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INTERTIDAL PONDS OF MESSINA'S BEACHROCK FAUNAL ASSEMBLAGE, EVALUATION OF ECOSYSTEM DYNAMICS AND COMMUNITIES' INTERACTIONS

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Abstract. Beachrock can be found in intertidal marine environments worldwide even though the knowledge about its ecological value in Messina's strait is still quite scarce. In this study, six tidal ponds of Messina's Beachrock were sampled from October 2016 to October 2017 to investigate the ecological status of the area, biotic and abiotic factors that can influence the faunal assemblage and the relationships among the communities inhabiting the various pools examined. A total of 13399 organisms, belonging to 5 Phyla, were identified by Visual Census. The surveyed stations showed biodiversity values and evenness that depend, above all, from the edaphic features and water exchange of the different tidal ponds. Tidal ponds characterized by a lower water exchange showed a faunal assemblage characterized by the presence of species tolerant to a wide temperature and salinity range, as Mugil cephalus, Clibanarius erythropus and Phorcus turbinatus. The pools with the most water exchange showed the highest abundance and evenness values; while the ponds characterized by hard bottom showed this feature as strong influence on the species composition. A preliminary mathematical study was also carry out to describe, qualitatively, the main mechanisms ruling the interaction between the Clibanarius erythropus and Phorcus turbinatus.

1. Introduction

Coastal ecosystems are complex systems influenced by a large amount of biotic and abiotic factors, such as the tide (Widdows and Brinsley 2002). The tidal daily oscillation creates a zone between high- and low-water levels named intertidal zone. This zone represents the union/separation point between the dry and the wet world (Sara *et al.* 2014). Organisms living within these zones must be able to tolerate a wide range of water parameters fluctuations (Lathlean *et al.* 2014; Capillo *et al.* 2018). The different intertidal zones may exhibit different characteristic features: the most significant one is related to the bottom compositions, which can be principally sandy, muddy or rocky. As easily understood, the rocky formations in the intertidal zone can create a habitat useful for the occurrences of ecosystems. Rocky intertidal formations are worldwide-distributed habitats (Kneale and

Viles 2000; Alexandrakis *et al.* 2013; Mauz *et al.* 2015), and are peculiar formations of those zones, named Beachrocks, which are hard coastal sedimentary formations consisting of beach sediments, rapidly cemented through the precipitation of carbonate cements that, in turn, typically consist of High-Magnesian Calcite (HMC) or Aragonite (Ar) (Vousdoukas *et al.* 2007). These formations play an important role in coastal areas, such as in beach morpho-dynamics, beach erosion mitigation effect, locking of the beach profile, alteration of the nearshore hydrodynamics, sediment supply changes, and many other (Vousdoukas *et al.* 2007). Messina's Beachrock represents an interesting zone, especially in terms of coastal ecology. In fact, the Beachrock represents the only hard substratum of natural origin in this bathymetric range that hosts complex ecosystems in Messina. This intertidal rocky bench is present in a trait of the Sicilian northeastern coast and is composed by a mid-Pleistocene conglomerate with irregular shapes and variable characteristics, extending almost two kilometers (Bottari *et al.* 2005; Cosentino and Giacobbe 2015). Due to its extreme variability, especially in shape, tidal ponds often occur along the beachrock creating microhabitat exploitable by several intertidal communities. Ponds, as the whole rocky formation, are highly influenced by the tidal oscillations and/or marine weather conditions. The principal water variables (temperature, salinity, pH, DO) are quite unstable with highly oscillating values and affect the ecosystem composition and the interactions among the different communities and organisms within the habitat (Fazio *et al.* 2013a). All these features contribute in creating an environment with peculiar biotic and abiotic characteristics. Despite the zone in which this environment persists, the Messina's Strait, has been extensively studied and reported in literature under different points of view (Giacobbe and Spanò 1996; Spanò 1998; Brandt *et al.* 1999; Spanò and De Domenico 2017) the data and information about the beachrock and its ecosystem dynamics are still quite scarce.

The present study aims at partially filling this gap by investigating several aspects of the Messina's beachrock. In particular, the goal is to assess:

- The ecological status of the area and its importance among the various coastal ecosystems
- The "natural" threshold toleration values for organisms inhabiting the intertidal zone
- The possible prey-predator interactions existing among the populations living within the different tidal ponds.

