A new threat to local marine biodiversity: filamentous mats proliferating at mesophotic depths off Rapa Nui

Javier Sellanes [Corresp., 1, 2] , **Matthias Gorny** [3] , **Germán Zapata-Hernández** [1, 2, 4] , **Gonzalo Alvarez** [5, 6] , **Praxedes Muñoz** [1] , **Fadia Tala** [1, 6, 7]

[1] Departamento de Biología Marina, Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Coquimbo, Chile

[2] Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Universidad Católica del Norte, Coquimbo, Coquimbo, Chile

[3] Oceana, Santiago, Chile

[4] Programa de Doctorado en Biología y Ecología Aplicada (BEA), Universidad Católica del Norte, Coquimbo, Coquimbo, Chile

[5] Departamento de Acuicultura, Universidad Católica del Norte, Coquimbo, Coquimbo, Chile

[6] Centro de Investigación y Desarrollo Tecnológico en Algas y otros Recursos Biológicos (CIDTA), Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Coquimbo, Chile

[7] Instituto Milenio en Socio-Ecología Costera (SECOS), Santiago, Chile

Corresponding Author: Javier Sellanes
Email address: sellanes@ucn.cl

Mesophotic and deeper habitats (~40 to 350 m in depth) around Rapa Nui (Easter Island) were investigated using a remotely operated vehicle. We observed extensive fields of filamentous cyanobacteria-like mats covering sandy substrates and mostly dead mesophotic *Leptoseris* spp. reefs. These mats covered up to 100% of the seafloor off Hanga Roa, the main village on the island, located on its western side. The highest mortality of corals was observed at depths between 70 and 95 m in this area. Healthy *Leptoseris* reefs were documented off the northern and southeastern sides of the island, which are also the least populated. A preliminary morphologic analysis of samples of the mats indicated that the assemblage is composed of at least four filamentous taxa, including two cyanobacteria (cf. *Lyngbya* sp. and *Pseudoanabaena* sp.), a brown alga (*Ectocarpus* sp.), and a green alga (*Cladophora* sp.). An ongoing eutrophication process is suggested as a potential driver of the proliferation of these filamentous mats off Hanga Roa village

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4 Javier Sellanes[1,2*], Matthias Gorny[3], Germán Zapata-Hernández[1,2,4], Gonzalo Álvarez[5,6], Práxedes

5 Muñoz[1] & Fadia Tala[1,6,7]

6

7 [1]Departamento de Biología Marina, Facultad de Ciencias del Mar, Universidad Católica del Norte,

8 Coquimbo, Chile.

9 [2]Millennium Nucleus for Ecology and Sustainable Management of Oceanic Islands (ESMOI),

10 Universidad Católica del Norte, Coquimbo, Chile.

11 [3]Oceana Chile.

12 [4]Programa de Doctorado en Biología y Ecología Aplicada (BEA), Universidad Católica del Norte,

13 Coquimbo, Chile.

14 [5]Departamento de Acuicultura, Facultad de Ciencias del Mar, Universidad Católica del Norte,

15 Coquimbo, Chile.

16 [6]Centro de Investigación y Desarrollo Tecnológico en Algas y otros Recursos Biológicos

17 (CIDTA), Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Chile.

18 [7]Instituto Milenio en Socio-Ecología Costera (SECOS), Santiago, Chile

19

20 *Corresponding author:

21 Javier Sellanes[1,2]

22 Email address: sellanes@ucn.cl

Abstract

Mesophotic and deeper habitats (~40 to 350 m in depth) around Rapa Nui (Easter Island) were investigated using a remotely operated vehicle. We observed extensive fields of filamentous cyanobacteria-like mats covering sandy substrates and mostly dead mesophotic *Leptoseris* spp. reefs. These mats covered up to 100% of the seafloor off Hanga Roa, the main village on the island, located on its western side. The highest mortality of corals was observed at depths between 70 and 95 m in this area. Healthy *Leptoseris* reefs were documented off the northern and southeastern sides of the island, which are also the least populated. A preliminary morphologic analysis of samples of the mats indicated that the assemblage is composed of at least four filamentous taxa, including two cyanobacteria (cf. *Lyngbya* sp. and *Pseudoanabaena* sp.), a brown alga (*Ectocarpus* sp.), and a green alga (*Cladophora* sp.). An ongoing eutrophication process is suggested as a potential driver of the proliferation of these filamentous mats off Hanga Roa village.

Introduction

Mesophotic coral ecosystems are deep reef communities that typically occur at a depth range of 30 or 40 to over 150 m (Baker et al., 2016). They are formed mainly by coral taxa adapted to living in low-light conditions and often also include other structure-forming taxa, such as sponge and macroalgae species (Baker et al., 2016; Slattery & Lesser, 2021). These ecosystems are now recognized as ecologically distinct and independent from their shallower counterparts and contain a substantial diversity of unique biota that is still unexplored in most parts of the world (Rocha et al., 2018). The lack of knowledge about these deep coral ecosystems is a consequence of the difficulty of accessing the depths at which they occur, as technical diving (e.g., rebreather diving using trimix) or sophisticated submarine equipment (e.g., remotely operated vehicles, autonomous

46 drop-cams, or manned submersibles) are required to carry out research. Mesophotic coral

47 ecosystems are vulnerable to a series of anthropogenic stressors, such as fishing, thermal stress,

48 diseases, pollution, invasive species, the marine aquarium trade, oil and gas exploration, cables,

49 and pipelines (Andradi-Brown et al., 2016).

