Rare coral and reef fish species status, possible extinctions, and associated environmental perceptions in Mauritius

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Abstract
Mauritius is reported to have the highest marine species endemism in the Western Indian Ocean faunal Province but the status of these species has not been evaluated. To address this knowledge gap, 119 reef sites were sampled to evaluate populations of 16 species of rare and endemic reef fish and corals using scuba-based surveys conducted by citizen scientists and marine science professionals. Additionally, we interviewed ~1,000 households in 27 coastal villages to determine their perceptions of the environmental concerns and rare and endemic marine species. In general, population numbers of both studied corals and fish were low and distributions were patchy, with little indication that the fisheries management zones were protecting these species. The Mauritian gregory and Mauritian anemonefish were the most abundant species. The Mauritian and Creole damselfishes, which are range-restricted Mascarene endemics, were not observed and potentially extinct. Endemic fish and coral population numbers were higher on the leeward than windward side of the island. The leeward side has higher tourism use and conservation activities that could promote endemic conservation. Environmental concerns of interviewees were high but varied by district and their socioeconomic contexts. Respondents showed an overall concern for the environment and agreed that endemic and rare species had a right to survive. Nevertheless, these rare and endemic coral reef species are threatened by isolation and habitat loss combined with rapid climate and human resource use change. National and district-specific plans of actions could help to secure their futures.

Keywords
Africa, citizen science, endemics, environmental perceptions, geographic isolation, Western Indian Ocean faunal province
1 | INTRODUCTION

Coral reefs are species diverse ecosystems being degraded by human activities and climate warming (Hughes et al., 2019; Roberts et al., 2002). For example, Roberts et al. (2002) revealed that between 7% and 54% of studied reef taxa have highly restricted ranges and many were clustered into centers of endemism. For example, the 10 richest centers of endemism cover 15.8% of the world’s reefs but include between 44.8 and 54.2% of the restricted-range species. Allen (2008) found that the highest diversity of 3,910 Indo-Pacific reef fishes was in the west Indo-Pacific but that a high percentage of the endemism was found in Easter Island, Baja California, Hawaiian Islands, Galapagos Islands, Red Sea, Clipperton Island, Marquesas, Isla del Coco, Mascarene Islands (Mauritius, Reunion, Rodrigues and smaller islands), and Oman. Based on a number of taxa, Roberts et al. (2002) ranked the Mascarene Islands as the fourth most threatened fauna based on endemism and human activities, after the Philippines, Gulf of Guinea, and Sunda Islands of Indonesia. Therefore, climate impacts and high human populations, economic development and subsistence-level use of marine resources could threaten endemics if there are no knowledge of their status and actions implemented to prevent their extinction (Fourrière, Reyes-Bonilla, Rodríguez-Zaragoza, & Crane, 2014).

1.1 | Coral reef endemism

Endemic fish and coral species are chiefly characterized by their small populations with low occupancy and low abundance within restricted geographic range (Chapman et al., 2018; Cowman, Parravicini, Kulbicki, & Floeter, 2017). However, some endemic reef fishes are locally dominant, including endemic damselsfishes and angelfishes in the remote Indian and Pacific Ocean islands (Crane et al., 2018; Hobbs, Jones, & Munday, 2010). High abundance may occur due to isolation, environmental barriers, restricted dispersal, high recruitment, and reduced competition (DiBattista et al., 2016; Eble, Toonen, & Bowen, 2009; Hobbs, Jones, & Munday, 2011; Jones, Caley, & Munday, 2002). Consequently, the ecological and evolutionary processes that created endemism are many and indicate a need to assess the causes of restricted ranges and subsequent conservation status on a case-by-case basis (Cowman et al., 2017; DiBattista et al., 2016).

In the western Indian Ocean faunal province, there are 11 distinct ecoregions (Spalding et al., 2007). Consequently, species are often restricted in their ranges to the faunal province but also ecoregions and specific islands and may be referred to as provincial, ecoregional or island endemics (Table 1). For example, the corals Acropora branchi, A. roseni and Horastrea indica have been reported in the Western Indian Ocean province but always in low numbers and not necessarily restricted to ecoregions (Obura, 2012). In contrast, many endemic damselfish in the province are restricted to a single ecoregion, such as the Mascarene Islands. Some species, such as the Mauritian damselfish (Plectroglyphidodon randalli), are restricted to the western Mascarene ecoregion or just Reunion and Mauritius (Table 1). Thus, the chances of local extinction should increase as species’ ranges are restricted, which appears to the case for a number of damselfish in the WIO province. Given this variability in the ranges of species, the status of rare and endemic species is difficult to assess without field surveys.

Because of the multiple local human and climate change-driven impacts, some predictions suggest that reef corals of Mauritius might face local “extinction dates” between 2025 and 2070, depending on level of adaptation of corals and the shifting thermal limits of bleaching (Bhagooli & Sheppard, 2012). A recent study found that nearly a third of studied coral taxa have already declined greatly, associated with repeated thermal stresses since 2004 (McClanahan & Muthiga, 2021). Three non-endemic coral taxa were found, for example, to potentially be locally extinct. Coral and anemone-dependent species, such as damsel and anemonefish, are potentially vulnerable because of their dependence on these heat-sensitive algal-hosting symbiotic invertebrate species, or corals and anemones (Graham et al., 2011). Studies of larval dispersal in this region identify the Mascarene Islands as a region with low larval connectivity (Crochelet et al., 2016; Maina et al., 2020), which should prevent re-establishment of affected species after local extinctions. Yet, a comprehensive evaluation of endemism, processes of connectivity, and the status of these species is lacking.

1.2 | Citizen science

Citizen scientists have participated in a number of studies to investigate problematic species of conservation concern (McKinley et al., 2017). Coral reefs are high diversity ecosystems, but this has not prevented useful studies of seasonal changes in species (Roelfsema et al., 2016), species distributions in a marine park, such as Tioman Island Marine Park in Malaysia (Lau et al., 2019) and a threatened and now extinct handfish species in Australia (Edgar, Stuart-Smith, Cooper, Jacques, & Valentine, 2017), and changing numbers of species in the Red Sea (Branchini et al., 2015). However, so far involvement in evaluating the status of rare and endemic reef species through citizen science methods has not covered a broad national scale, particularly in Africa.
TABLE 1 Species of (a) fish and (b) corals selected for the study in Mauritius

