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Long-Term Fishing Catch and Effort Trends in the Republic of the Marshall Islands, With Emphasis on the Small-Scale Sectors

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Small-scale fishing has been an important element of the livelihood and food security in Pacific island countries throughout history; however, such catches have been under-reported in the official fisheries data. Here, we reconstruct the total domestic catches and fishing effort of the Republic of the Marshall Islands (RMI) by fishing sectors for 1950–2017. Reconstructed total catches were estimated to be 27% higher than the data officially reported by the Food and Agriculture Organization (FAO) of the United Nations on behalf of the RMI. Catches of the truly domestic, but export-oriented, industrial tuna sector accounted for 84% of the total catch, dominating catches since the early 2000s. The subsistence component contributed 74% of total small-scale catches, of which 92% was deemed unreported. The remaining 26% of small-scale catches were artisanal, i.e., small-scale commercial, in nature, of which 45% was deemed unreported. Trends suggested steady growth in small-scale catches from 1,100 t·year^{-1} in the early 1950s to a relatively stable level of 4,500 t·year^{-1} since the 1990s. However, over the 2009–2017 period, there was a gradual reduction of 2% per year in subsistence fishing, which was paralleled by a concomitant increase in artisanal catches of 3% per year. This gradual shift from predominantly non-commercial to commercial small-scale fisheries may be related to efforts to commercialize small-scale fisheries in the past decades. Small-scale fishing effort increased approximately 13-fold from the early 1980s to the late 2000s, stabilizing at around 401,000 kWdays since then, while catch-per-unit-of-effort (CPUE) displayed an inverse pattern, declining eightfold between the 1980s and 1990s, and stabilizing around 15 kg·kWdays^{-1} in recent decades. These findings may assist sustainable coastal fisheries management in the RMI, which is particularly important given the increasing impacts of climate change on local stocks.

Keywords: catch reconstruction, artisanal fisheries, subsistence fisheries, fishing effort, fisheries catch data, catch-per-unit-of-effort, Pacific islands, shark catches

INTRODUCTION

For millennia, small-scale fisheries have been playing a prominent role in food security and livelihoods for Pacific island countries (Johannes, 1978). Despite the importance of these fisheries, their contribution to national catches has been largely underestimated in the official catch statistics in most Pacific island countries and territories (Zeller et al., 2015). This under-representation exemplifies the historical marginalization of small-scale sectors (Pauly, 2006), which is an issue that, thankfully is slowly being addressed (FAO, 2015; Pauly and Charles, 2015). The lack of comprehensive and representative data on small-scale fisheries is often attributed to the challenges in monitoring artisanal and subsistence catches, as these are generally landed at a large number of spatially dispersed landings sites that are hard to monitor. The poor accounting is also often justified by the incorrect assumption that catches from these sectors are not substantial in volume or economic importance (Zeller et al., 2006, 2015) and thus not a high government priority. However, reconstructions of the small-scale catches showed that these components account for approximately 70% of the total domestic catches in Pacific small-island countries, and are crucial for the food security and livelihood of local populations (Zeller et al., 2015). In the past, traditional societal rules provided some degree of management and control of fishing effort though spatial and temporal fishing restrictions as well as rotation of fishing grounds (Johannes, 1978). However, the transition to centralized government systems in many of these countries, and the advent of increased commercialization of small-scale fisheries has weakened these traditional control mechanisms, often without the implementation of adequate new approaches to effective management (Beger et al., 2008).

The seafood provided by small-scale fisheries constitutes a major food security resource and is critical for good nutrition in most coastal developing countries (Golden et al., 2016). In the Republic of the Marshall Islands (RMI, **Figure 1**), fishing is an important activity (Beger et al., 2008). Similar to other Pacific islands, annual consumption of fish in the RMI is disproportionally high compared to other coastal countries (Bell et al., 2009; Kronen et al., 2010). Recognizing the importance of the fisheries sector, the Marshall Islands government made strategic investments in the 1990s to develop the fishing industry (both small- and large-scale), aiming to improve the rural economy and meet the domestic demand for seafood in the main population centers on Majuro and Ebeye Islands (Smith, 1992; Gillett, 2010). Following the decrease in copra "dried coconut meat" exports, a former stable export, the government also focused on increasing foreign exchange earnings from fisheries resources by signing foreign fishing access agreements with several countries, including South Korea, Japan, and Taiwan, for offshore tuna fishing in the RMI Exclusive Economic Zone (EEZ) waters (Beger et al., 2008). These agreements accounted for the majority of foreign revenues generated by the large-scale fishing industry, and with further development of foreign industrial fishing, the contribution of this sector to the national economy increased from 7 to 27% of the gross domestic product (GDP) between the 1990s and the late 2000s (FAO/FishCode, 2005; FAO, 2009).

Fisheries in the RMI exploit both coastal, reef-associated stocks and offshore pelagic stocks. Coastal catches are attributed exclusively to the truly domestic small-scale fisheries (Beger et al., 2008), which include both the subsistence sector, i.e., non-commercial catches primarily for home and family consumption; and the artisanal sector, i.e., small-scale catches primarily destined for commercial sale (Zeller et al., 2016). Subsistence fishing is a very common activity in the RMI, particularly on the outer atolls where the availability of jobs and associated cash income for goods and services is more restricted (Beger et al., 2008; FAO, 2009; Gillett, 2016). Artisanal fisheries are important for supplying seafood to the main urban centers, and artisanal operations are more common on the main atolls of Majuro, Kwajalein, and Arno (**Figure 1**). The contribution of coastal fisheries to basic nutrition and food security is substantial in the RMI, with fish caught locally by the small-scale fisheries (both artisanal and subsistence) contributing to an overall consumption rate of around 82 kg per person per year (Gillett, 2016).

The offshore large-scale, industrial fisheries targeting pelagic species are conducted by both a domestic-flagged, locally-based fleet and larger foreign fleets from several countries that fish under different agreements (MIMRA, 2017). These industrial fleets operating in the EEZ of the RMI target mainly tunas, including skipjack (*Katsuwonus pelamis*), albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), and yellowfin tuna (*Thunnus albacares*) as well as other large pelagics such as billfishes. These fisheries also targeted pelagic sharks (Bromhead et al., 2012); however, this activity became illegal with the declaration of a shark-fishing ban in 2011 (Cramp et al., 2018).

The domestic industrial fleet started consistent operations relatively recently, as the first report of annual domestic catches of approximately 7,600 t occurred in 2000. Since then, the Marshallese-flagged industrial fleet has grown considerably, increasing from four long-liners and five purse-seiners in 2007 to 31 long-liners and 10 purse-seiners in 2017 (WCPFC, 2018b). However, part of this fleet (long-liners in particular) consists of chartered vessels operated by a foreign-owned (Hong Kong Chinese) joint-venture fishing company based in Majuro (MIMRA, 2017; WCPFC, 2017). True beneficial ownership of these fishing operations, including unknown levels of revenues, may still be largely foreign owned.

