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Review

Learning from small islands in the Western Indian Ocean (WIO): A systematic review of responses to environmental change

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ABSTRACT

Tropical small islands are particularly vulnerable to environmental impacts. In the small islands of the Western Indian Ocean (WIO), multiple stressors of environmental and socio-economic change interact and intensify at reduced spatial scales. Actors and institutions need to respond to these changes through responses – reactive or proactive actions planned or implemented by individuals, groups or organisations; aimed at responding to changing contexts and scenarios, by reducing, preventing and/or reverting the risks and impacts of environmental change. Through a mixed-method systematic review of academic literature from 2010 to 2020 using the Web of Science literature database, we document the types of responses, actors involved and elements of effective responses. We analysed 329 studies focusing on nine WIO small island states and territories (SISTs) – Zanzibar, Mafia, Seychelles, Comoros, Mayotte, La Réunion, Mauritius, Maldives and Lakshadweep. Using quantitative content analysis, we organised information into categories ranging from institutional (economic instruments, laws, policies and community based), social (educational and informational), infrastructural (engineered and technological) and ecological restoration-based responses. The articles varied in their geographical distribution, focus and depth with regard to the responses studied. Diverse responses are documented, that often overlap across categories and may be combined and pursued simultaneously. For example, responses range from coastal protection structures, land reclamation, land elevation and artificial islands to mangrove restoration, awareness raising programs, coastal zone regulations and climate induced migration and relocation policies. Responses were predominantly institutional (85% of 329 articles, n = 281) – mainly driven by governments. The most common social responses (53%, n = 183) were linked to environmental education programs and knowledge sharing platforms. Although the responses indicated an increasing interest in ecological restoration (27%, n = 91) and community-based initiatives (36%, n = 120), they were largely underrepresented in research. Cataloguing the different responses may help incorporate the diversity into well-informed decisions, offer alternative ways of thinking and highlight specific areas and response types that should be the focus of future research and practice. The elements influencing the effectiveness of responses were identified through thematic synthesis – relevance to the local social-ecological context, resources available (time and funding), knowledge (access, diversity, integration, transfer, innovative and anticipatory), governance of responses (coordinated, transparent, adaptive, equitable, participatory and polycentric) and iterative monitoring. These elements of effectiveness tend to be synergistic and no single element is effective in isolation. When these elements are not considered, the response intervention could be maladaptive or counterproductive. Poorly designed

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responses result in perverse social and ecological outcomes, further increasing the exposure and vulnerability to the environmental stressors and decreasing public confidence and support. This review documents current literature, points to knowledge gaps and highlights the potential for islands to learn from each other and to further apply these lessons to non-island settings, critically considering the local context.

1. Introduction

Small islands (<20,000 km^2; Glaser et al., 2018) are complex Social-Ecological Systems (SESs), representing tightly bound human-nature relationships. Although islands cover only 5.5% of the planet's land area, they significantly contribute to global biodiversity (Kueffer and Kinney, 2017). They exhibit high levels of endemism, with around 20% of the vascular plant species being endemic to islands (9.5 times higher than mainland continents) (Kier et al., 2009). Furthermore, 10 of the 36 global biodiversity hotspots are situated only or mainly on islands (Bellard et al., 2013; Critical Ecosystems Partnership Fund, 2021). Small islands provide vital ecosystem services, supporting diverse livelihoods and human well-being of 10% of the world's population (Kueffer and Kinney, 2017). Although commonly highlighted for their reduced land area, small islands are essentially 'large ocean states' with a high ratio of coastline to land area and large exclusive economic zones, thus having significant territorial claims on the surrounding oceans (Chan, 2018).

Tropical small islands are heterogeneous and unique places with diverse geomorphology, ecosystems, culture, politics and governance (Nurse et al., 2014). However, they share common insular characteristics including their small size, high degree of endemicity, susceptibility to natural hazards (e.g. storm surges, cyclones, volcanic risk and tsunamis), diverse - often overlapping - anthropogenic pressures on a small area (e.g. invasive species, climate change, land-use change, pollution), limited natural resources (e.g. freshwater shortage), often inadequate financial or technical resources, high population density in coastal areas and rapid growth in tourism (Polido et al., 2014; Connell, 2018; Glaser et al., 2018; Russell and Kueffer, 2019; Weir, 2020). These characteristics make tropical small islands especially vulnerable to environmental change, and challenge their progress towards sustainable development (see Fig. 1).

Islands are not isolated, confined spaces but rather have fluid boundaries and are connected to the larger scale via different interactions (Chandler and Pugh, 2021). The term "sea of islands" (Hau'ofa, 1994) describes the interconnectedness of island communities across the globe, with shared driving forces - histories (e.g. European colonisation, past and present military presence), cultures, environmental challenges and opportunities (Lazrus, 2012, Fig. 1). For example, an extreme event (e.g. volcano eruption) could impact an entire island area, while only part of the mainland. However, there are diverse ways of experiencing these common driving forces. Every experience of that change will be unique and understanding how different island communities operate in these systems, with similar underlying drivers, provide opportunities to learn from each other's experiences. Moreover, these valuable lessons on how islands react or pro-act to environmental change can also be useful in non-insular settings.

Tropical small islands are in the frontline of rapid environmental change, impacting people and nature (Newton and Weichselgartner, 2014; Glaser et al., 2018). Multiple drivers of environmental and socio-economic change act in a synergistic manner (Glaser et al., 2018; Newman et al., 2020; see Fig. 1). The drivers of change encompass a broad range of human-influenced or natural processes, acting at different spatial and temporal scales. Various anthropogenic pressures materialise at a local scale such as deforestation, urbanisation and land-use change, resulting from underlying drivers such as the role and impact of tourism (Newman et al., 2020). There are also larger-scale pressures like overexploitation and climate change that are mainly driven by larger economies of distant consumers (Lazrus, 2012).

However, anthropogenic pressures impact islands disproportionately and are intensified in their reduced spatial scale (Russell and Kueffer, 2019). Additionally, underlying causes of vulnerability including pressing societal issues, such as poverty, inequality, power imbalances, weak governance and political instability, further increase the complexity of addressing environmental problems in small islands (Mustelin et al., 2010; Newman et al., 2020). New response strategies need to be designed and implemented in order to deal with the interconnected effects of rapid environmental change (Russell and Kueffer, 2019). While environmental impacts are possibly more manageable in islands owing to the small size and scale (Kueffer and Kinney, 2017; Skjølsvold et al., 2020), the above mentioned island characteristics and causes of vulnerability make it more challenging to respond.

In this paper, we focus on the 'responses' to environmental change. We define responses as reactive or proactive actions proposed, planned or implemented by individuals, groups or organisations to address

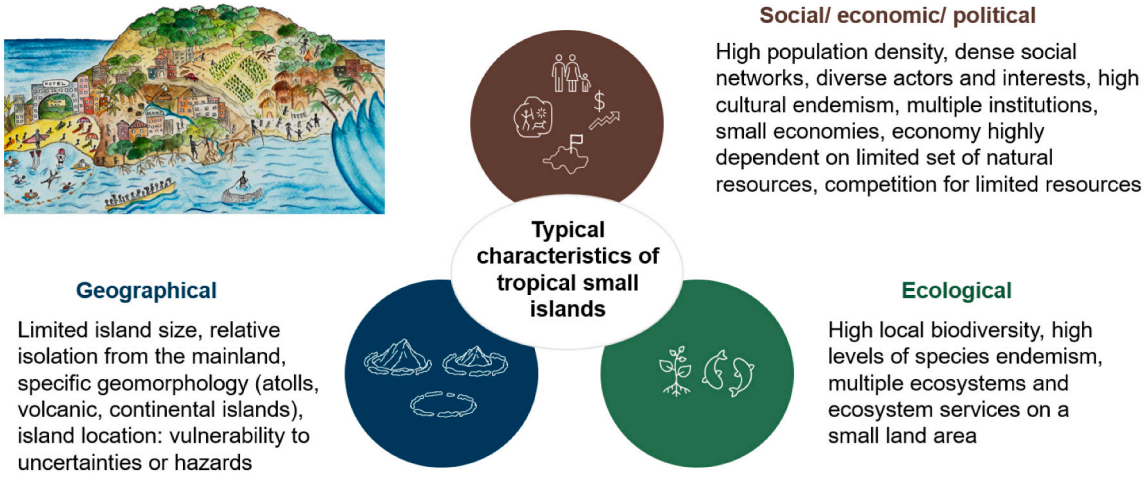

Fig. 1. Typical characteristics of tropical small islands (drawn based on information from Kueffer and Kinney, 2017; Glaser et al., 2018; Russell and Kueffer, 2019).

environmental change (Dahdouh-Guebas et al., 2021). Responses are aimed at reducing, preventing and/or reverting the risks and negative impacts of environmental change, to develop an overall positive or desirable change in the social-ecological system and to build its adaptive capacity (Oesterwind et al., 2016). By assessing and learning from the successes and failures of responses, actors and institutions may be better prepared to address future change (Sovacool, 2011).

