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ORIGINAL RESEARCH

Artisanal fishers in small island developing states and their perception of environmental change: the case study of Mauritius

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Abstract Small island developing states (SIDS) are highly dependent on coastal marine resources. Artisanal fishers in SIDS currently face multiple stressors related to global environmental change. Considering Mauritius (South Western Indian Ocean) as a case study, this paper characterizes artisanal fishers in SIDS and assesses their perception of global change using the Local Ecological Knowledge (LEK) approach. A semi-structured survey method was used to interview 247 fishers from all around the country. Artisanal fishers used multiple fishing areas and gears, with half of the fishers using Fish Aggregating Devices (FADs). Six main groups of fishers were identified according to their fishing strategies, which reflected different target species in their reported catches. The majority of fishers reported lower fish abundances and fewer species now compared to 10 to 15 years ago. All groups of fishers observed environmental change over the same period. Such ecological knowledge highlights the exposure of fishers to stressors induced by environmental change. The characterization of the groups of fishers and their fishing strategies will be useful to better evaluate adaptation strategies and support management measures to face global environmental change.

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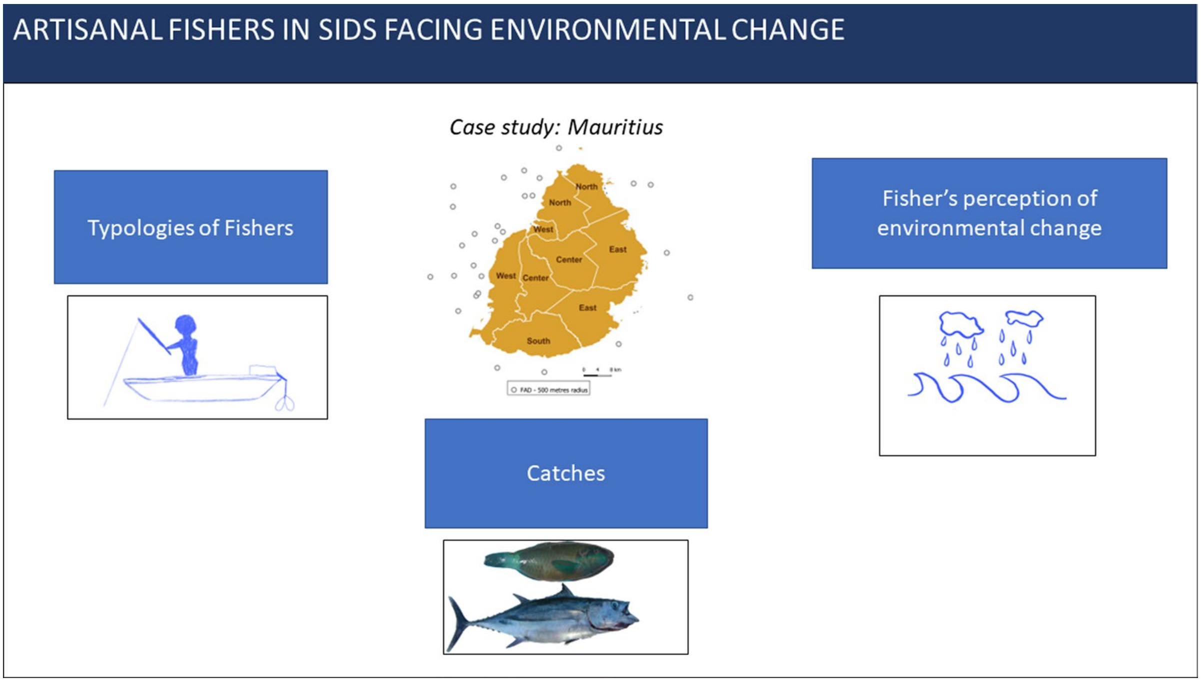
Graphical Abstract



Keywords Small scale fishers · Climate change · Local ecological knowledge · Fishing strategies · Indian Ocean

Introduction

Ensuring the sustainable and equitable use of oceans, seas and marine resources is a global challenge. Within the Sustainable Development Goal 14 (*Conserve and sustainably use the oceans, seas and marine resources for sustainable development*), the United Nations Agenda for Sustainable Development specifically targets the access for small-scale artisanal fishers to marine resources, with a focus on Small Island Developing States (SIDS) and least developed countries (United Nations 2015).

Small-scale fisheries, which employ over 90% of the world's capture fishers, supply more than half of the global annual fish catch (Berkes 2001; Oestreich et al. 2019) and play a major role on the livelihood of over 200 million people worldwide (McGoodwin 2001). In coastal developing countries, artisanal fisheries are vital for the socio-economic development of local communities and to ensure food security, by providing a large portion of the animal proteins consumed locally (Kolding et al. 2014; Campbell et al. 2016; Bennett et al. 2018; Ahern et al. 2021). SIDS are reported to have the highest per capita consumption of indigenous fish ([FAO] Food and Agricultural Organisation 2016). Due to their high dependence on marine resources, their well-being is directly related to healthy coastal ecosystems and their sustainable exploitation ([FAO] Food and Agricultural Organisation 2016; Thomas et al. 2020).

Coastal fishers are in the front line of global change, threatened by extreme weather events, changing ocean conditions, and biological stressors (Coulthard 2009; Newton et al. 2012; Cinner et al. 2012). Climate change has direct effects on the aquatic ecosystems and fish species (Domingues et al. 2008; Bahri et al. 2018). In tropical coastal ecosystems, coral reefs habitats are adversely affected by thermal stress, which causes their bleaching or death. They are also subject to ocean acidification, which leads to reduced coral calcification (Allison et al. 2009; Abdrabo et al. 2019). At the individual fish species level, global warming can lead to changes in physiology, morphology and behaviour while at the population level it can induce changes in processes that influence dispersal and recruitment (Barange and Perry 2009). Climate-driven changes also impact abundance and interactions among fish species (Harley et al. 2006). Consequently, fish and shellfish are exposed to a complex mixture of changing abiotic (e.g. temperature, salinity, oxygen) and biotic (shifting distribution, species composition, and abundance of predators and prey) conditions making it difficult to predict their responses and population trends (Hollowed et al. 2013). Furthermore, combined effects of coral bleaching and rising sea surface temperatures in coastal zones foster alterations in species distributions, biodiversity and productivity (Munday et al. 2008; Pratchett et al. 2008). Evidence of such impacts are visible in many coastal regions (Barange and Perry 2009; Hanich et al. 2019).

