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Small-scale fisheries catch and fishing effort in the Socotra Archipelago (Yemen) between 1950 and 2019

Brittany Derrick[1]*, Keanna Burns[1], Audrey Zhu[1], Vania Andreoli[2], Dirk Zeller[2]* and Daniel Pauly[1]*

[1]Sea Around Us, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada, [2]Sea Around Us – Indian Ocean, School of Biological Sciences, University of Western Australia, Crawley, ACT, Australia

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EDITED BY
Oscar Sosa-Nishizaki,
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Center for Scientific Research and Higher Education in Ensenada (CICESE), Mexico
José J. Castro-Hernández,
University of Las Palmas De Gran Canaria, Spain

*CORRESPONDENCE
Brittany Derrick
b.derrick@oceans.ubc.ca
Dirk Zeller
dirk.zeller@uwa.edu.au
Daniel Pauly
d.pauly@oceans.ubc.ca

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The Socotra Archipelago (Yemen), a group of four islands off the north-eastern tip of Africa in the western Indian Ocean, has a population that relies heavily on small-scale fishing for livelihoods and food security. However, the reporting of fisheries catches by Yemen has consistently been incomplete, with artisanal (small-scale, commercial) catches underreported and small-scale non-commercial subsistence and recreational catches not reported at all. Here, we reconstruct the total small-scale catches and fishing effort from the waters of the Socotra Archipelago for 1950 to 2019, and derive catch-per-unit-effort (CPUE) estimates for these fisheries. The catch officially reported by the Food and Agriculture Organization on behalf of Yemen that was assumed taken from the archipelago is thought to be around 20% of the total reconstructed catch for the archipelago. The reconstructed small-scale catch increased from ~1,500 t in 1950 to an all-time peak of 12,000 t in 2000 before declining to 3,300 t by 2014. Thereafter, catches increased again slightly to just over 3,700 t·year^{-1} by 2019. Artisanal catches accounted for around 70% of total small-scale catches prior to 2010, but made up only around 46% by 2019. Conversely, subsistence catches increased from ~1,000 t in 2010 to ~2,000 t in 2019, and accounted for 54% of total catches by 2019. Small-scale fishing effort increased by over 1000% since 1950 and reached over 11 million kWdays by 2019. The CPUE derived for small-scale fisheries declined by 78% since 1950, from 1.4 kg·kWday^{-1} to 0.3 kg·kWday^{-1} in 2019, with most of the decline occurring after 2000. Our findings suggest resource overexploitation, and may assist efforts to more sustainably manage the Socotra Archipelago's fish stocks. Small-scale fisheries support food and nutrient security of the local population, not least during political and humanitarian crises such as in Yemen.

KEYWORDS

artisanal fisheries, CPUE, fishing capacity, Indian Ocean, overexploitation, overfishing, recreational fisheries, subsistence fisheries

1 Introduction

The Socotra Archipelago, while part of Yemen, is located 350 km off the Yemeni mainland coast (Klaus and Turner, 2004) in the Arabian Sea (Figure 1). The Archipelago consist of the major island of Socotra, with a surface area of 3,400 km^2, and three smaller islands to its west, Abd al Kuri, Samha, and Darsa, and the small rock outcrops of Kal Farun and Sabuniya. The Socotra Archipelago is often referred to as the Galapagos Islands of the Indian Ocean due to its high biodiversity, high endemism, and its relatively remote location (UNESCO, 2006). However, the Socotra Archipelago is half as large as the Galapagos Archipelago, has been populated for thousands of years, yet remained almost untouched by external development until the airport opened in 1999 (UNESCO, 2006). Thus, as is generally the case for island cultures, coastal, small-scale fisheries have always played a substantial role in the economy and food security of the Socotra Archipelago (Botting, 1958; Boxhall, 1966; Brown, 1966; van Rensburg, 2016).

It has been proposed that the Socotra Archipelago should be its own ecoregion due to its unique taxonomic and ecological features (Hariri et al., 2002; Zajonz et al., 2022). The Socotra Archipelago was designated a UNESCO Man and Biosphere (MAB) Reserve in 2003 and a UNESCO Natural World Heritage Site in 2008, and since 2007 is a designated Ramsar Site (Van Damme, 2022). There are thought to be over 870 species of coastal fishes (Zajonz et al., 2019) and at least 458 marine invertebrate species in the archipelago (Van Damme, 2022). Furthermore, the eastern Gulf of Aden is a region of oceanic upwelling, which results in a high productivity of fish resources (Hariri et al., 2002). Fisheries in the archipelago were not well studied until a research project by a team from the Senckenberg Museum in Frankfurt, Germany, documented the main features of the coastal fisheries of Socotra in a series of publications (see Supplementary Materials Part A), which also forms the basis of much of the information used here. The current reconstruction of the small-scale, coastal fisheries catches and fishing effort data for the Socotra islands within the Yemeni Exclusive Economic Zone (EEZ; Figure 1) covers the years 1950 to 2019, which correlates to the earliest year for which the Food and Agriculture Organization of the United Nations (FAO) provides their global capture statistics (1950) and the most recent year (2019) for which FAO data were available at the time of this study. It is thus a longer period than the original research project of the Senckenberg Museum considered, and assumptions had to be made and extrapolations performed to address the entire time period.

Artisanal, i.e., small-scale commercial fisheries, operate from the around 86 coastal villages on the islands of Socotra, Samha, and Abd al Kuri, but these catches are thought to be declining (Zajonz

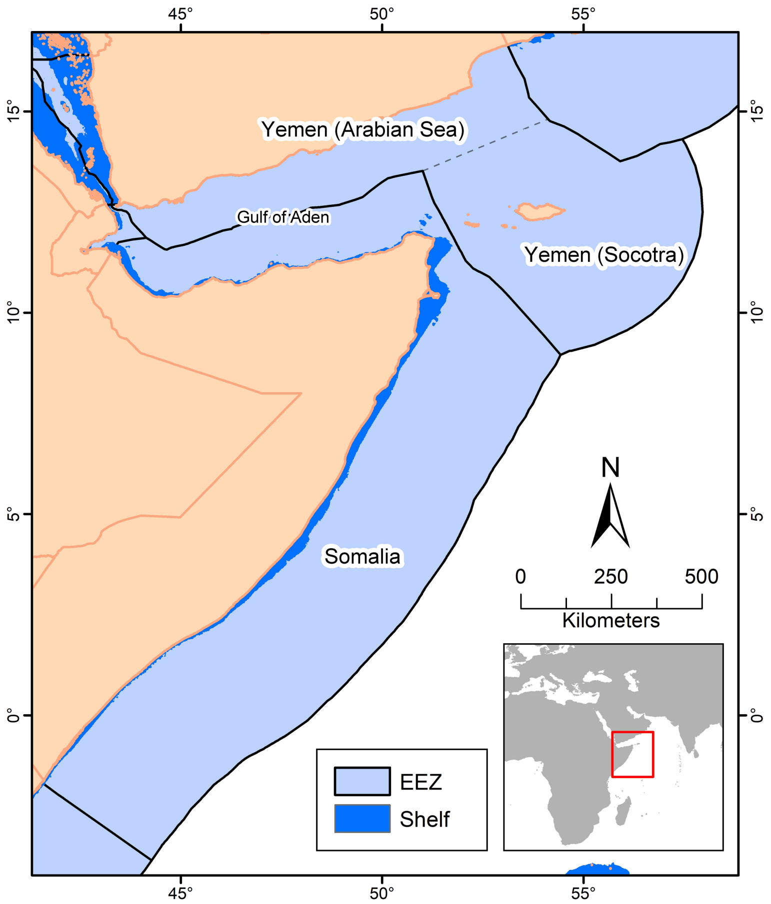

FIGURE 1
The Socotra Archipelago (Yemen) and its surrounding Exclusive Economic Zone area of 312,471 km^2, the southeastern part of the Yemeni mainland EEZ, and the EEZ of neighboring Somalia.

et al., 2016). Factors that have increased the pressure on the local fish resources in the past, include increased demand from the Yemen mainland and foreign buyers, local population growth, and the transition from a traditional pastoral livelihood to economically driven fishing (Zajonz et al., 2016). Moreover, since 2015, the civil war in Yemen has created a humanitarian crisis that is increasing pressure on fish resources to alleviate war-related famine, leading also to increased subsistence fishing to support the growing local population (Khalfallah et al., 2020).

