·year^{-1} since 2007. As the availability of alternative protein sources has increased over the years due to increased food imports, and demand for fresh seafood has declined, we linearly interpolated between 255 kg·person^{-1}·year^{-1} in 1950 and 171.8 kg·person^{-1}·year^{-1} in 2007 (held constant after 2007) to create a complete time series of fresh seafood demand in Tokelau.

Prior to 1980, there were no known seafood exports from Tokelau. However, by 1998 an estimated 5.4 tonnes of catch were exported from Fakaofo, and approximately 16.2 tonnes exported for all of Tokelau (Passfield, 1998). Exports have been steadily increasing since, and an estimated 125 tonnes of catch were exported in 2007 due to increased transport between Tokelau and other PICTs, such as Samoa (Gillett, 2009). Between 2005 and 2014, fish exports were estimated to have doubled, increasing to 192 tonnes in 2014 (Gillett, 2016). Although the majority of exports from Tokelau are considered to originate from subsistence fisheries, consisting of gifts of frozen and dried fish for friends and family (Hooper, 1985; Passfield, 1998; Gillett, 2009), artisanal exports have also been increasing in proportion in recent years (Gillett, 2016).

Fishing Effort (Fishing Capacity)

Fishing effort was estimated as fishing capacity of the small-scale fishing fleet using the method developed by Greer (2014), rather than as a temporal measure of fishing effort only (e.g., trip duration) or gear specific effort (e.g., hook-hours or net kilometers). Fishing capacity was chosen in order to remain consistent with global fishing effort database developments by the *Sea Around Us*, to allow standardized comparisons between a wide range of fishing fleets, gears and fishing approaches around the world. A literature search was performed to identify information about Tokelau's small-scale fishing fleets from 1950 to 2016, including the number, size, motorization and type of fishing vessels, the number of fishing days and the gears utilized. Prior to the first vessel census in 2003 (Chapman et al., 2005), we estimated the number of vessels for 1950 to 2003 by applying the rate of household vessel ownership in 2003 (85%)(Chapman et al., 2005) to historical population data (Bertram and Watters, 1984; Statistics New Zealand, 1992, 1998, 2002). Vessel surveys were subsequently conducted in 2006, 2011 and 2016 during the national censuses (Statistics New Zealand, 2007, 2012, 2017). These surveys were used as anchor points and linear interpolation was used to create a continuous vessel time series from 2003 to 2016. We assumed a constant household fishing participation rate of 99% across the study period (Chapman et al., 2005). For the households participating in fishing without a vessel, we assumed half of the household members were engaging in shore- or reef-based fishing activities. The manpower of these shore-based fishers was converted to a vessel equivalency using a ratio of 5 shore fishers to one unmotorized canoe, the largest crew size of a traditional Tokelauan fishing group, for a conservative estimate of fishing effort (Hooper and Tinielu, 2012).

Vessels were assigned a length based on available information. Tokelauan fishers traditionally used 7–10 m outrigger canoes built from wooden planks (Chapman, 2004). These were used exclusively until the importation of 3–5 m motorized aluminum dinghies beginning in the 1980s, and which were wide-spread by the 1990s (Watt and Chapman, 1998; Chapman, 2004). By the first vessel survey in 2003, aluminum dinghies were the most common fishing vessel, comprising more than 80% of the fishing fleet (Chapman et al., 2005).

Fishing effort (kWdays) was then estimated by the product of the number of vessels, vessel engine power and days fished. Engine power (kW) was inferred from the length of motorized fishing vessels using the equation:

$$kW = 0.436^{*}L^{2.021}$$

where L is vessel length in meters (Anticamara et al., 2011). Aluminum dinghies were assigned a power of 9.11 kW, assuming vessels were an average length of 4.5 meters. Unmotorized vessels (i.e., wooden canoes) were assigned an engine equivalent value of 0.37 kW, assuming that one fisher can produce 74.57 watts of work over an eight-hour work day (Avallone et al., 2007). We assumed that fishers spent 121 days per year fishing based on an average household estimate of 14 person-hours per week fishing (Passfield, 1998).

Finally, a fishing sector was assigned to the estimated fishing effort. We assumed artisanal fishing began in 2003 as no profits from fishing were reported in 2001, with the first reported profit from fishing in the subsequent census in 2006 (Statistics New Zealand, 2002, 2007). By 2014, an estimated 10% of small-scale fishers' catch was sold for profit (Gillett, 2016), i.e., was deemed artisanal. We linearly interpolated between 0 in 2002 and 10% in 2014 to assign a proportion of fishing effort to the artisanal sector for 2003 to 2013. Subsequently, we assumed that the proportion of artisanal fishing effort has remained constant.

