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## Resource use by three juvenile scarids (*Cryptotomus roseus*, *Scarus iseri*, *Sparisoma radians*) in Caribbean seagrass beds

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14 **ABSTRACT**

15 The bucktooth parrotfish *Sparisoma radians*, the striped parrotfish *Scarus iseri* and the  
16 bluelip parrotfish *Cryptotomus roseus* are three herbivorous fishes commonly found at  
17 juvenile stages in Caribbean seagrass beds. While the diet of the three species as adults is  
18 relatively well known, few studies have been conducted on the feeding patterns of juveniles.  
19 In this study, the resource use of the juveniles of three scarid species were studied using two  
20 complementary methods: gut content and stable isotope analyses ( $^{13}\text{C}:$  $^{12}\text{C}$  and  $^{15}\text{N}:$  $^{14}\text{N}$  ratios).  
21 Bayesian mixing model approaches were used to calculate the contribution of each food item  
22 to fish diets (SIAR, mixing models). The three parrotfish species appeared to rely essentially  
23 on the consumption of fleshy macrophytes. *Cryptotomus roseus* consumed more benthic  
24 invertebrates and presented a higher trophic level than the two other scarid species. *Scarus*  
25 *iseri* presented a higher assimilation of benthic biofilm, in accordance with the high  
26 percentage of sediment in its gut content, and *Sparisoma radians* assimilated more *Thalassia*  
27 *testudinum* leaves. This research highlighted a food resources partitioning among the  
28 juveniles of the three herbivorous fishes, probably to avoid inter-specific competitive  
29 interactions for the most palatable food at a critical stage of their life.

30

31 *Keywords:* Gut content analyses, trophic niche, stable isotopes analyses.

## 32 **1. Introduction**

33 Herbivorous fishes have been widely studied on coral reefs due to their major role in the  
34 control of algae and are known to mitigate their competitive interactions with corals  
35 (Burkepile and Hay, 2010 and references therein). On tropical seagrass beds, herbivorous  
36 fishes, such as parrotfishes (Scarinae), have received less attention (Del Moral *et al.*, 2016). In  
37 the Caribbean, three species of herbivorous fishes are commonly found on seagrass beds: the  
38 bucktooth parrotfish *Sparisoma radians* (Valenciennes, 1840), the bluelip parrotfish  
39 *Cryptotomus roseus* (Cope, 1870) and the striped parrotfish *Scarus iseri* (Bloch, 1789). The  
40 first two species are exclusively found on seagrass beds, whereas *Scarus iseri* can also be  
41 found on coral reefs at all life stages. During their juvenile stages, these three species cohabit  
42 in shallow seagrass meadows which represent their primary nursery habitat (Bouchon-Navaro  
43 *et al.*, 2004; Kopp *et al.*, 2010; Layman and Silliman, 2002; Weinstein and Heck, 1979).  
44 Indeed, studying seagrass meadows is particularly relevant due to their role as nursery areas  
45 for nearshore fishes (Tuya *et al.*, 2014).

46 Possibly due to anthropic pressures on seagrass meadows, the stocks of these three juveniles  
47 have dramatically decreased over the last ten years in Guadeloupe, although they were  
48 formerly common in this habitat (Y. Bouchon-Navaro, Pers. com. 2016).

49 Information on the diet of these herbivorous fishes in the literature is principally available for  
50 adults. *Sparisoma radians* mainly ingests turtlegrass *Thalassia testudinum* Banks & Sol. ex  
51 König, 1805, fleshy macroalgae like *Dictyota* sp. or *Acanthophora spicifera* (M. Vahl)  
52 Børgesen, 1910 and calcified macroalgae such as *Halimeda* sp. (Lobel and Ogden, 1981;  
53 Randall, 1967; Targett and Targett, 1990). Depending on the region, *Scarus iseri* is described  
54 as a feeder on microalgae from dead coral pavements, fleshy macroalgae or epiphytic  
55 filamentous microalgae (McAfee and Morgan, 1996; Nagelkerken *et al.*, 2006; Randall,  
56 1967). *Cryptotomus roseus* is described as strictly herbivorous, feeding on seagrass

57 (Carpenter, 2002), but its diet has not been studied in detail. However, little information is  
58 available for the juveniles of these three parrotfish species, although ontogenetic shifts in diet  
59 are common for tropical fishes (Cocheret de la Morinière *et al.*, 2003) or temperate  
60 herbivorous fishes (Havelanche *et al.*, 1997). Dietary changes are useful to understand their  
61 ecological role in seagrass beds, such as the regulation of the algal biomass.