Official catch records tend to underestimate true catches in Yemen, because fishers must pay a fee to the cooperative to which they belong based on registered catch value, which encourages under-reporting. Moreover, buyers must also pay a levy on the total purchase value that is shared between cooperatives, the Ministry of Fish Wealth, and the local Governorate (Alabsi and Komatsu, 2014; Zajonz et al., 2016). Also, catches from unofficial landing sites in remote areas of Yemen such as the Socotra Archipelago and from at-sea transfers are generally under-reported (Alabsi and Komatsu, 2014). Under-reporting is a serious challenge to the sustainability of the archipelago's small-scale fisheries, as targeted fish populations are thought to be likely overexploited (Zajonz et al., 2016). However, available official data may not accurately reflect actual resource status, and may lead to further degradation due to miss-informed development-oriented, extractive policies (Alabsi and Komatsu, 2014).

Industrial fishing, i.e., by large-scale vessels from various countries does occur in the EEZ waters around the Socotra Archipelago. Historically, bottom trawlers from the former USSR (i.e., from the Ukraine, the Russian Federation, Lithuania and Georgia) operated on the continental shelf of the Yemeni mainland, mainly in the Gulf of Aden from 1967 to 1990 (Tesfamichael et al., 2012). However, there are no indications in the available literature that these vessels ever operated in the waters of the Socotra Archipelago, and this fishery is thus not relevant here.

Various news outlets covering the Arabian Peninsula and adjacent regions have reported illegal fishing in the part of the Yemeni EEZ that surrounds the Socotra Archipelago, with the vessels in question also suspected of smuggling weapons to rebel militias in Yemen in recent years (Al-Batati, 2020; Al-Ahmadi, 2022). Yemen's ability to monitor and enforce fishing regulations disappeared with the civil war. Numerous vessels from Iran, the UAE and other countries took advantage of this instability and began to operate illegally in these waters (Al-Batati, 2020; Al-Ahmadi, 2022). The waters around Socotra and the north-eastern tip of Africa are a major industrial fishing ground for tunas and other highly migratory large pelagic species. Nominally, countries whose vessels fish in these industrial fisheries are expected to report their catches to the Indian Ocean Tuna Commission (IOTC, www.iotc.org), the Regional Fisheries Management Organization (RFMO) with data and management mandate for large pelagic fisheries in the Indian Ocean (Coulter et al., 2020; Heidrich et al., 2022). We assume that foreign vessels largely targeted tuna and other large pelagic fishes in these waters, and that much of that catch remains unreported. Thus, foreign industrial fishing in these waters warrant future investigations. Furthermore, we could not find any evidence of industrial fishing vessels being owned by Socotra fishers and based in (i.e., home ported) the Socotra Island. Thus, we assumed that no 'domestic' (i.e., Socotra-based) industrial fisheries exist, and did not estimate any industrial catches in this study.

In the present study, we reconstructed the likely total catches of the three small-scale fishing sectors, i.e., the artisanal, subsistence and recreational fisheries in the EEZ waters of the Socotra Islands for the 1950 to 2019 time period. Furthermore, we estimated the fishing effort of these small-scale fishing sectors, which allowed us to derive catch per unit effort (CPUE) trends over time for the coastal, small-scale fisheries in the Socotra Archipelago. Such data permit inferences on the state of the coastal fisheries resources underlying these crucial livelihood and food-security fisheries.

2 Materials and methods

2.1 Human population

In the present study we used human population time series to inform marine catch estimates for the artisanal and subsistence sectors. Data for the human population in the Socotra Archipelago could be sourced for 1966, 2002, 2003, 2011, 2014, and 2019 (Table 1). Linear interpolation was used to derive estimated population levels for years without data. For the 1950 to 1966 period, it was assumed that the population increased by ~2% each year, which was guided by the average increase per year of 2.7% between our two earliest population anchor points for 1966 (Ubaydli, 1989) and 2002 (Anon, 2016). The population of the largest island of the archipelago alone, Socotra Island, was estimated to be around 8,000 in 1958 (Botting, 1958), which makes our 1950 estimate for all islands combined of 11,581 reasonable. The population data for 2014 (90,000) based on Nagi (2020) and 2019 (100,000) represent a strong increase that was attributed to the arrival of people fleeing the war on the Yemeni mainland (Anon, 2019; Van Damme, 2022).

2.2 Artisanal catch

Official catch reports for the artisanal fisheries of Socotra are limited and of variable quality (Zajonz et al., 2016). Some data were available from unpublished reports of the UNDP Global Environment Facility (UNDP-GEF) and the European Union, and from records of fishing cooperatives (Zajonz et al., 2016). We estimated the amount of catch reported to the FAO for Yemen that came from the Socotra Archipelago based on the records of catch reported for 1981-1996 and 2005-2014 in Figure 13 of Zajonz et al. (2016) which we extracted using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer). We divided recorded catch by the overall FAO reported catch for Yemen for each year to derive the proportion of FAO catch coming from the Socotra Archipelago. We applied the average proportion for 1981-1996 to FAO catches for 1950-1980, interpolated the proportion between the 1996 and 2005 anchor points and used the average proportion for 2010-2014 of FAO catch for 2015-2019 to estimate reported catch for Socotra Archipelago for years without records.

TABLE 1 Human population data sources and assumptions used to derive a full population times series for the Socotra Archipelago, Yemen, for 1950 to 2019.

Year	Population	Source
1950	11,581	Backwards projection from 1966, assuming an annual population increase of ~2%
1966	16,000	Ubaydli (1989)
2002	43,000	Anon (2016)
2003	65,000	Average of 50,000-80,000 range in Klaus et al. (2003)
2011	44,750	Scholte et al. (2011)
2014	90,000	Nagi (2020)
2019	100,000[a]	Anon (2019); Van Damme (2022)

[a]The population of Socotra has increased strongly after the early-mid 2010s because of the arrival of people fleeing the civil war on the Yemeni mainland.
Values between the listed data point years were interpolated.

Artisanal catch estimates from 1981 to 2014 were presented by Zajonz et al. (2016) and we used these data to estimate artisanal catch for 1981 to 2014 by extracting the catch data from Figure 13 in Zajonz et al. (2016) using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer). The artisanal catches for 1981 and 2014 were then converted to *per capita* catch rates by dividing catch per year by the corresponding human population estimates as derived in Table 1, assuming catch rates would rise and fall with population. The 1981 artisanal *per capita* catch rate was held constant back to 1950 and applied to the population from 1950 to 1980 in order to estimate artisanal catches prior to 1981. The artisanal *per capita* catch rate derived for 2014 was assumed to remain constant and was applied to population data for 2015 to 2019 to estimate annual artisanal catch. Thus, we assumed that recent socio-political events, such as the civil war has not substantially affected the artisanal catch rate during the last few years examined here (2015-2019). This assumption should be examined in future data research on Socotra.

2.2.1 Taxonomic composition of artisanal catch

The artisanal catch was assigned to four taxonomic groups: 1) sharks; 2) large pelagic teleost fishes; 3) reef-demersal fishes; and 4) an undifferentiated 'other taxa' group (Table 2), based on the contribution of each group to the total catch between 2005 and 2007 in Zajonz et al. (2016). This group composition was applied to the full time series due to lack of additional information. The taxonomic composition of each of these larger taxonomic groups was further refined as detailed in the following sections.

