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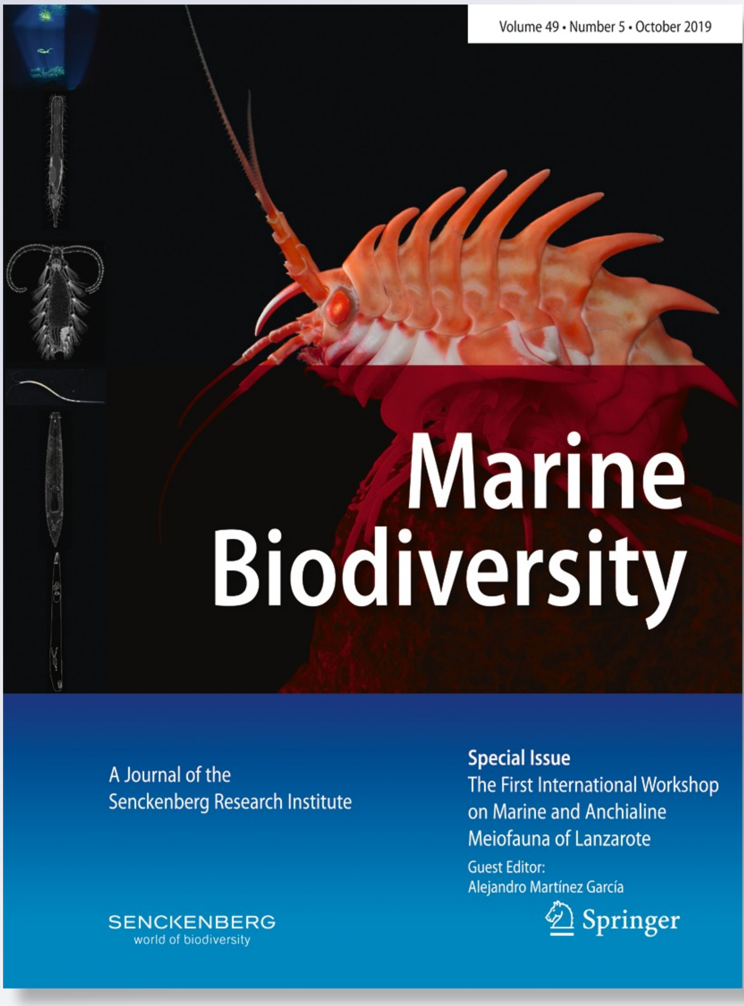

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SHORT COMMUNICATION

Species composition of Alcyonacea (Octocorallia) on coral reefs at Europa Island and associated connectivity across the Mozambique Channel

M. H. Schleyer[1] · N. J. Downey-Breedt[2] · Y. Benayahu[3]

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Abstract

The soft coral fauna (Octocorallia: Alcyonacea) on reefs around Europa Island (Western Indian Ocean) were surveyed in 2016. The species richness was rather low for a protected, relatively pristine environment in the region. While certain 'fugitive' alcyonacean species were noticeably abundant, other soft corals were rare or absent. Since Europa Island is remote and isolated, connectivity was thus investigated with other alcyonacean communities in the Mozambique Channel by particle transport modelling. This revealed that, while the north-west coast of Madagascar appears well-connected with the northern Mozambique coast, the most likely source of soft coral recruits at Europa Island would be the Tulear region further south in Madagascar.

Keywords Soft corals · Larval dispersal · Particle transport modelling · Oceanographic eddies · East Africa · Madagascar · Western Indian Ocean

Introduction

Europa Island (22.3677° S, 40.3580° E) forms part of the French *Îles Eparses* in the Western Indian Ocean (WIO) and is remotely located in the Mozambique Channel (Fig. 1). Its isolation renders it valuable as a baseline reference site in the WIO, particularly as its coral reefs have been free from fishing pressure for over two decades (Chabanet et al. 2017). The reefs of the *Îles Eparses* have recently been surveyed within the BioReCIE (Biodiversity, Resources and Conservation of coral reefs in the Scattered Islands) and GCRMN (Global Coral Reef Monitoring Network) programmes, revealing that the reefs at Europa Island are in good condition, with moderately high scleractinian biodiversity, high coral cover and commensurately low algal cover (Chabanet et al. 2017). Alcyonacea were only given superficial consideration in the aforementioned surveys but have since been comprehensively collected during expeditions to Mayotte (Schleyer and Benayahu 2018) and the Glorieuses Archipelago (Schleyer et al. 2018). A further expedition was conducted to the reefs that surround Europa Island in November 2016 under the auspices of the SIREME (Monitoring and inventory of coral reefs of Mayotte and the Scattered Islands) programme to assess their biodiversity (Chabanet et al. 2017). This expedition provided an opportunity to investigate the biodiversity of the Alcyonacea (Octocorallia) on Europa's coral reefs and, in view of the results, consider potential connectivity between this remote population with octocoral communities elsewhere in the Mozambique Channel.