The community-based approach with focuses on the human dimension as well as the value of local knowledge in understanding climate change and adaptation is highlighted in the review by McNamara and Buggy (2017). The use of indigenous knowledge and perceptions has gained importance in understanding climate change impacts on coastal livelihoods (Codjoe et al. 2014; Ankrah 2018). The Local Ecological Knowledge (LEK) approach consists in gathering the knowledge held by a specific group of people (e.g., fishers) about their local ecosystem, the interplay among organisms and between organisms and their environment (Olsson and Folke 2001). LEK is best conceptualized as a body or system of knowledge rather than a mere assemblage of facts (Thornton and Scheer 2012). According to Leithäuser and Holzhacker (2020), LEK can be used to understand the link between the users of a given resource and its sustainable exploitation. Fishers are among the main observers of the marine realm. They bear the consequences of global change and respond to them (Daw et al. 2009). In the context of fisheries, LEK relies on the practical knowledge of fishers on exploited marine ecosystems, based on their site-specific observations and experience. LEK from fishers has been used to infer on fish behaviour (Moreno et al. 2007; Macusi et al. 2017; Jauharee et al. 2021), biology (Silva et al. 2020) and habitat use (Silvano and Begossi 2012). LEK has also been used to identify fishing areas (Schafer and Reis 2008) and gather useful information for the management of marine protected areas (Gerhardinger et al. 2009).

Mauritius represents a typical example of SIDS facing the impacts of global change. In recent years, the Mauritian government aimed to make ocean activities a new and vital economic pillar for its development, taking advantage of its large maritime zone (2.3 million km^2 with an Exclusive Economic Zone of 1.96 million km^2 and a continental shelf of 396,000 km^2 co-managed with the Republic of Seychelles). The reef and lagoon ecosystems make a vital social and economic contribution by not only providing food security, but also supporting tourism, a major source of income for the country, representing 8.6% of the GDP (Ministry of Tourism 2019). In recent decades, the lagoons, coral reefs, and associated coastal habitats have been progressively degraded (Ragoonaden et al. 2017), threatening several ecosystem services, including the long-term viability of artisanal fisheries. While some of the loss of ecosystem functions may be attributed to climate change, overfishing, agricultural runoff and urban pollution are also major causes of the present situation.

Artisanal fisheries are highly important in Mauritius, as in any other SIDS. They contribute considerably to employment opportunities and as an animal-source protein to about 4,000 households in the marginal coastal regions of the country. There are around 2000 registered artisanal fishers, distributed as follows: 4% lagoon fishing (within reef area in small embarkations), 58% lagoon/off-lagoon fishing (both inside and outside lagoon) and 38% off-lagoon fishing (outside reef up to about 20 km offshore) (Lalljee et al. 2018). These fishers are the main supplier of fresh fish in the local market (Ministry of Ocean Economy 2018).

The use of anchored FADs (Fish Aggregating Devices) is widespread in artisanal and semi-industrial coastal fisheries (Chooramun and Senedhun 2013; Karama and Matsushita 2019; Khan et al. 2020; Jauharee et al. 2021; Tilley et al. 2019). FADs are floating objects that are used to attract fish and facilitate their capture (Sadusky et al. 2018). There are several reasons why fish aggregate at floating objects: a refuge place from predators, a place to meet other fish schools or a feeding place (Beverly et al. 2012; Castro et al. 2002; Fréon and Dagorn 2000). Artisanal anchored FADs can enhance food security and livelihoods of fishing communities in addition to providing economic benefits and improving safety at sea (Beverly et al. 2012). Anchored, nearshore FADs are suggested as a practical and efficient means of improving artisanal fishers' catch, making oceanic fish more available and accessible to them (Dempster and Taquet 2004; Sharp 2011; Campbell et al. 2016). FADs can be one of the climate adaptation strategies in the fisheries sector as highlighted by Dey et al. (2016). In Mauritius, FADs have been deployed off lagoons, to facilitate the access to pelagic resources and to divert fishing effort from lagoon (Chooramun and Senedhun 2013).

Assessing the typologies of artisanal fishers' and their perception of environmental change is key to guide adaptation planning in fisheries (Badjeck et al. 2010; Oestreich et al. 2019; McNamara and Buggy 2017). This study aims at characterising artisanal fishers in the face of environmental change in SIDS, using the Local Ecological Knowledge (LEK) framework to identify fishers' observations on climate-driven changes and related hazards. Considering the artisanal fishers of Mauritius as a case study, the methodology and findings of this study open new perspectives to support management measures aiming to mitigate the impacts of global environmental change on fishing communities in coastal developing countries. The methods applied in this study can be adapted and applied to other SIDS and small-scale fisheries.

Materials and methods

Study area

The island of Mauritius is located in the Western Indian Ocean, 800 km east of Madagascar (Fig. 1) between 19.58°S and 20.31°S, and between 57.18°E and 57.46°E. The island has a coastline of 322 km and is surrounded by a submarine continental shelf with 300 km^2 of fringing coral reef with a broad lagoon of 243 km^2 that protects much of the coastline in the north, east, south-west and north-west (Pichon 1971; Duvat 2009; Arndt and Fricke 2019; Bhagooli and Kaullysing 2019). The island was divided into four regions, north, east, south and west. The south is a region where there appears to be fewer fishing villages/fishers as there is much less coral reefs and also it has coasts which are directly exposed to high sea.

There are 28 FADs in Mauritius deployed around the island at mooring depths ranging from 215 to 3560 m and at a distance of 0.9 nm to 11.8 nm from

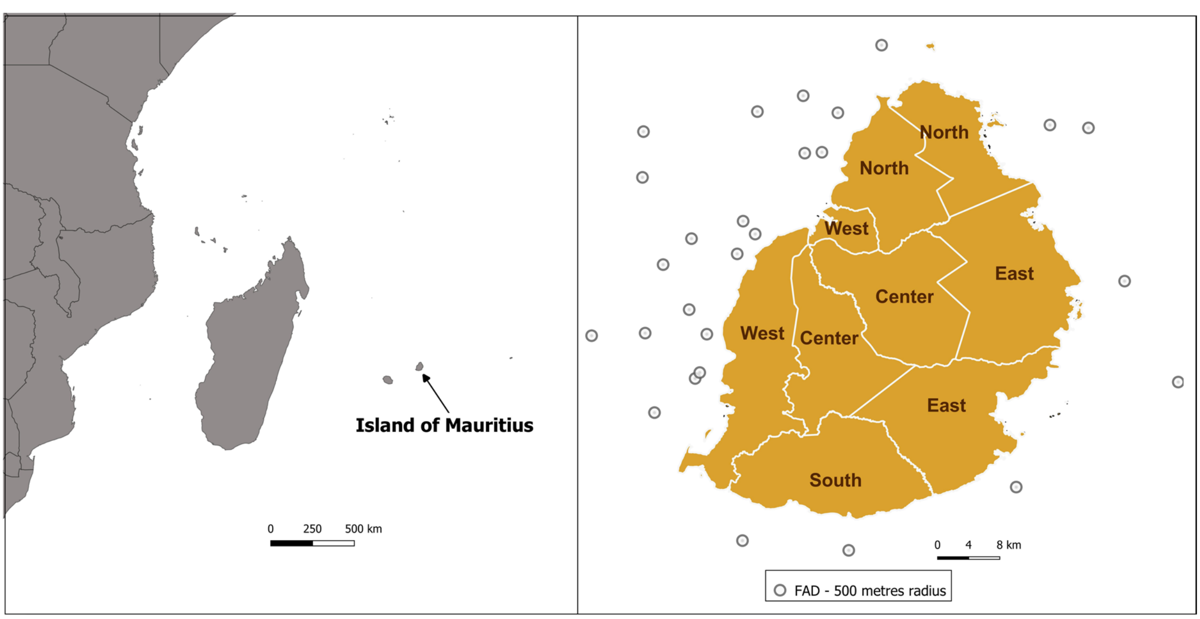


Fig. 1 Map of the study regions. Circles represent the FAD positions

the nearest coasts (Anon 2020). Most of the FADs are located in the west coast (Fig. 1). The FADs deployed in Mauritius are for artisanal fishers and consist of a type made of concrete block buoys and rope as depicted in a review by Karama and Matsushita (2019). Structural details on FADs or aFADS are given by Chooramun and Senedhun (2013), where aFAD in Mauritius has a life span of 500 days consists of 70 resistant plastic floats mounted in two rows with a mast and a radar reflector at the upper end and a mooring rope with a scrap iron and concrete weight as anchor at the lower end.