TABLE 2 Taxonomic group composition of the artisanal catch in the Socotra Islands reported in Zajonz et al. (2016) for 2005 to 2007.

Taxonomic group	Group composition (%)
Sharks	49
Pelagic teleost fishes	27
Reef-demersal fishes	23
Other taxa	1

These percentage compositions were used for the artisanal catch over the entire time period examined here.

2.2.2 Sharks

Artisanal fishers began targeting sharks around the Socotra Archipelago in the 1990s to export their catches to the Yemen mainland, where dried shark meat is eaten in coastal and inland communities (Jabado and Spaet, 2017).According to Saeed (2007), spot-tail shark (*Carcharhinus sorrah*) was the dominant shark species in the artisanal catch of Socotra with just over 42%, followed by blacktip shark (*Carcharhinus limbatus*) with around 32%. Lesser contributions were by scalloped hammerhead (*Sphyrna lewini*; around 9%), silvertip shark (*Carcharhinus albimarginatus*; around 8%), sandbar shark (*Carcharhinus plumbeus*; around 6%), and oceanic whitetip shark (*Carcharhinus longimanus*; around 1%). We assumed 80% of the overall catch for sharks (Table 2) consisted of these six species, in the proportions listed above and based on Saeed (2007). Furthermore, we assumed that the remaining 20% of total shark catches was split equally (i.e., 5% each) between the five species listed in Nichols (2001), these being blacktip reef shark (*Carcharhinus melanopterus*), blackspot shark (*Carcharhinus sealei*), graceful shark (*Carcharhinus amblyrhynchoides*), tiger shark (*Galeocerdo cuvier*), and shortfin mako shark (*Isurus oxyrinchus*).

2.2.3 Pelagic teleost fishes

We followed Saeed (2007) in allocating the catch of pelagic teleost fishes (Table 2) to individual taxa. Thus, the artisanal pelagic teleost fish catches of Socotra were dominated by narrow-barred Spanish mackerel (*Scomberomorus commerson*; 95.85%, kawakawa (*Euthynnus affinis*; 3%), swordfish (*Xiphias gladius*; 1%), yellowfin tuna (*Thunnus albacares*; 0.09%) and skipjack tuna (*Katsuwonus pelamis*; 0.06%).

2.2.4 Reef-demersal fishes

The taxonomic composition of the reef-demersal species catches, which accounted for 23% of the artisanal catch of Socotra (Table 2) was derived in a two-step process, based on information and data harmonized from key sources (Nichols, 2001; Mohsen, 2002; Ali et al., 2016).

Initially the catch totals for reef-demersal taxa was assigned to families (Table 3), following the data in Mohsen (2002) and Ali et al. (2016). The 1998 family composition (Mohsen, 2002) was carried back unaltered to 1950, and all values between data anchor point years were interpolated (Table 3).

The second step consisted of assigning species level compositions to the family level catch volumes as derived in Table 3. Species assignment to family was based on qualitative information in Nichols (2001); Mohsen (2002) and Ali et al. (2016) as summarized in Supplementary Table (S1). We assumed an equal proportion of catch for each species grouped within their respective families.

2.2.5 Other taxa (fishes and invertebrates)

The 'other taxa' group in the artisanal catch of the Socotra Islands contributes only around 1% of the total artisanal catch (Table 2). This category consists of a range of invertebrate and fish taxa (Table 4), including five species of panulirid lobsters, seven species of sea cucumbers, one species of cuttlefish, Indian oil sardine (*Sardinella longiceps*), as well as miscellaneous small marine fishes (Sanders and Morgan, 1989; Nichols, 2001; Hariri et al., 2002; Klaus and Turner, 2004; Scholte et al., 2011; Van Damme, 2011; Zajonz et al., 2016).

From 1950 to 1980, we assumed that miscellaneous small marine fishes, i.e., 'marine fishes nei' made up 50% of the 'other taxa' catch, while the remaining 50% was split evenly among the lobster species, Pharaoh cuttlefish, and Indian oil sardine (Table 4). While sea cucumbers were also caught before 1981 (Sanders and Morgan, 1989), we assumed that they contributed measurably to catches only after 1980. Thus, after 1980, miscellaneous small marine fishes were thought to make up 33% of the 'other taxa' catch, with the remaining catch split equally among sea cucumber species, lobster species, Pharaoh cuttlefish, and Indian oil sardine (Table 4).

TABLE 3 Percentage family composition of the reef-demersal fish catch in the Socotra Islands, based on Mohsen (2002) and Ali et al. (2016).

	Time period Source			
Family	1950 Assumed same as 1998	1998 Mohsen (2002)	1999 Mohsen (2002)	2002-2019 Ali et al. (2016)
Lethrinidae (Emperors)	33.5	33.5	35.1	35.6
Lutjanidae (Snappers)	29.2	29.2	27.3	27.3
Serranidae (Groupers)	23.4	23.4	23.9	23.3
Carangidae (Jacks & pompanos)	7.6	7.6	7.1	7.2
Haemulidae (Grunts)	6.3	6.3	6.5	6.6

Values between data anchor point years were interpolated.

TABLE 4 The taxonomic composition of the 'other taxa' category derived for the artisanal catch of the Socotra Islands.

Taxon group	Species	Composition of 'other taxa' (%)	
		1950-1980	1981-2019
Lobster	*Panulirus homarus*	7.14	4.78
	Panulirus versicolor	7.14	4.78
	Panulirus ornatus	7.14	4.78
	Panulirus longipes	7.14	4.78
	Panulirus penicillatus	7.14	4.78
Cuttlefish	*Sepia pharaonis*	7.14	4.78
Indian oil sardine	*Sardinella longiceps*	7.14	4.78
Sea cucumbers	*Holothuria nobilis*	0.00	4.78
	Holothuria scabra	0.00	4.78
	Holothuria fuscopunctata	0.00	4.78
	Holothuria fuscogilva	0.00	4.78
	Holothuria atra	0.00	4.78
	Holothuria edulis	0.00	4.78
	Holothuria leucospilota	0.00	4.78
Miscellaneous fishes	Marine fishes nei	50.00	33.00

'nei' – not elsewhere included. Sources: (Sanders and Morgan, 1989; Nichols, 2001; Hariri et al., 2002; Klaus and Turner, 2004; Scholte et al., 2011; Van Damme, 2011; Zajonz et al., 2016).

2.3 Subsistence catch

There are two types of subsistence catch in the Socotra Islands. The first subsistence catch type represents the catch taken home by artisanal fishers for family consumption and gifting, while the second subsistence catch type is reef/intertidal gleaning of shellfish.

2.3.1 Gifted and take-home catch

We leaned on the research by Tesfamichael et al. (2012) for Yemen to derive an estimate of the fraction of total artisanal catch that was assumed to be take-home or gifted for subsistence purposes in the Socotra Islands, based on the assumption that this gifting tradition also applied in the Socotra Islands. Gifting of food products is a very common tradition in the countries in the region, as also document by van Rensburg (2016) and Tesfamichael and Pauly (2016). On the Yemeni mainland this amounted to over 50% of artisanal catch (Tesfamichael et al., 2012), here we conservatively assumed that 30% of the artisanal catch from 1950 to 1974 was take-home or gifted catch. With the increase in motorization after 1975, we assumed this percentage declined to 20% in 1975 and 10% by 2015. This reduction in the gifting percentage was thought to account for the likely increase in catchability due to the increased effective effort provide through increased motorization, likely resulting in a smaller % of catch being destined to gifting. This was an assumption, and future research on Socotra should examine these assumptions. The percentages between 1975 and 2015 were interpolated, and the 2015 percentage was carried forward to 2019. We assumed that this subsistence fraction of the artisanal catch was unreported.

