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Fisheries subsidies exacerbate inequities in accessing seafood nutrients in the Indian Ocean

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Harmful, capacity-enhancing subsidies distort fishing activities and lead to overfishing and perverse outcomes for food security and conservation. We investigated the provision and spatial distribution of fisheries subsidies in the Indian Ocean. Total fisheries subsidies in the Indian Ocean, estimated at USD 3.2 billion in 2018, were mostly harmful subsidies (60%), provided to the large-scale industrial sector by mainly a few subsidising countries, including Distant Water Fishing countries. We also explored possible socio-economic drivers of the composition of subsidies, and show that the extent of harmful subsidies provided by Indian Ocean Rim (IOR) countries to their industrial sector can be predicted by the seafood export quantities of these countries. These results illustrate the inequity in accessing fisheries resources for the small-scale sector of nutrient insecure and ocean-dependant IOR countries. The present study can benchmark future assessments and implementation of fisheries subsidy disciplines in the region following the World Trade Organisation Agreement on Fisheries Subsidies.

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INTRODUCTION

Hunger and malnutrition are global challenges leading to health inequities in many countries[1]. In places where human nutrition is most dependent on seafood, nutritional security faces serious burdens if wild fisheries production is reduced[2].

Fisheries subsidies, which are direct or indirect financial transfers from public entities to fishing enterprises, can exacerbate or ease pressures on wild fish production. Therefore, fisheries subsidies are classified as either harmful, beneficial, or ambiguous, based on their impacts on fished stocks[3,4]. Harmful subsidies, also called capacity-enhancing subsidies, enable fishing capacity to increase to a point where resource exploitation exceeds the maximum sustainable yield, effectively resulting in overfishing[5]. Certain parts of the fishing industry rely heavily on these government subsidies that enable industrial fleets to reach the limits of geographical expansion[6,7] and maintain profitability despite diminishing returns[8]. Harmful fisheries subsidies thus pose risks for the security of human nutrition due to declining catch returns from overfished stocks, and create barriers to more equitable fisheries[8–10]. On the other hand, beneficial subsidies can promote fisheries resource conservation, management and sustainability. Some types of subsidies are defined as ambiguous because they can lead to either sustainable management or overexploitation, depending on how and to whom these programs are delivered. Additionally, 13 subsidy types have been identified within the broader categories of harmful, beneficial or ambiguous[11]. The harmful category includes fuel subsidies, non-fuel tax exemptions, fishing access agreements, boat construction, renewal and modernisation, development programs, port development, and market and storage infrastructure. Beneficial subsidies include fisheries management, fisheries research and development, and marine protected areas (MPAs). Fisher assistance, vessel buyback schemes and rural fisher community development are classified as ambiguous subsidy types due to their highly variable impact potential. Fisheries subsidies generally originate from governments and are provided to the private sector to support government objectives. Key objectives can comprise the maximisation of the net present value of a fishery as well as local community support or resource conservation[12].

Global fisheries subsidies amount to around USD 35.4 billion per year, with around 63% being categorised as harmful[3,11], thus driving overcapacity and overexploitation[12,13], and increasing greenhouse gas emissions in the fishing industry[14,15]. Consequently, harmful fisheries subsidies have been the focus of intense negotiation efforts at the World Trade Organization (WTO) for two decades[16–19]. A partial agreement to reduce harmful fisheries subsidies, based on the mandate of the United Nations Sustainable Development Goal 14.6, was reached in June 2022[20]. The agreement bans subsidies for Illegal, Unreported and Unregulated (IUU) fishing and for exploitation of overfished stocks. Additionally, it prohibits subsidies to exploit unregulated stocks on the High Seas, i.e., stocks that are not managed by Regional Fisheries Management Organisations[21,22]. The agreement will enter into force upon ratification by two-thirds of WTO members[21,22]. To date, 41 WTO members out of the 110 members required to reach the quorum have formally ratified the agreement[23]. Whilst a step forward, this agreement failed to completely prohibit harmful fisheries subsidies, and thus maintains numerous loopholes. For example, certain fishing activities taking place in Exclusive Economic Zones (EEZs) are largely excluded from the agreement, and the so-called 'sustainability test' allows members to maintain harmful subsidies for fishing on overfished stocks if "measures are implemented to rebuild the stock to a biologically sustainable level". In addition, this agreement fails to regulate all harmful subsidies which, in general terms, are likely to contribute to overfishing and overcapacity, such as subsidies for the purchase of machines and equipment for vessels, fuel subsidies as well as subsidies for the costs of personnel[24].

Studies that examine fisheries subsidies and their impacts are generally conducted at a global scale[8,25–27], or are specific to