Catch Per Unit Effort (CPUE)

As catch volumes and effort alone often do not provide sufficient information on the status of a country's marine resources, we derived catch per unit effort (CPUE) to better describe the development of fishing in Tokelau. We recognize that CPUE data needs to be treated with caution, and can be problematic as an indicator of stock status or abundance (Maunder et al., 2006; Harley et al., 2011), but in the absence of better data on abundance or biomass of exploited domestic fisheries stocks in Tokelau, we use CPUE here as a minimal indicator. A CPUE time-series was computed from 1950 to 2016 for both the artisanal and subsistence sectors. In order to derive the CPUE per sector each year, we divided the reconstructed catch time-series for each fishing sector by the calculated standardized effort (capacity) for the same sector for 1950 to 2016.

RESULTS

Domestic Catches

The reconstructed domestic small-scale catches by Tokelau from 1950 to 2016 summed to 25,400 tonnes, and averaged between 300 and 450 t·year^{-1} (**Figure 2A**). Subsistence catches increased from around 380 tonnes in 1950 to a peak of 458 tonnes in 1960 (**Figure 2A**), when the population on the islands reached a maximum of approximately 1900 people. This was followed by a gradual decline in subsistence catches due to declining human population trends and increasing alternative protein imports, such as canned meats. Thus, subsistence demand decreased after 1960 to an all-time low of 295 tonnes in 1996, before increasing again due to increasing exports to 424 tonnes by 2016 (**Figure 2A**). Artisanal catches gradually increase from around 3 tonnes in 2003 to 47 tonnes in 2016 (**Figure 2A**).

The domestic small-scale catches as reconstructed here for Tokelau (**Figure 2A**) are dominated by reef and reef-associated species (*Cypselurus* spp., Scaridae, and *Selar crumenophthalmus*) (**Figure 2C**), and domestic catches are very small compared to the industrial distant-water fleet catches of large pelagic species (mainly tuna and billfishes) taken within the EEZ of Tokelau (**Figure 2B**). However, while these foreign fleet-dominated fisheries provide substantial foreign exchange earnings for Tokelau, they do not contribute directly to food security and locally consumed seafood.

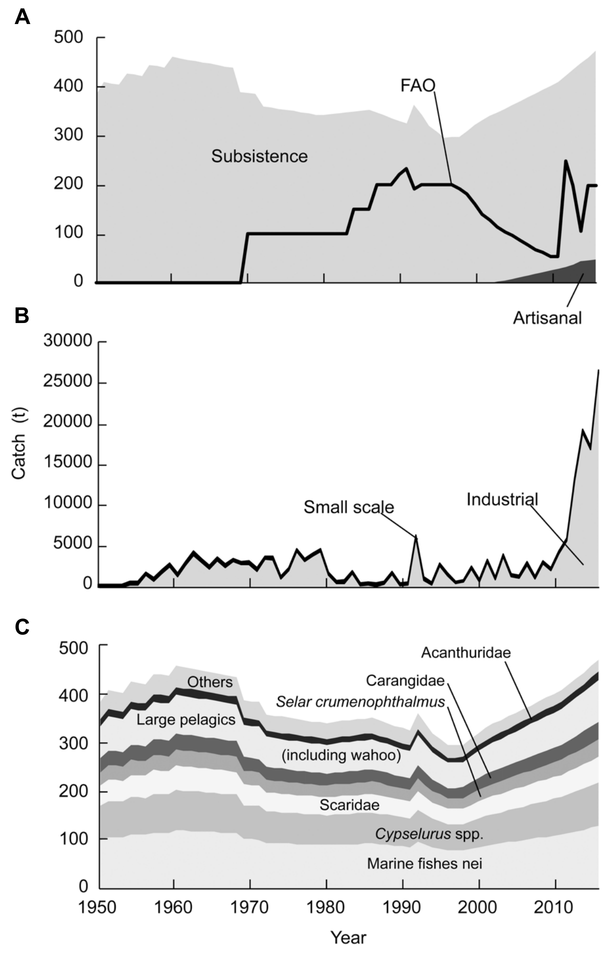

FIGURE 2 | Fisheries catches in Tokelau's EEZ, showing **(A)** domestic artisanal (small-scale commercial) and subsistence (small-scale non-commercial) catches for 1950–2016 as reconstructed here. The data reported to FAO by New Zealand on behalf of Tokelau are overlaid as a solid line; **(B)** total catches in the EEZ, consisting of both industrial distant-water fleet catches of large pelagics by foreign fleets (Le Manach et al., 2016) and domestic small-scale catches (as presented in **A**); and **(C)** taxonomic composition derived for Tokelau's small-scale (subsistence and artisanal) fisheries.

