Decline in coral cover and flattening of the reefs around Mauritius (1998 - 2010)

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Coral reefs are degrading through the impacts of multiple anthropogenic stressors. How are coral reef communities going to change and how to protect them for future generations are important conservation questions. Using coral reef data from Mauritius, we examined changes in cover in 23 benthic groups for a 13-yr period and at 15 sites. Moreover, we determined which land-based stressor out of four (human population, agriculture, tourism, rainfall) correlated the most with the observed changes in coral reef cover. Among the stony corals, *Acropora* corals appeared to be the most impacted, decreasing in cover at many sites. However, the non-*Acropora* encrusting group increased in cover at several sites. The increase in abundance of dead corals and rubble at some sites also supported the observations of stony coral decline during the study period. Additionally, the decline in stony corals appeared to be more important in second half of the study period for all sites suggesting that a global factor rather than a local factor was responsible for this decline. There was little change in cover for the other benthic groups, some of which were quite rare. Human population was significantly correlated with changes in coral reef cover for 11 sites, followed by tourism and agriculture. Rainfall, a proxy for runoff, did not appear to affect coral reef cover. Overall, our results showed that there has been a decline of stony coral especially the ones with complex morphologies, which in turn suggest that coral reefs around Mauritius have experienced a decline in habitat complexity during the study period. Our study also suggests that humans are an important factor contributing to the demise of coral reefs around the island.

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Abstract

Coral reefs are degrading through the impacts of multiple anthropogenic stressors. How are coral reef communities going to change and how to protect them for future generations are important conservation questions. Using coral reef data from Mauritius, we examined changes in cover in 23 benthic groups for a 13-yr period and at 15 sites. Moreover, we determined which land-based stressor out of four (human population, agriculture, tourism, rainfall) correlated the most with the observed changes in coral reef cover. Among the stony corals, *Acropora* corals appeared to be the most impacted, decreasing in cover at many sites. However, the non-*Acropora* encrusting group increased in cover at several sites. The increase in abundance of dead corals and rubble at some sites also supported the observations of stony coral decline during the study period. Additionally, the decline in stony corals appeared to be more important in second half of the study period for all sites suggesting that a global factor rather than a local factor was responsible for this decline. There was little change in cover for the other benthic groups, some of which were quite rare. Human population was significantly correlated with changes in coral reef cover for 11 sites, followed by tourism and agriculture. Rainfall, a proxy for runoff, did not appear to affect coral reef cover. Overall, our results showed that there has been a decline of stony coral especially the ones with complex morphologies, which in turn suggest that coral reefs around Mauritius have experienced a decline in habitat complexity during the study period. Our study also suggests that humans are an important factor contributing to the demise of coral reefs around the island.

Introduction

60 Coral reefs worldwide are declining through the impacts of many different types of natural and

61 anthropogenic stressors (Pandolfi et al., 2003). The planet's climate is changing at a pace faster

62 than ever observed before primarily due to the extensive burning of fossil fuels. As a result, the

63 oceans are warming (IPCC, 2014) and stony corals, the foundation species of coral reefs, have

64 been observed to bleach and die on a large scale (Roberts et al., 2002; Gardner et al., 2003;

65 Pandolfi et al., 2003; Bellwood et al., 2004; Graham et al., 2006; Bruno & Selig, 2007; Heron et

66 al., 2016; Hughes et al., 2017). Severe bleaching events are happening five times more often

67 today than in the 1980s (Hughes et al., 2018).

68 Over 60% of the world's coral reefs have been estimated to be threatened by local stressors

69 arising from anthropogenic activities (Burke et al., 2012). Land clearing for agriculture and

70 coastal urbanization have led to sediments, nutrients, and pollutants being discharged through

71 runoff into these coastal ecosystems (Smith et al., 1981; Fabricius, 2005; Markey et al., 2007;

72 Brodie et al., 2012). Overfishing has also caused significant changes in ecological communities

73 and contributed to the collapses of some coastal ecosystems (Jackson et al., 2001).

74 How are coral reef communities going to change in the face of multiple anthropogenic stressors

75 and what makes some species more resilient than others are critical conservation questions.

76 Inherent biological traits (e.g. morphology, growth rate and reproductive mode) and

77 physiological mechanisms of coral species are thought to play an important role in their

78 capabilities to respond to repeated assaults from multiple stressors (Edmunds & Gates, 2008;

79 Darling et al., 2012). For example, a study on coral community structure reported that coral

80 colonies with branching morphologies bleached and died before those with massive and

81 encrusting morphologies after a bleaching event (Loya et al., 2001). Theoretical work has also

82   shown that at the same flow rate, an organism with a flat morphology will have a higher mass

83   transfer or diffusion rate (of gases and nutrients to and from the organism) than an organism with

84   a branched morphology (Patterson, 1992). This could in turn also lead to faster removal of

85   harmful superoxides and toxic radicals produced during stressful thermal events (Lesser, 1997),

86   providing a competitive advantage to species with a flat morphology.

87   Physical external factors can also play an important role in helping coral reef organisms face

88   multiple stressors. Localized upwelling (Glynn & D'Croz, 1990), water-flow rates and flushing

89   of toxins have been reported to help stony corals weather thermal stresses (Nakamura & Van

90   Woesik, 2001; 2005). Decreased light stress, e.g., in the form of shading or cloud cover or

91   turbidity can also reduce some of the impacts from stressors (Hoegh-Guldberg, 1999; Moothien

92   Pillay, Terashima & Kawasaki, 2002; Jokiel & Brown, 2004; Coelho et al., 2017).

93   Both global and local efforts are needed to conserve coral reefs worldwide as they continue to

94   degrade because of increasing human population and their activities (Mora, 2008; Sandin et al.,

95   2008; Smith et al., 2016; Crane et al., 2017). Long-term coral reef monitoring and studies

96   disentangling the impacts of diverse anthropogenic activities are especially important to inform

97   conservation actions. We investigated the effects of four land-based stressors on the coral reefs

98   around Mauritius. This Indian Ocean island has one of the densest human population on earth,

99   with 618 individuals km^{-2} in 2017 (data.worldbank.org). Moreover, a large area of the island has

100   been converted to agricultural land and the island is a prime tourist destination in the Indian

101   Ocean. The two primary goals of this study were to examine changes in coral reef cover over a

102   13-yr period, and to investigate the relationship between the land-based stressors and changes in

103   benthic communities around Mauritius.