The foreign industrial fleets operating in the RMI EEZ include vessels flagged to various Asian countries, the United States, and other Pacific island countries. In 2017, 257 foreign-flagged vessels were licensed to fish in the RMI (MIMRA, 2017). These fleets consist mainly of purse-seine and long-line vessels, although a Japanese pole-and-line fishing fleet also operates in the country. Joint-venture fishing companies (Chinese and Taiwanese) also operate a Marshall Islands-based foreign fleet, with the largest of these ventures operating 24 vessels from China and the Federates States of Micronesia (MIMRA, 2017). The fishing access fees paid by foreign countries to fish in the EEZ waters of many Pacific island countries provide important foreign exchange earnings for the host countries in whose waters they operate. The access fees

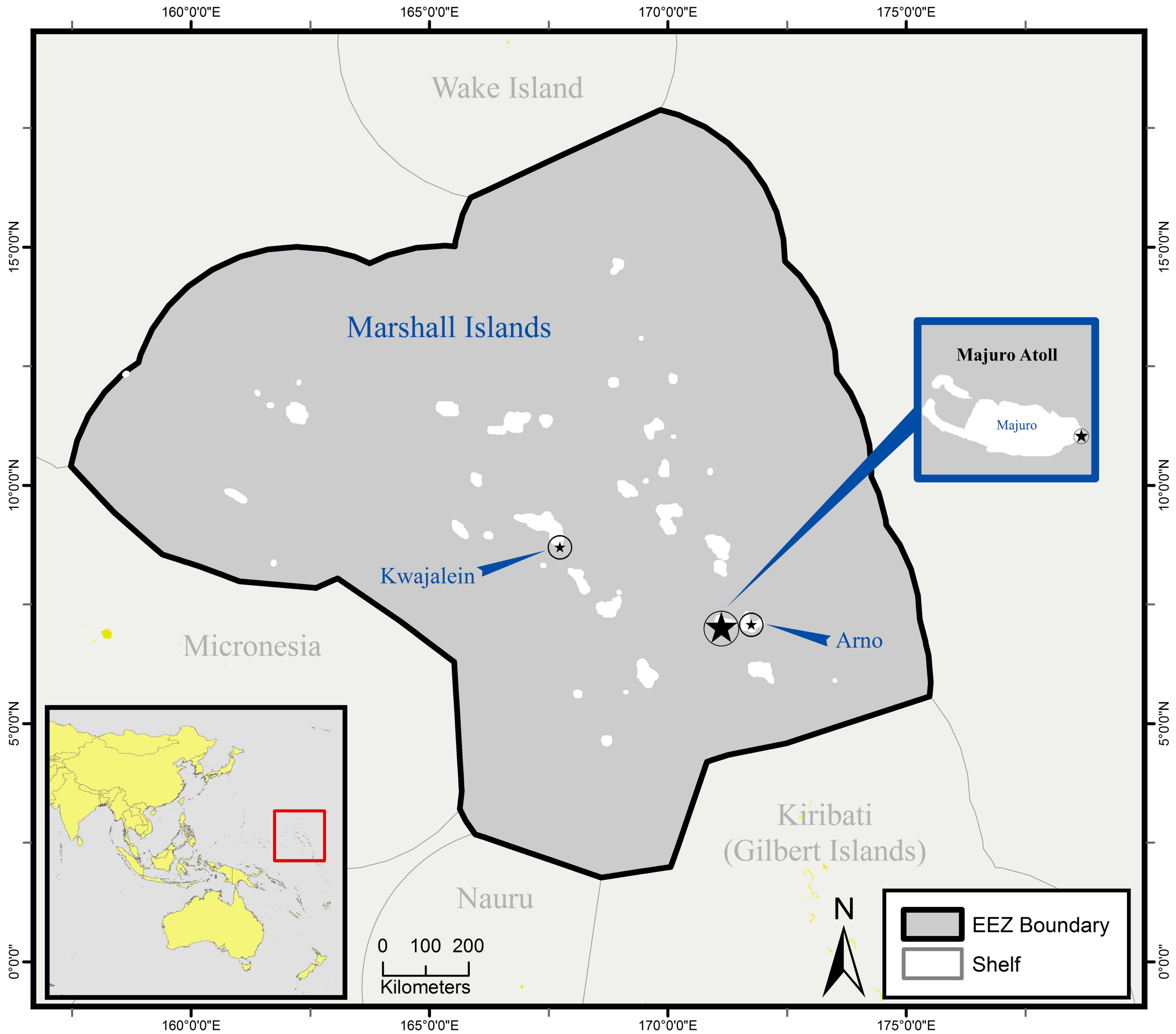

FIGURE 1 | The Exclusive Economic Zone of the Republic of the Marshall Islands, and the most populated atolls.

paid by foreign countries to the RMI generated approximately US$34.1 million in 2017, which were generated through fishing rights, vessel day scheme revenue, license fees, transshipment fees, fishing violation fines, boat chartering fees, and fishery observer fees (MIMRA, 2017).

Fisheries of coral reef species for the global aquarium trade also occur in the RMI, with operations occurring from Majuro and Ebeye. In 2014, exports were estimated to generate approximately US$50,000 (Gillett, 2016); with approximately 103,500 individual fish and 15,200 individual invertebrates exported in 2017 (MIMRA, 2017). The industry exports over 50 different species of fish from a variety of families, including Pomacanthidae, Chaetodontidae, Acanthuridae, Labridae, Serranidae, Pomacentridae, Balistidae, Cirrhitidae, Gobiidae, and Blenniidae (Dalzell et al., 1996), with the most common species being the flame angel, *Centropyge loriculus* (Gillett, 2011). As catches for the aquarium trade are not for human consumption, and constitute relatively small amounts in terms of tonnage, these were not addressed here.

The importance of the fishing sectors for the economic and food security well-being of the RMI is clear. However, the national government faces a challenge balancing both the economic benefits of the offshore industrial tuna fishery and the crucial food security benefits of sustainable use of marine resources for the local population (FAO, 2009). In this context, better understanding the historical patterns and trends over time in total catches by each fishing sector, but especially by the under-represented small-scale sectors, is crucial to enable informed and effective management decisions (Pauly, 1997). Therefore, the objective of our study was to derive a time series of the total catches taken by the domestic fisheries, i.e., large- and small-scale domestic fisheries in the RMI from

1950 to 2017, with particular emphasis on the small-scale sectors. We applied a structured catch reconstruction approach based on the principles described in Zeller et al. (2016), which uses publicly available sources of secondary data and information to complement the officially reported catch statistics, as reported to the global community by the Food and Agriculture Organization (FAO) of the United Nations on behalf of the RMI. We further combined the reconstructed catches with reconstructed estimates of fishing capacity and effort to present time series estimates of catch-per-unit-of-effort (CPUE) by fishing sector for 1950–2017.