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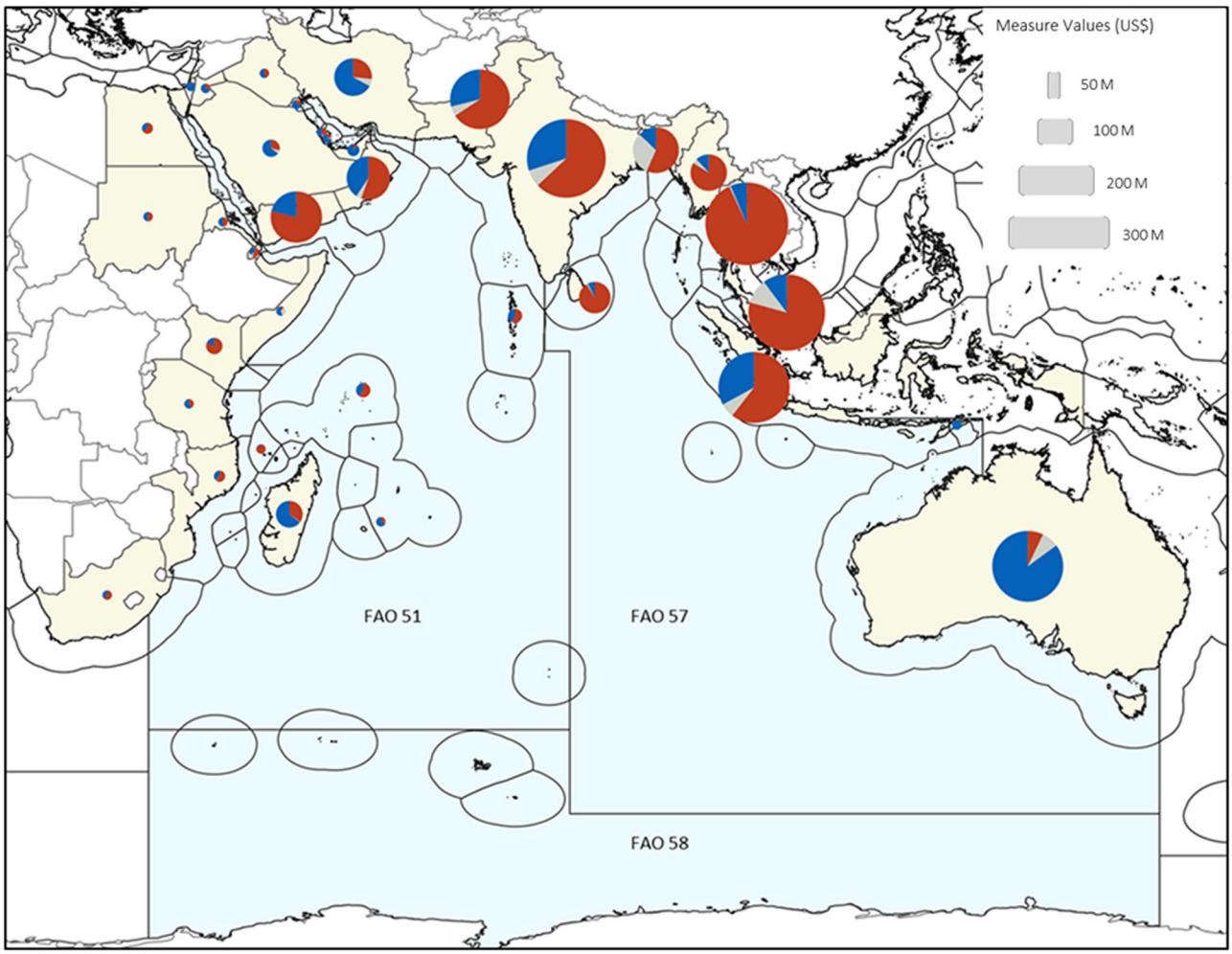

Fig. 1 Fisheries subsidies in USD provided in 2018 in the Indian Ocean (FAO areas 51, 57 and 58, including Red Sea and Arabian/Persian Gulf) by the Indian Ocean Rim (IOR) countries. The size of the pie charts denotes the amount of subsidies. Size is not scaled below USD 50 million. The colours of the pie charts denote the composition of subsidies by the three categories (red = harmful, blue = beneficial, grey = ambiguous).

regional fisheries or individual countries[28–30]. This dearth of intermediate-scale ocean basin studies exists despite such large-scale regional studies permitting a more nuanced examination of the impacts of these subsidies compared to global studies. Therefore, here we focus on the Indian Ocean and to our knowledge, this is the first time that a study explores the provision and impact of fisheries subsidies at the scale of an entire ocean basin. The Indian Ocean is over 70 million km^2 in size and includes Food and Agriculture Organization (FAO) statistical areas 51, 57 and 58, including the semi-enclosed Red Sea and Arabian (Persian) Gulf (Fig. 1). A diverse range of countries across a spectrum of economic development borders the region[31,32] and is home to one-third of the global population[33]. As such, the region is gaining geostrategic and economic importance[34,35]. More than 40% of global trade and two-thirds of the world's fossil fuel resources pass along shipping routes and through important access points in the Indian Ocean[36,37]. However, the region remains globally under-represented in the scientific literature[31,38], including on fisheries[39], even though it includes countries with the highest rate of malnourished populations[40].

The main objective of this study was to synthesise and assess the provision and distribution of fisheries subsidies in the Indian Ocean and explore potential drivers of subsidies. We first examined the overall provision of subsidies associated with fisheries in the Indian Ocean region, and especially the difference between domestic subsidies, i.e., subsidies provided by Indian Ocean Rim (IOR) countries, and Distant Water Fishing (DWF) subsidies, i.e., subsidies provided by fishing entities whose flag-associated territory lies outside the defined Indian Ocean (Fig. 1). Then, we investigated the spatial distribution of fisheries subsidies among the three Indian Ocean FAO statistical areas, and between EEZs and High Seas areas in this ocean basin. Lastly, we explored the relationships between the composition of subsidies, namely the amount of harmful, beneficial and ambiguous subsidies and their socio-economic drivers. The intent for our study is to provide a baseline for future assessments of fisheries subsidisation in the region, with the expectation to inform future steps in subsidies reform.