Materials and Methods

Study sites

This study was carried out at the southwestern Indian Ocean island of Mauritius (20° 10' S, 57° 31' E; Fig. 1a). The island has a surface area of 1,869 km^2 and possesses 240 km^2 of reef habitats (Turner & Klaus, 2005). It also lies within the cyclonic belt and is visited by cyclones seasonally, typically from January to March. The land area is also divided into 42 watersheds (or catchment areas; Fig. 1b) (Proag, 1995). A total of 15 sites, 11 back- and four fore-reef sites, were investigated. Back-reef sites (circles) were found all around the island and fore-reefs sites (stars) only on the west coast, which is sheltered from the prevailing southeast trade winds (Fig. 1b). The reefs around Mauritius are broken up by natural breaks that result in a series of distinct lagoons. Back-reef sites were found in the lagoons that are < 3 m deep and 1 – 8 km wide. Additionally, the island has one 10 km long barrier reef on the southeast coast where one of the back reef site was found. This barrier reef is also next to a deep channel (15 – 30 m) that flushes seawater offshore (Fig. 1b) (Turner & Klaus, 2005). The fore-reef sites were found outside the lagoons in 8 – 20 m deep waters.

Some 160 stony corals species have been reported in Mauritius (Moothien Pillay et al., 2002). The back-reefs of Mauritius consist mainly of branching and tabular *Acropora*, massive *Porites*, foliaceous *Montipora* and *Pavona*, and sand consolidated with seagrass. The narrow reef flats are made up mostly of dead coral platform, stony corals and macroalgae, and the outer slopes have a spur and groove system that is colonized by a diverse range of hard and soft coral genera (e.g. *Pocillopora*, *Favia*, *Porites*, *Sarcophyton* and *Lobophyton*). For a more comprehensive description of the coral reefs of Mauritius, see Turner and Klaus (2005).

126   **Datasets**

127   **(a) Benthic communities**

128   Benthic coral reef monitoring data spanning over 13 years (1998 to 2010) were obtained from

129   the Albion Fisheries Research Centre (AFRC), Government of Mauritius. The data were

130   collected from three 20 m long transects at each site; each transect was marked by two metal

131   stakes. The line intercept method (Kaiser, 1983) was used to survey these transects. A measuring

132   tape was laid down along each transect; all benthic groups touching the tape were recorded and

133   the number of centimeters that they covered along the tape was also recorded. The number in

134   centimeters for each benthic group was then converted to percentages such that each transect

135   would be equal to 100%. E.g. if sand was found from 0 cm to 23 cm, then sand would be equal

136   to (23-0)/(20*100)*100=1.15% of the transect. The three transects were considered as three

137   replicates for each site.

138   The data were originally collected twice a year, once in summer (December to May) and once in

139   winter (June to November). However, later in the study period, data were sometimes only

140   collected once a year and not all sites were surveyed each year during the study period (Table S1

141   – study years by site). During this 13-yr period, the data were collected by a small group of staff

142   from the AFRC, which minimized observer error in the data.

143
144   The back-reef sites surveyed were: Albion (ALB), Anse La Raie (ALR), Baie du Tombeau

145   (BDT), Bambous Virieux (BVX), Bel Ombre (BOM), Belle Mare (BME), Île aux Bénitiers

146   (BEN), Poudre d'Or (PDO), Pte aux Sables (PTE), Trou aux Biches (TBI), Trou d'Eau Douce

147   (TDO). The four fore-reefs sites were: Albion (ALB), Île aux Bénitiers (BEN), Pte aux Sables

148   (PTE) and Trou aux Biches (TBI). The back-reefs sites were in waters < 3m deep; the fore-reefs

149   sites ALB, BEN, PTE and TBI were set up respectively at 10m, 10m, 8m and 12 m deep.

150   The benthic cover data were recorded as one of the following 23 groups: *Acropora* branching,

151   *Acropora* digitate, *Acropora* encrusting, *Acropora* submassive, *Acropora* tabulate, non-*Acropora*

152   branching, non-*Acropora* encrusting, non-*Acropora* foliaceous, non-*Acropora* submassive, non-

153   *Acropora* massive, fungiid coral, turf algae, macroalgae, coralline algae, *Millepora* spp.,

154   sponges, soft corals, zoanthids, other live, dead corals, rubble, sand and rock. Dead corals

155   consisted of calcium carbonate coral skeletons that were more or less intact that would

156   eventually become rubble when they finally break down into smaller pieces.

157   **(b) Land-based stressors**

158   Four land-based stressors on the coral reefs, human population, tourism, agriculture, and rainfall

159   were investigated. Spatial data for the selected stressors were gathered for the period of 1998 to

160   2010 so that they would match the time period for which the benthic data were available. Data

161   for the first three stressors were obtained from the governmental organization 'Statistics

162   Mauritius' (statsmauritius.govmu.org). Rainfall data were obtained from the monthly

163   meteorological summaries (Mauritius Meteorological Services) that were made available by the

164   Mauritius Sugar Industry Research Institute (MSIRI) archives department.

165   Data for human population, agriculture and tourism were spatially reorganized using a

166   geographic information system (GIS; QGIS Lyon 2.12) such that each stressor would have one

167   value per watershed per study year (Fig. 1b). The human population data were organized as the

168   total number of people per watershed per year. The agricultural data were organized as total

169   surface area under cultivation per watershed per year. The agricultural data consisted of both

170   land under sugarcane and other food crop cultivation during the study period. For the tourism

171   data, a tourism index was created because the available data were rather coarse; only the number

172   of hotels per watershed per year and total number of tourist nights for the whole island per year

173   were available. This tourism index was created by dividing the number of hotels per watershed

174   by the total number of hotels for the whole island and multiplied by total number of tourist

175   nights. The resulting index gave an approximate number of tourist nights per watershed per year.