(a) Studied fishes

| Scientific and common name | Occurrence | Range status | Ecological niche |
|----------------------------|------------|--------------|------------------|
| *Stegastes pelvicieri* (Allen and Emery, 1985) Mauritian gregory (Cousse Cousse) | Inhabits rocky reefs, rubble substratum area in shallow and calm lagoon near crevices and holes (Fishbase.de, Terashima, Mosahbe, Paupiah, & Chineah, 2001) | Éparses Islands, Madagascar, Réunion, Mauritius and Rodrigues | Reef-associated and nonmigratory reported living in 2–20 m |
| *Stegastes limbatis* Ebony gregory (Cuvier, 1830) | Inhabits branching coral in the lagoon areas and exhibit territorial behavior | Mascarene endemic restricted to Mauritius and Reunion Islands | Territorial reef-associated |
| *Plectroglyphidodon randalli*, (Allen 1991) Mauritian damselfish | Inhabits lagoon and inshore coral reef areas | Western Mascarene endemic (Reunion and Mauritius) | Shallow inshore wave-exposed rocky reefs and localized |
| *Abudefduf margariteus* (Cuvier, 1830) Pearly sergeant | Inhabits coral and rocky reefs around lagoons and reef slopes (Terashima et al., 2001) | Mascarene endemic only in Reunion and Mauritius | Shallow water 2–8 m |
| *Amphiprion latifasciatus* (Allen, 1972) Madagascar anemonefish | Associated with a number of species of anemone including *Stichodactyla mertensii*. Resides both lagoons an outer reef (Fishbase.de) | Mozambique channel and Madagascar to Mascarene Islands | Specialist—habitat specific reported in shallow lagoons and reef slopes |
| *Amphiprion chrysogaster* (Cuvier, 1883) Mauritian anemonefish | Lives among a number of species of anemone, including *Heteractis magnifica*, *Stichodactyla hadloni*, *S. mertensii*, and *Macrodactyla doreensis*. | Limited to Mauritius | Found in depths of 2–40 m. Resides in both lagoons and outer reef and has been reared in aquaria |
| *Pomacentrus pikei* (Bliss, 1883) Blacklip damselfish | Inhabits rocky reefs, rubble substratum area in shallow and calm lagoon near crevices and holes (Terashima et al., 2001) | Madagascar, Reunion and Mauritius | Reef-associated and nonmigratory shallow lagoon and reef slope < 2 m |
| *Pomacentrus agassizii* Bliss, 1883 Creole damselfish | Inhabits lagoon and inshore coral reef areas | Madagascar, Reunion, and Mauritius | Reef-associated in shallow lagoons and localized |
| *Zebrasoma gemmatum* (Valenciennes, 1835) Spotted tang | Occurs mainly in the outer reef between 15 and 60 m, found chiefly in holes and crevices (Fishbase.de) | East to South Africa, and Madagascar and Mascarene Islands | Reef-associated in deeper water or 10–60 m |
| *Ostracion trachys* (Randall, 1975) Roughskin trunkfish | Occurs mainly in the outer reef between 15 and 30 m, found chiefly in holes and crevices. | Western Mascarene endemic restricted to Mauritius and Reunion Islands | Reef edge-associated between 15 and 30 m |

(b) Studied corals

| Scientific name | Occurrence | Status | IUCN red list* |
|----------------|------------|--------|---------------|
| *Acropora branchi* (Riegl, 1995) | Indian Ocean, coastal region in the upper reef slope (Veron, 2000) | Regionally Endemic Western Indian Ocean (Obura, 2012) | Status: Data deficient population trend: decreasing Acropora genus is declining in globally and in Mauritius |

(Continues)
TABLE 1 (Continued)

| (b) Studied corals |
|-------------------|
| **Scientific name** | **Occurrence** | **Status** | **IUCN red list** |
| Poecilopora indiana (Veron, 2000) | Indian Ocean, coastal region in the upper shallow reef (Veron, 2000) | Regionally endemic Western Indian Ocean (Obura, 2012) | Vulnerable Ecoregional population trend unknown but genus is declining in Mauritius (McClanahan & Muthiga, 2021) |
| Seriatopora hystrix (Dana, 1846) | Shallow reef environment (Veron, 2000) | Occurs in the tropical and subtropical reef regions | Least concern Global population trend unknown but decreasing in Mauritius (AFRC, unpublished, McClanahan & Muthiga, 2021) |
| Seriatopora caliendrum (Ehrenberg, 1834) | Upper reef slope (Veron, 2000) | Occurs in the tropical and subtropical reef regions | Near threatened Global population trend unknown but decreasing in Mauritius (AFRC, unpublished, McClanahan & Muthiga, 2021) |
| Stylophora pistillata | Widely distributed in the Indo-Pacific region | Occurs in the tropical and subtropical reef regions | Near threatened Global population trend unknown but very rare in Mauritius with complex taxonomy (Bhagooli et al., 2017; McClanahan & Muthiga, 2021) |
| Horastrea indica (Pichon, 1971) | Very rare coral, occurrence limited to sandy reef areas (Veron, 2000) | Regionally endemic Western Indian Ocean (Obura, 2012) | Vulnerable Global and Mauritian population status and trend unknown but seldom or never observed in prior studies |

Note: Sources of range information taken from Fishbase, Eschmeyer’s Catalog of Fishes located at the California Academy of Sciences website, and Terashima et al., 2001. Organized from oldest to youngest evolutionary lineages for fish after (Cooper, Smith, & Westneat, 2009) and corals after (Kitahara, Cairns, Stolarski, Blair, & Miller, 2010).

*Status taken from IUCN Red list accessed in July 2019.

and the western Indian Ocean. Yet, given the often sparse and isolated distributions of rare and endemic species and the numerous dive centers in Mauritius, a collaborative approach could help to overcome the costs of evaluating rare and endemic taxa.

Here, we describe efforts to develop a citizen- and marine-professional science program to evaluate the status of a selected group of rare and endemic fish and coral species present in Mauritius. The field study of these species was also combined with questionnaire surveys to evaluate the perceptions of coastal communities towards the environment in general and specifically to rare and endemic species. These two activities were combined to determine the ability and interest of citizenry, specifically the dive industry, to evaluate the status of a selected group of representative threatened species. This engagement was expected to better promote public awareness and to develop policies and management actions needed to better manage these species.

1.3 Mauritian ecological context

The main island of Mauritius is isolated from dispersal interactions with other species located on the sparsely distributed islands within the Mascarene plateau and the southwestern Indian Ocean (Crochelet et al., 2016; Maina et al., 2020). The island is surrounded by a large shallow lagoon of 243 km² enclosed by around 150 km of fringing reefs (Figure 1). The reefs are distinctly broken by natural breaks caused by rivers and tidal channel giving rise to a series of lagoons that define the geomorphology of depths, current pattern, and distance from the shore (Daby, 2006). The lagoon is generally shallow (<3 m) and often extends a few kilometers to the growing fore-reef edges that supports coral populations up to a depth of 30-m where expanses of rubble and sand dominate (Bhagooli & Kaullysing, 2019; Elliott et al., 2016; Fagoonee, 1990). The outer reef and location of most dive sites are frequently located in deeper water in or near these channels and deeper reef edges. The Mauritian eastern and southern-facing aspects are exposed to strong oceanic currents and less populated than the northern and western aspects that are protected from trade winds and strong oceanic conditions (Pous et al., 2014).

These eastern and southern ocean exposed environments have had the most extensive and intense exposure to the increasing thermal stresses and coral bleaching
For example, in 2005 a site-limited study found a decrease in coral cover of up to 50% at several reef sites, with one site experiencing a 90% decline in cover. In 2010, six studied sites exhibited a 96–100% decline in coral cover (Bhagooli et al., 2021). However, several studies have documented intra- and inter-species variability in coral responses that suggest the potential for resistance and sanctuary from stress (Bhagooli & Taleb-Hossenkhan, 2012; Louis et al., 2016; Louis et al., 2020; Mattan-Moorgawa, Bhagooli, & Rughooputh, 2012; Mattan-Moorgawa, Rughooputh, & Bhagooli, 2018; McClanahan et al., 2005). The consequences of thermal and other stresses on the habitats and status of the rare and endemic corals is, however, undocumented.