MATERIALS AND METHODS

A preliminarily reconstruction of the marine fisheries catches of the Marshall Islands (**Figure 1**) was conducted by Haas et al. (2014) for the 1950–2010 period. Here, we build on the original reconstruction to account for most recent data and new information that has become available and update the time series to the most recent year (data year 2017) of data officially reported by the FAO on behalf of the RMI. We obtained the reported baseline catch data from the FAO[1], which reports fisheries landings on behalf of each country (Garibaldi, 2012). Using secondary data and information from Gillett (2016), and following the reconstruction principles in Zeller et al. (2016), we estimated domestic demand for locally-sourced seafood, and compared this to the non-exported portion of FAO landings, which are deemed to remain in-country for domestic consumption. We considered the difference between these two components to represent the unreported catch of small-scale fisheries in the RMI (see **Table 1** for a summary of the reconstructions).

We classified the catches of pelagic species generally captured by the Marshallese-flagged industrial tuna fisheries and reported by the Western and Central Pacific Fisheries Commission (WCPFC) as the reported component of the domestic industrial fisheries, consisting mostly of tunas, billfishes, and pelagic sharks. Catches taken by foreign fleets fishing in the RMI EEZ were not included in the domestic catches presented here, but were addressed globally in Coulter et al. (2020).

Small-Scale Sectors

Small-scale catches were attributed to one of two sectors: artisanal or subsistence, although we recognize that there is often overlap between these two sectors (Zeller et al., 2016). Within the *Sea Around Us* global databases, small-scale fisheries are spatially limited to the *Inshore Fishing Area*, which is defined as the waters within 50 km from inhabited shores or waters up to 200 m depth, whichever comes first (Chuenpagdee et al., 2006; Chuenpagdee and Pauly, 2008; Zeller et al., 2016). Artisanal fisheries catches are defined as primarily for commercial sale, while subsistence fisheries have self- and family-consumption or local barter as primary purpose, rather than commercial sale (Zeller et al., 2007, 2016; Gillett, 2011).

[1] www.fao.org/fishery/statistics/collections/en

TABLE 1 | Anchor points and sources used to estimate time series of catches by sector in the Republic of Marshall Islands in 1950–2017.

Sector	Year	Catch (t)	Source
Artisanal	1950	0	Assumption
	1946–2008	–	Linear interpolation
	2009	1,230	Derived from Gillett (2016)
	2010–2013	–	Linear interpolation
	2014	1,500	Derived from Gillett (2016)
	2015–2017	–	Linear extrapolation
Subsistence*	1950	1,017	Assumption
	1951–2008	–	Linear interpolation
	2009	3,275	Derived from Gillett (2016)
	2010–2013		Linear interpolation
	2014	3,000	Derived from Gillett (2016)
	2015–2017	–	Linear extrapolation
Recreational**	1958	0	Assumption
	1959–1987	–	Linear interpolation
	1988	4.9	Anon (1988)
	1989–1997	–	Linear interpolation
	1998	6	Whitelaw (2003)
	1999–2017	–	Linear extrapolation
Industrial***	1950–2017	–	FAO catch data

**Subsistence catches estimated based on per capita population fish consumption (see methods). **Recreational catches estimated based on the reported number of tourists visiting the Republic of Marshall Islands (see methods). ***The retained bycatch was estimated and added to account for the unreported component of the catch (see methods).*

Artisanal Catches

As core data anchor points (Zeller et al., 2016) for artisanal catches, we used estimates of the artisanal catch component as a proportion of the total coastal catch, which were available for 2007 (Gillett, 2009) and 2014 (Gillett, 2016). To derive the artisanal catch component for each year between 2007 (25%) and 2014 (33%), we interpolated the proportion of artisanal to total coastal catch between these anchor points. To estimate the total volume of artisanal catch in each year, we applied the derived artisanal proportions to the independent estimates of total coastal catch of 4,510 t in 2009 and 4,500 t in 2014 (Gillett, 2016). We used these estimated values to interpolate the artisanal catch values for the years between 2009 (1,230 t) and 2014 (1,500 t). We assumed that artisanal fishing (i.e., small-scale commercial) began, or re-started after WWII with an assumed 0 metric tons of artisanal catch in 1945. We then interpolated the artisanal catch values linearly between 0 metric tons in 1945 and the artisanal catch anchor point in 2009. For 2015–2017, we linearly extrapolated the 2009–2014 time series of artisanal catch to 2017. We recognize that this increases the uncertainty around these estimates, and these data points will require revision once future data and information becomes available.

Prior to 2004, we considered the unreported component of the reconstructed artisanal catch to be the difference between the total reconstructed artisanal catch (as estimated above) and the official catches reported to FAO as the non-specific category "marine fishes nei." After 2004, tonnages for "marine fishes nei" reported to FAO outweighed the total reconstructed artisanal catches, thus for years after 2004, all reconstructed artisanal catches were deemed reported. Surplus "marine fishes nei" data reported to FAO after 2004 were accounted for under the reconstructed subsistence fishing catches (see below).

Separately to the reconstruction of general artisanal catches, we also reconstructed catches of trochus (sea snail) and sea cucumber, as these taxa were not typically consumed locally and were targeted for export (Gillett, 2016). Data reported to FAO by the RMI list trochus catches between 1987 and 2004. We thus conservatively assumed that the trochus target fishery started in 1987, and for 1987–2004, we considered total trochus catch to be equal to the amount reported to the FAO. For the 2005–2017 years, when trochus was no longer reported to FAO but the fishery was known to continue (Gillett, 2016), we approximated the catches by interpolating between the value of 0.25 t reported to the FAO in 2004 and the estimate of 9 t reported for 2014 in Gillett (2016). For 2015–2017, we held the 2014 amount constant.

The sea cucumber fishery is also an export fishery that developed in the RMI in response to demand by Asian markets in the 1990s. In order to reconstruct total sea cucumber catches, we used export data for dried, processed sea cucumber exports reported by the FAO commodity trade and production data (FAO, 2019), which present data for 1996, 1997, 2003, 2007, and 2011–2016. A national report suggested that commercial fishing of sea cucumber also occurred between 2002 and 2005 (MIMRA, 2014). Based on this information, we assumed sea cucumber fisheries to have started in 1996, when exports were first reported, but stop after 1997 until 2002, in 2003 exports restarted and continued until 2017. Based on the time series, we converted the exported amount of frozen, dried, and salted sea cucumbers (FAO, 2019) to wet weight on the basis of an average of 90% weight lost in processing (MIMRA, 2014).

Subsistence Catches

We obtained subsistence catch anchor points of 3,275 t for 2009 and of 3,000 t for 2014 from Gillett (2016), by subtracting the artisanal catch estimates from the total coastal fisheries catch estimates for these years. To derive a complete time series of subsistence catch estimates, we converted these point estimates of subsistence catch into *per capita* subsistence catch rates for 2009 (62.6 kg per person) and 2014 (56.7 kg per person) by using the total population data for the RMI in these years (World Bank 2019[2]). These *per capita* subsistence catch rates were then interpolated between 2009 and 2014, and extrapolated linearly to 2017, using the 2009–2014 time series trend. The increase in access to alternative food sources in urban centers of Pacific island countries in recent decades has been responsible for a progressive decrease in use of locally-sourced seafood (Thow et al., 2011). Due to the absence of information for earlier periods, we conservatively assumed an annual *per capita* subsistence catch rate of 78.2 kg per person for 1950, i.e., 25% higher than in 2009. Thus, we assumed that the RMI population relied more on subsistence fishing in the earlier decades than in more recent years. We then interpolated the catch rate linearly between 1950 and 2009. To derive the total subsistence catch, we multiplied the derived annual *per capita* subsistence catch rates by the corresponding human population of the RMI for 1950–2017. Population data were obtained from World Bank data for 2011–2017 and from census information by the RMI Office of Planning and Statistics[3] from 1950 and from 1960–2010. We interpolated the population between 1950 and 1960 to complete the time series.

