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REVIEWS

Arabian/Persian Gulf artisanal fisheries: magnitude, threats, and opportunities

Abdulrahman Ben-Hasan · Moslem Daliri

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Abstract The Arabian/Persian Gulf ('Gulf' hereafter) is bordered by eight countries that consider fishery as their most important renewable resource. This includes artisanal fisheries, which are a major contributor to seafood production and fishers' livelihoods. Despite the importance of the artisanal sector, in-depth studies examining aspects—like total and country-specific production trends, used fishing gears and main threats—remain limited. Inadequate knowledge about such fundamental aspects could jeopardize the sustainability of fisheries and muddle policy-making. Here, we provide a comprehensive account of artisanal fisheries in the Gulf. Specifically, we examined: (i) magnitude of the artisanal sector, (ii) types of fishing gears used, (iii) exploited functional groups, and (iv) threats to and opportunities for sustainable artisanal fisheries. We show that around 71% of the Gulf total catch is produced by artisanal fisheries, and this trend is growing. The dominating fishing gears are gillnets, traps, and lines—collectively accounting for 72% of the total catch. Among these fishing gears, gillnets alone account for a third of the production. Most of the artisanal catch comprises medium to large fish that are demersal, pelagic, and reef-associated. Fisheries are primarily based on gear restrictions, minimum size of capture, seasonal closures, and spatial restrictions. However, weak enforcement is a core issue for the effectiveness of management regulations. Mismanaged fisheries, coastal development, and climate change are primary threats facing fish abundance and essential fish habitats. Engaging artisanal fishers in management and preserving habitats can contribute toward sustainable artisanal fisheries in the Gulf.

Keywords Arabian/Persian Gulf · Artisanal fisheries · Fisheries management · Habitat modification · Overfishing

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A. Ben-Hasan (✉)
Marine Science Department, College of Science, Kuwait University, Kuwait City, Kuwait
e-mail: abdulrahman.benhasan@ku.edu.kw

M. Daliri
Fisheries Department, Faculty of Marine Sciences and Technology, University of Hormozgan, Bandar Abbas, Iran

M. Daliri
Research Department of Fisheries Management and Sustainable Development of Marine Ecosystem, University of Hormozgan, Bandar Abbas, Iran

Introduction

Contrary to what the name implies, small-scale or artisanal fisheries have a sizable contribution to food production, maintaining livelihoods and supplying essential nutrients to numerous communities

around the world (Kawarazuka and Béné 2010; World Bank 2012; Pauly and Zeller 2016; Short et al. 2021; Arthur et al. 2022). In general, artisanal fisheries involve low-cost and labor-intensive fishing operations that target a wide range of species using relatively small boats (Chuenpagdee et al. 2006; World Bank 2012; King 2013). Globally, artisanal fisheries produce 37 million tons of harvest—representing 40% of the global inland and marine capture fisheries (FAO 2022). Along the value chain of fisheries, the artisanal sector directly employs around 60 million people (part- and full-time), representing 90% of the total people employed in capture fisheries worldwide (FAO 2022). Shedding light on artisanal fisheries is, therefore, crucial to facilitate effective and participatory governance of this relatively understudied fishing sector. However, because many aspects of artisanal fisheries can be context-specific, a region-by-region examination is often required.

The Arabian/Persian Gulf ('Gulf') is a semi-enclosed basin surrounded by eight countries: Iran, Iraq, Kuwait, the Kingdom of Saudi Arabia (KSA), Bahrain, Qatar, the United Arab Emirates (UAE), and Oman (only Musandam Peninsula) (Fig. 1). Each of these countries has its own exclusive economic zone (EEZ) (Table 1). The Gulf is located in an arid region that is characterized by dry and hot weather, leading the marine system to experience more extreme oceanographic conditions, such as: sea surface temperature that surpasses 36 °C in summer and plummets to below 15 °C in winter, and elevated salinity due to low precipitation and high evaporation (Riegl and Purkis 2012a; Vaughan et al. 2019). Such conditions, however, do not preclude the existence of productive habitats—like mudflats, coral reefs, seagrasses, and mangroves—and the development of fisheries (Grandcourt 2012; Bayani 2016; Vaughan et al. 2019). Fish resources, in particular, are the most important renewable resources in the Gulf (Sale et al. 2011; Grandcourt 2012). Many of these fish stocks are likely shared between the eight countries bordering the Gulf, owing to the relatively small size of the Gulf (Hoolihan 2004).

The Gulf fisheries are primarily artisanal in nature, although they operate on a scale that can be considered commercial (Grandcourt 2012). They use different traditional fishing gears to exploit a wide range of fish species, such as wire traps and stake nets (Fig. 2). Artisanal fisheries are crucial in fulfilling the growing demand and per capita consumption of fish and

Fig. 1 Map of the Arabian/Persian Gulf

Table 1 Size of the exclusive economic zone (EEZ), shelf area, inshore fishing area (IFA), and the fraction of IFA relative to EEZ for the Arabian/Persian Gulf countries

Country	EEZ (km^2)	IFA (km^2)	IFA/EEZ (%)
Iran (Excluding Sea of Oman)	97,860	67,933	69
UAE	54,580	51,330	94
KSA	33,840	26,565	79
Qatar	31,800	24,274	76
Kuwait	11,860	9,658	81
Bahrain	7,596	6,224	82
Oman (Musandam)	6,678	6,678	100
Iraq	601.4	531	88

IFA is defined as the area that expands to either 50 km from shore or 200 m depth contour, whichever comes first (Chuenpagdee et al. 2006). UAE is United Arab Emirates, and KSA is Kingdom of Saudi Arabia. The size of the EEZ is obtained from (Van Lavieren and Klaus 2013) except for Iran (excluding Sea of Oman) and Oman (Musandam Peninsula only), which, along with IFA areas are obtained from www.seaaroundus.org/. There are some marine areas that are still contested. Countries are ordered based on the size of EEZ

Fig. 2 Fishing gears and practices of artisanal fishery in the Gulf. **A** Gillnet fishery in Bushehr province (Source: Milad Moein). **B** Traps (locally known as Gargoor) in Qeshm Island (Source: Moslem Daliri). **C**. Sale of catch in one of Bandar Abbas fish markets (Source: Abdulrahman Ben-Hasan). **D**. Gathering of fish caught by a stake net (Source: Mehrnaz Ghanbarzadeh)

seafood in the Gulf, which have risen from around 34 kg in 1961 to 63–91 kg in 2017 (Supplementary Information, Figures S1 and S2). Indeed, they significantly contribute to the total fishery capture production in the Gulf (Al-Abdulrazzak et al. 2015). The Gulf artisanal fisheries have high accessibility to much of the EEZ area (Table 1). The inshore fishing area, an area of a maximum of 50 km from the coast or to 200 m depth in which artisanal fisheries are assumed to operate, occupies a large fraction of all of the countries' EEZs (Table 1) (Chuenpagdee et al. 2006). Artisanal fisheries also sustain thousands of livelihoods in the Gulf (Bayani 2016); for example, in the Hormozgan province of Iran, around 22,500 fishers depend on artisanal fisheries for their livelihoods (Fig. 2) (Daliri et al. 2016).