Island communities have been noted to show high creativity, diversity and adaptability in responding to rapid social and environmental change (Fröcklin et al., 2014; Comte et al., 2016; Weir and Pittock, 2017). Long traditions of interacting with, learning and observing the environment has enhanced the adaptive capacity and social resilience of islanders (Lazrus, 2012). These 'island ways of knowing' represent a rich bio-cultural heritage (Hong, 2013; Weir et al., 2017). The resulting local knowledge generated through the relational entanglements between humans and nature has the potential to inspire both island and non-island imaginaries (Chandler and Pugh, 2021). However, paradoxically, the islanders' capacity to respond to environmental change can also be negatively challenged by their inherent social-ecological characteristics such as unique biodiversity, high reliance on natural resources for their economy and vulnerable island geographies (Glaser et al., 2018). Island ecosystems are ecologically more vulnerable than comparable areas of mainland, due to the evolution of specific life forms in isolation, limited extent of habitats, and smaller population sizes (Russell and Kueffer, 2019).

With the urgency in addressing environmental change, there is a growing body of knowledge on response efforts in small islands (Robinson, 2017; Klöck and Nunn, 2019). According to Noble et al. (2014) these efforts on ground are progressing at a faster rate than the production and dissemination of academic research on this topic. Current research efforts predominantly focus on the impacts of climate change on islands and the associated adaptation. In this review, we broaden the scope by mapping responses to the impacts of multiple interacting drivers (beyond climate change).

Although research on responses to environmental change is growing, it remains fragmentary with significant geographical bias (Klöck and Nunn, 2019). Most research focuses on Small Island Developing States (SIDS), islands in the Pacific and Caribbean and 'core' areas of island states and territories, where there are more economic opportunities, resources and services compared to the 'peripheral' islands (Weir et al., 2017; Klöck and Nunn, 2019; Clissold et al., 2020). Despite environmental change being an immediate threat to islands in the Western Indian Ocean region (WIO), there has been little research on adaptation. Further, within the WIO, there is more focus on the SIDS, while islands that are Sub-National Island Jurisdictions (SNIJs) – territories that are dependent on larger mainland states – have received less attention (Klöck and Nunn, 2019). Poor allocation of research attention and funds means that the impacts and responses are not adequately understood and managed (Freed and Granek, 2014). Thus, there is a need to document, understand, evaluate and communicate about the responses in this region.

The WIO region is undergoing some of the fastest social and ecological changes seen globally, with profound impacts on the islands. The region has been warming for more than a century and at a faster rate than any other region of the tropical oceans, resulting in more intense and frequent extreme events (Roxy et al., 2014; Taylor et al., 2019). Moreover, anthropogenic pressure including development in industrial fishing, shipping, oil and gas exploitation, tourism and urbanisation are rapidly growing (Laffoley et al., 2020). The island economies and livelihoods in this region are facing increasing economic hardship from the exploitation and degradation of resources due to the various interacting pressures and impacts of global environmental change (Rakotobe, 2012).

The islands of this region vary in specific contexts (Table 1). However, they share common insular characteristics: heavily depend on marine resources for subsistence and livelihoods related to fishing and tourism, multiple ecosystem services, several have strong colonial histories (with some islands thought to be not or not permanently inhabited before European colonisation), face similar environmental pressures and impacts and to an extent respond in similar ways to this change (Andriamahefazafy et al., 2019). This provides the potential to learn from each other.

The objective of this systematic review paper is to (a) document the suggested, analysed or implemented responses to environmental change in nine small island states and territories (hereafter referred to as 'SIST' or 'SISTs' for plural) in the WIO, (b) list the actors involved in the responses, and (c) explore the elements that influence the effectiveness of responses in addressing environmental change.

2. Materials and methods

2.1. Geographic scope

The Indian Ocean, covering an area of approximately 68.5 million km^2 and bounded by landmasses on three sides, is the world's third-largest ocean (O'Loughlin and Luke, 2010). In this paper, we define the Western Indian Ocean (WIO) as the region extending from the continental margins of eastern Africa to the western coast of India (30°–75°E), situated between the latitudes 12°N and 30°S (Laffoley et al., 2020). The region has been an important route for human migration and trade of goods, transport of biota both before and after the colonial period.

The WIO region covers a variety of marine and coastal settings including small islands and large mainland territories with extensive coastlines, tropical and subtropical climates. All the islands in the region are small in land area, except for Madagascar which is outside the scope of this paper (587,041 km^2 in land area and a population of 26 million). The remainder have a total population of about 4.2 million and a total land area of only about 10,000 km^2 (Table 1).

Our systematic literature review focuses on nine inhabited SISTs in the Western Indian Ocean – Zanzibar, Mafia, Seychelles, Comoros, Mayotte, La Réunion, Mauritius, Maldives and Lakshadweep (see Fig. 2). The islands represent a diversity of insular settings across the WIO region. They differ in size, physical geography, population, culture, international position, political status (i.e. Small Island Developing States, dependent islands and Sub-National Island Jurisdictions), economy, human development and type of governance (see Table 1 for a comparison of small islands in the WIO) (Anckar, 2013; Bouchard et al., 2019; Kamranzad et al., 2020).

2.2. Systematic literature review

We followed a three-step process described below:

a. Systematic literature selection based on inclusion and exclusion criteria (Fig. 3).
b. Extraction and categorisation of information based on pre-defined response and actor categories (Section 2.2.1).
c. Exploring key elements of effective responses (Section 2.2.2).

Academic research on responses to environmental change in islands is predominantly in the form of individual case studies. We investigate these case studies to characterise and structure responses in small WIO islands in the last decade. These studies cover a variety of political, economic and social contexts that shape responses.

We conducted a mixed-method systematic review, as it is a transparent research process that identifies, appraises and analyses relevant evidence on a given topic that fits pre-specified eligibility criteria in order to address a specific research question (Fig. 3, Petticrew and Roberts, 2006; Pham et al., 2019). It provides a critical synthesis and map of the prevailing literature, thus providing a baseline understanding of the research (Klöck and Nunn, 2019). We include details about

Table 1
Description of key characteristics of the nine selected archipelagos in the Western Indian Ocean (WIO) region.

