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Short Note

Impacts of the non-indigenous seaweed *Rugulopteryx okamurae* on a Mediterranean coralligenous community (Strait of Gibraltar): The role of long-term monitoring

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A R T I C L E I N F O

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A B S T R A C T

The Mediterranean is one of the most biodiverse and anthropogenically impacted seas and the coralligenous is one of its most diverse habitats. Its presence is indicative of well-preserved areas and its associated species are considered among the best bioindicators for monitoring nearshore rocky habitats. This study aims to report the temporal fluctuations of the coralligenous community in the marine protected area of Jbel Moussa (Strait of Gibraltar) in a period concomitant with the rapid expansion of the non-indigenous species *Rugulopteryx okamurae* (E.Y.Dawson) I.K.Hwang, W.J.Lee & H.S.Kim in the area. From year 2015 to 2019, an area covering 36 m^2 of the coralligenous habitat was monitored across three sites, including temperature logs from 2017 to 2019. After its first record in the area in 2017, *R. okamurae* became the most abundant species in only one year, followed by a change in the coralligenous community structure and a regression of the bioindicator species *Paramuricea clavata* (Risso, 1826) and *Mesophyllum expansum* (Philippi) Cabioch & M.L.Mendoza. These species are sensitive to increases in water temperature and were already under a gradual regression due to anthropogenic disturbances and previous biological invasions, all of which could have reduced niche competition in the area and favoured the impacts caused by *R. okamurae* in the area. Results highlight the need of a rapid administrative response to increase mitigation efforts on this protected habitat. Due the potential expansion of this non-indigenous invasive species to the Mediterranean Sea, the present study could provide valuable information for future monitoring, conservation and management actions.

1. Introduction

Long-term monitoring programmes can increase our knowledge of natural ecosystems dynamics and contribute to the identification and quantification of ecological impacts (UNESCO, 2003). For example, the impacts derived from global warming and non-indigenous species proliferation, which are primary threats to global biodiversity (Molnar et al., 2008; Smale et al., 2019). In those cases, monitoring programs can provide data before the alteration and generate information for a better quantification of ecological impacts (Sukhotin & Berger, 2013; UNEP/MAP, 2016).

Usually, some species are targeted as bioindicators when planning monitoring programs (Cecchi et al., 2014). To increase resources efficiency, bioindicator species should be easy to handle, sensitive to small variations in environmental stress, applicable in extensive geographical areas or environments, relevant to policy and management needs, and should exclude natural fluctuations (UNESCO, 2003). On subtidal rocky habitats, macrobenthic species meet most of these criteria and have been extensively used as bioindicators (UNESCO, 2003; Linares et al., 2008a; García-Gómez, 2015). Coralligenous habitats, supporting one of the most diverse benthic communities of the Mediterranean Sea, protected by the SPA/BIO Protocol of the Barcelona Convention and the Habitat Directive of the European Union, have been widely studied in this regard (Boudouresque, 2004; Cecchi et al., 2014). The Mediterranean coralligenous habitat face several pressures such as trawling by ghost nets, collection by the local population, the effects of

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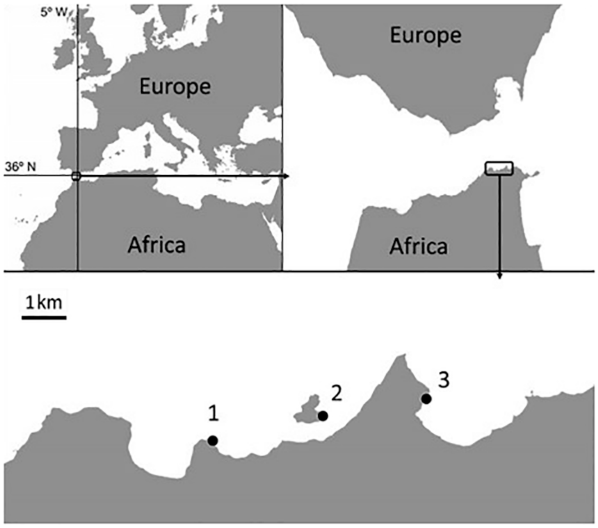