176   A more extensive spatial analysis was done on the rainfall data using ArcView GIS. Simulated

177   monthly rainfall totals generated by Staub et al. 2014 were averaged across months and then by

178   watershed for each study year. In their study, monthly rainfall totals (2000-2011) from 85

179   stations, a digital elevation model (DEM) and location-specific landscape characteristics were

180   used to calculate linear relationships between mean rainfall and landscape characteristics on

181   Mauritius. The time and space-varying nature of the modeled relationships were then explored

182   by estimating separate models for each month (Staub, Stevens & Waylen, 2014). Finally,

183   monthly rainfall totals for 1998 to 2011 were generated by removing the variability characteristic

184   to each month from the observed data, interpolating these values across space using ordinary

185   kriging, and adding these back to the spatial mean model for the corresponding month (Staub,

186   Stevens & Waylen, 2014). Since rainfall was a proxy for runoff in this study the rainfall data

187   (mm) per watershed per year was multiplied by their respective watershed areas (m^2) and divided

188   by 1000 to obtain a volume of rainfall per watershed (m^3) per year.

189   **(c) Linking the stressor effects arising within watersheds to study sites**

190   Landscape characteristics including mountains and riverbeds were used to determine which

191   watershed(s) drained into which lagoons. This was done as multiple back-reef sites were found

192   in different lagoons and were thus impacted by different levels of land-based stressors. Study

193   sites and their respective watersheds were color-coded and are displayed in Fig. 1b. When sites

194   from different lagoons shared a common watershed, one of the sites was colored white and the

195   watersheds to which it was linked were shaded (Fig. 1b). The fore-reefs sites were linked to the

196   same watersheds as their complementary back-reef sites. Table S2 in Supplemental Materials

197   provides the long-term mean of each of the four local stressors by site for the period spanning

198   1998 to 2010.

199

200   **Statistical analysis**

201   All statistical tests in this study were done using R (R Core Team, 2015).

202   **(a) Trends in benthic cover for 1998 - 2010**

203   Temporal changes in benthic cover on the back- and fore-reefs were examined. A stacked bar

204   graph was made for 1999 to show how the benthic cover varies by site. The benthic groups were

205   aggregated into eight groups as it was difficult to visualize 23 groups (23 colors). The eight

206   groups were: *Acropora* corals, non-*Acropora* corals, macroalgae, turf algae, coralline algae, dead

207   corals, other living organisms and non-living organisms (included rubbles).

208   A mean percent cover per year for each benthic group was calculated for each season and for

209   each study site. This was done by averaging data from the three transects. These mean values

210   were then used in Spearman's rank correlation tests to determine whether there were any

211   correlations between the benthic group cover and year. Only sites that had at least five or more

212   years of observation were considered for this study. Year 2001 was also not considered as only

213   four back- and two fore-reefs sites were surveyed, and therefore the data for this year were not

214   representative of the whole island.

215 Temporal changes in total stony coral percent cover were also studied. A long-term mean for

216 each site was calculated by averaging the annual percent cover of total live stony coral for the

217 13-year period for each site. This long-term mean for each site was subtracted from their

218 respective annual means and the resulting values were used to create anomaly plots. These plots

219 showed the mean annual deviations in total live stony coral cover for the 1998 to 2010 period.

220 Two sets of anomaly plots were created, one from summer data and one from winter data.

221 **(b) Land-based stressors – relationship with benthic cover trends**

222 Temporal trends in land-based stressors were first examined by plotting total human population,

223 total land area under agriculture, total number of tourists and total rainfall per year for the whole

224 island against time. A Z-score was used on the y-axis to facilitate comparisons between stressors,

225 which had widely different ranges.

226 To investigate the effects of the land-based stressors on the benthic communities, we used a

227 combination of non-Metric Multidimensional Scaling analyses (nMDS) on Bray-Curtis distances

228 (Borcard, Gillet & Legendre, 2011) and the 'envfit' function of the package vegan in R (Oksanen

229 et al., 2015). The mean percent cover per benthic group per year were first calculated using data

230 from both summer and winter; the seasonal data were combined since we only had one set of

231 annual data for the land-based stressors (no seasonal data) to which the benthic data were tested

232 with. The mean percent cover values were then used in nMDS to generate ordination plots for

233 each site. The ordination plots indicate the scale of changes in community structure at each site.

234 Then, using the 'envfit' function, data from the four stressors were fitted onto these ordinations

235 to determine which ones had a significant correlation with the placement of benthic community

236 observations in ordination space. The 'envfit' function considered the effects of each stressor

237 individually.

238   **Results**

239   **1. Changes in benthic cover**

240   **(i) Individual sites**

241   Stony corals were the most abundant group at all sites. The back-reef sites had in general more

242   *Acropora* corals while the fore-reef sites had more of the non-*Acropora* corals (Fig. 2). All sites

243   had rubble and/or rocks (non-living category). The fore-reefs had in general more rocks. Turf

244   algae and macroalgae were present at most sites albeit in varying amounts. Coralline algae were

245   rarely detected. All sites had some dead corals; back-reef sites tended to have more dead corals

246   than the fore-reef sites. Very little of other living organisms were recorded at the study sites.

247   Changes in benthic cover varied a lot among sites (Table 1). The 'X' was used to indicate

248   benthic groups not observed during the survey. The *Acropora* coral groups experienced a

249   decrease in cover over time. Although some non-*Acropora* coral groups also showed a

250   significant decreased, a few groups increased in abundance. In particular, non-*Acropora*

251   encrusting increased in cover at four back-reefs sites. Non-*Acropora* foliaceous, massive and

252   submassive also increased at one site each.

253   Other benthic groups studied showed variable responses (Table 1). The cover of dead corals

254   increased at four sites and decreased at one site. The cover of rubble increased at one site and

255   decreased at three sites. Turf algae cover increased at one and three sites. The cover of

256   macroalgae increased at three sites and decreased at two sites. Coralline algae increased at two

257   sites and soft corals at one site. Sand increased at two sites and decreased at three sites.