Features	Zanzibar	Mafia	Seychelles	Comoros	Mayotte	La Réunion	Mauritius	Maldives	Lakshadweep
Area (km^2)	2654[a]	435[b]	459[c]	2235[c]	374[d]	2504[d]	2040[c]	298[c]	32[e]
Number of islands	2 main inhabited islands and 50 islets[a]	1 main inhabited island and many islets (administratively 2 divisions)[b]	155 islands (8 permanently inhabited)[c]	3 main inhabited islands and many islets[c]	3 inhabited islands	1 main inhabited island	1 main island and many smaller islands and islets (2 inhabited islands)[c]	1190 coral islands grouped into 26 atolls (188 inhabited islands)[c]	36 islands (10 inhabited) grouped into 12 atolls[e]
Population	1,303,569 (2012)[a]	46,438 (2012)[f]	98,462 (2020)[g]	869,595 (2020)[g]	288,926 (2021)[h]	855961 (2018)[h]	1,386,129 (2021)[g]	540,542 (2020)[g]	64,473 (2011)[i]
Population density (persons per km^2)	603 (2012)[a]	107 (2012)[f]	214 (2020)[g]	467 (2020)[g]	770 (2021)[h]	330 (2018)[h]	631 (2021)[k]	1802 (2020)[g]	2149 (2011)[i]
Size and population density of main settlement	Zanzibar city (15.5 km^2) 14,000 persons/km^2 [a]	Kilindoni ward (36 km^2) 386 persons/km^2 [b]	Victoria city (20 km^2) 1144 persons/km^2 [g]	Moroni city (30 km^2) 3700 persons/km^2 [g]	Mamoudzou city (41 km^2) 1700 persons/km^2 [h]	Saint Denis city (142 km^2) – 1100 persons/km^2 [h]	Port Louis city (46 km^2) – 2941 persons/km^2 [j]	Malé (8.3 km^2) – 65,201 persons/km^2 [k]	Kavaratti (4.22 km^2) 2659 persons/km^2 [i]
Island geology	Land-bridge or continental island[l]	Land-bridge or continental island[l]	42 granitic and 113 coralline islands[m]	Volcanic islands[m]	Volcanic islands[m]	Volcanic island[m]	Volcanic islands[m]	Coral islands[m]	Coral islands[n]
Highest elevation (m)	119 m	53 m	905 m[c]	2360 m[c]	660 m	3070 m	828 m[c]	5 m[c]	5 m[e]
Exclusive Economic Zone (km^2)	ND	ND	1,329,000[o]	164,000[o]	63,000[o]	315,000[o]	1,270,000[o]	915,000[o]	400,000[c]
Gini index[r]	0.31 (2019)[a]	ND	0.32 (2018)[g]	0.45 (2014)[g]	ND	0.53 (2011)[p]	0.36 (2017)[g]	0.31 (2016)[g]	ND
GDP[s]	1.8 billion USD (2020),[a]	ND	1.06 billion USD (2020),[g]	1.2 billion USD (2020),[g]	2.4 billion USD (2015),[h]	20.4 billion USD (2015),[h]	10.9 billion USD (2020),[g]	3.74 billion USD (2020),[g]	ND
GDP per capita income	1099 USD (2020),[a]	ND	10,,764 USD (2020),[g]	1420 USD (2020),[g]	10,258 USD (2015),[h]	23,985 USD (2015),[h]	8627 USD (2020),[g]	6924 USD (2020),[g]	ND
Economy	Tourism (47% GDP), agriculture, forestry (spice plantations) and fishing (22% GDP)[a]	Fishing, fisheries-related activities, tourism and subsistence agriculture[b]	Tourism (55% GDP), tuna fishing. Shift to offshore financial, ICT sectors and renewable energy[m]	Agriculture (fishing, hunting, forestry) (50% GDP)- vanilla, cloves, ylang. Depend heavyily on foreign grants and technical assistance[m]	Agriculture (fishing and livestock raising). Depend heavily on French financial and technical assistance	Tourism, agriculture (fishing and forestry)	Transformed from agriculture based economy to a diversified, upper middle-income economy with growing industrial, financial and tourist sectors[m]	Transformed to a middle-income economy, driven by rapid growth in tourism and fisheries[m]	Tuna fisheries, coconut cultivation, tourism is emerging[e]
Number of tourist arrivals annually	260,644 (2020)[a]	5412 (2017/2018)	428,000 (2019)[q]	45,100 (2019)[g]	50,700 (2015)[h]	507,563 (2018)[h]	1,418,000 (2019)[g]	1,703,000 (2019)[g]	7752 (2014/2015)[e]
Precolonial population	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
Type of island governance	Sub National Island Jurisdiction (SNIJ) (semi-autonomous region of the United Republic of Tanzania)	Dependent state of the United Republic of Tanzania	Independent country and Small Island Developing State (SIDS)	Independent country and Small Island Developing State (SIDS)	Sub National Island Jurisdiction (SNIJ) of France	Sub National Island Jurisdiction (SNIJ) of France	Independent country and Small Island Developing State (SIDS)	Independent country and Small Island Developing State (SIDS)	Sub National Island Jurisdiction (SNIJ) of India

Data sources.
[a] Office of the Chief Government Statistician (2021).
[b] Holberg (2008).
[c] Mercer et al. (2014).
[d] Bouchard et al. (2019).

[e] Union Territory Administration of Lakshadweep (2021).
[f] NBS Tanzania (National Bureau of Statistics Tanzania) (2013).
[g] World Bank (2022).
[h] INSEE (Institut national de la statistique et des études économiques) (2022).
[i] Office of the Registrar General and Census Commissioner India (2011).
[j] Republic of Mauritius (2021).
[k] Government of the Maldives (GoM), National Bureau of Government of the Maldives National Bureau of Statistics (2015).
[l] Prendergast et al. (2016).
[m] CIA (Central Investigative Agency (2021).
[n] Arthur et al. (2013).
[o] Levin et al. (2018).
[p] Govind (2020).
[q] NBS (National Bureau Statistics) (2019). ND = no data available.
[r] Gini index is a measure of the degree of inequality in the distribution of income across a population. It ranges between 0 (perfect equality) and 1 (extreme inequality). Higher the Gini index, higher the inequality.
[s] Gross domestic product (GDP) is the total monetary or market value of all the final goods and services produced within the borders of a country in a specific time period.

each stage of the review process, the guiding research questions, the eligibility criteria for literature selection (inclusion and exclusion criteria) and the methods used to search for and analyse the content of the literature (in line with Newig and Frisch, 2009; Berrang-Ford et al., 2015).

We systematically reviewed English-written peer reviewed literature related to responses to environmental change in the nine SISTs, in the last decade (2010–2020). We used the Web of Science® Core Collection, a leading literature database with several advantages such as advance search function, comprehensive sources (indexing around 34,000 journals) and multidisciplinary focus (Birkle et al., 2020; Mohamed Shaffril et al., 2020).

We used a combination of search terms, specific to each island (Fig. 3a). The search terms were broad to encompass a wide scope of articles related to responses to environmental change in islands. We used research title, abstract, and keywords as the literature search queries. The searched terms needed to be present in any one of those fields to be considered for the next step of selection. The total number of search results from Web of Science was 1311 articles.

We used two filters of selection based on the eligibility criteria presented in Fig. 3. First, we read the abstract to ensure that the study was related to the research topic. At this stage we selected 567 articles. Second, we conducted detailed reading of each selected article. Consequently, we selected 329 articles for further content analysis (see Supplementary Material for a full list of selected articles). We referred to the exclusion criteria mentioned in Fig. 3 at all stages of selection.

We restricted the analysis to English peer-reviewed studies from one database (i.e., Web of Science) as it is one of the most widely-used and comprehensive search engines covering various disciplines (Berrang-Ford et al., 2015). We omitted grey literature as it presents challenges in the vast amount of literature available of highly variable quality. It would require different methods (eligibility criteria and search terms) to review grey literature (Berrang-Ford et al., 2015). We acknowledge that selecting a single database is a limitation, and should be viewed as a snapshot of documented research. Moreover, we consider our sample large enough to gain a systematic overview of one type of knowledge (peer-reviewed literature).

2.2.1. Categorising the response strategies and actors

We used quantitative content analysis, a widely used systematic review method to categorise data in the form of frequency counts (Snilstveit et al., 2012). We organised the information by assigning relevant labels based on pre-defined categories to highlight the response measures and actors mentioned. A codebook was created for data coding using Microsoft Excel. We provide quantitative information in the form of frequencies to show the trends in the qualitative data across different islands. Summary data is provided in the Supplementary Material.

We modified the categorisation framework provided by Noble et al. (2014) in the 'IPCC's AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability Report' to divide the responses into 4 main overarching categories with nested sub-categories within each: (1) infrastructural or physical responses which include technology and engineering or built environment interventions; (2) ecological restoration responses that assist in the repair and recovery of the ecosystems; (3) social responses that provide education and information to the stakeholders; (4) institutional responses that structure financial instruments, laws and regulations, policies and programs and community based initiatives and stakeholder participation.