There are conflicting sources on the taxonomic composition of Socotra's subsistence catch. Hariri et al. (2002) emphasized that groupers, emperors, snappers, and grunts are consumed in the Socotra Islands. However, in a United Nations Development Programme report on a marine related development in the Socotra Islands (UNDP, 2012), sharks, kingfish and tunas were considered food staples in Socotra, while lobsters and reef fish were generally sold to fishing vessels from other countries. Therefore, we assumed the same taxonomic composition for the gifted and take-home subsistence catch as for the commercial artisanal sector catch, with the exclusion of invertebrates such as lobster, cuttlefish and sea cucumbers, which were deemed not to be part of the Yemeni gifted or take-home subsistence catch.

2.3.2 Shellfish gathering or 'gleaning'

There is no quantitative data and very little qualitative information available on reef and intertidal gleaning in the Socotra Islands. Therefore, information for nearby Oman (Bose et al., 2013) was used to inform estimates of shellfish gleaning. Shellfish is consumed by the entire population of the Socotra Islands, but the intertidal gathering of shellfish is primarily done by women and children, as it is often seen as 'shameful' for men to do this (van Rensburg, 2016). However, men do collect and eat shellfish during the southwest monsoon season when it is difficult to catch fish or when they are camping away from home (van Rensburg, 2016). Here, we focused on women only, and did not account for children helping with the gleaning. We also assumed that the amount of shellfish that men collect is negligible. In the absence of any additional information, we assumed that half of all women in the Socotra Islands glean shellfish. As women make up 49%[1] of the total population on the islands, we assumed that 24.5% of the total population on the islands (Table 1) participate in shellfish gleaning.

Women in Oman gather 2.4 kg of shellfish per person per week, with the hooded oyster (*Saccostrea cucullata*) being the primary target species (Bose et al., 2013). We assumed the same catch rate for women in the Socotra Islands, which is probably conservative given the much higher reliance and dependence of the residents of Socotra on local seafood (Myriam Khalfallah, Bloom and FHI360, pers. comm., July 20, 2021). We assumed that gleaning occurred during 40 weeks of the year. Furthermore, we assumed that 20% of the shellfish gleaned by women is sold to local traders or in markets and the remainder is for household consumption, as was also reported for Oman (Bose et al., 2013). The taxonomic composition for gleaned shellfish catch was derived from Janssen (2000), supported by information in SeaLifeBase (https://www.sealifebase.ca/) to determine edible, intertidal shellfish species in waters of the Socotra Islands. We assigned 59% of the gleaned catch to the hooded oyster (*Saccostrea cucullata*), 14% to oxpalate nerite (*Nerita albicilla*), 11% to rayed limpet (*Cellana rota*), 6% to coronate moon turban (*Lunella coronata*), 4% to top shells (Trochidae), 3% to Rudolph's purpura (*Purpura panama*) and 3% to other nerite snails (Neritidae), based on Janssen (2000).

2.4 Recreational catch

The recreational catch was reconstructed using unconventional sources such as web blog entries and photos from tourism websites, by adapting the methods of Belhabib et al. (2016). Based on information from tourism websites describing recreational fishing tours, we assumed that all recreational fishers in the Socotra Islands are foreign tourists. This assumption also avoids the possibility of confounding the subsistence catch of people living in Socotra with potential local recreational catch. Given the socio-economic conditions on Socotra, it is unlikely that truly domestic recreational fishing occurred. We assumed that tourist-based recreational fishing started in 2000, the year after Socotra's international airport was opened. This made the Archipelago more accessible to international tourist (Burdick, 2007). The number of tourists ranged from a few hundred per year to a maximum of 5,000 in 2014 (Supplementary Table S2).

There is a small number of tourism operators in Socotra that conduct recreational fishing tours (Supplementary Table S3). With the start of the civil war in 2015, tourist numbers declined strongly until the early 2020s (Middle East Eye, 2021). Most recreational fishing tours range from 7 to 12 days, with the recreational fishing season being March-April and October-November (Supplementary TableS3). We estimated the total number of recreational fishers per tour by multiplying the number of boats by the number of anglers

1 https://socotra.info/republic-of-yemen-general-information.html

per boat for each anchor point in Supplementary Table (S3). We assumed that the tour guide and vessel crew would not be fishing recreationally. Next, we divided the number of total calendar days per season by the number of fishing days in one tour to get the maximum total number of tours per season. This information was used to determine the assumed number of recreational fishers per season for 2014, 2018, and 2020, based on the data in Supplementary Table (S3). Values for intervening years were interpolated. We assumed that between 2014 and 2020, recreational fishing tour companies would be operating at best at two-thirds of their maximum capacity due to the civil war disruptions to tourism. We thus used a conservative approach and adjusted the number of recreational fishers per season based on the two-third capacity of all the offered fishing tours. For the period prior to the civil war (2000-2013), we carried back the 2014 proportion of fishers to tourists as a fixed proportion.

2.5 Recreational catch and catch composition

We used photos of recreational fishers holding their catch from Socotra's tourism websites and blogs to approximate the potential total weight of fish caught per recreational fisher from 2000 to 2020, following Belhabib et al. (2016). Fifty-one photos were found and analyzed for 2014, 2018, and 2020 on the websites of Wild Sea Expedition,[2] Socotra Trek Tours,[3] Fish Me,[4] The Mission,[5] Socotra Adventure,[6] Socotra Fishing Adventures,[7] and Socotra Professional Tours.[8] The species on the photos were identified using FishBase (www.fishbase.org) and the '*Online Atlas to the Commercial Fishes of Socotra*' (http://socotra.senckenberg.de/FishAtlas).

The lengths of the fish in the photos were approximated based on their relation to the assumed average height of the persons in the same photo. Then, the species-specific length-weight relationship obtained from FishBase was used to approximate the weight of each fish. The total weight of fish represented in each photo was divided by the number of persons on that photo, and an average catch per fisher per day of ~47 kg was derived. This per-person recreational catch rate was then multiplied by the number of recreational fishers and the average tour duration of 11 days over the time series.

2 https://www.wildseaexpedition.com/en/socotra-fishing

3 http://socotra-trek.com/our-offer/fishing-tours/

4 https://www.fishfishme.com/fishing-charter/yemen/socotra-island/socotra-fishing-adventure

5 https://themissionflymag.com/2020/12/31/the-long-way-home/

6 http://www.socotra-adventure.com/socotra-fishing-tours-the-prime-spots-for-gt-fishing/

7 https://socotra-fishing.blogspot.com/2014/11/socotra-sport-fishing-tour.html

8 https://socotra.info/professional-fishing-tours-to-socotra-archipelago.html

The percentages of all the species in the 51 photos (Table 5) were used to taxonomically disaggregate the recreational catch over the entire period considered here. Specifically, the taxonomic breakdown for the recreational sector was calculated using the weight of a species divided by the total weight of the 51 observations and held constant across the time series (Table 5). The giant trevally (*Caranx ignobilis*) was the species seemingly most targeted by recreational anglers (72%) and it is described as the most desirable trophy fish by many of the recreational angling websites. Yellowfin tuna (*Thunnus albacares*; 10%), yellow-edged lyretail (*Variola louti*; 3%), and green jobfish (*Aprion virescens*; 3%) were the other species most frequently observed in the recreational catch photos analyzed here.