Given the nature of the data reported by the RMI to the FAO, for 1950–2004, all subsistence catch was deemed unreported, as the reconstructed artisanal catch (see section "Artisanal Catches") outweighed the reported catch of coastal taxa for these early years. Furthermore, data collection and reporting in the earlier years was more likely to only address commercial fisheries. After 2004, the reported component of subsistence catch was assumed to equal the remaining FAO catch data for "marine fishes nei" attributed to the small-scale sector, after the reported artisanal catch was accounted for (see section "Artisanal Catches"). Unreported subsistence catch was assumed to be the difference between the assumed reported subsistence catch and the total estimated subsistence catch for 2004–2017.

Recreational Catches

Recreational fishing in the RMI is an activity conducted mainly by international tourists. To reconstruct catches for this sector, we assumed recreational fishing to be proportional to the number of tourists visiting the country annually. Data on annual visitors were obtained from the Economic Policy, Planning, and Statistic Office of the RMI[4]. We assumed recreational tourism fishing to have only started with the phasing out and subsequent ceasing of nuclear testing by the United States in the RMI in 1958. Thus, we interpolated from an assumed zero fishing-tourists in 1958 to the first year of the reported total number of tourists time series (1995–2017[4]) to obtain a complete time series estimate for tourists. We used the recreational catch estimates of 4.9 metric tons in 1988 and 6 metric tons in 1998 (Anon, 1988; Whitelaw, 2003) as catch data anchor points and derived recreational catch rates per tourist for 1988 and 1998. We interpolated the derived recreational catch rates for the years between 1988 and 1998, and held the rates constant before 1988 and after 1998, before applying them to the time series of tourists for 1958–2017. While our anchor points report demersal fish catches to some extent, these studies were mainly focused on pelagic fish (Anon, 1988; Whitelaw, 2003); therefore, our estimates of recreational catches are likely conservative and underestimate recreational catches of demersal species.

Taxonomic Composition

We used information from Dalzell et al. (1996) and Gillett (2011) to derive a taxonomic composition of the estimated combined (artisanal plus subsistence) small-scale catches. This breakdown was applied to the reported catches labeled as "marine fishes nei" in the FAO data, and to the unreported subsistence and artisanal catches estimated here.

[2]https://data.worldbank.org/country/marshall-islands?view=chart

[3]https://rmi.prism.spc.int/index.php

[4]https://rmi.prism.spc.int/

Recent improvements in the taxonomic classification of invertebrates in the data reported by the FAO on behalf of the RMI were taken into account in the reconstruction, which allowed for a more accurate taxonomic breakdown of the catches of trochus (Trochidae), spiny lobsters (Palinuridae), and mud crabs (Portunidae), reported as artisanal catches. The catches of sea cucumbers were disaggregated to species level based on the taxonomic breakdown described in MIMRA (2017).

Large-Scale Sector

The industrial fleet in the RMI targets mainly large tuna species; however, other large pelagic species such as sharks and billfishes are also captured, either as incidental bycatch or targeted catch (Bromhead et al., 2012). Often, because billfishes are valuable and exportable, they are thought to be reported in the data supplied to the FAO, while many other species are not. We attributed all reported catches of tunas and other large pelagic species such as billfishes and pelagic sharks to the large-scale sector within the RMI EEZ by flag state of the fishing entity. To estimate the amount of unreported retained bycatch taken by the domestic industrial fleets in the RMI, we combined the total catches of the four major tuna species, skipjack (*K. pelamis*), albacore (*T. alalunga*), bigeye (*T. obesus*), and yellowfin tuna (*T. albacares*) reported by the Marshallese-flagged fleet and allocated the total by gear type, maintaining the percentages of the catch composition from the total catch. Based on information in Gillett (2011), we attributed 75% of the reported catch of the four species combined to the purse-seine fleet and 25% to the long-line fleet. Using anchor points for under-reporting by gear type from Gillett (2009), we increased all purse-seine catches by 5%, and all long-line catches by 30%, and treated these catches as unreported, retained bycatch.

The taxonomic composition of the estimated unreported bycatch was derived using data in MIMRA (2009), which details the non-target species caught in the locally-based offshore fleet (**Table 2**). The top 15 non-target species by weight for the year 2008 were identified by the percentage of the non-tuna catch (MIMRA, 2009), and these percentages were applied to the unreported catch time series. We recognize that this does not take into account potential inter-annual variability in composition or consistent trends over time of unreported catches, or the contributions of minor taxa to unreported catches.

Because the catches of foreign fleets are either landed in foreign ports (mainly in Asia or the United States) or are transshipped in Majuro (FAO, 2009) for direct export shipping, these are assumed to be accounted for in the FAO fisheries landing data reported by these foreign flag countries, and are therefore not included in this study. However, a recent study reported substantial under-reporting of industrial tuna fisheries due to transshipment activities in the Western and Central Pacific (Anon, 2019), which highlights the need for a comprehensive reconstruction of unreported catches of global tuna fisheries (Coulter et al., 2020).

Discards

The large-scale tuna fisheries in the Pacific Ocean were considered to have an overall average discard rate of 10.8% for 1950–2010 (Schiller, 2014; Coulter et al., 2020). We estimated the total volume of catches that were likely discarded by the domestic industrial fisheries by applying this discard rate to the reconstructed landed catch by this sector. We reconstructed the taxonomic composition of discards by applying the taxonomic composition of discards by the entire tuna fishery in the Pacific region to our estimates (Schiller, 2014). We recognize that this does not take into account inter-annual variability or time series trends in the discarding behaviors or patterns. Particularly for sharks, our estimates of discards represent a conservative estimate, as the implementation of the prohibition of retention of sharks in 2011 may have influenced the discard patterns.

TABLE 2 | Non-tuna catch composition of pelagic species in the large-scale sector of the Republic of the Marshall Islands. Based on MIMRA (2009).

Common name	Taxon name	% Non-tuna catch
Blue marlin	*Makaira mazara*	7.9
Black marlin	*Istiompax indica*	0.3
Striped marlin	*Kajikia audax*	4.2
Swordfish	*Xiphias gladius*	1.0
Other billfishes	Istiophoridae	1.3
Blue shark	*Prionace glauca*	10.5
Mako shark	*Isurus oxyrinchus*	1.1
Oceanic whitetip shark	*Carcharhinus longimanus*	5.0
Silky shark	*Carcharhinus falciformis*	21.9
Other sharks/rays	Elasmobranchii	36.9
Rainbow runner	*Elegatis bipinnulata*	1.7
Wahoo	*Acanthocybium solandri*	3.5
Common dolphinfish	*Coryphaena hippurus*	2.7
Triggerfishes	Balistidae	0.3
Opah	*Lampris guttatus*	1.7

Percent composition is with reference to non-target industrial catch.