50 Rapa Nui (Easter Island; 27° 07′ S, 109° 22′ W), which formed ~0.8 Mya, is a remote island located

51 at the westernmost end of the large chain of seamounts comprising the Salas y Gómez ridge,

52 relatively close to the East Pacific Rise (Rodrigo, Díaz & González-Fernández, 2014). Located in

53 the easternmost apex of the Polynesian triangle, it is recognized for the high overall endemism

54 levels of its coastal marine fishes (~22%; Randal & Cea, 2010) and invertebrate taxa (4% to 34%;

55 see Fernández et al., 2014). However, this unique marine biodiversity is severely threatened by

56 several anthropogenic impacts, including overfishing (Zylich et al., 2014), plastic pollution

57 (Hidalgo-Ruz et al., 2021), exacerbated tourism (Figueroa & Rotarou, 2016), coastal erosion and

58 terrestrial runoff (Mieth & Bork, 2005), and potential pollution from the percolation of domestic

59 sewage and landfill contaminants into aquifers (Rosa, 2013).

60 Recently (2015–2018), through the use of a remotely operated vehicle (ROV), we have been able

61 to access unexplored marine habitats (from ~40 to 350 m deep) around the island, as well as at

62 nearby seamounts, allowing for a first assessment of the biodiversity of mesophotic ecosystems

63 and deeper sites (Easton et al., 2019), generation of new records of fauna, including fishes (e.g.,

64 Easton et al., 2017) and echinoderms (Mecho et al., 2019), and reports of vast fields of the solitary

65 mesophotic mushroom coral *Cycloseris vaughani* (Hoeksema, Sellanes & Easton, 2019). In these

66 surveys, a chance discovery was the presence of dense and extensive fields of filamentous mats,

67 covering the seafloor and nearby reefs at mesophotic depths at several locations around the island.

68 It is known that cyanobacteria are a common constituent of coral reef ecosystems (Stal, 2000) and

69 play an important role in nitrogen fixation and primary production (Charpy et al., 2012). However,

70 under certain conditions, they can undergo massive proliferation, affecting the health of the

71 ecosystem (Bakker et al., 2017; Ford et al., 2017). These events have been associated with variation

72 in irradiance, nutrient supply, and other natural and anthropogenic disturbances (Ford et al., 2018).

73 These proliferation events seem to be increasing at a global scale because of alterations in local

74 biogeochemical cycles related to climate change (Paul, 2008; Paerl & Paul, 2012). These

75 filamentous mats could develop into such dense blooms that they could even wash ashore,

76 producing a mass accumulation, as reported by Nagle and Paul (1999) for Guam. At this location,

77 benthic marine cyanobacterial blooms often occur in the presence of diverse assemblages of

78 herbivorous fishes and urchins, but the underlying factors causing these proliferations, as well as

79 the interaction mechanisms between grazers and these mats (since cyanobacteria are known to

80 produce feeding-deterrent compounds), are still poorly understood (Cissell, Manning & McCoy,

81 2019; Ford et al., 2021). In addition, cyanobacteria have been directly linked with ciguatera fish

82 poisoning outbreaks (Laurent et al., 2008), and mats can create suitable habitats for other toxic

83 microalgae, including toxin-producing dinoflagellates, thus generating co-occurring blooms (Paerl

84 & Otten, 2013). Although several microalgae species are not toxic, their growth could produce

85 low oxygen conditions as a consequence of organic matter accumulation and associated

86 degradation processes in the bottom water, thus affecting the benthic communities (Albert et al.,

87 2012). It is also possible that the rise of fixed nitrogen may modify its budget in the system,

88 promoting the growth of macroalgae, further increasing the organic matter content within the

89 sediments, and decreasing porewater oxygen content (Brocke et al., 2015; 2018). In some

90 environments, mats form associations with sulfate-reducing bacteria, producing sulfide, which is

91 toxic for corals and establishes black band disease (Myers & Richardson, 2009; Charpy et al.,

92 2012).

93 It has also been reported that in littoral reefs, green algae (chlorophytes) are common indicators of

94 eutrophication (Barile, 2004). Most of the species in this group proliferate due to increased nutrient

95 inputs, tolerate a wide range of environmental conditions, aggressively compete against sensitive

96 corals, and have sub-lethal effects on several of the biological functions of corals (Koop et al.,

97 2001; Fabricius, 2005; Birrel et al., 2008).

98 In this context, the aims of the present study were: (1) to provide a first approach to the spatial

99 coverage of filamentous mats in the benthic ecosystem around Rapa Nui, (2) to evaluate the extent

100 of the mesophotic coral reefs potentially impacted by these mats, and (3) to provide a preliminary

101 description of the taxonomic composition of these mats.