Fig. 1. Location of the three monitoring sites in the marine area of Jbel Moussa. 1: Marsa; 2: Leila; 3: Belyounech.

global change, potential spills and competition with non-indigenous species (Coll et al., 2010; Nachite et al., 2020). In recent years, some of its species, such as *Mesophyllum expansum (Philippi) Cabioch & M.L. Mendoza, Ircinia* Nardo, 1833 spp., *Petrosia (Petrosia) ficiformis* (Poiret, 1789)*, Spongia (Spongia)* Linnaeus, 1759 spp., *Astroides calycularis* (Pallas, 1766)*, Corallium rubrum* (Linnaeus, 1758)*, Eunicella* Verrill, 1869 spp., *Paramuricea clavata* (Risso, 1826), *Parazoanthus axinellae* (Schmidt, 1862), *Pentapora fascialis* (Pallas, 1766) and *Halocynthia papillosa* (Linnaeus, 1767), have experienced several mass mortality events led by heat waves (see Linares et al., 2005; Garrabou et al., 2009; 2019;; Lejeusne et al., 2010; Linares and Doak, 2010).

Within the Mediterranean Sea, the Strait of Gibraltar is a biodiversity hotspot but also a highly populated and urbanized area with an intense maritime traffic (Coll et al., 2010; Nachite et al., 2020). The brown seaweed *Rugulopteryx okamurae* (E.Y. Dawson) I.K.Hwang, W.J.Lee & H. S.Kim, native from temperate-subtropical north-west Pacific, was first detected in the Strait of Gibraltar, in 2015, from unusually abundant littoral wrack deposits (Ocaña et al., 2016; Altamirano et al., 2016). After the first record of this bloom, it quickly expanded through all the Strait of Gibraltar coastal areas; colonizing a wide range of habitats from 0 to 40 m depth (Altamirano et al., 2017; El Aamri et al., 2018; García-Gómez et al., 2018; 2020a). According to these studies, *R. okamurae* has been observed competing with most local shallow communities and growing by epibiosis on coralligenous species such as the gorgonian *P. clavata*. *Paramuricea clavata* is a species of ecological and conservational importance in the Mediterranean Sea and is under regression due to anthropogenic impacts and the effects of global change (Linares et al., 2007; Lejeusne et al., 2010; Garrabou et al., 2009; 2019).

This study aims to report the temporal fluctuations of the shallow coralligenous community and associated water temperature in the marine area of Jbel Moussa (Strait of Gibraltar). This area is designated as a Site of Ecological and Biological Interest by the Moroccan Authorities (PDAPM, 1996) and proposed as a future Protected Area of Mediterranean Importance (Bazairi et al., 2016). This study observations were concomitant with the rapid expansion of the non-indigenous species *R. okamurae* in the area (El Aamri et al., 2018; García-Gómez et al., 2018; 2020a).

2. Methods

In autumn 2015, three fixed monitoring stations were placed in three sites of the marine area of Jbel Moussa (Fig. 1) by scuba diving and following the Sessile Bioindicators Permanent Quadrats (SBPQ) methodology (García-Gómez, 2015; García-Gómez et al., 2020b; see Video Abstract). Each monitoring station was composed of three datums, installed at ca. 20 m depth and separated by>5 m from each other. Datums were screwed on vertical rocky substrata dominated by a coralligenous community, each indicating the position of four 1 m × 1 m sub-quadrats (4 m^2 per replicate and 12 m^2 per site). Since September 2017, hourly variations in water temperature were also recorded for each site using five HOBO Pendant® data loggers (two units in each Marsa and Leila and one in Belyounech; see Video Abstract).

Sites were sampled in September of 2015, 2017, 2018 and 2019. Following SBPQ methodology, sixteen 0.25 m^2 pictures were taken for each 4 m^2 replicate to maximize images resolution for species identification. The coverage of macro-benthic species (>1 cm) was obtained by superposing a 10 × 10 digital grid over each 1 m × 1 m sub-quadrat and counting species presence/absence for each cell of the grid (García-Gómez et al., 2020b). Bioindicator species were chosen following the categorization of taxa in García-Gómez (2015) and complemented with local and regional studies information (Linares et al., 2005; Garrabou et al., 2009; 2019;; Lejeusne et al., 2010; Cecchi et al., 2014; Peña et al., 2015) (see Appendix A). When present on images, the dead sections of *Paramuricea clavata* were also quantified.

