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10 **Material type and roughness influence structure of intertidal communities on coastal**

11 **defences**

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22 **Abstract**

23   On a global scale, urbanisation has resulted in substantial proportions of the coast being

24   replaced by artificial structures such as marinas, breakwaters or seawalls. There is broad

25   consensus that coastal defence structures are poor surrogates of the natural habitats they

26   replace. Here we investigate the effect of the type and roughness of materials used for the

27   construction of artificial structures on the biota by comparing abundances and distribution

28   of key intertidal taxa between natural shores and coastal defences. Lower abundance of

29   gastropods and barnacles were found on artificial coastal defence structures (regardless of

30   the material type). At small–spatial scales, there was a significant effect of roughness which

31   increased the abundances of key taxa. Results suggest that choice of materials used for the

32   construction of coastal defence structures *per se* has little effect on community structure,

33   but that enhanced roughness could make coastal defences better surrogates of natural

34   habitats by supporting assemblages that are more similar to those found on natural shores.

Introduction

The extent of natural coastal habitats converted for urban use, including the construction of coastal defence structures such as seawalls, breakwaters or groynes, is increasing globally (Goodsell 2009; Firth *et al*. 2013). This trend is likely to continue, given predictions for sea level rise and increased storminess (Thompson *et al*. 2002; Wong *et al*. 2014). There is thus a clear interest in understanding the environmental consequences of these artificial habitats (Moschella *et al*. 2005), with several studies highlighting the importance of understanding the underlying ecological processes (Moreira *et al*. 2006; Munari 2013) when planning developments along shores (Chapman & Bulleri 2003).

Construction of artificial structures provides additional hard substrata for epibenthic organisms. These structures, however, can have a strong effect on the structure and functioning of flora and fauna assemblages in adjacent hard- or soft-bottom habitats (e.g. Martin *et al*. 2005; Martins *et al*. 2009; Bertasi *et al*. 2007). Moreover, although epibiotic communities on artificial structures can be qualitatively similar to those on natural rocky shores, differences in the diversity, abundance, behaviour and/or phenology of epibiota on breakwaters, seawalls or groynes have been reported by many authors (e.g. Chapman 2003; Chapman & Bulleri 2003; Bulleri *et al*. 2004; Moschella *et al*. 2005; Moreira 2006; Moreira *et al*. 2006; Martins *et al*. 2009; Firth *et al*. 2013). Collectively, these studies suggest that artificial structures cannot generally be considered surrogates of the natural habitats they replace.

Some studies consider that artificial structures built with locally quarried materials are likely to have minimal effect on intertidal assemblages, and therefore predict that the

59   epibiotic communities on those structures would be similar to those colonizing nearby

60   natural rocky habitats (see Thompson *et al*. 2002; Branch *et al*. 2008). However, there is

61   evidence that this is not always true and differences have been found between assemblages

62   on natural habitats and artificial structures made of locally quarried rock (see Bulleri &

63   Chapman 2010, for review). Moreover, current literature on the effects of coastal

64   urbanisation includes ambiguous results, revealing both positive and negative effects on the

65   maintenance of local populations. For instance, the outcomes of investigations on the

66   effects of coastal urbanisation on the distribution of limpets have been variable. Some

67   authors (Moreira *et al*. 2006; Díaz–Agras *et al*. 2010) found no differences in the

68   abundance or frequency of occurrence of limpets inhabiting artificial substrata and rocky

69   shores, while other authors reported greater numbers of limpets on either natural (e.g.

70   Bulleri & Chapman 2004; Bulleri *et al*. 2004) or artificial structures (Guerra–García *et al*.

71   2004).

72   Modification of artificial structures to make them better surrogates of natural habitats is a

73   form of mitigation that is receiving increasing attention (Moreira *et al*. 2007; Chapman and

74   Blockey 2009; Martins *et al*. 2010; Firth *et al*. 2013). Some attempts to reduce their

75   ecological impacts have been addressed by adding elements (e.g. wetland vegetation) or

76   features of habitat (e.g. rock-pools) that are absent from urban structures (Zedler & Leach

77   1998; Bulleri & Chapman 2010). Natural rocky shores differ from artificial structures in a

78   number of important features (Chapman and Blockey 2009; Firth *et al*. 2013) namely

79   differences in material composition and structural roughness, and there is now a substantial

80   body of work highlighting the important role of substratum heterogeneity in structuring

81   intertidal communities (Thompson *et al*. 1996; Pinn *et al*. 2008; Griffin *et al*. 2009; Skov *et*

82   *al*. 2011; Gartner *et al*. 2013). Artificial structures generally fail to provide the array and

83   diversity of habitat heterogeneity found on most natural shores (Chapman 2006; Firth *et al*.

84   2013; Browne & Chapman 2014). For instance, seawalls generally lack microhabitats such

85   as rock pools that retain water during low tide allowing the establishment specialist species

86   (Chapman & Blockley 2009; Firth *et al*. 2013; Browne & Chapman 2014). Likewise,

87   seawalls or groynes have steep inclinations, which reduce the areal extent of the intertidal

88   zone compared to the generally gentler slope of natural habitats (Moreira *et al*. 2007;

89   Bulleri & Chapman 2010). Therefore, we hypothesize that artificial structures with rougher

90   surfaces, i.e., more similar to natural habitats, will benefit intertidal species, at least those

91   small-sized which can easily find refuge from the harsh intertidal conditions.