METHODS

According to the *Sea Around Us* research initiative, there were 35 IOR countries and 18 DWF countries that fished in Indian Ocean waters between 2014 and 2018[41] (Fig. 1). We accessed the reconstructed and spatially allocated catch data from the *Sea Around Us* (www.seaaroundus.org) based on the 2018 data version 48.0[41–43]. We first derived the 5-year average (2014–2018) of global catches and Indian Ocean catches for each fishing country, filtering for "landings" only. We then derived the fraction of each country's retained and landed catch that was obtain from Indian

Ocean waters. It was assumed that the distribution of fisheries subsidies provided by each fishing country was proportional to that country's fraction of the catch that comes from the Indian Ocean. Given the primary goal of any fishing industry is to maximise catches, the impact of subsidies must, to some extent, be relative to the scale of fisheries in a given place[25,44]. Unfortunately, the lack of spatialised information on fisheries subsidies makes it difficult to test this assumption at this point. The subsidies data used are the most recent estimates[11], which compiled fisheries subsidies by maritime country for 2018 in USD by 13 subsidy types, each pertaining to one of the three categories, i.e. harmful, beneficial and ambiguous. For IOR countries, we then applied the same procedure to the fishing subsidies that each of these countries provided to the small-scale and industrial fishing sector[45]. A slightly modified approach was used to calculate subsidy allocation for the 18 DWF countries fishing in the Indian Ocean. We assumed that only large-scale industrial fleets operate in distant waters given logistical constraints of DWF[42]. Therefore, the fraction of subsidies provided by each DWF country to its Indian Ocean fisheries was calculated on the large-scale industrial sector subsidies only, excluding small-scale sector subsidies. The analysis regarding the DWF country group focused on the subgroup of the top 10 DWF countries by level of subsidisation, as they accounted for >99% of the total DWF subsidies in the Indian Ocean.

We performed analyses on the amounts of harmful, beneficial and ambiguous subsidies in three stages. Firstly, the sources of subsidies in the Indian Ocean were explored. We estimated the total provision of subsidies by IOR countries and DWF countries and within each country group we identified the major subsidising entities.

Secondly, we estimated the extent to which different areas of the Indian Ocean are impacted by subsidies. We apportioned fisheries subsidies to each of the three Indian Ocean FAO areas, and to either the EEZs or the High Seas within each FAO area, based on the *Sea Around Us* spatial catch allocated, as described in Zeller et al. (2016)[42] and used globally in Pauly and Zeller (2016)[43]. We identified which EEZs of the Indian Ocean are the most impacted by total subsidies and by subsidies from other IOR countries or from DWF countries. We then computed the subsidy intensity metric (IM) by IOR or DWF country groups and EEZ or High Sea in each FAO area (See Supplementary Methods A).

Lastly, we used predictive models to test the relationship between the composition of fishing subsidies, i.e., the proportion of harmful, beneficial and ambiguous subsidies provided by each country as a function of socio-economic variables sourced from open-source databases (Supplementary Table S1). For example, we hypothesised that economic variables of income growth, seafood export quantity and GDP expenditure in other public sectors influence the composition of fisheries subsidies. The hypothesis for inclusion of GDP expenditure in other public sectors considers the fact that governments have scarce resources to spend among public sectors. Thus, the more financial resources are allocated to one public sector, the fewer resources there are for aquatic subsidisation. As a proxy of GDP expenditure in other public sectors, we tested the expenditure of the GDP in the public health sector. We also used indices for nutritional, economic and coastal dependencies on seafood from Selig et al. (2019)[46]. Previous studies suggested that countries where labour abuses at sea and illegal fishing are documented, appear to provide higher levels of harmful fisheries subsidisation[47]. Given these aspects could be deemed related to corruption[48], we tested a corruption index[49]. We performed correlation analyses between each independent variable to ensure that any two variables with correlation coefficient $r > 0.6$ were not both included. The set of independent variables used in the IOR countries (Supplementary Table S2) and DWF countries (Supplementary Table S3) analyses ensured the independence of variables. For model details see Supplementary Methods B.

RESULTS

Provision of Indian Ocean fisheries subsidies

Our analysis suggested that over USD 3.2 billion in annual fisheries subsidies were provided to Indian Ocean fisheries in 2018 (Table 1). Just under USD 2 billion (61%) were harmful, USD 1 billion (33%) were beneficial and about USD 190 million (6%) were ambiguous subsidies. Fisheries subsidies were provided by both IOR countries and DWF countries, with the former accounting for approximately 92% (USD 2.9 billion) of total subsidies (Table 1). Of the subsidies provided by IOR countries, 60% were harmful, 34% beneficial and 6% ambiguous, while 73% of the USD 260 million fisheries subsidies provided by DWF countries were harmful, 24% were beneficial and 3% were ambiguous (Table 1). More than 20% of IOR countries' subsidies went towards fisheries management, i.e., a beneficial subsidy type. Conversely, almost 35% of the DWF subsidies provided for Indian Ocean fishing were in the form of harmful fuel subsidies (Supplementary Table S4).

The amounts of subsidies provided varied significantly among IOR countries (Fig. 1). Total subsidies ranged from a low of USD 79,000 in Israel to a high of USD 290 million in Thailand (Supplementary Fig. S1a). The major IOR subsidisers were Thailand, India, Malaysia, Indonesia, Australia and Pakistan, which, combined, provided 52% of the total fisheries subsidies provided by IOR countries in the Indian Ocean in 2018. There is also a substantial difference between the amounts of subsidies provided by the Western Indian Ocean countries and Eastern Indian Ocean countries (Fig. 1). Specifically, the latter provided 1.5 times more subsidies than the former. All East African countries combined (USD 262 million) provided fewer fisheries subsidies than Malaysia alone (USD 269 million).