2.6 Fishing effort of small-scale fisheries

The method for reconstructing boat-based and shore-based small-scale fishing effort for the Socotra Archipelago was adapted from Greer (2014) and Zeller et al. (2021). *Nominal* fishing effort was derived by multiplying the number of fishing boats by their engine power (in kW), depending on their length class and motorization level (Supplementary Table S4). Non-motorized vessel power was assumed equivalent to ¼ of motorized engine power for the same length class (Supplementary Table S4), assuming two fishers per smallest non-motorized vessel length class, each employing slightly less than 1.2 kW per fishing day (McCleary, 2009). For *effective* fishing effort, the *nominal* effort (kW) was multiplied by the average number of fishing days per year, resulting in the core *effective* fishing effort measure of kWdays per year. The *effective* fishing effort was computed by explicitly accounting for technological improvements of the fishing gear over time, e.g., transitioning fishing gear from Manila fiber to plastic netting, improvement in boat design, navigation aids (GPS) and fish finding technology such as echosounders, as can be done using an empirical model (Palomares and Pauly, 2019). However, the rate of increase in *effective* fishing effort was set very conservatively at a low 0.5% per year.

2.6.1 Types of artisanal vessels in Socotra

Descriptions of Socotra's fishing vessels were used to assign length class and motorization levels to the total number of boats, considering the limited quantitative information available. Rafts, Socotra's earliest and longest lasting fishing vessel, were used until the mid-20th century (van Rensburg, 2016). Date-palm frond boats were crafted on Socotra by traditional weaving techniques and were used until 1944, followed by sewn boats (van Rensburg, 2016). These traditional fishing crafts were phased out with the introduction and increasing affordability of more modern vessels (Agius et al., 2010; van Rensburg, 2016). Here we assumed that the rafts, date palm-frond and sewn boats were no longer in use by the 1950 start date of the present study.

The 'huri' is a wooden dugout canoe that has been in use since the 18th century, and can be propelled by a paddle and sail, i.e., it remains 'non-motorized', or be fitted with an outboard engine, and

TABLE 5 Proportion of the total weight of 51 photographic observations of recreational species from tourism websites and blogs on Socotra.

Species	%	Species	%
Caranx ignobilis	72	*Sphyraena barracuda*	1
Thunnus albacares	10	*Cephalopholis miniata*	1
Variola louti	3	*Scomberomorus guttatus*	1
Aprion virescens	3	*Carcharhinus amblyrhynchos*	1
Aphareus rutilans	2	*Carangoides chrysophrys*	<1
Istiophorus platypterus	2	*Gymnocranius grandoculis*	<1
Epinephelus multinotatus	2	*Scarus ghobban*	<1
Caranx melampygus	1		

thus become 'motorized' (van Rensburg, 2016). Fiberglass boats were first introduced in 1979, and being perceived as made of 'plastic', they were categorized into 'blastik' of 7 to 8 m length, or 'huri blastik' of 9 to 10 m length (van Rensburg, 2016). Here, we treat all fiberglass vessels as motorized.

Another type of fishing vessel is 'sanbuks', or fishing dhows, with lengths ranging from 10 to 20 m. The first record referring to sanbuks being owned by fishers on Socotra is Morris (2002), who states that in the 20th century several villages on Socotra and the outlying islands owned one or more wooden sanbuks for fishing. However, van Rensburg (2016) excluded sanbuks, stating that they do not accurately depict Socotra's fishing vessels. On the other hand, Hariri et al. (2002) stated that the Yemeni fleet included 50 sanbuks from Socotra, and Zajonz et al. (2016) included sanbuks as part of Socotra's small-scale fishery. Here we assumed that sanbuks were used throughout our time series by Socotri fishers. We assumed sanbuks became motorized in the 1960s and used sails before motorization.

2.6.2 Numbers of artisanal fishers and vessels

Some data on the number of fishers were available for various years, and the number of fishers between 1993 and 2014 were interpolated between the available data anchor points (Table 6). The proportions of the number of fishers (Table 6) to the total population of the archipelago (Table 1) for 1944 and 1993 were also interpolated, then multiplied by the population to determine the number of fishers for 1950 to 1992. The number of fishers in relation to the total population in 2014 was carried forward unaltered to 2019. The number of fishers was used to reconstruct the number of fishing boats for years lacking data on the number of boats, as detailed here.

Data on the number of fishing boats were available for some years (Table 7) and linear interpolations were used to fill in years between anchor points. The proportions of the number of fishing boats to the number of fishers (Table 6) in 1944 and 1996 were interpolated, then multiplied by the derived number of fishers to estimate the likely number of boats. The proportion based on the number of boats to the number of fishers in 2014 was carried forward unaltered to 2019. A recent increase in the number of fishing boats in the Socotra Archipelago, despite the constraints of the civil war on the mainland is also supported by the fact that the UAE donated 110 million USD of development aid to the Socotra islands in the mid-2000s (ANI, 2021). This aid package included fishing boats, fish market and fish factory construction, and refrigeration equipment.

TABLE 6 Data and sources on the number of small-scale fishers in the Socotra Archipelago between 1944 and 2014.

Year	Mean number of fishers	Source
1944	999	Scott et al. (1946)
1993	1515	Zajonz et al. (2016)
1996	2068	Zajonz et al. (2016); Scholte et al. (2011)
1999	2650	Scholte et al. (2011)
2000	2760	Zajonz et al. (2016)
2004	2730	Scholte et al. (2011)
2006	3850	Zajonz et al. (2016); Scholte et al. (2011)
2010	5000	Hariri et al. (2002)
2012	3608	Zajonz et al. (2016)
2014	3800	Zajonz et al. (2016)

Data points were extracted from graphed data in some of the sources using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer).

TABLE 7 Data and sources for the number of small-scale fishing vessels in the Socotra Archipelago between 1944 and 2014.

Year	Mean number of fishing boats	Sources
1944	506[a]	Scott et al. (1946)
1996	791	Scholte et al. (2011); Zajonz et al. (2016)
1998	822	Scholte et al. (2011)
2000	990	Zajonz et al. (2016)
2004	810	Scholte et al. (2011)
2006	1385	Zajonz et al. (2016)
2010	1250	Hariri et al. (2002)
2014	1200	Zajonz et al. (2016)

[a]The population of Socotra Island of 7000 provided by Scott et al. (1946) and the estimate of the population of the Socotra Archipelago derived in Table 1 was used to raise the 1944 estimate of 344 boats by 68%. This estimate remains highly uncertain.
Data points were extracted from graphed data in some of the sources using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer).

2.6.3 Motorization of the artisanal fleet

We assumed that motorization of the archipelago's fleet started in the 1960s, as motorization of fishing vessels started to have an impact in Yemen by 1975 (Tesfamichael et al., 2012). Although motorization increased over time, the use of non-motorized boats continued (van Rensburg, 2016). For 1999, the number of boats by boat type were available and these numbers were used to derive an estimate of motorized and non-motorized boats based on the motorization of each boat type (van Rensburg, 2016). The proportion of boats that were motorized (~85%) by 1999 was interpolated from zero motorization in 1959 prior to the assumed introduction of motors in 1960 and applied to the total number of boats to reconstruct the number of motorized vessels. The remaining boats were assumed to be non-motorized. The 1999 motorization proportion of 85% was carried forward to 2019 unaltered, as no other boat numbers by boat type were available. However, it is possible that motorization rates have increased by the late 2010s.

Boats were assigned to length class ranges (Supplementary Table S4) and we generated assumed proportions of each boat type within each length class and motorization characteristic (Supplementary Table S5). Before motorization, it was assumed the fleet consisted of wooden 'huris' of 3 to 11 m length (Saeed, 2007), which were distributed equally between length class 1 and length class 2, as the size range of these boats span both length classes and their actual breakdown by length is unknown. The number of non-motorized 'sanbuks' between 1950 and 1960 was assumed to be the same as motorized 'sanbuks' in 1960. After motorization, wooden 'huris' were distributed equally between length class 1 and length class 2, both motorized and non-motorized. The boats reported as 'huri blastik' of 7 to 16 m length (Alabsi and Komatsu, 2014) were assumed to belong mainly (90%) in length class 2, with the rest in length class 1, while the smaller 'blastik' boats of 7 to 9 m length (Saeed, 2007) were assumed distributed equally between length class 1 and length class 2. Finally, the 'sanbuks' of 10 to 20 m length (Alabsi and Komatsu, 2014) were distributed equally between length class 2 and 3.

