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Barriers to effective monitoring and evaluation of small-scale fisheries in small island developing states: An example from Mauritius

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ABSTRACT

Managing small-scale fisheries (SSF) is complicated because fishers rarely selectively target valued species but try to maximise their catch by keeping everything regardless of species or size. About 50% of the fish captured for human consumption globally, is produced by SSF, however, there has been repeated failures of fisheries management to effectively regulate this resource by data poor countries due to poor or non-existent long-term monitoring and evaluation (M&E). To understand the challenges to effective M&E in Small Island Developing States (SIDS), we looked at the current M&E system of Mauritius from the point of view of its effectiveness in managing its SSF. Major barriers to effective M&E identified were (i) a lack of quality fisheries information and understanding of ecosystem functioning resulting from a limited ability to collect quality data and analyse it effectively, (ii) a lack of collaborative research and other cost-effective approaches (iii) a failure to assess the effectiveness of no-take reserves and (iv) a lack of inclusion of catches from all sources when calculating the total catch. These barriers are mostly due to a lack of qualified personnel, specialised equipment and a lack of funding. Therefore, achieving management objectives designed to provide benefits to both humans and the environment, requires a series of approaches to improve data collection, integration and emphasising appropriate decision-making, data collection and analysis frameworks.

1. Introduction

Fishing contributes directly to the livelihood of millions of people worldwide who depend on protein-rich fish as an important source of food security [1]. In Madagascar for instance, 87% of the adult population work in the small-scale fisheries (SSF) sector which generates about 82% of all household income, and provides the only source of protein in 99% of household. In 2010, 83% of the estimated 5524 metric tons of fish and invertebrates caught by small-scale fishers in Madagascar generated fishing revenues of approximately $6.0 million while the total annual subsistence catch was estimated to be $6.9 million [2]. Additionally, ancillary activities such as net-making, boat-building, engine repair and maintenance, etc. provide additional fishery-related employment and income opportunities in the fishing communities [3,4].

The 58 Small Island Developing States (SIDS) [5,6], draw substantial economic and livelihood benefits from fisheries because the marine exclusive economic zones (EEZ) of many SIDS are extensively larger than their land area [7–9]. For instance, the income from coastal subsistence fishing in Fiji, Papua New Guinea and Tuvalu were estimated at USD 29 292 929, USD 66 731 518 and USD 1 120 287 respectively for the year 2014 [10–12]. In fact, about 50% of the harvest of the world's capture fisheries used for human consumption is produced by small scale fisheries [1]. This aligns with the fact that the majority of the world's fishers live in developing countries, with over 90% of the 4.72 million vessels active in the world classified as small-scale fishing craft [13]. The level of activity in SSF is even more intense than indicated by the number of craft because many of these fisheries operate from the shore in coastal or inland waters [14]. Even though these fisheries' contributions are poorly quantified, they are essential to the national and regional economies of developing countries [15].

Marine fisheries contribute about 240 billion USD to the world economy [16] and have long been perceived as an unlimited resource.

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However, Pauly et al. [17] suggested that during the last two decades of the 20th century the perception that marine fisheries are inexhaustible has given way to a realisation that it is a sector in crisis [18] (but see Amoroso et al. [19] for an updated view of the global footprint of fishing). This change in perception results from an understanding of the risk that overfishing poses to human development and livelihoods [1] and recognition of the ecological vulnerability of fisheries ecosystems [20].

In the past, fisheries management has often focused on the value of the catch of target species while overlooking factors such as habitat quality, predator-prey relationship of the target species and other ecosystem constituents, and the connectivities that determine fisheries resilience and longevity [21]. Destruction of habitats, incidental mortality through by-catch, evolutionary alterations in population demographics, and modified operation of ecosystems that are inadvertent outcomes of fishing, are rapidly gaining recognition as major issues influencing fisheries viability [21], leading to the realisation that ecosystems need to be conserved and used sustainably to optimize social-ecological benefits [22]. Consequently, for effective fisheries governance, it is vital to manage access to marine resources to promote their sustainable use, and because of the complexity of resource utilisation, it is essential to manage every group involved in capture fisheries productively [23,24].

The complexity of the biological, social and economic factors involved, and the paucity of understanding of those factors, is likely to drive a continued pattern of unexpected and rapid depletion of fishery stocks as demand exceeds biological capacity [25–27]. These factors include poorly defined biological understanding of even the most basic parameters underpinning fish stock health and resilience, poor understanding of human and environmental interactions and an absence of effective governance [27,28]. These issues are amplified in small tropical countries where marine fisheries governance is complicated because the coastal fisheries in SIDS involve various species, complex and diverse habitats, several fishers, multiple gears, different landing sites and distribution channels per unit of catch [29, Dalzell & Schug [30] Cited Hamnett 1990]. Furthermore, fish stocks need to simultaneously support large-scale commercial fisheries operations, local-level market and traditional fisheries, and subsistence fisheries – an intersection of commercial, livelihoods and food security issues [27,31–35]. As a result, sustainable fisheries production is a complex multifaceted problem that needs to be solved across multiple scales; local, regional and global. At the same time as fisheries sustainability needs to assure the long-term health of both fish stocks and the ecosystems that support them, fisheries governance objectives need to be set in the context of whole-of-ecosystem conservation with multiple goals. This needs to address social needs, together with the increasingly dynamic nature of marine systems and their climatic drivers [27,31,34,35]. Hence, it is vital to have quality data that will convey a detailed, accurate and relevant understanding of the different factors implicated to provide a sound basis for quality decision-making through an appropriate framework that will promote sustainable use and productivity of the marine resources.

In most SIDS, the government is responsible for managing coastal fisheries. Many governments rely primarily on Western models for fisheries management to regulate the biological and economic wastes that occur in a vigorously used open-access fishery through a set of rules/regulations such as restrictions on fishing areas, seasonal closures, gear and catch quotas etc. [36]. While this type of management is necessary where fisheries stock is widely dispersed or where different life-history functions are conducted in different geographic locations there is still a role for traditional methods like community-based management. This is particularly advantageous where a major part of the resource is contained in the area controlled by a community or where the overall resource viability is unlikely to be adversely impacted by local actions. Giving communities the right to allocate and manage their fisheries resource can provide substantial social benefits. For instance, community management by those with local property rights, can allow villagers living close to a resource to inherit part of the financial benefits arising from people/companies using those resources [37].

However, both types of management have limitations. For example, fishers generally use their locally acquired knowledge for locating and maximising their catches [38]. This can be detrimental in some situations. For instance, allowing community management where the whole local recourse comprised a vital nursery ground would be likely to adversely impact the fisheries stock as a whole. On the other hand, with the Western models, the management requires the collection of biological information on fish stocks, catch and effort etc., to enable regulations to be devised. This process can be costly and even lengthy if an agreement has not been reached among fishers regarding the regulations [39]. Hence, it has been proposed that the community-based management be integrated into the Western models to produce a framework of co-management to cater for the limitations of both types of management [40]. For this to provide effective and integrated fisheries management, the government and other responsible stakeholders need to take into account all the aspects of fisheries governance (ecological, social and economic). Well-designed monitoring and evaluation (M&E) systems are critical components of such programs.

Monitoring and evaluation plays a crucial role in wildlife management because ecological systems are under constant change and influenced by a diversity of factors, meaning that their responses to management actions are rarely predictable with a high level of certainty [41]. Monitoring is the routine quantitative or qualitative collection of data for the purpose of status evaluation, while evaluation involves data collection to investigate the effectiveness and impact of management strategies and actions [42]. The two are usually interlinked [43] and best treated as an integrated M&E process [44]. Well prepared and implemented M&E systems are fundamental components of effective management [44] and gathering information for the implementation of effective management, should include indicators to determine if planned objectives were met [45]. This means M&E schemes need to be developed as part of the planning process; and as a corollary, that it is problematic to monitor and evaluate poorly planned projects. Additionally, the M&E schemes need to integrate participatory monitoring and evaluation approaches where the different levels of participation and inclusion of traditional knowledge could be used for natural resources management [46,47].