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Material and methods

Europa Island and sampling strategy

Europa Island is an uplifted atoll that lies about 370 km WNW of Tulear (Toliara) in Madagascar and 120 km SE of Bassas da India, another French overseas territory. It is one of the most

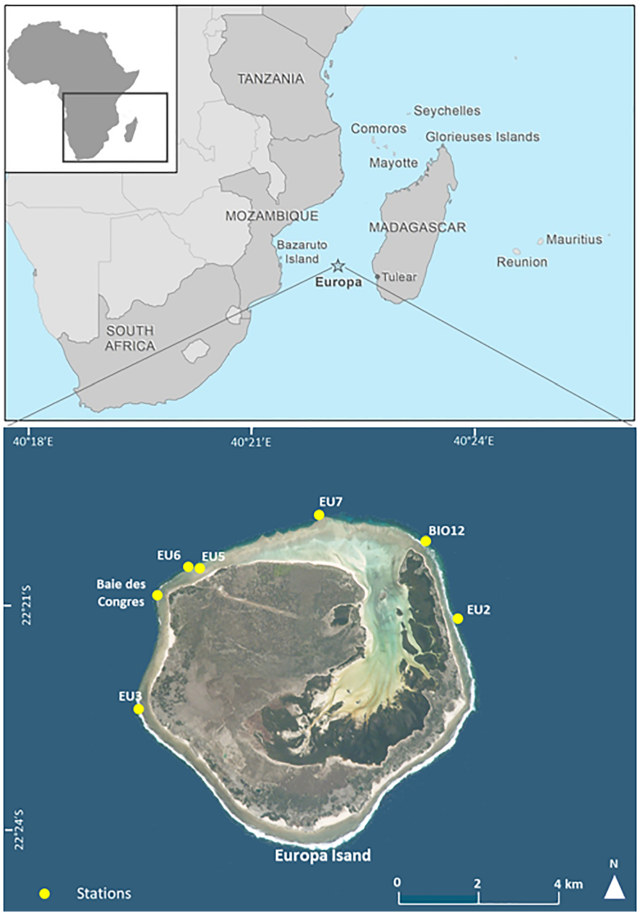

Fig. 1 Location of Europa Island and a satellite image of the island and its surrounding reefs labelled with the study sites at which alcyonacean octocorals were collected. Satellite image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

important nesting sites for green turtles, has the second largest colony of great frigate birds in the Western Indian Ocean (WIO) and is administered and protected by *Terres Australes et Antarctiques Françaises* (TAAF; Quétel et al. 2016). It is small (31.6 km^2) and conspicuously vegetated with *Euphorbia stenoclada* scrub forest interspersed by sedges in its western half, but has a large mangrove forest in the eastern half, the broad lagoon of which opens to the NE (Fig. 1). The island is surrounded by fringing reefs that comprise a narrow reef top and steep outer walls that mostly drop off to sand at a maximum depth of 27 m. The inner reef lagoon is narrow and is littered in places with shallow coral bommies.

Alcyonacean octocorals were collected during seven unstratified dives undertaken to a maximum depth of 25 m at seven Europa reef sites (Fig. 1, Table 1). While octocorals were sought and collected within all the above reef habitats, their relative abundance was also visually recorded as being rare, occasional, common or abundant. The colonies were

Table 1 Co-ordinates of alcyonacean sampling sites around Europa Island

Station	Latitude °S	Longitude °E
EU2	22.35291	40.39673
EU3	22.37300	40.32483
EU5	22.34121	40.33763
EU6	22.34063	40.33716
EU7	22.32943	40.36508
BIO12	22.33533	40.38888
Baie des Congres	22.34741	40.32875

photographed underwater before sampling, and the samples were fixed in 4% formal saline overnight before transfer to 70% ethanol for identification and storage in the Steinhardt Museum of Natural History, Tel Aviv University, Israel (SMNH), with ZMTAU Co. numbers.