2.1. Statistical analyses

For multivariate analyses, the raw coverage data obtained from the sub-quadrats was summed up for each 4 m^2 quadrat (replicates) and a dispersion-based weighting was applied to identify and reduce the contribution of taxonomic entities with erratic distribution, spatially clustered and/or big body size to multivariate dissimilarities (Warwick, 1993; Clarke et al., 2006; Clarke and Gorley, 2006). A square root transformation was later applied and three resemblance matrices were calculated based on Bray-Curtis dissimilarities: (1) including all variables, (2) excluding *Rugulopteryx okamurae* from the dataset and (3) using only bioindicator taxa. PERMANOVA and PERMDISP analyses (1999 permutations) were carried out using these resemblance matrices and testing the orthogonal factors Site (random, 3 levels: Marsa, Leila

Table 1
Mean percent coverage of *R. okamurae* and the bioindicator taxa with > 5% mean coverage and results for the Repeated Measures ANOVAs. Year 2015 was excluded from analyses because Belyounech station was lost and had to be relocated in 2017. Bold: pair-wise comparisons were carried out for *P. clavata*: 2017 > (2018 = 2019) for all sites; *R. okamurae*: 2018 = (2017 < 2019); *C. rubrum*: Leila > (Marsa = Belyounech); *M. expansum* in Marsa: 2017 > (2018 = 2019); *M. expansum* in Belyounech and Leila: no temporal differences.

Taxons	Mean coverage	Factor Year		Factor Site		Year × Site	
		F	P	F	P	F	P
Paramuricea clavata	12.12%	6.47	<0.05	2.94	0.13	4.61	**<0.05**
Rugulopteryx okamurae	10.39%	11.53	**<0.01**	0.66	0.55	2.34	0.12
Corallium rubrum	8.32%	0.91	0.43	8.20	**<0.05**	2.64	0.09
Astroides calycularis	7.93%	0.97	0.41	3.32	0.11	0.66	0.63
Mesophyllum expansum	7.27%	4.34	<0.05	30.44	<0.01	10.25	**<0.01**
Axinella sp.	5,29%	1.37	0.29	0.01	0.99	1.14	0.38
Leptopsammia pruvoti	5.20%	0.03	0.97	2.91	0.13	0.10	0.98

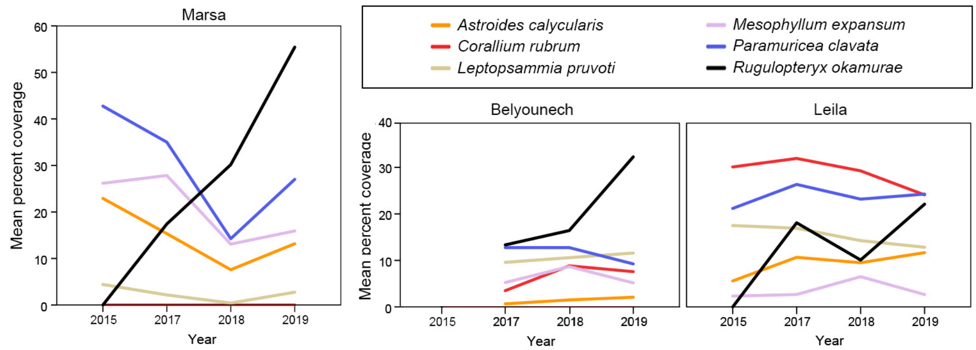

Fig. 2. Mean coverage of *Rugulopteryx okamurae* and those bioindicator species with>5% coverage for all monitored sites and years (year 2015 is missing at Belyounech, where the monitored quadrats had to be relocated in 2017).