Fishing Effort (Fishing Capacity)

Total fishing effort estimated as fishing vessel capacity has grown from 11,900 kWdays in 1950 to 180,600 kWdays in 2016 (**Figure 3A**). Despite a gradual decrease in the total number of vessels from a maximum of 273 vessels in 1966 to 212 in 2016 (**Figure 3B**), fishing effort in terms of vessel capacity has

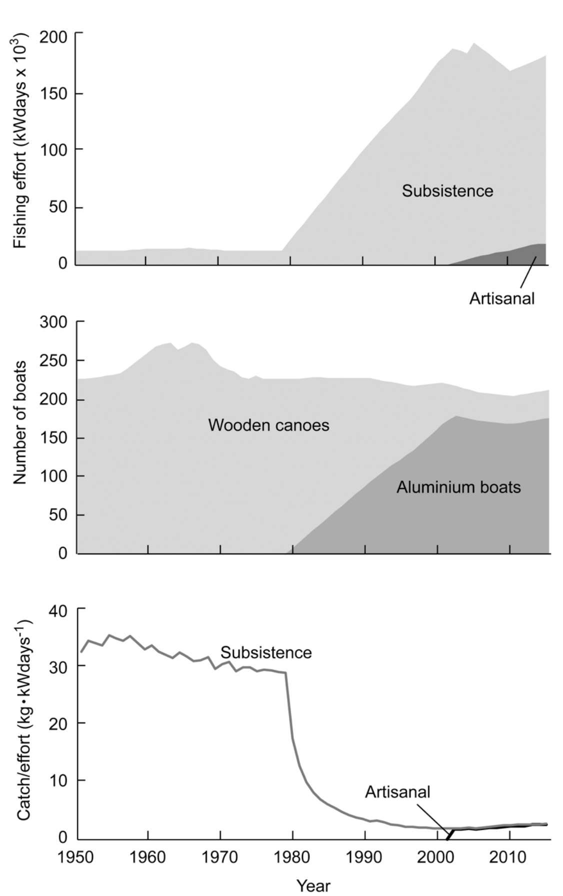

FIGURE 3 | Fishing effort for the domestic, small-scale fisheries in Tokelau as **(A)** fishing capacity (kWdays) by fishing sector; **(B)** total number of vessels by vessel type from 1950 to 2016; and **(C)** catch-per-unit-effort (CPUE) of Tokelau's domestic subsistence and artisanal fisheries from 1950 and 2003, respectively, until 2016.

increased rapidly since 1980. This effort (capacity) increase is entirely due to the introduction and wide-spread change of vessel type from canoes to motorized aluminum dinghies since 1980. Artisanal fishing began in 2003, with 1,565 kWdays of effort exerted, and has grown to 18,000 kWdays in recent years (**Figure 3A**).

Catch Per Unit Effort (CPUE)

The subsistence CPUE declined steadily from a peak of around 35 kg·kWdays^{-1} in the mid 1950s to approximately 29 kg·kWdays^{-1} in the late 1970s (**Figure 3C**). From 1970 to the mid-1990s the CPUE for the subsistence fisheries declined strongly, driven exclusively by the increased fishing capacity with the introduction of motorized aluminum vessels, followed by a stabilization at around 2.2 kg·kWdays^{-1} since 2000.

The artisanal CPUE increased from 1.7 kg·kWdays^{-1} at the start of the artisanal fishery in 2003 to a peak of 2.6 kg·kWdays^{-1} in 2015, while in 2016 the CPUE dropped slightly to 2.1 kg·kWdays^{-1} (**Figure 3C**).

DISCUSSION

Fresh fish has been a staple in the diet of the Tokelauan people for a long time (Passfield, 1998). This tradition is reflected in the reconstructed subsistence catch, which mirrors the changes in human population size on the islands, especially in earlier years (see **Figure 2A**). In more recent years, subsistence catches declined due to the declining human population and increases in alternative protein imports, with a minimum subsistence catch of 295t in 1996 (Gillett, 2016). Subsequently, increasing availability of motorized aluminum fishing boats in the late 1990s, allowing more rapid and easier movement between local fishing areas and islands led again to a rise in subsistence catches, generally driven by non-commercial exports to friends and family out-of country (Gillett, 2009). As we did not account for alternative factors (e.g., extreme weather events) potentially leading to inter-annual variations in catches, the fluctuations in the subsistence catch from 1950 to 2016 are due to human population changes, exports (gifts) and imports (alternative proteins).