An individual-based model (IBM) was used to simulate potential cross-channel transport of particles between Mozambique and Madagascar, and between their shores and Europa Island. The IBM was developed using Ichthyop 3.2, a free Java tool designed to study the effects of physical and biological factors on ichthyoplankton dynamics (Lett et al. 2008) and is driven by the ROMS (Regional Ocean Model

Table 2 Model release sites along the East African and Madagascan coastlines

East Africa		Madagascar	
Latitude °S	Longitude °E	Latitude °S	Longitude °E
9.8083	39.9399	12.0000	49.2170
11.3083	40.5168	13.5000	48.1586
12.8083	40.6410	15.0000	46.9731
14.3083	40.8819	15.7429	45.4013
15.8083	40.4533	16.5000	44.2636
17.3083	38.6000	18.0000	43.8826
18.8083	36.6483	19.5000	44.3059
20.3083	35.0342	21.0000	43.7661
21.8083	35.4999	22.5000	43.2052
23.3083	35.5634	24.0000	43.6021
24.8083	35.1612	25.4000	44.7134
25.5295	33.1762	25.3088	46.2217
27.0295	33.0232	13.5000	50.1166
		15.0000	50.4130
		16.5000	49.8944
		18.0000	49.4472
		19.5000	48.9708
		21.0000	48.4853
		22.5000	47.9244
		24.0000	47.5195

Table 3 Soft corals photographed and collected at Europa Island (*photographic record only) with their collection numbers, distribution and relative abundance. Bold type indicates the two species that were abundant. ZMTAU = Zoological Museum, Department of Zoology, Tel Aviv University

	ZMTAU Co. numbers	Stations							Abundance
		EU					BIO12	Baie des Congres	
		2	3	5	6	7			
Family Alcyoniidae									
Cladiella australis (Macfadyen, 1936)*	–				•				Rare
Cladiella kashmani Benayahu & Schleyer, 1996	37546				•				Rare
Cladiella krempfi (Hickson, 1919)	37540					•			Rare
***Cladiella laciniosa* (Tixier-Durivault, 1944)**	37534	•			•				**Abundant**
Cladiella latissima (Tixier-Durivault, 1944)	37552	•							Rare
Cladiella madagascariensis (Tixier-Durivault, 1944)	37544	•							Rare
Cladiella pachyclados (Klunzinger, 1877)	37548				•	•			Rare
Klyxum flaccidum (Tixier-Durivault, 1966)	37526				•		•		Rare
Klyxum utinomii (Verseveldt, 1981)	37538				•				Rare
Lobophytum crassum von Marenzeller, 1884	37543			•					Rare
Lobophytum pauciflorum (Ehrenberg, 1834)	37547		•		•			•	Occasional
Lobophytum venustum Tixier-Durivault, 1957*	–					•		•	Rare
***Rhytisma fulvum* (Forskål, 1775)**	37545	•	•		•	•		•	**Abundant**
	37568								
Sarcophyton ehrenbergi (von Marenzeller, 1886)	37527					•		•	Rare
	37530								
Sarcophyton glaucum (Quoy & Gaimard, 1883)	37529				•				Rare
Sarcophyton trocheliophorum von Marenzeller, 1886	37542					•			Rare
Sinularia abrupta Tixier-Durivault, 1970	37571			•				•	Rare
Sinularia erecta Tixier-Durivault, 1945*	–	•	•	•	•	•		•	Common
Sinularia gravis Tixier-Durivault, 1970	37553						•		Rare
Sinularia heterospiculata Verseveldt, 1974	37549		•						Rare
Sinularia hirta (Pratt, 1903)	37554	•			•	•		•	Occasional
	37555								
	37563								
	37575								
	37577								
Sinularia humesi Verseveldt, 1971	37566	•			•	•		•	Occasional
Sinularia loyai Verseveldt & Benayahu, 1983	37562							•	Rare
Sinularia molesta Tixier-Durivault, 1970	37550	•	•		•	•		•	Occasional
	37558								
	37564								
	37570								
Sinularia numerosa Tixier-Durivault, 1970	37531	•	•		•	•		•	Occasional
	37532								
	37541								
	37577								
	37560								
	37561								
	37565								
Sinularia polydactyla (Ehrenberg, 1834)	37569			•				•	Occasional
	37573								
Sinularia terspilli Verseveldt, 1971	37528		•						Rare
Sinularia variabilis Tixier-Durivault, 1945	37574					•			Rare
Sinularia vrijmoethi Verseveldt, 1971	37539		•		•	•			Occasional
Sinularia whiteleggei Lüttschwager, 1914	37551			•	•				Occasional
	37556								
Family Nephtheidae									
Dendronephthya sp.*	–	•	•		•			•	Occasional
Lemnalia africana (May, 1898)	37533	•	•		•				Common
	37536								
	37567								
	37572								
	37576								
Lemnalia flava (May, 1898)	37535			•		•		•	Common
	37537								
Stereonephthya sp.*	–	•	•		•			•	Common
Family Tubiporidae									
Tubipora musica Linnaeus, 1758*	–				•				Rare