Coral reefs in Mauritius have been regularly monitored through the efforts of government fisheries and oceanographic bodies, namely the Albion Fisheries Research Centre and the Mauritian Oceanographic Institute. Studies include near-annual collection of common coral and fish populations in 11 shallow lagoons and 4 deeper fore-reefs beginning in 1998. Most analyses of these data have, however, focused on coral and benthic population changes over time (Bhagooli et al., 2021; Elliott, Patterson, Staub, Koonjul, & Elliott, 2018). The benthic cover studies have evaluated 23 benthic functional and some gross taxonomic categories. Collected data lacks the sampling intensity and taxonomic resolution to evaluate the status of rare and endemic species. Time series arising from the benthic studies indicate periods of thermally-induced coral bleaching and mortality followed by recovery as well as potential impacts of human use in the watersheds (Elliott et al., 2018). More detailed taxonomic studies of corals indicated that these methods were not detecting changes of many coral taxa, including a number of local extirpations of genera over a 15-year period (McClanahan & Muthiga, 2021).

**FIGURE 1** Map of Mauritius showing the locations of the dive and social survey sites. Studied district and major towns are also shown. National marine parks, fishing reserves, and voluntary marine conservation areas are identified.
1.4 Mauritius’s social context and perceptions of the environment

Historically, Mauritius lacked a native population and was colonized and governed by the Dutch, French, and British before independence in 1968 (Seetah, 2010). With these multiple waves of colonization, the introduction of slave labor from the African continent and indentured laborers from South Asia (Seetah, 2010), Mauritius is today a multi-ethnic, lingual, and cultural nation. Within Africa, Mauritius is ranked highest in terms of democratic and economic governance (https://data.worldbank.org/country/MU). Coastal areas have high economic value with, for example, ~1.9 million international tourists arrived in 2019 (Anisimov, Magnan, & Duvat, 2020). Therefore, coastal development and tourist numbers are promoting the economy but also causing increasing habitat degradation and conflicts over local access to resources (Lalljee, Velmurungan, & Singh, 2018; Magnan, 2007). With an Exclusive Economic Zone (EEZ) of 2.3 million km², the Government of Mauritius is prioritizing the ocean economy as an important pillar for development. The fisheries sector, which accounts for 20% of total exports, is one of its main sectors (https://data.worldbank.org/country/MU).

In terms of area-based management, Mauritius has proclaimed 8 Marine Protected Areas (MPA), covering an area of 7,190 ha (de la Mata, 2012), that include 6 Fishing Reserves and 2 Marine Parks, all of which are established in the Fisheries and Marine Resources Act (2007). The Fishing Reserves, which are gear-restricted areas, include Poste Lafayette, Poudre D’Or, Trou d’Eau Douce, Port Louis, Grand Port and Black River Fishing Reserves. The two Marine Parks, Baclava and Blue Bay Marine Parks, are multiple-use MPAs and include a no-take conservation zone (Republic of Mauritius, 2017). Based on its high marine biodiversity, the Blue Bay Marine Park was also listed as a Wetland of international importance under the Ramsar Convention in 2008. Mauritius has two community conservation sites led by local marine NGOs, locally known as Voluntary Marine Conservation Areas (VMCAs), which encourage an inclusive stakeholder participation where users voluntarily agree to not extract resources or use destructive practices. The creation of these managed systems indicates a concern for conservation and potential to protect the studied species of concern. Environmental perceptions of local stakeholders were therefore explored in more detail through a standard environmental questionnaire.

2 MATERIAL AND METHODS

2.1 Selecting study species and sampling

Recognition of the lack of assessments of threatened endemic species, prompted a meeting of the Mauritius National Coral Reef Network committee to evaluate the potential to assess the endemic and rare reef fish and coral species (Meeting held in August 2016, Albion Fisheries Institute Conference Hall). This led to an evaluation of the literature on potential species and consultation with the then Ministry of Ocean Economy, Marine Resources, Fisheries and Shipping, University of Mauritius, and conservation organizations concerned with coral reefs. Given the limited resources for undertaking a nation-wide study of potentially rare and uncommon species, it was decided that the large dive industry in Mauritius could provide a means to evaluate some of the more recognizable species. The list of 10 endemic fish and 6 rare or endemic coral species were then compiled and a field guide of the targeted taxa prepared for surveying both shallow lagoons and the dive sites (Figure 2).

The 10 regionally rare and endemic reef fishes targeted were the Mauritian gregory (Stegastes pelicieri), Mauritian anemonefish (Amphiprion chrysozoster), Blacklip damselfish (Pomacentrus pikei), Ebony gregory (Stegastes limbatus), Roughskin trunkfish (Ostracion trachys), Pearly sergeant (Abudefduf margariteus), Spotted tang (Zebrasoma gemmamum), Madagascar anemomefish (Amphiprion latifasciatus), Creole damselfish (Pomacentrus agassizi) and Mauritian damselfish (Plectroglyphidodon randalli). The 6 selected provincially or eco-regionally endemic or rare coral species were Acropora branchi, Horastrea indica, Pocillopora indiana, Seriatopora hystrix, Seriatopora caliendrum, and Stylophora pistillata.

There is a global conservation concern for a number of these species (Table 1). For example, the corals H. indica and P. indianaia are listed in the IUCN RedList of threatened species (IUCN, 2020) as Vulnerable, S. pistillata is listed as Near threatened and A. branchi as Data Deficient. Two of the fish species, the Pearly sergeant (A. margariteus) and Spotted tang (Z. gemmamum) are also listed as Data Deficient indicating little is known of their abundances and distribution. The limited study of coral taxa over time, suggest that a number of the coral species are declining (McClanahan & Muthiga, 2021) but the population trends of these selected fish is lacking.

A waterproof underwater field guide slate was created as well as a training course that was given to interested dive centers (see Acknowledgments). The distribution
and training started with a meeting of the Mauritian Scuba Diving Association (MSDA) in March 2018 where members were introduced to the concept and asked for their participation. Thereafter, follow-up meetings, trainings, and distribution of dive slates were undertaken between April 2018 and June 2019 to specific amenable dive centers located around the island. The participant observers were asked to record the GPS locations and depth of their dives and the number of individuals of the above species per dive. These data were submitted to Reef Conservation, a Mauritian marine conservation Non-Governmental Organization. Data were compiled, mapped, and analyzed for presence and abundance by national districts and marine management zones.

The aim of the study was to assess the occurrence of endemic and rare coral and reef fish species both in the shallow lagoons of depths <5-m and reef-edges of depths >5-m. Therefore, sites were selected around the island to include both area-based management and sites with no fishing restriction. Overall, 65 shallow lagoons and 54 fore-reef edge diving sites were completed by 2019, which was largely from the dive community. Data were
also provided by experienced marine scientist collaborators who focused their sampling efforts on shallow sites not frequently sampled by the dive centers.

2.2 Environmental perceptions

The social study was conducted from January to September 2019 along 27 rural coastal villages and the Mauritian capital of Port Louis. The study sites included villages with fish landing stations around marine management areas and varied from 1 to 7 per district depending on the number of management areas in the district. Control villages included those with fish landing stations but no marine management sites to ensure that all villages sampled had an active fishing community (Figure 1).

Household surveys were undertaken using questionnaires, based on the revised globally applied New Ecological Paradigm (NEP) questions (Dunlap, Van Liere, Mertig, & Jones, 2000). The survey questions were first piloted with local community representatives for their clarity and relevance to local contexts before being deployed among village inhabitants. The surveys were conducted in the preferred language of the respondent, which was either English, French, or Mauritian Creole by trained local enumerators. Interviewees were students of the marine science program of the University of Mauritius who were trained in interview methods and the specific NEP questions. The respondents were chosen using a stratified sampling approach targeting coastal residents to include both fishers and non-fishers in studied villages along the coast of Mauritius. A small number of surveys (<2%) were incomplete in terms of filling the gender question but all 1,016 surveys were used in the analysis.