92   The ecological impacts of coastal infrastructure in shallow coastal waters may vary

93   accordingly with the nature of the surrounding habitat (Bulleri & Chapman 2010). Most of

94   the research to date has considered coastal defences that lie behind soft sedimentary

95   shorelines that are at risk form erosion (Gacia *et al*. 2007), thus providing additional hard

96   surface for colonization by benthic organisms where it was previously absent (Chapman &

97   Bulleri 2003; Moschella *et al*. 2005). This study was conducted in the Azores, an oceanic

98   archipelago where volcanic rubble and steep cliffs constitute the most common marine

99   habitats. In the Azores, most artificial structures are used to protect nearby towns from high

100 sea levels during winter storms. In contrast to many other locations worldwide, coastal

101 defences in the Azores are typically built on top of former natural stretches of rocky coasts,

102 thus showing similarities in physical nature (i.e., hard substrate) to adjacent natural

103 environments. Therefore, unlike areas where artificial structures are deployed on soft-

104 bottom areas, we hypothesize that assemblages on most of the Azorean artificial structures

105   will be of similar composition to those found on adjacent natural environments. However,

106   given the well known effect of substratum type in structuring intertidal assemblages (e.g.

107   Connell & Glasby 1999; Glasby 1999), the first objective in this study was exactly to

108   compare patterns of distribution and abundance of intertidal organisms on natural rocky

109   shores with that of coastal defence structures (boulders and blocks) made of either basalt

110   (locally quarried rock) or concrete (a non–natural substratum, and probably the most

111   common material used in coastal urbanisation). We are interested in testing if using rocks

112   that were locally quarried would somehow minimise the impacts of coastal urbanisation. In

113   addition to this, we also investigated how natural small-scale variability in substratum

114   topography (within artificial structures made of basalt) influences the structure of intertidal

115   assemblages. We predict that areas of the substratum with rougher topography will support

116   assemblages that differ from those found in areas of the substratum with smoother

117   topography.

118   This information will help to understand the effects of hard defence structures, and may be

119   potentially provide information that can be used to mitigate the ecological impacts of

120   coastal urbanisation (e.g. Martin *et al*. 2005; Moschella *et al*. 2005; Martins *et al*. 2010).

121   **Material and Methods**

122   The study was conducted on São Miguel Island (Azores, Fig. 1), where maximum tidal

123   range is approximately 2 m and the coast is exposed to medium to high levels of wave

124   action. In general, three zones can be recognized in the São Miguel Island rocky intertidal,

125   following classical zonation schemes (Stephenson & Stephenson 1972): the low–shore is

126   characterized by a covering of coarsely branched, coralline and turf–forming species of

127 macroalgae; the mid–shore is dominated by the barnacle *Chthamalus stellatus*, whereas the

128 gastropod littorinids *Tectarius striatus* and *Melarhaphe neritoides* usually inhabit in the

129 upper–shore (Martins *et al*. 2008b).

130 To characterize the intertidal assemblage community composition and abundance, sampling

131 was carried out on natural rocky shores of basaltic nature (hereafter referred to as Natural

132 shore), and artificial coastal defence structures built of either basalt (hereafter Basalt

133 artificial structures) or concrete (hereafter Concrete artificial structures) located along the

134 coastline of São Miguel (176 km perimeter, length 65 km, width 8–15 km) (Fig. 1). Only

135 the seaward sides of natural and artificial habitats were sampled to standardize for wave

136 exposure. Five locations representative of the three habitat types (Natural shore, Basalt

137 artificial structures and Concrete artificial structures) were randomly selected (Fig. 1). All

138 locations were separated by tens of kilometers and similarly exposed to incoming oceanic

139 swell. Within each location, five replicate quadrats (25x25 cm) were randomly placed at

140 least 2 m apart on emergent substrata at low–, mid– and upper–shore levels, visually

141 determined by the presence of macroalgae, barnacles and littorinid respectively. The

142 assemblage structure was hence assessed at each level. Percentage cover of sessile

143 organisms (e.g. macroalgae, barnacles) and bare rock (a measure of unoccupied space)

144 were obtained following the methodology described in Dethier *et al*. (1993), in which the

145 abundance of organisms within each of the 25 5x5 cm sub–quadrats (that add up a sampling

146 quadrat) was assigned a score ranging between 0 (absent) and 4 (100% cover of the sub–

147 quadrat). Total percentage cover is then estimated by summing the scores of all sub–

148 quadrats (see Dethier *et al*. 1993 for further details). Macroalgae were identified and

149 grouped into distinct morpho–functional groups (FGs), based on species's morphology and

150   the way they compete for resources (Steneck & Dethier 1994; Arenas *et al*. 2006; Veiga *et*

151   *al*. 2013). The selected FGs were: Ephemerals (considering first colonizers, including

152   diatomaceous biofilms, microalgae and filamentous algae such as *Chaetomorpha*,

153   *Cladophora*), Foliose (e.g. *Pophyra*, *Ulva rigida*), Coarsely branched (e.g. *Caulacanthus*

154   *ustulatus*), Coenocytic (*Codium adhaerens*), Articulated calcareous (e.g. *Corallina*

155   *elongata*), Leathery (e.g. *Fucus spiralis*), Calcified crustose (e.g. *Lithophyllum*), and Non–

156   calcified crustose (e.g. *Nemoderma*). Taxa present within quadrats but not reaching a score

157   of 1 were given a nominal value of 0.5%. Motile invertebrates were identified up to species

158   level, counted and expressed as number of individuals per quadrat. All surveys were made

159   between the 24th June and 4th August 2013, during low–water spring tides.