System) outputs of the South-West Indian Ocean Model (SWIM) (Halo 2012; Halo et al. 2014). The SWIM was designed to simulate the mesoscale circulation in the Mozambique Channel and has a longitudinal resolution of 0.20° (~22 km), and a latitudinal resolution of 0.14° (~16 km) in the south and 0.20° (~22 km) in the north of the channel (Halo 2012; Halo et al. 2014). It spans 0 to 77.5° E and 3 to 47.5 °S, and satisfactorily reproduces the pathways of the currents and mean volume transports in the Mozambique Channel (Halo 2012; Halo et al. 2014). Although the mesoscale circulation in the Mozambique Channel is well-represented in the model, shelf dynamics are not accurately resolved at this resolution (Halo 2012; Halo et al. 2014). The model was nevertheless considered suitable to explore cross-channel connectivity pathways.

Release sites for the model spanned the East African coastline from southern Tanzania to Kosi Bay in NE South Africa, and the full coastline of Madagascar. They were placed as close to the coastline as possible, at relatively equidistant intervals, resulting in a total of 13 release sites off East Africa and 20 off Madagascar (Table 2). Cross-channel 'recruitment zones' were incorporated into the model using a bathymetric mask (< 200 m) placed on the opposite coastline or Europa Island, allowing particles crossing the channel and reaching the continental shelf, or the island, to be recorded. Ten particles were released from each site per day for a model year. Particle transport was arrested upon entering the 'recruitment zone', or 60 days after release. The fastest transport route from each release site was overlaid on line density plots of the trajectories of all particles released. Trajectories of particles reaching the opposite shelf were used to identify the main cross-channel transport patterns in the model simulations.

Results

The soft coral collection comprised 49 specimens that yielded 29 species in seven genera; an additional three genera and four species were photographed in the field. These are listed with their distributional records and relative abundances (Table 3). Snorkel dives were also undertaken in the mangrove lagoon but yielded no soft corals.

The fastest cross-channel transport routes were generated by SWIM for surface particles travelling from Mozambique to Madagascar, or Madagascar to Mozambique (Fig. 2a, b). In both plots, all trajectories are shown in grey; the trajectory density (seen in grey scale) is thus an indicator of the number of particles following that route.

Various cross-channel transport pathways became evident in the model simulations (Fig. 3). Successful transport from Mozambique to Madagascar took place primarily in the channel narrow by way of almost direct cross-channel transport, taking as little as 3 days (Fig. 2). Transport from Madagascar

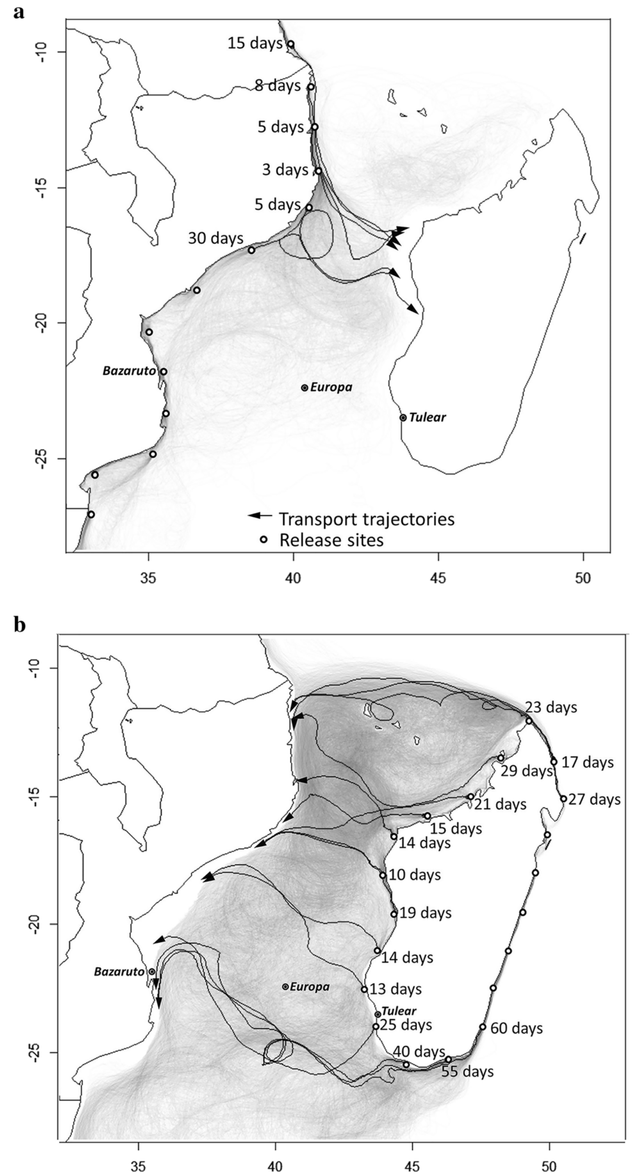

Fig. 2 The surface transport of particles (grey) released from 13 sites off Mozambique (**a**); and 20 sites off Madagascar (**b**), with the fastest cross-channel transport route (within a maximum transport time of 60 days) from each release site in black