We listed the actors and institutions mentioned in the description of the response, when that information was available. We adapted the actor categories proposed by Robinson (2017). The eight actor categories we covered are – (1) national governments, (2) sub-national governments, (3) local communities, (4) research, (5) corporate sector - businesses, industry, developers, (6) non-governmental organisations, civil society organisations, (7) external actors - other country governments, development banks, intergovernmental organisations, regional

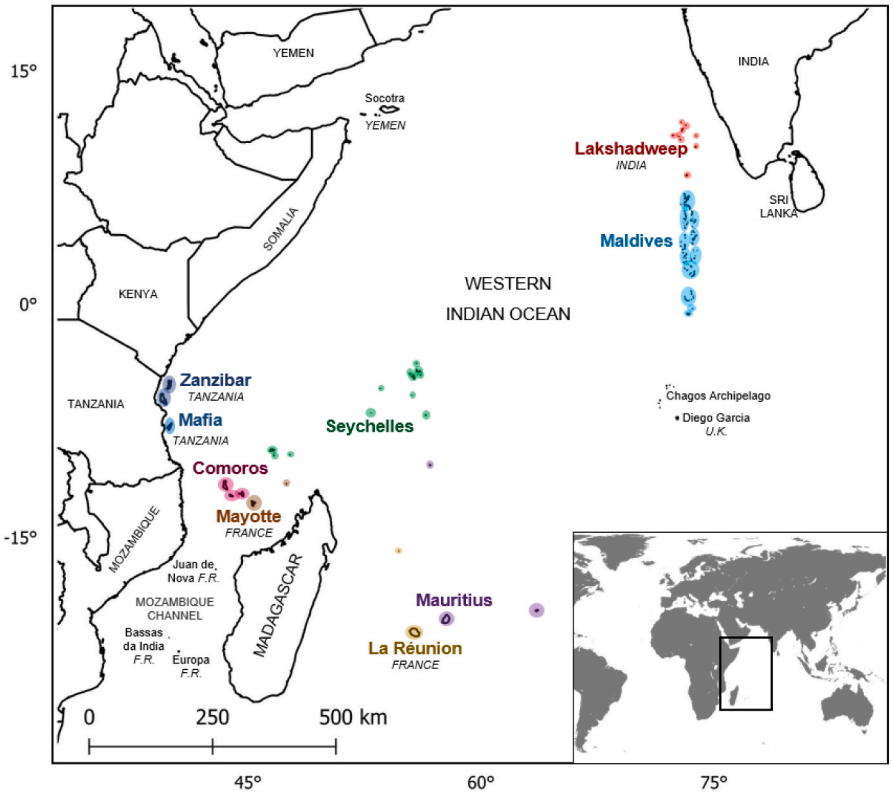

Fig. 2. Map locating the small islands of the Western Indian Ocean (WIO). The nine small island states and territories (SISTs) (Zanzibar, Mafia, Seychelles, Comoros, Mayotte, La Réunion, Mauritius, Maldives and Lakshadweep) included in the review paper are highlighted in bold and coloured according to their territorial status.

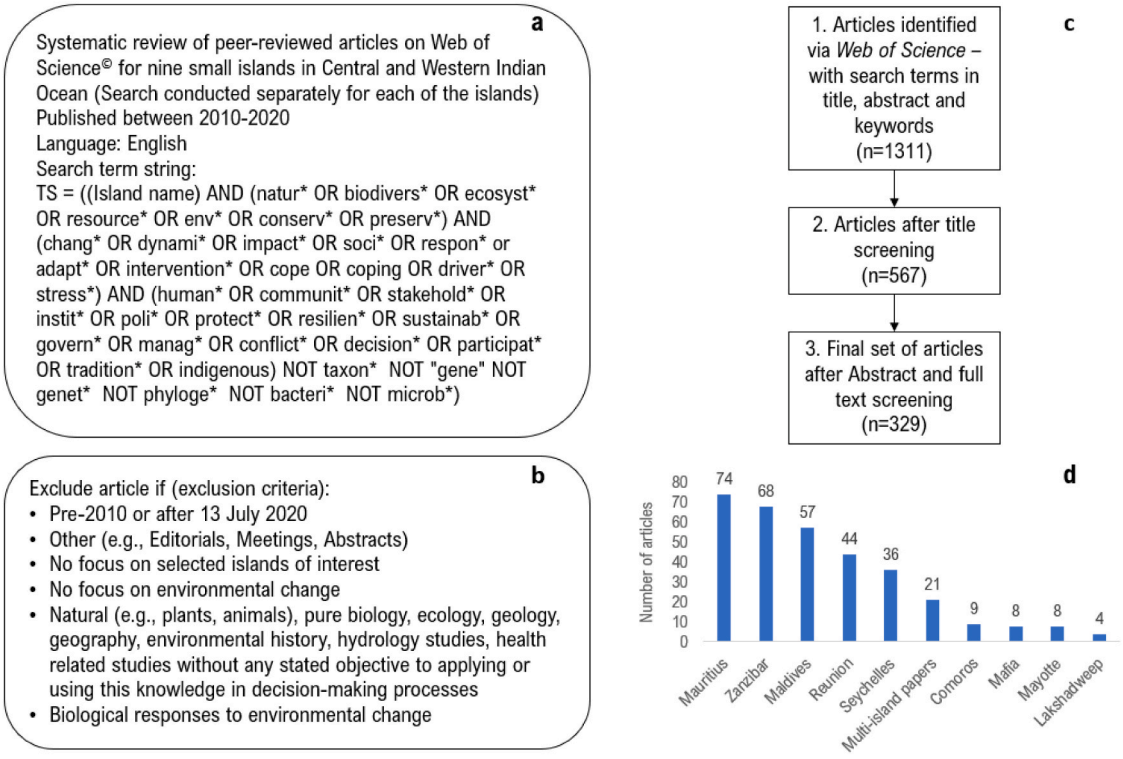

Fig. 3. Summary figure showing the systematic literature review process including the (a) search string combination, (b) exclusion criteria, (c) selection of papers and (d) number of papers selected across the nine islands. The numbers in the graph indicate the number of papers selected on the various islands.

organisations, (8) media.

2.2.2. Exploring the elements of effective responses

To explore the elements of effective responses, we used thematic synthesis (Snilstveit et al., 2012). In contrary to the previous classification of responses and actors, we did not use a pre-existing framework to categorise the elements. Firstly, we used open coding to assign codes to recurrent keywords that were often mentioned as 'levers', 'barriers' or recommendations for effective responses. With open coding, the content is broken down into discrete themes and sub-themes. We reviewed the literature until no new themes emerged. Second, we used axial coding to find how the themes and sub-themes can be grouped into overarching categories that represented the main elements (themes) of effective responses and nested elements (sub-themes). Finally, we created a visual mind map to show the relationships between the various elements of effective responses. Nine of the 329 studies did not report any levers or barriers to the effectiveness of a response.

3. Results

Based on our inclusion criteria (described in Figs. 3b), 329 (out of 1311) peer-reviewed articles were selected for in-depth analysis (25%).

Peer-reviewed research on response strategies to environmental change is clearly not equally distributed across all the reviewed islands (Fig. 3d). The number of publications reporting on responses varied widely between the islands in the WIO, ranging between 4 papers in Lakshadweep to 74 papers in Mauritius (Fig. 3d). Papers that focused on more than one island of interest were grouped into the 'multi-island papers' category.

Studies varied widely in their approach, objectives and content: some studies specifically evaluated concrete response interventions (such as hard coastal protection structures, vegetation planting), while some provided mainly generic recommendations on responses (such as recommending unspecified protection measures). Further, some studies assessed a specific response intervention that may include many smaller response actions within a large-scale project such as the Maldives 'Safer Island' strategy and 'Integrating Climate Change Risks Program' (Sovacool, 2011; Lama and Becker, 2019).

3.1. Diverse responses to environmental change

We found that responses often overlapped across the four main categories – infrastructural, ecological restoration, social and institutional responses (see Table 2 for an overview). In total, there were 140 specific responses (see Table 3 for examples and Supplementary Material for a detailed overview of the specific responses).

Most responses included an institutional component (85%, n = 281), particularly linked to the sub-category - government policies and programs (77%, n = 254). These policies included natural resource management strategies, adaptation planning, tourism policies, alternative livelihood strategies and corporate sector policies amongst many others. The laws and regulations (formal and informal) subcategory (53%, n = 175) represented approaches to regulate access of resource use and extraction, such as protected areas, fisheries gear restrictions and building regulations. Within the economic subcategory (30%, n = 101), examples included external donor funding, tourism-funded conservation, environmental taxes and payments for ecosystem services. Community-based and stakeholder participation initiatives (36%, n = 120) included community participation, co-management, strengthening local institutions and community based conservation.