Despite the importance of artisanal fisheries in the Gulf, a comprehensive understanding of this fishing

sector remains limited. Here, we first examine the magnitude of artisanal fisheries in the Gulf region in terms of fish production. Second, we identify the main fishing gears and targeted fish groups. Third, we provide an overview of the available management actions and regimes that are implemented to sustain fish stocks, along with the core issues in the existing fisheries management plans. Fourth, we underscore mismanaged fisheries, coastal development, and climate change as major threats to fish stocks. We conclude with some considerations for fisheries governance in the Gulf.

Magnitude of artisanal fisheries

To determine the magnitude of artisanal fisheries in the Gulf, we used the Sea Around Us Project (SAUP), a freely accessible database, to obtain the catch time-series data for the Gulf as a marine ecoregion (Pauly et al. 2020). We further classified the total artisanal catch by fishing sector (e.g., artisanal and industrial fishing sectors), gears, and exploited taxa. Because we relied on SAUP database in examining artisanal catch, we followed its definition of artisanal sector, in which the sector comprises the following characteristics: small-scale (e.g., hand lines and gillnets) and fixed fishing gears, catch is sold commercially with a small fraction being consumed or given away by the crew, fishing occur predominantly in the exclusive economic zone and limited to coastal waters of 50 km from the coast or to 200 m depth (Chuenpagdee et al. 2006).

Generally, the reconstruction of SAUP catch datasets rests on two basic principles: (i) unavailable data (i.e., 'NA' or 'no data') are not turned into zero, (ii) instead, an approximate and conservative estimate of catch, which can be based on, for example, number of fishing vessels and average catch rates, is inserted in all such cases (Pauly and Zeller 2016). A full account of SAUP catch reconstructions is provided by (Pauly and Zeller 2015).

Fisheries production

Fisheries production in the Gulf is rapidly increasing over the last two decades, with the total catch in 2018 amounting to around 671,000 tons (Fig. 3 A). Out of this catch, artisanal fisheries dominate production in the Gulf (507,000 tons in 2018; Fig. 3B). For example, the relative contribution of artisanal fisheries to the total catch over the last decade is 71% (Fig. 3B; Supplementary Information, Table S1). The increase in the total catch can be attributed to a number of reasons, including e.g., the sheer increase in the artisanal fishing effort, particularly in Iran; the productivity of the ecosystem; and the expansion of fisheries to new fishing grounds (Morgan 2004; Rousseau et al. 2019). It is also notable that the catch trend of the industrial sector has been declining since the mid-1990s (Fig. 3B). A possible reason for this decline could be the "artisanalization" of the industrial fishing fleet: because the artisanal fishing sector in the

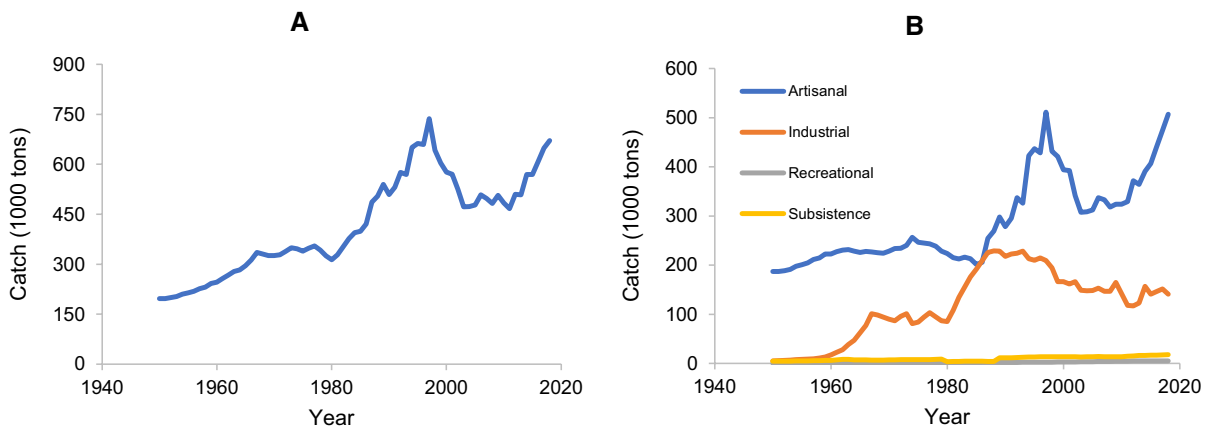

Fig. 3 Catch trends in the Arabian/Persian Gulf between 1950 and 2018. **A** Total catch; **B** Total catch by fishing sector

Gulf is cost-efficient, industrial fisheries are likely substituting part of their fishing fleet with artisanal vessels (e.g., dhow boats). This "artisanalization" was implied, for example, in Kuwait's industrial shrimping fleet: fishing companies responded to the high maintenance costs and reduced catch rates by exchanging 27 double-rigged industrial trawlers for 38 dhow boats (Al-Husaini et al. 2015).

The largest artisanal fisheries in the Gulf occur in Iran, with a growing fish production from ~ 147,000 tons to ~ 342,000 tons between 2009 and 2018 (Figs. 4A and B). In most of the Gulf countries, the artisanal catch is much larger than that obtained by the industrial sector—and it is growing (Supplementary Information, Figures S3–S10). Though questions remain around the sustainability of Gulf artisanal fisheries, the supply of wild-capture fish is crucial to meet the growing fish consumption in the Gulf (Supplementary Information, Figures S1 and S2). Overall, these results highlight that artisanal fisheries are expanding and are the most significant fishing sector in the Gulf. This contrasts with the global catch pattern, which shows that industrial fisheries are the dominant sector (though the contribution of artisanal fisheries is growing) (Pauly and Zeller 2016).

Fishing gears and exploited taxa

The Gulf artisanal fleets harvest predominantly with gillnets, traps, and lines (e.g., hand lines and long lines) (Fig. 5; Supplementary Information, Table S2 for a description of each fishing gear). Collectively, these three fishing gears provided 72% of the total artisanal catch over the past ten years. Gillnets, in particular, provide around a third of the total artisanal catch in the Gulf. In general, gillnets are widely applied by artisanal fisheries in coastal waters of many countries due to their simplicity, efficiency, and relatively low operating costs (Valdemarsen 2001; Northridge et al. 2017). The contribution of some fishing gears to total catch is rising (e.g., bag nets and cast nets), whereas others, notably encircling nets, have experienced an overall decline over the past two decades (Fig. 5).