160   A complementary small-scale study investigated the role of substratum roughness in

161   determining patterns of species distribution on coastal defence structures by comparing the

162   abundance of organisms in blocks with smooth and rough surfaces visually selected *a*

163   *priori* on a basalt seawall at two sites selected 10's of meters apart. Five replicate plots on

164   smooth *vs*. rough blocks were sampled. In this case, only mid– and upper–shore was

165   sampled in this survey, since low–shore roughness was hidden by dense macroalgal

166   dominance. A pin–microrelief method (Vázquez *et al*. 2009) was adapted to measure

167   substratum random roughness (RR) in the sampled plots. Differences in substratum surface

168   height were recorded in 15 cm transects with spacing between readings of 2.5 mm, and RR

169   index was calculated as the standard error among heights (Allmaras *et al*. 1966). This

170   survey was made between August 12th and September 12th 2014, during low–water spring

171   tides. Sampling of the biota was done as described above.

172   Data analysis

173   Multivariate analysis.

174   Differences in the structure of assemblages were investigated for each tidal height using a

175   two–way permutational analysis of variance (PERMANOVA) with habitat (Ha, fixed, with

176   three levels: Natural shores, Basalt artificial structures and Concrete artificial structures)

177   and location (Lo, random, nested in habitat, with five levels) as factors. PERMANOVA

178   analyses were run on Bray Curtis similarity matrix of both untransformed and presence–

179   absence transformed complete epibenthic assemblage (i.e. including percentage cover of

180   macroalgae/barnacles and abundance of gastropods). Pair-wise tests were used to compare

181   the effects within significant factors.

182   Univariate analysis.

183   The numbers of macroalgal FGs as well as the relative abundance of taxa were compared

184   among habitats following the same procedure as described before but using, in this case,

185   traditional analysis of variance. Prior to analyses, Cochran's test was used to detect

186   heterogeneity of variances and data were transformed where appropriate (Underwood

187   1997). When homogeneity of data was not achieved after transformation, analyses were run

188   on the untransformed data but using a more conservative significance level ($P < 0.01$)

189   (Underwood 1997).

190   The role of roughness in determining small–scale patterns of species distribution in hard–

191   defence structures, namely the abundance of gastropods and the percentage cover of

192   barnacles, was also investigated using an approach similar to that described above, but

193   including roughness (Ro, fixed, two levels: Smooth and Rough) and site (Si, random, two

194   levels) as factors.

195   Multivariate analyses were run using PRIMER 6 statistical package with the

196   PERMANOVA+ add–on (PRIMER–E, Plymouth Marine Laboratory, UK), whereas

197   univariate analysis were run using GMAV5 (University of Sydney).

198   **Results**

199   Multivariate analysis.

200   Assemblage structure (both on the untrasformed, Table 1a, and presence–absence data,

201   Table 1b) did not differ significantly among habitats (i.e., Natural shore, Concrete and

202   Basalt artificial structures) on the lower–shore. On the mid–shore, assemblage structure

203   differed significantly between Natural and Basalt when considering abundance data (Table

204   1a), but not when considering only compositional data (Table 1b). Significant differences

205   on the assemblage structure were detected between Natural shores and both artificial

206   habitats (Concrete and Basalt artificial structures) on the upper–shore, when considering

207   abundance (Table 1a) but not presence-absence (Table 1b) data.

208   Univariate analysis.

209   The numbers of macroalgal FGs were generally similar among habitats at all tidal levels,

210   although differences were found among locations ($P < 0.001$, Table 2, Fig. 2).

211   Al low-shore level, the abundance of macroalgal FG showed no differences among habitats,

212   although differences were found among locations ($P < 0.001$, Table 3, Fig. 3).

213   At mid-shore level, only coarsely branched algae were significantly more abundant on

214   Natural shores than on artificial reefs (means of 6.0% on Natural *vs*. 0.8% on Basalt and

215   0.7% on Concrete artificial structures; Table 3, Fig. 3). The abundance of the remaining

216   functional groups (coenocytic, foliose, articulated calcareous, leathery and calcified and

217   non–calcified crusts) did not vary significantly among natural shores and basalt and

218   concrete artificial habitats, although differences were always found among locations (Table

219   3, Fig. 3). The number of both M. *neritoides* and *T. striatus* was significantly greater on

220   natural shores than in artificial structures (Table 4, Fig. 4). Mean numbers of littorinids

221   from 0.08 to 1.6 ind. 0.06 m^{-2} were observed on coastal defences, while densities between

222   10.9 and 12.8 ind. 0.06 m^{-2} were observed on natural shores (Fig. 4). The abundance of

223   *Patella* spp. did not significantly differ between habitats (Fig. 4, Table 4), while the cover

224   of *C. stellatus,* was significantly greater on Natural shores compared to Basalt artificial

225   structures (28.3 *vs*. 5.5 % respectively, Fig. 4, Table 4).