We used the New Ecological Paradigm (NEP) scale (Dunlap et al., 2000; Dunlap & Van Liere, 1978) to compare pro-ecological behavior between the 7 coastal districts of the island. As one of the earliest and most frequently used measures of an ecological worldview, the NEP scale measures beliefs regarding humanity's ability to disrupt nature, the existence of limits to economic growth and development, and the right of humanity to rule over nature (Dunlap et al., 2000; Dunlap & Van Liere, 1978). The calculated NEP scale consisted of 15 items with a 5-point Likert scale. We made a minor change to the original scale (Dunlap et al., 2000) where statement 7 added the term “endemic” to the first word in the statement—plants and animals have as much right as humans to exist. Responses to scale items were coded as 1 = strongly disagree, 2 = disagree, 3 = Neither agree nor disagree, 4 = agree, and 5 = strongly agree. The 7 even-numbered statements were anti-environmental statements and therefore coded in reverse in order to make all scales positive for the environmental concern scale and analyses. Sociodemographic information (gender, age, level of education, and head of household status) was also collected from the participants for the analyses (Table S1).

2.3 Data analysis

2.3.1 Distributions of fish and corals

Maps of the surveys were produced for (1) all survey sites and the presence of study species, (2) the endemic and rare fish, and (3) the endemic and rare corals. Maps were produced using sf packages in R software (R Core Team, 2020; R package version 0.9-5; https://CRAN.R-project.org/package=sf) (Pebesma, 2018) and visualized using ggplot2 version 3.3.2; https://CRAN.R-project.org/package=ggplot2 (Wickham, 2016). Count data were pooled into management categories where Marine Park sites were categorized as sites of high restriction, Fishing Reserve sites were categorized as medium restriction, and VMCAs were categorized as low restriction.

2.3.2 Tests of variability in abundance of endemic/rare fish and coral species

Raw and transformed densities of endemic fish and corals failed tests of normality. Therefore, nonparametric Wilcoxon tests of significance were used to test for differences in the district’s mean abundance based on the population density or number of individual observed per 40-min search. Consequently, post hoc nonparametric Dunn's test for all possible pairs were tested with the Bonferroni for differences of mean numbers of individual fish and coral species in the different districts and fisheries management zones.

2.3.3 Environmental perceptions

The scale of environmental perceptions was evaluated and tested for differences between the 7 coastal districts including the port district where there was no sampling of corals and fish, due to the industrial port. Although the 15 questions are sourced from multiple facets of human psychology, the NEP scale was designed to measure a single latent pro-environmental psychological trait. Therefore, response scores can be pooled into associated categories or summed and averaged to obtain a total
### TABLE 2  
(a) Fish and (b) coral densities and standard deviations (mean ± SD, numbers/40 min) for individual species and taxa in surveyed districts

| Fish species          | Total numbers observed | Mauritius coastal districts | Test of significance          |  |
|-----------------------|------------------------|-----------------------------|-------------------------------|---|
|                       |                        | Grand port | Riviere du Rempart | Black River | Pamplemousses | Flacq | Savanne | Kruskal-Wallis for districts | Kruskal-Wallis |
| Mauritius gregory     | 92                     | 1.13 ± 4.12 | 0.86 ± 2.61 | 0.55 ± 0.54 | 0.39 ± 1.13 | 1.11 ± 3.33 | 0.11 ± 0.37 | 12.10; 0.03 | 0.68 ± 2.30***(-) |
| Mauritius clownfish   | 93                     | 0.53 ± 1.6 | 0.8 ± 1.94 | 0.47 ± 0.51 | 1.1 ± 2.16 | 0 ± 0 | 0 ± 0 | 7.94; NS | 0.69 ± 1.69***(-) |
| Blacklip damselfish   | 46                     | 1.4 ± 2.82 | 0.43 ± 1.82 | 0.18 ± 0.39 | 0.11 ± 0.41 | 0 ± 0 | 0 ± 0 | 10.64; NS | 0.36 ± 1.48(-) |
| Ebony gregory         | 32                     | 0 ± 0 | 0 ± 0 | 0.47 ± 1.28 | 0.17 ± 0.93 | 0.11 ± 0.41 | 0 ± 0 | 12.11; 0.03 | 0.17 ± 0.81(-) |
| Rough-skin trunkfish  | 23                     | 0 ± 0 | 0.2 ± 0.62 | 0.53 ± 0.51 | 0.18 ± 0.41 | 0 ± 0 | 0 ± 0 | 24.66; 0.0002 | 0.18 ± 0.52**(-) |
| Pearly sergeant       | 0                      | 0 ± 0 | 0.27 ± 1.64 | 0.12 ± 0.33 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 7.41; NS | 0.10 ± 0.92(-) |
| Spotted tang          | 9                      | 0 ± 0 | 0.03 ± 0.16 | 0.06 ± 0.24 | 0.24 ± 1.12 | 0 ± 0 | 0 ± 0 | 2.75; NS | 0.08 ± 0.57(-) |
| Madagascar anemonefish| 5                      | 0 ± 0 | 0.14 ± 0.59 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 4.47; NS | 0.04 ± 0.33(-) |
| Creole damselfish     | 0                      | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0.00; NS | 0 ± 0 |
| Mauritius damselfish  | 0                      | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0.00; NS | 0 ± 0 |
| Fish species mean     | 0.31 ± 0.52           | 0.27 ± 0.35 | 0.24 ± 0.16 | 0.22 ± 0.24 | 0.11 ± 0.33 | 0.11 ± 0.18 | 42.46; <0.0001 | 99.16; <0.0001 |

(b) Coral taxa

| Coral taxa             | Total numbers observed | Seriatopora hystrix | Pocillopora indiana | Stylophora pistillata | Horastrea indica | Acropora branchi | Seriatopora caliendrum | Coral taxa means |
|------------------------|------------------------|--------------------|---------------------|-----------------------|-----------------|-----------------|------------------------|-----------------|
|                       |                        | 0.69 ± 1.54        | 0.05 ± 0.33         | 0.12 ± 0.33          | 0.07 ± 0.37 | 0 ± 0 | 0 ± 0 | 8.94; NS | 0.14 ± 0.64***(-) |
| Seriatopora hystrix    | 25                     | 0 ± 0              | 0.23 ± 0.82         | 0.53 ± 0.51***(+)    | 0.03 ± 0.19 | 0.11 ± 0.33 | 0 ± 0 | 31.52; <0.0001 | 0.16 ± 0.54***(+) |
| Pocillopora indiana    | 23                     | 0 ± 0              | 0.19 ± 0.88         | 0 ± 0 | 0.34 ± 1.86 | 0 ± 0 | 0 ± 0 | 2.68; NS | 0.14 ± 1.04** (+) |
| Stylophora pistillata  | 17                     | 0 ± 0              | 0.29 ± 0.47***(+)   | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 31.05; <0.0001 | 0.04 ± 0.2** (+) |
| Horastrea indica       | 5                      | 0 ± 0              | 0.08 ± 0.36         | 0 ± 0 | 0.16 ± 0.61 | 0 ± 0 | 0 ± 0 | 2.35; NS | 0.07 ± 0.38(-) |
| Acropora branchi       | 4                      | 0 ± 0              | 0.11 ± 0.66         | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 2.22; NS | 0.03 ± 0.37(-) |
| Seriatopora caliendrum | 4                      | 0 ± 0              | 0.11 ± 0.59         | 0.17 ± 0.37***(+)    | 0.10 ± 0.81 | 0.02 ± 0.14 | 0 ± 0 | 35.40; <0.0001 | 17.60; 0.004 |

Note: Kruskal–Wallis and Dunn’s tests of significance (Chi-square; p-value) of all and pair-wise comparisons of individual species by districts. NS = no statistical significance and (*) denotes level of significance. Taxa are organized from most to least abundant. Positive (+) and negative (-) superscripts shows fish species and taxa above or below species mean across the district.