Overall, harmful subsidies predominated in most IOR countries (Fig. 1). Among the 12 IOR countries that individually provided over USD 100 million in total fisheries subsidies, harmful subsidies prevailed, with the exception of Australia and Iran (Fig. 1). Thailand, India, Malaysia and Indonesia combined provided almost 45% of all harmful subsidies in the region (Fig. 1, Supplementary Fig. S1a). In proportional terms, fisheries subsidies in the Comoros, Thailand and Sri Lanka were over 90% harmful (Supplementary Fig. S1b). Only one IOR country, Timor Leste, provided beneficial subsidies only (Supplementary Fig. S1b).

IOR countries allocate fisheries subsidies across both their industrial and small-scale sectors (Fig. 2). We estimated that nearly 70% (USD 2 billion) of the total subsidies provided by IOR countries was allocated to the industrial sector and the remaining 30% (USD 925 million) to the small-scale sector (Fig. 2). Approximately 63% of the industrial IOR subsidies were harmful, 36% beneficial and 1% ambiguous, whilst the IOR subsidies to the small-scale sector were 53% harmful, 30% beneficial and 17% ambiguous (Supplementary Fig. S2). The small-scale sector is receiving more subsidies than the industrial sector only for fisher

Table 1. Amount of 2018 fisheries subsidies (in million USD) in the Indian Ocean provided by Indian Ocean Rim countries (IOR) and Distant Water Fishing countries (DWF) by harmful, beneficial and ambiguous subsidy categories.

Subsidies (USD × 10^6)				
	Harmful	Beneficial	Ambiguous	Total
IOR	1801	1010	178	2989
DWF	191	63	8	262
Total	1992	1073	186	3251

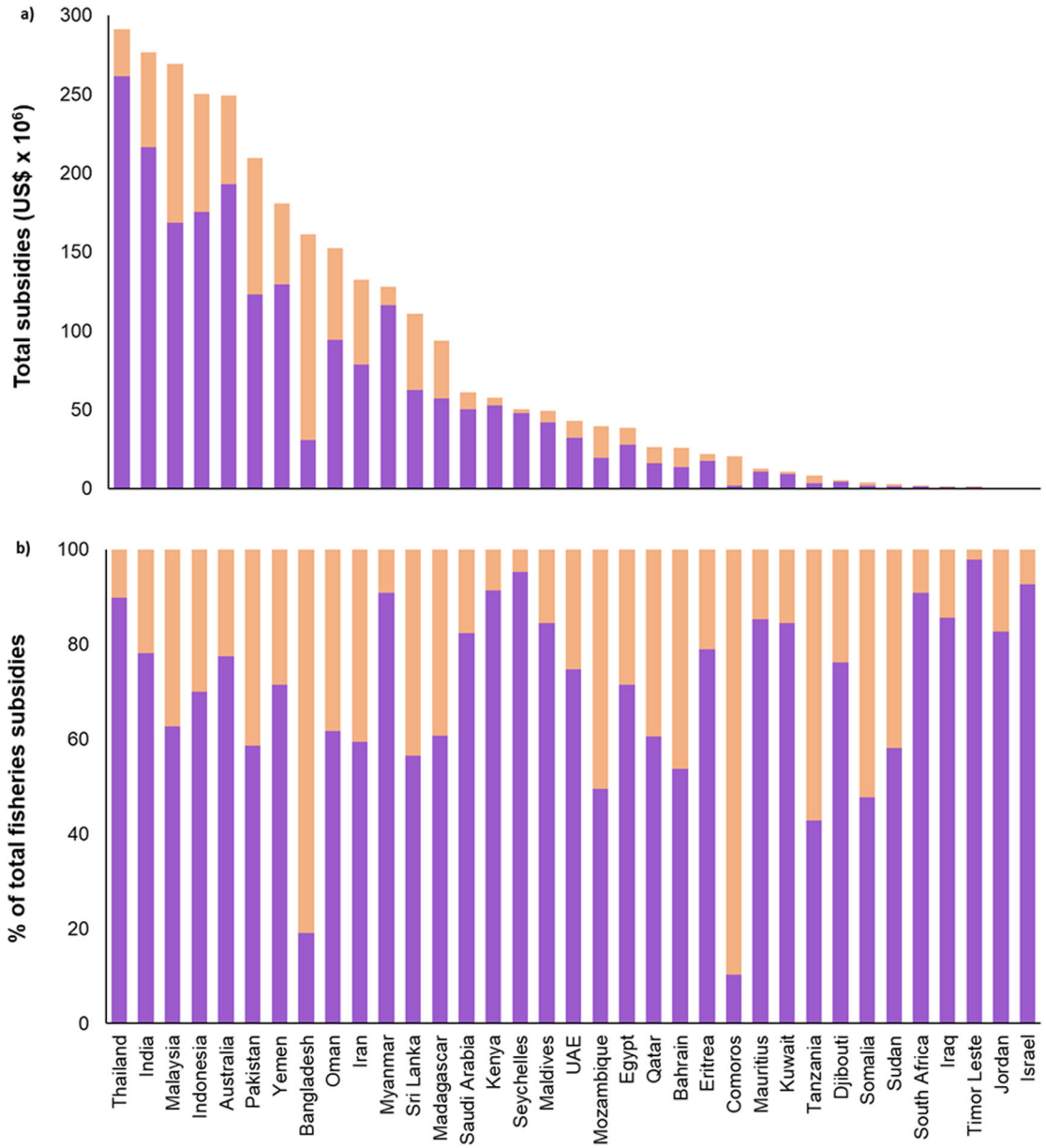

Fig. 2 Fisheries subsidies provided in 2018 in the Indian Ocean by Indian Ocean Rim countries. Data presented by fishing sector (purple = industrial, orange = small-scale) and presented in **a** in million USD and **b** as percentage of total fisheries subsidies.

assistance and rural fisher community development, two types of ambiguous subsidies that are usually associated with small-scale fisheries.