226   Regarding the upper-shore, significant differences were detected among habitats when

227   considering the percent cover of ephemerals, more abundant on Basalt artificial structures

228   (0.14%) than in Concrete artificial structures (0.04%, Table 3, Fig. 3). Articulated

229   calcareous and calcified crusts showed differences among locations ($P < 0.001$, Table 3,

230   Fig. 3), but not among habitats. The abundance of *T. striatus* significantly differed between

231   habitats (Fig. 4, Table 4), with numbers of 11.8 ind. 0.06 m^{-2} in natural shores and 1.5 in

232   artificial structures. The numbers of the remaining faunal species were similar among

233   habitats, although differences were found among locations ($P < 0.05$, Table 4, Fig. 4).

234   Small-scale effect of substratum roughness.

235   There were significant differences in substratum roughness between the *a priori* selected

236   smooth *vs*. rough surfaces, with values of 0.18 ± 0.02 mm (mean ± SE, *n* = 20) and 0.05 ±

237　0.01 respectively (ANOVA, Mid–shore: $F(1,17)$ (pooled) = 16.13, $P < 0.001$; Upper–shore:

238　$F(1,17)$ (pooled) = 16.22, $P < 0.001$).

239　At mid-shore level, significant differences were found in the mean abundance of *M.*

240　*neritoides* and *C. stellatus* between rough and smooth blocks although these effects were

241　site-dependent. *M. neritoides* was significantly more abundant on rough blocks (mean

242　values of 10.4 in rough *vs.* 0.10 ind. 0.06 m^{-2} in smooth surfaces) at site 1, while *C.*

243　*stellatus* was significantly more abundant on smooth blocks on both sites (mean cover of

244　39.4% in smooth *vs.* 6.8% in rough blocks; Fig. 5, Table 5). The littorinid *T. striatus* was

245　significantly more abundant on rough surfaces at both the mid– and the upper–shore (mean

246　number of 12.3 in rough *vs.* 0.2 ind. 0.06 m^{-2} in smooth surfaces on mid– and 16.7 *vs.* 1.0

247　ind. 0.06 m^{-2} on upper–shore levels; Fig 5, Table 5).

248　**Discussion**

249　As we hypothesized, qualitatively similar assemblages of animals and plants were found on

250　both the coastal defence structures and natural habitats. There were, however, relevant

251　effects of urbanisation on the abundance of some intertidal organisms. For instance, the two

252　littorinid species and the cirripid barnacle were substantially (and significantly) less

253　abundant on the artificial structures. Moreover, this effect was generally similar on defence

254　structures made of either concrete or basalt suggesting that they were not directly

255　influenced by the material type of the substratum *per se*. Results from the small–scale study

256　showed that these species were highly influenced by small–scale variation in roughness.

257　The lower abundance of littorinids found on artificial structures may thus be related to the

258　general lack of microtopographic features that are important as habitat for these molluscs.

259   This is in accordance with the wider literature showing that littorinids generally tend to

260   aggregate around small–scale features of the substratum (Chapman 1995; Jones &

261   Boulding 1999; Silva *et al*. 2014). Both the physical characteristics of the habitats

262   (roughness; e.g. Gray and Hodgson 2004) and also the presence of *C. stellatus*, could

263   provide refuges for this fauna. As observed by other authors (Silva *et al*. 2014), small

264   gastropods were observed inhabiting the tests of dead barnacles, acting therefore as

265   biogenic microhabitats (Aguilera *et al*. 2014), altering the complexity of the substratum and

266   providing shelter and protection from physiological stress to intertidal organisms

267   (Underwood *et al*. 1983; Jernakoff 1985). Roughness has been also considered an important

268   variable on barnacle settlement (e.g. Chabot & Bourget 1988; Skinner & Coutinho 2005).

269   Barnacles had lower abundance on artificial structures (as observed e.g. by Aguilera *et al*.

270   2014), but in our case, within the artificial structures the effect of roughness contrasted that

271   found for littorinids (i.e., lower abundance on smooth surfaces). Although we did not

272   expect biotic or abiotic factors to differ between sites within the artificial shore, e.g.

273   chemical cues generated by barnacle adults could be influencing our results, since barnacles

274   are known to respond positively to the presence of conspecifics (Skinner & Coutinho

275   2005), and we could no separate such effects from those related to roughness.

276   Due to their key role in intertidal assemblages, changes in limpet abundance among habitats

277   may indirectly influence the distribution of other organisms (Hawkins *et al*. 1992). In the

278   present study, and in contrasts with Bulleri & Chapman (2004) or Bulleri *et al*. (2004),

279   although natural habitats supported greater densities of limpets than basalt at low–shore

280   levels, no differences were found on the mid–shore, where limpets are usually more

281   abundant (Martins *et al*. 2010). In this and other systems (e.g. Oliva & Castilla 1986,

282   Branch & Moreno 1994, Moreno 2001) , substantial harvesting of limpets, a traditionally

283   important source of income for many families (Ferraz *et al*. 2001; Martins *et al*. 2008a)

284   may have masked natural patterns of distribution.