Fishing Effort and CPUE

For RMI fishing effort, we used fishing effort data from the global database of reconstructed fishing effort developed by the *Sea Around Us* and available online[5]. The effort data presented in this database were reconstructed according to the methodology described in Greer (2014). Briefly, this methodology utilizes the number and average engine power of vessels ($kW \cdot boat^{-1}$) and estimates of the number of days fished by each fleet/gear sector to estimate fishing effort/capacity by each fishing sector, as a measure of energy spent fishing in a determined period of time (kWdays). Effort estimates for small-scale fisheries accounted for the fact that some fisheries may not utilize vessels, i.e., fishing from shore and reef gleaning. These estimates also accounted for the increase in use of motorized vessels, reported to occur from the 1980s onward (Chapman, 2004). The increase in vessel motorization in the small-scale fisheries in each year was estimated based on country data on the proportion of motorized small-scale vessels in key regions of the country in 2007 (Pinca et al., 2009). These proportions were interpolated between 1980, when motorization of vessels started, and the 2007 anchor point. We

[5]www.seaaroundus.org/data/#/fishing-entity-effort/132

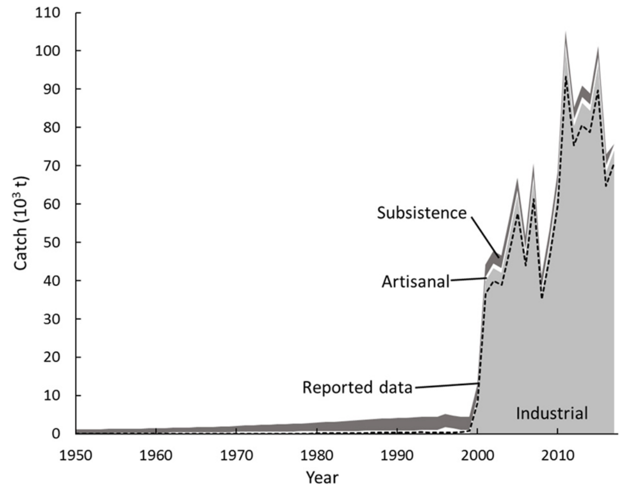

FIGURE 2 | Total reconstructed catch by fishing sector for the Republic of the Marshall Islands (RMI) for the time period 1950–2017, with data reported by FAO on behalf of the RMI overlaid as a dashed line.

then linearly extrapolated the time series to 2017. Information and data on the fishing fleets, as well as changes over time were sourced from the scientific and gray literature (Greer, 2014) and were used as anchor points to reconstruct a time series of likely effort for each fishing sector in the RMI between 1950 and 2017.

We derived a time series of CPUE by combining our reconstructed catches with the reconstructed effort data by fishing sector over the entire time period of the study.

RESULTS

Total reconstructed catches for the domestic fisheries of the RMI were estimated at slightly over 1.3 million t between 1950 and 2017, which is 27% higher than the 1.037 million t reported by the FAO on behalf of the RMI for the same time period (**Figure 2**). Overall, the domestic industrial sector targeting large pelagic species, which only became important after 2000 (**Figure 2**), dominated total catches and accounted for over 84% of total reconstructed catches, while small-scale sectors accounted for around 16% (**Figure 2**). Following the beginning of domestic industrial fishing operations in the early 2000s, the catches in this fishery initially increased steeply, followed by a period of catches around 49,000 t·year^{-1} between 2001 and 2009. After 2010, catches increased to around 82,000 t·year^{-1} (**Figure 2**). Overall, these fisheries discarded a total of 119,000 t between 2000 and 2017, with an average of around 6,600 t of fish discarded per year (**Figure 3A**).

The domestic industrial fishing effort began in the early 1990s with intermittent attempts to establish a long-line domestic fishery. However, consistent fishing effort started in 2000 reaching about 2.9 million kWdays in 2005 (**Figure 3B**). After 2006, fishing effort increased at a rate of 13% year^{-1}, peaking in 2011 with a total effort estimated at just over 5.4 million kWdays,

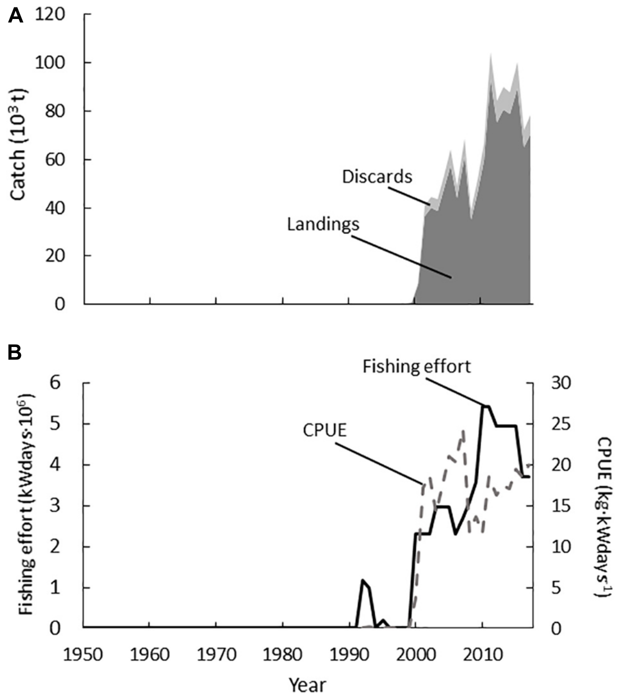

FIGURE 3 | Reconstructed catch and effort for the industrial fishing sector for the Republic of the Marshall Islands for the time period 1950–2017. **(A)** Catch separated by landed catch (landings) and discarded catch. **(B)** Fishing effort and catch-per-unit-of-effort (CPUE).

before dropping slightly to 3.7 million kWdays by 2017. Due to the patterns of catch and fishing effort over time, the mean CPUE of the domestic industrial fishery from 2001 to 2017 was 17.5 kg·kWdays^{-1} (**Figure 3B**).

Due to the predominance of the export-oriented industrial fisheries for large pelagics, fishes from the family Scombridae comprised the largest portion (77%) of the total reconstructed catch (**Figure 4A**), with skipjack tuna (*K. pelamis*) accounting for 57% of the total. Sharks also represented a large component of the industrial catch, with a reconstructed total of just under 83,000 t over the entire time period, and around 6,000 t·year^{-1} in recent years. Silky (*Carcharhinus falciformis*) and blue sharks (*Prionacea glauca*) were the two species that contributed the most to catches of sharks, accounting for approximately 29 and 14% of the volume of sharks caught, equaling around 1,740 and 840 t·year^{-1} in recent years, respectively. These catches were largely due to bycatch in the domestic industrial fishery. Major discards consisted of both target and non-target species, including blue sharks (37%), skipjack tuna (19%), silky sharks (5%), and yellowfin tuna (4%), while other fish and other sharks accounted for 36 and 5%, respectively.