The number of motorized or not motorized boats in each length class was derived by multiplying boat type data for the year 1999 (van Rensburg, 2016) by the assumed proportion of boat type in each length class and motorization category (Supplementary Table S5). The number of boats in each length class was then divided by the total number of boats by motorization category to obtain the fractions of length class of total non-motorized and motorized boats.

2.6.4 Number of artisanal fishing days

Overall, small-scale fisheries were estimated to operate for 160-180 fishing days per year, with the maximum number of fishing days per year estimated at 220 (Zajonz et al., 2016). However, 'huris' were also reported to operate for 245 fishing days per year (Hariri et al., 2002), thus we averaged the estimates of 220 and 245 fishing days per year and assumed this average of 232 days to be the number of fishing day for 'huris' across the time series. 'Sanbuks' were estimated to operate 160 days per year (Hariri et al., 2002). It was assumed that a small-scale fishing day would be 12 hours. Furthermore, we assumed 1.5 hours each day would account for subsistence fishing (take home catch of artisanal fishers) and the remaining 10.5 hours per day would be commercial, artisanal fishing. Thus, for 'huris', the estimated annual number of days fishing for subsistence purposes would be 29 days and fishing for artisanal purposes would be 203 days. For 'sanbuks', the estimated annual number of days fishing for subsistence purposes would be 20 days and fishing for artisanal purposes would be 140 days.

2.6.5 Shore-based subsistence fishing effort for shellfish gleaner

A shore-based fisher is assumed to expend the equivalent to 0.08 kW per fishing day (Krendel et al., 2007). Shore-based fishing activities were converted to the *nominal* fishing effort (kW) by multiplying the number of shore-based fishers with 0.08 kW. To obtain the *effective* fishing effort, we multiplied the *nominal* effort by the average number of days per year for which shore-based fishing was assumed to occur in the Socotra Islands. In Oman, shore-based shellfish gleaners spent between 2-4 hours per day working (Bose et al., 2013); thus, the gleaners in Socotra were assumed to be undertaking shore-based gleaning for 3 hours per day. Using the average of 213 fishing days in Yemen (Greer, 2014) results in an estimated 639 hours of shore-based shellfish gleaning per year.

2.6.6 Recreational fishing effort

The number of recreational tour fishing boats across the time series was estimated based on the time series of recreational fishers described previously and assuming an average of three recreational fishers per boat based on tour data (Supplementary Table S3). The number of recreational boats was disaggregated by length classes according to proportions derived from tourism websites (Supplementary Table S3). Engine power per recreational fishing vessel (nominal effort in kW) was determined by length class and motorization (Supplementary Table S6). The number of recreational fishing days per tour was estimated by multiplying the average number of tours per season (i.e., 10 tours) by the average number of days per tour (i.e., 11 days), minus the first and last day of each tour that were assumed to be vessel travel days (Supplementary Table S3). Thus, the assumed number of fishing days per tour was 9 days. It was assumed that recreational tour vessels would spend 6 hours a day fishing on the 9 fishing days per tour, based on a recreational fishing tour itinerary[9]. Thus, the number of fishing days per boat and per tour was multiplied by 6 hours per day to get the total hours fished recreationally per season.

3 Data uncertainty

The catch time series reconstructed here were assessed with respect to their data and data source reliability using the method applied in all maritime countries globally by Pauly and Zeller (2016) as described in Pauly and Zeller (2017) and Heidrich et al. (2023). This approach represents a form of uncertainty assessment, using the scoring system summarized in Supp. Table S7. The 'reliability' scores used, i.e., high score = very high 'reliability' and hence less uncertainty, were based on those developed by the Intergovernmental Panel on Climate Change to help quantify the uncertainty of its assessments by evaluating the quality of, and the agreement between their underlying data and information sources (Mastrandrea et al., 2010).

4 Results

Total reconstructed catches for the domestic small-scale fisheries in the Socotra Archipelago increased steadily from around 1,500 t in 1950 to around 4,000 t·year^{-1} in the early 1990s (Figure 2A). Catches grew strongly during the 1990s to reach an all-time high of just under 12,200 t in 2000, before declining rapidly to a low point of around 3,300 t by 2014, Thereafter, catches began increasing again to just over 3,700 t by 2019 (Figure 2A). Based on the largely uncertain assumptions made here, the catch reported by the Food and Agriculture Organization of the United Nations (FAO) on behalf of Yemen that was assumed to relate to the Socotra Islands only accounted for around 20% of the total reconstructed catch estimated here (Figure 2A). The artisanal sector dominated the small-scale fisheries on Socotra in the earlier decades, accounting on average for around 72% of the total catch prior to 2010. However, in the most recent years the artisanal sector contribution had declined to around 46%, while the subsistence sector had increased substantially in importance to account for 54% of total small-scale catches by 2019 (Figure 2A). The subsistence sector catch began to increase rapidly after 2010, reaching just over 2,000 t in 2019 (Figure 2A). As recreational fishing was assumed to have been introduced only in 2000, the total catch for this sector was low at about 537 t for 2000 to 2019, or 26 t·year^{-1}.

4.1 Taxonomic composition

Overall, Spanish mackerel (*Scomberomorus commerson*) accounted for the largest portion (20%, ~63,200 t) of the total reconstructed small-scale catch (Figure 2B). Reef-demersal species made up the second largest portion (18%, ~57,100 t), followed by other shark and large pelagic species (17%, ~51,400 t), *Carcharhinus sorrah* (13%, ~40,800 t), *Saccostrea cuccullata* (11%, ~34,900 t), *Carcharhinus limbatus* (11%, ~33,000 t), and miscellaneous mollusks (8%, ~25,100 t) over the full 1950-2019 time period (Figure 2B). However, due to the considerable increase in subsistence fishing in recent years (Figure 2A), the hooded oyster (*Saccostrea cuccullata*) and miscellaneous mollusks dominated total catches by 2019, accounting for 37% and 26%, or 1,300 t·year^{-1} and 970 t·year^{-1}, respectively (Figure 2B).

Total reconstructed shark catches of the small-scale fisheries in the Socotra Archipelago were estimated at over 120,000 t over the nearly 70-year period examined here, and in recent years accounted for around 630 t·year^{-1}. In the early 1950s, sharks and other large pelagic species accounted for around 50% of the total reconstructed catch, which decreased to around 25% by 2019. For reef-demersal species, members of the Lethrinidae made up the largest portion of catch (~34%), followed by Lutjanidae (~28%), Serranidae (~23%), Carangidae (~7%), and Haemulidae (~6%).

4.2 Fishing effort and CPUE

The reconstruction of small-scale fishing effort suggested that the number of fishing boats in the Socotra Archipelago rose steadily between 1950 and 2000, from just over 500 vessels in 1950 to around 1,000 vessels by 2000 (Figure 3A). After 2000, a period of fluctuation in vessel numbers followed, but was enmeshed in a generally more rapid increase in the number of fishing vessels, leading to around 1,300 vessels by 2019 (Figure 3A). The pattern of motorization of the small-scale fleets in the Socotra Islands assumed here (Figure 3A) suggested a steady increase in the use of motors starting in 1960, with close to 90% of all vessel motorized since around 2000. The data on active fishing vessels and rate of motorization are uncertain, and warrant detailed *in situ* data collection.