62 Trophic niches of fishes can be described on the basis of gut content analyses (Ogden, 1976;  
63 Randall, 1967) or direct observation of their feeding behaviour in the field by the counting of  
64 “bites” (Cardoso *et al.*, 2009; Lobel and Ogden, 1981; McAfee and Morgan, 1996;  
65 Overholtzer and Motta, 1999). However, these methods provide a description of a species’  
66 diet at a specific time and present several practical problems (Bearhop *et al.*, 2004). With gut  
67 content analyses, the principal difficulty results from the ability of herbivorous fishes, such as  
68 Scarinae, to grind the ingested matter into small fragments with their fused beak and their  
69 pharyngeal mills (Bellwood and Choat, 1990; Randall, 1967). The relative proportions of  
70 food items in gut contents are estimated with varying degrees of accuracy by different authors  
71 and on the basis of different parameters (occurrence, weight or volume percentages). With  
72 field observations, it is difficult to discriminate between potential dietary targets (e.g. between  
73 seagrass leaves and epiphytes) and the ingestion of some food items, such as detritus, is  
74 difficult to quantify. For these reasons, determining the trophic niches of herbivorous fishes  
75 remains challenging.

76 More recently, stable isotope ratios of fish muscles ( $^{13}\text{C}:^{12}\text{C}$  and  $^{15}\text{N}:^{14}\text{N}$ ) have been used to  
77 determine their trophic niche. Isotopic ratios measured in consumer tissues are closely linked  
78 to those of their diet and increase in a stepwise fashion with each trophic level.

79 The mean trophic isotopic enrichment, or fractionation factor ( $\Delta^{15}\text{N}$  and  $\Delta^{13}\text{C}$ ), was estimated  
80 at  $+ 3.4 \pm 1.1\text{‰}$  for nitrogen (Minagawa and Wada, 1984) and  $+ 0.4 \pm 1.3\text{‰}$  for carbon (Post,  
81 2002). However, Mill *et al.* (2007) demonstrated a higher  $\Delta^{15}\text{N}$  for herbivorous fishes (4.7‰

82 for *Acanthurus sohal* and 4.1‰ for *Sparisoma* spp.) and Sweeting *et al.* (2007) recommended  
83 a  $\Delta^{13}\text{C}$  ranging between 1.5‰ and 2‰ for marine fishes.

84 Stable isotope analysis is considered to be a powerful tool to reflect the feeding behaviour of  
85 individuals over long periods (approximately three months in the muscles of adult fishes) for  
86 fish muscles in adults), corresponding to the turnover of the tissues of consumers (Bearhop *et*  
87 *al.*, 2004).

88 Several methods using C and N stable isotopes ratios, expressed as  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , have been  
89 developed to understand and interpret fish ecology. Isotopic signatures of the consumer and  
90 those of its potential food sources can be used in mixing models to calculate and estimate the  
91 contribution of several food sources to the diet of a consumer (see Phillips, 2012 and Phillips  
92 *et al.*, 2015 for reviews). Results of mixing models can be used to describe and compare  
93 trophic niches between fish species (Dromard *et al.*, 2015; Plass-Johnson *et al.*, 2013).  
94 Despite the fact that numerous potential organic matter sources occur in seagrass beds, mixing  
95 models have been used before for fish species living in this habitat (Benstead *et al.*, 2006;  
96 Hyndes and Lavery, 2005; Loneragan *et al.*, 1997). However, few studies have been done in  
97 the Caribbean seagrass beds (Nagelkerken and van der Velde, 2004).

98 In the present study, we analysed the diet of juveniles of three parrotfish species in a  
99 Caribbean seagrass bed to describe and compare their trophic niche, combining stable isotope  
100 and gut content analyses.

101

## 102 **2. Materials and methods**

103 The study was carried out in the Bay of the Grand Cul-de-Sac Marin, located in the northern  
104 part of Guadeloupe Island (Lesser Antilles) (Fig. 1). In the south, the bay is bordered by  
105 mangroves and the northern part is partially enclosed by a coral barrier reef. Shoals of the bay  
106 are colonized by seagrass meadows dominated by the turtlegrass, *Thalassia testudinum*.