Fisher's survey using local ecological knowledge (LEK) approach

The study relies on a semi-structured questionnaire to collect information on fishers around the island of Mauritius. The questionnaire involved a total of 90 questions sub-divided into (1) socio-economic and demographic characteristics, (2) fishing technology (3) fishers' perception of FADs, (4) fishers' perception of environmental change over the last 10 to 15 years, and (5) catch data of the last fishing trip and fishing location. The questionnaire was applied into Kreol Morisien (local language used by both interviewers and interviewees), to best communicate with interviewees, understand and gather their local ecological knowledge. All fishers who participated in this survey gave their verbal consent. The questionnaire was first piloted with trainee project assistants and some fishers to check on the length of time taken to be filled in, understanding of questions and question refining prior to the start of the survey. Training for conducting the interview was done by the principal investigator, to ensure good understanding of all the questions, reassuring and convincing fishers to participate, non-disclosure of information gathered to third party, preparedness to work in an environment involving fishers, information on security issues and availability of the principal investigator for any queries that may arise on the field. The study was overseen by the office of Pro-Vice Chancellor Academia of the University of Mauritius. The specific questions that were investigated in this study, which focused on fishing strategies and fishers' perception of environmental change, can be found in Table S1 in the Supplementary Information.

Fishers were chosen across the four regions of the island (North, East, South, and West, see Fig. 1). The collection of data started in November 2019 and ended in June 2020. The lockdown period (March 2020) caused a short interruption in the data collection process.

A total of 247 fishers were surveyed, representing 12% of the registered fishers, with a relatively balanced distribution of the surveyed fishers across regions, apart from the South region which corresponded to only 10% of the surveyed fishers (Fig. 2A).

Data analysis

Artisanal fishers' variables

Statistical data (mean and standard deviation, pie plots or histograms) of the fishers' answers related to their region, fishing area, fishing gears, engine type, boat type and FAD used (see detailed questions 1–6 in Table S1) was compiled. To draw up characteristic typologies of fishers, these variables were further analysed through a Fuzzy Correspondence Analysis followed by a Clustering analysis. The Fuzzy Correspondence Analysis (FCA—Chevenet et al. 1994) is used for dimensionality reduction (similar to the Principal Component Analysis) and allows to display and summarize data along synthetic axes, while preserving as much of the data's variation as possible. The peculiarity of FCA consists in mixing qualitative variables with exclusive modalities (Boat Type, Engine, Region and FAD use) and qualitative variables with "fuzzy" modalities, i.e. when several answers are allowed (Fishing area, Gear). The fishers were projected along the FCA synthetic axes according to their answers to each question. Modalities corresponding to small number of answers (<10 fishers) were removed before the analysis. Furthermore, a hierarchical clustering analysis of the fishers was performed, based on their projections on the main axes of the FCA with Euclidean distances and Ward's minimum variance method (Murtagh and Legendre 2014). The dendrogram was cut based on the Ward's criterion to identify homogeneous groups of fishers. Finally the relevance of the variables in determining the groups of fishers was assessed through a test comparing for each modality the proportion in each group to the overall proportion, the sign of the statistic indicating over- or under-representation (Husson et al. 2010; Lebart et al. 2006).

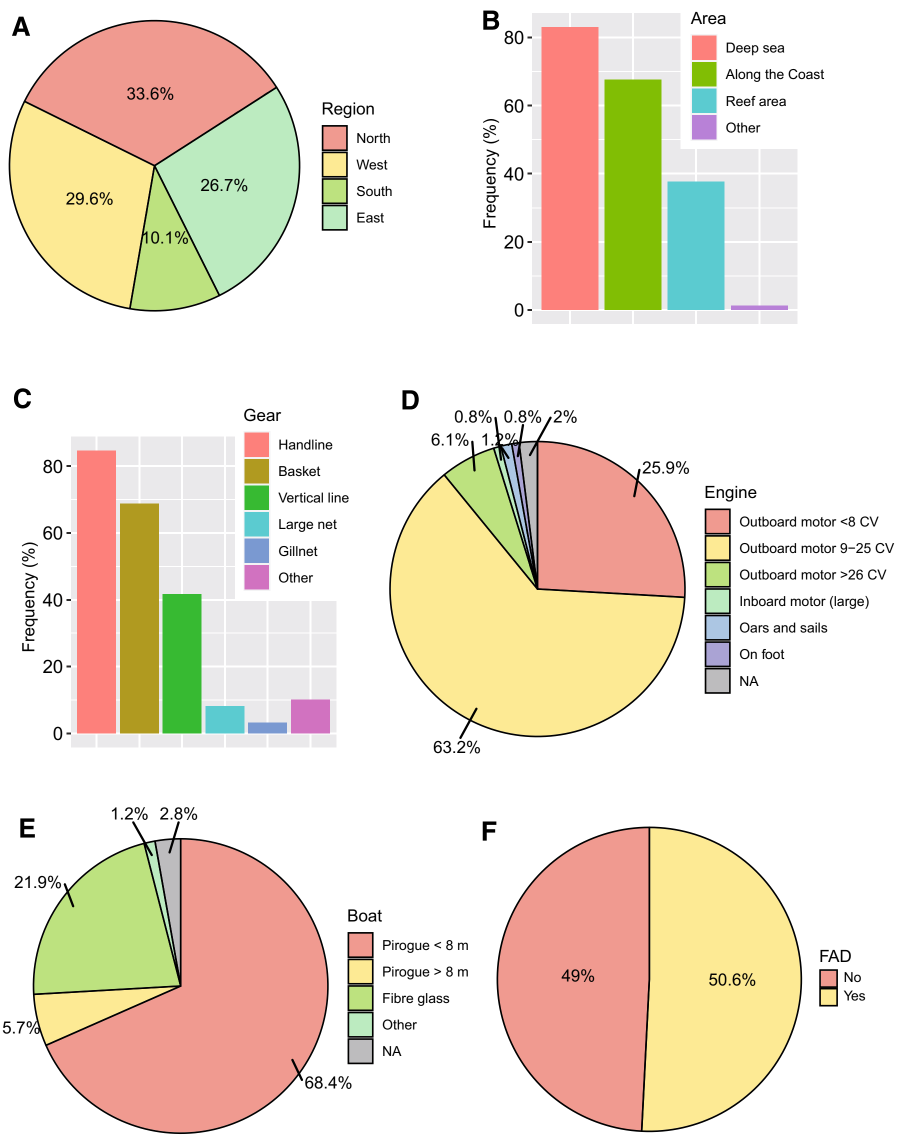


Fig. 2 Fishers' characteristics: region (**A**), fishing area (**B**), gear type (**C**), engine (**D**), boat type (**E**), FADs use (**F**). (Total number of interviewed fishers = 247)

Fisher's perception of environmental change

Basic statistical information related to the fishers' perception of environmental change (rainfall pattern, frequency of torrential rain, sea temperature, fish abundance, see detailed questions 7–12 in Table S1) was provided (mean and standard deviation of fishers' answers). For each question, Pearson's Chi-squared tests were applied to assess whether the groups of fishers (identified above through the combined FCA and cluster analysis) had different perceptions of environmental change. When the result was significant, a post-hoc test was performed to determine in which group the observed counts differed significantly from the expected counts.