Most of the artisanal catch consists of demersal fish, followed by reef-associated and pelagic fish (Fig. 6 A and B; further details of each category are provided in Supplementary Information, Table S3, and Figures S11–S14). The proportion of demersal species in the total catch has been stable over the years at around 30–40%, whereas both reef-associated fish and pelagic fish are experiencing upward trends (Fig. 6 **B**). The catch is mostly composed of medium and large fish: around 86% of the catch is categorized as medium (30–89 cm) and large (> = 90 cm) fish over the last decade (Fig. 7A). Medium fish, both demersal and reef-associated, as well as large pelagic and large reef-associated fish, comprised the largest fraction of the catch during the period 2009–2018 and are increasingly targeted (Fig. 7B). Larger fish species are often more desirable due to their market value and therefore fished more widely. They are also

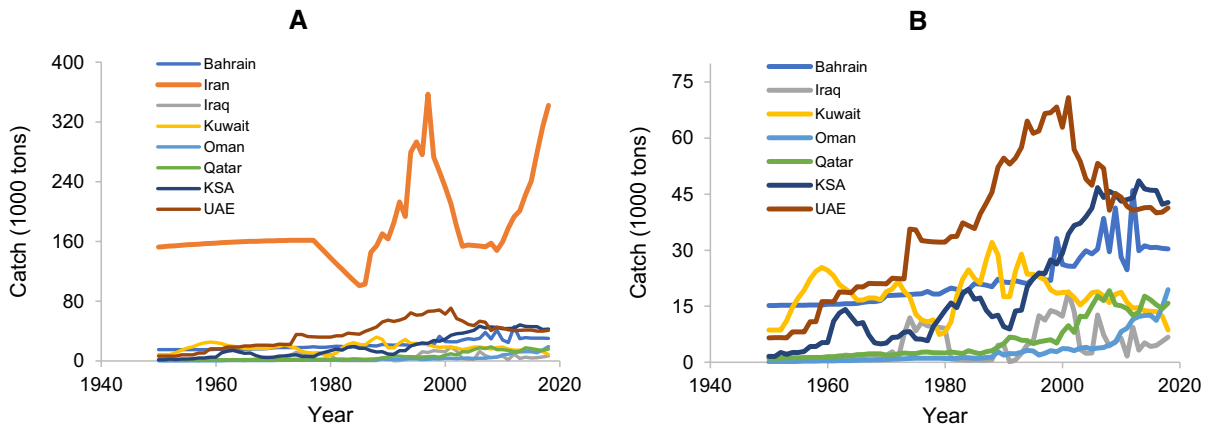

Fig. 4 Catch trends of artisanal fisheries in the Arabian/Persian Gulf between 1950–2018. **A** Artisanal catch by country; **B** Without Iran's catch

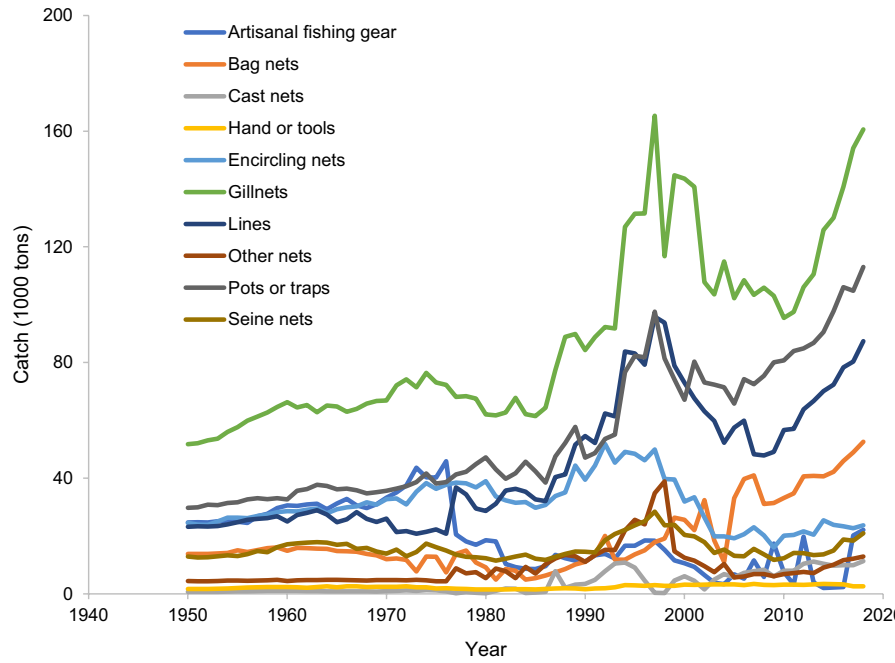

Fig. 5 Total catch in the Arabian/Persian Gulf by fishing gear between 1950 and 2018 (a description for each fishing gear is provided in Supplementary Information Table S2)

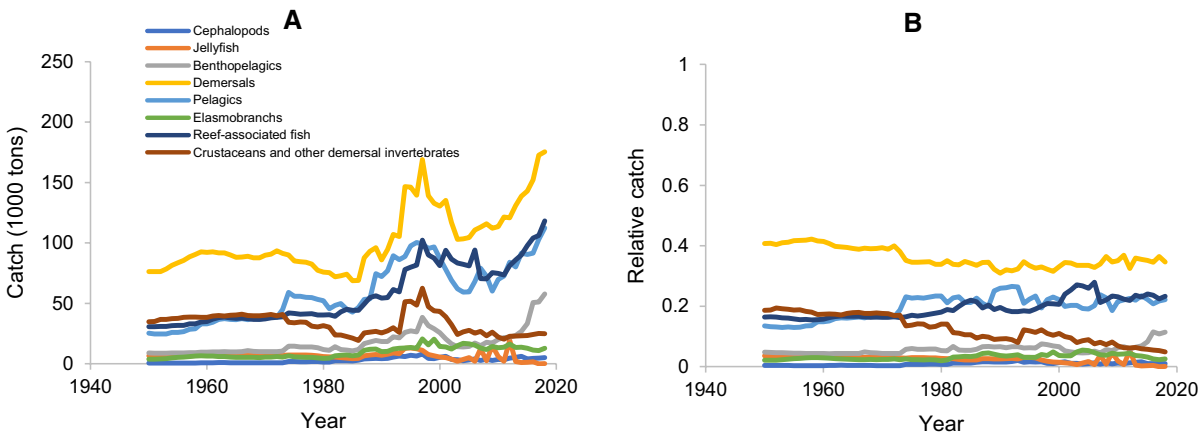

Fig. 6 Catch trends of the functional groups caught by artisanal fishries in the Arabian/Persian Gulf between 1950 and 2018. **A** Catch by functional groups; **B** Relative catch of each functional group to the total catch

more vulnerable to a range of fishing gears (Dulvy and Reynolds 2002; Pauly et al. 2005; Sadovy de Mitcheson et al. 2013). While it is recognized that larger fish species are the first to be depleted, fisheries can generally sustain or increase their catches by expanding to previously unfished areas (Pauly et al. 1998; Bhathal and Pauly 2008).