Despite the ubiquitous participation in small-scale fishing in Tokelau, present day *per capita* fish consumption rates are not as high as in many neighboring atoll countries due to the availability of easy imports of non-fish proteins from New Zealand (Gillett, 2016). In the past, all or nearly all members of the community participated in the catching of small fishes and invertebrates on the reefs (often led by women), or poled for larger pelagic fishes on the outer edges of the reefs and in near-reef oceanic waters (Chapman, 1987; Toloa et al., 1991; Ono and Addison, 2009). With almost 100% of Tokelau's population actively engaged in fishing (Gillett, 2016; Weissbach, 2017), marine resources are arguably the most important socio-economic entity in Tokelau, and have been fundamental to the traditional Tokelau lifestyle (Toloa et al., 1991).

The introduction of new fishing technologies such as goggles, nets and spear guns has considerably increased the pressures on existing resources, with the most notable being the introduction of motorized aluminum boats in the 1980s. New technology has allowed for intensified pressure on and faster access to reef dwelling fishes, but has also allowed fishers to fish in near-reef oceanic waters targeting more pelagic fishes (Chapman, 2004). This intensification in fishing capacity is clearly evidenced here in the strong increase in estimated fishing effort (**Figure 3A**) despite little changes in the number of vessels (**Figure 3B**). Though capacity is an imperfect proxy for fishing effort, as it does not capture the true extent of fishing activities (Bell et al., 2017), we made the assumption of proportionality in absence of detailed information on fishing activities performed by small vessels with low mechanization. Tokelau's fisheries are highly integrated into society and driven by subsistence need. Despite this importance to the wellbeing of Tokelauan society, very little information is available about their fisheries. We encourage investigations by local and regional experts to develop and disseminate more knowledge and data from these data-poor fisheries.

This strong increase in fishing effort measure (in terms of fishing capacity) has led to strongly declining catch per unit effort rates (CPUE) during the same time period (**Figure 3C**). The changes in CPUE suggest that despite the new technologies the catch rates may not have improved but have rather declined (King, 1991; Toloa et al., 1991). It is important to note that although artisanal CPUE displayed an initially increasing trend, both the subsistence and artisanal CPUE show a period of rapid change, followed by what appears to be a settling of the catch rates. Single assessments sometimes skew measures of fish stock health, particularly CPUE studies as they often do not account for spatial information such spatial expansion in the area fished (Walters, 2003; Maunder et al., 2006). Domestic fishing in Tokelau may have slightly expanded beyond the atoll reef boundaries with the increased availability of motorized vessels, increasingly targeting more pelagic species. However, with the largest vessels being ~5 m open aluminum dinghies, fishing range is most likely still relatively restricted spatially, considering the full scale of the EEZ. Thus, due to the localized nature of Tokelau's domestic small-scale fisheries, we suggest that the potential growth in fished areas due to technological effort developments has not significantly impacted the CPUE measure (**Figure 3C**).

In the late 1980s to early 1990s, the average South Pacific CPUE for large pelagic species (e.g., *Katsuwonus pelamis* and *Thunnus albacares*) in the troll line fisheries was 5 kg·line^{-1}·h^{-1}, almost half that of Tokelau's 9 kg·line^{-1}·h^{-1} (Dalzell et al., 1996). Tokelau had the largest troll line CPUE rate range in the study and was assessed before the commencement of artisanal fishing and expansion of industrial fishing within the EEZ. Immediate neighbor American Samoa had an equivalent CPUE of 3 kg·line^{-1}·h^{-1} (Dalzell et al., 1996), declining to 1 kg·line^{-1}·h^{-1} by the early 2000s (Craig et al., 2008). The average CPUE for beach seines for Tokelau in the 1980s and 1990s was 14 kg·set^{-1}, similar to Cook Islands 13 kg·set^{-1} but low compared to the 131 kg·set^{-1} in Kiribati (Dalzell et al., 1996). Gillett and Tauati (2018) estimated annual small-scale tuna catches of 41 kg·person^{-1}·year^{-1}, matching our 2016 estimates. Tuna (*Thunnus albacares* and *T. obesus*) per capita catch rates have been increasing throughout the time series, peaking with 41 kg·person^{-1}·year^{-1} in 2016.