*<p < .05. **<p < 0.001. ***<p < 0.0001.
measure of an individual’s environmental perception (Dunlap, 2008). Here, we evaluated each question separately and combined to obtain question-specific and overall perceptions of the environment by district. A test of reliability was conducted to measure the internal consistency, which produced a Cronbach’s alpha value of 0.68. This value falls within the acceptable range of reliability that is typical of the more commonly studied developed western countries (Dunlap et al., 2000; Hawcroft & Milfont, 2010). Tests of differences between districts for each question were undertaken using the Kruskal–Wallis tests of significance and post hoc analyses. Principal Component Analysis (PCA) was then employed to visualize the distribution of the responses to the 15 statements among the 7 sampled districts. Statistics software used for the above analyses included JMP 12.0 and R version 4.0.2 https://www.R-project.org/ (R Core Team, 2013; Sall, Lehman, & Creighton, 2001).

3 | RESULTS

A total of 119 marine underwater surveys from 20 dive groups or individuals were recorded. Surveys included a mix of members of a conservation non-government organization (Reef Conservation), 11 dive centers, and 4 experienced marine scientists. This resulted in a sample of 65 shallow lagoons and 54 reef edge diving sites distributed around the island (Figure 1). The mean recorded survey time was 43.9 ± 0.8 (SD) minutes per survey or a total of ~87 hr but all data presented below were normalized to 40 minutes for pooling and statistical comparisons. Surveys occurred on all aspects of the island but higher clusters of sampling were located around regular dive sites, notably the west and northwest leeward side of the island.

Surveys were undertaken in all the major fisheries management zones with few difference in numbers of studied corals or fish among the four management systems (Table S2). The one statistically emergent pattern of pooling sites by management, was more numbers of Mauritian gregory in the poorly-sampled (n = 3) medium restriction fisheries closures. Numbers of all and taxa-specific corals did not differ among the management systems. More differences were observed when species were evaluated at the district level (Table 2). Population densities were, however, low and patchy and differences were moderate. This suggests that the uneven sampling effort caused by diver’s non-random site selection was not a large problem for population estimates among the preferred selected habitats, or reef lagoons and fore-reef edges and channels. For example, the districts with the least number of total endemic fish had 0.11 while the highest had 0.31 individuals per 40 min. Numbers of coral taxa were even lower than fish, ranging from 0.0 to 0.17 per 40 min.

3.1 | Occurrence and distribution of fishes

The total number of the 10 selected endemic and rare reef fishes observed in ~87 hr ranged from none for the Creole and Mauritian damselfishes to 92 individual Mauritian Gregory (Table 2a). There were some significant differences in the types of reef or depth profiles among these species (Table 3). For example, the Ebony gregory were only observed in the shallow lagoons, while the Roughskin trunkfish, Pearly sergeant, Spotted tang, and Madagascar anemonefish were found only in the fore-reef edge and channel dive sites. The Mauritian gregory, Mauritian clownfish, and blacklip damselfish were found in all habitats.

In terms of distribution around the island, there was more heterogeneity by species (Figure 3a). The more abundant Mauritian anemonefish and gregory were widely distributed. The uncommon species were seldom seen in the eastern district of Flacq and the southern district of Savanne (Table 2). One exception was the Ebony gregory, which was patchily abundant in Savanne district. Overall, the northern and the western reefs had higher species occurrence both in terms of number of species per site and individuals per species. Three of the leeward districts, namely Riviere du Rempart, Black River, and Pamplemousses, had the highest numbers of species with 6 or 7 of the 10 targeted species found in these districts (Table 2). Grand Port, which contains Blue Bay Marine Park, had only 3 of the 10 species mostly the widespread Mauritian anemonefish, Mauritian gregory, and the Blacklip damselfish.

3.2 | Occurrence and distribution of corals

The total number of colonies of the 6 targeted endemic and rare corals observed in ~87 hr ranged from 4 to 25 colonies (Table 2b). Three species, namely S. hystrix, P. indiana, and S. pistillata were found in both reef lagoons and fore-reef edges (Table 3b). The remaining 3 species were only seen on fore-reef edges, where the majority of colonies were observed (fore-reef edge = 0.13 ± 0.57 vs. lagoon 0.05 ± 0.62 colonies per 40-min sample). Only 1 taxa was recorded in all 3 windward districts while the 3 leeward districts had 4 or 5 of the studied coral taxa (Table 2). The relatively high abundance of
TABLE 3  Averages of (a) fish and (b) coral species densities with standard deviation (mean ± SD) and their tests of significance in deep reef edges (>3 m depth) and shallow lagoons (<3 m depth)

| Sample sizes | Fore-reef edges | Shallow lagoons | Kruskal–Wallis test |
|--------------|-----------------|-----------------|---------------------|
|              | 79              | 39              |                     |
| (a) Fish species |                 |                 |                     |
| Mauritian gregory | 0.88 ± 2.69     | 0.40 ± 1.54     | 0.79 NS             |
| Mauritian clownfish | 0.05 ± 2.02     | 0.10 ± 0.66     | 17.12 <.0001        |
| Blacklip damselfish | 0.52 ± 1.81     | 0.13 ± 0.74     | 4.23 .04            |
| Ebony gregory | 0 ± 0           | 0.43 ± 1.25     | 9.46 .002           |
| Rough-skin trunkfish | 0.31 ± 0.64     | 0 ± 0           | 13.86 .0002         |
| Pearly sergeant | 0.17 ± 1.20     | 0 ± 0           | 12.02 NS            |
| Spotted tang | 0.13 ± 0.74     | 0 ± 0           | 2.72 NS             |
| Madagascar anemonefish | 0.07 ± 0.43     | 0 ± 0           | 1.34 NS             |
| Creole damselfish | 0 ± 0           | 0 ± 0           | 0 NS                |
| Mauritian damselfish | 0 ± 0           | 0 ± 0           | 0 NS                |
| Fish average per depth | 0.31 ± 1.35     | 0.10 ± 0.71     | 22.30 <.0001        |
| (b) Coral taxa |                 |                 |                     |
| *Seriatopora hystrix* | 0.20 ± 0.79     | 0.04 ± 0.29     | 2.00 NS             |
| *Pocillopora indiana* | 0.24 ± 0.62     | 0.05 ± 0.36     | 6.72 .01            |
| *Stylopora pistillata* | 0.10 ± 0.64     | 0.21 ± 1.46     | 0.04 NS             |
| *Horastrea indica* | 0.07 ± 0.26     | 0 ± 0           | 3.43 NS             |
| *Acropora branchi* | 0.12 ± 0.48     | 0 ± 0           | 3.43 NS             |
| *Seriatopora caliendrum* | 0.06 ± 0.47     | 0 ± 0           | 0.66 NS             |
| Taxa average per depth | 0.13 ± 0.57     | 0.05 ± 0.62     | 14.72 .0001         |

Note: The population density is the number of individuals observed in 40 min. Species arranged from highest to lowest numbers.