2. Materials and methods

2.1. Study area. The Strait of Messina is the geographical point of union between the Ionian and Tyrrhenian basins. These basins, although in continuity, are distinct in their different physical and chemical parameters as well as in their physiographic characteristics. The large difference in heights of surface water masses generates very strong currents at each change of tide. Strong tidal currents allow the presence of a unique ecosystem in the Mediterranean Sea.

The sampling area is located in the north-eastern part of Messina, between the villages of Ganzirri (38°25'69"N, 15°61'24"E) and Faro (38°15'43" N, 15°38'13" E) (see Figure 1), which is also included in the Oriented Natural Reserve of Capo Peloro (Messina, Italy) SCI (ITA030008). This zone, named Beach Rock, is a sedimentary formation, represented by an extensive stretch of coastline, that ranges from the intertidal zone to the upper fringe

FIGURE 1. Study area, white lines correspond to the sampled tidal ponds.

of the infralittoral (Fazio *et al.* 2013a). The total length of the rocky formations is about 2 kilometers. As already mentioned, the Messina's Beach Rock is characterized by the presence of tidal ponds, which present different shapes and connections with the sea and, as a result, they undergo in different ways the high and low tide flows.

2.2. Sampling design. The study was conducted over a one-year period ranging from October 2016 to October 2017. In such a period, we examined six fifty-meter long randomly selected stations named from A to F (see Figures 1 and 2).

2.2.1. *Species census.* In order to determine the faunal assemblage, the Underwater Visual Census was carried out, suitably modified depending on the characteristics of the sampling area. The underwater visual census method is based on on-site visual counts of organisms following a pre-measured rope. Census methods can be done in a variety of ways, the most common of which is by snorkeling or scuba diving. In our case, being a low-depth zone, the survey was made from the surface using a plastic tube with a glass at the bottom that permits to see the organisms. The method was also adapted to the reduced width of the stations: in fact, in each station, the transept was located parallel to the coastline. The organisms detected through this technique were hence listed on a field protocol and subsequently digitalized on a spreadsheet for graphical and statistical elaborations.

2.2.2. *Water variables.* Determining the principal water variables of every water body is of fundamental importance to understand both water quality and adaptation ranges of organisms inhabiting in. Temperature, Salinity, pH and Dissolved Oxygen (DO), were

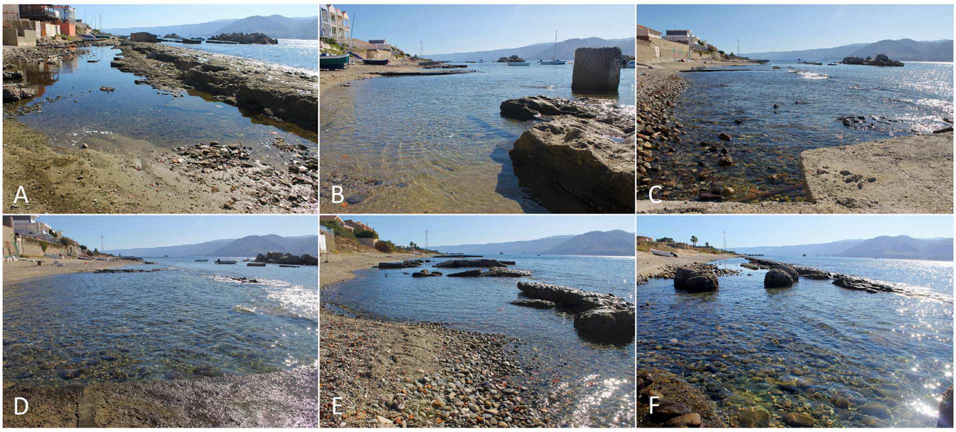

FIGURE 2. Study area, sampled tidal ponds. From the figures the different characteristics of each station can be noted.

measured in situ, using a multi-parametric probe IM201 (Idromar s.r.l., Milano, Italy). In order to calibrate the oxygen sensor, Winkler method was used for the determination of DO (Sanfilippo *et al.* 2016).

2.2.3. *Ecological indices.* The Shannon–Wiener and Pielou indices has been used. Shannon–Wiener describes the diversity of a community. It is calculated in the following formula (1):

$$H^{'} = \sum_{j=1}^{S} p_j \ln p_j \tag{1}$$

where p_j is the proportion of individuals found in species j. For a well-sampled community, we can estimate this proportion as $p_j = n_j/N$, where n_j is the number of individuals in species j and N is the total number of individuals in the community, whereas S indicates the number of species. According to the above definition of p_j, it results that and it justifies the presence of the minus sign in eq. (1). Typical values of H' are in the range between 1.5 and 3.5 in most ecological studies, rarely it is greater than 4. The Shannon-Wiener index increases with the increase of both the richness and the evenness of the community. To calculate the evenness of species, the Pielou's Evenness Index J is taken into account (2):

$$J = H^{'}/\ln S \tag{2}$$

Pielou's index shows how the Shannon-Wiener diversity can be subdivided in a hierarchical way.