When considering the small-scale sectors only, the reconstruction suggested that actual total small-scale catches were around 3.9 times higher than the assumed small-scale catches reported by the FAO on behalf of the RMI (**Figure 5**). The small-scale artisanal and subsistence sectors accounted for 4 and 12% of the total reconstructed catches, respectively

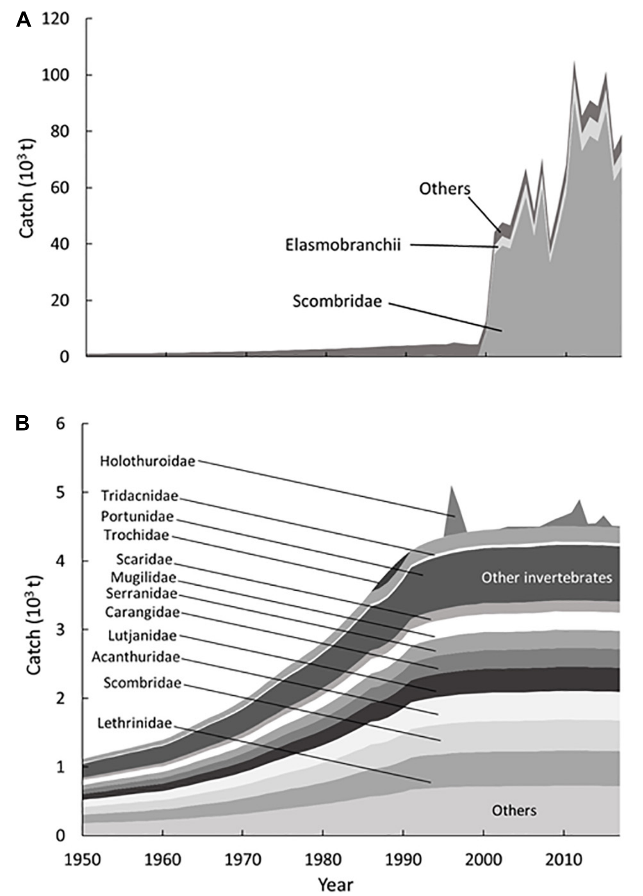

FIGURE 4 | Taxonomic composition of: **(A)** the total reconstructed catches for the Republic of the Marshall Islands for the time period 1950–2017 by major taxonomic categories ("Others" represents 54 additional taxonomic categories, largely from the small-scale sectors) and **(B)** the small-scale sectors only (artisanal, subsistence and recreational). "Others" comprise 18 additional taxa (including 14 families) with minor contributions to the catch.

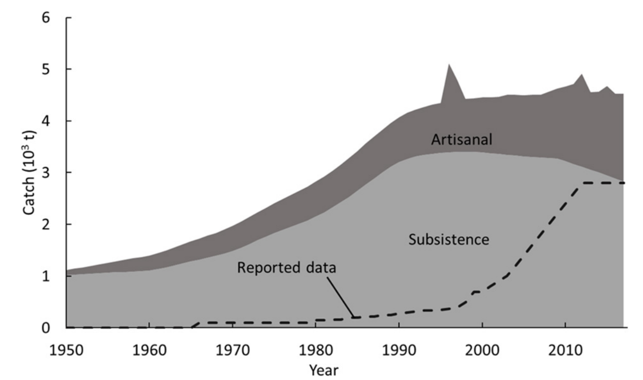

FIGURE 5 | Reconstructed catches for the small-scale sectors of the Republic of the Marshall Islands (RMI) for the time period 1950–2017. Data reported by the FAO on behalf of RMI, overlaid as a dashed line, represent assumed reported landings excluding the reported large pelagic tuna, billfish, and shark catches, which were targeted specifically by the large-scale industrial sector. Due to the low values, recreational catches are not visible in the graph.

(**Figure 5**). Looking at the small-scale sector individually, the artisanal and subsistence sectors accounted for 26 and 74% of the catches over the entire period, respectively. Estimated unreported artisanal catches accounted for over 45% of artisanal catches, while unreported subsistence catches accounted for substantially more, at around 92% of subsistence catches. Catches by the recreational fishing sector accounted for at least 233 t (0.1% of small-scale catches) over the time period, with an average catch of approximately 4 metric tons per year. Our reconstructed recreational catch estimate is likely conservative, particularly for demersal reef species, as catches of this group were likely underrepresented by the anchor points available.

Overall, small-scale catches increased steadily from around 1,100 t·year^{-1} in 1950 to the early 1990s, after which catches seemed to level off at around 4,500 t·year^{-1} (**Figure 5**). A few smaller peaks of up to 5,100 t·year^{-1} occurred in 1996, 2011, and 2014 due to the artisanal boom-and-bust sea cucumber (Holothuroidea) fisheries (**Figures 4B**, **5**). Artisanal sector catches increased steadily over time, reaching approximately 1,700 t·year^{-1} in 2017. Catches of the subsistence sector increased from 1,000 t·year^{-1} in 1950 to 3,200 t·year^{-1} in 1990, and remained relatively constant at just over 3,300 t·year^{-1} between 1990 and 2008. From 2009 onward, reconstructed catches by this sector declined by 2% per year, on average. This apparent decline by the subsistence sector was compensated by an average increase of 3% per year in catches by the artisanal fishing sector (**Figure 5**).

Catches of the small-scale sector consisted of approximately 75% finfishes and 25% invertebrates (**Figure 4B**). The predominant fish species in the small-scale catches were the humpback red snapper (*Lutjanus gibbus*) and humpnose big-eye bream (*Monotaxis grandoculis*), each accounting for around 5% of small-scale catches in recent years. Skipjack (*K. pelamis*) and yellowfin tuna (*T. albacares*) were also important components of the small-scale fisheries, and combined accounted for around 8% of the catches over the last 10 years. For invertebrates, elongate giant clam (*Tridacna maxima*), bear paw clam (*Hippopus hippopus*), and scaly or flute giant clam (*Tridacna squamosa*) together accounted for around 35% of the invertebrate catch (**Figure 4B**).