Catch data

Catch data (number of fish individuals caught for each species) recorded on the last fishing trip (question 21) was analysed to investigate the link between the typology of fishers defined through the cluster analysis and the species profile of their catches. To this purpose, a Pearson's Chi-squared test was applied to the contingency table crossing the groups of fishers with the 14 main species in their catches. A clustered heatmap was used to summarise the standardised residuals of the Chi-squared test (Agresti 2007). Clustering of groups of fishers and species used Euclidean distances and the Ward agglomerative method (Murtagh and Legendre 2014).

All statistical analyses were run using the R software (R Core Team 2020). The Fuzzy Correspondence Analysis used the ade4 package (Thioulouse et al. 2018) and the function catdes of the FactoMineR package for assessing the relevance of the variables for each group of fishers (Lê et al. 2008). The function pheatmap of the pheatmap package (Kolde 2019) was used for the graphical representation of the results of the catdes function and of the Chi-squared residuals of the catch data. The function chisq.posthoc.test of the chisq.posthoc.test package (Ebbert 2019) was used for the post-hoc Chi-squared test of the fishers' perception of global environmental change. The code is available on GitHub (https://github.com/umr-marbec/LEK_Mauritius).

Results

Characterization of artisanal fishers in Mauritius

Fishers interviewed were males and their age at the time of the survey ranged from 15 to 92 years old, with a mean value of 52.5 ± 13.1 years and a mode around 55 years. The surveyed fishers globally used multiple fishing areas (Fig. 2B), with large proportions of fishers operating in the deep sea (83%) and along the coast (67.6%). Similarly, multiple fishing gears were used (Fig. 2C), with a predominant use of the handline (84.6%) and basket traps (68.8%). The most common engine was an outboard engine of 9–25 CV (63%, Fig. 2D) and about 68% of the fishers navigated on small wooden pirogues (< 8 m) (Fig. 2E). Finally, half fishers (50.6%) used FADs (Fig. 2F).

Before the FCA analysis, the fishers answering Boat Type = "Unknown" ($n = 7$) or "Other" ($n = 3$) and Engine = "Unknown" (5), "Inboard Engine" (2), "Oars and sail no engine" (3) or "On foot" (2) were removed. Fishers who did not answer to Fishing area ($n = 2$), Gear ($n = 2$) and FAD ($n = 1$) questions were also removed, resulting in a data table of 225 fishers. The projection of the fishers along the first two axes of the FCA highlighted the main tendencies concerning their fishing habits (Fig. 3). Axis 1, summarizing 19.7% of the total variance opposed fishers from the East region, using small wooden pirogues (< 8 m), small outboard engine < 8 CV), baskets and not fishing on FADs (on the right side of the FCA projections in Fig. 3) to fishers from the West region, using fibre glass boats with big outboard engine (> 26 CV), fishing in the deep sea with vertical lines and using FADs (on the left side). Axis 2, summarizing 13.5% of the total variance, opposed fishers from the North region, using larger outboard engine (> 26 CV) (on the top side of the FCA projections in Fig. 3) to fishers from the West region with medium outboard engine (9–25 CV) (on the bottom side).

Hierarchical clustering of the fishers based on their position on the first two axes of the FCA (Figure S1) allowed defining six homogeneous groups of fishers (Fig. 4). The groups were characterized by the modalities of the variables according to the significance of the test (Figure S2).

On the bottom right side of Fig. 4, group G1 (Small pirogue coastal fishers), gathered 32 fishers, from the South (9), West (12) and East (11) regions. They all used small pirogues (< 8 m), mainly with outboard engine between 9 and 25 CV (28/32). They fished along the coast (28/32); no specific gear was identified as most of them used handlines (28/32) and baskets (22/32). Fishers from group G1 had no preference concerning FADs (17/32 fishers used FADs).

Group G2 (47 fishers) (East basket fishers) gathered fishers mainly from the East of the Island (42/47); using small wooden pirogues (< 8 m) (45/47), with outboard engine < 8 CV for a majority of them (26/47). They fished along the coast (43/47) or in the reef area (39/47), mainly using baskets (43/47). Only one fisher for group G2 used FADs.

Group G3 (North basket fishers) corresponded to 55 fishers mainly located in the North region (37/55), with no clear specificity concerning the type of boat, but with a high proportion of outboard engine < 8 CV (30/55). They fished along the coast (47/55) and half of them in the reef area (28/55), mainly with baskets (51/55). Only 10 fishers among 55 fished near FADs.

Group G4 (FAD fishers with medium engine) corresponded to 47 fishers from the West (23/47) and the North (22/47) regions. They mainly used fibre glass boats (30/47), with outboard engine between 9 and 25 CV (41/47). They fished in the deep sea (45/47) and