102

Materials and methods

104 Rapa Nui is a triangular-shaped island, delimited by the volcanoes Rano Kau in the southwest,

105 Terevaka in the north, and Poike in the east, with Hanga Roa, the main village, located on the

106 western side (Fig. 1). Aiming to have a representative spatial and bathymetric (~40 to 350 m deep)

107 characterization of the mesophotic habitats on the three sides of the island, a remotely operated

108 vehicle (ROV), controlled from local fishing boats, was deployed in 56 mostly independent sites

109 around the island. There were 18 deployments each in January 2018 and 2019, and 20 during

110 November and December 2019 (Fig. 1). The ROV, model Commander MKII (Mariscope

111 Meerestechnik, Kiel, Germany), was equipped with two laser pointers, 10 cm apart, and a front-

112 pointing HD video camera (Panasonic SD 909), angled at 45° and recording at 30 fps with a

113   resolution of 1920 × 1080 pixels. The videos were analyzed at half their normal speed using GOM

114   Player 2.3.19 (GOM & Company; https://www.gomlab.com/).

115   As mentioned in the Introduction, some of the results of these and previous ROV surveys have

116   been presented elsewhere (Easton et al., 2017; Easton et al., 2019; Hoeksema, Sellanes & Easton,

117   2019; Mecho et al., 2019, for selected biotic components). For the present study, however, the

118   focus was to evaluate the spatial coverage of filamentous mats in the benthic ecosystem, and the

119   extent of mesophotic reefs potentially impacted by these mats, as well as their overall health

120   conditions. The presence and coverage of filamentous mats were assessed semi-quantitatively by

121   observing the seafloor in a stepwise manner as the ROV advanced over the ground along transects.

122   Bottom-time varied between 10 and 42 min (mean: 25 min) per transect. In general, a portion of

123   10 to 20 min of video, considering mainly those segments in which the ROV was displaced at a

124   steady velocity and a suitable distance from the bottom, was selected and analyzed per site. For

125   each transect, we analyzed an area of at least 10 m^2, corresponding to ~15 non-overlapping frames.

126   We exclusively analyzed those frames when the ROV was approximately 25 cm above the ground

127   or in front of the reefs. As calibrated with the ROV on land, at these distances the images covered

128   an area of ~0.65 m^2 (width ~117 cm × height ~65 cm).

129   According to the extent to which the bottom or the coral was covered by filamentous mats, the

130   transects were cataloged into four groups: (1) without patches of filamentous mats, (2) low

131   coverage (less than 50% coverage in at least five non-overlapping frames of the video of a

132   transect), (3) high coverage (50% to 75% coverage in at least five frames of the video of a transect),

133   and (4) very high coverage (100% coverage). Statistical comparisons of the mean depth between

134   the four categories of filamentous mat coverage were evaluated using the Kruskal-Wallis test. *Post*

135   *hoc* analyses were performed using pairwise comparisons with the Wilcoxon rank sum test and the

136 *p*-value was adjusted using the Holm method (Holm, 1979). Before comparisons, normality and

137 homogeneity of variance were tested using the Shapiro-Wilk and Levene tests, respectively.

138 Statistical analyses were performed using RStudio (R Studio Team, 2020), specifically the "car"

139 package (Fox and Weisberg, 2019) and the "ggplot2" package for boxplots (Wickham, 2016).

140 We used the same ROV survey approximation to assess the extent of live coral coverage as a proxy

141 for coral health status. Three categories were considered: (1) a healthy reef with > 75% of the

142 corals alive, (2) some damage with 25% to 75% of the corals alive, and (3) mostly damaged with

143 < 25% of the corals alive (mainly dead corals or fragments). Dead corals were easily identified by

144 their generally greenish or darker colors. Some were also covered by filaments.

145 To characterize the taxonomic composition of the filamentous mat assemblage, in May 2019, a

146 small benthic trawl with a horizontal aperture of 30 cm was deployed at a site off Hanga Roa,

147 where patches with 100% coverage were frequent. Mat samples were fixed using a 4% aqueous

148 solution of formaldehyde (ACS Reagent; Sigma-Aldrich, St. Louis, MO, USA). For morphological

149 characterization, filaments were observed using an Olympus IX71 inverted microscope equipped

150 with phase contrast and epifluorescence (Olympus Co., Tokyo, Japan). Micrographs were taken

151 using a camera ProgRes C3 (JENOPTIK AG, Jena, Germany), and measurements of cells (length

152 and width) were carried out using ProgRes® CapturePro (JENOPTIK AG) analytical software.

153 Monographic publications, floristic studies, and systematic articles were used for taxonomic

154 identification of the macroalgae composing the mats, at least to the genus level (Santelices, 1989;

155 Loiseaux-de Goër & Noailles, 2008; Cormaci, Furnari & Alongi, 2014; Ramirez et al., 2018).

156 Guides and systematic articles were used to identify the cyanobacteria inhabiting the mat samples

157 (Komarek & Anagnostidis, 2007; Yu et al., 2015; Brocke et al., 2018; Zubia et al., 2019). The

158 identification of taxa was performed at the genus or species complex level.