258   *Millepora* and sponges respectively decreased at one site and increased at one site. The group

259   'other live' decreased at two sites. No clear seasonal signal was detected except for turf algae

260   and macroalgae, which appeared to be more abundant in summer than in winter.

261 **(ii) Anomaly plots - stony corals**

262 The summer anomaly plots showed that a large number of sites had a mean annual cover above

263 their respective long-term mean (more circles with warm colors) till 2005, after which this trend

264 was reversed; most sites afterwards had a mean annual cover below their respective long-term

265 mean (more circles with cold colors; Fig. 3). Not a single site in 2009 and 2010 had a mean

266 annual cover above their respective long-term mean. A similar trend was observed from the

267 winter anomaly plots, although not as clear as those from the summer data (Fig. 4).

268 **2. Island-wide trends for land-based stressors**

269 When local stressor trends for the whole island were examined, there were clear increases in

270 human population and the tourism index over the study time (Fig. 5). There was a general

271 decline in land area under agriculture from 2001 and 2008, after which more land were

272 cultivated. The big dip in cultivated land area in 1999 coincided with the big dip in annual

273 rainfall, the year with the lowest rainfall during the study period. There was more rain after 1999,

274 but it fluctuated quite a big over time.

275 **3. Land-based stressors - relationship with benthic cover**

276 Significant effects of human population were detected at 11 of the 15 study sites (Table 2).

277 Tourism and agriculture had significant effects respectively at five and four study sites. No

278 significant effects of rainfall were detected at any of the study sites. There were insufficient data

279 to carry out this test at Belle Mare (BME). The 'X' in the table indicates that there were either

280 only a few years or no tourism data in the watersheds linked to these study sites. Therefore, it

281 was not possible to test for the effects of tourism at these sites.

282 **Discussion**

283 Some significant changes in benthic cover occurred around the island of Mauritius during the

284 period of 1998 to 2010. Among the stony corals, *Acropora* coral groups appeared to have been

285 the most impacted, decreasing in abundance at many sites. While the non-*Acropora* coral groups

286 also decreased in abundance at many sites, some groups however experienced an increase over

287 time. The increase in abundance of dead corals and rubble at some sites also supported the

288 observations of stony coral decline during the study period. Additionally, the decline in stony

289 corals appeared to be more important in second half of the study period for all sites. There was

290 little change in cover for the other benthic groups, some of which were quite rare. Our study also

291 suggests that humans are an important factor contributing to the demise of coral reefs around the

292 island.

293 The decline of *Acropora* corals around the island was expected as *Acropora* corals have been

294 reported to be most sensitive to natural and anthropogenic stressors (Marshall & Baird, 2000;

295 Loya et al., 2001; Rachello-Dolmen & Cleary, 2007; Cleary et al., 2008; Côté & Darling, 2010).

296 In contrast, the non-*Acropora* coral groups, particularly ones with encrusting morphologies,

297 appeared to be more successful competitors on the reefs. Their morphology could be a key aspect

298 allowing them to have a higher mass transfer rate for gases and nutrients (Patterson, 1992),

299 which in turn could lead to faster removal of harmful superoxides and toxic radicals produced

300 during stressful events (Lesser, 1997). A study done in Japan also reported the greater survival of

301 corals with massive and encrusting morphologies after a bleaching event (Loya et al., 2001).

302 This increase of encrusting corals coupled with the loss of branching, digitate and tabulate

303 *Acropora* corals also suggest that the coral reefs around Mauritius have flattened and

304 experienced a decline in habitat complexity. Similar flattening of reefs has been observed in the

305 Caribbean (Alvarez-Filip et al., 2009).

306 Interestingly, all study sites appeared to have experienced a more significant decline in stony

307 coral cover during the second half of the study period, i.e. around 2005 and onwards. These

308 observations suggest that a global rather than a local factor was involved. The 50-km Degree

309 Heating Weeks (DHW) data from Coral Reef Watch NOAA website for 2005 showed that the

310 reefs around Mauritius experienced severe heat stress (4°C-weeks and above) for three

311 consecutive summer months (ending 29 March, 30 April and 31 May; Table S3). Therefore,

312 temperature was a most likely stressor contributing to impact severely the corals during 2005,

313 which led to subsequent declines in cover. This temperature stress from 2005 was so severe that

314 the corals had not recovered by 2010.

315 The cover of other benthic groups such as macroalgae and turf algae did not change much at

316 most of the study sites, but they did appear to grow more in summer. These observations suggest

317 that there was in general a good top-down control by herbivores at these study sites. Herbivore

318 biomass is known to play an important role in coral reef dynamics and in mediating reef regime-

319 shifts (Jouffray et al., 2014). As observed on the Great Barrier Reef (De'ath, Lough & Fabricius,

320 2009), herbivorous fish on the reefs of Mauritius also face less significant fishing pressure as

321 artisanal fisheries target mainly piscivorous fishes.

322 Coralline algae is important for coral larval settlement (Harrington et al., 2004) and their cover

323 did not change much at most sites; they only increased at two sites. *Millepora* spp, sponges, soft

324 corals, zooanthids and other live group were either quite rare at most sites and/or did not appear

325 to experience much change during the study. The lumping of species into larger groups could,

326 however, have obscured temporal trends for individual species. For these rare groups, more

327 targeted approaches are needed to study them.

328 Human population was the land-based stressor that appeared to impact the most sites around

329 Mauritius. High human densities have previously been reported to impact negatively coral reef

330 communities (Mora, 2008; Sandin et al., 2008; Smith et al., 2016; Crane et al., 2017). However,

331 as also argued, it is not the number of people, but rather their activities that affect the coral reefs

332 (Sanderson et al., 2002; Mora, 2008). Tourism was the second most common stressor to impact

333 the reefs. Therefore, it appeared that the activities of the growing local population and the

334 tourism industry have contributed the most to affect the coral reefs. The fore-reef sites located on

335 the west coast also appeared to be primarily impacted by human population. These observations

336 suggest that fore-reefs may not be far enough from land to be isolated from the impacts of the

337 local human population. However, we had data for only four fore-reefs sites all located on the

338 west coast of the island, and this small sample size may not be adequate to draw broad

339 conclusions.