107 Sampling was performed in a shallow seagrass bed (< 2 m depth), at mid-distance between  
108 the coast and the barrier reef, far from the influence of mangroves, at the end of the wet  
109 season (October to December 2010). The sampling area covers 1 km<sup>2</sup> approximately.

110

### 111 2.1. Sampling protocol

112 Three herbivorous fish species (*C. roseus*, *S. iseri* and *S. radians*) were sampled during 6  
113 purse seine samples (Table 1). The total length of fish was measured to the nearest millimetre  
114 and individuals were weighed to the nearest milligram (Table 2). All specimens sampled were  
115 below their minimum size at first maturity (Bouchon-Navaro *et al.*, 2006). The main potential  
116 organic matter (OM) sources in the seagrass beds were sampled and treated for stable isotope  
117 analysis (Table 1). The dominant species or genera of fleshy macroalgae occurring in seagrass  
118 beds were collected and cleaned with distilled water: *Anadyomene stellate* (Wulfen) C.  
119 Agardh, 1823, *Caulerpa cupressoides* (Vahl) C. Agardh, 1817, *Chaetomorpha* sp., *Dictyota*  
120 *cf pulchella* Hörnig & Schnetter, 1988 and *Padina* sp., along with the calcified macroalgae  
121 *Halimeda incrassata* (J. Ellis) J.V. Lamouroux, 1816 and *Udotea flabellum* (J. Ellis &  
122 Solander) M.A. Howe, 1904. Two seagrasses were collected, *Thalassia testudinum* and  
123 *Syringodium filiforme* Kützinger, 1860. Samples of *T. testudinum* were sorted into two  
124 categories: old leaves (O) and young leaves (Y), both selected without epiphytes. Around  
125 100g (wet weight) of each species of macroalgae and seagrass were collected on field.  
126 Epiphytes colonising old leaves of *Thalassia* were gently scrapped with a scalpel blade and  
127 stored apart. Benthic invertebrates (amphipods, copepods, decapods, gastropods) collected  
128 with seagrass and macroalgae samples were sorted. When collected, macroalgae and  
129 *Thalassia* leaves were preserved in plastic bags in order to retain the detritus, composed of  
130 organic matter and bacteria (Crossman *et al.*, 2001), deposited on algal thalli and seagrass  
131 leaves. Plastic bags were then opened in plastic boxes, macroalgae and *Thalassia* were gently

132 shacked on water and detritus settled were collected at the bottom of the boxes. Due to the  
133 small amounts, invertebrates were pooled together to constitute another type of food source.  
134 Gastropods were acidified to remove their hard shells before analyses. Particulate organic  
135 matter (POM) present in the water column above seagrasses was collected by filtering  
136 subsurface water on preweighed Whatman GF/F filters precombusted for 4 hours at 450°C.  
137 The first centimetre of surface sediment was collected to analyse the biofilm mainly  
138 composed of benthic diatoms, bacteria, detritus and settling POM (Belicka *et al.*, 2012). To  
139 ensure a sufficient quantity of material for the analyses, around 10g (wet weight) of epiphytes,  
140 invertebrates, detritus, POM and biofilm were sampled.

141

## 142 2.2. Gut content analyses

143 Ten individuals of each species had full stomach and were studied for gut content analyses.  
144 Two methods were used according to the fish species. For *C. roseus*, food categories were  
145 sorted, oven dried and weighed separately as described by Hyslop (1980), because it was  
146 possible to isolate the different food items. Diets of the two other fish species were studied  
147 using the method of point-intercepts, described by Jones (1968). Food categories were  
148 expressed as percentages of the total dry-weight for *C. roseus* and as percentages of point-  
149 intercepts for *S. iseri* and *S. radians*.