Fisheries management

Local fisheries regulations in the Gulf are primarily based on: (i) gear restrictions; (ii) minimum size of capture; (iii) seasonal closures; and (iv) spatial restrictions (marine protected areas) (Table 2) (Siddeek et al. 1999; Van Lavieren and Klaus 2013; Al-Husaini et al. 2015; Lin et al. 2021).

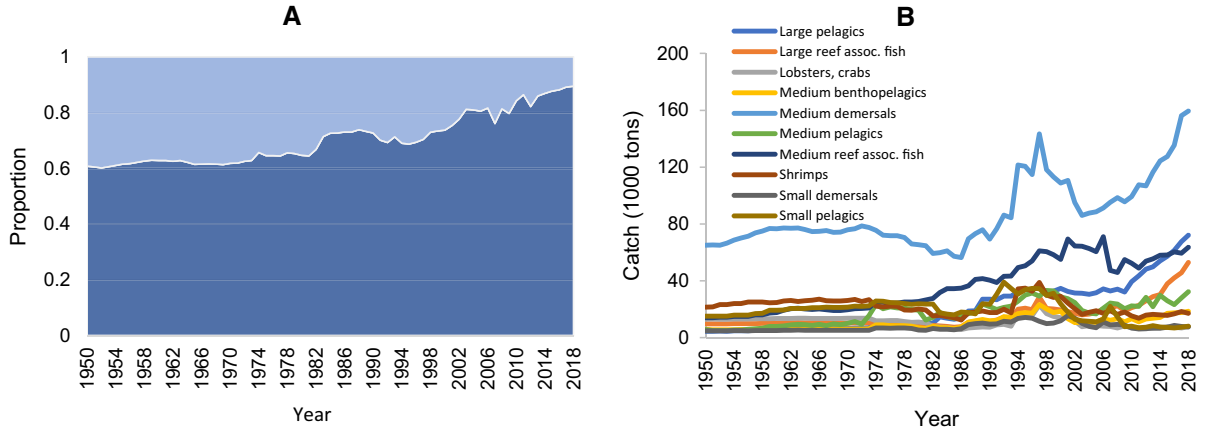

Fig. 7 Catch trends of the main taxa targeted by artisanal fisheries in the Arabian/Persian Gulf between 1950 and 2018 and categorized according to the following size ranges: large (>=90 cm), medium (30–89 cm) and small (<30 cm) (Supplementary Information, Table S3). **A** Proportion of medium and large size fish groups (dark blue) relative to the total catch; **B** Top ten exploited taxa

Restrictions on fishing gears vary among the Gulf countries (Table 2) (GCC 2017). The use of drift gillnets is banned in KSA and UAE; however, it is regulated in the other countries through, for example, specifying mesh sizes and defining fishing grounds for using drift gillnets (GCC 2017). For example, the management agency in Kuwait specifies the size of the mesh of drift gillnets for different pelagic fish (e.g., mullet species), while in Bahrain they can only be used to capture the narrow-barred Spanish mackerel (*Scomberomourus commerson*) with fishing conducted three-miles away from the coast (GCC 2017). Trawl nets are banned in Oman, Qatar and UAE (Table 2). In Bahrain, Kuwait, KSA and Iran, they are largely used to target shrimp, and similar to the drift gillnet, trawl nets are regulated by limiting the mesh size, the depth, and the area in which trawl nets are deployed. Overall, the highest diversity of applied fishing gears is found in Bahrain (8 out of 9; only beach seine is banned) and Iran (8 out of 8), whereas fishing gears diversity is least in Qatar (4 out of 9) and UAE (3 out of 8) (Table 2).

Closed seasons are mainly imposed to safeguard the spawning stock of commercially important shrimp and fish species in the Gulf. For example, there is a seasonal closure for catching shrimp (notably, the green tiger shrimp (*Penaeus semisulcatus*)) in Kuwait and for catching white-spotted spinefoot (*Siganus canaliculatus*) and spangled emperor (*Lethrinus nebulosus*) in UAE (Al-Husaini et al. 2015; EAD 2021). Size limitations, which determine the legal sizes at which fish can be retained, are commonly implemented across the Gulf. For example, the minimum size limitation for the orange-spotted grouper (*Epinephelus coioides*) in the UAE and Kuwait is 45 cm, and the Malabar red snapper (*Lutjanus malabaricus*) has a minimum size limitation of 40 cm in Kuwait and 35 cm in UAE (MOEW 2015; PAAAFR 2015). Additionally, all Gulf countries have established marine protected areas (MPAs) so as to protect sensitive habitats and nursery areas, though the fraction of protected areas differs among countries: UAE has the highest fraction of MPA relative to its EEZ, while Oman has the lowest (Table 2) (Van Lavieren and Klaus 2013).

Mechanisms for communication between governments and fishers through unions, associations, and cooperatives exist in most Gulf countries (Table 2). However, this co-management is largely consultative: decisions are predominantly taken by government agencies, and fishers' views are incorporated on an ad hoc basis (De Young 2006; Pomeroy and Rivera-Guieb 2006). This is in contrast to the cooperative type of co-management, where fishers are treated as equal partners in decision-making (Pomeroy and Rivera-Guieb 2006). There is, therefore, limited effective cooperation between government agencies and artisanal fishers to take responsibility for and manage exploited fish resources in the region. However, authorities in Iran and UAE show a greater

Table 2 Selected fisheries regulations and management regimes in the Arabian/Persian Gulf (see Supplementary Information, Table S4, for references).

Country	Gear-based regulations									Size limitation?	Closed season?[a]	MPA (% of EEZ)	Co-management	International fisheries management
	Surrounding net	Trawl net	Drift gillnet	Set gillnet	Trap	Stake net	Trammel net	Longline	Beach seine					
Bahrain	R	R	R	A	R	R	R	R	B	Y	Y	7.9	Fisheries cooperative	RECOFI agreement to manage kingfish
Iran	R	R[b]	R	R	R	R	NA[c]	R	R	N	Y	8.2	Fishermen associations	RECOFI agreement to manage kingfish; Agreement to catch silver pomfret with Kuwait
Iraq	–	–	–	–	–	–	–	–	–	–	Y	0	Fisherman's cooperative	RECOFI agreement to manage kingfish
KSA	NA[c]	R[d]	B	R	R	R	B	A	B	Y	Y	6.8	-[e]	RECOFI agreement to manage kingfish
Kuwait	B	R	R	R	R	R	B	B	B	Y	Y	5.3	Fishermen Union	RECOFI agreement to manage kingfish; Agreement to catch silver pomfret with Iran
Oman[f]	R	B[g]	R	UR	R	NA[c]	NA[c]	A	R	Y	Y	0.06	Senate Al-Bahar[h]	RECOFI agreement to manage kingfish