340 Agriculture appeared to affect only four study sites, however total land area under agriculture

341 was used as a proxy for its effects and may not be representative of its negative impacts, e.g., the

342 excessive use fertilizers and their detrimental effects are well documented (Markey et al., 2007;

343 Brodie et al., 2012). Similarly, rainfall did not appear to affect the coral reefs; the negative

344 impacts of runoff bringing pollutants to lagoons are also well documented (Fabricius, 2005;

345 Brodie et al., 2012). Therefore, investigating the impacts of specific human activities would

346 provide greater insights on the root causes of reef degradation around Mauritius.

347   The coral reefs as we know them are changing rapidly and will continue to degrade under the

348   pressure of multiple natural and anthropogenic stressors. How coral reefs are going to change

349   and how to protect them so they maintain important ecosystem functions for future generations

350   remain a challenge. Our results showed that *Acropora* corals have been declining and suggest

351   that corals reefs are flattening. Moreover, our results also suggest that human are a contributing

352   factor to coral reef degradation and loss. Therefore, reducing the impacts of human activities

353   remains very important. Other studies focusing on biological traits that convey resilience in the

354   face of multiple stressors are needed better understand how benthic communities are going to

355   change in the future.

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503

504 **Captions for figures and tables**

505 **Figure 1.** Mauritius. (a) The island of Mauritius in the southwestern Indian Ocean. (b) Map of

506 the island showing back- (circles) and fore- (stars) reef sites. Land area is divided into several

507 watersheds (catchment areas). Study sites were connected to adjacent watersheds(s) and are

508   color-coded identically. The back-reef site colored white is connected to adjacent shaded

509   watersheds.

510   **Figure 2.** Benthic cover by site for 1999. The benthic cover data (23 categories) were aggregated

511   into eight groups to facilitate visualization of the data.

512   **Figure 3.** Anomaly plots for stony coral cover– Summer data. a) Long-term means for each site

513   for the period of 1998 – 2010; year 2001 was not included as very few sites were surveyed

514   during that year. (b-m) Data for each year excluding 2001. Warm colors indicate cover was

515   above long-term mean and cold colors indicate that cover was below long-term mean.

516   **Figure 4.** Anomaly plots for stony coral cover – Winter data. a) Long-term means for each site

517   for the period of 1998 – 2010; year 2001 was not included as very few sites were surveyed

518   during that year. (b-m) Data for each year excluding 2001. Warm colors indicate cover was

519   above long-term mean and cold colors indicate that cover was below long-term mean.

520   **Figure 5.** Trends in land-based stressors for 1998 – 2010. The total human population (total

521   number of local people), total number of tourists, total surface area under agriculture and the

522   total rainfall for each year are shown.

523   **Table 1.** Temporal trends in benthic cover at individual sites. Spearman rank correlation results.

524   Only significant results are shown (p <0.05). The 'X' indicates that benthic group was not

525   observed. Only sites that had at least five years of observation were used in this test. See M&M

526   for full site names.

527   **Table 2.** Land-based stressors and their relationship with benthic cover.

528

529   **Supplementary materials**

530   **Table S1.** Number of study years available by site. See M&M for site names.

531

532   **Table S2.** Long-term mean of local stressor by site for 1998-2010. Numbers in brackets indicate

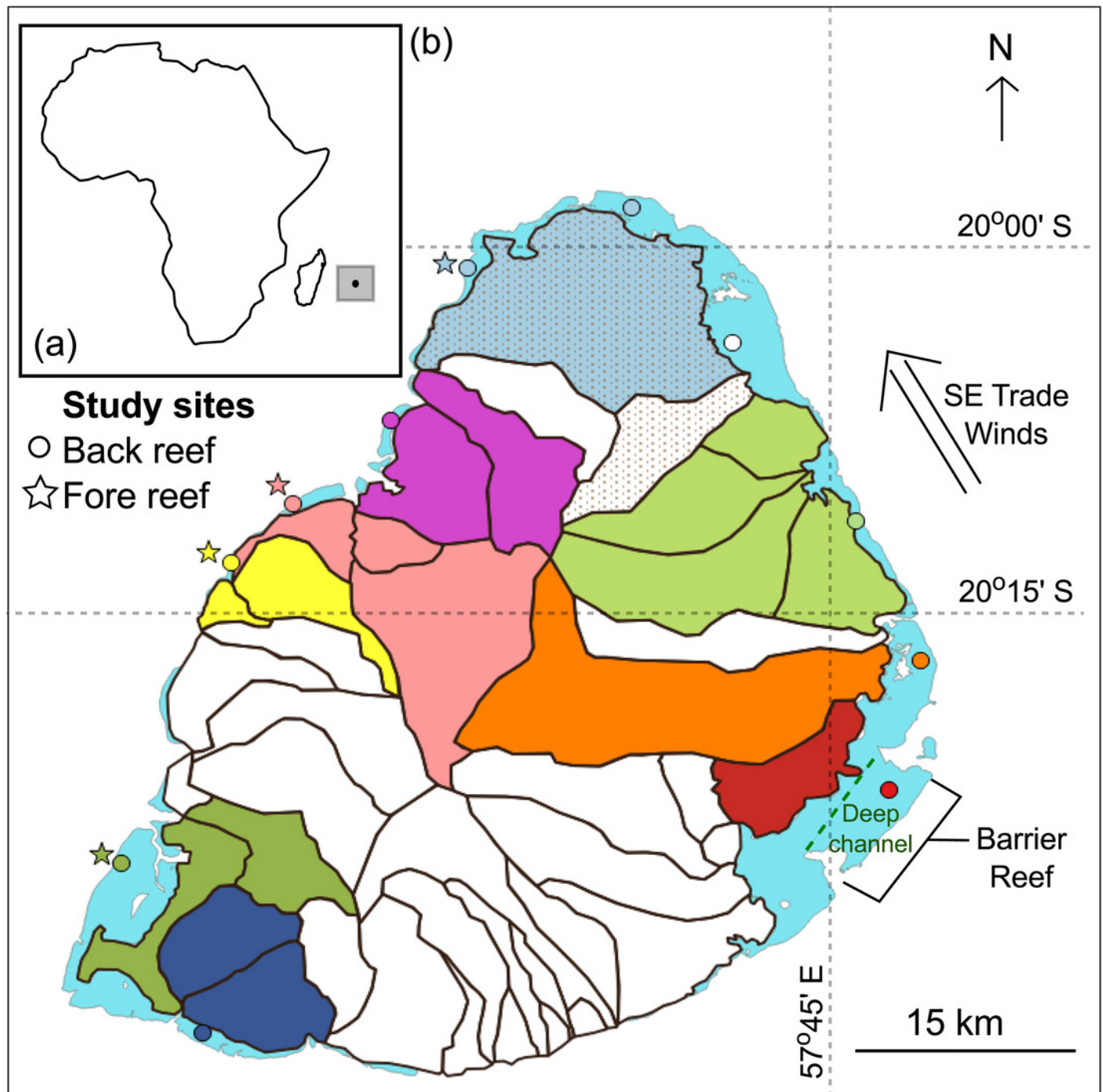
533   rank of each station. Rank goes from least to most abundant. See M&M for full site names.