150

## 151 2.3. Stable isotope analysis

152 Dorsal fish muscles cut into small pieces and all seagrass carbon sources were oven dried at  
153 50°C to a constant weight and ground into a homogenous fine powder. Carbon and nitrogen  
154 stable isotope ratios were performed on two subsamples for food sources that may contain  
155 carbonates: POM, biofilm, detritus, epiphytes, invertebrates and calcified macroalgae. For  
156  $\delta^{13}\text{C}$ , a subsample was acidified with 1N HCl to remove calcified material that presents a less



157 negative  $\delta^{13}\text{C}$  than organic material (De Niro and Epstein, 1978). For  $\delta^{15}\text{N}$ , a non-acidified  
158 subsample was used, because acidification can distort  $\delta^{15}\text{N}$  values (Pinnegar and Polunin,  
159 1999). For each sample (and each subsample), 1mg of dry weight was used for analysis.  
160 Nitrogen and carbon isotope ratios were determined by a continuous flow mass spectrometer  
161 (Thermo Fisher™, delta V Advantage). Elemental concentrations of carbon and nitrogen  
162 ([C]% and [N]%) were measured with an elementary analyser (Thermo Fisher™, Flash EA  
163 1112). Isotopic ratios were expressed in standard delta notation [ $\delta$  values (‰)] according to  
164 the following formula:  $\delta_X = [(R_{\text{sample}}/R_{\text{standard}} - 1)] \times 1000$ , where X is  $^{13}\text{C}$  or  $^{15}\text{N}$  and R the  
165 ratio  $^{15}\text{N}:^{14}\text{N}$  or  $^{13}\text{C}:^{12}\text{C}$  of samples or international standards (Vienna Pee Dee belemnite  
166 limestone carbonate for carbon and atmospheric air for nitrogen). The measurement precision  
167 was  $<0.1\text{‰}$  for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ . Percentages of organic C and organic N were measured on  
168 acidified sub-samples for those treated by HCl, using the elemental analyser and were used to  
169 calculate the sample C/N ratio. Low C/N ratio indicated higher nutritional value and  
170 digestibility of food sources.

171

#### 172 2.4. Mixing models

173 The Bayesian stable isotope mixing model SIAR v4.0 (Stable Isotope Analysis in R)  
174 developed by Parnell *et al.* (2010) was used to estimate the proportional contribution of food  
175 sources to the diet of the three herbivorous fishes. As there were too many sources of carbon  
176 in seagrass beds, we reduced their number to eight. Some were not taken into account in  
177 mixing models, as they were not or hardly consumed by the juvenile scarids: MOP,  
178 calcareous macroalgae (*Halimeda incrassata* and *Udotea flabellum*) and the seagrass  
179 *Syringodium filiforme*. Even if some juvenile scarids scraped calcified *Halimeda* (Overholzer  
180 and Motta, 1999), they probably mainly ingest epiphytes. Other prey were combined when  
181 presenting not significantly different C and N stable isotopic values. Epiphytes, detritus and

182 *Dictyota* were considered as one food source, as were old and young leaves of *Thalassia*  
183 combined. Three models were run according to each fish species. In each model, we entered  
184 the individual isotopic values of fish muscles and the mean carbon and nitrogen signatures ( $\pm$   
185 SD) of the eight potential food sources. Mixing models took into account carbon and nitrogen  
186 fractionation factors ( $\Delta^{13}\text{C}$  and  $\Delta^{15}\text{N}$ ). In this study, we fixed mean enrichments ( $\pm$  SD) of  $1.5$   
187  $\pm 0.5\text{‰}$  for carbon and  $3.9 \pm 0.5\text{‰}$  for nitrogen as the mean difference between  $\delta^{15}\text{N}$  values  
188 of all sources taken into account and juvenile scarids. This  $\Delta^{15}\text{N}$  is slightly lower than those  
189 given for adult herbivorous fishes by Mill *et al.* (2007) (4.3 to 5.7‰), and higher than those  
190 indicated by Wyatt *et al.* (2010) (1.7 to 2.5‰). Mean contributions (Bayesian Credibility  
191 Interval 95%) of food sources to fish diets were expressed as percentages.

192

### 193 2.5. Statistical analyses

194 Data were tested for normality with Shapiro tests. When the data were normal, nitrogen and  
195 carbon signatures among fish muscles and among food sources were compared using one-way  
196 analyses of variance (ANOVA), followed by *post hoc* Tukey tests. Otherwise a non-  
197 parametric Kruskal-Wallis analysis of variance was used. Hierarchical clustering based on  
198 normalized Euclidean distance and Ward's criterion was performed on mean isotopic ratios to  
199 identify groups of species with similar C and N isotopic ratios. All tests were performed using  
200 the program R.