159   Sample collection was performed with permission Res. Ext N°41/2016 and N°3314/2017 from

160   SUBPESCA (National Fishing Authority of Chile) granted to the Universidad Católica del Norte.

161   This project was also presented to the local *Consejo del Mar de Rapa Nui* (Council of the Sea of

162   Rapa Nui), which permitted the capture of underwater footage and sampling around the island.

163

164   **Results**

165   The ROV transects around the island covered a depth range of 43 to 347 m. This allowed us to

166   visualize the spatial and bathymetric distribution of sites with different levels of filamentous mat

167   coverage (Figs. 1, 2), and the distribution of mesophotic reefs and their health status around the

168   island (Fig. 3). Mesophotic corals were represented by reef-forming *Porites lobata* and

169   *Pocillopora* spp. at shallower depths (< 60 m), *Leptoseris* spp., and *C. vaughani* at depths between

170   70 and 117 m, and sea-whips (*Stichopathes* spp.) between 127 and 327 m (Fig. 2). Other

171   scleractinians were occasionally sighted deeper than 120 m (e.g., cup corals), but they were too

172   small to identify using ROV images.

173

174   **Spatial distribution of filamentous mats and corals**

175   Filamentous mats were absent (category: without) from 34 of the studied sites around Rapa Nui,

176   and low to very high coverage was observed at the remaining 22 sites, commonly on the western

177   side of the island (Fig. 1A) and in water shallower than ~130 m (Fig. 1B). Statistical comparisons

178   confirmed the significant differences between the depths of the mat-coverage categories (Kruskal-

179   Wallis, $Chi^2 = 12.9$, df = 3, $p = 0.005$), in particular between the categories without and very high

180   (Wilcoxon test, $p = 0.023$; Fig. 1B). Other comparisons between categories were not significant

181   (Wilcoxon test, $p > 0.05$). Indeed, high coverage was observed in the northwest corner (close to

182   Hanga O'teo) at a depth of 123 m, and high and very high coverages were observed mainly off

183   Hanga Roa (Fig. 1B) from 70 to 95 m deep.

184   Corals were observed in 50% of the 56 transects (Fig. 3A), and *Leptoseris* was present in 11 of

185   them. Off Hanga Roa, the location where filamentous mats were most frequent, they were observed

186   covering the sediments (Fig. 2A, B), fringing fields of the zooxanthellate mushroom coral *C.*

187   *vaughani* (Fig. 2C, Fig. 3A; see also Hoeksema, Sellanes & Easton, 2019), and close by dead

188   *Leptoseris* reefs (~80 m deep), which were also overgrown by filamentous mats (Fig. 2D). Healthy

189   *Leptoseris* reefs were documented mainly off the northern and southeastern parts of the island

190   (e.g., near Anakena, La Perouse, and Vinapú) at depths of 68 to 82 m (Fig. 3B). Of the six locations

191   with the healthiest *Leptoseris* reefs, four of them had no filamentous mats, or a sporadic presence

192   of them, whereas at the three sites where the reefs were completely dead, filamentous mat coverage

193   was high or very high (see also supplementary material).

194

195   **Taxonomic characterization of the filamentous mat assemblage**

196   Morphological analyses of samples of mats collected off Hanga Roa indicated that mats are an

197   assemblage of at least four taxa: one Chlorophyta (*Cladophora* sp.), one Ochrophyta (*Ectocarpu*s

198   sp.), and two Cyanobacteria (*Lyngbya* s.l. ([sensu lato] and *Pseudoanabaena* sp.) (Fig. 4) as

199   follows:

200   *Cladophora* sp. (Fig. 4A, B): thallus of green to light green branched uniseriate filaments with 2–3

201   cm in total length. Basal part of the filaments fixed to the substrate by a primary rhizoid.

202   Presence of unilateral branches inserted laterally or obliquely on the filament. Principal axis

203   constituted by cylindrical cells measuring of 998.9 ± 69.2 µm in length and 223.3 ± 9.5 µm in

204 diameter. Apical cells cylindrical, round ended with a diameter of 250.0 ± 7.6 µm and length of

205 701.8 ± 76.0 µm. Zoosporangia were not observed.

206 *Ectocarpus* sp. (Fig. 4C, D): thallus of light brown to olive sparingly branched filament 0.1–0.5 cm

207 in total length. Cells conform to uniseriate filaments ending in a rounded apical cell. Cells barrel-

208 shaped, 50.0 ± 7.3 µm in length, and 14.1 ± 3.4 µm in diameter. Plurilocular sporangia were

209 present, elongated with cylindroconical form, 80–130 µm in length and 20–30 µm in diameter.