Table 2 (continued)

Country	Gear-based regulations									Size limitation?	Closed season?[a]	MPA (% of EEZ)	Co-management	International fisheries management
	Surrounding net	Trawl net	Drift gillnet	Set gillnet	Trap	Stake net	Trammel net	Longline	Beach seine					
Qatar	B	B	R	B	R	R	B	R	B	Y	Y	2.1	No[i]	RECOFI agreement to manage kingfish
UAE	NA[c]	B	B	B	R[j]	R	B	B	R	Y	Y	12.7	Fisheries cooperative	RECOFI agreement to manage kingfish

[a]There is a scheduled closed season for the narrow-barred Spanish mackerel (*Scomberomorus commerson*) in all countries, in addition to being implemented to manage local species

[b]For shrimp trawlers

[c]In Iran, Oman and UAE, the fishing gears are not used (GCC 2017); in KSA, the fishing gear is regulated in the Red Sea but there is no mention on its use in the Arabian/Persian Gulf (GCC 2017)

[d]For bottom trawl nets targeting shrimp. There is no midwater trawling

[e]There are fisheries cooperatives along the coast of Red Sea but no information was found for the Arabian/Persian Gulf

[f]The major fisheries of Oman occur in the Sea of Oman and the Arabian Sea

[g]For bottom trawl nets

[h]In Oman "Senate Al-Bahar" is a traditional management regime that is based on conventions and informal social sanctions that fishers follow to manage fishery resources (Al-Qartoubi and Al-Masroori 2020). In 2018, Oman Fishermen Association has also been established (MoSD 2020)

[i]In 2021, there were calls to establish fisheries cooperative in Qatar (Raya 2021)

[j]Banned in Abu Dhabi waters (MOEW 2019)

"R" indicates regulated; "A" indicates allowed; "B" indicates banned; "Y" indicates yes; "EEZ" indicates exclusive economic zone; "NA" indicates not applicable; "N" indicates no; and "UR" indicates unregulated. The term "regulated" describes fishing gears that are mentioned in the legislation and there are laws that regulate its use; the term "unregulated" describes fishing gears that are not mentioned in the legislation; the term "banned" describes fishing gears that are prohibited from being used by law; and the term "allowed" implies that fishing gears are mentioned in the legislation, but there are no laws that regulate its use. These descriptions were obtained from (GCC 2017) after translation, except for the term "allowed", which did not have a clear description in the reference. Gear-based regulations include, e.g., restrictions on mesh size, depth, and area of fishing grounds (see main text). No detailed information was found for Iraq, though marine gillnets in general are regulated through restrictions on mesh size but with minimal enforcement (De Young 2006). The list of fisheries regulations may include other fishing sectors

extent of fishers' involvement in fisheries assessment and management (Daliri et al. 2016; EAD 2021). In the UAE, for example, fishers are increasingly engaged in the management framework: traditional fishing knowledge of the fishing community are collected to inform management about the status of fish stocks in UAE (EAD 2021). Information gathered from traditional fishing knowledge, alongside formal quantitative approaches, has been key for the launch of the National Framework for Sustainable Fisheries (2019–2030), which initiated efforts to rebuild fisheries in the UAE.

On the international level, there are few fishing arrangements among countries to harvest transboundary fish stocks (Table 2). Members of the Regional Commission for Fisheries (RECOFI), which includes the eight countries in Table 1, recently reached an agreement to implement a seasonal closure for the narrow-barred Spanish mackerel (*S. commerson*) from mid-August to mid-October (RECOFI 2021). A similar agreement exists between Iran and Kuwait to harvest the silver pomfret (*Pampus argenteus*) in the northern Gulf, where a 45-day ban takes place between May to June (Al-Husaini 2003).

Issues in fisheries management

We underscored three central issues in the management of the Gulf fisheries: (i) lack of systematic data collection and stock assessment, (ii) absence of effective international fisheries management, and (iii) weak enforcement of regulations (Siddeek et al. 1999; Morgan 2004; Al-Abdulrazzak and Pauly 2014a; Al-Abdulrazzak et al. 2015; Jabado and Spaet 2017; Ben-Hasan and Christensen 2019; Ben-Hasan et al. 2020). Below we discuss each of these points in more detail.

Lack of routine data collection and stock assessment

The majority of fisheries in the Gulf are poorly or unassessed, which in part explains the scarcity of management actions like catch limits or rebuilding plans (Table 2) (Siddeek et al. 1999; Ben-Hasan and Christensen 2019). Imposing a science-based limit on the total annual catch requires long-term data—e.g., historical information sources on the total removal of fish, indices of relative abundance—and conducting stock assessment models that use such data to estimate a sustainable harvest level. The limited or lack of data collection programs and stock assessment also complicates designing and setting rebuilding plans, which, along with catch limits, have been shown to be essential instruments in sustaining fisheries around the world (Worm et al. 2009; Melnychuk et al. 2012, 2021). Nevertheless, fish stocks in Abu Dhabi, UAE, are continuously assessed, where the typical number of stocks assessed per year ranges between 3 to 9 (EAD 2021). Additionally, the coverage of these assessments is expanding: the representation of stocks assessed in terms of their contribution to total catch was 30% in 2015, but after four years, the representation increased to 93% (EAD 2021).

Limited international fisheries management

The Gulf countries are considered to share many valuable fish stocks; for example, the silver pomfret, hilsa shad (*Tenualosa ilisha*), orange-spotted grouper (*E. coioides*), javelin grunter (*Pomadasys kaakan*), sailfish (*Istiophorus platypterus*), narrow-barred Spanish mackerel (*S. commerson*) and the green tiger shrimp (*P. semisulcatus*) (Siddeek et al. 1999; Ye et al. 2003; Hoolihan 2004; Morgan 2004; Hoolihan et al. 2006; Al-Husaini et al. 2015). Studies have emphasized the need for effective international management of shared stocks (Munro et al. 2004; Bailey et al. 2010; Grønbæk et al. 2018). The rationale behind such emphasis is that fishing transboundary stocks in the EEZ of one country impacts fishing opportunities in the other country's EEZ (Sumaila 1999). Still, there are limited effective international cooperations to manage shared fish stocks in the Gulf. In addition, the biological and fishery dynamics of most shared fish stocks remain largely unknown. Fishing for silver pomfret—a highly valuable species—between Iran and Kuwait fishing fleets is one of the few studied cases that highlight competition in the Gulf (Al-Husaini 2003; Ben-Hasan et al. 2020). After the Iran-Iraq war (i.e., from 1980 to 1988), silver pomfret catches in Iran soared because of a growing fishing fleet; this has likely resulted in decreased catches in both countries by 75–90% between 1995 and 2017 (Ben-Hasan et al. 2020). There has been positive progress in targeting other shared fish stocks, namely the narrow-barred Spanish mackerel (*S. commerson*) (RECOFI 2021). While it is still pre-mature to evaluate the cooperation to implement the Gulf-wide seasonal closure, it

is an important step toward effective management of shared fish stocks in the region.