534   **Table S3.** Degree Heating Weeks data from NOAA. The seawater around Mauritius experienced

535   severe temperature stress during the months of March to April 2005.

Figure 1

Mauritius

(a) The island of Mauritius in the southwestern Indian Ocean. (b) Map of the island showing back- (circles) and fore- (stars) reef sites. Land area is divided into several watersheds (catchment areas). Study sites were connected to adjacent watersheds(s) and are color-coded identically. The back-reef site colored white is connected to adjacent shaded watersheds.

Benthic cover by site for 1999

The benthic cover data (23 categories) were aggregated into eight groups to facilitate visualization of the data.

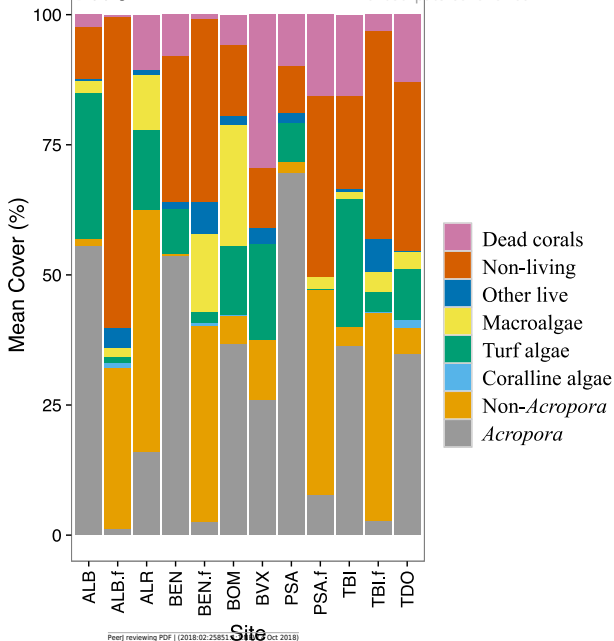



Figure 3

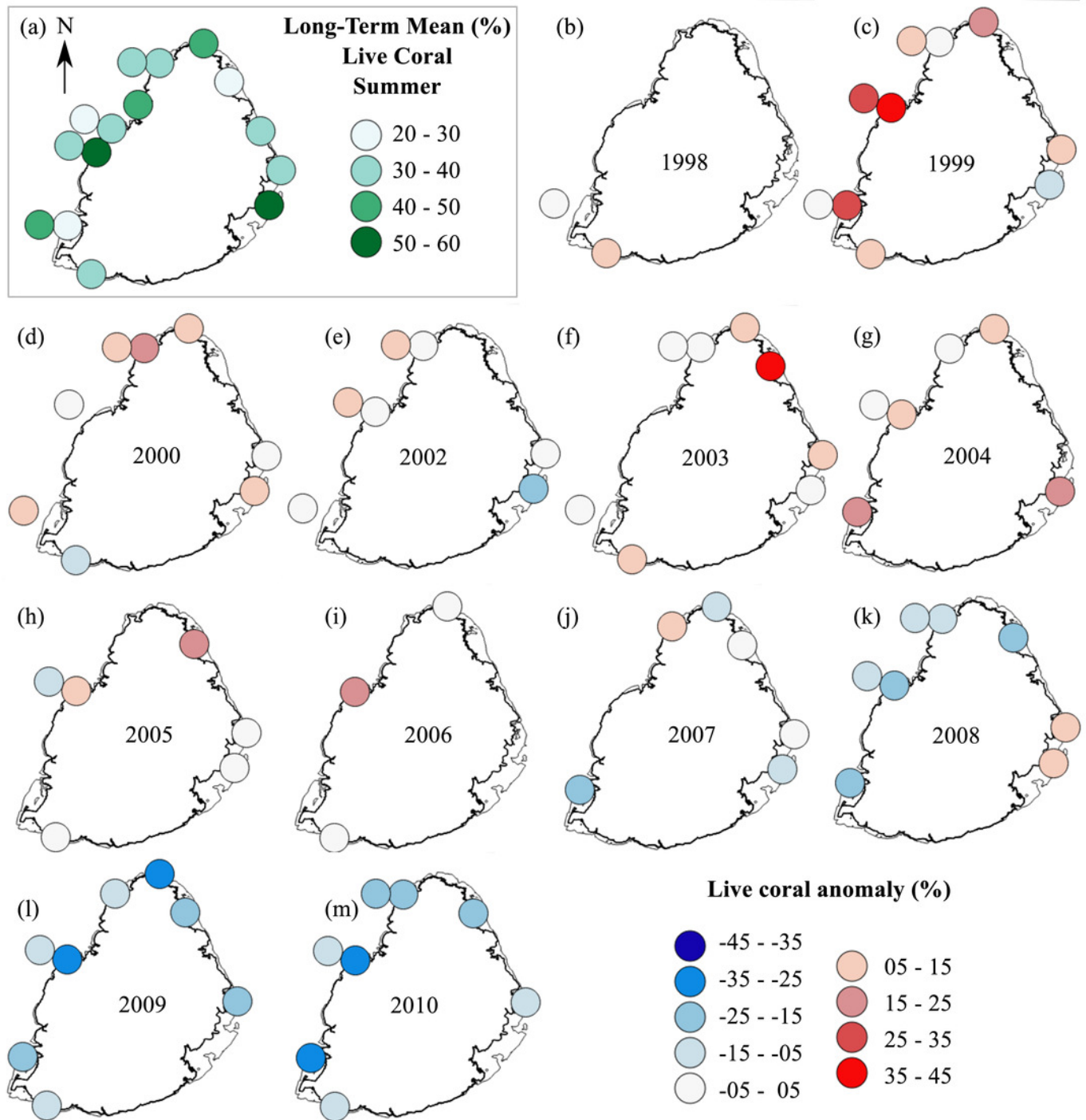
Anomaly plots for stony coral cover– Summer data