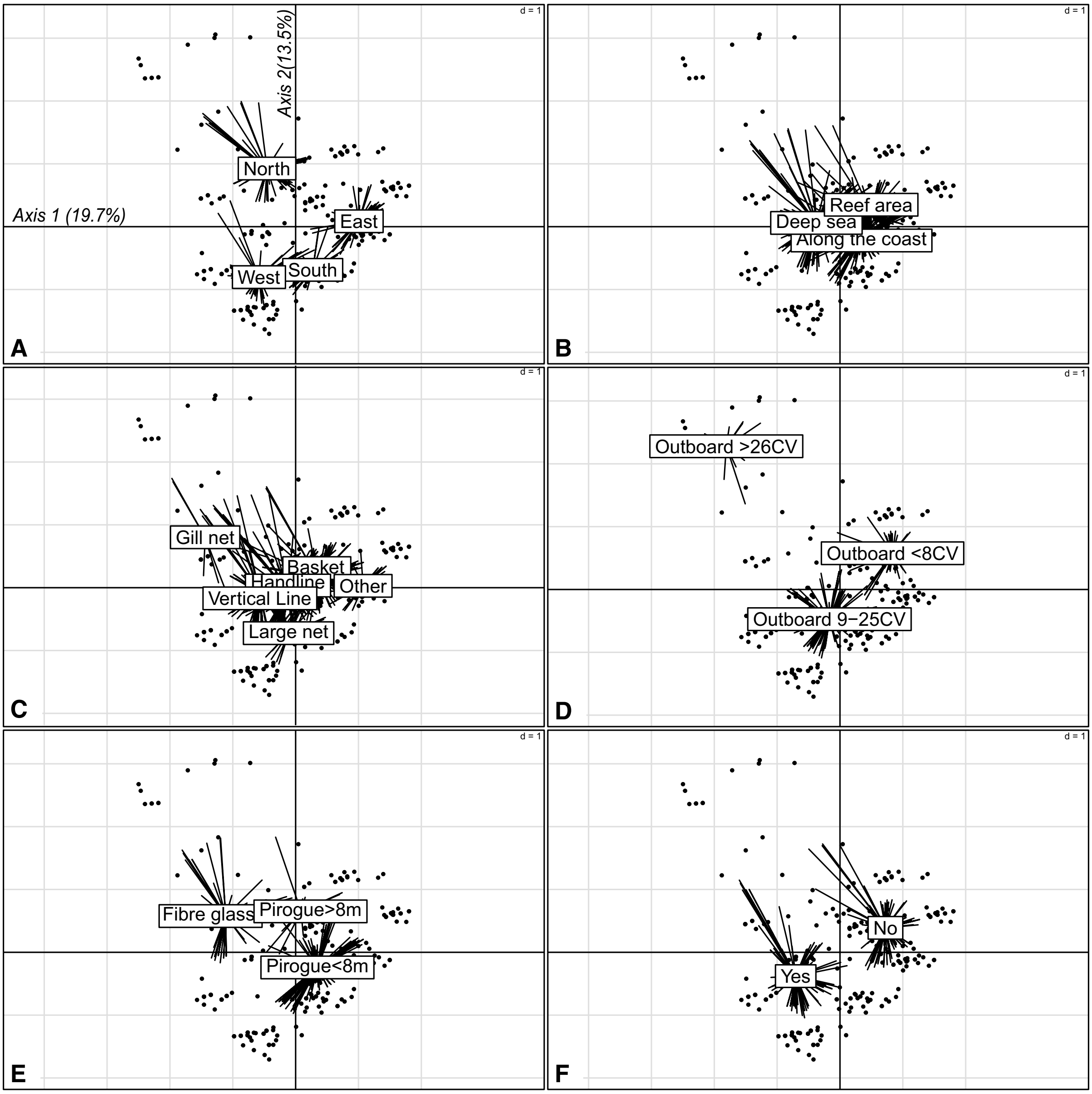


Fig. 3 Fuzzy Correspondence Analysis. Projection of the fishers (dots) on the factorial plane defined by the first two axes (axis 1: horizontally, axis 2: vertically). The six variables are represented separately to allow a better readability. a: region; b: fishing area; c: fishing gear; d: engine; e: type of boat; f: use of FADs. For each variable, the modalities are located at the average position of the fishers representing that modality. Lines link fishers to their answers (only 50% of their total length for readability)

used handlines (45/47) and vertical lines (32/47). All fishers for group G4 (except one) fished near FADs.

Group G5 (North deep-sea fishers with fibre glass boats and powerful engine), gathering 11 fishers, was clearly identified on the top left side of Fig. 4. All fishers in this group came from the North region; they mostly used fibre glass boats (10/11), all with outboard engine > 26 CV. They all fished in the deep-sea area, but never along the coast and rarely in the reef area (2/11). They fished preferentially with handlines (8/11) or vertical lines (6/11) and rarely used baskets (2/11). The proportion of fishers using gillnets in

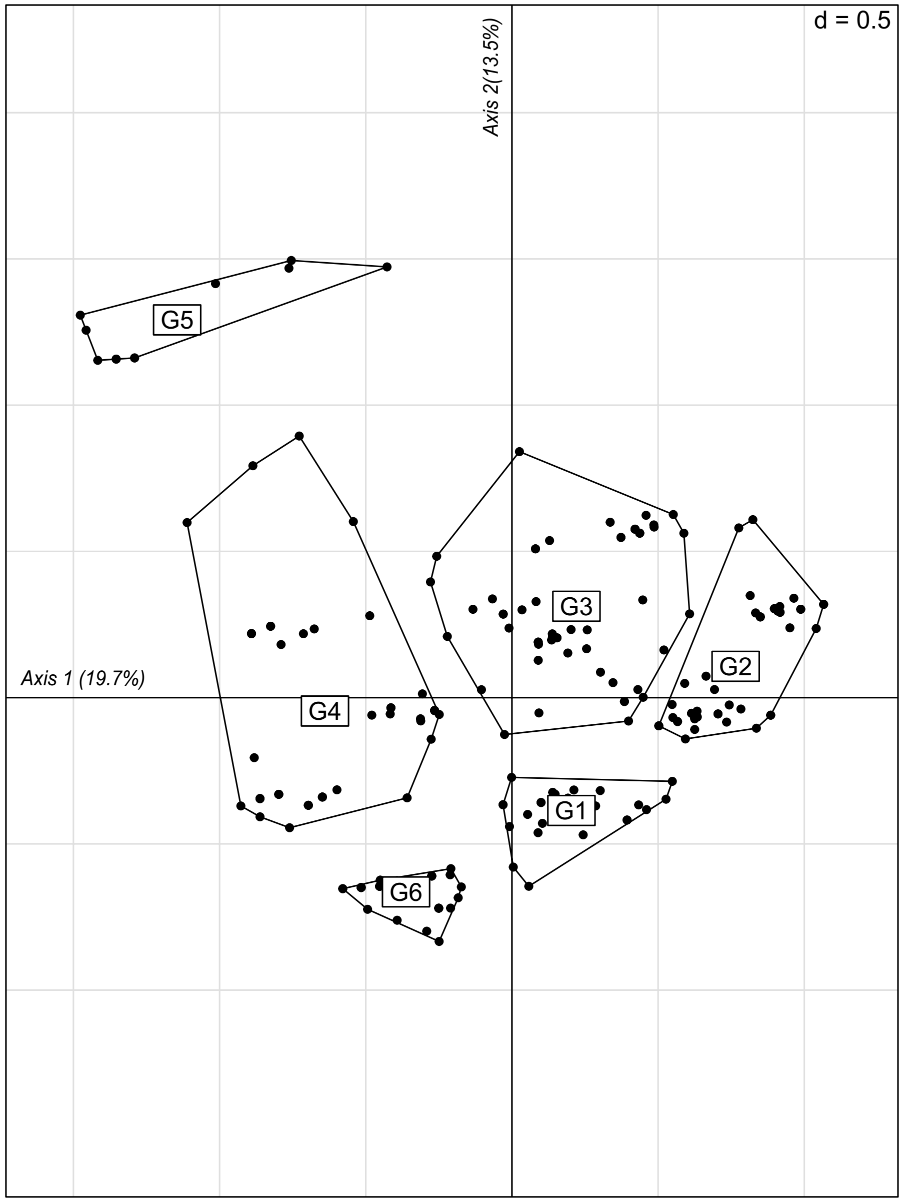


Fig. 4 Projection of fishers (dots) grouped into the 6 groups defined by hierarchical clustering on the first two axes of the FCA (see Figure S1)

Table 1 Summary of the answers of the fishers to questions expressing their perception of global change (GC). 194 fishers have answered these questions

Question	Percentage (%)		
GC1. Have you observed any change in rainfall pattern/distribution over the last 10–15 years?	Yes: 89.2	No: 10.8	
GC2. Do you find a change in the frequency of torrential rain over the last 10–15 years?	Less: 24.2	Same: 7.7	More: 68.1
GC3. Have you observed more or less fish in summer over the last 10–15 years?	Less: 53.1	More: 46.9	
GC4. Have you observed more or less fish in winter over the last 10–15 years?	Less: 83.5	More: 16.5	
GC5. Are there any change in the number of species of fish compare 10–15 years to now?	Less: 81.4	Same: 9.8	More: 8.8

this group was higher (22%) than in the other groups but it corresponded to only 2/9 fishers. Fishers from group G5 had no clear preference concerning FADs (7/11 fishers used FADs).