Social responses were mentioned in 55% (n = 183) of the reviewed papers. The educational sub-category (28%, n = 95) included examples such as awareness raising programs, training in response interventions and participatory research. The informational sub-category (47%, n = 156) that aims at communicating data to support decision-making included examples such as knowledge integration initiatives, participatory planning, decision support tools scenario building, spatial planning and integrated systems thinking.

Infrastructural and physical responses (39%, n = 130), included engineered or built environment and technological sub-categories. For example, engineered responses (20%, n = 67) included hard coastal protection structures, land reclamation activities, ground elevation, artificial islands and waste management systems. Technological responses (30%, n = 101) included renewable energy systems, information and communication technologies, early warning systems and coastal observatories.

Ecological restoration interventions (27%, n = 91) included nature-based approaches or soft response measures such as vegetation planting, invasive species management, agroforestry, coral reef restoration and artificial habitats.

3.2. Actors mentioned in the responses to environmental change

Different actors were mentioned to play a role in the responses. National governments were reported most frequently (84%, n = 279), closely followed by local level governments (70%, n = 233). A total of 188 studies (57%) mentioned that responses should be (or were) targeted at local communities. Researchers and universities were reported to play an important role in designing response strategies. External institutions mainly included other country governments, development

Table 2
Number of responses in each category and sub-category distributed across the nine reviewed islands in the Western Indian Ocean (WIO).

Response category	Zanzibar	Mafia	Seychelles	Comoros	Mayotte	Réunion	Mauritius	Maldives	Lakshadweep	Multi-island	TOTAL	Percentage of papers %
Infrastructural/ Physical	9	0	6	3	5	22	43	32	2	8	130	39
Engineered and built environment	4	0	4	3	1	9	15	29	2	0	67	20
Technological	6	0	6	0	4	18	39	20	0	8	101	30
Ecological restoration	17	0	18	2	2	15	21	12	1	3	91	27
Social	40	3	18	8	6	28	43	25	1	11	183	55
Educational	21	1	9	6	1	17	19	16	0	5	95	28
Informational	34	2	18	6	6	26	34	20	1	9	156	47
Institutional	65	7	26	9	5	34	61	53	2	19	281	85
Economic	23	2	13	6	0	6	23	21	1	6	101	30
Laws and regulations	45	7	24	8	3	16	33	25	2	12	175	53
Government policies and programs	56	6	25	9	5	29	54	49	2	19	254	77
Community-based initiatives and stakeholder participation	42	7	9	8	1	14	18	18	0	3	120	36

Table 3
Response categories, sub-categories and examples of responses documented in the literature (detailed list of examples available in the Supplementary Material).

Response category	Sub-category	Examples of specific responses
Infrastructural/ Physical (n = 130)	Engineered and built environment (n = 67)	hard coastal protection structures - seawalls, groynes (n = 27); energy efficient infrastructure (n = 15); waste management systems (n = 13); land reclamation (n = 13); water storage/harvesting system (n = 10)
	Technological (n = 101)	renewable energy (n = 35); waste management systems (n = 21); recycling (n = 18); energy efficient infrastructure (n = 11); information and communication technologies (n = 8); early warning systems (n = 8)
Ecological restoration (n = 91)		vegetation planting, natural buffers (n = 42); invasive species control and removal (n = 27); agroforestry (n = 11); coral reef restoration (n = 9); island level restoration (n = 6); artificial habitats (n = 5)
Social (n = 183)	Educational (n = 95)	environmental education/ awareness-raising (n = 70); training in response intervention/capacity building (n = 30); participatory research - mapping, planning, workshops (n = 23); citizen science (n = 2)
	Informational (n = 156)	knowledge integration, transfer, sharing (n = 67); participatory research - mapping, planning, workshops (n = 44); scenario building (n = 42); spatial planning and modelling (n = 31); integrated planning - systems thinking, holistic planning (n = 18); decision support tool (n = 16)
Institutional (n = 281)	Economic (n = 101)	external donor funding - international institutions, intergovernmental organisations, NGOs, environmental trust funds (ETFs) (n = 40); financial incentives (n = 16); tourism-funded conservation - visitor fees, restoration funds from tourism (n = 14); environmental taxes - tourism, waste management, energy, fossil fuel (n = 12); National adaptation fund (n = 10); payments for ecosystems services - REDD+, carbon offsetting programs (n = 8)
	Laws and regulations (n = 175)	regulation on natural resource use and extraction (n = 64); marine protected areas (n = 38); no-take zone (n = 31); fisheries gear restriction (n = 26); new institutional arrangements (n = 24); international agreements and law (n = 16)
	Government policies and programs (n = 254)	marine/coastal resource management - coastal zoning, fisheries management (n = 87); adaptation planning and policies (n = 56); spatial planning and management (n = 34); conservation and restoration programs (n = 31); terrestrial resource management - land use planning, agriculture, forest restoration (n = 29); sustainable tourism policies (n = 27)
	Community-based initiatives and stakeholder participation (n = 120)	community participation (n = 91); participatory research - mapping, planning, workshops (n = 45); local ecological knowledge (n = 28); local institutions - self organisation (n = 24); community-based conservation (n = 23); co-management (n = 18)

banks, intergovernmental and regional organisations and were reported to play an important role in funding interventions. Other organisations mentioned were non-governmental and civil society organisations, mentioned in 84 studies (25%). A total of 110 studies mentioned the role of corporate actors (33%). The media were mentioned in 14 studies (4%).

3.3. Elements of effective responses

Based on the thematic synthesis (as described in section 2.2.2), we identified themes and sub-themes of elements influencing the effectiveness of responses. Five themes were identified namely contextual factors, resources, knowledge, governance of responses and monitoring and evaluation. Further analysis of the themes resulted in 21 sub-themes (see Fig. 4). We propose a mind map to visualise the elements of effective responses. The left side of the figure describes the contextual factors of the islands and the right side describes the elements of effectiveness (derived from the open and axial coding) including the resources, knowledge and governance of responses. The elements are united by a circular process of monitoring and evaluation.

4. Discussion

4.1. Patterns and diversity of responses

Environmental problems on small islands are complex and interlinked: driven by various interacting stressors, occurring at different spatial and temporal scales and including multiple stakeholder interests (Fig. 4). Responding to these problems involves altering human behaviour, institutions, infrastructure and ecosystems at different scales (Sovacool et al., 2017).

A diversity of responses has been reported in the literature we reviewed (Table 2, Table 3). This diversity suggests that there are many ways to respond to environmental change and that no single strategy is sufficient (as also stated in Russell and Kueffer, 2019) (Table 3). For example, responses in small islands range from coastal protection structures, land reclamation, land elevation and artificial islands to mangrove restoration, awareness raising programs, coastal zone regulations and climate induced migration and relocation policies. The various examples of multi-dimensional responses suggest that Ostrom's (and others') call not to rely on hypothetical universally valid solutions ('panaceas'), has been heard (Ostrom et al., 2007).

In many cases, responses are interlinked and overlap across categories. For example, to set up coastal observatories and early warning systems, there is need for built infrastructure, technology, information from multiple sources, funding and institutional support (cf. Mahabot et al., 2017). Sometimes different approaches are combined and pursued simultaneously. Hard and soft strategies maybe complementary and effective when mixed together, critically depending on the site considered. For example, in some cases to address coastal erosion and sea level rise, 'hard' strategies (large-scale, expensive, expert driven and