3. Results

Owing to the complexity of the beachrock system, in the following subsections we will examine, separately, the key features characterizing this environment.

TABLE 1. Tidal ponds main features, dimensions are given in cm. WE: Water exchange; Depth and width: expressed in cm; Edaphic characteristics, HB: Hard Bottom; S: Sandy; G: Gravel.

	A	**B**	**C**	**D**	**E**	**F**
WE	1	6	4	5	3	2
Depth	50	65	70	70	55	60
Width	950	550	1150	1200	1050	750
Edaphic characteristics	HB	S	G	G	G	HB

3.1. Tidal ponds shape and characteristics. The six tidal ponds studied exhibit different characteristics in terms of connection with the sea, medium depth, maximum width, and edaphic characteristics (see Figure 2). A first classification has been done with respect to the water exchange with the sea. Depending on the degree of connection with open waters, at each tidal pond has been assigned a value between 1 and 6 (WE, water exchange), where the value 1 (6) corresponds to the tidal pond with the minimum (maximum) water exchange. The classification and the main characteristics are summarized in Table 1. As reported in Table 1, tidal ponds depth resulted to vary between 50 and 70 cm (these values have to be considered on average). Moreover, the tidal ponds here studied showed a quite high variability in width, varying from 550 (Stat.B) to 1200 (Stat. D). The edaphic characteristics showed that A and F shared the same hard bottom composition as C, whereas D and E had the same edaphic characteristics, that is mainly composed by gravel. The B showed different characteristics respect to the others both for the edaphic components and open degree; in fact, the bottom of St. 2 showed sandy characteristics and the maximum opening.

3.2. Species census and Ecological indexes. The list of species recorded during this study is reported in Table 2. A total of 13399 organisms have been recorded belonging to the phyla: Porifera, Cnidaria, Mollusca, Arthropoda, Echinodermata, Chordata. The total counted organisms expressed in percentage of each phylum has been plotted in the pie chart (Figure 3), whereas the bar chart of Figure 4 reports the same data divided per tidal ponds. For each station, we then calculated the ecological indexes of diversity (Shannon–Wiener's H') and evenness (Pielou J). Corresponding results are reported in Table 3.

TABLE 2. Species list sorted by Phyla and their presence in the different tidal ponds.

Phylum	Species	A	B	C	D	E	F
porifera	*Axinella damicormis*			x			
cnidaria	*Actinia equina*		x	x	x	x	x
	Aiptasia mutabilis						x
	Anemonia sulcata			x	x	x	x
Mollusca	*Aplysia dactylomela*			x	x	x	x
	Aplysia fasciata			x			
	Arca noae						x
	Cerithium vulgatum	x	x	x	x	x	x
	Cyprea pantherina						x
	Hexaplex trunculus	x	x	x	x	x	x
	Patella caerulea	x	x	x	x	x	x
	Phorcus turbinatus	x	x	x	x	x	x
	Sepia officinalis				x		
Arthropoda	*Clibanarius erythropus*	x	x	x	x	x	x
	Eriphia verrucosa	x	x	x	x	x	
	Maja squinado			x			x
	Pachygrapsus marmoratus	x	x	x	x	x	x
	Pagurus bernhardus					x	x
	Palaemon elegans	x		x	x	x	x
	Percnon gibbesi		x				
	Pilumnus hirtellus	x					
	Xantho poressa			x			x
Echinodermata	*Arbacia lixula*	x	x	x	x	x	x
	Coscinasterias tenuispina	x	x	x	x	x	x
	Echinaster sepositus		x		x		x
	Holoturia sanctori		x	x			
	Holoturia tubulosa			x	x	x	
	Marthasterias glacialis				x		
	Paracentrotus lividus			x		x	x
Chordata	*Apogon imberbis*		x				
	Chelon ramada		x				
	Epinephelus marginatus						x
	Gobius niger		x		x	x	
	Mugil cephalus	x	x	x		x	
	Neogobius melanostomus				x		
	Oblada melanura						x
	Parablennius gattorugine			x		x	x
	Scorpaena porcus		x		x		
	Scorpaena scrofa			x			
	Thalassoma pavo		x	x	x	x	x
	Tripterygion tripteronotus	x	x	x	x	x	x