Finally, Group G6 (Pirogue FAD fishers) gathered 33 fishers from the West (25) and South (8) regions, who all used small wooden pirogues (< 8 m), with outboard engine between 9 and 25 CV. They rarely fished along the coast (13/33) or in the reef area (5/33) and they used mainly handlines (30/33) and vertical lines (23/33), but rarely baskets (7/33). All fishers for group G6 fished near FADs.

Fishers' perception of global change in Mauritius

Fishers showed a pronounced agreement (89.2%) (Table 1) that there is a change in rainfall pattern and distribution over the last 10–15 years. They reported that the frequency of torrential rain over the past 15 year is higher nowadays relative to 10–15 years ago (68.1%). There was also a general agreement that fish abundance is lower in winter (83.5%). However, in case of summer, there does not appear to be an agreement (less: 53.1%, more: 46.9%). Finally, 81.6% of fishers reported that there are less fish species now compared to 10 to 15 years ago.

Chi-squared tests between the questions related to the fishers' perception of global change and the membership of a group of fishers obtained through the clustering analysis were non-significant, apart from question GC3 which was on whether fishers have observed more or less fish in summer over the last 10–15 years (Table 1, Table S2). According to the post-hoc Chi-squared test, the significant difference was in group G4 (FAD fishers with medium engine, p value = 0.0004), where the proportion of fishers observing less fish in summer compared to 10–15 years from now was only 25.6%, thus significantly lower than the global proportion (53.1%–Table 1).

Main species caught during the last trip

The number of fish individuals caught by the fishers during their last trip were recorded for each species, leading to a total of 1681 individuals and 42 taxa (Table S3). The main species caught was the Parrotfish (*Scarus ghobban*), recorded in almost 13% of the total number of individuals caught. Doublebar goatfish (*Parupeneus trifasciatus*), Bluespine unicornfish (*Naso unicornis*), Spangled emperor (*Lethrinus nebulosus*), Sky emperor (*Lethrinus mahsena*) and groupers (*Epinephelus fasciatus, Epinephelus rivulatus*) each represented between 5 and 10% of the total, while the tuna and tuna-like species (Yellowfin tuna (*Thunnus albacares*), Skipjack tuna (*Katsuwonus pelamis*) and tuna (unspecified species)) each represented a lower proportion of the catches (2 to 5% of caught individuals). The Chi-squared test among the 6 groups of fishers defined above and the catches of the 14 main taxa (each representing > 2% of the total number of caught individuals and 83% of the overall catches in total) was highly significant (Chi-squared = 914.8, df = 65, p value < 2.2e-16), allowing to conclude that the groups of fishers did not have the same target species. The standardised residuals of the Chi-squared showed (Fig. 5) that the fishers from the groups G1 (Small pirogue coastal fishers), G2 (East basket fishers) and G3 (North basket fishers) were globally characterised by positive residuals (meaning that the observed number of caught individuals was higher than expected under the null hypothesis that all groups have the same species catches) for reef and demersal species such as Surgeonfish (*Acanthurus mata*), Sky emperor (*Lethrinus mahsena*) (except group G3), Golden trevally (*Gnathanodon speciosus*) (except group G2), Bluespine unicornfish (*Naso unicornis*) and Doublebar goatfish (*Parupeneus trifasciatus*) (especially in group 1 for these last two species). On the opposite, these 3 groups had negative residuals for pelagic species such as tuna and tuna-like species (Yellowfin tuna, Skipjack tuna (except group G1), tuna), Blacktip grouper (*Epinephelus fasciatus*) and Dolphinfish (*Coryphaena hippurus*). The four remaining species showed different profiles according to the group: Parrotfish and Halfmoon grouper were more abundant in group 3, while Spangled emperor and Shoemaker spinefoot (*Siganus sutor*) were particularly caught by fishers from group G2. These 4 species were all less abundant in group G1. Fishers from groups G4 (FAD fishers with medium engine), G5 (North deep sea fishers with fibre glass boats and powerful engine) and G6 (Pirogue FAD fishers) presented an opposite pattern, with positive residuals for tuna and tuna-like species (especially Yellowfin tuna in group G6 and tuna (unspecified) in group G4), Blacktip grouper and Dolphinfish (especially in group G4). All the other species were generally less abundant than expected under the null hypothesis of equivalence in these 3 groups.