to Mozambique, however, was more variable, and the shortest transit periods were 10 days in the channel narrow, and 13 days further south in the vicinity of Europa Island (Fig. 2). Five transport categories could be distinguished (Fig. 3): (a) transport within eddies, (b) advection towards/onto the continental shelf by eddies in the channel narrow, (c) almost direct cross-channel transport (probably in interstitial waters between eddies), (d) particles caught up in southward travelling eddies and (e) fast transport in interstitial waters between westward propagating eddies. The last suggests that the most likely marine link to Europa Island would be with Madagascan reefs in

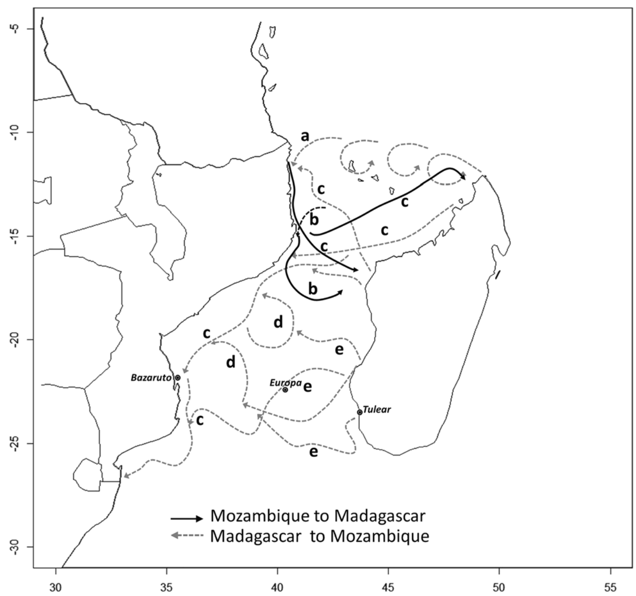

Fig. 3 The main transport pathways observed in model simulations: **a** transport within eddies; **b** advection towards/onto the continental shelf by eddies in the channel narrow; **c** almost direct cross-channel transport (probably in interstitial waters between eddies); **d** particles caught up in southward travelling eddies; and **e** fast transport in interstitial waters between westward propagating eddies