210 *Lyngbya* s.l. (Fig. 4E, F): thallus caespitose, brownish-red, filaments slightly curved, sheet

211 colorless, lamellated with apices not attenuated at the end. Trichome not constricted at the cross-

212 wall, cylindrical cells very short 3.5 ± 0.3 µm in length and 7.1 ± 0.1 µm in diameter, sheath 1.6 ±

213 0.3 µm, end cells rotund, calyptra absent. *Pseudoanabaena* sp. (Fig. 4G, H): trichomes solitary or

214 crowded in clusters, straight or almost straight, pale blue-green. Cells barrel-shaped, 2.8 ± 0.8 µm

215 in length and 1.2 ± 0.1 µm in diameter, intensely constricted at cross walls, no heterocysts or

216 sheath, end cells round.

217

218 **Discussion**

219 Although we have provided only a preliminary taxonomic characterization of the filamentous mats

220 covering sandy areas and dead mesophotic reefs off Rapa Nui, our findings indicate that these mats

221 are composed of at least two cyanobacteria. We are aware of, and recognize the limitations

222 associated with our approach to identifying mat taxa, based only on morphology. As indicated by

223 Komárek (2016), *Lyngbya*, *Okeania*, and *Moorea* cannot be distinguished from each other using

224 light microscopy. Thus, we refer to *Lyngbya* s.l. ([sensu lato] and suggest that genetic analysis is

225 needed to clarify this classification. Cyanobacteria-dominated microbial mats are known to be

226 typical components of coral reef systems and often undergo massive proliferation (Stal, 2000).

227   These events have been associated with natural processes (e.g., variation in irradiance), but mostly

228   with anthropogenic disturbances that increase nutrient concentrations in the marine environment

229   (Ford et al., 2017). The highest coverage of mats was observed mainly off Hanga Roa village,

230   which has the highest concentration of the island's human population (7,750 inhabitants;

231   www.ine.cl) and where most tourists engage in recreational activities. Figueroa & Rotarou (2016)

232   reported ~20,000 visitors per year in the late 1990s, whereas ~150,000 were reported during 2019

233   (www.sernatur.cl), representing an approximately eight-fold increase over the last two decades.

234   Factors such as overtourism, the absence of a wastewater collection and treatment system (most

235   of the residences have cesspools and a minor proportion have septic tanks), and the unlined landfill

236   (Rosa, 2013) potentially pose a great threat to the marine environment off Hanga Roa village,

237   owing to the potential input of organic matter, nutrients, and contaminants. Pollutants can reach

238   the sea by runoff or percolation to aquifers that eventually discharge into the sea. On Rapa Nui,

239   submarine groundwater discharges are ubiquitous in intertidal environments around the island

240   (Brosnan, Becker & Lipo, 2018), and could hypothetically also seep through deeper sediments

241   (Montgomery & Associates, 2011), potentially conducting nutrients of anthropogenic origin

242   directly to mesophotic habitats. Indeed, very low salinities (4.7–16.8 psu) have been measured in

243   the overlying water of unperturbed sediment cores obtained off Hanga Roa where filamentous

244   mats proliferate, further suggesting percolation of pollutants to aquifers in the area (P. Muñoz,

245   unpublished data). A similar situation has been observed at the western flank of Hawai'i Island,

246   where freshwater from onshore aquifers can flow through permeable fractured basalts, mix with

247   seawater to form freshened groundwater, and seep into offshore (mesophotic) benthic areas (Attias

248   et al., 2020). Furthermore, the observation of low salinity bottom water is concomitant with

249   relatively high NO_3^- concentrations (1.87 and 3.03 µM), compared to two other sites where nitrate

250 concentrations were undetectable in overlying waters with normal salinities (~35 psu) (P. Muñoz,

251 unpublished data). Therefore, it is feasible that the benthic fluxes and submarine groundwater

252 discharges could channel nutrients to mesophotic depths, enhancing algal and cyanobacterial

253 growth, to the detriment of corals. A similar situation, albeit caused by groundwater nutrients

254 derived from bird guano, was observed in the coral reefs of Heron Island (Great Barrier Reef,

255 Australia; McMahon & Santos, 2017). In addition to the potential impacts of pollutants, the

256 permanent coastal erosion around Rapa Nui and terrestrial runoff during rainy seasons (May to

257 October) could also increase nutrient inputs to the coastal environments, including ammonia,

258 nitrate, and silicate, which are known to have negative consequences for corals (D'Angelo &

259 Wiedenmann, 2014). Furthermore, the volcanic origin of Rapa Nui, together with enhanced

260 erosion could also increase the iron concentration in the marine ecosystem. Iron from shipwrecks

261 has been found to directly drive cyanobacteria expansion in iron-limited reefs in the Pacific (Kelly

262 et al., 2012; Mangubhai & Obura, 2019). Increased iron added to a decrease in the N:P ratio could

263 even further stimulate the proliferation of cyanobacteria (Ford et al., 2018).