Large-scale industrial fleets of DWF countries also operate in the waters of the Indian Ocean (Fig. 3). Highly developed East Asian countries, mainly Taiwan, South Korea, China and Japan accounted for 55% of total DWF subsidies in the Indian Ocean, while the rest came from European countries, predominantly Spain and France (Fig. 3). Overall, the DWF countries combined provided more harmful subsidies to Indian Ocean fleets than any individual IOR country, except for Thailand and Malaysia.

Geographic distribution of Indian Ocean fisheries subsidies

Approximately 30% of the Indian Ocean waters are within EEZs of coastal states and the remaining 70% is High Seas, i.e., areas beyond national jurisdiction. Each of these areas is impacted by varying amounts of subsidies (Table 2). Around 54% of all subsidies (USD 1.7 billion, Table 2) were allocated to fishing in the Eastern Indian Ocean (FAO 57), while 45% (USD 1.5 billion, Table 2) were allocated to the Western Indian Ocean (FAO 51). About 90% of total subsidies in the Indian Ocean, i.e., USD 2.9 billion were allocated to EEZs, while about 10% of subsidies drove fishing on the High Seas. Across the three Indian Ocean FAO areas, IOR countries provided the most subsidies in the EEZs (98%, USD 2.85 billion), while DWF country subsidies were prevalent in the High Seas (63%, USD 189 million, Table 2). The Antarctic FAO area 58 attracted the least amount of subsidies, with USD 23 million per year, approximately evenly distributed between EEZs and High Seas areas (Table 2).

The EEZs of the Indian Ocean were substantially more impacted by fishing subsidies than the High Seas. Many EEZs in the Indian Ocean were impacted not only by domestic subsidies but also by foreign fleet subsidies, i.e., subsidies provided by other IOR countries and/or DWF countries (Supplementary Table S5). The countries with highest total subsidies being expended within their

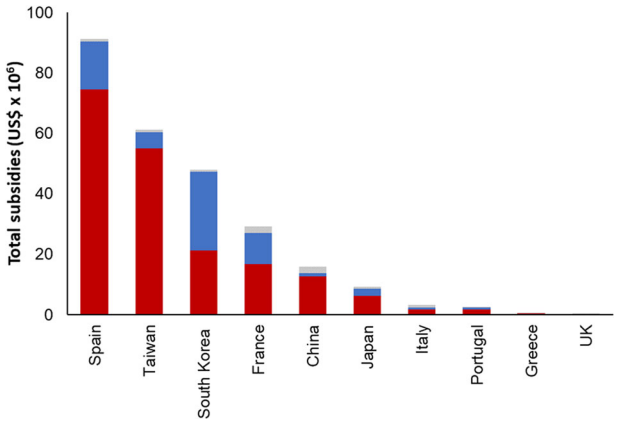

Fig. 3 Fisheries subsidies provided in 2018 in the Indian Ocean by Distant Water Fishing countries. Data presented for the top ten Distant Water Fishing countries in million USD by the three subsidies categories (red = harmful, blue = beneficial, grey = ambiguous).

Table 2. Amount of 2018 total fisheries subsidies (in million USD) in the Indian Ocean provided by Indian Ocean Rim countries (IOR) and Distant Water Fishing countries (DWF), within the EEZs and High Seas in the three FAO areas of the Indian Ocean.

Subsidies (USD × 10^6)							
FAO area	EEZ			High seas			Total
	IOR	DWF	Subtotal	IOR	DWF	Subtotal	
Western (51)	1350	64	1414	27	35	62	1476
Eastern (57)	1521	6	1527	83	153	236	1763
Antarctic (58)	8	3	11	0	1	1	12
Total	2879	73	2952	110	189	299	3251

Table 3. Subsidy Intensity Metric calculated as the amount of subsidies (in USD) per tonne (t) of catch for each FAO area, within EEZs and on High Seas and by Indian Ocean Rim (IOR) countries or Distant Water Fishing countries (DWF).

Subsidy intensity metric (USD/tCatch)				
FAO area	EEZ		High seas	
	IOR	DWF	IOR	DWF
Western (51)	243	419	188	569
Eastern (57)	188	358	321	607
Antarctic (58)	1687	365	1761	668

EEZ waters were India (mainland), Indonesia and Malaysia. However, the EEZs targeted by most foreign subsidies were Somalia and Iran in the Western Indian Ocean (FAO 51), and Indonesia, Myanmar and India (mainland) in the Eastern Indian Ocean (FAO 57). On average, 40% of the subsidies expended in these five EEZs were foreign subsidies.