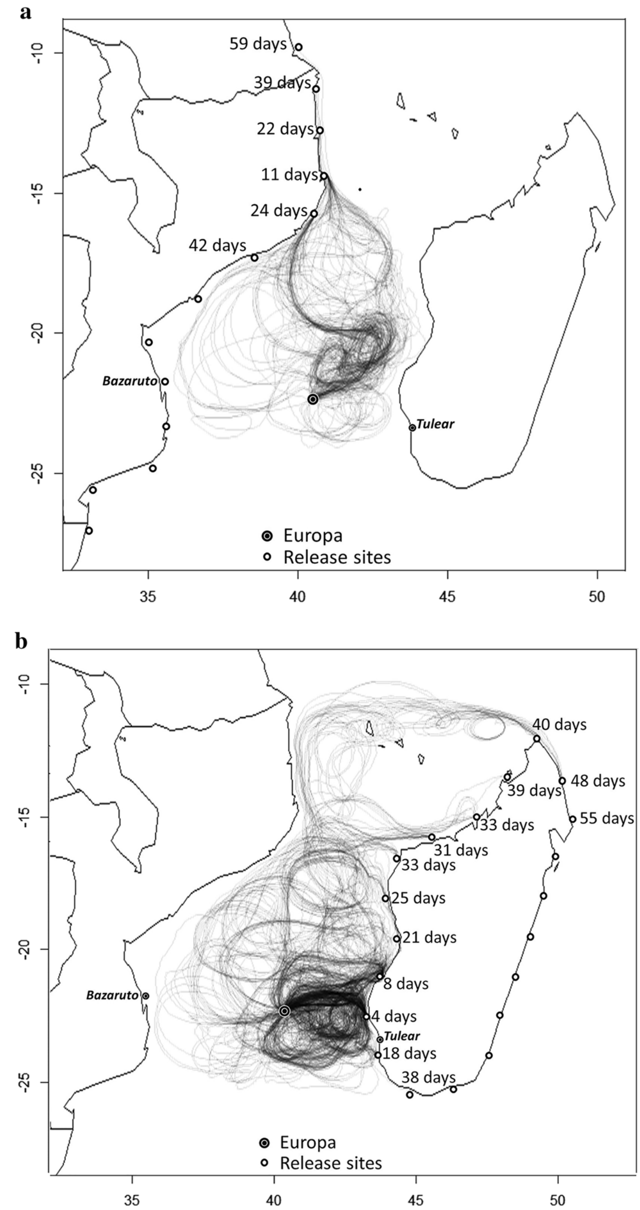

Fig. 4 The surface transport of particles (grey) released from 13 sites off Mozambique (**a**); and 20 sites off Madagascar (**b**), with the fastest cross-channel transport route to Europa Island (within a maximum transport time of 60 days) from each release site in black

the vicinity of Tulear (Fig. 3). This proved to be the case when landings at Europa Island were considered, taking as little as 4 days from the region of Tulear (Fig. 4b).

Discussion

Three features were conspicuous in the Europa soft coral community. Firstly, it must be noted that it was low in diversity. If field observations are included, Mayotte has 71 species of Alcyonacea (Schleyer and Benayahu 2018), Glorieuses 42 (Schleyer et al. 2018) and Tanzania 44 (van Ofwegen and Benayahu 1992), but Europa only 33 (this study).

The second notable attribute of this soft coral community is that no members of the Family Xeniidae were encountered. This is remarkable as the family is conspicuous on reefs at all the other islands in the Mozambique Channel, and on the East African and north-western Madagascan coasts (Tixier-Durivault 1966; Verseveldt 1969, 1971, 1973a, b, c; van Ofwegen and Benayahu 1992; Schleyer and Benayahu 2018; Schleyer et al. 2018; Benayahu and Schleyer 1996; Benayahu et al. 2002). Members of this family are usually described as 'fugitive' species because, unlike slower-growing, more persistent soft corals, xeniids are fast-growing opportunists (Fabricius 1995). In this regard, corals may come and go in some areas (i.e. as 'fugitives'), particularly at higher latitudes (Harriott et al. 1994), but can generally be found on some coral reefs within a locality. The absence of xeniids was thus surprising as habitat was certainly available for them; the Europa reefs were in good condition and are not subject to high turbulence or perturbation.

The third conspicuous feature of the Europa soft corals is that only two species were abundant. Of these, *Rhytisma fulvum* was the most prolific and is a fast-growing alcyoniid that forms a thin rind that spreads over exposed reef surfaces (Fig. 5a, b). The other abundant soft coral, *Cladiella laciniosa*, was noticeably prolific within large patches (Fig. 5c) at two