Table 2
Variables with > 1% mean coverage and an average index of dispersion ($\overline{D}$) > 15. $\overline{D}$ is calculated separately for each variable and is the result of averaging the indexes of dispersion ($\overline{D}$) obtained within each Site × Year group of replicates. All these variables tested positive ($P < 0.05$) on the analysis of over-dispersion and were downweighted prior multivariate analyses by dividing their coverage on each replicate by $\overline{D}$ (Clarke et al., 2006).

Downweighted variables	$\overline{D}$
Rugulopteryx okamurae	85,04
Sphaerococcus coronopifolius	63,48
Corallium rubrum	42,07
Leptopsammia pruvoti	38,40
Astroides calycularis	20,24
Paramuricea clavata	17,24
Dictyota spp.	16,56
Encrusting sponges	15,51

and Belyounech) and Year (fixed, 4 levels: 2015, 2017, 2018 and 2019). Multivariate analyses were carried out using PRIMER 6 & PERMANOVA + β 17 software (Clarke and Gorley, 2006; Anderson et al., 2008).

For univariate analyses, the percent coverage of: *R. okamurae,* the dead sections of *P. clavata* and those bioindicator species with a mean coverage higher than 5% was averaged across replicates. Analyses were carried out on these variables using Repeated Measures ANOVA on a Site × Year orthogonal design. Sphericity was assumed when Mauchly's test null-hypothesis was accepted, while the Greenhouse-Geisser correction was applied for the rest of the cases. Finally, a Pearson correlation analysis was carried out between the coverage of dead sections of *P. clavata* and the coverage of *R. okamurae*. Univariate analyses were carried out using IBM SPSS Statistics 22.

3. Results

Fifty-three taxonomic entities were recorded on the monitored quadrats (see Appendix B), including three NIS (*Asparagopsis armata* Harvey, *Caulerpa cylindracea* Sonder and *Rugulopteryx okamurae*) and 30 bioindicator taxa. From the 53 variables, 35 had<1% mean coverage while 9 accumulated 72% of the total biotic coverage. These were: *R. okamurae*; the bioindicator taxa *Astroides calycularis, Axinella* Schmidt, 1862, *Corallium rubrum*, *Leptopsammia pruvoti* Lacaze-Duthiers, 1897, *Mesophyllum expansum* and *Paramuricea clavata* (see Table 1); also encrusting sponges (10,5% mean coverage) and *Lithophyllum* spp. Philippi, 1837 (7% mean coverage).

According to PERMANOVA results, the structure of the community differed between 2015 and both 2018 and 2019 for: (1) all variables (Year: pseudo-F = 2.09; $P(perm) < 0.01$), (2) all variables excluding *R. okamurae* (Year: pseudo-F = 1.87; $P(perm) < 0.01$) and (3) only bioindicator taxa (Year: pseudo-F = 1.61; $P(perm) < 0.05$) (see Appendix C). For all cases, PERMDISP found no differences on multivariate dispersion among years ($P(perm) > 0.05$). The main driver of those differences was *R. okamurae,* which clearly become one of the most abundant species over quadrats in 2018–2019, from 0% in 2015 to 37% mean coverage in 2019 (Fig. 2), while the coverage of the bioindicator species *P. clavata* and *M. expansum* was reduced (see Table 1). In the case of *P. clavata*, epibiosis by *R. okamurae* was frequently observed in 2018 and 2019, when the dead sections of the gorgonian (visible due to its white skeleton) were more abundant than in 2015 and 2017 (Year: F = 4.99; $P < 0.05$). The dead sections were more abundant on the replicates with higher coverage of *R. okamurae* (Pearson: $R^2 = 0{,}392$, $P < 0.01$).

According to their dispersion index ($\overline{D}$), some variables were spatially clustered, as it is the case for *C. rubrum* and *R. okamurae* (Table 2). Seemingly, big-sized taxa such as *Sphaerococcus coronopifolius* Stackhouse, occupied a high coverage when present and were over-dispersed. These variables were down-weighted prior to multivariate analysis. In the case of *R. okamurae* and *C. rubrum*, the high dispersion was due to the spatial distribution of the two species, which were observed to be occupying different areas of the monitored surface (see Graphical Abstract). As a result, the coverage of these two species was negatively related among replicates, which was tested post-hoc with a Pearson correlation test ($R^2 = 0.16$, $P < 0.05$).