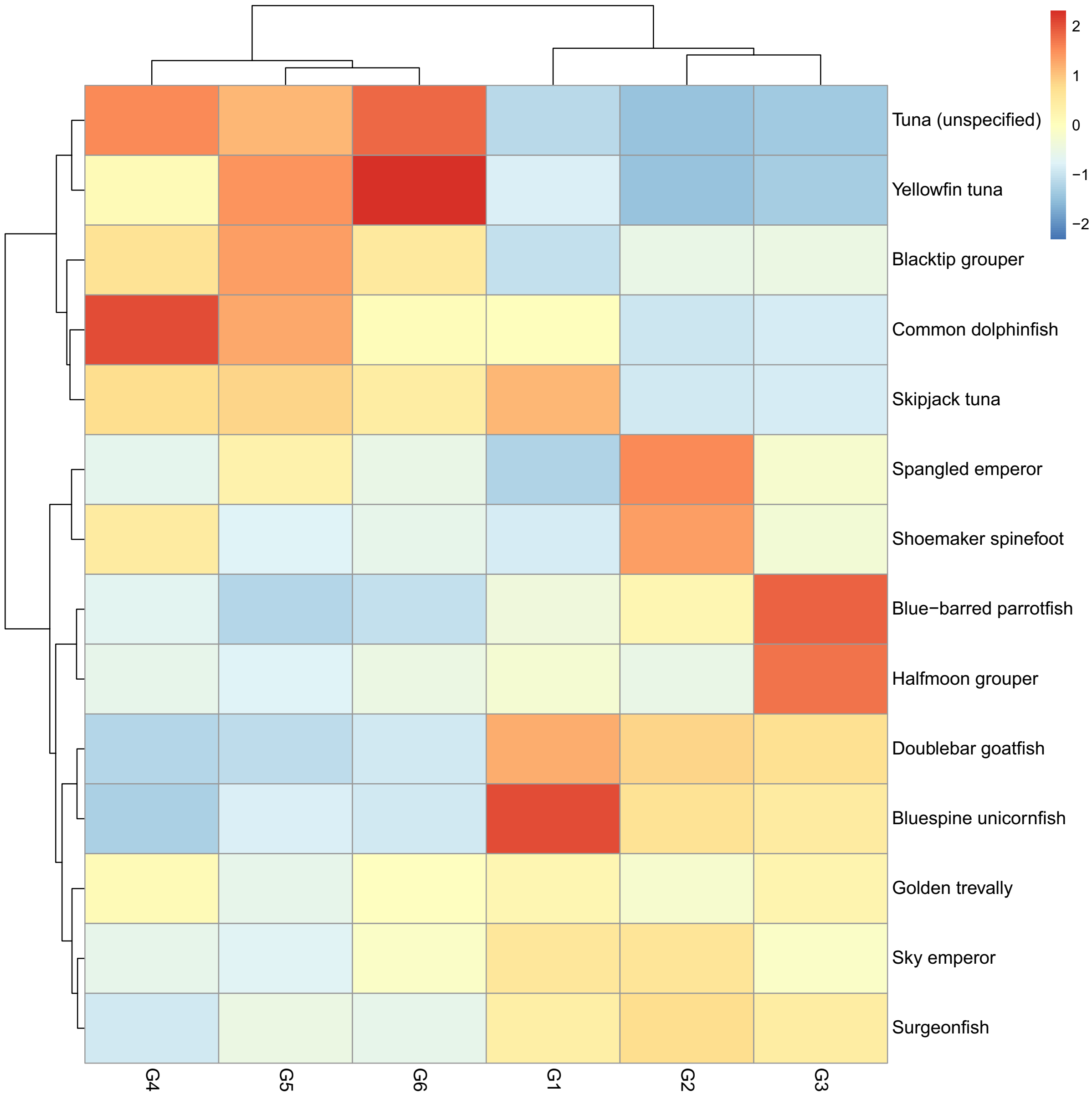


Fig. 5 Clustered heatmap of the standardised residuals of the Chi-squared test of the cross table between the 6 groups of fishers (G1 to G6) and the 14 main species caught. Colours indicate the standardised residuals of the number of individuals caught for each species. Blue cells correspond to negative residuals (Observed < Expected), yellow cells to average residuals (Observed ~ Expected) and orange cells to positive residuals (Observed > Expected). The higher the absolute value of the residual, the more intense the colour. The groups of fishers and the species were re-ordered according to their clustering, the dendrograms being plotted on the left and above the table respectively

Discussion

This study provided novel insights on the fishing practices and perception of environmental change for artisanal fishers in SIDS, considering the case study of Mauritius. The clustering analysis demonstrated a highly versatile nature of the artisanal fishers in Mauritius, who can use multiple gears (from handlines to basket traps) and fishing areas (from the reef/coastal areas to the open ocean). Six characteristic groups of fishers have been identified based on their location, fishing practices and the equipment they possess. Despite the multiple fishing gears employed by each fisher and the variety of fishing areas exploited, the methodology developed in this study, relying on a combination of FCA and clustering approach, allows to draw synthetic fisher's profiles highlighting their specific traits. The comparison of the catches from the last fishing trip obtained from each group demonstrated that this classification of fishers was consistent with their target species. Overall, half of the identified groups (G1, G2, G3) tend to catch demersal fish while the other three groups (G4, G5 and G6), which all use FADs, tend to catch pelagic species. The main species caught by fishers from groups G1, G2 and G3 during the last trip correspond to demersal/reef species, such as the Parrotfish (*Scarus ghobban*), the Doublebar goatfish (*Parupeneus trifasciatus*), the Bluespine unicornfish (*Naso unicornis*), the Spangled emperor (*Lethrinus nebulosus*) and the Sky emperor (*Lethrinus mahsena*). In contrast, the tuna and tuna-like species (Yellowfin tuna (*Thunnus albacares*), Skipjack tuna (*Katsuwonus pelamis*) and tuna (unspecified), represented a lower proportion of the catches in these groups and were caught by the fishers who fish at FADs (groups G4, G5, G6). A more simplistic separation of fishers' into two groups, targeting respectively demersal and pelagic fish species could be possible based on the catch data. However, our survey also highlights a large spectrum of fishing equipment, ranging from small pirogues to fiber glass boats. The boat engine is also a variable that significantly vary among the six identified groups. This study confirms that marine resources in Mauritius are exploited by artisanal fishers in an extensive and diversified manner, rather than in an intensive and specialized manner, as it generally happens for small-scale fisheries in SIDS and other coastal developing countries. Fishers are known to be versatile and can use multiple gears. For example, in other parts of the Western Indian Ocean, this was demonstrated in a study based on LEK in Zanzibar (Berkström et al. 2019), in Kenya (Samoilys et al. 2017) and in Tanzania (Chande et al. 2019). Similar characteristics were also found in other regions, such as Bangladesh (Rashed et al. 2016) and Brazil (Cunha et al. 2016) to name a few examples.

Accounting for the multiple characteristics of artisanal fisheries is key to support future fisheries management measures in Mauritius and, more generally, in SIDS and coastal countries. In this respect, the methodology developed in this study can be applied in other SIDS or small-scale fisheries. Smith and Basurto (2019) provide a review on the definitions of small-scale fisheries used in literature over the last six decades. There are several characteristics used to define these fishers with the most common ones ranging from fishing gear, boats, sociocultural, species, motorization, catch disposal, ecology and habitat. However, definitions may have an overreliance on harvesting methods and may overshadow other components. Within the Food and Agriculture Organization's (FAO) *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication*, a definition of artisanal fisheries is intentionally not provided ([FAO] Food and Agricultural Organization 2015). The FAO Guidelines highlight the importance of characterizing which activities and operators are considered small-scale according to their specific context at a regional, subregional or national level. Recently, a multi-criteria matrix approach to relationally characterize small-scale fisheries has also been proposed (Funge-Smith 2018). The approach presented in this study, which classifies fishers according to their multiple characteristics without relying on definitions made "a priori" on the groups, can be considered as another possible methodology. Future studies could also consider the socio-economic dimensions of these groups, to further evaluate their exposure, sensitivity, and adaptive capacity to environmental change (Allison et al. 2009). Another aspect to be investigated is food security and how much of the proteins consumed by each group of fishers come from their catches (Nash et al. 2022).