The overall fishing effort of the small-scale sectors was relatively low until the end of the 1970s, at around 14,300 kWdays. Due to the introduction of motorization and growth in the number of boats (**Figure 6A**), small-scale fishing effort increased from just under 31,000 kWdays in the early 1980s to around 490,000 kWdays in 2017 (**Figure 6B**). Throughout this time period, the fishing effort per vessel increased almost three times more for the artisanal sector (14–196 kWdays·vessel^{-1}) when compared to the subsistence sector (7–42 kWdays·vessel^{-1}, **Figure 6A**). Due to this pattern of fishing effort over time, the CPUE of the small-scale sector remained constant at around 122 kg·kWdays^{-1} between 1950 and 1980. This period was followed by a sharp decline of eightfold in the CPUE, with stabilization of the mean CPUE around 15 kg·kWdays^{-1}

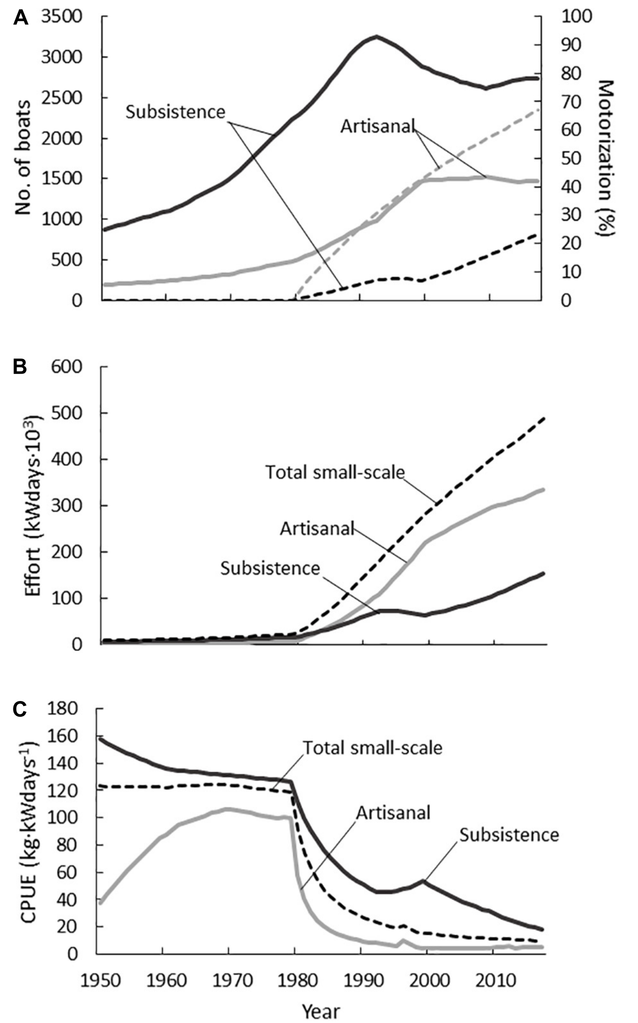

FIGURE 6 | Fishing effort for the small-scale fisheries sectors in the Republic of the Marshall Islands for 1950–2017 as reconstructed based on Greer (2014). **(A)** Number of boats (solid lines) and percentage of motorized boats (dashed lines). **(B)** Fishing effort. **(C)** Catch-per-unit-of-effort (CPUE).

from the 1990s to 2017 (**Figure 6C**). In this period, the mean CPUE of artisanal and subsistence fishing were around 6 and 38 kg·kWdays^{-1}, respectively.

DISCUSSION

The reconstructed total domestic catches for the RMI were estimated to be 27% higher than the landings reported by the FAO on behalf of the country. However, analysis of the reconstructed catches of the small-scale coastal fisheries sectors alone revealed that reconstructed catches for these sectors were 3.9 times the data reported by FAO. The differences were largely due to the under-representation of small-scale artisanal and particularly small-scale subsistence sectors in the data collection, estimation, and reporting system, which is a common issue for small-scale fisheries in many countries (Zeller et al., 2015). To address this data gap for the RMI, our reconstruction focused on improving the estimates of total domestic small-scale catches back to 1950, with a particular focus on separating artisanal and subsistence fisheries, as these are the most important sectors for the food security of the local population (Charlton et al., 2016).

Subsistence fisheries accounted for 74% of the small-scale catches since the 1950s, highlighting the exceptional food security importance of this sector for the local population (FAO, 2015; Pauly and Charles, 2015; Zeller et al., 2015). Despite representing the largest percentage of total small-scale catches, the subsistence fishery appears to be the most underrepresented sector in the official statistics, with unreported subsistence catches seemingly accounting for 68% of total small-scale catches. The small-scale fisheries sectors are the major source of fresh seafood for the population of the RMI, and are considered by the government as strategic for the development of the domestic economy, particularly outside the main population centers (Gillett, 2010). While this recognition is important, the magnitude of the unreported catches revealed here suggests that the actual degree of socio-economic, and especially food security, importance of these two small-scale sectors to the country likely continues to be under-estimated. This highlights the necessity of ongoing improvements in the monitoring and estimation of data for small-scale fisheries in the RMI, which is also the case elsewhere throughout the Pacific (Zeller et al., 2015).

Trends in small-scale fisheries in the RMI have changed over time, with a progressive increase in catches from 1950 to the early 1990s, followed by stabilization of total small-scale catches at around 4,500 t·year^{-1} (**Figure 5**). This can be partially explained by a stabilization in the domestic demand for fish as a consequence of a gradual reduction in the *per capita* consumption of fresh seafood, which itself was partially offset by the positive human population growth. Several studies have reported shifts in the diet of the population of many Pacific island countries, including the RMI, with reduction of consumption of local products such as fresh fish, and replacement with imported industrialized food such as canned meats (Cortes et al., 2001; Gittelsohn et al., 2003; Ahlgren et al., 2014; Charlton et al., 2016). This shift has been more pronounced in the main population centers and has been associated with the increase in nutritional health issues and chronic diseases in the RMI (Ahlgren et al., 2014).

Despite the relative stability of small-scale fisheries catches over the last two decades, trends for the specific sectors differ. Since the late 2000s, declining non-commercial subsistence catches have been partially compensated by a steady increase in catches by the commercially focused artisanal sector. In the 1990s, the government established a program to purchase fish from the outer atolls for sale in the major urban centers (Gillett, 2016; MIMRA, 2017). This increased commercialization of part of the small-scale catches from the outer atolls could explain the observed sectoral trend differences. This substitution suggests a gradual increase in the importance of a cash-based economy among small-scale fishers and increased commercialization of seafood otherwise caught for subsistence purposes. Despite accounting for a smaller proportion of the total small-scale catches since 2010, the subsistence sector still accounts for approximately 65% of total small-scale catches in the RMI. This contribution is comparable to other small-island countries and territories in the Pacific, where in 2010 the subsistence sector accounted for 69%, on average, to total domestic catches when export-oriented industrial tuna fisheries were not considered (Zeller et al., 2015). This contribution is likely to be much higher in the outer atolls of the RMI, where most households are involved in subsistence fisheries and the supply of imported food is more limited than in the urban centers (FAO, 2009).

The effective fishing effort (fishing power or capacity) for the small-scale sectors increased 13-fold between 1980 and 2010, mainly due to the wide-spread introduction of motorization and new boats in the fisheries (Chapman, 2004). The effect of motorization was more evident in the artisanal fleet, which despite having a smaller number of boats when compared to the subsistence sector, was the main driver of the increase in fishing effort by the small-scale fisheries in the RMI (**Figure 6**). A similar pattern of sharp increase in fishing effort by artisanal fisheries due to the introduction of motorized vessels is also evident in other developing countries, including small-island countries in the region (e.g., White et al., 2018).