Weak enforcement of regulations

The biggest issue facing the sustainability of the Gulf fisheries is probably weak enforcement of the management actions, which is likely commonplace in the region (Siddeek et al. 1999; Morgan 2004; De Young 2006; Al-Abdulrazzak 2013; Al-Abdulrazzak and Pauly 2014a, b; Al-Abdulrazzak et al. 2015; Jabado and Spaet 2017; Jabado et al. 2018; Ben-Hasan et al. 2021). For example, illegal fishing occurs during seasonal closures in Bahrain and Kuwait—and undersized fish are likely frequently captured despite legal minimum size limitations (Siddeek et al. 1999; Ben-Hasan et al. 2021). Additionally, even though fishing gears such as trammel nets and stake nets are banned or regulated in some countries, they are illegally used in major fisheries (Siddeek et al. 1999; Al-Abdulrazzak and Pauly 2014a; Al-Husaini et al. 2015; Jabado and Spaet 2017; Ben-Hasan et al. 2021). In Qatar, for instance, the most common type of violation—in both marine and terrestrial activities—is the use of banned fishing gears and fishing in closed areas, which occur 2–3 times every day (Richer 2009).

Most importantly, while in principle the currently applied management actions can be effective in rebuilding and sustaining fisheries, the lack of strict enforcement is potentially undermining their benefits (Worm et al. 2009; Prince and Hordyk 2019; Cabral et al. 2019). For instance, seasonal closures are generally imposed with a specified start date aimed at preventing growth overfishing (individuals in the recruiting cohort are still small) and a closing date aimed at preventing recruitment overfishing (ensuring sufficient spawning that produces a strong cohort) (Ben-Hasan et al. 2019). Thus, continued fishing during seasonal closure is expected to jeopardize the protection of the spawning stock (through recruitment overfishing) and reduce the maximum potential catch (through growth overfishing). Further, size composition data of the Malabar blood snapper (*L. malabaricus*) in Kuwait shows that fish are caught at much smaller sizes than the legal minimum size limits (Ben-Hasan et al. 2021). Catching small and immature individuals in conjunction with high fishing pressure led to growth and recruitment overfishing, which are major causes of reducing annual catch by ~ 95% between 1995 and 2009 (Ben-Hasan et al. 2021). If high minimum size limits were to be enforced rigorously, projections of Malabar blood snapper catch and biomass trends suggest a substantial recovery over the long term (Ben-Hasan et al. 2021).

Main threats to fish stocks

While there are diverse threats to fish stocks in the Gulf, we focus on (i) mismanaged fisheries, (ii) coastal development, and (iii) climate change because they are recognized as primary threats in the Gulf, and because evidence shows that their observed and/or expected impacts can affect fish at the stock or population levels (Fig. 8) (Siddeek et al. 1999; Sheppard et al. 2010; Van Lavieren et al. 2011; Grandcourt 2012; Cheung 2018; Wabnitz et al. 2018; Brown et al. 2019; Buchanan et al. 2019; Melnychuk et al. 2021).

First, mismanaged fisheries often leads to overexploitation, which unsustainably reduces fish abundance and forgoes some of the potential long-term catch that can be harvested by lowering fishing pressure (Hilborn 2010; Melnychuk et al. 2021). To examine the status of exploited fish stocks in the Gulf, studies primarily used two different approaches: conventional stock assessment methods and the International Union for Conservation of Nature (IUCN) methodology. Stock assessments are rarely applied to infer the status of fish stocks in the Gulf (Siddeek et al. 1999; Grandcourt 2012; Al-Abdulrazzak et al. 2015; Ben-Hasan and Christensen 2019). However, for exploited species with enough data, assessments indicate that Gulf's fish stocks are generally in a precarious condition (Chen et al. 2007; Jayabalan et al. 2011; Niamaimandi et al. 2015; Ben-Hasan et al. 2017, 2020; Ben-Hasan et al. 2021). For example, studies assessing important finfish stocks in the Gulf, like the Malabar blood snapper (*L. malabaricus*), orange-spotted grouper (*E. coioides*), and silver pomfret (*P. argenteus*), suggest that excessive fishing pressure is one of the main drivers of declining catches and abundances (Al-Husaini 2003; Grandcourt 2012; Ben-Hasan et al. 2017, 2020; Ben-Hasan et al. 2021). The IUCN methodology has been applied to chondrichthyans in the Gulf to investigate extinction risks, with findings indicating that around 42–51 chondrichthyans per 100 km^2 are threatened—i.e., "Endangered", "Critically Endangered", and "Vulnerable"