Fishers can use different strategies to cope with reduced yields as highlighted by Coulthard (2009) and Selgrath et al. (2018) where a LEK based approach was used. These include differentiating and changing fishing gears (Musinguzi et al. 2016), increasing fishing effort (by spending more time at sea), increasing fishing capacity (by increasing the number, size or efficiency of gears or fishing technology) or fishing farther or deeper than previously, targeting new fish species or adopting alternative livelihoods (Muringai et al. 2022). Fishers can adapt to reduced yields by relying on their detailed knowledge (LEK) of local oceanographic conditions and behaviour of target species (Early-Capistrán et al. 2020). The LEK approach used in current study provides information both on the fishing grounds and the exploited species. Our results indicate that in Mauritius half of the groups of fishers (groups G4, G5, G6) exploit deep sea fishing grounds and target pelagic fish species. For two of these groups (G4 and G6), the use of FADs appears as a significant variable. The use of nearshore anchored FADs aims at transferring some fishing effort from coastal demersal fish to tuna and other large nearshore pelagic fish. It is recognised as a practical way of increasing fishers' access to pelagic resources (Bell et al. 2018a; Hanich et al. 2018a; Rosegrant et al. 2016), diversifying catches and reducing fishing pressure on reef species that are more vulnerable to global change. For over 30 years, FADs use has been promoted in coastal developing states and SIDS to improve livelihoods, safety at sea in addition to food security (Bell et al. 2015; Campbell et al. 2016; Montesa et al. 2019). Trials of use of FADs in small island states like Timor Leste show positive effects on catch rates (Tilley et al. 2019). As shown in Kenya, FADs also represent an avenue for the capture of high valued fish species like tuna, thus improving income to coastal fishers (Onyango et al. 2021). Anchored FADs are widely used in the Philippines and Indonesia (Macusi et al. 2015; Khan et al. 2020). Other countries in the Indian Ocean using FADs extensively include the Maldives, where a FAD array is used on a semi-industrial scale by the tuna pole and line fishery and is managed by the government (Jauharee et al. 2021). The use of FADs may be an adaptation method to diversify fishing methods in the wake of climate change as highlighted by Bell et al (2018b) in the Pacific Islands.

In the case of Mauritius, this study outlines that the use of FADs was uneven across the island, with a major contribution for the fishers located in the West and in the North. This pattern reflects the uneven structure of the FAD array in Mauritius (Fig. 1), which has a higher FAD density along the Western coast of the island. Overall, there are less FADs in the East, since the eastern and southern parts of the island are more exposed to the Southeast trade winds throughout the year. Therefore, despite the widespread use of FADs in Mauritius, the findings indicate that the proximity of FADs to the port of origin of the fishers strongly affects their use. In the past, in order to support the local artisanal fisheries, the government incentivized the use of FADs and the shift towards more enginized boats. The Ministry of Blue Economy, Marine Resources, Fisheries and Shipping disposed of funds aiming at providing financial support to the fishers and enable them to purchase better equipped boats named 'canottes', that could allow them to fish off-lagoon (Cervigni and Scandizzo 2017). To further assess the importance of FADs as a solution to mitigate the impacts of global change in Mauritius, it will be important to monitor the seasonal abundance and variability of the pelagic resources caught at FADs. In addition to that, since FADs have an impact on the volume and species composition of the catches, they can affect the local prices of fish. Monitoring the evolution of fish prices in local markets will therefore be essential to evaluate the impact of FADs both in terms of generating income for the fishers and also on the purchasing power of consumers. Finally, pelagic fish species are highly mobile and their ocean-wide stocks are generally shared between multiple countries. FAD fisheries can have ecological impacts on target species, non-target species and marine habitats (Dagorn et al. 2013). Therefore, to ensure their sustainability, FAD management plans should be adopted. It is also essential that the artisanal fisheries using FADs in SIDS be accompanied by sufficient biological monitoring of the catches (including the catches/bycatch of vulnerable species such as pelagic sharks and rays), shared at the Regional Fisheries Management Organizations level.

Due to their accessibility to the artisanal fishers, reef fishes and coastal species have traditionally constituted the main target species for fishers in SIDS. According to a review by Tyler et al. (2021), there has been an increase in global fishing effort of reef-associated fish from 1950 to 2010. This fishing pressure further increased the vulnerability of reef fish and other coastal species, and therefore of artisanal fishers in SIDS targeting them, to climate change. Assessing the impacts of climate change on reef-species in SIDS and other coastal developing countries often needs to cope with scarce data availability. In such contexts, the use of LEK constitutes an interesting alternative relative to other methodologies relying on scientific surveys or fisheries-dependent data to assess the health status of marine resources (Leduc et al. 2021), as well as to provide complementary information that are useful in fisheries management (Berkshtrom et al. 2019, Colloca et al. 2020, Silva et al. 2020). The LEK survey conducted in this study demonstrated a high consensus on the perception of environmental change by the Mauritian fishers, with a large majority of them reporting a decrease in the observed fish species and abundance over the years. In Mauritius, several studies have shown temperature-related stresses. Thermal stress affecting corals have been observed by Mattan-Moorgawa et al. (2012), Louis et al. (2016) and McClanahan and Muthiga (2021). Environmental stressors may also be the reason for extinction of some endemic fish species (McClanahan et al. 2021). Intuitively, one would expect a higher depletion for the groups of fishers who mainly target the reef species. The observed absence of patterns in the fishers' perception to environmental change with respect to their fishing practices can be related to their versatile behavior: since fishers generally operate with multiple gears and target multiple species, they all observed changes in species diversity and abundance. Moreover, in a recent study by Dhurmeea et al. (2020), on albacore tuna, it was observed that nutritional condition was lower in albacore from the tropical than temperate waters, implying that increased sea surface temperature as a result of climate change could negatively affect population dynamics and nutritional quality of pelagic fish species. Although the current study focused on environmental change, other anthropogenic activities such as pollution can impact fisheries and the fishers. One such example for Mauritius is the major oil spill which happened in August 2020, and this was an important global stressor to the environment of the fishers, especially those in the south-east coast. The impacted sites had 631 fishers (De Rosnay et al. 2021). The fishers could not carry out their fishing activities due to fishing restrictions and a 72% reduction in revenue from fishing was noted. The fisher community in Mauritius was also affected by exogeneous factors such as COVID-19 where access to the sea was restricted during lockdown periods.

Conclusion

The participation of stakeholders is essential for any effective fisheries management system. This study, relying on fishers' interviews, provided a first quantitative picture of artisanal fisheries in Mauritius. The study first highlighted fishers using multiple gears and fishing areas. A large consensus was found among fishers relative to their perception of global change, both in terms of species abundance and diversity. The incentives of having enginized boats and the management actions taken by the relevant authorities have enabled fishers to exploit FADs and diversify their catches. However, FADs are not uniformly present along the island and their proximity strongly affects their use by fishers. This study provides a concrete example of FAD adoption by artisanal fishers in SIDS and discusses how FADs can strengthen their resilience to global change. Such knowledge on the fishers and their strategies will be useful to better guide management and adaptation strategies in the future. SIDS are among the most vulnerable countries to disasters and environmental change (SIDS in numbers 2020). Just like Mauritius, many other SIDS, such as the Pacific islands countries and territories and especially their small-scale fishers and fisheries, are vulnerable to environmental change (Hanich et al. 2018b). There is a need to supporting decision makers, to foster the response capacity of these countries and prepare them to adapt to such changes (Finkbeiner et al. 2018). In this respect, the methodology and approach presented in this study can be applied to other SIDS or small-scale fisheries at a sub-regional, regional or national level.

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Declaration

Competing interests Authors do not have any competing interest to report.

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