FIGURE 3  Map of Mauritius showing the distribution and densities of (a) Mascarene Island endemic fish and (b) rare and provincial or ecoregional endemics coral species in each district. Marine parks, fishing reserves and voluntary marine conservation areas are identified.
S. hystrix in Grand Port was the only exception to the general overall abundance and numbers of taxa patterns (Figure 3b).

### 3.3 Scaling and distribution of environmental perceptions

Scoring of environmental concerns of the 1,016 completed questionnaires found high scoring for all questions and some differences among NEP statements and districts (Table 4). For example, respondents strongly agreed (i.e., scaling >4) that humans were abusing the environment (question 5), that interfering with nature will have bad consequences (question 15), and that endemics have the right to survive (question 7). Respondents were more skeptical about the possibilities of nature’s ability to compensate for human impacts (question 8), humans having unlimited resources (questions 7 and 9), and being able to overcome resource limits and mistakes (question 6). Thus, they agreed there is an environmental crisis and that there are limits to nature’s and human capacity to overcome these limits. More critical to this study, the belief in the rights of species to exist was ranked second in agreement among all questions.

Differences among districts were not strong and limited to paired comparisons. For example, eight of the 15 questions were not statistically different among districts by the Kruskal–Wallis test. Yet, the paired Dunn’s test found more differences when comparing specific districts and questions. For example, respondents in the windward district of Flacq believed more than other districts that humans have the right to modify the natural environment and the ability of nature to cope with human impacts. Moreover, respondents in the nation’s capital port district of Port Louis, which is the only fully urban district, held the strongest opinions in favor of the rights of endemics to exist.

Evaluating the districts using the PCA analysis indicates that a large amount of variance was explained for both the first (41%) and second axis (31.7%) (Figure 4). The first axis most clearly separated the capital city or port district of Port Louis from the windward and rural districts of Grand Port and Savanne. Port Louis respondents were more concerned about limits to the number of people the Earth can support, the scale of environmental destruction, and the rights for the survival of endemics. But, they also saw the “environmental crises” as overestimated. The more rural Grand Port and Savanne districts believed more strongly in nature’s ability to cope with modernization, the limits nature imposes on humans, and also the existence of an impending environmental catastrophe. The second axis separated Black River and Flacq from the two northern districts of Riviere du Rempart and Pamplemousses. The northern districts, which are heavily reliant on tourism, believed more strongly that human ingenuity and nature’s abundance allows people to rule and develop sustainable resource use. Black River respondents were more concerned about nature’s fragility and upsetting the balance of nature whereas Flacq district respondents scaled the abuse of the environment higher.

### 4 DISCUSSION

#### 4.1 Status of endemics and rare species

Mauritian endemics and rare fish and corals were not abundant and with a few exceptions were not widely distributed around the island. Only 4 out of the 10 studied fishes could be considered to have moderate population numbers, namely the Mauritian gregory, Mauritian anemonefish, Blacklip damselfish, and Ebony gregory. These species were broadly distributed in terms of depth and habitat. The rarer Rough-skin trunkfish, Pearly seargent, Spotted tang and Madagascar anemonefish were more restricted to fore-reef edges. Two species, namely the Creole damselfish, and Mauritian damselfish were not observed and, therefore, likely to be highly threatened with extinction, particularly the more range-restricted Mauritian damselfish. An alternative to the extinction explanation is that we did not sample within their preferred habitats. The Mauritian damselfish is reported to inhabit rocky inshore wave-exposed reefs (Allen, 1991) that might have been missed or undersampled by divers. Yet, these species were not observed by the marine professionals who visited some of the less sampled shallow and windward sites. The somewhat more broadly distributed Creole damselfish has been reported to inhabit lagoons and inshore reefs, which were the main sampling locations. This suggests that a more habitat-specific and stronger sampling design may be needed to determine the conservation status and potential extinction of the more shallow-water habitat specialists, or Mauritian damselfish.

The studied corals were uncommon and suggest the potential for local extirpation. However, unlike the studied fishes, the corals have broader distributions in the WIO province. For example, H. indica has a western Indian Ocean provincial distribution that includes most oceanic islands and the coastline of the African continent. The two species of Seriatopora also have broad distributions that also include the Red Sea but, as seen here, were rare in Mauritian. Provincial endemics appear to have naturally low population numbers, particularly...
### Table 4: New Ecological Paradigm (NEP) statements with mean and standard deviation of responses

| NEP statements/sample size | Grand-port | Pamplemousses | Flacq | Riviere du Rempart | Port Louis | Black River | Savanne | Tests of significance |
|---------------------------|------------|---------------|-------|--------------------|------------|-------------|---------|-----------------------|
| 1. We are approaching the limit of the number of people the Earth can support | 3.38 ± 1.18 | 3.3 ± 1.13 | 3.46 ± 1.1 | 3.44 ± 1.16 | 3.65 ± 0.98 | 3.35 ± 1.21 | 3.16 ± 1.22 | Kruskal-Wallis test: 7.60; NS | Dunn’s test for districts: 3.37 ± 1.17*** |
| 2. Humans have the right to modify the natural environment to suit their needs | 3.23 ± 1.19 | 3.25 ± 1.26 | 3.63 ± 1.17* | 3.3 ± 1.1 | 3.51 ± 1.04 | 3.26 ± 1.26 | 3.19 ± 1.17 | Kruskal-Wallis test: 15.59; 0.02 | Dunn’s test for districts: 3.31 ± 1.19*** |
| 3. When human interfere with nature, it often produces disastrous consequences | 4.08 ± 0.78 | 4 ± 0.83 | 4.12 ± 0.75 | 4.03 ± 0.73 | 4.08 ± 0.68 | 4.06 ± 0.75 | 4.09 ± 0.71 | Kruskal-Wallis test: 15.59; 0.02 | Dunn’s test for districts: 4.07 ± 0.74*** |
| 4. Human ingenuity will ensure that we do not make the earth unlivable | 2.84 ± 1.12 | 2.98 ± 0.8 | 2.83 ± 1.07 | 2.87 ± 0.94 | 2.86 ± 0.86 | 2.65 ± 1.03 | 2.75 ± 1.01 | Kruskal-Wallis test: 9.37; NS | Dunn’s test for districts: 2.79 ± 1.01*** |
| 5. Humans are seriously abusing the environment | 4.38 ± 0.75 | 4.46 ± 0.55 | 4.56 ± 0.57 | 4.38 ± 0.65 | 4.43 ± 0.83 | 4.4 ± 0.74 | 4.41 ± 0.72 | Kruskal-Wallis test: 6.87; NS | Dunn’s test for districts: 4.42 ± 0.7*** |
| 6. The Earth has plenty of natural resources if we just learn how to develop them | 2.12 ± 1.01 | 2.32 ± 1.06 | 1.89 ± 0.75 | 2 ± 0.86 | 1.86 ± 0.87 | 1.89 ± 0.81 | 2.06 ± 0.95 | Kruskal-Wallis test: 11.54; NS | Dunn’s test for districts: 1.99 ± 0.88*** |
| 7. Endemic plants and animals have as much right as humans to exist | 4.24 ± 0.91 | 4.45 ± 0.64 | 4.46 ± 0.64 | 4.3 ± 0.81 | 4.76 ± 0.43* | 4.31 ± 0.8 | 4.18 ± 1.01 | Kruskal-Wallis test: 17.26; 0.0084 | Dunn’s test for districts: 4.32 ± 0.82** |
| 8. The balance of nature is strong enough to cope with the impacts of modern industrial nations | 3.29 ± 1.12* | 3.23 ± 0.84 | 3.2 ± 1.19* | 2.99 ± 1.04 | 2.62 ± 0.72 | 3.1 ± 1.21 | 3.11 ± 1.18 | Kruskal-Wallis test: 17.58; 0.0074 | Dunn’s test for districts: 3.11 ± 1.13*** |
| 9. Despite our special abilities, humans are still subject to the laws of nature | 4.05 ± 0.77 | 3.79 ± 0.98 | 3.89 ± 0.85 | 3.81 ± 0.79 | 3.76 ± 0.8 | 3.96 ± 0.71 | 3.93 ± 0.83 | Kruskal-Wallis test: 11.51; NS | Dunn’s test for districts: 3.91 ± 0.79*** |
| 10. The so-called “ecological crisis” facing humankind has been greatly exaggerated | 3.53 ± 1.19 | 3.47 ± 0.89 | 3.49 ± 1.03 | 3.56 ± 1.01 | 3.78 ± 1 | 3.44 ± 1.1 | 3.59 ± 1.06 | Kruskal-Wallis test: 4.75; NS | Dunn’s test for districts: 3.52 ± 1.07*** |
| 11. The earth is like a spaceship with very limited room and resources | 3.44 ± 1.18 | 3.23 ± 1.05 | 3.51 ± 1.11 | 3.28 ± 1.06 | 3.11 ± 0.91 | 3.53 ± 1.1 | 3.26 ± 1.15 | Kruskal-Wallis test: 18.52; 0.0051 | Dunn’s test for districts: 3.39 ± 1.11*** |
| 12. Humans were meant to rule over the rest of nature | 3.72 ± 1.15** | 3.77 ± 1.01 | 3.11 ± 1.25 | 3.69 ± 0.96** | 3.81 ± 0.79 | 3.32 ± 1.23 | 3.58 ± 1.07 | Kruskal-Wallis test: 34.3; <0.0001 | Dunn’s test for districts: 3.51 ± 1.14*** |