The *effective* fishing effort for the small-scale fishing sector grew from around 1 million kWdays in 1950 to over 11 million kWdays

9 https://socotra-fishing.blogspot.com/2014/11/socotra-sport-fishing-tour.html

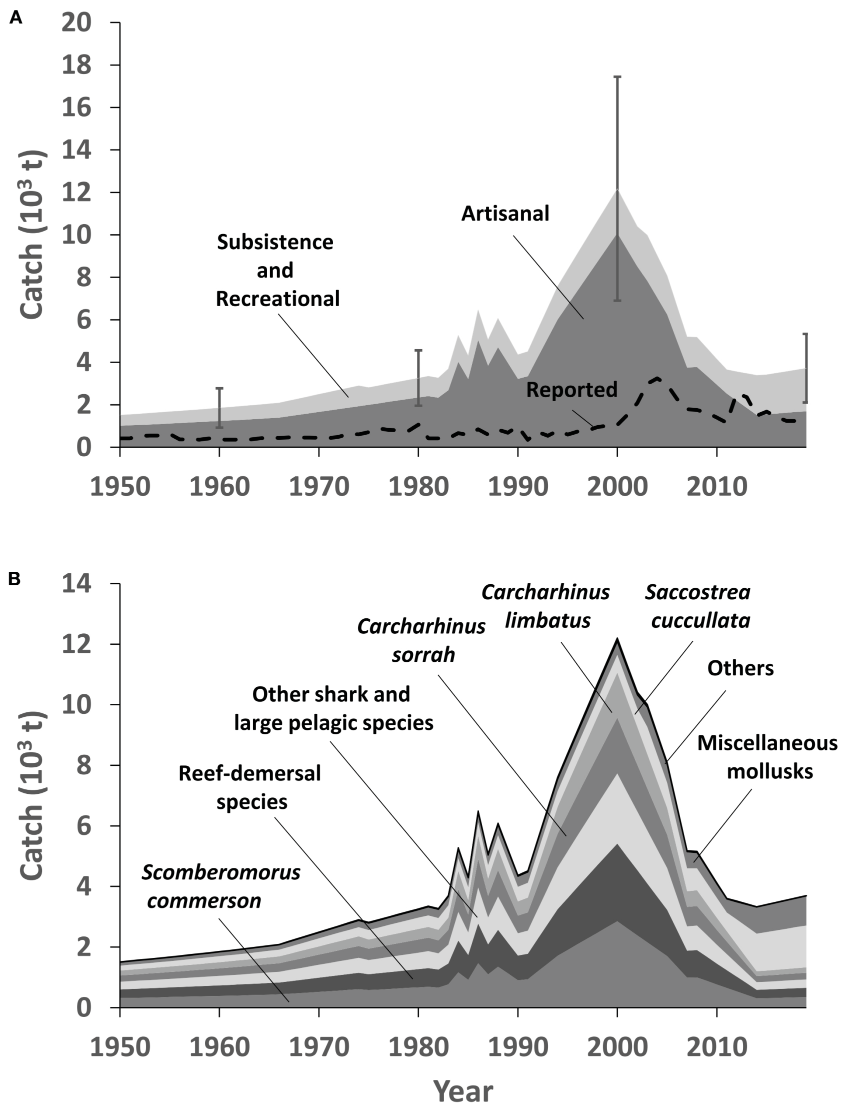

FIGURE 2
Reconstructed marine catch of the small-scale fisheries in the Socotra Archipelago (Yemen) for 1950 to 2019, by **(A)** fishing sector, with data reported by the FAO on behalf of Yemen and assumed to account for Socotra catches overlaid as a dashed line. Recreational catches are extremely small and do not display separately here; and **(B)** taxonomic composition of the total reconstructed catches for small-scale fisheries. The "others" component includes 15 additional taxa.

in 2019, a 11-fold increase in fishing effort over the nearly 70-year period considered here (Figure 3B). Combining the separately reconstructed time series of catch and fishing effort suggested that the small-scale CPUE experienced a highly variable pattern over time until the early 2000s, after which the CPUE declined strongly (Figure 3B). Overall, the small-scale CPUE declined more than four-fold from 1.4 kg·kWdays^{-1} in 1950 to 0.3 kg·kWdays^{-1} in 2019 (Figure 3B).

5 Discussion

Catches of small-scale fisheries are widely under-reported in national and global statistics, such as those reported by the FAO on behalf of countries (Zeller et al., 2015; Pauly and Zeller, 2016; Zeller et al., 2021; Zeller et al., 2023). The same under-representation of small-scale fisheries occurs in the data reported by the FAO for Yemen, which owns the Socotra Archipelago (Zajonz et al., 2016). The substantial under-representation of these fisheries within reported statistics and the published literature is problematic, considering that artisanal fishing is the main source of income in Socotra (Hariri et al., 2002) and subsistence catch is important for local food security. There is little agriculture except for modest gardening on the Archipelago and the population relies on local fish, meat, milk, and dates (Anon, 2016). The poverty rate in Socotra surpassed 65% in 2018 (Anon, 2022), so imported food products are unaffordable for the vast majority of the population (Anon, 2016).

During the 1950s and 1960s, the small population of Socotra engaged in fishing for subsistence and local trade purposes (Botting, 1958; Boxhall, 1966; Brown, 1966). Several historical events influenced the development of the artisanal sector starting in the 1970s. There was an internal population redistribution from inland

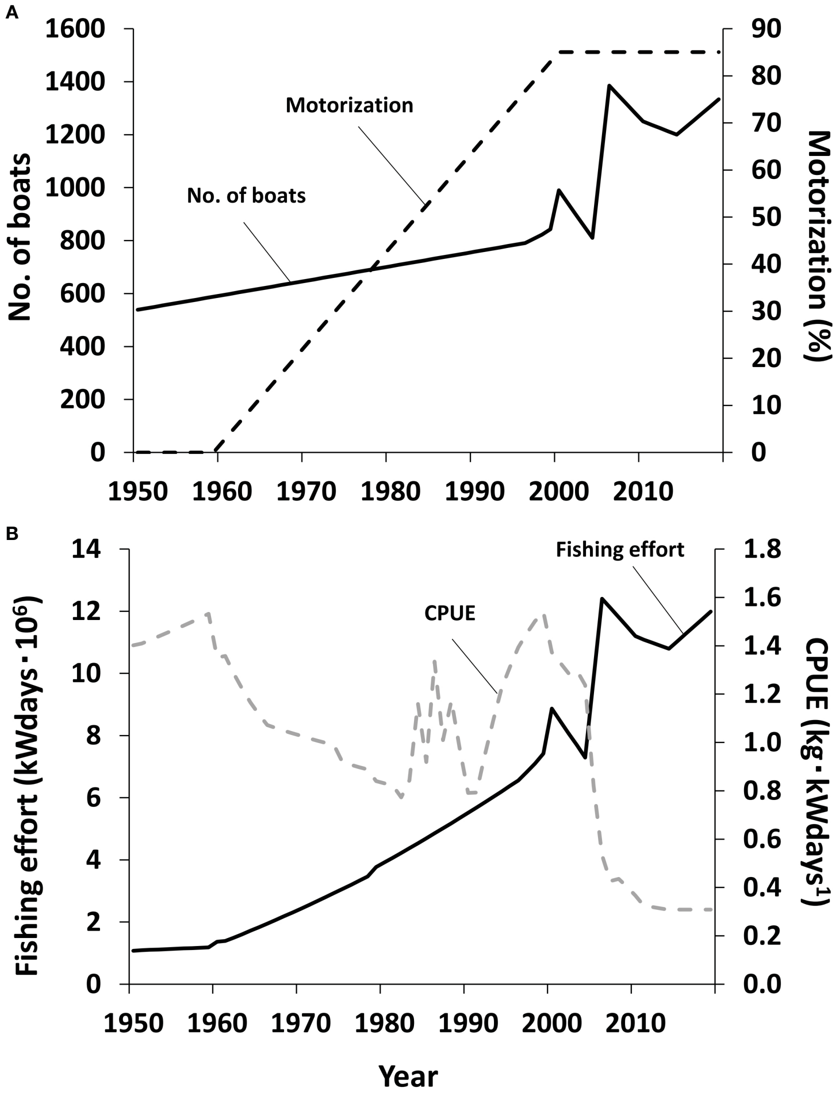

FIGURE 3
Fishing capacity, fishing effort and CPUE of the small-scale fisheries in the Socotra Archipelago for 1950 to 2019, by **(A)** the number of fishing boats and the assumed percentage of motorization; and **(B)** reconstructed effective fishing effort and catch-per-unit-of-effort (CPUE).