The most notable change in the general domestic fisheries system in Tokelau over the last 60+ years was the commencement of small-scale commercial (i.e., artisanal) fisheries. Artisanal fishing was non-existent prior to the early 2000s, mainly due to Tokelau's community structure, traditional community sharing culture, small population and isolation. Commercial small-scale fisheries have slowly been growing, in part due to new technological adaptations such as motorized aluminum dinghies and modernized fishing gear (Watt and Chapman, 1998; Chapman et al., 2005) as well as increased market access (Gillett, 2016). The expansion in fishing for profit in many Pacific Islands has created a divide in traditional fisheries management practices (King, 1991; Gillett and Tauati, 2018). In the past, each atoll in Tokelau self-governed their communities and the surrounding reefs (Toloa et al., 1991). Self-governing controlled by elders included everything from releasing live small fish, preventing harmful fishing methods and total fishing bans (lafu) in certain areas (Toloa et al., 1991). However, when fishing for profit becomes a prominent component of income for some members of a community, fishing bans and other restrictions can lead to strong opposition, often resulting in less effective management (Voyer et al., 2014; Gillett and Tauati, 2018). As artisanal fishing grows, Tokelau will be faced with the need to take more official and formal management steps such as licensing and restrictions on the taxonomic composition of catch (targeting), as well as gear use and place and time of permitted fishing (Walters, 2000; Allison and Ellis, 2001).

Over the same time period when these changes to domestic fisheries occurred, foreign fishing for large pelagics has also increased in Tokelau's EEZ waters (**Figure 2B**). This has the potential for future conflict between domestic and foreign tuna fishing, risking clashes between domestic food demand and foreign exchange earnings for Tokelau. With the ever-rising global demand for seafood, in particular tuna (Jacquet and Pauly, 2007), controlling and restricting the expansion of industrial fisheries within the Tokelau EEZ is vital. Tokelauans do not have the facilities to monitor large offshore fishing vessels, thus as a key stake-holder in the future of Tokelau's fisheries, New Zealand has the incentive for promoting sustainable fishing practices (Carpenter, 2015; Gillett, 2016). As a member of the Pacific Islands Forum Fisheries Agency (FFA) Tokelau receives support for ecosystem based management to avoid oceanic mismanagement (FFA, 2017), a main driver of the collapse of fisheries (Jacquet and Pauly, 2007).

Tokelau is particularly vulnerable to the effects of climate change due to its low atoll elevation, small landmass, geographic remoteness, food and water insecurity, as well as its dependence on financial support and food imports from New Zealand (Hastings, 2009; Lam et al., 2016; Valmonte-Santos et al., 2016). With the predicted climate variability, weather extremes, sea level rise and ocean warming, Tokelau can expect significant impacts on its natural ecosystems, economy and way of life (Diamond et al., 2012; Storlazzi et al., 2018). As Tokelau is a low-lying atoll, the most serious environmental impacts will almost certainly present as severe weather events, coastal erosion, land inundation and degradation, sea level rise driven flooding, larger shore-waves, and fresh water contamination (Connell, 2016; Barnett, 2017; Storlazzi et al., 2018). Even if Tokelau remains habitable in the long term, these effects are estimated to devastate the already extremely limited agriculture potential, as well as damage infrastructure, such as boats and docks, and decrease coastal fish stocks (Barnett, 2010; Storlazzi et al., 2015, 2018).

Given that domestic fishing in Tokelau is currently heavily reef based or reef-associated, a main concern of climate change is the accelerated rate of ocean warming with combined effects leading to an overall decline in reef fishes (Cheung et al., 2013; Barnett, 2017; Cheng et al., 2017). Overall, the effects of likely increasing fishing pressures from both the small- and large-scale fisheries, combined with climate change will likely have a negative effect on the marine resources of Tokelau, although Tokelau's EEZ is thought to benefit from climate change driven increases in some pelagic species availability due to a rise in El Niño systems (Bell et al., 2011a). Emigration is already common in Tokelau, mainly for economic reasons, and currently assists in maintaining a semblance of sustainability (Hooper and Huntsman, 1973). Despite the desire for independence, Tokelau's reliance on New Zealand for alternative protein imports, financial assistance, and emigration will likely grow as climate change challenges local terrestrial and marine resources. Although the potential surge in pelagic fishes can lead to more foreign exchange earnings (Bell et al., 2013), domestic catches will most likely remain low. Realistically, these economic gains provide no direct benefit to the traditional Tokelauan lifestyle and do not directly increase local food security. The increasing dependence on imports will decrease traditional practices, and likely the health of the Tokelauan people, as activity declines and consumption of canned foods increases (Valmonte-Santos et al., 2016).

AUTHOR CONTRIBUTIONS

RW and ARC: catch reconstruction and synthesis, drafted the manuscript. AC: effort reconstruction and synthesis, drafted the manuscript. MP, DP, and DZ: expertise and guidance of reconstruction and data management, drafted and edited the manuscript.

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