(a) Long-term means for each site for the period of 1998 – 2010; year 2001 was not included as very few sites were surveyed during that year. (b-m) Data for each year excluding 2001. Warm colors indicate cover was above long-term mean and cold colors indicate that cover was below long-term mean.

Figure 4

Anomaly plots for stony coral cover – Winter data

a) Long-term means for each site for the period of 1998 – 2010; year 2001 was not included as very few sites were surveyed during that year. (b-m) Data for each year excluding 2001. Warm colors indicate cover was above long-term mean and cold colors indicate that cover was below long-term mean.

(a) N Long-Term Mean (%)
Live Coral
Winter

20 - 30
30 - 40
40 - 50
50 - 60

(b) 1998

(c) 1999

(d) 2000

(e) 2002

(f) 2003

(g) 2004

(h) 2005

(i) 2006

(j) 2007

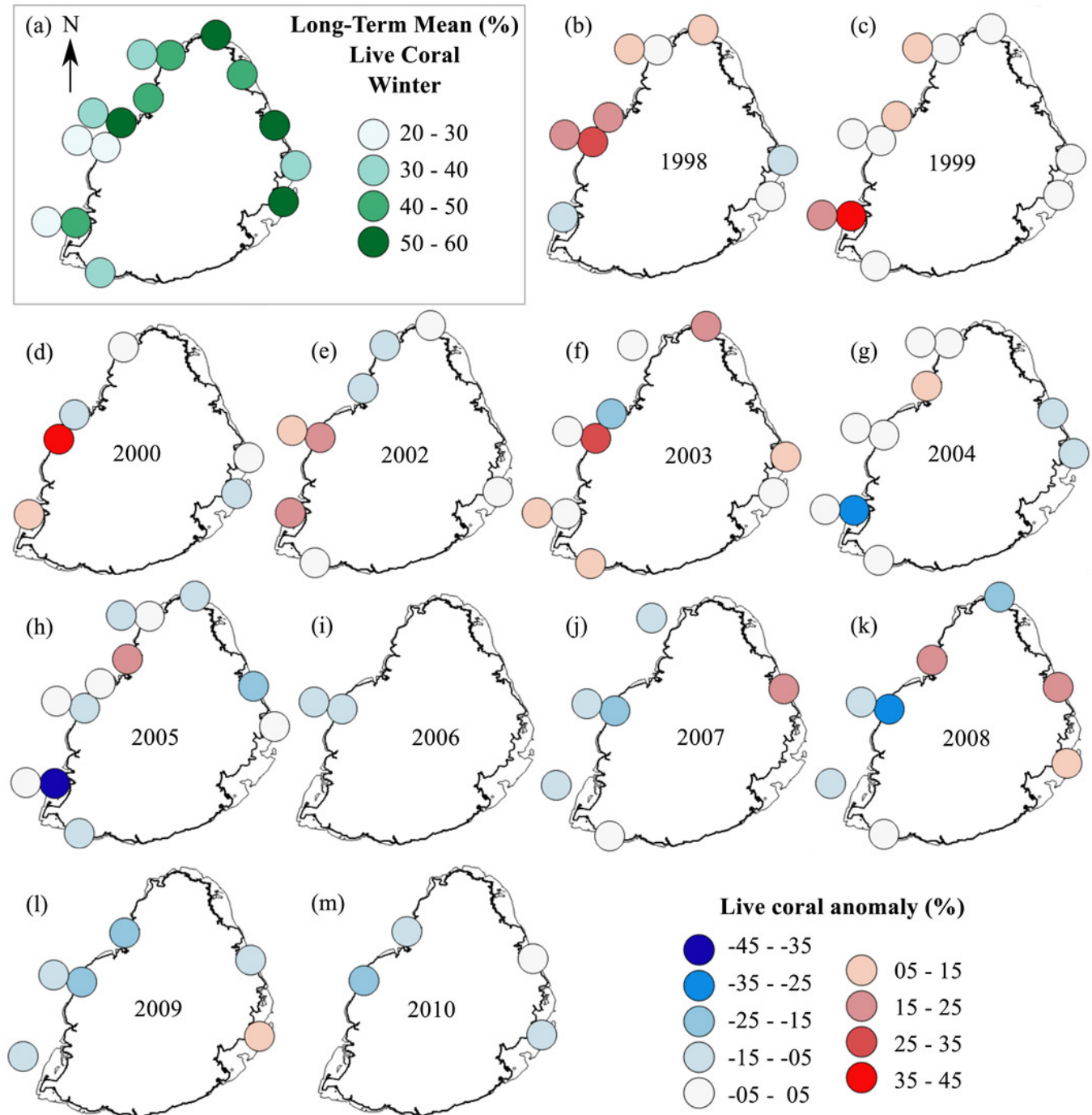
(k) 2008

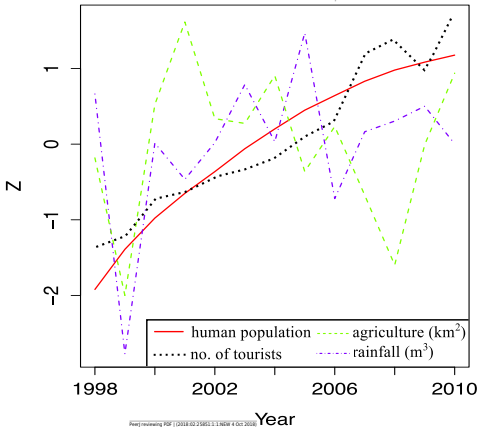
(l) 2009

(m) 2010

Live coral anomaly (%)