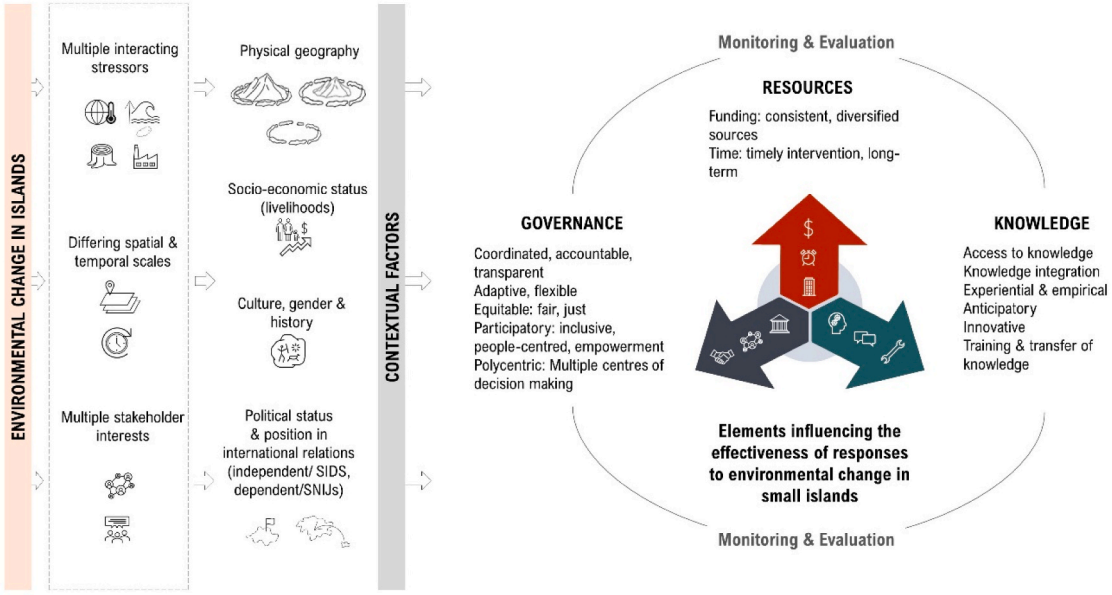

Fig. 4. A practical mind map illustrating the elements that influence the effectiveness of responses to environmental change in small islands. There are multiple interacting stressors that drive environmental change, that differ in spatial and temporal scale and affect multiple stakeholder interests in islands that are made up of different contextual factors. These factors include the islands' physical geography, socio-economic status, culture, gender, history, political status and position in international negotiations. Effectiveness of responses depends on different elements – the contextual factors, resources available, knowledge, governance, routine monitoring and evaluation (as symbolised by the circular arrows).

inflexible engineering) such as coastal protection infrastructure and centralised decision-making are combined with nature-based approaches or soft strategies (simple, flexible and modular) such as mangrove restoration and community driven adaptation (Mustelin et al., 2010; Khan and Amelie 2015; Ratter et al., 2016; Zhang and Bakar 2017; Anisimov et al., 2020). Although in some cases hard protection such as seawalls may aggravate coastal erosion and hinder natural sedimentation, planners, local communities and donor organisations often prefer hard measures as they often provide short-term benefits and are perceived to be "solid, modern and safe" (Betzold and Mohamed, 2017). Before implementing responses, the risks need to be carefully evaluated and tested at smaller scales (as suggested by (Sovacool et al., 2017; Betzold and Mohamed, 2017). It is particularly important for infrastructure-based projects to undergo comprehensive environmental impact assessments (EIAs) to ensure the suitability of projects to the local context, to make informed trade-offs and to uphold the accountability of the developers (Feagin et al., 2010). Thus, particular institutional responses (such as EIAs and community participation) are needed when planning hard measures, yet regulatory frameworks are not always up to the challenge. Zubair et al. (2011) for example, highlight that although environmental management policies in the Maldives have improved in the last two decades, the regulatory framework for infrastructure and development projects are seriously inadequate and need to be strengthened.

4.2. Elements of effective responses

Assessing effectiveness in general is challenging and even more so considering the wide range of presented responses in this review. Firstly, many strategies are planned, proposed and designed but very rarely implemented and evaluated. Secondly, there is the need for long-term data to assess the effectiveness of a response over time. Much of the research carried out provide snapshots of responses and rarely provide a comprehensive overview of longitudinal data. Long-term monitoring and evaluation is critical in maintaining the sustainability of responses and to inform future choices. Finally, interpreting the effectiveness (success) of responses is at least partly subjective (based on the point of view of the actors involved). A response "may be successful for one actor at a given time but mal-adaptative for another actor, another location, and a different point in time" (Klöck and Nunn, 2019). Thus, owing to these difficulties, many studies do not evaluate the effectiveness of responses in detail, but briefly mention the levers and barriers of the strategy (Suckall et al., 2014).

While there is no blueprint on what makes a response effective, there are particular elements that influence effectiveness. In the papers we reviewed, effectiveness is framed in different ways and we further synthesise these conceptualisations as key elements of effectiveness (as shown in Fig. 4, the mind map). The elements include the compatibility with the social-ecological context, the resources, knowledge and governance, embedded in an iterative and continuous monitoring and evaluation process. These elements tend to be synergistic and build upon each other; no single element is effective in isolation. If these elements of effectiveness are not considered, the response intervention could be maladaptive or counterproductive. Poorly designed adaptation-labelled responses result in perverse social and ecological outcomes, further increasing the exposure and vulnerability to the impacts of environmental change (Suckall et al., 2014; Magnan and Duvat, 2018). Moreover, the failure or lack of effectiveness leads to the erosion of public confidence and support. This loss of confidence and urgency is a major threat as it is difficult to regain the trust of people. The boundary between adaptive and maladaptive responses may shift over time, due to biophysical changes for instance (Wise et al., 2014), yet the general elements of an effective response (as outlined in Fig. 4) remain stable. We now discuss the elements of effective responses.

4.2.1. Social-ecological context

Responses might be diverse but need to be relevant to the complex social-ecological context of the island. There are no one-size-fits-all panaceas to respond to environmental change. Various characteristics including their physical geography, ecology, socio-economy, political status, power dynamics, position in international relations (links, support), culture, gender and history shape the island's context (Figs. 1 and 4).

The outcomes of different response measures are heavily dependent

on the island's geography (Owen, 2020). For example, responses implemented in Maldives, a sovereign small island state of low-lying coral atolls might not necessarily work in La Réunion, a steep volcanic island that is a dependent territory of France (see Table 1). The physical, environmental and social realities between these islands differ. Anisimov et al. (2020) discuss a maladaptive intervention in Mauritius where the government transferred gabions (hard coastal protection infrastructure) that were successful in South Africa against coastal erosion. The design was inappropriate for the coastal morphology of the sites in Mauritius and further increased coastal erosion-related risks.

Even within the same archipelago, contexts may vary between core and peripheral islands and different approaches are required. In many archipelagos, peripheral islands are not given adequate adaptation resources, services and attention (Petzold and Ratter, 2019; Mcnamara et al., 2019; Clissold et al., 2020). Similarly, Duvat and Magnan (2019) highlight that in the context of atoll states like Maldives, responses should be designed to suit the island spatial scale rather than the archipelagic scale because of the differing social-ecological contexts.

The 'small' size of the islands does not mean that adaptation needs and capacity are less significant or simpler (Williams et al., 2020). Compared to non-island contexts, the complex interaction of drivers and impacts of environmental change make it especially challenging to respond in small islands. In many of the developing islands of the WIO, the social-ecological context covers a variety of interacting drivers and impacts at different scales such as climate change, development (especially tourism), invasive species, overexploitation, freshwater scarcity, habitat loss and degradation, deforestation, land use change, demographic growth, social inequity, political instability, poverty and gender inequality (e.g. Gustavsson et al., 2014; Ratter et al., 2016; Wanyonyi et al., 2016; Newman et al., 2020).

Many papers highlight that urgent underlying social needs and drivers (such as political instability, poverty and gender relations) are not always taken into account when designing and implementing responses (Eriksson et al., 2015; Moshy et al., 2015; Fröcklin et al., 2018). Any attempt of responding to environmental change has to include the notion of inclusive development and enhanced well-being of islanders (Mustelin et al., 2010). For example, Carius and Job (2019) discuss the setting up of a protected area and of tourism-revenue strategies in the Jozani-Chwaka Bay National Park and Biosphere Reserve, Zanzibar as a 'good' example of addressing multiple challenges including environmental degradation, tourism development and poverty by setting up a co-managed reserve, increasing local community employment and equitable sharing, community development funding, designing and training in alternative livelihoods such as agriculture and beekeeping. In an another example from Zanzibar, to address the multiple challenges of seaweed farming (inadequate technology, climate change, depleting seaweed resources, economic inefficiencies and gender constraints), an important small-scale livelihood for women, a new technology using tubular nets was introduced. They adopted a combined 'innovation-cum-empowerment' approach to enhance the women's ownership and guardianship of the new technology through capacity building and training in basic seafaring and safety skills (Brugere et al., 2020).