DWF countries in the Indian Ocean generally spent 2 to 3 times more subsidies per tonne of catch generated than IOR countries, i.e., their subsidy Intensity Metric (IM) was higher everywhere in the Indian Ocean except for the Antarctic FAO area 58, which is dominated by subsidies from Australia (Table 3). In the EEZs of the Western and Eastern Indian Ocean (FAO 51, 57) and in the High Seas of the Eastern Indian Ocean (FAO 57), DWF countries spent twice as much per tonne of catch than did IOR countries. However, in the High Seas waters of the Western Indian Ocean (FAO 51),

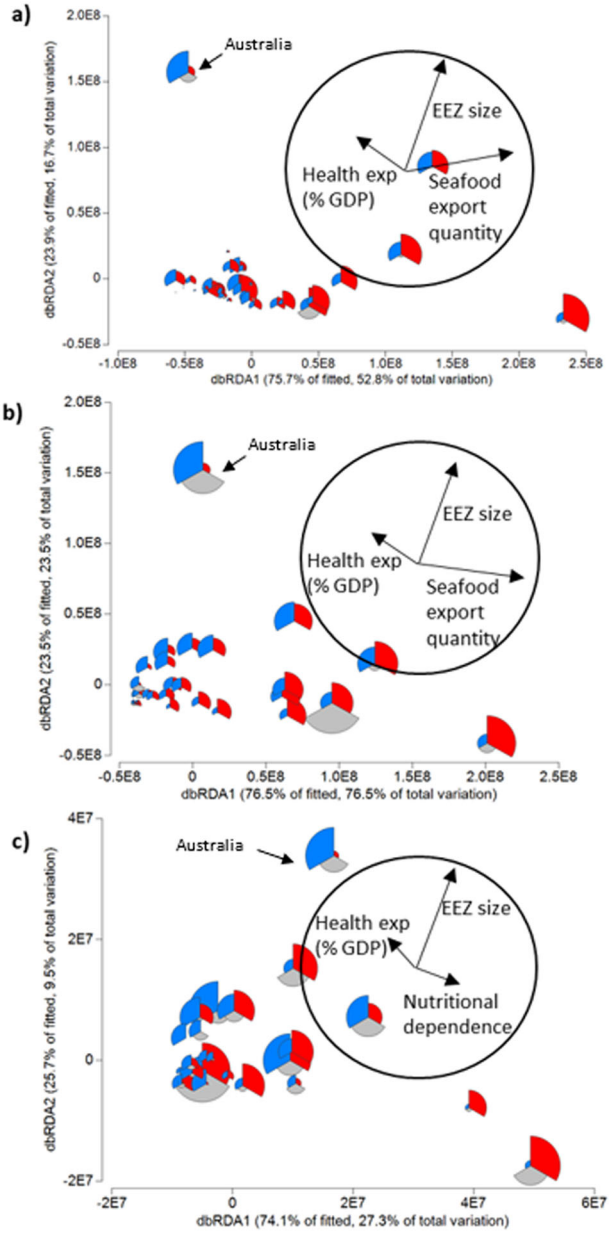

Fig. 4 Distance-based Redundancy Analysis (dbRDA) bubble plot of fisheries subsidies of Indian Ocean rim countries. Plots show **a** total subsidies, **b** industrial subsidies, and **c** small-scale subsidies and illustrate the distance-based Linear Modelling (DistLM) based on the composition of subsidies (red = harmful, blue = beneficial, grey = ambiguous) and independent variables with their vectors (strength and direction of effect of the variable). The size of the subsidies pie charts among the three models have different scales: **a** 0–2.9E + 08, **b** 0–2.6E + 08, **c** 0–1.3E + 08.

DWF countries spent 3 times more subsidies per tonne of catch than IOR countries (Table 3).

Fisheries subsidies predictors

EEZ size, seafood export quantity and domestic health expenditure as a percentage of the GDP were the main drivers of total as well as industrial sector subsidy composition in IOR countries. In contrast, nutritional dependence, EEZ size and domestic health expenditure explained the composition of small-scale IOR subsidies. Countries that provided high beneficial subsidies for total, industrial and small-scale sectors were also those with large

Table 4. Regression results for 2018 subsidies (in USD) provided by Indian Ocean Rim countries in the Indian Ocean. Model of their (a) total fisheries subsidies, (b) industrial fisheries subsidies; and (c) small-scale fisheries subsidies by category (harmful and beneficial).

Model	*p*	R2	adjR2	SE (millions)	Intercept (se) (millions)	Variable 1	Coefficient (se)	Variable 2	Coefficient (see)
(a) Total subsidies									
Harmful	2.82E-07	0.65	0.62	42.98	66.98 (18.30)***	Seafood export quantity	100.09 (15.5)***	Health expenditure	−8.18E + 6 (3.4e + 6)*
Beneficial	4.34E-07	0.64	0.60	25.65	11.90 (10.92)	EEZ size	19.05 (2.70)***		
(b) Industrial subsidies									
Harmful	1.06E-09	0.76	0.73	28.50	37.15 (12.14)**	Seafood export quantity	92.30 (10.29)***		
Beneficial	8.9E-10	0.76	0.74	16.51	7.65 (7.03)	EEZ size	16.33 (1.74)***		
(c) Small-scale subsidies									
Harmful	0.005751	0.35	0.29	18.37	28.85 (7.54)***	Nutritional dependence	38.56E + 6 (14.85)*	Health expenditure	−4.65E + 6 (1.43E + 6)**
Beneficial	0.05	0.21	0.14	10.60	4.68 (4.35)	EEZ size	2.76 (1.08)*		

Significance levels: '***' denotes $p < 0.001$, '**' < 0.01, '*' < 0.05.

EEZs (Fig. 4). This finding is highly influenced by Australia, the country with both the largest total beneficial subsidies and largest EEZ in the Indian Ocean (Fig. 1). Seafood export quantity and annual health expenditure were inversely associated with the composition of subsidies, with seafood exports associated with countries with a higher proportion of harmful subsidies, and annual health expenditure associated with countries with a higher proportion of beneficial subsidies. This pattern held for total subsidies as well as for industrial sector subsidies (Fig. 4a, b). For the small-scale sector, greater nutritional dependence was associated with countries with a higher proportion of harmful subsidies, while the other two factors, EEZ size and health expenditure remained relationally the same (Fig. 4c).