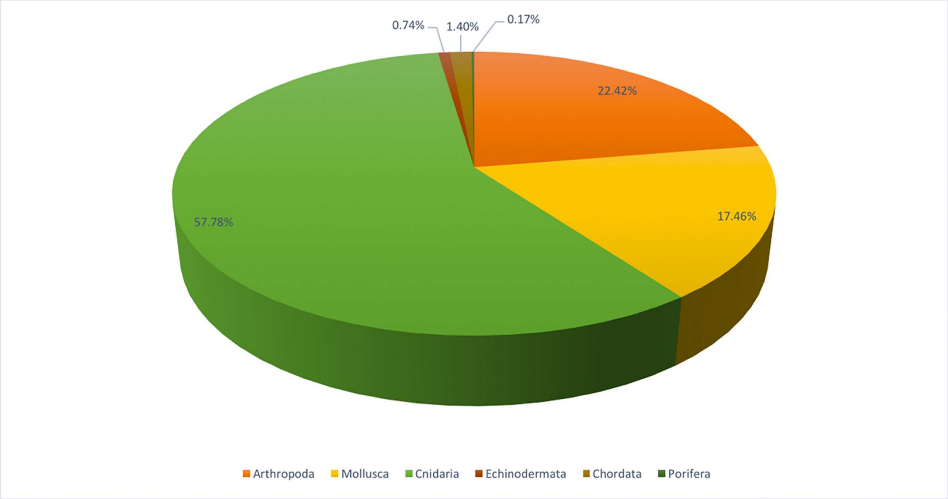

FIGURE 3. Percentage of each phylum in the study area.

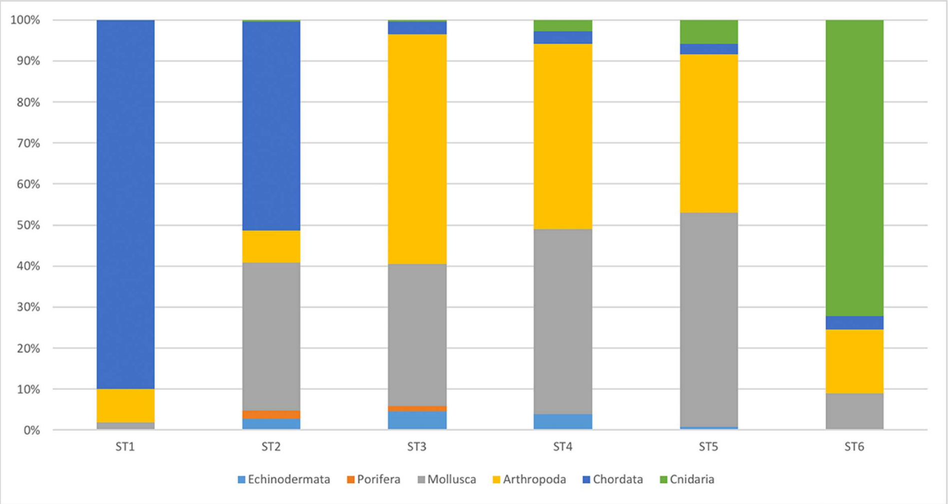

FIGURE 4. Ponds faunal composition divided per Phyla.

As it can be noticed, the indices showed significant differences among the various tidal ponds. The values of the Shannon–Wiener's (H') diversity, in detail, resulted to be in the range between a maximum of 2.76 in St. B and a minimum of 0.72 in St. A. Analogously, the Pielou (J) values take the maximum of 0.90 in St. B and the minimum of 0.27 in St. A.

3.3. Water variables. Principal water variables (Temperature, salinity, pH, DO) have been also recorded in order to extract more information on the tidal ponds here investigated. In

TABLE 3. Ecological indices for different tidal ponds.