Our reconstruction suggests that the increase in fishing capacity resulted in a strong decline in CPUE of the small-scale fisheries from 120 kg·kWdays^{-1} in 1980 to 15 kg·kWdays^{-1} by the 2010s, before stabilizing. This decline in CPUE, driven by the increased fishing power of motorized vessels, suggests that the underlying stocks may have experienced a substantial decline in abundance. The CPUE of the subsistence sector remained consistently higher when compared to the artisanal sector through the entire time series; however, there was a decreasing trend in the subsistence CPUE since 1990. This may suggest localized overexploitation of near-shore habitats as these represent the main fishing grounds, which may be easily accessed by subsistence boats with lower levels of motorization. Comparatively, the mean CPUE of the subsistence sector of the RMI in the 2010s was approximately 20 times higher than in countries in West Africa, where fish stocks have been heavily over-exploited by industrial and artisanal fisheries (Belhabib et al., 2018). Within the Pacific, the subsistence CPUE in the RMI was approximately 12 times higher when compared to Tokelau (White et al., 2018), suggesting that the catches of this sector may still be proportionally high for the region.

Projections of expected national demand for fish protein suggest that the RMI has the potential to supply its own demand with enough local fish to assure good nutrition of the population (Bell et al., 2009). Similar projections have been made globally, but require careful control and restriction of export-oriented distant water fishing fleets that do not contribute to domestic food security in developing countries (Hicks et al., 2019; Pauly, 2019).

The predicted impacts of climate change on small-scale fisheries, including loss in productivity and resilience, are expected to be particularly accentuated in tropical areas (Cheung et al., 2009, 2010; Pauly and Cheung, 2018), and especially so in small-island countries such as the RMI (Hanich et al., 2018). Effective and careful management of the coastal fisheries and protection of habitats to enhance resilience of stocks may partially alleviate or delay the detrimental impacts of climate change (Burden and Fujita, 2019; Rogers et al., 2019). As such, monitoring and careful estimation of comprehensive catch and effort data for each fishing sector in the RMI is crucial to provide appropriate data baselines to monitor and evaluate changes in stocks. Specifically, collection and estimation of comprehensive and detailed catch data at species level over time will allow stock assessments to be undertaken, given recently developed, continuously improved, and freely available data-limited assessment methods (Froese et al., 2017; Palomares and Froese, 2017; Palomares et al., 2018).

The domestic, locally based industrial fishing sector was responsible for the largest portion of total fisheries catches reported by FAO on behalf of the RMI. These catches consist mainly of tuna and other large pelagic species, and account for the majority of the country's seafood exports (Gillett, 2016). Catches of skipjack tuna, which account for most of the industrial catches in the Marshall Islands, are highly affected by inter-annual variation of environmental variables, and result in oscillation of the annual domestic industrial catches (Gillett, 2011). However, the official contribution of fisheries to the national GDP has increased in the last few years, mainly as a consequence of increased revenues from the fishing access fees paid by foreign-flagged industrial vessels, but also due to an increase in fish export earnings from the RMI-flagged industrial fisheries (Gillett, 2016; MIMRA, 2017). Questions around the true and full socio-economic benefits to RMI of re-flagging and locally based joint-venture operations with majority foreign beneficial ownership, versus foreign access fees remain to be examined in detail.

In 2011, the RMI declared a complete ban on commercial shark fishing, retention, and trade of sharks and shark parts within its EEZ, stipulating that sharks caught by industrial fleets, whether foreign or domestic, have to be released (Ward-Paige, 2017). Our reconstructed estimates showed that the amount of sharks caught annually before the implementation of the shark fishing ban was noteworthy, with around 4,800 t in 2010. The official data reported by FAO on behalf of the RMI did not document cartilaginous fishes (sharks, skates, and rays) prior to 2009, after which a specific category for this taxon was included. However, frozen sharks and shark fins were documented frequently in national catch (MIMRA, 2009) and export data for the RMI (Gillett and Lightfoot, 2002; Muller, 2006; Gillett, 2009). Since the introduction of the reporting category in the FAO data after 2009, small but regular shark catches have been reported on behalf of the RMI, with the highest landings reported to FAO in 2017 (231 t), clearly indicating that despite the official shark fishing ban, landings of sharks by the industrial fisheries still occur to some extent.

The effectiveness of the fishing ban regulation in reducing shark mortality is largely unknown. However, reported mortality rates of oceanic whitetip (*Carcharhinus longimanus*, IUCN status: Vulnerable) and silky sharks (*Carcharhinus falciformis*, IUCN status: Vulnerable) caught by the industrial fisheries in the RMI in 2017 and 2018 were 46–60 and 71–93%, respectively (WCPFC, 2017, 2018a). Post-release mortality of sharks in offshore fisheries is known to be high (Campana et al., 2009), further contributing to a high mortality rate of sharks interacting with these fisheries. Moreover, evidence from satellite telemetry suggests that illegal fishing is also inflicting high mortality rates on reef shark species, i.e., gray reef sharks (*Carcharhinus amblyrhynchos*, IUCN status: Near Threatened), in coastal waters with transshipment at sea and landing at distant ports (Bradley et al., 2019). Therefore, it is highly likely that, despite the shark fishing ban, the industrial sector is still inflicting considerable direct and indirect fishing mortality on the shark populations across different habitats of the RMI.

In 2017, an amendment to the shark fishing ban weakened the initial regulation, allowing possession of sharks and shark parts obtained by the industrial fisheries outside RMI waters (Republic of the Marshall Islands, 2017; Cramp et al., 2018). The RMI has an observer program for monitoring of the large-scale commercial fleet, which largely focuses on the monitoring of purse-seiners (MIMRA, 2017). This program has been progressively improved over the years (MIMRA, 2017; WCPFC, 2017), with increasing monitoring of the long-line fleet; however, onboard coverage of this fleet remains limited (WCPFC, 2018a). The weakening of legislation, especially without having a full observer program in place for long-line fleets, which impose the largest mortality on sharks (Bromhead et al., 2012), effectively minimizes any limited control of the origin of the sharks and parts retained by this fleet, potentially stimulating illegal catch of sharks within RMI waters. Thus, it is important that the observer program expands to cover all fishing vessels and all fishing trips within the RMI EEZ. Such complete or near-complete observer coverage and associated, independent accountability, transparency, and traceability needs to be treated as a normal cost of doing business by industrial fleets (Zeller et al., 2011).

We reconstructed the total domestic catch of the RMI by complementing the officially reported baseline catch data as presented by the FAO on behalf of the RMI with conservative estimates of unreported catch components from secondary data and information sources (Zeller et al., 2016). Thus, the uncertainty of the reconstructed data is directly related to the underlying secondary data sources and associated assumptions. Despite the likely higher uncertainty around the reconstructed catch estimates compared to the undocumented and unreported uncertainty around the official catch records (Pauly and Zeller, 2016, 2017), the catch data presented here provide for a more comprehensive account of the likely total domestic catch history in the RMI. Given the crucial food security importance of the small-scale fisheries to the country, our study highlights the need for improved monitoring and estimation of the small-scale fisheries, which would allow for more representative data reporting nationally and internationally, as well as provide a better data foundation for management decisions.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

GV analyzed the data and drafted the manuscript. EH, BD, RW, and LH analyzed the data and edited the manuscript. DZ was an expertise and provided guidance in reconstruction and data management, and drafted and edited the manuscript.

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