M&E is the foundation of effective decision making because it enables successful management outcomes and provides a basis for measuring the success of actions [44]. In fact, M&E is essential at every step during the progress of a project [45]. The first important role of an M&E programme is to determine the state of the system before establishing the procedures that will be implemented as components of the management cycle. Secondly, it is essential to have an M&E programme so the efficacy of management actions, and their correspondence to the established objectives, can be evaluated. Thirdly, given that conservation and wildlife management is complex, an adaptive management approach is essential; M&E is the learning process that provides knowledge of the system to better achieve and improve the objectives of the management cycle [41].

M&E are fundamental components of effective fisheries management and, consequently, poor or non-existent long-term M&E is a major contributor to the repeated failure of conventional fisheries management [22]. This issue is particularly relevant for SIDS, where location- and situation-specific knowledge about physical, chemical and biological processes that drive population dynamics and their operation is often almost totally lacking. Furthermore, there is often a limited capacity to conduct M&E activities [48], and this is compounded by uncertainty of the extent to which knowledge developed in one location is transferable to the situation in question, and assumption that is rarely validated [49].

Almost invariably, limited location-specific information is available for SIDS, and there is limited capacity to collect additional data. As a result, effective M&E processes, that includes filtering and integration of

Table 1
Characteristics of the metadata collected for the management of artisanal fishery in Mauritius for the period 2000–2011. Numbers in the table indicate the number of studies with data for a variable, while - indicates no data were collected for that variable and NA indicates that no data were available. Shaded cells indicate variables likely to have sufficient data to provide a reasonable basis for decision-making.

Type of data collected	Number of dataset available for each variable						
	Lagoon	Off lagoon	Fish Aggregating Devices (FADs)	Blue Bay Marine Park (BBMP)	Balaclava Marine Park (BMP)	Gear Type	Number of active fishermen
Total Catch	12	12	8 (not reported for 2000, 2001, 2002 & 2007)	-	-	12	-
Monthly Catch	12	12	2 (reported for 2009 & 2011 only)	-	-		
Fishing Effort	12	12	-	-	-		
Catch per Unit Effort (CPUE)	12	12	-	-	-		
Gear Type	-	-	-	-	-	NA	12
Licences & permits	-	-	-	10	-	12	-
Number of Illegal fishing cases	12	-	-	8	1 (reported for 2004 only	12	NA
Species Caught	-	-	1 (reported for 2003-2006 only)	-	-	-	-
Biological characteristics	1 (Length & weight of fish species reported for net fishing season of 2008 only)	-	-	-	-	-	-
Environment (% substrate cover)	9	-	-	11 (not reported for 2002)	9 (not reported for 2002-2004)	NA	NA
Abundance of fish, sea urchins & sea cucumbers	9	-	-	10 (not reported for 2002 & 2003)	9 (not reported for 2002-2004)	NA	NA

available knowledge, and feeds into appropriate decision-making frameworks are required. Because of the complex knowledge constraints and the unique conditions prevailing in many SIDS, developing M&E frameworks appropriate to these constraints needs to be a priority. As a first step towards establishing the underpinnings of a comprehensive M&E process, that addresses the needs of SIDS, we identify and evaluate the barriers faced by SIDS in the implementation of effective monitoring and evaluation using the Mauritian small-scale fishing industry as a case study.

2. Barriers to effective monitoring and evaluation

Barriers affecting the implementation of effective M&E were identified using published literature as well as websites and published reports from the Government of Mauritius (refer to Appendix A for more details). The annual reports of the Fisheries Department of the Government of Mauritius for the period 2000 to 2011 provided information on the characteristics of the metadata collected by the government for management purposes of SSF in the country (Tables 1 and 2), and the government website provided information on relevant laws and regulations (Appendix B).

Table 2
Components of the data collected for the small-scale fisheries studies in Mauritius [50–61].

Type of data collected	No. of components
Total Catch	Lagoon, Off lagoon, FADs, Gear type
Monthly Catch	Lagoon, Off lagoon, FADs
Fishing Effort	Lagoon, Off lagoon
Catch Per Unit Effort (CPUE)	Lagoon, Off lagoon
Gear Type	Line, Basket trap, Basket trap & line, Large net, Gill net, On foot/harpoon
Licences & Permits	**Lagoon/Off lagoon**: Large net, Gill net Fishmonger, bait net. **BBMP**: Boat/vessel, Basket trap, line fishing, commercial activities, recreational, interference, **BMP**: Recreational
Number of Illegal fishing cases	Underwater fishing, Net fishing, Others
Species Caught	Common name, Scientific name
Biological Characteristics	Length, Weight
Environment (substrate cover)	**Lagoon**: Coral, algae, abiotic, others. **BBMP**: Live coral, Dead coral, Sea urchins, Macroalgae, Seagrass, Sand/rubble. **BMP**: Acropora branching, Acropora tabular, Coral encrusting, Coral foliose, Coral massive, Coral submassive, Mushroom coral, Soft coral, Rubble, Rock, Sand, Turf algae, Macroalgae, Coralline algae, Dead coral.
Abundance of fish, sea urchins & sea cucumbers	**Lagoon**: Pomacentridae & Chaetodontidae, Acanthuridae, Labridae, Scaridae, Sea cucumber, Sea urchin. **BBMP**: Acanthuridae, Balistidae, Blennidae, Chaetodontidae, Gobidae, Labridae, Monocanthidae, Mugilidae, Mullidae, Scaridae, Serranidae, Zanclidae, Plotosidae, Pomacentridae. **BMP**: Acanthuridae, Aulostomidae, Balistidae, Chaetodontidae, Cirrhitidae, Labridae, Lethrinidae, Monocanthidae, Mullidae, Scaridae, Serranidae, Siganidae, Holocentridae, Pomacentridae.

2.1. Data quality and quantity

Managing a fishery is particularly complex and requires understanding of the different factors affecting that fishery. For example, artisanal fishers do not selectively catch valued species, or retain only individuals of appropriate sizes (e.g. non-targeting of pre-reproductive fish), so tend to try to maximise catch instead of managing impact on the resource as a whole [62]. These fishers generally form part of the poor communities who have to fish for subsistence. Hence, they will not target species that have an economic value, but will also capture a diversity of species and a range of sizes during each fishing trip in order to maximise their revenue. This can work to spread the impact of fisheries across species and prevent the waste that can flow from injured discards. On the other hand, it may mean that individuals of inappropriate sizes are retained and that fishing mortality causes severe local depletions across the species spectrum. In fact, the quality of management outcomes is closely linked to the quality and quantity of available data, with the lack of reliable and up-to-date data on the current status of a managed population, presenting a substantial barrier to the implementation of effective management decisions [63]. One of the most common fisheries evaluation needs is stock assessment. Even though several methods have been developed to estimate population abundance in data-poor situations, they cannot be used if a minimum information on either exploitation or life history is unavailable. Therefore, there is the need to develop appropriate stock assessment methods (e.g. Chrysafi & Kuparinen [64] and Geromont and Butterworth [65]).

The minimum data requirements for successful fishery assessments are quite specific [66,67] and include: (i) catch identity resolved to species, (ii) total catch, (iii) total catch (TC) for each species, (iv) amount of fishing, (v) fishing effort, (vi) gear type, and (vii) biological characteristics of the catch (size, age etc …). However, very often these data are deficient (Fig. 1). For example, out of ten SIDS countries namely Bahamas, Bahrain, Belize, Comoros, Fiji, Guyana, Mauritius, Papua New Guinea, Singapore and Tuvalu [5,6,50–61,68–81], nine countries collect data on TC (Landing estimates) [50–61,68,69,72–76,78–81], two countries collect data on catch identity resolved to species [79–81], two countries collect data on total catch for each species [68,69,79], three countries collect data on gear type [50–61,76,79], four countries collect data on fishing effort [50–61,72,73,79] and none collect data on biological characteristics of the catch and amount of fishing (Fig. 1 & Table 1). Consequently, by not collecting the minimum required data for their SSF management, SIDS are putting the entire fishery and their population in jeopardy. The TC data refers to all removals by all the fisheries from the stock and should not omit any minor fisheries components such as subsistence or sports fisheries, unreported/illegal and discarded catch [66,82]. Similarly, for a multi-species fishery like the small-scale fishery, TC estimates should include all species [83]. TC estimates are generally calculated against a reference which is the combination of a geographical area, a reference period and a specific boat/gear category [67].