264 Regarding mesophotic reefs, two species of the genus *Leptoseris* have been reported for Rapa Nui,

265 *L. scabra* and *L. solida*, both collected in 1999 off Hanga Roa at depths of 43 m and 80 to 100 m,

266 respectively (Glynn et al., 2003). Given the depth of our observations as well as the plate-like

267 structure of the colonies, as indicated by Glynn et al. (2003), the damaged reef off Hanga Roa

268 village was probably composed mainly of *L. solida*. A piece of evidence, also obtained in

269 November 1999 during the first ROV survey ever done off Hanga Roa at ~80 m deep, suggests

270 that the same *Leptoseris* reef that is currently dead was healthy ~20 years ago (Fig. 2D; Gorny &

271 Retamal, 2000). In the present study, live *Leptoseris* reefs were documented mainly off the

272 northern and southeastern sides of the island (e.g., Anakena, La Perouse, and Vinapú).

273   Despite the circumstantial indication of the health status of the mesophotic reefs off Hanga Roa a

274   few decades ago, the ecological impacts on the biodiversity and ecosystem functioning associated

275   with anthropogenic causes are still unknown and need further investigation in the short term.

276   Further research should address a more detailed taxonomic characterization of these mats, for

277   example, through molecular techniques; assessment of the seasonal, spatial, and structural patterns

278   of the assemblage; their eventual role in reef deterioration; recognition of eutrophication

279   mechanisms; and long-term monitoring of dissolved organic matter and nutrient dynamics. These

280   studies are encouraged to inform the implementation of effective and integrated land-sea

281   management actions, including a wastewater treatment system. This information should also be

282   key to inform the implementation of management strategies of the recently created Marine

283   Protected Area of Multiple Uses (MPA-MU) of Rapa Nui, currently the largest in Latin America.

284   This protected area encompasses ~579,000 km^2 (Paredes et al., 2019) and aims to protect this

285   unique world biodiversity heritage site. In addition, this study will also serve as a baseline for

286   future studies of changes in the mesophotic ecosystem off Rapa Nui after closure of the island to

287   tourism, from March 2020 to date, due to the COVID-19 pandemic.

288

289   **Conclusions**

290   Based on opportunistic video observations, we provide the first report of filamentous mats

291   covering sandy areas and dead mesophotic reefs (*Leptoseris* spp.) off Rapa Nui. A preliminary

292   morphological analysis of mat samples suggested that the assemblage is constituted by at least four

293   filamentous taxa, including two cyanobacteria (*Lyngbya* s.l. and *Pseudoanabaena* sp.), a brown

294   alga (*Ectocarpus* sp.), and a green alga (*Cladophora* sp.). Whereas a highly damaged, even

295   completely dead, *Leptoseris* reef was observed in the waters off the main village on the western

296   side of the island, reefs in much healthier conditions were observed off the less populated northern

297   and southeastern parts of the island (e.g., Anakena, La Perouse, and Vinapú). Circumstantial

298   evidence indicates that the *Leptoseris* reef off Hanga Roa was alive ~20 years ago. Our preliminary

299   evidence suggests a link between ongoing eutrophication associated with human population

300   expansion and deficient management of wastewater and urban runoff on the western side of the

301   island, the proliferation of filamentous mats, and consequent damage to mesophotic *Leptoseris*

302   reefs.

303

Acknowledgments

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525   **Compliance with ethical standards**

526   Conflict of interest: The authors declare that they have no competing interests.

527

528   **Electronic Supplementary Material (ESM):** Video footage of the cyanobacteria-like mats, live

529   *Cycloseris* sp. fields, and dead *Leptoseris* spp. reefs.

530

Figure 1

Map of Rapa Nui showing the main features of the island, the sites surveyed in the present study, and the extent of coverage of filamentous mats at these sites.