	A	B	C	D	E	F
Shannon-Wiener/s (H')	0.72	2.76	2.54	2.73	2.30	1.42
Pielou (J)	0.27	0.90	0.78	0.89	0.74	0.42

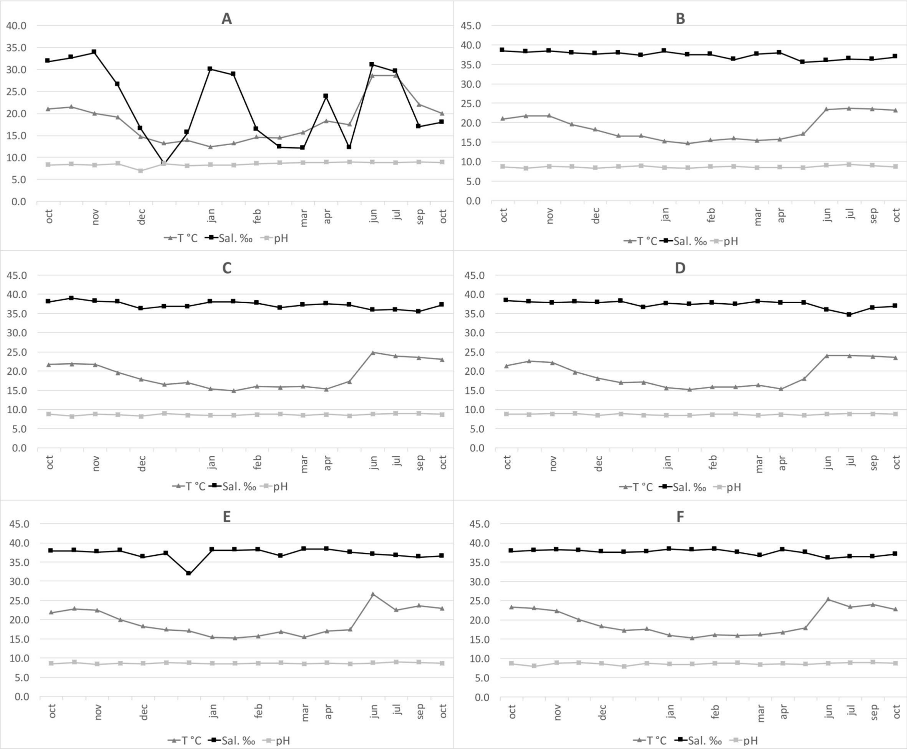

FIGURE 5. Water variables of the tidal ponds during the survey.

order to inspect the behavior in each station here considered, results are plotted separately (see Figure 5). The tidal pond labeled "A" showed the highly oscillating water parameters, with the annual maximum salinity of 33.8 PSU on November, 3rd while the annual minimum was of 8.5 PSU on December, 14th. Temperature (and salinity) showed fluctuating values with a range between the minimum of 12.4 °C on January,12th and maximum of 28.6 °C both in June and July. The measured PH showed a homogeneous yearly trend with the only exception occurred on December, 6th when the pH value resulted to be 7. In the other tidal ponds (B-F), the water variables showed a linear trend. The salinity had a yearly trend ranging between 35 and 40 PSU except for St. E in which on December,27th the measured value was 31.8 PSU. The temperature varied between a maximum of 26.6°C (St.E in June) and a minimum of 12.4°C (St. A in January). High oxygen levels (above 90 % of saturation) were measured throughout the survey.

4. Discussion

Beachrock is "the consolidated deposit that results from lithification by calcium carbonate of sediment in the intertidal and spray zones of mainly tropical coasts" (Scoffin and Stoddart 1983). The entire zone, named beachrock, represents a complex ecosystem, comprehending interaction of bottom composition, different physical-chemical variables and organisms that inhabit this area. Due to the extremely variable shapes of the beachrock, tidal ponds often occur in which complex ecosystems are present. All-over the world, numerous beach rock formations are present and have been extensively studied in term of orogenesis, faunal assemblage, water variables, etc (Kneale and Viles 2000; Bottari *et al.* 2005; Shen *et al.* 2017). Despite the Messina's beachrock formations are quite important for their ecological values, hosting an extended vermetus formations (Caruso and Chemello 2009) (a biotope protected by the European Habitat Directive (92/43/EEC)), the scientific information on this coastal hard formations' ecosystem are quite scarce; the only data present in literature are those by Bottari *et al.* (2005), Cosentino and Giacobbe (2015), and Spanò and De Domenico (2017). Bottari and collaborators reported about Genesis and geomorphologic and ecological evolution of the Ganzirri salt marsh (Messina, Italy) and report about the possible beachrock formation; Cosentino and Giacobbe considered in their study the mollusc assemblages of the upper sub-tidal fringe of the beachrock, while Spanò and De Domenico (2017) just reviewed the known characteristics of the Messina's beachrock.