The most notable feature of the 244 data sets (recorded from the 12 annual reports) for small-scale fisheries in Mauritius (Table 1) is the lack of consistency of the variables collected, even at the coarse level represented by the metadata. Even variables as fundamental as total catch and fishing effort are not available for all or even most sites, the amount of fishing was not collected at all and even where data are available, their collection is inconsistent over time. Clearly, when considered in light of Gulland's [66] and FAO's [67] lists of variables essential for stock assessment there is a lack of the comprehensive data required for proper monitoring and evaluation of the SSF in Mauritius. For instance, the TC data for FADs were not reported for the years 2000, 2001, 2002 and 2007, while no catch data were recorded for Marine Parks. The health status inside and outside marine parks as well as the non-compliance within the parks should be monitored because the marine parks in Mauritius comprise multiple use zones [84]. Therefore, ecological and catch (subsistence, recreational and illegal) data should be collected for effective M&E. In fact, the inconsistency of data collection means that only a few sets of variables have the potential to be useful for management purposes (Tables 1 and 2), and the value of these is likely to be very question-dependent. This lack of fundamental data is clearly a substantial barrier to effective management of the fishery, and goes a long way to explaining why Mauritius has been unable to prevent the depletion of its coastal fish stocks, despite the many laws and regulations that should provide a strong basis for management (Appendix B). In addition, management of Mauritius' lagoon fish stocks face challenges with regards to institutional/policy support framework, Government's capacity to implement fisheries management plan, services to fishers and lack of expertise in new techniques such as FADs [85]. All of these rely on the quality of available knowledge, so all are impacted by the poor quality of the available M&E data.

When the Mauritius fisheries data are considered in finer detail (e.g. focussing on the level of detail and the way data are reported), even apparently similar data are often incompatible (Table 2). Firstly, it is clear that spatial and temporal patterns were not considered when calculating fishing effort, introducing the potential of seriously bias results, particularly if data sets are combined. Jennings & Kaiser [86] and Pet-Soede et al. [87] have shown that fishing effort is influenced by spatial and temporal patterns. For example, the use of motorised vessels by commercial fishers increases the number of fishing sites that can be visited, reducing stress on particular fishing areas because fishers are able to extend their effort over larger spatial scales [86]. In contrast, small-scale subsistence fishing is generally confined to a restricted number of sites, resulting in intensified localised pressure on resources [86]. As a result, the dynamics of effort over time, and thus the impact of fishing, is very different for the two groups. The consequences of such factors are complex. For instance, if intense fishing pressure leads to the depletion of stocks of the initially targeted species, small-scale fishers

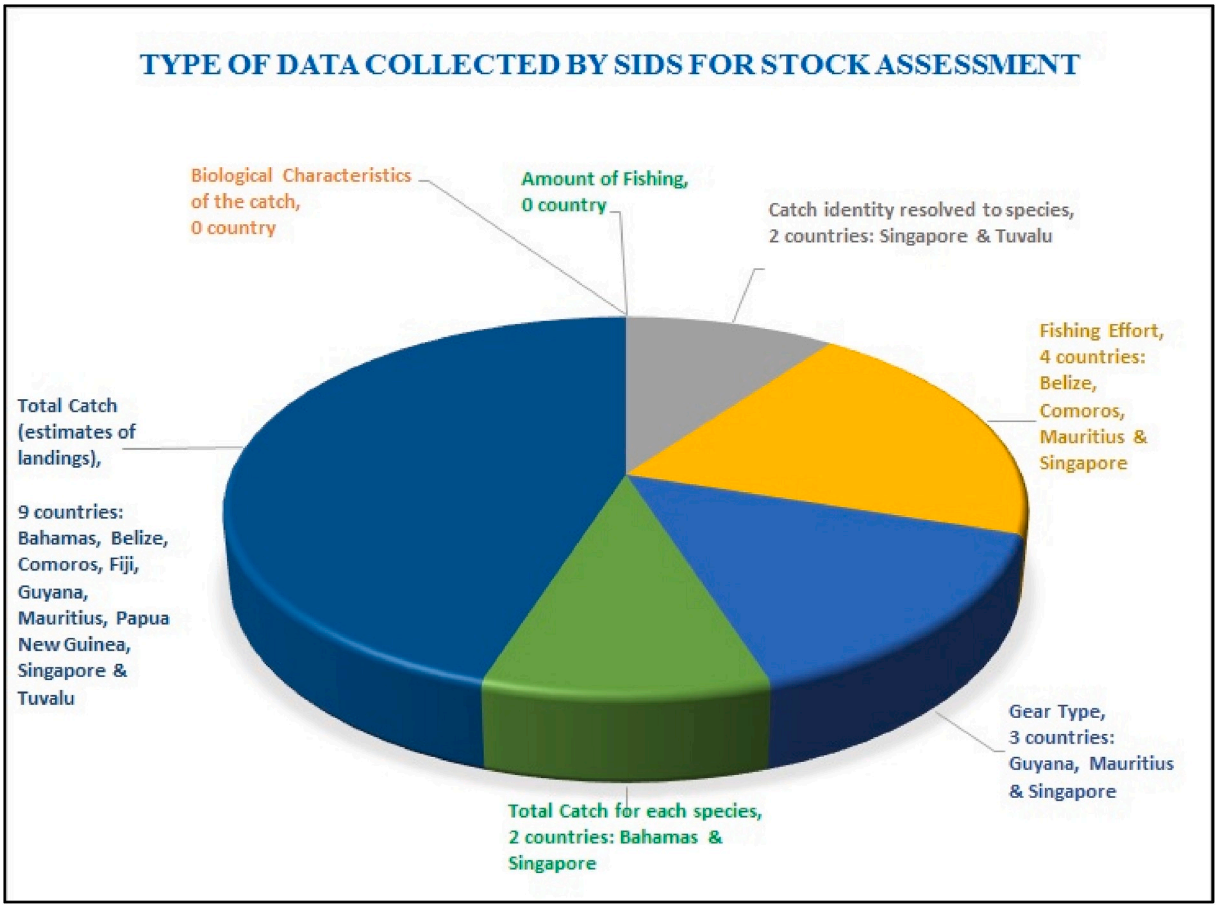

Fig. 1. Type of data that are collected by SIDS for the stock assessment of their small-scale fisheries.

will switch to catching other species within their resource space [86], causing a transfer of pressure from one target species to another, likely leading to complex changes in local trophic interactions leading to unexpected food web outcomes. Temporal factors also influence the patterns of fishing effort directly, with fishing patterns varying at a variety of temporal scales; within a year between seasons, within months, and between days, and these two vary for different fisher groups. For example, small-scale fishers often prefer to travel shorter distances multiple times a day to maximise their fishing time, compared to large-scale fishers who would travel to other locations to maximise their catch [87]. Additionally, the spatial and temporal scale used by fishers will depend on the type of fishing activities being undertaken (large--scale, medium-scale or small-scale), with large-scale fisheries resource spaces being as great as 2800 km^2 while a small-scale resource space might be as small as 50 km^2 [87]. These substantial variations mean it is necessary for Mauritius and other SIDS to consider both spatial and temporal factors when allocating fishing effort.