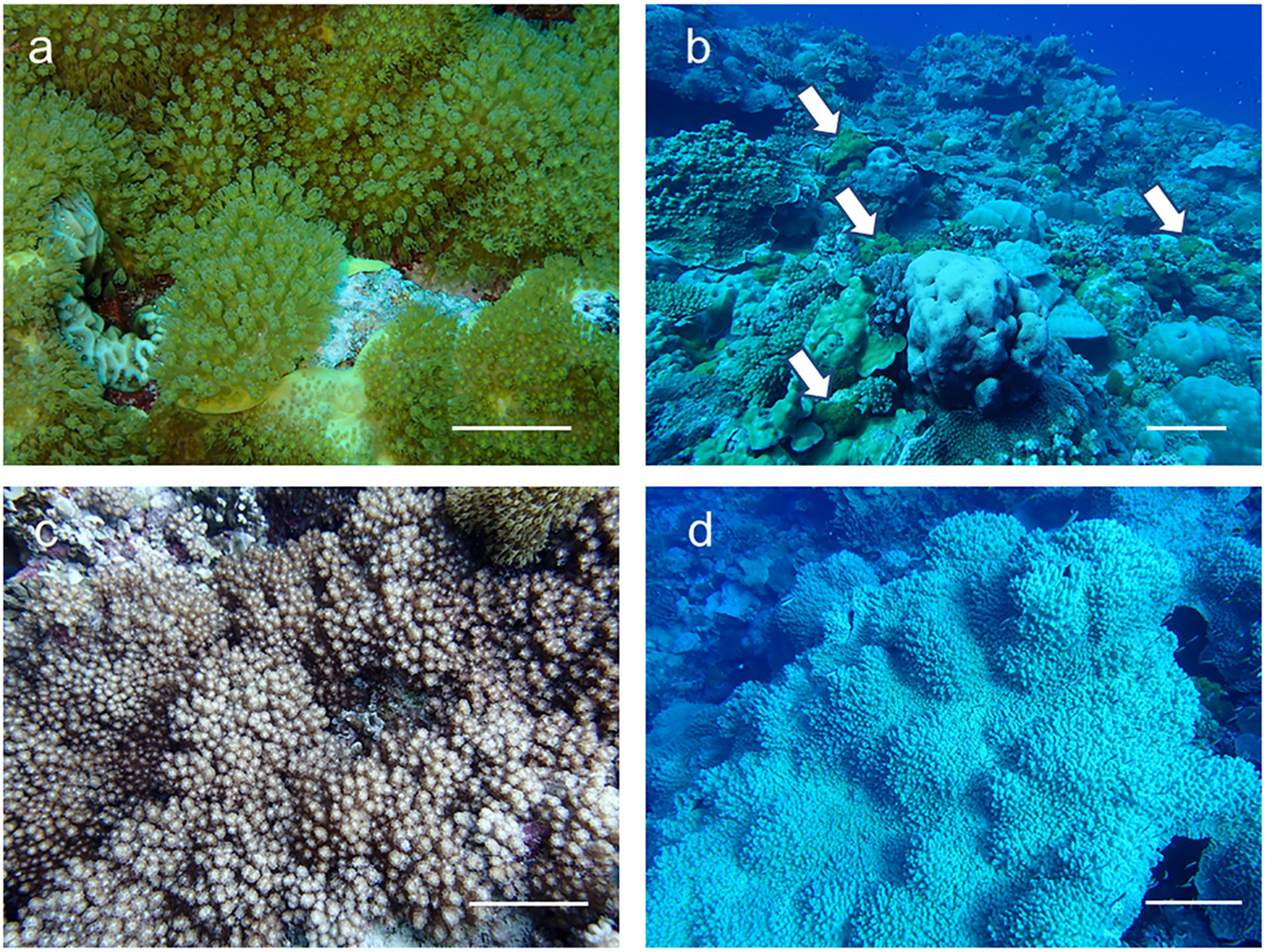

Fig. 5 **a** A colony of *Rhytisma fulvum* with **b** a view of a reef carpeted in patches by this species (arrows mark four examples); extensive colonies of **c** *Cladiella laciniosa* and **d** *Sinularia erecta*. Scale **a** = ~ 3 cm; **b** = ~ 40 cm; **c** = ~ 5 cm; **d** = ~ 50 cm

sites, EU2 and EU6, particularly the latter. Only a few large colonies of *Sinularia* formed more typical, extensive carpets on the reefs in some areas (Fig. 5d). The Scleractinia on the reefs appeared to have sufficient competitive advantage (see Chabanet et al. 2017) to prevent *Sinularia* spp. from gaining such a foothold.

The balance of the soft corals found at Europa were, at best, fairly common in isolated areas or were rare and only single specimens were encountered during dives. All of these factors suggested that Europa's soft coral community is possibly unique in its impoverishment within the Mozambique Channel, and the underlying reasons for this may be due to relative isolation of its reef communities, as suggested by the results of SWIM analyses.

These revealed that cross-channel transport of surface-born particles was fastest across the narrowest section of the Mozambique Channel, from northern Mozambique to central Madagascar (Fig. 2a). From here, inshore coastal currents could facilitate the movement of propagules and migrants from settlers southwards. The more likely link with the Europa reefs, however, would be with reefs in SW Madagascar (Fig. 4b); the duration of cross-channel transport that could feed alcyonacean propagules to the island from Tulear (~ 370 km away) would be well within the larval competency of Alcyonacea (Ben-David-Zaslow and Benayahu 1996, 1998). Alcyonacean records provided for the Tulear region by Tixier-Durivault (1966) would tend to indicate that, when her study was undertaken, its alcyonacean community was as impoverished as that of Europa Island (ca. 22 species in 11 genera). However, it must be borne in mind that the identification of much of Tixier-Durivault's (1966) material merits reinvestigation, and that the record is probably incomplete (see Schleyer and Benayahu 2018).

It is noteworthy that there appears to be no connection between the alcyonacean community at Bazaruto Island (29 species in 11 genera; Benayahu and Schleyer 1996; Schleyer and Celliers 2005) at 21.5° S (Figs. 2a, 3 and 4a), ~ 510 km away and at roughly the same latitude as Europa Island (22.4° S; Fig. 4a).