201

## 202 3. Results

203

### 204 3.1. Gut content analyses

205 Due to the difficulty of accurately identifying all fragments of seaweeds and seagrasses in gut  
206 contents, it was not possible to calculate the proportion of each plant species ingested by the

207 three fish species. Gut contents were sorted into four categories: sediment, vegetal matter  
208 (including microalgae, turfing algae, macroalgae and seagrass), benthic invertebrates and  
209 unidentified organic matter (Table 3). Benthic invertebrates (amphipods, isopods and  
210 decapods) were found only in the gut contents of *Cryptotomus roseus*. *Scarus iseri* and  
211 *Sparisoma radians* presented similar diets with a dominance of vegetal matter (Table 3).

212

### 213 3.2. Stable isotope analyses

214 Nitrogen and carbon signatures of fish muscles and food sources are represented as a bi-plot  
215 (Fig. 2, Table 1). *Cryptotomus roseus*, *Scarus iseri* and *Sparisoma radians* presented the most  
216 enriched nitrogen isotopic signatures ( $\delta^{15}\text{N} \pm \text{SD}$ ), with values of  $7.0 \pm 0.7\text{‰}$ ,  $5.7 \pm 0.8\text{‰}$  and  
217  $5.7 \pm 0.6\text{‰}$ , respectively.  $\delta^{15}\text{N}$  of fish muscles were significantly different between *C. roseus*  
218 and the two other fish species ( $F = 12.30$ ,  $p < 0.001$ ), while *S. radians* differed significantly  
219 from *C. roseus* and *S. iseri* by its higher  $\delta^{13}\text{C}$  value ( $-9.6 \pm 0.8\text{‰}$  vs  $-11.5 \pm 1.6\text{‰}$  and  $-11.9 \pm$   
220  $0.9\text{‰}$  respectively;  $F = 14.01$ ,  $p < 0.001$ ). Nitrogen signatures of OM sources ranged from  $5.1$   
221  $\pm 0.2\text{‰}$  for invertebrates to  $1.2 \pm 0.1\text{‰}$  for *Udotea flabellum* and their carbon signatures  
222 ( $\delta^{13}\text{C} \pm \text{SD}$ ) varied between  $-17.2 \pm 0.7\text{‰}$  for *Chaetomorpha* sp. and  $-4.7 \pm 0.1\text{‰}$  for  
223 *Syringodium filiforme* (Fig. 2, Table 1). Significant differences in C and N isotopic signatures  
224 were found among OM sources ( $\delta^{13}\text{C}$ :  $X^2 = 69.7$ ,  $p < 0.001$ ;  $\delta^{15}\text{N}$ :  $X^2 = 58.3$ ,  $p < 0.001$ ).  
225 However, no significant difference was observed between old and young leaves of *Thalassia*,  
226 and between epiphytes, *Dictyota* and detritus ( $p > 0.05$  for both groups). They were thus  
227 pooled together into two food categories for mixing models.

228

### 229 3.3. Mixing models

230 Three mixing models were performed, i.e. one per fish species. Eight types of food sources  
231 were introduced into each model: invertebrates, biofilm, *Thalassia testudinum* (O and Y

232 leaves combined), the group epiphytes-detritus-*Dictyota* and four macroalgae likely to be  
233 consumed by juvenile scarids (*Anadyomene stellata*, *Caulerpa cupressoides*, *Chaetomorpha*  
234 sp. and *Padina* sp.). The results of the mixing models were largely undetermined, with a  
235 broad overlap in the 95% confidence intervals, due to the number of sources and the wide  
236 range of isotopic values in the macroalgae (Table 4). However, macroalgae constituted the  
237 largest part of the food assimilated by juvenile scarids (mean contribution: 42%, 53% and  
238 57% in *C. roseus*, *S. iseri* and *S. radians* respectively), followed by the group epiphytes-  
239 detritus-*Dictyota* between 10% and 15% (Fig. 3). The three other food sources discriminated  
240 better the three fish species. *C. roseus* assimilated a higher proportion of invertebrates (mean  
241 contribution: 21%) than the two other species (*Scarus iseri* S.i: 4% and *Sparisoma radians*  
242 S.r.: 5%), *S. iseri* a higher proportion of biofilm (mean contribution: 22% vs *Cryptotomus*  
243 *roseus* C.r.:15% and S.r.: 10%) and *S. radians* a higher proportion of *Thalassia testudinum*  
244 (mean contribution: 17% vs C.r.: 8% and S.i.: 11%) (Fig. 3, Table 4). While seagrass,  
245 macrophytes and epiphytes presented high C/N ratios (10 – 38), invertebrates, biofilm and  
246 detritus had lower C/N values (6 - 9), testifying their higher nutritional quality (Table 1).  
247 These high quality food items contributed around 50% of the food assimilated by *C. roseus*,  
248 36% by *S. iseri* and 25% by *S. radians*, epiphytes and *Dictyota* being included.