Secondly, as Gulland [66] emphasises, TC are among the most essential data and, to prevent underestimation, should comprise all removals from the stock [88]. However, in the case of the Mauritian SSF, the TC did not include removals by minor fisheries or illegal fishing, with only the number of illegal cases reported, but not details of the seized catch. This lack of attention is perhaps a reflection of the emphasis in national planning. Even though the Mauritian National Plan of Action to prevent deter and eliminate illegal, unreported and unregulated fishing (NPOA-IUU) caters for the collection of catch and effort data for the artisanal fishery, the emphasis is on measures to combat IUU

Table 3
Groupings of fish comprising Mauritius fish data [50–61].

Mauritian names of the species	Common names in English
Homard	Lobster
Crab & Crevettes	Shrimp
Vieille Rouge	Blacktip grouper
Vacoas	Green jobfish
Sacre chien	(Rubby snapper, Flame snapper or Crimson jobfish
Capitaine	Spangled Emperor
Dame berry	Sky emperor
Octopus	Octopus
Carangue	Rainbow runner, Small spotted dart or Giant trevally
Cordonier	Shoemaker spinefoot
Rouget	Goatfish
Tuna	Tuna
Mullet Voile	Flathead Mullet
Bordemar	Mangrove red snapper
Licorne	Unicornfish
Cateau	Parrotfish
Shark & Other fish	Shark and unassigned fisheries species

Table 4
Key information required to enable effective management.

Biological Characteristics	Life history, Growth & Mortality rates, Reproduction, Dietary preferences, Spatial distribution and Stock size [98].
Reserves set up	Size, Placement and Spacing of no-take reserves, Number of protected habitats, Mobility of target species and Socio-economic factors [95,96].

fishing in the exclusive economic zone and commercial fishery rather than eliminating illegal activities in the coastal fishery (Appendix C). Clearly, it is essential that none of the minor fisheries are omitted. In the case of Mauritius fisheries TC calculations should include catch from the lagoon, off-lagoon, both Marine Parks, FADs, sports/recreational, bait and Illegal fishing datasets.

A further issue with data quality is a lack of consistency in the data recorded. For example, rather than being recorded separately for different species, the TC was recorded for inconsistent groupings (Table 3). Clearly, each species has unique biological characteristics and life cycles, as well as their own specific importance to the ecosystems they occupy, and so it is essential that each species be treated separately and not collectively. Consequently, the data collection strategies of Mauritius need to be revised to determine which types of data are required and which should no longer be collected, so avoiding the collection of unnecessary data that requires a large amount of resources.

Moreover, literature has shown that government cuts in funding and staff reductions limit the capacity of governments to collect appropriate data on complex environmental challenges [89]. In the same way, excess capacity in fishing fleets increases pressure on governments and fishing authorities to agree to higher limits, larger quotas, and higher number of permits, than modelling indicates is appropriate to ensure sustainable fishing [24]. Consequently, governments are often reluctant to disclose the full extent of catch, and are likely to fail to disclose accurate catch statistics so as not to embarrass parties engaged in illegal activities [88]. Similarly, in Mauritius, the lack of appropriate funding and qualified personnel [90] promote the collection of poor quality data, a problem exacerbated by political interference in the operation of fisheries management [33,91]. Such factors lead to incomplete reporting of true catch levels, again resulting in poor quality data and underestimation of the actual catch.

Clearly, the lack of data quality and consistency are major issues constraining informed management. Many factors contribute to this problem. While there are no simple solutions, the first step is the development of a consistent approach to data collection. Such a framework would provide clear and consistent direction to the data collection process, and could include details of the types of data required for each component and the steps for the data collection (e.g. Fig. 3).

2.2. Data analysis

In addition to the lack of data consistency, once collected, data handling and analysis were often deficient in the case of the Mauritian SSF. For instance, although some annual reports suggested that the decline in fish catch “may be due to a decrease in fishing days or fishing effort and movement of fishers to the Fish Aggregating Devices (FADs) associated fishery” [50,51], they included no quantitative evidence supporting those arguments. In fact, no statistical analysis was carried out in any of the annual reports, except in the report of 2011, where the average price by species was estimated. Consequently, the ‘evaluation’ component of the M&E system is not being implemented, making it impossible to assess the effectiveness of the M&E system, rendering it largely ineffective. As a result, appropriate solutions and management strategies aimed at preventing the continued depletion of coastal fish stocks cannot be implemented.

A key step to improving the situation is to ensure that personnel are appropriately trained, understand the biological and ecological functioning of each species, and are skilled in appropriate data analysis. An important step would be the development of a framework for data analysis (see Fig. 4 for an example), detailing the types of analyses (quantitative or modelling) and the different steps to be undertaken for proper analysis.

2.3. Critical science gaps

A lack of appropriate knowledge and understanding of ecosystem functioning means that information aimed at supporting management decisions will often be inappropriate. Therefore, there are gaps in critical scientific knowledge that present further barriers to effective M&E in fisheries management. For instance, coral reef ecosystems, as well as other interconnected ecosystems such as mangroves and seagrasses, are important components of artisanal fisheries because they sustain the abundance of fish and other commercially important marine organisms in highly inter-connected marine ecosystems [92–94]. However, in the case of Mauritius, the understanding of the dynamics of fisheries and their environment is lacking because the data collected by the different units within the Fisheries Department are generally treated separately under individual projects (Appendix D). This means for example, that no analysis is done to assess the relationship or the connection between the environment (coral reef ecosystems, water quality etc.), fish abundance and catch data, nor the effect that the components have on each other.

Another critical gap is a lack of complimentary information (Table 1) needed to convert the available data into actionable knowledge. For instance, even though catch data are a fundamental variable in fisheries management, without information on stock size they can be misleading. Predicting sustainable catch is impossible if we do not know both annual harvest and the size of the available stock [95]. Similarly, to determine the status of fisheries and the efficiency of the production, the environment, abundance and catch data need to be treated as interconnected components [95].

The availability of sufficient and appropriate underpinning knowledge is also a prerequisite when setting up such things as closed seasons and no-take reserves. No-take reserves are aimed at providing protection to the biodiversity and insurance against overfishing, but are rendered ineffective if there is a lack of biological knowledge to direct their development and management [96]. For instance, although Mauritius has two marine protected areas and six fishing reserves [97] key information needed to enable management is not available. These data needs are extensive (Table 4), particularly because artisanal fisheries are involved meaning a diversity of species are exploited.

Although understandable in the light of the complexity of the information involved, this lack of knowledge on ecosystem functioning and the links between the different components is a significant barrier to the SSF management, that will require concerted efforts to address if measures such as no-take reserves are to be effective. Additionally, the efficacy of the reserve needs to be tested through research using appropriate experimental designs [95,96].

Another critical science gap is the lack of understanding of the human-environment interactions. SSF governance does not involve only fish stock management but also, the livelihood management of artisanal fishers. Even though SSF provide food security and social safety nets for poor communities, it is generally difficult to settle issues of equity, and social justice because policy makers tend to avoid the difficult decisions that need to be made [99,100]. Very often governments try to resolve social issues by providing subsidies to artisanal fishers. They encourage fishers to use motorisation to fish outside the lagoon to reduce fishing pressures on coastal stocks. However, capacity-enhancing subsidies provided by governments were observed to contribute to overfishing because they drove an increase in fishing capacity, thereby threatening the sustainability of marine resources and so the livelihoods of those who depend on them. Consequently, the appropriate knowledge on the human-environment interactions needs to be an integral part of effective M&E of SSF to support the fair distribution of the generated benefits from the SSF management [100,101].