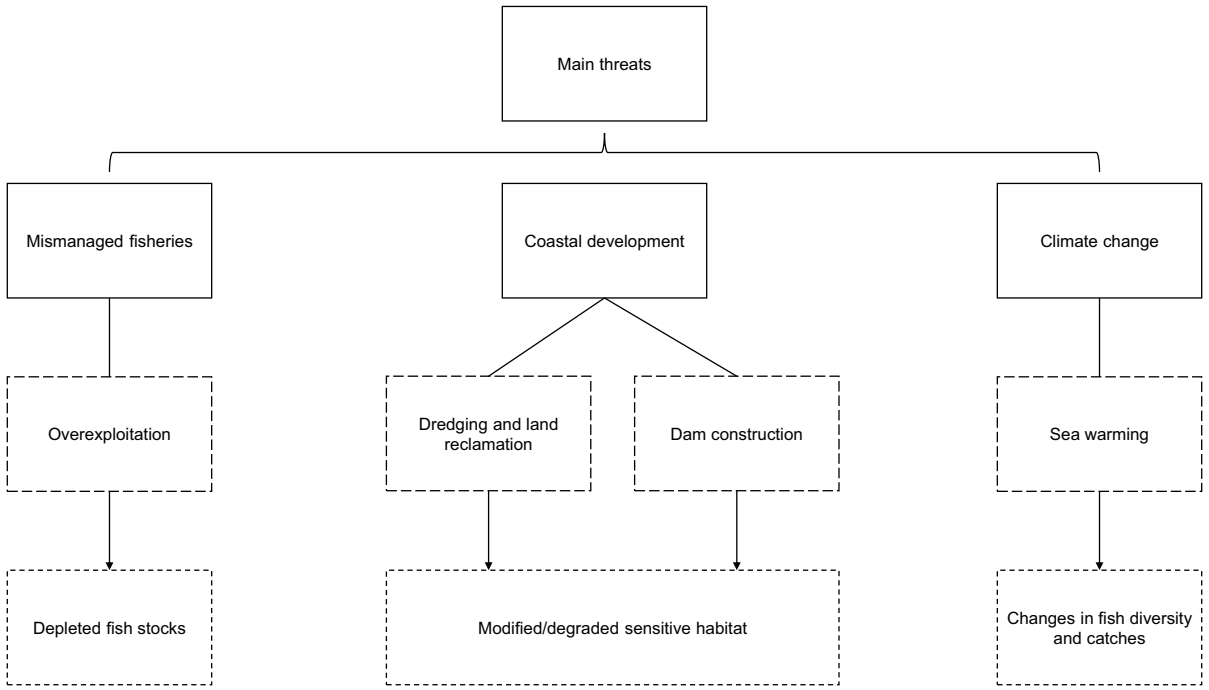

Fig. 8 Outline of some of the main threats, drivers (long-dash boxes), and effects (short-dash boxes) on fish stocks and habitats in the Arabian/Persian Gulf. "Dam construction" mainly refers to damming Tigris-Euphrates Rivers, resulting in a reduction in the Shatt Al-Arab River, a major source of freshwater discharging into the northern part of the Arabian/Persian Gulf (refer to the main text for references)

(Jabado et al. 2018). Furthermore, the IUCN classification conservatively identifies the orange-spotted grouper—the most commercial grouper species in the Gulf—as "Vulnerable", though it is qualified to be under the "Endangered" category.

Second, the coastal area of the Gulf comprises a range of productive habitats like—for example, rocky shores, mudflats, mangrove forests, and coral reefs—and is considered an important nursery and rearing area for various commercial fish and invertebrate stocks (Al-Husaini et al. 2015; Vaughan et al. 2019; Al-Yamani et al. 2021; Edmonds et al. 2021; Lin et al. 2021). Such habitats underpin the productivity of many fish stocks and fisheries in the Gulf. Dam construction in the basins of Tigris-Euphrates Rivers and the extensive dredging and land reclamation activities are significant drivers of coastal habitat degradation and modification (Sheppard et al. 2010; Van Lavieren et al. 2011; Burt 2014; Ben-Hasan et al. 2017, 2018; Al-Yamani et al. 2021). In the northern Gulf, the discharge of Shatt Al-Arab River—formed by the confluence of Tigris-Euphrates Rivers—creates the largest and most important estuarine system (Sheppard et al. 2010). This system provides critical nursery grounds for numerous fish and invertebrate species (Al-Husaini et al. 2015). Because of extensive dam construction, however, the flow of Shatt Al-Arab River has drastically weakened, with salinity levels rising over the last three decades (Sheppard et al. 2010; Lawler 2016; Al-Yamani et al. 2017, 2021). Besides overfishing, the deteriorating discharge of Shatt Al-Arab—and hence the alteration of the estuarine system—is suspected to be a chief cause driving catch declines of important fish stocks in the northern Gulf (Al-Husaini et al. 2015; Ben-Hasan et al. 2017, 2018).

In most of the Gulf countries, the coastal area has undergone extensive changes due to urbanization and industrialization (Burt 2014). A significant part of coastal development projects is dredging and land reclamation activities (Van Lavieren et al. 2011; Sale et al. 2011; Naser 2015). Because coastal developments have often been associated with little environmental considerations, there has been a fast

and widespread degradation of vital coastal habitats (Burt 2014). Dredging and reclamation activities can be environmentally deleterious since they generally involve removing and burying sensitive habitats (Van Lavieren et al. 2011). Such coastal developments have caused severe impacts on many crucial habitats in the Gulf; for example, fragmentation and degradation of thousands of hectares of seagrass beds; burial of coral reef habitats; and a substantial decline in mangrove forest areas in some countries (Spalding 2010; Van Lavieren et al. 2011; Erftemeijer and Shuail 2012; Burt et al. 2013; Burt 2014). Unless the impacts are mitigated, critical habitats like coral reefs, which have contributed to an average of 23% of the total catch in the Gulf over the past decade (Fig. 6 B; "reef-associated fish" category), are expected to further degrade or disappear over the short term (Van Lavieren et al. 2011; Sheppard 2016).

Third, sea surface temperature (SST) is increasing under climate change, with the most rapid warming observed in land-locked or semi-enclosed seas (Belkin 2009; Lima and Wethey 2012). In the Gulf, the annual rate of SST increase differs between the east and west coasts (Hereher 2020). Along the eastern side, the rate of SST change ranges between 0.08 and 0.11 °C/decade but on the western side, it ranges between 0.56 and 0.7 °C/decade (Hereher 2020). Sea warming can have direct effects on fish diversity and fishery catches (Neuheimer et al. 2011; Hannah et al. 2013; Pinsky et al. 2013). Future projections show that local extinctions would be experienced throughout the Gulf, with the highest reductions in the number of species and future catch potential are expected to be along the coast of the western side of the Gulf, including Bahrain, Qatar, Saudi Arabia, and UAE (Wabnitz et al. 2018). Also, the effects of a further increase in sea temperature extend to essential fish habitats like coral reefs. The Gulf coral reefs exhibit greater thermal tolerance than corals in other geographical regions (Riegl and Purkis 2012b; Burt et al. 2019). However, they are not immune to excessively hot summers (Riegl et al. 2018). Recurrent bleaching events have substantially declined the average cover of some corals across the Gulf, and a progressing change in the coral community composition has been recorded with an increased frequency of bleaching events (Riegl et al. 2017; Burt et al. 2019). The increased frequency of mass bleaching and the regional warming rate, which exceeds the global rate, is challenging the capacity of the Gulf coral reef to recover (Burt et al. 2019).

Overall, the proportion of threatened fish species (8.2%) in the Gulf is twice that reported in other regions, with fisheries, coastal development and habitat loss, and climate change affecting 86% of 471 bony fish species (Buchanan et al. 2019).

Opportunities for sustainable fisheries

Artisanal fisheries are the dominant fishing sector in the Gulf: they produce an average catch of around 390,000 tons or 71% of the total catch. This degree of dependence on artisanal fisheries needs profound attention to its sustainability, especially with an expected increase in the demand for seafood. However, local and international fisheries management in the Gulf are largely inadequate, essential data and routine assessments are limited, and enforcement of current regulatory actions is generally weak. Besides the poor fisheries management, a large fraction of coastal areas—comprising primary nursery grounds and other sensitive habitats on which fisheries exist—have experienced substantial modifications or degradation. While it is notable that catches are generally increasing in the Gulf, exploitation rates are also probably climbing, and therefore biomass would decline over time. Below we discuss opportunities for—and highlight bright spots of—fisheries management and habitat restoration, which may help progress toward fisheries sustainability in the region.