-45 - -35
-35 - -25
-25 - -15
-15 - -05
-05 - 05

05 - 15
15 - 25
25 - 35
35 - 45

Trends in land-based stressors for 1998 – 2010

The total human population (total number of local people), total number of tourists, total surface area under agriculture and the total rainfall for each year are shown.

Temporal trends in benthic cover at individual sites

Spearman rank correlation results. Only significant results are shown (p <0.05). The 'X' indicates that benthic group was not observed. Only sites that had at least five years of observation were used in this test. See M&M for full site names.

1 **Table 1.** Temporal trends in benthic cover at individual sites. Spearman rank correlation results. Only significant results are shown (p
2 <0.05). The 'X' indicates that benthic group was not observed. Only sites that had at least five years of observation were used in this
3 test. See M&M for full site names.

Reef (Back or Fore)	Stations	Season (S or W)	n	Acropora branching (ab)	Acropora digitate (ad)	Acropora encrusting (ae)	Acropora submassive (as)	Acropora tabulate (at)	non-Acropora branching (nb)	non-Acropora encrusting (ne)	non-Acropora foliaceous (nf)	non-Acropora massive (nm)	non-Acropora mushroom (nu)	non-Acropora submassive (ns)
B	ALB	W	12	-0.87	X	X	X				-0.58			-0.80
B	ALR	S	7		X		X	X			-0.96			
B	ALR	W	6		X		X	X						
B	BDT	W	6		X	X	X		X	+0.87				
B	BEN	S	8		-0.76	X	X	-0.91			X			
B	BEN	W	7			X	X			-0.80	X			
B	BME	W	6		X	X	X				X	X	X	X
B	BOM	S	8	-0.71	X	X	X						X	
B	BOM	W	7		X	X	X						X	
B	BVX	S	8				X			+0.87	+0.70			
B	BVX	W	8	-0.88			X	-0.73	-0.85		+0.95			
B	PDO	S	6	X	X	X	X		X		-0.93	-0.84		-0.82
B	PSA	S	8	-0.78	X	X		X		X	X			
B	PSA	W	5		X	X		X		X	X			
B	TBI	S	9				X	-0.78	X	+0.78				
B	TBI	W	5				X	X	X					-0.86
B	TDO	S	9				X	X	-0.73	-0.73	+0.83		+0.67	+0.82
B	TDO	W	6				X	X						
F	ALB	W	10					X			-0.76		X	
F	BEN	S	5					X					X	
F	BEN	W	7		-0.97			X		-0.80		-0.82	X	
F	PSA	S	8				-0.76	X						-0.80
F	TBI	S	6	-0.84			X			-0.84			X	-0.86
F	TBI	W	6				X						X	

7   Table 1 continued

Reef (Back or Fore)	Stations	Season (S or W)	n	Turf algae (ta)	Macroalgae (ma)	Coralline algae (ca)	Millepora spp. (mi)	Sponges (sp)	Soft corals (sc)	Zoanthids (zo)	Dead corals (de)	Rubble (ru)	Sand (sa)	Rock (ro)	Other (ot)
B	ALB	W	12	-0.81			X			X		+0.83			
B	ALR	S	7	+0.79						X	+0.85			X	
B	ALR	W	6							X				X	
B	BDT	W	6				X		X			-0.94		X	X
B	BEN	S	8				X			X	+0.83				X
B	BEN	W	7	-0.93		+0.75	X		X	X	+0.82		+0.86		-0.80
B	BME	W	6		+0.94	X	X	X	X	X		-0.83			X
B	BOM	S	8	X			X	X	X				-0.79	X	
B	BOM	W	7				X	X	X					X	
B	BVX	S	8					X	X					X	
B	BVX	W	8					X	X			+0.71		X	
B	PDO	S	6		+0.82		X		X	X				X	X
B	PSA	S	8		+0.91		X			X	-0.90	+0.95			
B	PSA	W	5				X			X		+0.90	-0.90		
B	TBI	S	9			X		X	X	X	+0.78		-0.68		X
B	TBI	W	5	-0.94	-0.93	X		X	X	X					X
B	TDO	S	9				X					-0.82			
B	TDO	W	6				X					-0.93			
F	ALB	W	10		-0.78		-0.70		+0.84						
F	BEN	S	5				X	X	X					X	
F	BEN	W	7				X	X	X					X	
F	PSA	S	8					X			X				
F	TBI	S	6				X				X				
F	TBI	W	6			+0.97	X	-0.83			X		+0.81		-0.82

Land-based stressors and their relationship with benthic cover.

nMDS results.

1   **Table 2.** Land-based stressors and their relationship with benthic cover.

Station	N	Reef	2-D Stress	Population	Tourism	Agriculture	Rainfall
ALB	12	Back	0.03	*	X	*	
ALR	11	Back	0.09	*	*		
BDT	8	Back	0.06				
BEN	11	Back	0.06	*	*	*	
BME	7	Back	Insufficient data				
BOM	12	Back	0.20		X		
BVX	11	Back	0.09	*	X		
PDO	8	Back	0.04	*	*	*	
PSA	11	Back	0.07	*		*	
TBI	11	Back	0.11	*	*		
TDO	11	Back	0.10	*	X		
ALB	11	Fore	0.09	*	X		
BEN	10	Fore	0.11				
PSA	10	Fore	0.10	*			
TBI	10	Fore	0.09	*	*		
TOTAL				11	5	4	0