Nevertheless, when compared to taxonomic records in the literature, the results of the soft coral survey at Europa Island and the SWIM analyses would suggest that the island's alcyonacean community is most closely connected with a similar community in the Tulear region of southern Madagascar. This, in turn, is probably connected by long-shore currents with communities further north in Madagascar, which are more closely connected with the soft coral communities in northern Mozambique than islands in the mouth of the Mozambique Channel. This aspect of the study constitutes the first of its kind in the region.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Sampling and field studies All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements, if applicable.

Ethical approval This article does not contain any studies with animals performed by any of the authors.

Data availability All data generated or analysed during this study are included in this published article.

References

Benayahu Y, Schleyer MH (1996) Corals of the south-west Indian Ocean III. Alcyonacea (Octocorallia) from Bazaruto Island, Mozambique, with a redescription of *Cladiella australis* (Macfadyen 1936) and description of *Cladiella kashmani* spec. nov. Invest Rep Oceanogr Res Inst 69:1–21

Benayahu Y, Shlagman A, Schleyer MH (2002) Corals of the South-west Indian Ocean VI. The Alcyonacea (Octocorallia) of Mozambique; with a discussion on soft coral distribution along south equatorial East-African reefs. Zool Verh 345:49–57

Ben-David-Zaslow R, Benayahu Y (1996) Longevity, competence and energetic content in planulae of the soft coral *Heteroxenia fuscescens*. J Exp Mar Biol Ecol 206:55–68

Ben-David-Zaslow R, Benyahau Y (1998) Competence and longevity in planulae of several species of soft corals. Mar Ecol Prog Ser 163: 235–243

Chabanet P, Andréfouët S, Barroil P, Bec B, Bélières A, Bigot L et al (2017) Suivi et inventaire des récifs coralliens de Mayotte et des îles Eparses: Glorieuses 2015, Mayotte 2016 et Europa 2016. Programme SIREME. Rapport IRD pour le compte des TAAF, AFD, UE et Département de Mayotte

Fabricius KE (1995) Slow population turnover in the soft coral genera *Sinularia* and *Sarcophyton* on mid- and outer-shelf reefs of the Great Barrier Reef. Mar Ecol Prog Ser 126:145–152

Halo I (2012) The Mozambique Channel eddies: characteristics and mechanisms of formation. PhD dissertation, University of Cape Town, 200 pp

Halo I, Backeberg B, Penven P, Ansorge I, Reason C, Ullgren JE (2014) Eddy properties in the Mozambique Channel: a comparison between observations and two numerical ocean circulation models. Deep-Sea Res 100:38–53

Harriott VJ, Smith SDA, Harrison PL (1994) Patterns of coral community structure of subtropical reefs in the Solitary Islands Marine Reserve, Eastern Australia. Mar Ecol Prog Ser 109:67–76

Lett C, Verley P, Mullon C, Parada C, Brochier T, Penven P, Blanke B (2008) A Lagrangian tool for modelling ichthyoplankton dynamics. Environ Model Softw 23:1210–1214

Quétel C, Marinesque S, Ringler D, Fillinger LA, Changeux T, Marteau C, Troussellier M (2016) Iles Eparses (SW Indian Ocean) as reference ecosystems for environmental research. Acta Oecol 72:1–8

Schleyer MH, Benayahu Y (2018) The soft coral fauna (Octocorallia: Alcyonacea) of Mayotte. Mar Biodivers 48:1643–1650

Schleyer MH, Celliers L (2005) The coral reefs of Bazaruto Island, Mozambique, with recommendations for their management. West Ind Ocean J Mar Sci 4:227–236

Schleyer MH, Bigot L, Benayahu Y (2018) Coral reefs of the Glorieuses Islands, Western Indian Ocean. Afr J Mar Sci 40:331–339

Tixier-Durivault A (1966) Octocoralliaires de Madagascar et des iles avoisinantes. Faune de Madagascar 21:1–456

van Ofwegen LP, Benayahu Y (1992) Notes on Alcyonacea (Octocorallia) from Tanzania. Zool Med 66:139–154

Verseveldt J (1969) Octocorallia from north-western Madagascar (part I). Zool Verh 106:1–38

Verseveldt J (1971) Octocorallia from north-western Madagascar (part II). Zool Verh 117:1–73

Verseveldt J (1973a) Octocorallia from north-western Madagascar (part IIIA). Proc K Ned Akad Wet Ser C 76:69–100

Verseveldt J (1973b) Octocorallia from north-western Madagascar (part IIIB). Verh K Ned Akad Wet 117:89–157

Verseveldt J (1973c) Octocorallia from north-western Madagascar (part IIIC). Verh K Ned Akad Wet 117:158–171