285   Generally, no differences were found in the number of macroalgal functional groups among

286   habitats. However, a lower number of functional groups tended to be found on the upper–

287   shore on natural shores. These macroalgae vary in consistent ways along physical gradients,

288   including, e.g., wave exposure and desiccation (Menge 2000). Wave splash operates

289   vertically, allowing organisms to extend upwards (Ballesteros & Romero 1988; Hobday

290   1995). In the case of artificial structures, the steep slope may break waves violently against

291   the artificial structures (Allsop *et al*. 2005), encompassing long–term exposure to waves

292   (wetting gradient, Chappuis *et al*. 2014). This could directly affect the vertical distribution

293   of some functional groups, such as calcified and non–calcified crustose algae. Only on the

294   mid– and upper–shore was the epibenthic assemblage composition of coastal defences

295   different from natural habitats. Unlike results from Bulleri & Chapman (2004) who found

296   compositional differences (differences in species identities) in assemblages on seawalls and

297   adjacent rocky shores, we did not find such compositional differences. In our study system,

298   differences found between natural shores and artificial structures were largely restricted to

299   changes in species abundances (not identity).

300   Conclusion

301   Information about patterns of distribution of species in natural and artificial habitats is

302   essential in order to understand the ecological impacts of coastal infrastructures (Bulleri &

303   Chapman 2010). Some studies have suggest that artificial structures provide habitat for

304   epibiotic communities that are qualitatively similar to those found inhabiting nearby natural

305   reefs (e.g. Branch *et al*. 2008) but quantitative studies (e.g. Moschella *et al*. 2005; Firth *et*

306   *al*. 2014), have shown artificial structures have significantly lower abundance of

307   gastropods, barnacles and coarsely branched algae, indicating some lack of similarity with

308   natural rocky shores. Our study indicates that roughness, rather than substratum type *per se*,

309   can play a key role in determining the distribution of barnacles and littorinids. Our results

310   indicate that selection of materials with rougher surfaces (i.e. enhanced roughness) when

311   building hard–defence structures may be an effective way to make them more similar to

312   natural substrata, enabling them to support taxa abundance more similar to those found on

313   natural shores.

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530 **Figures**

531 **Fig. 1** Sampling locations on Natural shores and Basalt and Concrete artificial structures
532 around São Miguel (Azores).

Fig. 1 Cacabelos *et al.*
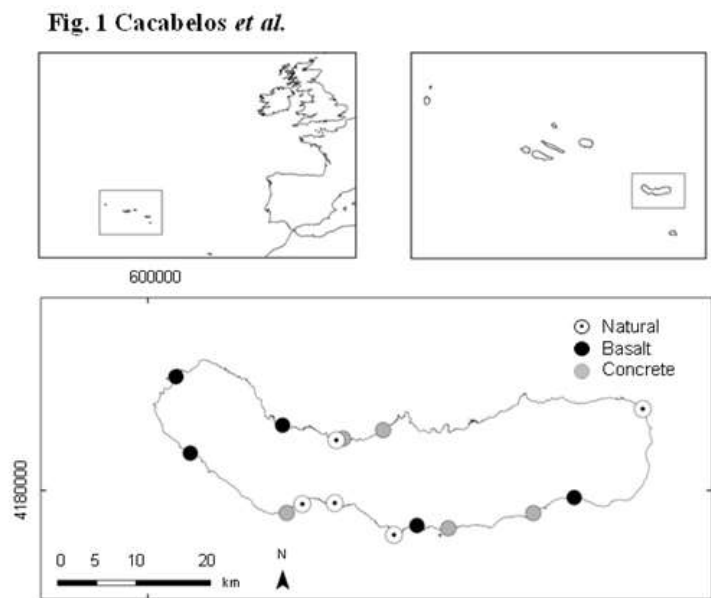
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543   **Fig. 2** Macroalgal morpho–functional groups (mean number + SE, $n = 25$) on Natural
544   shores and Basalt and Concrete artificial structures at different intertidal levels.

Fig. 2. Cacabelos _et al._

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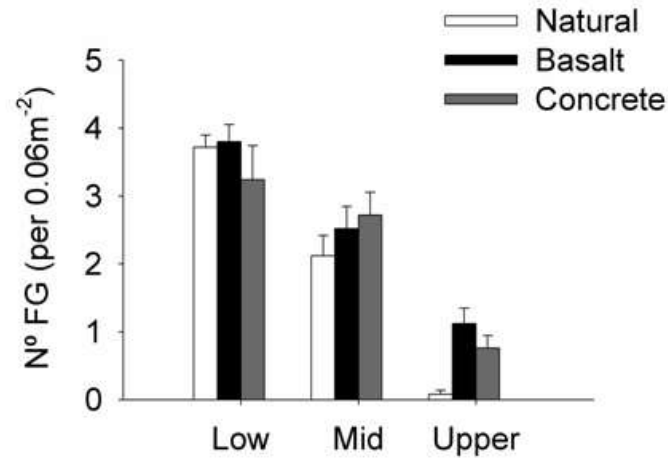559 **Fig. 3** Covers of macroalgal morpho–functional groups (mean + SE, *n* = 25) associated
560 with Natural shores and Basalt and Concrete artificial structures at different intertidal levels
561 (E, Ephemeral Algae; CB, Coarsely branched; Co, Coenocytic; F, Foliose; AC, Articulated
562 calcareous; L, Leathery; CC, Calcified crustose, NCC, Non–calcified crustose).