(Continues)
TABLE 4 (Continued)

| NEP statements/sample size | Grand-port | Pamplemousses | Flacq | Riviere du Rempart | Port Louis | Black River | Savanne | Tests of significance |
|---------------------------|------------|---------------|-------|-------------------|------------|-------------|---------|-----------------------|
| 13. The balance of nature is very delicate and easily to upset | 3.92 ± 0.9* | 3.63 ± 0.88 | 3.9 ± 0.75 | 3.7 ± 0.74 | 3.41 ± 0.93 | 3.93 ± 0.81* | 3.65 ± 0.88 | Kruskal-Wallis test: 32.44; <.0001 Dunn's test for districts: 3.8 ± 0.83*** |
| 14. Humans will eventually learn enough about how nature works to control it | 3.24 ± 1.13 | 3.32 ± 0.93 | 2.86 ± 1.12 | 3.15 ± 1.06 | 2.89 ± 0.88 | 3.01 ± 1.18 | 3.18 ± 1.13 | Kruskal-Wallis test: 15.05; 0.02 Dunn's test for districts: 3.09 ± 1.12*** |
| 15. If things continue on their present course, we will soon experience a major catastrophe | 4.53 ± 0.7 | 4.46 ± 0.81 | 4.31 ± 0.73 | 4.38 ± 0.75 | 4.3 ± 0.88 | 4.45 ± 0.72 | 4.37 ± 0.8 | Kruskal-Wallis test: 11.39; NS Dunn's test for districts: 4.41 ± 0.75*** |
| NEP average per district | 3.60 ± 1.19* | 3.57 ± 1.09 | 3.55 ± 1.18 | 3.53 ± 1.11 | 3.52 ± 1.11 | 3.51 ± 1.21 | 3.50 ± 1.18 | Kruskal-Wallis test: 15.5; 0.02 Dunn's test for districts: 4,432.85; <0.0001 |

Note: Values are presented such that larger numbers indicate positive views of the environment. Therefore, for the even-numbered statements, which present questions that scale against the environment, are reverse coded prior to calculating the mean and standard deviation. Individual NEP statements were coded as 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree, with a higher value indicating higher level of agreement with the statement. Kruskal–Wallis and Dunn's tests of significance (Chi-square; p-value) of all and pair-wise comparisons of districts for individual NEP statements across districts are presented. Post hoc analyses for district averages and for individual NEP statements across districts were also conducted. NS denotes no significance and (*) denotes level of significance. Districts arranged from highest to lowest combined NEP values.

*p < 0.05. **p < 0.001. ***p < 0.0001. *Reverse coded to align and be comparable with the pro-environmental direction of the overall.
*H. indica*, in recent evolutionary times (Obura, 2012; Veron, 2000). The reasons for this scarcity are unclear but suggest the importance of understanding the historical environmental and geographic forces creating the provincial isolation and low abundance (DiBattista et al., 2016). Consequently, Mauritius findings alone and in the absence of an historical baseline, will fail to determine the status of provincial endemics in the wider WIO province or Mascarene ecoregion. The two species with the most restricted distributions, *A. branchi* and *P. indiana*, were not common and therefore most at risk of extinction. These taxa are likely to be susceptible to thermal stresses, similar to findings of an endemic pocilloporid in temperate eastern Australia (Kim et al., 2019). Their low abundance in Mauritius suggests they do not have a sanctuary on this island. Given the lack of a baseline it is also unclear if their abundance has changed or always been low.

*S. pistillata* has a very broad distribution extending east to the Coral Triangle. The interest in Mauritius is, however, that it is rare and has a unique coloration and complex morphology that makes it difficult to classify. This single-species name may contain either hidden species or subspecies (Bhagooli et al., 2017; McClanahan et al., 2005). It is possible that many of the species, particularly pocilloporids with brooding life histories, are isolated in Mauritius or the Mascarene islands and have genetically drifted or evolved into unique species that are currently not recognized by morpho-based taxonomy (Veron, 2000). Genetic analysis among other techniques may help to illuminate their taxonomic and evolutionary status (Cooper et al., 2009). The findings here confirm

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**FIGURE 4** Multivariate principal component analysis of environmental perceptions of people pooled and evaluated by the 7 coastal districts. See Table 4 for more explanation of the question numbers N1 to N15 and response values per district.
that these species are rare and that Mauritius may provide limited habitats for their persistence.

Findings here differ from some areas, notably the Coral Triangle, where endemics had variable numbers that were not clearly related to their distributions (Hughes, Bellwood, Connolly, Cornell, & Karlson, 2014). Huang, Goldberg, Chou, and Roy (2018) argued, based on a time-calibrated evolutionary tree, that the Coral Triangle endemics are not a product of recent isolation but rather of range expansion of species that were isolated and evolved elsewhere. While genetic studies are needed for the Mascarene islands, it may be more likely that the endemics arise from isolation and limited connectivity in this region (Maina et al., 2020). Thus, this difference may have played a role in their lower abundance than the studied “endemic species” in the Coral Triangle. Isolation in some Pacific islands has been associated with high population densities (Crane et al., 2018), but this is not the case for Mauritius. Red Sea endemics numbers are variable and have broad distributions throughout the Red Sea without strong sub-regionalism (DiBattista et al., 2016). In total, these findings suggest the considerable lack of consistent demographic patterns among range-restricted species.