(A) Abundance of filamentous mats in the benthic ecosystems at the survey sites. (B) Depth range of the remotely operated vehicle stations for each category of filamentous mat coverage used in this study. Green: no mats observed, yellow: low coverage, orange: high coverage, and red: very high coverage. The box plots show the mean (red diamonds), median (horizontal black line), and lower and upper quartiles; the whiskers indicate the depth range for each category. The letters (a, b) indicate homogenous groups identified using the Wilcoxon *post hoc* test.
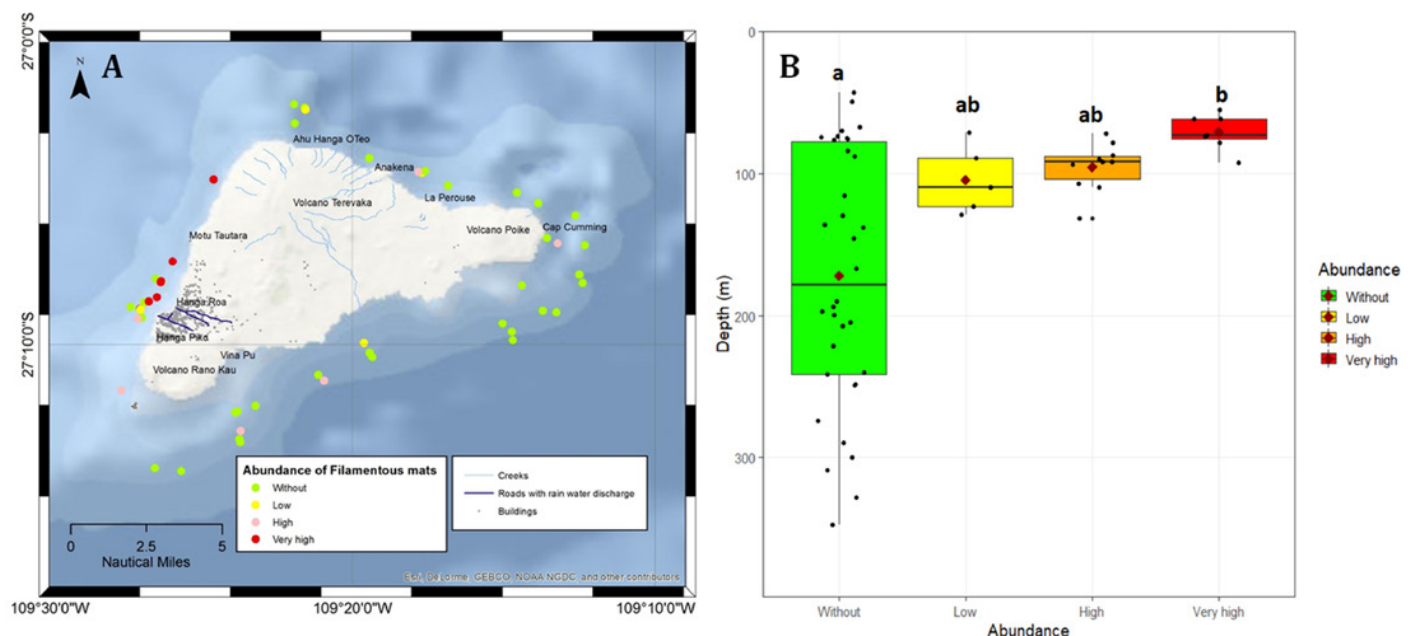
Figure 2

Remotely operated vehicle (ROV) images of the filamentous mats and mesophotic reefs off Rapa Nui.

(A) Field of filamentous mats at ~80 m deep off Hanga Roa, Rapa Nui. (B) Close up view of the filaments. (C) Filaments among *Cycloseris vaughani* individuals. (D) Dead *Leptoseris* reef ~80 m deep overgrown by filaments. (E) Healthy *Leptoseris* reef off Anakena ~80 m deep. (F) Healthy *Leptoseris* reef off Hanga Roa filmed during prospective ROV surveys during the "CIMAR-5 Islas" cruise conducted in 1999. Scale bars: 10 cm (A, B, C) and 25 cm (D, E, F). Images: Matthias Gorny, OCEANA.
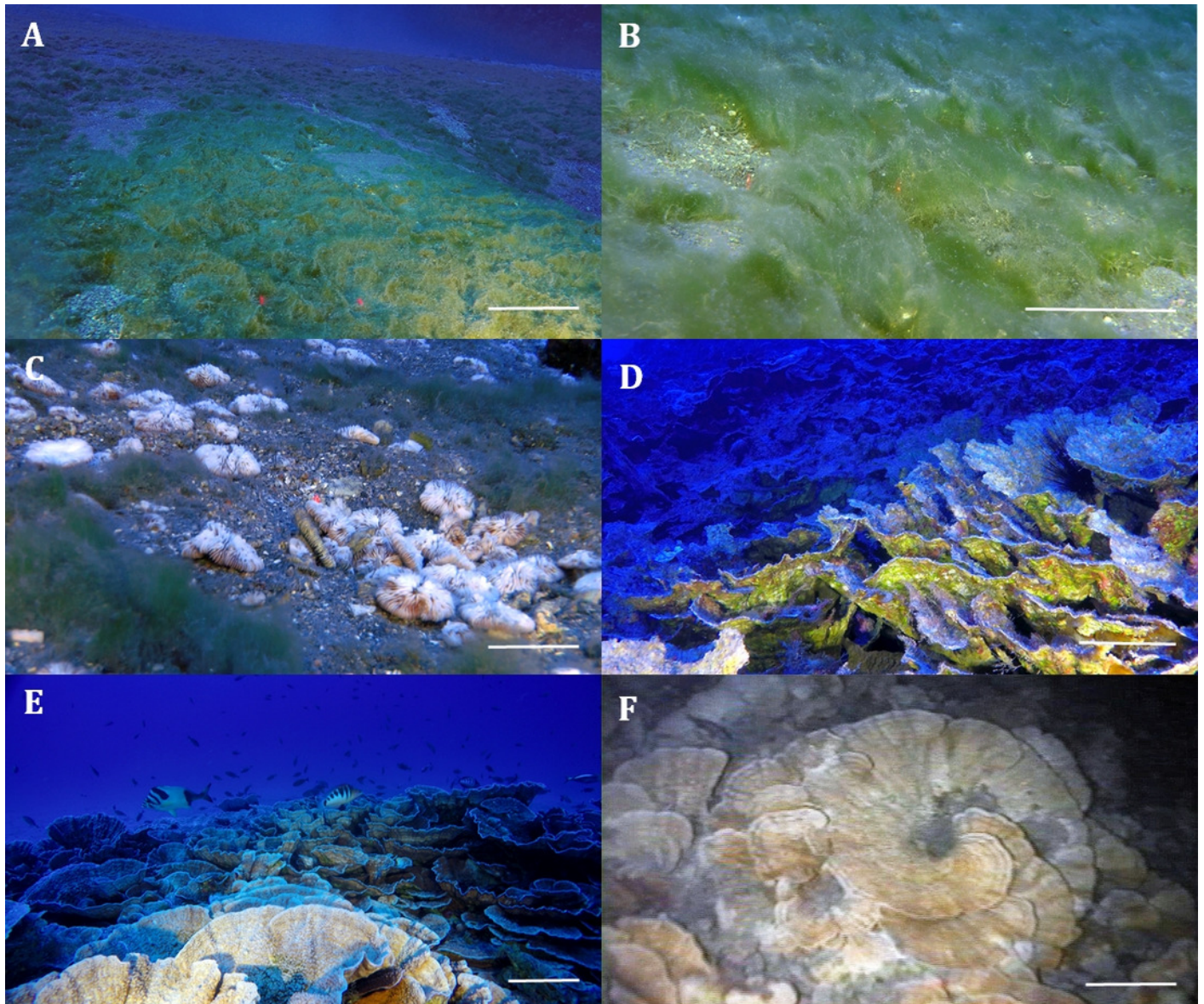
Figure 3