Fig. 3. Cacabelos *et al.*

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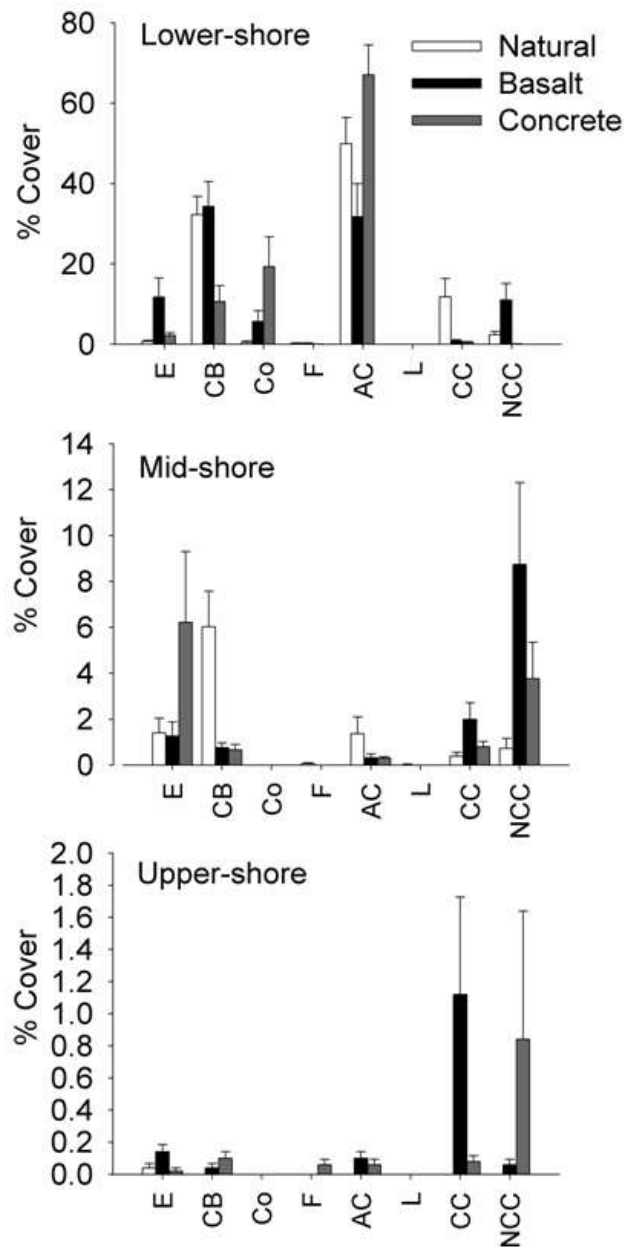
Fig. 4 Gastropod (mean number + SE, *n* = 25) and barnacle (percent cover + SE) abundance associated with Natural shores and Basalt and Concrete artificial structures at mid– and upper–shore (molluscs: T.str, *T. striatus*; M.ner., *M. neritoides*; Pat, *Patella* spp.; barnacle *C. stellatus*, C.ste.).

Fig. 4. Cacabelos *et al.*
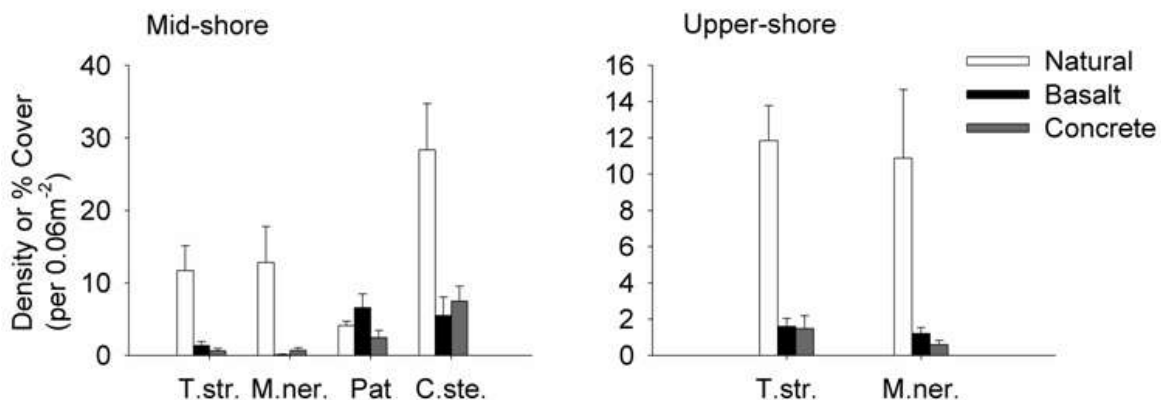
584 **Fig. 5** Gastropod (mean number + SE, *n* = 10) and barnacle (percent cover + SE)
585 abundance associated with rough and smooth surfaces at mid– and upper–shore (molluscs:
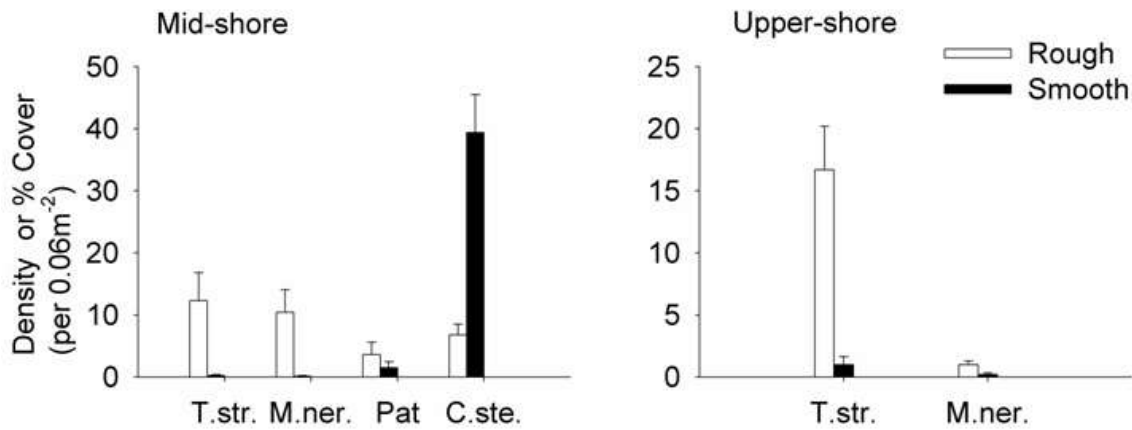586 T.str, *T. striatus*; M.ner., *M. neritoides*; Pat, *Patella* spp.; barnacle *C. stellatus*, C.ste.).