2.4. Collaborative research

The complexity of the tasks and the need for well-trained personnel means that transforming the no-take reserves into an effective management tool requires substantial investment and effective collaborations [96]. These collaborations are complex and need to include scientists, management and fishing communities [96,102], and are important during the initiation and review stages, but also need to continue through the life of the marine protected area [102]. However, management has often perceived fishers as passive recipients rather than partners in fisheries management [91], and it is clear from the 2000–2011 annual reports that data for assessment have been collected without collaboration with commercial and artisanal fishers. This is unfortunate because, although direct catch data are often lacking in developing countries due to logistical challenges [103], recent studies have shown that the effectiveness of management systems can be improved if community members are integrated in the assessment of artisanal fisheries [102,104]. Fishers could provide historical data from their experiences, as well as recent biological and physico-chemical data with spatial (fishing effort per area) and temporal (seasons) dimensions [87]. Likewise, fishers and citizens could be involved in research in collaboration with government agencies, non-government organisations and researchers to monitor, tract and respond to issues affecting the community [87,105,106]. Therefore, increasing collaborative involvement in research provides an opportunity for improved acquisition of knowledge about Mauritian fisheries, as well as promoting community-based fisheries understanding. In addition, providing the appropriate capacity building to community members, such as fishers, could help with the collection of data that would provide a much more extensive coverage than is possible with Fisheries Department surveys alone. Additionally, the information that needs to be collected on SSF's catch is often extensive, highly distributed and difficult to collect [107], therefore, "community engagement" or "exploratory fishing" would provide an efficient sampling strategy for the collection of a greater volume of information at cheaper cost, particularly given that locals usually have more knowledge about the coastal regions than outside researchers [87,96,102,104]. This will improve the effectiveness of the M&E system of SIDS in the face of limited resources and funding. Besides, fisheries governance can only be achieved if all the necessary information is available. Reason why, collaborative research is needed to collect the right data.

2.5. Other possible barriers to effective M&E

Fisheries species use a wide range of habitats for feeding, refuge and reproduction [108] and tend to have marine larval phases that extend pre- and post-settlement distributions across the coastal seascape [109]. Consequently, understanding the biological characteristics of each species involved is crucial in fisheries management. The lack of effectiveness of conventional methods used for monitoring is a contributing factor to the ineffectiveness of the M&E of artisanal fisheries. Conventional site-specific methods often used in research generally provide low spatial and temporal resolution because high spatial and temporal replication can be very labour intensive when traditional methods are employed. The rapid development of sensor techniques (e.g. water quality sensors, underwater video, sonar), and the increasing availability of diverse arrays of sensors can provide large amounts of data, essentially automatically [109–115]. However, the large amounts of data produced by these approaches brings with problems of handling and analysing massive, complex data sets. Consequently, capacity development needs extend beyond training in the use of traditional methods and modern sensor techniques, to data technology and machine learning [116–119] that can help process and streamline the analysis of massive data sets.

3. Conclusion

Although small-scale fishery is an important resource for many SIDS, most still have, either an ineffective M&E or they lack an M&E altogether. Even though the objective of Mauritius is to ensure long-term sustainable fish production, very little consideration is given to strategies for fisheries resource management [91]. For example, the Fisheries Department of Mauritius does not have a set of objectives that are specific for its SSF; instead it has a set of objectives that covers fisheries in general (Appendix E). This lack of specificity in designing the appropriate objectives for SSF management will obviously result in weak strategies and inadequate management methods as observed in our analysis (refer to section 2.1-2.5). Similarly, SIDS like Bahamas, Bahrain, Fiji and Papua New Guinea do not have a well-defined national fisheries management system or plan for their small-scale/subsistence fisheries [68–71,74,75,78]. Some of these countries put more emphasis on large scale/commercial fisheries compared to the SSF [68,69,74,78–81]. On the other hand, even though some SIDS have a SSF management system, they still face major barriers such as (i) a lack of quality fisheries information (Fig. 1), (ii) a lack of collaborative research and other efficient and cost effective approaches (iii) a failure to assess the effectiveness of no-take reserves and (iv) a lack of inclusion of catches from all sources when calculating the total catch. These barriers are mostly due to logistical challenges such as a lack of qualified and trained personnel, lack of specialised equipment, appropriate transportation, and lack of financial support [103]. Therefore, achieving effective management objectives in data-poor fisheries require effective filtering and integration of available knowledge and an appropriate decision-making framework.

Multiple M&E frameworks can be utilised to achieve high level of management, but all need to fulfil a set of logical criteria. The first step is to institute a management panel that includes all stakeholders involved in the SSF to take account of all interests. With the collaboration of all stakeholders, it is then possible to identify the issues regarding the SSF and develop well-defined aim and objectives to address the relevant issues. Once the scope of the M&E has been identified it is then possible to start gathering the right data to evaluate the fisheries status. The data collected are then processed and analysed to formulate conclusions and decisions that would be implemented into recommended actions, which can in turn be evaluated to better achieve and improve the objectives. The M&E process can be conceptualised as a cyclic activity with feedbacks and interventions between the various stages (Fig. 2). Unfortunately, the two major hurdles identified in this study were a lack of quality data and appropriate analysis which hindered the ability to develop effective M&E of SSF. For that reason, data collection and analysis are two fundamental steps in fisheries management that requires full consideration and given the complexity of the problems, the best way to do this is by putting these tasks into two organised frameworks, one for data collection (Fig. 3) and one for data analysis (Fig. 4). Only then a well-structured M&E system could be developed for the management of the SSF. These frameworks were designed based on the list of barriers identified in Mauritius as well as through our literature search, to provide an example on the type of data that need to be collected and the type of analysis required. They were also designed to provide guidance to SIDS who are willing to set up their own M&E system for their SSF or to assess the status of their current M&E system and identify areas of improvement. These guidelines can as well be used to allocate the necessary resources and funding to the required activities that are involved in the management of the SSF to produce cost effective and efficient M&E systems and positive outcomes for the various stakeholders.