Regression analysis confirmed the statistical significance of some of the identified variables in predicting the intensity of harmful or beneficial subsidies provided by IOR countries (Table 4). Health expenditure and seafood exports explained 65% of the variation in total harmful subsidies (Table 4a). The higher the percentage of GDP an IOR country allocated to its health sector, the less money the country spent on harmful fisheries subsidies, whilst larger quantities of exported seafood were associated with higher levels of harmful subsidies. In the industrial sector (Table 4b) seafood exports alone explained 76% of the variation in the amount of harmful subsidies, actively driving the provision of harmful subsidies. Health expenditure and nutritional dependence combined explained 35% of the variation in harmful subsidies in the small-scale sector (Table 4c). Harmful subsidies in the small-scale sector were negatively associated with health expenditure and positively associated with nutritional dependence. Beneficial subsidies in total fisheries (Table 4a) as well industrial (Table 4b) and small-scale sectors (Table 4c) were predicted only by the EEZ size, with countries with larger EEZs providing more beneficial subsidies. Beneficial subsidies were also examined without Australia, which was identified as a possible outlier (Fig. 4). While EEZ size was confirmed as driver of beneficial subsidies in the total and industrial sector, it was not confirmed in the small-scale sector when we excluded Australia (Supplementary Table S6). No patterns or drivers could be identified between the range of variables used here and subsidies provided by DWF countries in the Indian Ocean.

DISCUSSION

This is the first study to examine fisheries subsidies specifically in the Indian Ocean and investigate their potential drivers. Almost three-quarters of total fisheries subsidies in the region were provided to the industrial fishing sector in the form of harmful subsidies. This is similar to the global pattern, where 80% of total subsidies were provided to industrial fisheries, mainly in the form of harmful subsidies[45]. Harmful subsidies artificially enhance the economic viability of industrial fleets relative to vessels in the small-scale sector[45], which in the Indian Ocean supports millions of jobs and plays a vital role for local nutritional security in already disadvantaged countries[50]. The disproportionate allocation of harmful subsidies between the two fishing sectors intensifies inequities and poverty in small-scale fishing communities by further jeopardising their access to a healthy source of nutrients and income[10,51]. Harmful subsidies drive the expansion and uneconomical operation of industrial fleets and support continuing resource-grabbing behaviour by many industrial and DWF fleets with serious consequences for overfishing and resource depletion[52]. Thus, it is clear that harmful fisheries subsidies in the Indian Ocean exemplify the trend of "survival of the richest not the fittest"[51].

The most important finding of our study was that the levels of harmful subsidies provided by IOR countries to their industrial sector were strongly predicted by the quantity of seafood exported by that country. This single economic variable, seafood export, predicted nearly 80% of the variation in harmful subsidies in the industrial fishing sector of IOR countries. Such subsidies increase local and regional inequity as IOR countries are deliberately sustaining and empowering their industrial sectors to extract resources that are largely directed towards international export. Thus, industry profit is prioritised over food and nutritional security of IOR populations. This result also highlights the strong influence on government policy by key stakeholders and special interest groups, usually more concentrated at the industrial level and with a prominent role in export generation. Contrary to our expectations, variables related to affluence and corruption, which we hypothesised to be important in predicting harmful subsidies in the industrial sector, were not found to influence their scale in the Indian Ocean. It is likely that, rather than using national variables for affluence and corruption, a focus on interest groups concentration at the sectoral level would provide better insights into subsidy assignation and continuation. Future research should examine this aspect of subsidisation. The level of harmful subsidies provided by IOR countries to their small-scale sector were positively correlated with a country's nutritional dependence on marine resources. Harmful, capacity-enhancing subsidisation of small-scale fisheries in nutrient-dependent countries is politically

understandable in light of the high nutritional dependence on fisheries. However, this becomes problematic in the longer term, because harmful subsidies will exacerbate overfishing and therefore diminish future availability of seafood and their associated critical nutrients[2]. To this end, considerations should be given to restructuring small-scale sector subsidisation increasingly towards beneficial subsidies. This should take the form of increased co-management and local community support, as well as active support for spatial management and habitat restoration. This should include situation-specific no-take MPAs and inshore industrial sector exclusion zones in a carefully designed co-management approach with local small-scale fishers' communities, which proved to be effective in providing several co-benefits[53–55].

Harmful subsidies in the small-scale sector are negatively correlated with a country's decision to provide economic resources to the health sector. Countries with a higher share of GDP spent on public health provided fewer harmful subsidies to their small-scale fishing sector. This suggests that countries with good health services may be countries with well-managed small-scale fisheries that may not require artificial support via harmful subsidies to remain functioning. Even though a substitution effect between the sectors is plausible, there are limits to how far this idea can be taken and we do not exclude the possibility that the result for small-scale fisheries could be a statistical artefact. It was more complex identifying drivers of harmful subsidies in the small-scale sector than in the industrial sector, and the model captured less variation in small-scale harmful subsidies. This is likely due to the small-scale sector being more deeply connected to local identities and histories of the various Indian Ocean populations[50,56] and thus it may be more complex to find common drivers. Country-specific examinations of small-scale subsidisation are required, which also need to account for the influence and importance of fisher organisations and local communities. Crucially, more engagement and co-management approaches are required between governments and such organisations.