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Table 1 Two-way PERMANOVA comparing a) untransformed and b) presence/absence
transformed assemblage structure data (including numbers of gastropods and percentage
cover of macroalgal functional groups and *C. stellatus*) among habitats (N Natural shore, B
Basalt artificial structure, C Concrete artificial structure) and locations (five per habitat, see
in Fig. 1) at different intertidal levels.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

	Source	df	Low-shore		Mid-shore		Upper-shore	
			MS	*Pseudo-F*	MS	*Pseudo-F*	MS	*Pseudo-F*
a)	Habitat	2	13146.0	1.59	13478.0	1.74*	21666.0	4.15**
	Location(Habitat)	12	8291.0	12.47***	7730.1	4.03***	5218.8	4.62***
	Residual	60	665.2		1917.8		1130.4	
	Total	74						
	Pair-wise comparisons					N diff. B*		N diff. B** N diff. C**
b)	Habitat	2	9033.2	1.70	9687.7	1.77	8696.0	1.92
	Location(Habitat)	12	5321.2	6.74***	5480.6	5.25***	4525.9	4.95***
	Residual	60	789.9		1044.4		913.9	
	Total	74						

Table 2 Two-way ANOVA comparing the numbers of macroalgal morpho-functional groups among habitats (Natural shore, Basalt artificial structure, Concrete artificial structure) and locations at different intertidal levels.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

Source	df	Low-shore MS	Low-shore F	Mid-shore MS	Mid-shore F	Upper-shore MS	Upper-shore F
Habitat	2	2.29	0.49	0.03	0.07	0.90	3.25
Location(Habitat)	12	4.63	4.96***	0.37	4.24***	0.28	5.16***
Residual	60	0.93				0.05	
Total	74						
Cochran's test		ns, 0.1786		ns, 0.2303		ns, 0.232	
Transformation		None		X^0.1		Sqrt(X+1)	

Table 3 Two-way ANOVA comparing the cover of macroalgal morpho-functional groups among Habitats (Natural shores N, Basalt artificial structure B and Concrete artificial structure C) at different intertidal levels. E, Ephemerals; CB, Coarsely branched; Co, Coenocytic; F, Foliose; AC, Articulated calcareous; L, Leathery; CC, Calcified crustose, NCC, Non-calcified crustose.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$. Natural (N).

			Low-shore		Mid-shore		Upper-shore	
		df	MS	F	MS	F	MS	F
	Habitat	2	0.56	0.50	0.39	0.45	0.10	4.77*
	Location(Habitat)	12	1.12	7.03***	0.85	4.04***	0.02	0.76
	Residual	60	0.16		0.19		0.03	
	Total	74						
	Cochran's test		ns, 0.1856		ns, 0.1425		ns, 0.1765	
E	Transformation		X^0.1		X^0.1		None	
	Pair-wise comparisons							B diff. C*
	Habitat	2	4320.10	2.93	8.11	7.82**	0.06	2.11
	Location(Habitat)	12	1473.90	3.27***	1.03	2.40*	0.03	1.64
	Residual	60	450.28				0.02	
	Total	74						
	Cochran's test		ns, 0.2037		ns, 0.2391		$P < 0.05$, 0.2727	
CB	Transformation		None		Ln(X+1)		None	
	Pair-wise comparisons				N diff. B* N diff. C*			
	Habitat	2	2380.3	0.84				
	Location(Habitat)	12	2846.7	44.67***				
	Residual	60	63.7					
	Total	74						
	Cochran's test		$P < 0.01$, 0.5898					
Co	Transformation		None					
	Habitat	2	0.24	0.40	0.03	1		
	Location(Habitat)	12	0.61	4.45***	0.03	6**		
	Residual	60	0.14		0.01			
	Total	74						
	Cochran's test		$P < 0.01$, 0.6341		$P < 0.01$, 1.000			
F	Transformation		None		None			
	Habitat	2	7816.6	1.16	0.44	0.67	0.06	0.79
AC	Location(Habitat)	12	6719.6	21.72***	0.66	4.61***	0.08	9.86***