249

#### 250 **4. Discussion**

251 Coupling gut contents and stable isotope analyses allows the description of fish diets with  
252 greater accuracy. These two complementary methods have been used before in *Thalassia*  
253 seagrass beds to study fish feeding behaviours (Harrigan *et al.*, 1989; Vaslet *et al.*, 2015), but  
254 few such studies have been conducted on fish juveniles (Lugendo *et al.*, 2006; Nagelkerken  
255 and van der Velde, 2004) or on herbivorous fishes (Cocheret de la Morinière *et al.*, 2003).

256

## 257 4.1. Gut content and isotopic mixing model problems

258 Observations of gut contents showed that the three species principally ingested vegetal matter  
259 (including micro- and macroalgae, seagrass and their epiphytes). Gut content analyses give  
260 interesting results but present several limitations, as previously discussed, especially for  
261 Scarinae which grind their food. As these three parrotfish species differed significantly in  
262 their stable isotopic values, this suggested that they might have different feeding patterns.  
263 Results of stable isotope mixing models (SIAR) showed that juveniles of these three species  
264 indeed assimilated mainly macroalgae, but presented nevertheless some food partitioning,  
265 which was in accordance with the results of gut content analysis. *C. roseus* presented a more  
266 enriched  $\delta^{15}\text{N}$  than the two other species and assimilated more benthic invertebrates, such as  
267 small crustaceans, in accordance with gut content analysis. *S. iseri* had a more depleted  $\delta^{13}\text{C}$   
268 and assimilated a higher proportion of biofilm, which might explain the higher proportion of  
269 sediment in the gut content of this species. *S. radians* presented an enriched  $\delta^{13}\text{C}$  and a higher  
270 assimilation of *Thalassia testudinum* leaves. However, the results of the mixing models were  
271 largely undetermined, with a wide range of mean contributions (95% CI, Table 4) and should  
272 be taken with caution. This lack of resolution was due, firstly, to the wide range of food  
273 sources taken into account in the mixing models, even in selecting the most susceptible ones  
274 to be eaten by juvenile scarids and in combining those with close isotopic values; and  
275 secondly to the wide range of  $\delta^{13}\text{C}$  in macroalgae and their rather close  $\delta^{15}\text{N}$  (cf Table 1).  
276 *Chaetomorpha* presented a highly negative  $\delta^{13}\text{C}$  value close to the biofilm, while *Caulerpa*  
277 and *Padina* exhibited enriched  $\delta^{13}\text{C}$  values close to those of *Thalassia* leaves. Grouping these  
278 food categories together to reduce the number of sources used in the mixing models would  
279 have resulted in more determined models, but would not have had any ecological meaning.  
280 Juvenile parrotfishes consume a wide range of food resources on Caribbean coral reefs  
281 (Overholtzer and Motta, 1999) and seagrass beds (this study). Taking into account too many

282 food resources leads to inconclusive mixing model results (cf. Brett, 2014; Fry, 2013 and  
283 Philipps *et al.*, 2015, for critical reviews on stable isotope mixing models). Thus the selection  
284 of a reduced number of food sources improve the results of mixing models but may lead to an  
285 oversimplification of fish diets that would be inconsistent with field observations. Combining  
286 gut content and stable isotope analyses with DNA analysis of the food ingested, field  
287 observations and feeding trial experiments may be necessary to fully resolve the problem of  
288 parrotfish feeding.

289

#### 290 *4.2. Interspecific differences*

291 Few data are available on the diet of *Cryptotomus roseus*, which is assumed to feed mostly on  
292 *Thalassia testudinum* (Carpenter, 2002). However, the morphology of its teeth (separated  
293 teeth) could explain its greater consumption of invertebrates compared to the other species.  
294 The use of benthic invertebrates by young herbivorous fishes could also result from a relic of  
295 their previous carnivorous stage (early post-settlement stage). Ontogenetic shifts in diet from  
296 carnivorous to herbivorous have been described before for Scarinae in the Pacific region  
297 (Bellwood, 1988; Chen, 2002).