The actual knowledge on a so important and protected zone is still in its infancy (Capo Peloro Lagoon Natural Oriented Reserve, DA n. 437/44 del 21.06.2001). Basic information are still scarce especially about faunal assemblage and communities' interactions (Fazio *et al.* 2012; Faggio *et al.* 2014; Pagano *et al.* 2016, 2017). As already mentioned, the beachrock represents the only natural hard substrates in this bathymetric range (Spanò and De Domenico 2017) and the occurrences of tidal ponds represent a very important feature in term of habitat creations. The Messina's Strait represents an incredible spot of bio-diversity thanks to its water variables characteristics and intense hydrodynamics; but the presence of strong currents creates also difficulties to the organisms inhabiting the coastal areas, in term of habitat exploitation (Beachrock, with its tidal ponds represent "calm" environments that can host many faunal and floral assemblages (Gravem and Morgan 2017).

The area of the Strait of Messina occupied by the beachrock is quite large almost (2 km) so, in order to provide an implementation of knowledge about the zone, six tidal ponds have been randomly selected and studied. From the surveys in tidal ponds, a total of 13399 organisms belonging to five phyla have been censed demonstrating the presence of suitable habitats for the insurgence of ecosystems. Among the various tidal ponds a great variability has been recorded, that can be ascribed principally to the water exchange degree that affects the principal water variables and edaphic composition (Ng *et al.* 2015), and then the faunal assemblage composition.

For instance, tidal pond named A, having the minor WE and the high fluctuating water variables and hard bottom, showed a faunal composition composed principally by species tolerant to wide ranges of salinity and temperature such as, Mugil cephalus, Clibanarius erythropus and Phorcus turbinatus (Cardona 2000; Tirelli *et al.* 2007; Boucetta *et al.* 2016). The abundance of M. cephalus specimens has largely affected the values of Shannon-Wiener ($H' = 0.72$) and Pielou ($J = 0.27$) indices, that thus indicate the lowest bio-diversity degree among the selected stations. The other tidal ponds, despite the variability of WE degrees, showed physical-chemical characteristics more stable than A, in agreement with literature data related to the Strait of Messina (author personal data) (Brandt *et al.* 1999).

Station B showed the phylum Chordata as the most representative one, with specimens belonging to seven different species. Moreover, apart from the seven-fish species, other phyla were present. Consequently, the Shannon-Wiener ($H' = 2.76$) and Pielou ($J = 0.90$) indices were the highest among the tidal ponds: this feature can be ascribed to both the most open degree and bottom characteristics of the St.B. Despite the mentioned characteristic of higher water exchanges degree, the St.B remains a tidal pond. In fact, during the low tide, it is separated from the sea; this consideration leads to the hypothesis that the St.B creates an intertidal habitat for different coastal, benthic and demersal species that exploit this zone to live protected from currents and predators (Gravem and Morgan 2017).

In the stations C and D, the bottom composition was the same (G), the two tidal ponds were separated only by a human-made hard construction; despite this, there was a different WE degree. Both the third and fourth tidal pond showed higher abundances in species belonging to the phyla Mollusca and Arthropoda. The Shannon-Wiener and Pielou indices showed different values between C and D, and precisely the data highlighted that D had higher bio-diversity and evenness values ($H' = 2.73, J = 0.89$) than C ($H' = 2.54, J = 0.78$). Despite the two tidal ponds showed very similar characteristics, the differences in indices values can be ascribed to the different water exchanges degree, as already proposed for B; in fact, the D tidal pond had higher water exchanges fluxes than the C.

The indices for the other tidal ponds (E and F) resulted highly affected by both WE and edaphic characteristics. E tidal pond had values of 2.30 (H') and 0.74 (J) reflecting a quite homogeneous distribution of organisms over the various species. The quite low values ($H' = 1.42$ and $J = 0.42$) for ecological indices of tidal pond F is highly affected by its edaphic characteristics, WE, and massive presence of the n Anemonia sulcata that is well known as a species that forms populations with high number of individuals, as for other cnidarians (Mills 2001). Among the various species living the tidal ponds of the Messina's beachrock, Phorcus turbinatus and Clibanarius erythropus were particularly interesting from an ecological point of view. In fact, they were seemed to be linked by a prey-predator relationship. The relationship between the two species will be discussed in the next Section.