3.1. Monitoring and evaluation framework

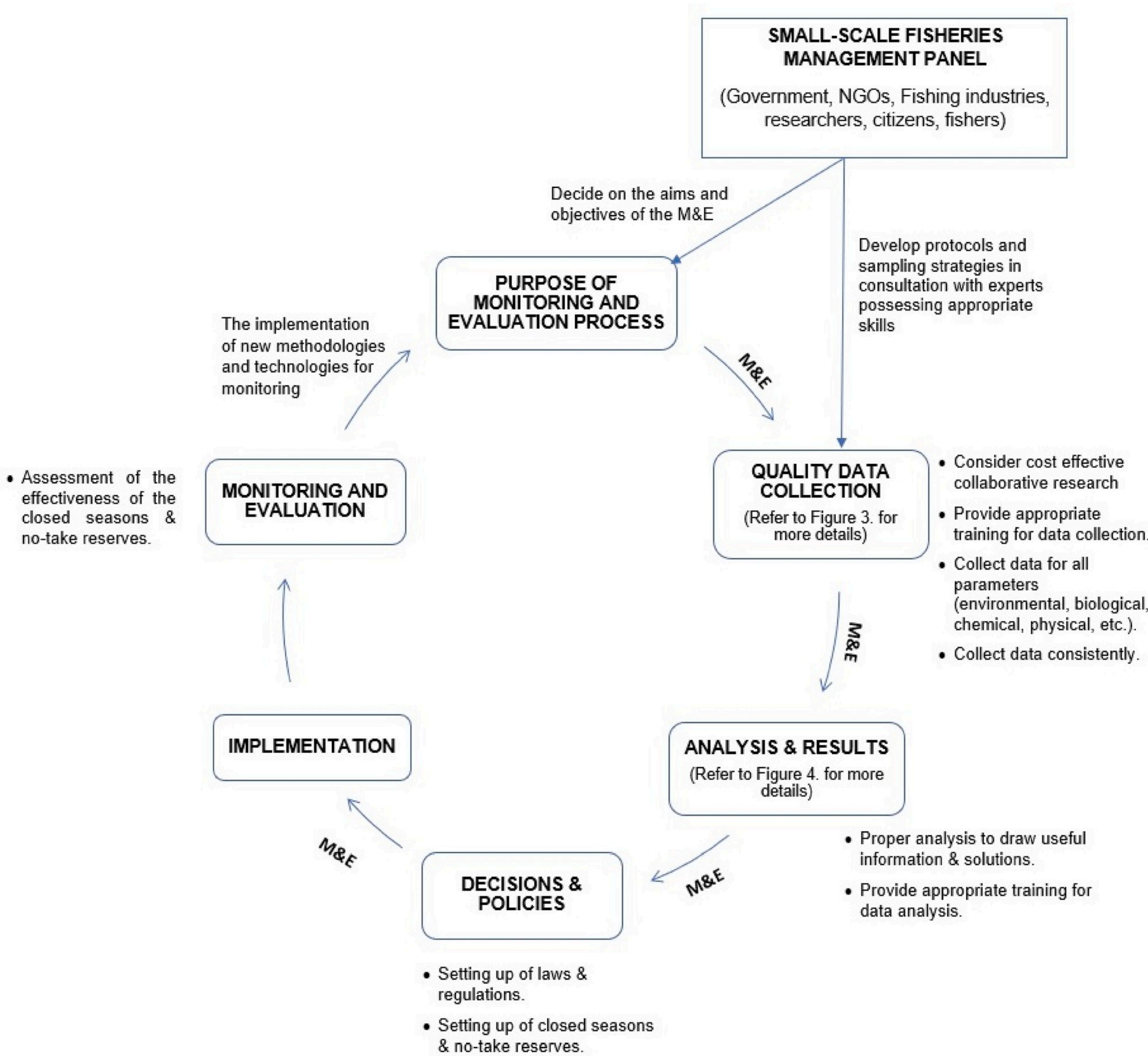

Fig. 2. The programme/project cycle of Woodhill [45] adapted to provide an example framework for the monitoring and evaluation process for small-scale fisheries management with the essential M&E at every step.

3.2. Data collection framework

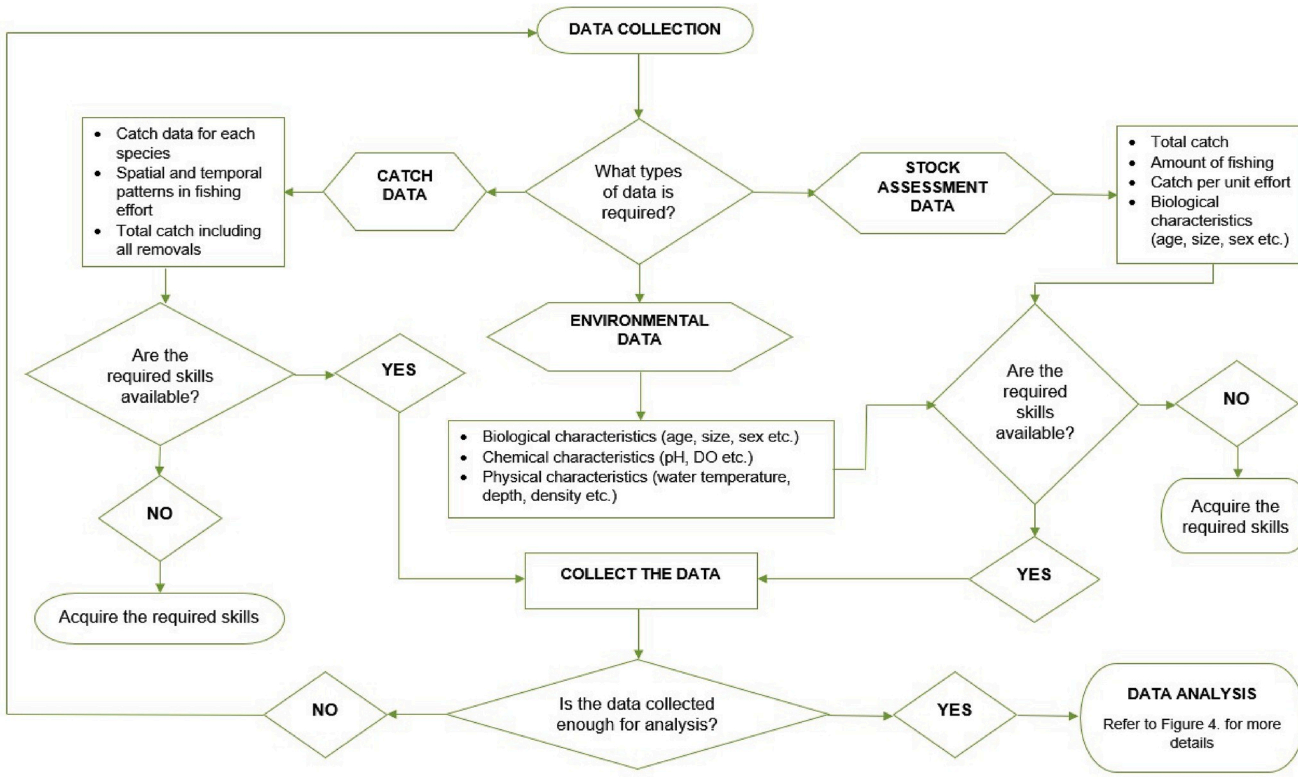

Fig. 3. A potential framework of data collection process for small-scale fisheries management.

3.3. Data analysis framework

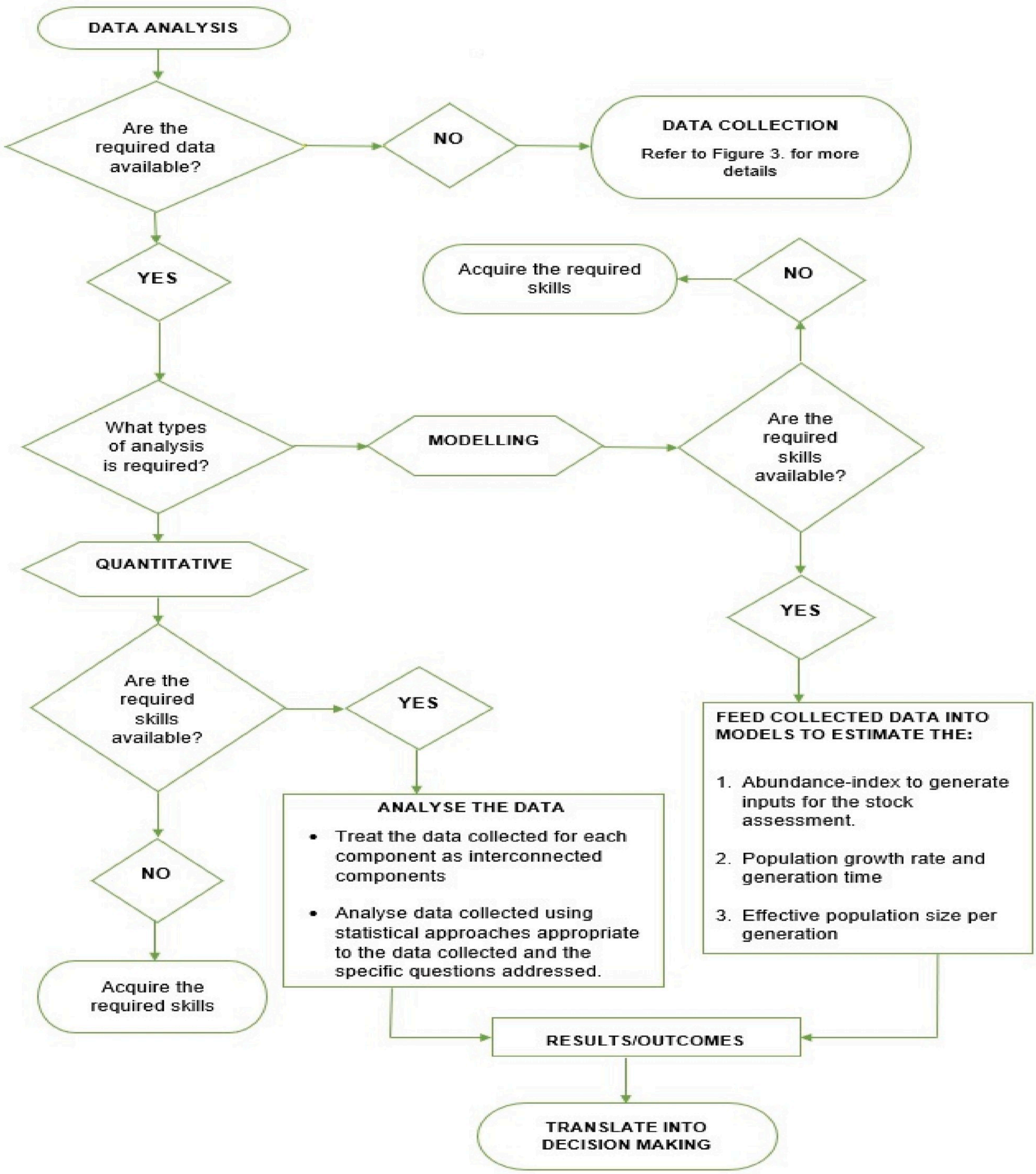

Fig. 4. A potential framework of data analysis process for small-scale fisheries management.