298 Adult individuals of *Scarus iseri* are described as feeders on microalgae and consumers of  
299 algal turf, especially when found on coral reefs (Dromard *et al.*, 2015; McAfee and Morgan,  
300 1996; Nagelkerken *et al.*, 2006; Randall, 1967; van Rooij *et al.*, 1996), on macroalgae  
301 (Cardoso *et al.*, 2009; Randall, 1967; Wolf, 1985), or epiphytes from seagrass leaves  
302 (Nagelkerken *et al.*, 2006). In Guadeloupean seagrass beds, *S. iseri* juveniles were  
303 characterized by a higher assimilation of biofilm compared to the two other fish species. The  
304 shift of diet between juvenile and adult stages could result from the ontogenetic change of  
305 habitat, from seagrass beds to coral reefs. Algal turf, constituted by filamentous macroalgae  
306 heavily grazed by adults, was not found in the studied seagrass bed because of the lack of

307 dead pavement support. The greater quantity of sediment in *S. iseri* gut content could be due  
308 to the consumption of biofilm developing at sediment surface.

309 Previous studies showed that adult *Sparisoma radians* consume between 88 and 95% of  
310 *Thalassia testudinum*, including epiphytes from leaves (Lobel and Ogden, 1981; Montague *et*  
311 *al.*, 1995; Randall, 1967), because this fish is undeterred by chemical and physical defences of  
312 *T. testudinum* (Goecker *et al.*, 2005; Targett and Targett, 1990). In the present study, the  
313 proportion of *T. testudinum* assimilated by juveniles of *S. radians* was estimated to be 17%,  
314 most of the vegetal matter ingested coming from macroalgae. *S. radians* seems thus to exhibit  
315 an ontogenetic diet shift, possibly due to a gradual physiological adaptation allowing *S.*  
316 *radians* to consume and digest *T. testudinum*. Several authors have shown the importance of  
317 epiphytes of *Thalassia* leaves in the diet of *S. radians* and *S. iseri* (Cocheret de la Morinière *et*  
318 *al.*, 2003; Montague *et al.*, 1995; Nagelkerken *et al.*, 2006). In the present study, the  
319 respective assimilation of detritus, epiphytes and *Dictyota* could not be estimated because of  
320 their close isotopic values. The high proportion of detritus in the diets of herbivorous fishes  
321 has been underlined by several authors (e.g. Crossman *et al.* 2001; Dromard *et al.*, 2013) and  
322 related to their high nutritional quality estimated by their low C/N ratio, as also observed in  
323 this study. The proportion of food sources with low C/N ratios (invertebrates, biofilm, detritus  
324 and epiphytes) differed among the three juvenile parrotfishes, in the following decreasing  
325 order, *C. roseus* (50%), *S. iseri* (36%) and *S. radians* (25%). These differences suggested that  
326 they differed in their ability to consume, process and assimilate plant material. Further studies  
327 focussed on the physiological processes involved in nutrient extraction and utilisation in  
328 herbivorous fishes, as highlighted by Clements *et al.* (2009), should be conducted in order to  
329 fully understand interspecific differences in scarid diets.

330 Thus, the juveniles of the three scarid species seem to present a high overlap in their use of  
331 food resources, with high consumption of macroalgae, but nevertheless displayed different

332 preferences for specific food sources: invertebrates for *C. roseus*, biofilm for *S. iseri* and  
333 *Thalassia* leaves for *S. radians*. These results indicated some early food partitioning among  
334 juvenile scarids of different species, differences which would increase with individual growth.

335

## 336 **5. Conclusions**

337 The lack of dietary redundancy observed for adult scarids on Indian Ocean coral reefs (Plass-  
338 Johnson *et al.*, 2013) seems to be also observed for juvenile scarid species in Caribbean  
339 seagrass beds. At a juvenile stage, the three fish species live together in seagrass meadows,  
340 their primary nursery habitat, forming multispecific shoals. The present study indicated that,  
341 while macroalgae formed a large part of their diets, some differences in the use of food  
342 resource occur between these juveniles, in spite of the lack of robustness of mixing model  
343 results. The difference of diet between the three herbivorous scarid species could contribute to  
344 their coexistence in seagrass beds without inter-specific competitive interactions during their  
345 juvenile stage, as observed among other juvenile parrotfishes on coral reefs in Florida Keys  
346 (Overholtzer and Motta, 1999). The comparison between juveniles (present study) and adults  
347 (from the literature) also suggested that ontogenetic dietary changes occurred in these three  
348 scarid fish species, resulting in higher trophic niche differentiation in adults.