Effective local fisheries management

The existing management actions in the Gulf are adequate to sustain artisanal fisheries and protect fish stocks against overexploitation (Worm et al. 2009; Gutiérrez et al. 2011). However, a core issue that is likely undermining the benefits of existing regulations is weak enforcement. To tackle this issue, one approach is to effectively involve stakeholders in collaborative management arrangements (Gutiérrez et al. 2011; Cinner et al. 2012; Worm and Branch 2012). This cooperative management regime is shared by fishers, management representatives, and scientists (Worm and Branch 2012). Importantly, evidence shows that collaborative regimes that consider fishers' goals and enable fishers to develop and enforce

rules about extractive activities are crucial for fishers' compliance and help improve it (McClanahan et al. 2006, 2011; Gutiérrez et al. 2011). In addition, they may facilitate data collection programs. For example, survey programs can be designed among stakeholders, and fishers collect data as they travel to and from fishing areas. Such data can then be used to provide scientific recommendations to achieve both conservation and fishery goals (Worm and Branch 2012).

The progress to sustainable fishing in UAE in general, and Abu Dhabi in particular, is a bright spot of fisheries management in the region. The average biomass of assessed fish stocks in Abu Dhabi waters, including 16 exploited species representing 93% of the total catch, has been steadily recovering in recent years in response to the effective reduction in fishing mortality (EAD 2021). Assessments conducted in 2020 and in previous years by the Environment Agency – Abu Dhabi, indicated that the majority of assessed species (22 out of 32) are sustainably exploited (EAD 2021). The experience with the recovery of Abu Dhabi's fish stocks included several essential ingredients: (i) systematic collection of biological and fishery data; (ii) routine assessment of fish stocks, and inclusion of traditional fishing knowledge, both allowing for the evaluation of stock status; (iii) launch of a long-term strategy aimed at mitigating overexploitation and attaining sustainable fish stocks; and (iv) strict implementation of the strategy through a series of fisheries regulations, including, e.g., banning or regulating the most productive fishing gears so as to reduce the catch of overexploited stocks (EAD 2021).

Effective international fisheries management

The Gulf countries with internationally shared fish stocks should consider cooperating in harvesting transboundary stocks because overfishing these stocks in one EEZ would impact their availability in other EEZs. Some underlying strategies for international cooperation include effective (i) shared scientific collaboration, (ii) shared enforcement, and (iii) a resilient management regime. Below we dissect how each of these strategies can serve the sustainability of artisanal fisheries.

The first strategy, shared scientific collaboration, can provide valuable information on estimating sustainable harvest levels and the mechanism of allocating fish stocks among countries. Internationally coordinated monitoring and data collection programs help in creating a shared scientific understanding of, for example, the biology and migratory patterns of shared fish stocks. Such information, which covers the entire or a large fraction of the distribution of shared fish stock, is central to allocating sustainable harvest quotas based on zonal attachment (i.e., harvest is assigned based on the amount of time the resource spends in each) (Hannesson 2018). The zonal attachment principle has been key in establishing harvest allocations of many major fish resources for two or more countries (Sissener and Bjørndal 2005; Hannesson 2018).

The second strategy, shared enforcement, is possible through an exchange observer program—countries exchange observers on their control ships—or coordinate satellite tracking systems. Such methods, for example, have helped in establishing an organized response to extensive illegal, unreported, and unregulated fisheries between Norway and Russia (Stokke 2009).

The third strategy underscores the need for a resilient management regime. For a long-term successful cooperation, a management regime should entail time-consistency or "resilience" in the face of unpredictable environmental, economic, or political shocks. If the arrangement lacks resilience, a previously effective international management arrangement may fall apart, with cooperation degenerating into competition (e.g., Norwegian Spring Spawning herring) (Hannesson 2018). A resilient regime would be crucial to, for example, manage "species on the move", where the distribution of fish stocks in the Gulf—and hence catch composition and amount—is expected to shift under climate change (Wabnitz et al. 2018; Pinsky et al. 2018).

Habitat preservation and restoration

The modification and deterioration of habitats are one of the biggest threats to fish species in the Gulf (Buchanan et al. 2019). In fact, even if there is good control of fishing pressure, the destruction of essential fish habitats can affect stock productivity and, ultimately, fisheries production (Ben-Hasan et al. 2017; Brown et al. 2019). Restoration and protection of essential fish habitats are critical, at least for the continued supply of recruitment to fisheries;

however, protection is usually more effective than restoration (Brown et al. 2019). Although MPAs are implemented in all gulf countries, their coverage is less than the 10% of coastal and marine areas indicated in the United Nations Sustainable Development Goals 14 (target 14.5); except for UAE, where around 12% of its EEZ is protected (Van Lavieren and Klaus 2013; Andriamahefazafy et al. 2022). Attempts to preserve sensitive habitats in Abu Dhabi emirate have included, e.g., placing major fractions of critical habitat inside established, declared or proposed protected areas. The representation of Abu Dhabi's critical habitats like coral reefs, seagrass, intertidal mudflats, and saltmarshes in such protected areas is 65.4%, 40.8%, 32.8%, and 19.45%, respectively (EAD 2017).

For degraded habitats, many countries in the Gulf are conducting restoration interventions, and where development can not be prevented, countries are establishing environmental compensation programs (Van Lavieren et al. 2011; Deb and McCarthy 2014; Edmonds et al. 2021). For example, experiments to replant mangroves have commenced in several parts of Kuwait with promising results, and afforestation programs in eastern Qatar have increased forested areas, though coastal development remains one of the significant threats to mangrove forests (Al-Khayat and Balakrishnan 2014; Burt et al. 2017; Edmonds et al. 2021). Generally, restoration activities are costly to conduct, even for reasonably accessible habitats like mangroves and coral reefs, and complete failure of restoration projects is common (Bayraktarov et al. 2016). However, bright spots of restoration efforts show that such efforts can be effective over large coastal marine systems (1,000 s–100,000 s ha), persist over long periods of time, and are cost-effective (Saunders et al. 2020).

Conclusion

In summary, artisanal fisheries are the most important fishing sector in the Gulf. The trend of fish harvested by the artisanal fishery is rising in most of the Gulf countries. This suggests that the continued supply of wild capture fish and the maintenance of numerous livelihoods hinges on the sustainability of artisanal fisheries. However, the increasing trend of the total catch is probably accompanied by increasing exploitation rates, which are not met with effective management. Further, extensive coastal development projects threaten essential habitats on which many fish stocks depend. In response to these trends, we discussed four aspects to sustain artisanal fisheries in the Gulf: (i) routine collection of basic fisheries-related data that facilitates robust recommendations for management; (ii) enhanced enforcement of regulation through cooperative management to maximize the benefits of existing management actions; (iii) attempts from countries with internationally shared fish stocks to establish effective cooperation for harvesting shared fish stocks; and (iv) preserving and restoring essential fish habitats. These actions are fundamental for the sustainability of fishery resources in the Gulf.

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