5. A prey-predator mathematical model: qualitative analysis

In this Section we consider a mathematical prey-predator model to gain insights into the mechanisms that rule the interaction between the populations previously investigated. In particular, from a direct inspection of Table 2 and Figures 3 and 4 we notice that the two most significant species are represented by the Phorcus turbinatus and Clibanarius erythropus. In fact, for the whole duration of the survey, these populations have been constantly detected in all the considered stations (tidal ponds) and, at the same time, they belong to a trophic chain in which the P. turbinatus plays the role of prey and the C. erythropus acts as predator. On the other hand, the phylum Cnidaria, that represents the most abundant population here detected, does not take part in such a study because this species has a very localized distribution and indeed it has been found in few stations and with high abundance only in St.6.

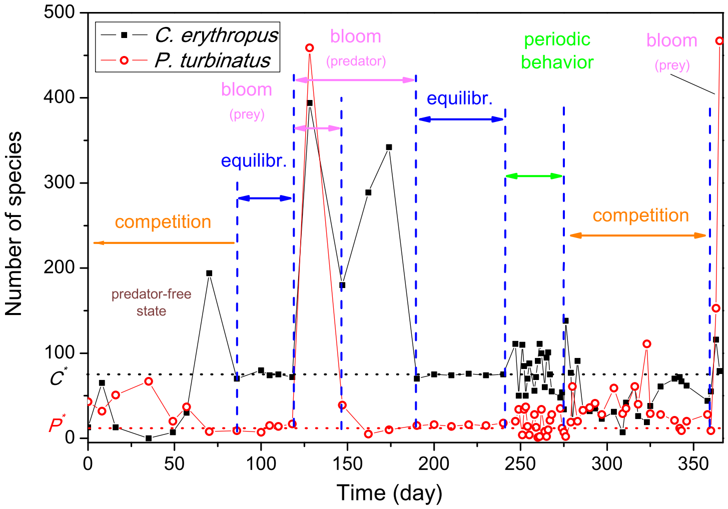

FIGURE 6. Time evolution of the number of species of *C. erythropus* (filled symbols) and *P. turbinatus* (open symbols) over a one-year period. Horizontal dotted lines denote the equilibrium populations whereas vertical dashed lines are used to separate different dynamical regimes.

Therefore, it is of a certain interest to provide a qualitative description of some key dynamics occurring between these two-above species and that have been observed experimentally. To this aim, through the visual census procedure described previously, we also took note of the amount of these species present in each station. Then, by summing over the six stations, we have been able to reconstruct the behavior of the two population sizes over a one-year period. Results are shown in Figure 6.

The figure reveals the existence of four dynamical regimes:

I) competition: prey and predator mutually interact, so that any increase of predator's population leads to a decrease of prey's one and vice versa;

II) equilibrium: the absence of interaction between preys and predators keeps the corresponding population sizes almost constant;

III) bloom: a sudden increase of the populations (experimental data indicate that predators undergo a single bloom period per year, whereas two bloom periods/year have been reported for preys);

IV) periodic behavior: populations of prey and predator mutually interact in such a way their sizes oscillate periodically in time about their equilibrium values.

To achieve the abovementioned goal, we make use of a prey-predator model (also discussed in Barbera *et al.* (2015)), where spatial effects are neglected:

$$\begin{cases} \frac{dP}{dt} = \beta P\left(1-\frac{P}{k}\right) - \frac{\lambda P^2}{\mu^2+P^2}C \\ \frac{dC}{dt} = \alpha\left(\frac{\lambda P^2}{\mu^2+P^2} - \delta\right)C \end{cases} \tag{3}$$

In (3), $P(t)$ and $C(t)$ denote the number of species of P. turbinatus and C. erythropus, respectively, at time t; the prey growth is assumed to take a standard logistic form with β the intrinsic growth rate and k the carrying capacity; the parameters λ and μ denote the maximum predator grazing rate and the half-saturation constant for grazing, respectively; the coefficient α represents the predator growth efficiency and $\alpha\delta$ gives the predator mortality. In deriving this model, we made some simplifying assumptions: diseases and infections are neglected; predation follows a Holling type-III functional response; predator mortality is linear; the trophic chain is limited to two compartments only.

This model admits three equilibrium states in the form $E^{eq} = (P^{eq}, C^{eq})$:
i) $E_1^{eq} = (0,0)$, the trivial state denoting an empty ecosystem;
ii) $E_2^{eq} = (k,0)$, the predator-free state;
iii) $E_3^{eq} = (P^*, C^*)$, the coexistence state characterized by $P^* = \mu\sqrt{\frac{\delta}{\mu-\delta}}$ and , $C^* = \frac{\beta}{\delta}P^*\left(1-\frac{P^*}{k}\right)$, which is meaningful if and only if the condition $\delta < \frac{k^2}{\mu^2+k^2}\lambda = \delta_{cr}$ is fulfilled.