4.2.2. Resources

The availability and access to monetary and time resources are key components in planning and implementing responses. However, many of the small islands in the WIO have limited financial resources and infrastructure for capital-intensive, large-scale adaptation efforts (see Comte et al., 2016; Zuhair and Kurian, 2016; Betzold and Mohamed, 2017). The insularity and small size means that island economies are affected by high costs per capita in relation to infrastructure, which means that infrastructural works requiring large costs cannot be easily downscaled to the island size and population (e.g. Hammar et al., 2012; Naylor, 2015; Tung, 2017). The effort and carrying capacity for investment also depend on the governance or political state structure. Adaptation costs are higher in islands compared to the mainland. For example, when impacted by extreme events such as cyclones and droughts, the entire territory of the SIST might be affected, majorly impacting the island's economy in comparison to a larger mainland state where only a small part of the land area and economy is affected (Kelman et al., 2015). Costs per capita are especially high for islands with smaller land area, greater distance to the mainland or core island, which increases transport costs (e.g. Romano et al., 2016; Liu et al., 2018; Clissold et al., 2020).

The socio-economic and political status plays an important role in the island's access to resources (Table 1). The islands of La Réunion and Mayotte are dependent territories of France, a high-income country, and may have better access to social services, regulatory measures and more consistent means of funding through national and European Union funds (e.g. Pioch, 2011; Eriksson et al., 2015; Levin et al., 2018; Eggertsen et al., 2020). Conversely, Comoros being an independent low-income country, has lesser access to financial resources from within the state and may often depend on foreign aid, an inconsistent means of funding (Ratter et al., 2016; Betzold and Mohamed, 2017). Despite high environmental and economic vulnerability (high foreign debt), high-income small island states like Mauritius and Seychelles are not eligible for many external adaptation funds (Schutter and Hicks, 2019). This may have initiated innovative financing mechanisms and partnerships in the WIO region. For example, Seychelles established the first-ever debt--for-nature swap financing which commits to protecting 30% of its EEZ in exchange for its bilateral or multilateral debt reduction, cancellation or buyback (Chan, 2018). Seychelles converted USD 21.6 million of the state's debt into investments in coastal protection and adaptation (Chan, 2018). These avenues for mobilising climate and conservation finance from a diversity of sources is receiving more attention and will help transform debt into adaptation opportunities for small islands. Moreover, as discussed by Thomas and Theokritoff (2021), this structural funding could be used for the long-term monitoring and evaluation of responses, capacity building and strengthening human resources at national and local institutions.

External donors may play an important role in funding adaptation actions in some small islands, especially SNIJs. We found that external actors were mentioned to play a role in 28% of the reviewed papers. Considering that global environmental change is driven majorly by larger, richer and more distant countries, external donors should ideally contribute to fund adaptive responses (Sovacool et al., 2017). However, it is crucial for adaptation to be locally driven and not merely formulated by external actors (see, for example, Lawther, 2016). Commonly, external-driven actions are in the form of top-down, climate change-focused, short-term capacity building and pilot projects that need quick results and are not built up to scale (Betzold and Mohamed, 2017; Anisimov et al., 2020; Shumais and Mohamed 2020). Moreover, these projects are rarely monitored or evaluated for follow up (Betzold and Mohamed, 2017; Anisimov et al., 2020). Implementation of responses should be seen as a long-term process embedded in the local island realities, rather than projects with fixed deadlines (e.g. report of successes of local actions in Hauzer et al., 2013; Comte et al., 2016; Anisimov et al., 2020; Shumais and Mohamed 2020).

Studies on disaster risk management in islands show that responses driven by aid money, take shape rapidly in the immediate aftermath of disasters (see, for example, Naylor, 2015). Reactive responses can quickly appear to be maladaptive in the longer term as they typically leave underlying causes of vulnerability unaddressed and focus on proximate and not on distal causes of change (Kelman, 2014). It is important for decision-makers to integrate incremental actions on proximate causes, with the transformative aspects of large-scale societal change in the WIO islands (in line with Wise et al., 2014). Lessons from disaster recovery in islands indicate the importance of disaster preparedness through anticipatory and proactive responses with long-term goals directed to build resilience (e.g. Naylor, 2015; Chacowry et al., 2018). This is recognised in the literature, as illustrated by the frequent mentioning of e.g. early warning systems for volcanic, seismic and

meteorological risks (see Khan and Amelie, 2015; Chacowry, 2016, 2018; Jhagdambi and Zhong, 2018).

4.2.3. Knowledge

There is an increasing recognition that knowledge exchange, integration, capacity building and skill development, especially at local levels, helps build the adaptive capacity of island communities and decision-makers (e.g. Freed et al., 2016; Zhang and Bakar, 2017; Hein et al., 2019; Hakkarainen et al., 2020; Williams et al., 2020). Awareness raising, training and capacity building programs are common channels for sharing information and disseminating knowledge on different response options (e.g. Carius and Job, 2019; Wallner-Hahn et al., 2016, Table 3). Education was mentioned as a response in 28% of the reviewed papers (e.g. Damerell et al., 2013; Nordlund et al., 2013) and 47% explicitly mention information collection and sharing systems (e.g. Jeanson et al., 2014; Jhagdambi and Zhong, 2018; Shabtay et al., 2020).

When setting up infrastructure-based responses, technology transfer (appropriate to the local context) is critically needed to facilitate human resource capacity and to maintain the long-term application of technologies (e.g. BahriBrikké and Vairavamoorthy, 2016; Brugere et al., 2020). The absence of which could lead to unintended maladaptation. For instance, the lack of local human resource capacity and monitoring in the Maldives prevented the repair of a newly installed solar PV system (Shumais and Mohamed, 2020). More than just merely providing training, socio-cultural relevance and existing capacities need to be taken into account (see, for example Brugere et al., 2020).

We found that research stakeholders (researchers and universities) were highlighted as key actors in identifying and designing appropriate responses in 55% of the reviewed papers (Table 4) and in facilitating exchange of knowledge between policy-makers and island communities (e.g. Lagabrielle et al., 2010; Kaiser-Bunbury et al., 2015; Hakkarainen et al., 2020). Researchers play multiple roles as knowledge producers and 'honest brokers' or mediators (sensu Pielke, 2007). However, it is important to note the bias here as the reviewed papers are written by researchers and they perceive their role to be key. Similarly, nongovernmental organisations (NGOs) have also been noted to play a bridging role in providing education, capacity building and knowledge sharing, in addition to funding response actions (e.g. Dogley, 2010; Levine, 2016). The presence of these bridge figures in wider socio-political context can build collaboration, trust and knowledge sharing (Freed et al., 2016). However, in some cases, processes designed by researchers and external NGOs raise ethical considerations as they may lead to asymmetrical power relations, marginalisation (e.g. Baker and Constant, 2020) and postcolonial contexts (e.g. Hakkarainen et al., 2020).

Participatory research and planning efforts focusing on co-producing knowledge are called for in 44 reviewed papers (13%) (e.g. Fagerholm et al., 2012; Käyhkö et al., 2019). Engaging communities in forward planning or foresight, creates a platform of learning, collaboration, dialogue and developing practical solutions to enhance preparedness for future change (Lagabrielle et al., 2010; Lestrelin et al., 2017; Käyhkö et al., 2019). Participatory scenario building is one such foresight approach that fosters creative thinking on constructing future desirable scenarios, often with multiple stakeholders (Lagabrielle et al., 2010; Graveline et al., 2014). For example, Lestrelin et al. (2017) organised scenario land-use planning workshops in La Réunion, to study the impacts of different urbanisation scenarios in the island. These simulations were critical in raising awareness and facilitating dialogue between different stakeholders, finally contributing to the establishment of a science-policy bridging organisation.

Table 4
Actors mentioned to play a role in the response.

Actors	Count	Percentage of papers %
National governments	279	84
Sub-national governments	233	70
Local communities	188	57
Research	182	55
Corporate sector - businesses, industry, developers	110	33
External actors - other country governments, development banks, intergovernmental organisations, regional organisations	94	28
Non-governmental organisations, civil society organisations	84	25
Media	14	4

While the value and importance of integrating local or experiential knowledge in the response to environmental change in small island communities is recognised, many studies indicate that this knowledge is often excluded from decision-making processes (see for example, Hakkarainen et al., 2020). Moreover, not many studies we reviewed involved traditional community-based responses. For example, Chacowry et al. (2018) highlight that in Mauritius, experiential knowledge on floods was crucial in adopting suitable coping strategies of households and communities. In Comoros, Comte et al., 2016 found that to address freshwater scarcity large diameter traditional wells were more effective and sustainable than modern boreholes.