The maximum temperatures in 2018 were: 21.8 °C (Marsa), 21.6 °C (Leila) and 20.6 °C (Belyounech); in 2019: 19.8 °C (Marsa) and 22.8 °C (Leila) (see Supplementary figure D.1). This last temperature peak was registered by only one of the two data loggers installed in Leila, while the other recorded a maximum of 20 °C for the same period. Data is incomplete for Belyounech, as the logger was lost for the period 2018 to 2019.

4. Discussion

Until 2015, the habitat monitored in Jbel Moussa was dominated by bioindicator species, which were abundant within the Natural Park (Bitar, 1987; Bazairi et al., 2016; Espinosa et al., 2019). Unfortunately, *Rugulopteryx okamurae* became dominant in the area in 2018 and 2019, quickly producing a shift in the coralligenous habitat and its bioindicator community.

The most impacted species within the studied habitat was the gorgonian *Paramuricea clavata*. *Paramuricea clavata* is a long-life species with a limited capacity of dispersal and recover after a mortality event (Linares et al., 2005, 2008b). This species is vulnerable to water warming, as heat waves can cause a thickening of the gorgonian branches, a weakness of the polyps and a subsequent increase in diseases and epibionts (Garrabou et al., 2009; Linares and Doak, 2010). Besides, the fitness of this species can be reduced by invasive algae (see Cebrian et al., 2012). Hereby, the observed impacts were probably favoured by the combined effect of global warming and the epibiosis that *P. clavata* suffered from R. okamurae (García-Gómez et al., 2018; 2020a; see Video Abstract). As the impacts described here were observed to be generalized in the area occupied by R. okamurae, the distribution and connectivity of P. clavata populations may have been reduced (García-Gómez et al., 2018; 2020a).

The sciaphillic endangered species *Corallium rubrum* was not particularly impacted, although *R. okamurae* was highly abundant on the surfaces adjacent to the unlit areas inhabited by this species. On the contrary, the species inhabiting photic hard bottoms, such as the gorgonian *Eunicella singularis* (Esper, 1971), are interacting with *R. okamurae* and their populations may be also receiving an important impact (Linares et al., 2008a; García-Gómez et al., 2018; 2020a; see Video Abstract). Gorgonians are ecological engineers and play a key role on the ecosystems so their regression may have uncertain ecological consequences (Linares et al., 2005; 2007; 2010; Navarro-Barranco et al., 2019). For this matter, it would be interesting to further develop conservation measures such as pruning, which has proven successful in the gorgonian *Ellisella paraplexauroides* Stiasny, 1936 (Sánchez-Tocino et al., 2017).

5. Conclusions

This article provides first quantitative evidence of the effects of *Rugulopteryx okamurae* on the Mediterranean coralligenous habitat. Besides, it constitutes the first steps towards the implementation of Common descriptors C1, C2 and C6 of the Ecological Objectives EO1 and EO2 of the Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria (IMAP) in this area of the Mediterranean. A reinforcement of the Mediterranean monitoring networks is needed for tracking this and other bioinvasions, but a rapid response is required if we want to catch up with *R. okamurae*, as the species has already been sighted in central Alboran Sea (unpublished data) and could potentially expand through the Mediterranean region (Muñoz et al., 2019). Therefore, the present study could provide valuable information for future monitoring, conservation and management actions. In those cases, species such as *P. clavata* could be easily monitored to estimate the extent of the impact.

CRediT authorship contribution statement

Juan Sempere-Valverde: Investigation, Formal analysis, Visualization, Writing - original draft. **Enrique Ostalé-Valriberas:** Investigation, Data curation. **Manuel Maestre:** Investigation, Data curation. **Roi González Aranda:** Investigation, Data curation. **Hocein Bazairi:** Resources, Funding acquisition, Project administration, Writing - review & editing. **Free Espinosa:** Investigation, Validation, Resources, Project administration, Supervision, Writing - review & editing.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2020.107135.

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