In order to inspect the stability character of the above equilibria, we linearize system (3) around each equilibrium E^{eq} for small time-dependent perturbations and take the coefficient δ as the control parameter. Results of this analysis indicate that: E_1^{eq} is always unstable; E_2^{eq} is stable for $\delta > \delta_{cr}$ (where E_3^{eq}does not exist) whereas the stability character of E_3^{eq} is given by:

$$\begin{array}{lcc} \text{for } \delta \le \tilde{\delta} & \Longrightarrow & \text{always} \\ \text{for } \delta > \tilde{\delta} & \Longrightarrow & \text{if } \frac{2\mu\delta}{2\delta-\lambda}\sqrt{\frac{\delta}{\lambda-\delta}} > k \end{array} \tag{4}$$

being $\tilde{\delta} = \frac{\lambda k^2}{4\mu^2+k^2} < \delta_{cr}$. It can be verified that, at the critical value of $\delta = \delta^H$ satisfying $\frac{2\mu\delta^H}{2\delta^H-\lambda}\sqrt{\frac{\delta^H}{\lambda-\delta^H}} = k$, the system undergoes a Hopf bifurcation leading to the appearance of time-periodic oscillations.

We believe that the mathematical model (3), despite its simplicity, could be adequate enough to capture some of the dynamical features reported in Fig.6. Among the most significant ones: (i) the trivial (empty) state E_1^{eq} is never detected; (ii) the predator-free configuration E_2^{eq} might be identified at approximately day 35 and, because of its spotted nature, it should confirm the unstable character (indicating that $\delta < \delta_{cr}$); (iii) the existence of limit cycles, corresponding to a periodic behavior of the interacting species, might be compatible with some experimental observations (and providing further information on the value of δ, being $\delta < \delta_{cr}$). In fact, results obtained in the time window ranging from day 245 to day 273 reveal a periodic oscillation of the populations of the two species about the coexistence state (E_3^{eq}), that qualitatively agrees with the model prediction Figure 7.

More detailed analytical investigations, together with possible generalizations of the model (Barbera *et al.* 2013, 2015; Consolo *et al.* 2017), are beyond the scope of the present paper and will be presented elsewhere.

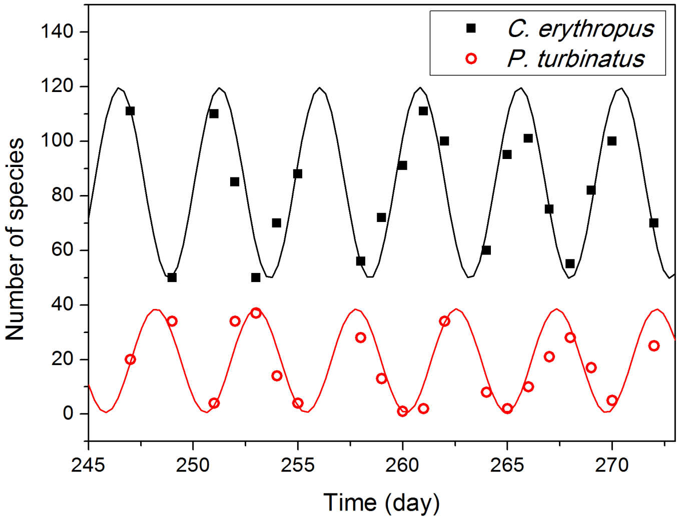

FIGURE 7. A zoom of the time window in which a periodic behavior of the two species is observed, together with a periodic fit of the experimental data (solid lines).

6. Conclusions

In conclusion, it is clear that the beachrock's morphological characteristics and their tidal ponds offer a good habitat, supporting the settlement of several benthic and demersal communities of both vertebrate and invertebrate species. The hydrological and sedimentological context seems to have a strong influence on the specific assembly of benthic invertebrates, in particular, the shape of the pools and the water exchange could be determining factors on the presence, or not, of some species.

Further studies are, of course, needed to deepen the knowledge on this interesting ecosystem. For instance, it could be of a certain interest to inspect in more detail the dynamics occurring among the species of the trophic chain; to elucidate the seasonality of the species and, finally, to examine the site fidelity of individuals visiting pools throughout the tidal cycle.

Acknowledgments

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