However, there are comparatively fewer documented examples of traditional responses in the reviewed WIO papers than in the literature from the Pacific Island Countries (PICs) (see Gero et al., 2011; McNamara, 2013; Janif et al., 2016; Buggy and McNamara, 2016; Weir et al., 2017; Bryant-Tokalau, 2018) and Caribbean islands (see Mycoo, 2017; Mycoo and Donovan, 2017; Robinson and Wren, 2020). This could be potentially explained by the rich sea-based cultural history of pre-colonial human populations in the Pacific islands (Nunn, 2009). Some of the WIO islands (e.g. Mauritius) were recently settled by diverse people during the colonial periods and thus have shorter lived experience (Glaser et al., 2018). Moreover, unlike the small islands in the Pacific and Caribbean, WIO islands do not have many island-based regional organisations that focus entirely on issues related to environmental change in the small islands. The paucity of these networks could mean that historically and currently, there have been lesser learning opportunities between the islands that face similar challenges. Strengthening existing networks such as the Western Indian Ocean Marine Science Association (WIOMSA) and the Indian Ocean Commission (IOC) could play a key role in transferring knowledge between key island stakeholders in the region. By bringing people together in a governance network there is potential in learning about each other's preferences, expertise and knowledge gaps (Mercer et al., 2014). Moreover, specialist skills can be shared through the regional organisations to reduce the pressure on national agencies (Weir, 2020).

Overall, effective responses need to be built on a balanced body of knowledge originating from various sources. The transformation to open knowledge systems, called for at the global level by Cornell et al. (2013) is translated into a set of recommendations in the papers we have reviewed. Elements of these open knowledge systems include collective problem framing (as shown in reviewed paper Hakkarainen et al., 2020; Newman et al., 2020), effective dialogue processes (as shown in Lestrelin et al., 2017 and Rasheed and Abdulla, 2020) and open access to data and knowledge sharing (Torresan et al., 2016; Benard and Dulle, 2017) among others.

4.2.4. Governance of responses

Governance of responses refers to the way responses are planned, organised and implemented. In the diverse contexts of WIO islands, there is no one-size-fits-all model of governance (not all responses are organised or managed in the same way). However, based on the reviewed literature scholars suggest that adaptive, polycentric (see, for example, Sovacool, 2011; Hauzer et al., 2013; Levine, 2016; Sovacool et al., 2017) and collaborative arrangements (as shown in Fagerholm et al., 2012; Mercer et al., 2014; Lestrelin et al., 2017), are better to address complexity.

Particularly in the context of dynamic environments such as islands, studies emphasise that response governance should be 'adaptive':

learning-driven, iterative, anticipatory, proactive, innovative and flexible (Mustelin et al., 2010; Fröcklin et al., 2013; Anisimov et al., 2020). However, most responses are ad hoc and reactive (responding to stress or stimulus after it has occurred), where the focus is on maintaining the past and favouring short-term goals (Sovacool et al., 2017; Betzold and Mohamed, 2017; Anisimov et al., 2020). Studies call for a shift towards proactive responses (responding prior to environmental change impacts) that focus on forward planning and increasing preparedness for future uncertainties or surprises (Newman et al., 2020; Williams et al., 2020).

Effective responses are often described in the reviewed papers as embracing co-management, which involves the sharing of power, knowledge and responsibility between different stakeholders, such as the government, the corporate sector, scientists and local communities (Freed et al., 2016; Wallner-Hahn and de la Torre-Castro, 2018). In comparison to non-island contexts, small islands have a complex and dense network of actors that all have a stake in planning and implementing the responses (Khan and Amelie, 2015; Williams et al., 2020). However, this does not translate to simpler institutional arrangements and coordinated action (Williams et al., 2020). de la Torre-Castro and Lindström (2010) argue that gaining knowledge on the institutional arrangements, how stakeholders interact and the wider political setting while planning a response is a critical investment that is beneficial in the long run. They exemplify this in the context of small-scale fisheries in Zanzibar, where the imposition of new regulations without considering the underlying existing institutions contributed to management failure.

Our review also indicates a heavy reliance on (and/or high expectations from) governmental actors (89% of the reviewed papers mention the role of the government in the response planning and implementation) at national (84%) and local (70%) level. While many studies clearly refuse a top-down approach in which the government takes the overall lead in designing responses to environmental change (as shown in reviewed papers Gustavsson et al., 2014; Katikiro et al., 2015; Ratter et al., 2016), the government is still seen as having to play a major institutional role. This can reflect the expressed need for coordination (as expressed in BahriBrikké and Vairavamoorthy, 2016; Freed et al., 2016; Zhang and Bakar, 2017; Lestrelin et al., 2017), and for large-scale collective action (Hauzer et al., 2013; Freed et al., 2016; Ratter et al., 2016; Gehrig et al., 2018), but can also reflect a lack of trust in assigning key responsibilities to non-governmental actors (Baker and Constant, 2020; Hakkarainen et al., 2020). For example, one of the main obstacles to the implementation of responses is the poor coordination between government sectors and tiers as a major obstacle to adaptation in small islands (Sovacool, 2012; Betzold, 2015; Clissold et al., 2020). However, the increased focus on governmental action may potentially mean that community-based, non-state action and corporate sector action receive lesser research attention.

5. Conclusion

This systematic review of 329 published research articles synthesises the diversity of documented responses to environmental change and the actors mentioned to play a role in these responses. Further, we explore the elements influencing the effectiveness of responses. The proposed effectiveness framework (Fig. 4) provides an outline to compare sites despite contextual differences. While these effectiveness elements may seem general, we highlight they are critical focus points to consider when designing responses. This review contributes to existing knowledge as no other study documents the elements in this organised manner and it provides the basis for future explorations.

By assessing peer-reviewed literature in the last decade, we provide a snapshot of current knowledge in the selected islands in the WIO region. Carrying out a review is an important first step in designing responses as it offers a rigorous and uniform means of characterising what is known, the gaps in literature and highlight the potential for islands to learn from each other. This review allows to zoom out by providing general recommendations on what makes an effective response (Fig. 4), while also zooming in with detailed categorisation on the specific responses suggested and implemented in different islands. Cataloguing the different responses may help incorporate the diversity into well-informed decisions, offer alternative ways of thinking and highlight specific areas and response types that should be the focus of future research and practice.

The capacities for island communities to develop and implement their own context-specific responses rely heavily on the information and knowledge about the extent of change, the drivers and consequences of the change and about the different response options available. This in turn depends on the extent to which they can learn from the experimentation of others via social and institutional networks. It is also important for communities to first identify and define the needs and necessities before further planning responses. Different responses should be tested over a long time to assess their impacts and effectiveness. The continuous learning and monitoring allows for response options to be altered based on the predefined triggers. Further, these experiences should be documented and disseminated widely for communities and decision-makers to learn from them and to avoid similar mistakes.

Going forward, there should be more focus on long-term assessment of the successes and failures of responses, strengthening coordination and collaboration between institutions, increasing funding, multi-pronged approaches to target multiple drivers and meaningful local participatory decision-making. Genuine cross-scale collaborations at the local, national and regional levels will foster feedback and learning. Learning enhances the adaptive capacity of the responses, making actors and institutions more open to new ideas and encourages innovation. An 'extended peer community' approach on proactive response design, implementation and evaluation will further strengthen learning. Nonetheless, this will depend on the willingness of the diverse actors and the political will to meet local social-ecological needs.

While it comes with no surprise that the responses are diverse, our study highlights that the drivers of environmental change are strongly interlinked and that one-size-fits-all solutions that address the drivers in isolation may not work. Additionally, by systematically documenting this diversity, future studies may draw on the Supplementary Material we provide to analyse the effectiveness of responses to specific drivers of change (e.g. coastal erosion, overfishing) in the nine selected island jurisdictions and beyond. Further investigations on effectiveness of responses are encouraged. The presence numbers indicated across the response categories indicate future areas of focus. For example, although there is a gradual shift and increasing interest towards nature-based responses, these still remain largely underrepresented in research and practice. Thus, this broad systematic account of responses to environmental change offers a stepping stone for future case study based research in island and non-island contexts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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