Transects surveyed off Rapa Nui in the present study showing sites with mesophotic corals.

(A) Map showing the main mesophotic coral taxa at each site. (B) Health status of *Leptoseris* reefs indicated by color: green = healthy (no noticeable impact), yellow = some damage (25%–75% of corals damaged), and red = destroyed (only dead corals or fragments observed).
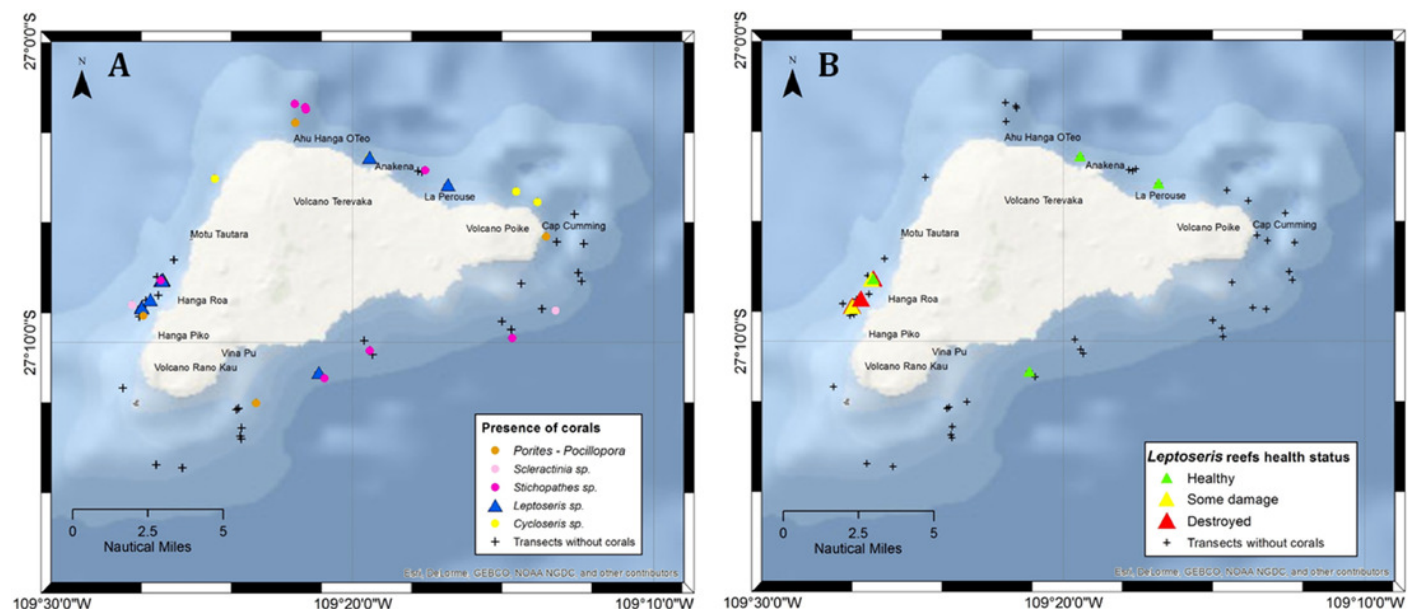
Figure 4

Micrographs of four filamentous taxa in samples from mats collected off Hanga Roa, Rapa Nui at mesophotic depths. A–E and G were photographed using phase-contrast and F and H using epifluorescence techniques.

A, B) *Cladophora* sp. (C, D) *Ectocarpus* sp. (E, F) *Lyngbya* s.l. (G, H) *Pseudoanabaena* sp.

Scale bars represent A: 500 µm, B: 200 µm, C: 100 µm, D: 30 µm, E and F: 20 µm, and G and H: 30 µm.