Thailand, India, Malaysia and Indonesia were found to be the largest providers of harmful subsidies in the Indian Ocean. These four countries alone provided nearly half of all harmful fisheries subsidies in the region. This is serious cause for concern for the sustainability of fisheries and the nutritional equity in the region[7]. Food insecure countries that depend heavily on the ocean for crucial nutrients, such as countries in the Western Indian Ocean[46,57], are especially vulnerable to the human health consequences that can be caused by harmful fisheries subsidisation. It seems that harmful fisheries subsidies provided by only a few IOR countries trigger and drive a vicious cycle of diminishing returns in the race to fish[47], thereby exacerbating nutritional inequities. These countries are all emerging economies in the Indian Ocean basin and are also recognised to be large subsidisers at the global level[3]. Our results corroborate the trend, first noted by Hopewell and Margulis (2022)[58], that fisheries subsidies are no longer a problem created only by developed and affluent countries. Future research should examine why these specific countries offer such substantial harmful subsidies.

No clear patterns emerged in our analysis of the subsidies provided by DWF countries fishing in the Indian Ocean. However, we were able to show that DWF countries in the Indian Ocean generally spent 2 to 3 times more subsidies per tonne of catch generated than IOR countries. The absence of readily identifiable drivers of DWF subsidisation may reflect the small number of countries that are responsible for DWF globally or the fact that drivers other than those examined here may be influencing the DWF subsidisation in the Indian Ocean. Approximately half of the subsidies provided by DWF countries fishing in the Indian Ocean are from European countries and the other half from East Asian countries. International efforts should focus on disciplining and eliminating these fisheries subsidies[16], but this will be difficult without first understanding the motives behind them. Further exploration is needed to inform policy makers on how to address this destructive practice.

The overall amounts of harmful fisheries subsidies provided by DWF countries in the Indian Ocean is greater than the amount provided by any IOR country, except for Thailand and Malaysia. DWF countries heavily offset the travelling and fishing costs of their industrial fleets in the Indian Ocean through the provision of substantial harmful fuel subsidies, and such subsidisation raises doubts about the profitability of these fishing operations, as has been shown clearly at the global scale[8]. Subsidies by DWF countries in the Indian Ocean were found mainly in the EEZs of Iran and in the nutrient insecure countries of Somalia and India, in addition to the High Seas. This is consistent with observations of foreign fishing activities using satellite-based Automatic Identification System data in African and Indian waters[59–62]. Fisheries in Iran are largely an unknown entity in public accountability[63], but it is thought that Iran hosts considerable DWF fleets. In contrast, the presence of DWF fishing activities in Somali waters is due to historically extremely weak state institutions, widespread corruption and poverty[64]. The provision of substantial harmful subsidies by DWF countries allows their fleets to shift their effort and their overcapacity, and associated overfishing problems, away from their own waters. This displaces their fishing impact into the waters of the Indian Ocean and towards poorer fish-dependent countries[10,52]. Fisheries subsidies to DWF fleets thus create an inequitable competition for marine resources.

We show that the EEZs in the Indian Ocean were substantially more impacted by fishing subsidies than the High Seas. This outcome is not surprising, given the distinct differences in fisheries productivity between the High Seas and the EEZs. The EEZs mainly comprise continental shelves where fish tend to cluster[65]. Biological production on shelves supports around 90% of global fisheries catches. However, in the High Seas we found mainly subsidies provided by DWF countries from outside the ocean basin. These results are important in the context of the new WTO subsidies reduction agreement[21], which primarily only covers IUU fishing and unregulated High Seas fishing, but fails to generally reduce or eliminate harmful subsidies or address EEZ-level subsidisation[24]. The amount of harmful subsidies that can potentially be eliminated through the current WTO agreement still needs to be quantified. Importantly, our results highlight how it is within the control of individual governments to reduce harmful subsidies that impact their domestic waters, and revise the terms of access, reduce or even eliminate foreign fishing access to preserve important resources for domestic prioritisation. Regional countries in the Indian Ocean should redirect harmful subsidies to activities that implement more sustainable co-benefits for and from the ocean, including biodiversity protection, domestic food provision and carbon storage.

This study largely analyses pre-existing databases, with their associated limitations. Subsidy estimation studies have identified scarcity of information and lack of transparency as the main challenge in providing estimates of fisheries subsidies[3,45]. Furthermore, the present study assumed the distribution of fisheries subsidies in the Indian Ocean to be proportional to a country's fraction of the catches that comes from the Indian Ocean. The only other studies that mapped the distribution of subsidies used landed value instead of landed catches to apportion subsides to space[7,8,25]. We suggest here that data on landed catches are likely more robust than landed values because the latter is derived from ex-vessel prices, which themselves likely contain higher uncertainties than catch data.

We are not aware of any other study that has analysed fisheries subsidies at an ocean basin scale. Here, we investigated sources and distribution of fisheries subsidies in the Indian Ocean, and analysed socio-economic drivers of subsidisation. Studies of this

kind create benchmarks to assess fisheries subsidisation for the current and future WTO subsidy agreements. A better understanding of the drivers of subsidisation can help policy makers identify steps to reduce or eliminate harmful, capacity-enhancing fisheries subsidies that threaten long-term sustainability and nutritional equity. This study suggests that the substantial reduction and elimination of harmful fisheries subsidies is urgent and necessary in the Indian Ocean, where further degradation of productive capacity of fisheries puts food and nutritional security of millions of people at risk.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, V.A., upon reasonable request.

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AUTHOR CONTRIBUTIONS

V.A., J.J.M. and D.Z. conceived and designed the study. V.A. analysed the data. All authors discussed the results, contributed to the manuscript, and read and approved the submitted version.

COMPETING INTERESTS

The authors declare no competing interests.

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