	Source	df	MS	F	MS	F	MS	F
	Residual	60	309.3		0.14		0.12	
	Total	74						
	Cochran's test		ns, 0.2397		ns, 0.1543		*P* < 0.01, 0.4286	
	Transformation		None		X^0.1		None	
	Habitat	2	13.52	1.02	17.67	2.15	9.76	1.50
	Location(Habitat)	12	13.23	98.5***	8.21	1.97*	6.50	2.71**
	Residual	60	0.13		4.18		2.40	
	Total	74						
	Cochran's test		ns, 0.2174		ns, 0.4581		*P* < 0.01, 0.9806	
CC	Transformation		Sqrt(X+1)		None		None	
	Habitat	2	1.84	1.98	2.09	2.14	5.49	0.73
	Location(Habitat)	12	0.93	6.17***	0.98	6.43***	5.89	0.01
	Residual	60	0.15		0.15		5.22	
	Total	74						
	Cochran's test		ns, 0.1427		ns, 0.1923		*P* < 0.01, 0.9981	
NCC	Transformation		X^0.1		X^0.1		None	

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Table 4 Two-way ANOVA comparing the numbers of faunal species (density of *T. striatus, M. neritoides* and *Patella* spp. and percent cover of *C. stellatus*) among habitats (Natural shores N, Basalt artificial structure B and Concrete artificial structure C) and locations at different intertidal levels.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

			Mid-shore		Upper-shore	
		df	MS	*F*	MS	*F*
T. striatus	Habitat	2	15.96	6.89**	25.43	18.42**
	Location(Habitat)	12	2.32	3.30**	31.38	3.60**
	Residual	60	0.70		0.38	
	Total	74				
	Cochran's test		ns, 0.1918		ns, 0.2141	
	Transformation		Ln(x+1)		Ln(x+1)	
	Pair-wise comparisons			N diff. B* N diff. C*		N diff. B** N diff. C***
M. neritoides	Habitat	2	2.28	3.84*	0.91	0.79
	Location(Habitat)	12	0.60	3.57**	1.15	7.11***
	Residual	60	0.17		0.16	
	Total	74				
	Cochran's test		ns, 0.1905		ns, 0.1377	
	Transformation		X^0.1		X^0.1	
	Pair-wise comparisons			N diff. B* B diff. C*		
C. stellatus	Habitat	2	17.25	4.66*	0.11	0.16
	Location(Habitat)	12	3.70	5.39***	0.70	4.97***
	Residual	60	0.69		0.14	
	Total	74				
	Cochran's test		ns, 0.2250		ns, 0.1122	
	Transformation		Ln(X+1)		X^0.1	
	Pair-wise comparisons			N diff. B*		
			Mid-shore		Low-shore	
		df	MS	*F*	MS	*F*
Patella spp.	Habitat	2	3.07	0.94	0.05	0.17
	Location(Habitat)	12	3.28	4.52***	0.31	2.57*
	Residual	60	0.73		0.12	
	Total	74				
	Cochran's test		ns, 0.1873		ns, 0.1866	
	Transformation		Ln(X+1)		X^0.1	

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Table 5 Two-way ANOVA comparing the numbers of faunal species (density of *T.*
striatus, M. neritoides and *Patella* spp. and percent cover of *C. stellatus*) between
roughness (Smooth surface S, Rough surface R) and sites (Site 1, S1; Site 2, S2) at different
intertidal levels.*** *P* < 0.001.

			Mid-shore		Upper-shore	
	Source	df	MS	*F*	MS	*F*
T. striatus	Roughness	1	17.02	18.35***	35.81	28.84***
	Site	1	0.84	0.91	0.27	0.22
	Pooled Data	17	0.93		1.24	
	Total	19				
	Cochran's test		ns, 0.5710		ns, 0.5099	
	Transformation		Ln(x+1)		sqrt(x+1)	
M. neritoides	Roughness	1	3.98	4.46		
	Site	1	0.25	1.67		
	Roughness x Site	1	0.89	6.05*		
			*(S1, R>S***; S2, R=S)*			
	Residual	16	0.15			
	Total	19				
	Cochran's test		ns, 0.4034			
	Transformation		X^0.1			
Patella spp.	Roughness	1	22.05	0.84		
	Site	1	4.05	0.15		
	Pooled Data	17	26.40			
	Total	19				
	Cochran's test		ns, 0.4715			
	Transformation		None			
C. stellatus	Roughness	1	5313.80	6.69		
	Site	1	405.00	2.71		
	Roughness x Site	1	793.80	5.32*		
			(S1, R<S; S2, R<S***)*			
	Residual	16	149.20			
	Total	19				
	Cochran's test		ns, 0.4871			
	Transformation		None			

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