Table 5
Source of information on the types of data collected for fisheries management in the 10 selected SIDS countries.

GEOGRAPHIC REGION	SIDS	SOURCE OF INFORMATION
Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS)	Bahrain	FAO 2003 [70], FAO 2004 [71] & FAO 2019 [120]
	Comoros	Breuil & Grima [73] & FAO 2019 [121]
	Mauritius	Annual reports 2000–2011 [50–61]
	Singapore	Fishery Statistical Bulletin of Southeast Asia 2016 [79]
Caribbean	Bahamas	Sherman et al. [68], Moultrie et al. [69] & FAO 2019 [122]
	Belize	FAO 2018 [72] FAO 2019 [123]
	Guyana	FAO 2000 [76], Maison & Haraldsson 2007 [77] & FAO 2019 [124]
Pacific	Fiji	FAO 2002 [74], FAO 2019 [10]& FAO 2019 [75]
	Papua New Guinea	FAO 2002 [78] & FAO 2019 [11]
	Tuvalu	FAO 2002 [80], Fisheries Department 2017 [81] & FAO 2019 [12]

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CRediT authorship contribution statement

Bhavnah Komul Kalidin: Conceptualization, Methodology, Validation, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Carlo Mattone:** Writing - review & editing. **Marcus Sheaves:** Conceptualization, Methodology, Validation, Data curation, Writing - original draft, Writing - review & editing, Supervision.

Appendix A

Methodology

Google scholar was the main search engine utilised to find published literature on the topic. A systematic search was done using the following words: fisheries management, small scale fisheries, small island developing states, conservation, effective monitoring, barriers to monitoring, and monitoring and evaluation. Additionally, because the focus of the research was not solely on journal articles but also aimed at government and industry reports the search was extended to Google web search and Research gate as well as to books on fisheries management strategies. Moreover, the annual reports of the Fisheries Department of the Government of Mauritius were accessed and information collected for the period 2000 to 2011. The most recent report that was available after 2011 was that of 2016/2017, thus our choice to analyse the reports for the period 2000–2011, to assess the consistency in data collection and reporting. The information obtained from the reports were analysed to determine the characteristics of the metadata collected (Table 1) for the management of the SSF in Mauritius.

59 documents (including journals and technical reports) out of the several documents that were reviewed to identify the barriers to effective monitoring and evaluation were found to be relevant to our research. A compiled list of barriers to effective M&E and recommendations for effective M&E through the literature search was used to assess the reported information for M&E in Mauritius. The barriers identified in the 59 documents through the literature search and through the assessment of the information in the annual reports of Mauritius were down listed into major barriers namely, (i) a lack of quality fisheries information and understanding of ecosystem functioning resulting from a limited ability to collect quality data and analyse it effectively, (ii) a lack of collaborative research and other cost-effective approaches (iii) failure to assess the effectiveness of no-take reserves and (iv) a lack of inclusion of catches from all sources when calculating the total catch. These barriers are discussed in more details in sections 2.1-2.5.

For the purpose of this study, we also assessed the type of data that are being collected for fisheries management in 10 SIDS countries. SIDS are broken down into three geographic regions: the Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS), the Caribbean and the Pacific [5,6]. To have an overview of the SSF management in SIDS from these 3 geographic regions as well as to identify the type of data that are collected by SIDS for fisheries management, a sample of 10 SIDS countries were selected (Table 5). 3 SIDS countries were randomly selected from each region and Mauritius was included as the tenth SIDS country. We conducted a qualitative search for information on catch identity resolved to species, total catch for each species, amount of fishing, fishing effort, gear type, biological characteristics of the catch, and total catch (landing estimates) on government websites, in technical and statistical reports, on FAO's websites and in scientific papers. Information on the types of data collected for fisheries management in those 10 countries were not readily available and if found the information was not up-to-date (Table 5). However, the limited information obtained from our exploratory research still gave us an overview of the type of data that were collected by SIDS for the stock assessment of their small-scale fisheries. The information was represented graphically to highlight the lack of necessary data for effective M&E in SIDS (Fig. 1).

Moreover, the information obtained on the laws and regulations implemented by the country from the Government website were summarised in Appendix B, the information on illegal, unreported and unregulated fishing were summarised in Appendix C, the projects undertaken by each division of the Fisheries Department were summarised in Appendix D and the vision, mission and objectives of the Fisheries Department were listed in Appendix E. Consequently, information obtained from past literature, the national laws and regulations, books on fisheries management strategies as well as our findings were used to assess the effectiveness of the M&E system used in SIDS like Mauritius to manage its SSF sector as well to determine the barriers to monitoring. The past literature and our findings were also used to identify solutions to the barriers.

Appendix B

The laws and regulations that provide conservation and management measures for artisanal fisheries in Mauritius [125] are:

- The Fisheries and Marine Resources (Prohibition of Removal of Coral and Sea-Shell) Regulations 2006;

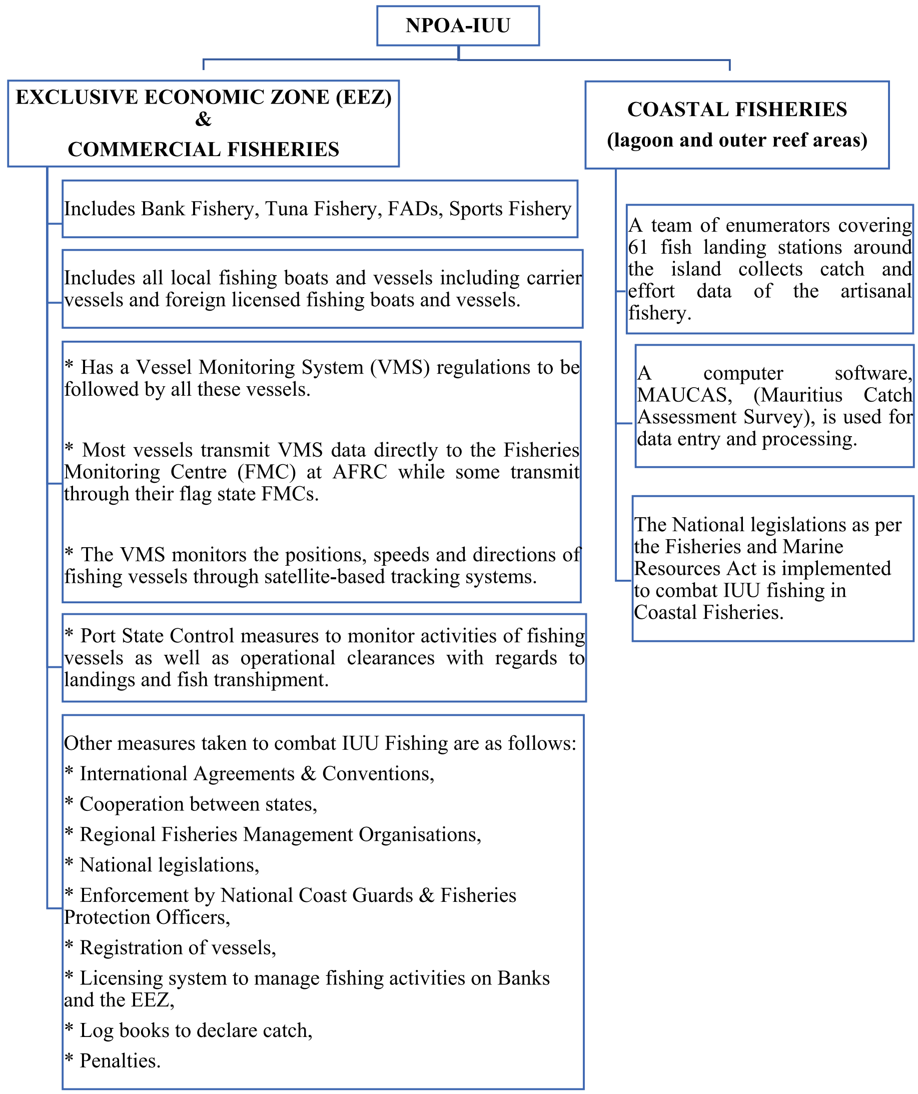
- The Fisheries and Marine Resources (undersized Fish) Regulations 2006;
- The Fisheries and Marine Resources Act 2007;
- The Fisheries and Marine Resources Act 2007 amended;
- The Fisheries and Marine Resources (Fishing of Sea Cucumbers) Regulations 2008, 2009 & 2012 (Amendment);
- The Fisheries and Marine Resources (Extension of Net Fishing Season) Regulations 2009, 2010, 2011, 2012 & 2013;
- The Fisheries and Marine Resources (Prohibition of the Use of hooks of Small Size) Regulations 2011 and
- The Fisheries and Marine Resources (Bait Gear Licence and Licence fees) Regulations 2012.