Previous studies of oceanography and species distributions and diversity have concluded that acute thermal stresses are a major impact. The strongest impacts occur offshore on the eastern and southern windward sides of the island (Louis et al., 2016; McClanahan et al., 2005; Pous et al., 2014). A number of coral taxa were extirpated from windward reefs between 2004 and 2019 (McClanahan & Muthiga, 2021). The distribution patterns seen here support previous findings that the highest numbers of species are located on the leeward rather than windward reefs. It also suggests that the potential area of potential habitat and sanctuary from disturbances are located in a limited number of locations and habitats and not the whole island.

4.2 Environmental perceptions

Mauritians generally have a strong environmental awareness associated with a number of concerns. These perceptions were generally widespread but there were notable district-level differences that may be associated with the environmental conditions, associated livelihoods and the rural-urban demographic gradients. It must also be acknowledged that across all districts, most respondents were males as they were generally more willing to participate in the survey, hence creating a male-bias in the perception scores. Although some NEP statements can be highly culturally contextualized, a combined NEP score above 3 generally suggest a pro-environmental protection perception compared to the human-use priority worldview. The pro-environment perceptions are common to many mid- to fully-developed countries but probably less common among the poorly-sampled African countries (Ogunbode, 2013; Van Petegem & Blieck, 2006). The island or isolated nature of Mauritius may provoke awareness of limited resources. Moreover, the need to access resources over wider areas, such as the open ocean, neighboring islands, and tourism. Nearshore coral reef fisheries in Mauritius have been heavily exploited and potentially promoted by subsidies to fishers. Subsidizing salaries through hazard pay has created incentives to stay in the fishery, overexploit resources, and a low interest in changing professions (Daw et al., 2012). The stock biomass of fish in Mauritius have been recorded at very low levels in about half of the reefs (i.e., <30 tons/km²). Consequently, the recovery of fisheries could take 4–8 years without fishing to reach sustainable levels (McClanahan, Maina, Graham, & Jones, 2016). Consequently, we suggest these conditions make coastal Mauritians aware of environmental problems and a potential crises in the context of inadequate compensatory policies or enforced restriction with existing regulations.

Perceptions at the district level suggest there were some important nuances in Mauritius that are potentially important for framing conservation and management activities. For example, urban populations in the Port Louis district showed the strongest support for endemics, which may represent an acknowledgement of rights to life that can be common in urbanized populations sharing democratic principles (McClanahan & Rankin, 2016). Northern districts were more likely to support management interventions to improve resource use and sustainability, which may arise from their high reliance on tourism around the many dive locations and the Balaclava Marine Park. Black River inhabitants in the south might be prompted to enact conservation by framing issues around the fragility of nature and the need for people to intervene and nurture threatened species. Perhaps this perception influenced the Black River coastal area proposal to designate it as a “Hope Spot” by Mission Blue (Mission Blue, 2019). Black River does, however, have a gear-restricted fishing reserve with generally low compliance, suggesting some resistance to current management. Nevertheless, where these endemics species were most prevalent or the leeward villages, there may be a latent pro-environmental perception that may provoke efforts to improve conservation. This perception could promote greater concern and support for policy and management actions to protect these species. To date, there is no special legal protection status or management plan for the...
studied species at either the district or national levels of government.

### 4.3 Challenges to management

Many of these species provoke conservation concern because, even after nearly 90 hr of searching by a diverse group of amateur and professional naturalists, most taxa were not commonly encountered. Protected area and fisheries management appeared to play little role in influencing the abundance and distribution of these species. Managing rare and endemic species is a challenge for a variety of reasons. These include their rarity, their lack of direct economic value, poor knowledge of their environment and habitat requirements, and a potential lack of advocates to steward the management of their populations. Here, we developed the information to heighten awareness of the problem but we have less information about most immediate threats, the species needs, and the potential for human advocacy.

Mauritius faces many problems that threaten its reef ecosystems. These include coral mortality and loss of structural complexity mainly due to prolonged period of thermal stress and human disturbances, including degraded watershed from intense agriculture and coastal development, fishing, and coral damage by divers and boats (Bhagooli et al., 2021; Bhagooli & Kaulysing, 2019; Elliott et al., 2018; McClanahan & Muthiga, 2021). For example, ship traffic and oil spill threats increased acutely after this survey when the Japanese ship, MV Wakashio grounded on a coral reef on August 6th, 2020 in the Pointe D’Esny area and leaked 800 t of crude oil. Coastal tourism reached ~1.9 million tourist in 2019 before the Covid-19 shutdown in 2020 (Statistic Mauritius, 2020). Sea-based tourism has increased the diversification of marine related activities with many water sports activities and associated conflicts (Graham, McClanahan, Letourneur, & Galzin, 2007). Thus, the number of hotels, tourist residences and guest houses have proliferated with building permits increasing from 367 building permits in 2000 to 1,162 in 2011 (Digest of Environment, 2018). Finally, there were ~2,000 registered fishers, catching about 800 metric tons of fish yearly, which are principally aimed for the tourist and local market (https://statsmauritius.govmu.org; FAO, 2020). All of these local disturbances occurring along with the ongoing rise in episodic thermal stress and global economic and tourism instability. Yet, there is considerable concern and location-specific values about the environment among stakeholders that can be harnessed to help respond to the environmental challenges.

### 4.4 Conclusions

Despite the past recognition of the high endemism in Mauritius (Allen, 2008; McClanahan & Obura, 1996; Roberts et al., 2002), this is the first of its kind country-scale study of threatened reef species. The scale, intensity, and design of our study does, however, limit confident inferences about status and extinctions. However, we did overcome the limitations of costs by using available and interested partnerships among existing marine recreation, education, and science stakeholder. The cost reduction was also able to increase awareness through education and participation. Species-learning sheets and training courses might be augmented to include more of this information in future efforts and to develop improved sampling designs. For example, future surveys could be improved if more details of the habitats and exposure to threats were included. Additionally, efforts to understand how surveys could be better aligned with, for example, a highly replicated random-stratified by habitat sampling design is a high priority for future participatory programs. Nevertheless, the findings here were useful for getting a broad-scale evaluation of the status and conservation needs of these species and people's environmental concerns. Studied populations of the rare and endemic species of Mauritius are not secure. Continued studies, mapping habitats, threats, resource requirements, and population trends are, therefore, warranted.

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CONFLICT OF INTEREST
The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS
Tim McClanahan: conceptualized, designed the ecological and social surveys, undertook the ecological fieldwork, supervised the analytic methods, and led the writing of the paper. Vikash Munbodhe: conceptualized, designed the citizen science surveys, undertook the ecological field surveys, and contributed to the writing of the paper. Josheena Naggea: conceptualized, designed the social study, supervised and undertook the social surveys, and contributed to the writing of the paper. Nyawira Muthiga: conceptualized, undertook the ecological field surveys, and contributed to the writing of the paper. Ranjeet Bhagooli: conceptualized the study and contributed to the writing of the paper.

DATA AVAILABILITY STATEMENT
Data are available at Mendeley Data—https://data.mendeley.com/datasets/dt42dytvxd/1.

ETHICS STATEMENT
The social survey work was cleared by the Stanford University Institutional Review Board.

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