areas to the coast with the introduction of a land redistribution policy in 1970 that promoted fishing and farming (Ismael and Ismael, 1986; Elie, 2010). Furthermore, during this time, the Yemeni Ministry of Fish Wealth began to support the development of the artisanal sector as a response to local fishers establishing fishing cooperatives (Elie, 2010). This promoted fishing over pastoralism as a livelihood (Elie, 2010). Subsequently, the return of one million expatriates to Yemen from Saudi Arabia after the 1991 Gulf war added substantially to the number of people entering the artisanal fishery (Alabsi and Komatsu, 2014).

Starting in the 1990s, environmental conservation and ecological restoration initiatives began to be established in response to the decrease in productivity in local fisheries (UNDP, 2012). In 1996, the Socotra Island Protected Area was designated as an MPA (Khalfallah et al., 2020). Furthermore, in 2000, a Conservation Zoning Plan became the legal basis for conservation efforts in the archipelago (Scholte et al., 2011) and the Roush MPA gained official legal status as a marine sanctuary (UNDP, 2012). In 2003, the Socotra Island Protected Area was designated as a UNESCO-MAB Biosphere Reserve (Khalfallah et al., 2020) and nature sanctuaries were forecasted to bring revenue from ecotourism (Scholte et al., 2011). Despite these conservation and sustainability efforts, the artisanal fishing sector started to decline steeply during the 2000s and well into 2014, as also evidenced in the reconstructed catch data presented here. This was likely driven by the prolonged overexploitation of many fish stocks since the 1970s, especially for sharks, as fishers on Socotra Island reported declining shark availability (Hariri et al., 2002). Given the high fishing vulnerability of many shark species driven by their susceptible life history dynamics, such declines are exceedingly common (Davidson et al., 2016; Pardo et al., 2016; Dulvy et al., 2017).

Subsistence catches, especially in the form of reef and intertidal gleaning of mollusks, on the other hand, began to increase rapidly in the early 2010s, accounting for 63% of total catches by 2019. This more or less mirrors the trend on the Yemeni mainland, where subsistence catches have been increasing since around 2010 (Tesfamichael et al., 2012; Palomares et al., 2021). In Socotra, this can be attributed to an increase in the population with the arrival of people fleeing the civil war on the Yemeni mainland (Nagi, 2020). Such intertidal gleaning is an important subsistence and livelihood activity for the rural poor in coastal regions of many developing countries (Zeller et al., 2015; Grantham et al., 2020; Harper et al., 2020). Gleaning activities are often overlooked as a relevant and often crucial fishing sector in policy and research, as it is a fishing activity primarily carried out by women and children (Harper et al., 2013; Zeller et al., 2015; Grantham et al., 2020; Harper et al., 2020). Unfortunately, there has been an inaccurate gendered narrative for far too long that gleaning is only for subsistence and does not contribute to household income, which excludes women from contributing to decision-making in fisheries management and receiving development assistance and technical training (Sze Choo et al., 2008). Further studies in this area will be important for the Socotra Archipelago, as our study suggests that shellfish gleaning is increasingly contributing the majority of local catch.

Recreational fisheries by foreign tourists in Socotra were a fairly recent development, linked to the construction of the international airport in 1999 (Burdick, 2007). Recreational fishing tours peaked in 2014 at 5,000 tourists, before the Yemeni civil war led to a strong decline in tourist numbers from 2015 to 2018. These recreational fishing tours may increase the exploitation pressures on sharks and pelagic fishes that may increasingly be targeted as trophy fish, despite the relatively low total catch tonnages from recreational fishing documented here. More recently, news outlets suggested that the UAE may have increased its presence on Socotra, potentially facilitating the entry of foreign tourists to Socotra via direct flights from the UAE without coordination with the Yemeni government (Middle East Eye, 2021). Political conflicts and the associated instabilities and increased risks are known to result in significant reductions in the tourism industry (Saha and Yap, 2014). Furthermore, the potential political impact of apparent UAE-influenced tourism on Socotra without official Yemeni government coordination may be leading to uncertainty within Socotra's tourism industry. This suggests that it may become increasingly important to monitor the recreational fishery over time due to the economic importance of ecotourism in Socotra.

The uncertainty around our catch estimates are notable (see Figure 2A, Suppl. Table S8), which is to be expected given the scarcity of underlying data sources and the resulting number of assumptions we had to make in this study. Nevertheless, the catch time series derived here can serve as the currently best available estimates of small-scale catches in the Socotra Archipelago, as they represent the first, and to our knowledge, only time series for all fisheries extractions in the region. We hope our study can serve in support of future sustainable management efforts in these waters, as well as encourage further studies to fill identified data gaps and improve data collection for all fishing sectors in the region.

The trend in fishing effort of the small-scale fisheries on Socotra illustrates the common pattern of an initial gradual increase, followed by a more rapid growth in effort in the more recent decades. The 11-fold growth in small-scale fishing effort over the last 6+ decades documented here for the Socotra Archipelago is a sign of concern, as it is clearly not sustainable for small-scale fisheries. This is illustrated by the 78% decline in CPUE observed here between 1950 and 2019, most of which occurred after 2000. This mirrors the strong decline in small-scale fisheries CPUE between 1950 and 2017 in the Seychelles, which was attributed to the increasing number of fishing vessels and motorization that increased the pressure on fish stocks over time (Christ et al., 2020). Similar patterns of strongly declining CPUEs have been documented also in other small-scale fisheries in the Indo-Pacific (Vianna et al., 2020; Zeller et al., 2021). While trends in CPUE need to be interpreted cautiously with regards to their correlation to changes in underlying biomass of fished species, they can serve as good first-order indicators in the absence of stock assessments (Zeller et al., 2021). In such situations, a clearly declining trend in CPUE can suggest a decline in the relative abundance of the underlying fisheries resource.

The observed decline in CPUE after 2000 suggests that Socotra's fish stocks may be overfished or at high risk of overexploitation, which is further supported by observations in the literature that on-going unsustainable yields by the artisanal fisheries in Socotra have depleted fish populations (Zajonz et al., 2016). This is a critical finding, as the human population on these islands is reliant on small-scale fisheries for livelihood and food security, particularly in light of the population growth in recent years as a result of migration of people to Socotra to escape the civil war in mainland Yemen.

Small-scale fisheries have always been important to the people of Socotra for food security and livelihoods. Socotra's dependence on its small-scale fisheries is only increasing, but the current severe political and humanitarian crisis is creating growing pressures on already overfished stocks. Our study suggests that improved monitoring and estimation of small-scale fisheries data in the Socotra Archipelago is needed to assess and support better conservation and sustainability initiatives for Socotra's fisheries and marine ecosystems.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://www.seaaroundus.org/data/#/eez/977?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10.

Author contributions

BD: Advised on methods, reviewed and edited the manuscript. KB: Completed data reconstruction to 2019 and drafted and revised the manuscript. AZ: Completed earlier fishing effort data reconstruction and edited the manuscript. VA: Contributed to, reviewed and edited the manuscript. DZ: Advised on methods, guided analysis, contributed to the manuscript and reviewed and edited the manuscript. DP: Initiated and guided the conceptualization of the study. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1201661/full#supplementary-material

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