They have made provisions for the types of fishing methods and gears that are allowed or prohibited as well as the different types and sizes of nets permitted; size and gender of certain fish species that are not allowed to be caught; prohibition to catch crab or lobster in berried state; prohibition to catch marine turtles and their eggs, and marine mammals; registration of fishers, fishing boats and fishing vessels; fishers should have gear licences (including bait gear licence) to operate; limitations on number of licences (gear licence is not transferable and conditions accompanies the disposal of licence gears); prohibition of underwater fishing and fishing with the aid of artificial lights; landing of fish at fish landing stations; setting closed seasons and prescribing the type of gears and fishing times allowed during the open seasons; regulated operation of Fish Aggregating Devices and sports and recreational fishing; conditions regarding fish farming, right to fish in a fish farm, control of disease outbreak on a fish farm; demarcation of fishing reserves, marine parks or marine reserves; protection of aquatic ecosystem including corals and shells, marine protected areas and artificial reefs; and offences and penalties.

Furthermore, the Ministry has recently, started implementing a new closure season of 3 months for the octopus fishery in 2016 from 15 August to 15 October. The trial produced good results in terms of quality and quantity of the catch after the re-opening [90].

Appendix C

The National Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (NPOA-IUU) addresses All State responsibilities, Flag State responsibilities, Coastal State responsibilities, Port State measures, Trade related measures, Conformity measures regarding Regional Fisheries Management Organisations & Measures taken by Mauritius to combat IUU fishing [126]. The structure of the NPOA-IUU is as follows:



Appendix D

Projects undertaken by the Fisheries Department of the Ministry of Ocean Economy, Marine Resources, Fisheries and Shipping [50–61,84]:

1. Fisheries Planning & Licensing Division
   - Planning unit is responsible for planning, implementation of fisheries policies, compiling and processing of fisheries information.
   - Licensing Unit issues fishing licences, renews licences and registers vessels on VMS register.
2. Aquaculture Division

   Responsible for aquaculture developments, marine ranching programmes and seed production of a few fresh water species.
   Projects:

(a). Plankton culture,
(b). Freshwater Fish culture: Brood stock & seed production.
(c). Ornamental fish culture.
(d). Appraisal of aquaculture projects.
(e). Marine ranching programme.
(f). Monitoring of marine/freshwater aquaculture projects

3. Laboratories and Documentation Division

Involved in the long-term monitoring of coastal water quality in terms of physico-chemical and microbiological parameters as well as the long-term monitoring of harmful marine microalgae.

Projects:

(a). Coastal water quality: Physico-chemical parameters, trace metal analysis, audits on wastewater projects, fish mortality and alleged pollution & monitoring of coliform bacteria at public beaches.
(b). Ecotoxicology: Fish toxicity tests & monitoring of harmful marine microalgae.

4. Fisheries Management Division

Responsible for research and assessment of fish stocks, monitoring of fishing activities and the dissemination of information on fisheries matters.

5. Marine Conservation Division

Responsible for promoting sustainable use through the long-term protection and conservation of marine biodiversity and habitats while maximising economic and social benefits from the coastal zones.

Projects:

(a). Blue Bay Marine Park: Monitoring, control and surveillance of permissible activities, Permits for activities, Coral reef ecosystem monitoring at the park.
(b). Balaclava Marine Park: coast and afloat patrols in the marine parks, Coral reef ecosystem monitoring at the park.
(c). Permits and Clearances: Interference permits within marine protected areas, Firework displays, Environmental Impact Assessment, underwater surveys in connection with coastal development projects.

6. Marine Science Division

Responsible for the long-term monitoring of the coastal ecosystems for sustainable management and decision making through the collection of ecological data on coral reefs, mangrove and seagrass ecosystem.

Projects:

(a). Long-term monitoring of coral reef ecosystems around the island except for the marine protected areas: coral cover & visual census for fish.
(b). Coral farming.
(c). Ad-hoc ecological surveys of ex-mining sites, aquaculture farms, proposed dredging of boat passage, sewage outfall, sea cucumber abundance and distribution etc.
(d). Mangrove propagation.

7. Fisheries Training and Extension Centre (FITEC)

Responsible for the empowerment of Fishers through courses and trainings in small scale tuna longline fishing, fish handling, preservation and marketing. Deploy & maintain FADs as well as FAD fishery monitoring.

8. Fisheries Protection Services

Enforcement arm of the Ministry that caters for overall control over fishing activities around the island in the lagoon as well as off-lagoon. Responsible for the registration of artisanal fishers and artisanal fishing boats as well as issue gears licences to artisanal fishers.

9. Seafood Hub

It provides services to facilitate the administrative procedures for loading/unloading/export of fish and fish products.

10. Competent Authority Seafood

Responsible for the verification and certification of fish and fish products for export mainly to the European Union (EU) as well as to non EU countries.

11. Monitoring Control Surveillance/Vessel Monitoring System/Port State Control and Import/Export Division

Responsible for the monitoring of fishing boats/vessels, monitoring of IUU fishing, licenced fishing boats/vessels in the EEZ of Mauritius through the VMS, for keeping the port free of illegal fishing boats/vessels as well as illegally caught fish and for controlling the import and export of fish and fish products.

Appendix E

The vision, mission and objectives of the Fisheries Department of the Ministry of Ocean Economy, Marine Resources, Fisheries and Shipping [50–61]

Vision.

The fisheries sector is an economic pillar with due regard to sustainability of aquatic resources and social development.

Mission.

To provide an enabling environment for the promotion of the sustainable development of the fisheries sector and to ensure its continued contribution to economic growth and social development within the framework of good governance and conservation measures.

Objectives.

- Establish a conducive environment in which the fishing industry can develop
- Contribute towards the development of Mauritius in a world class seafood hub and derive optimal benefits from marine living resources
- Promote and regulate the optimal long-term sustainable utilisation of living marine resources
- Carry out and promote applied research, development and management of aquatic living resources
- Ensure that all fisheries activities allow for the conservation of vital marine resources
- Foster the interest of Mauritius within the international fisheries community, including encouraging the international trade of fish commodities within the framework of international law and conventions
- Provide professional, responsive and customer friendly services
- Deliver our services efficiently and effectively providing value for money
- Promote the social welfare status of fishermen

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