349

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356



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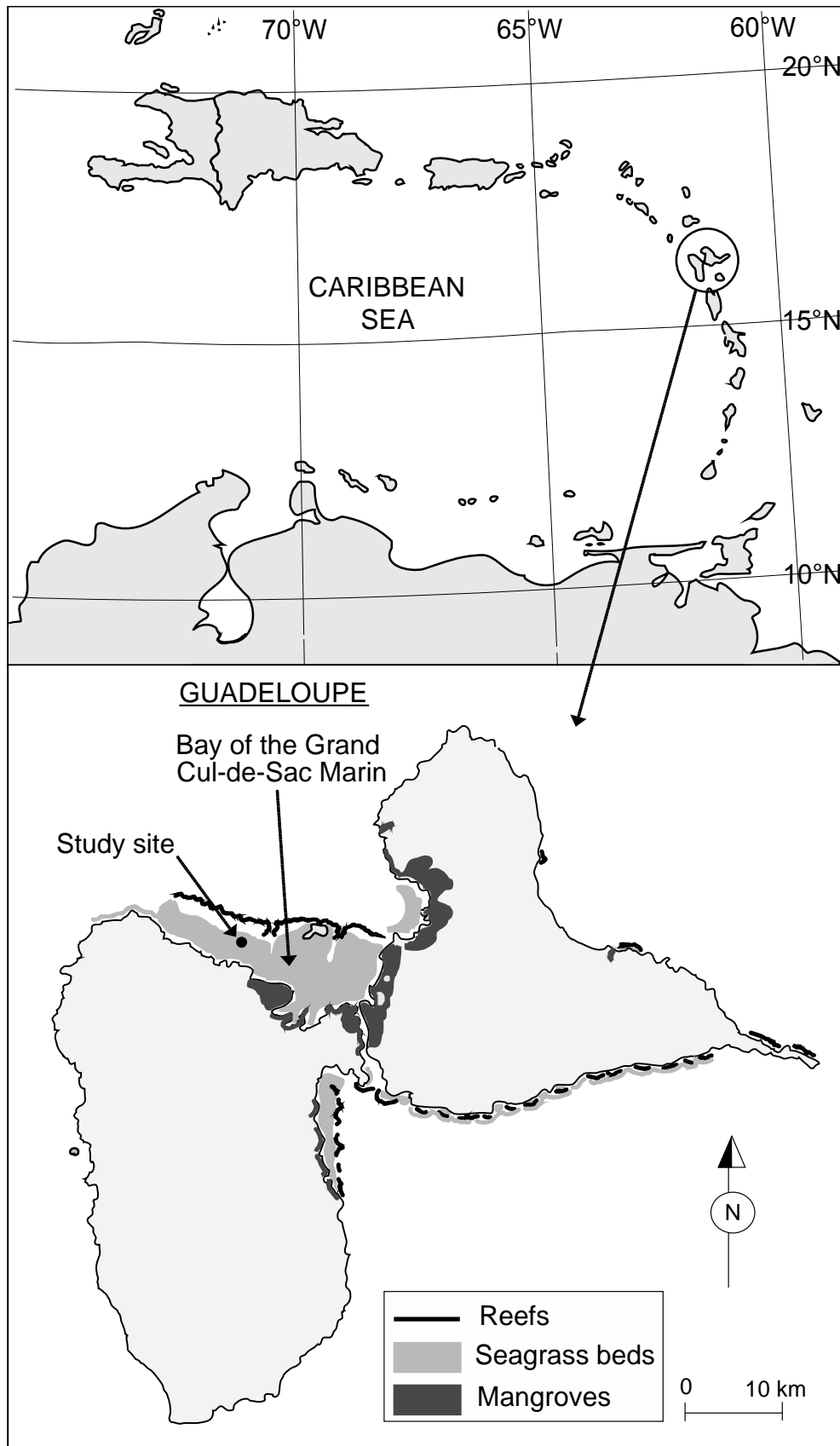
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501 **List of figures**

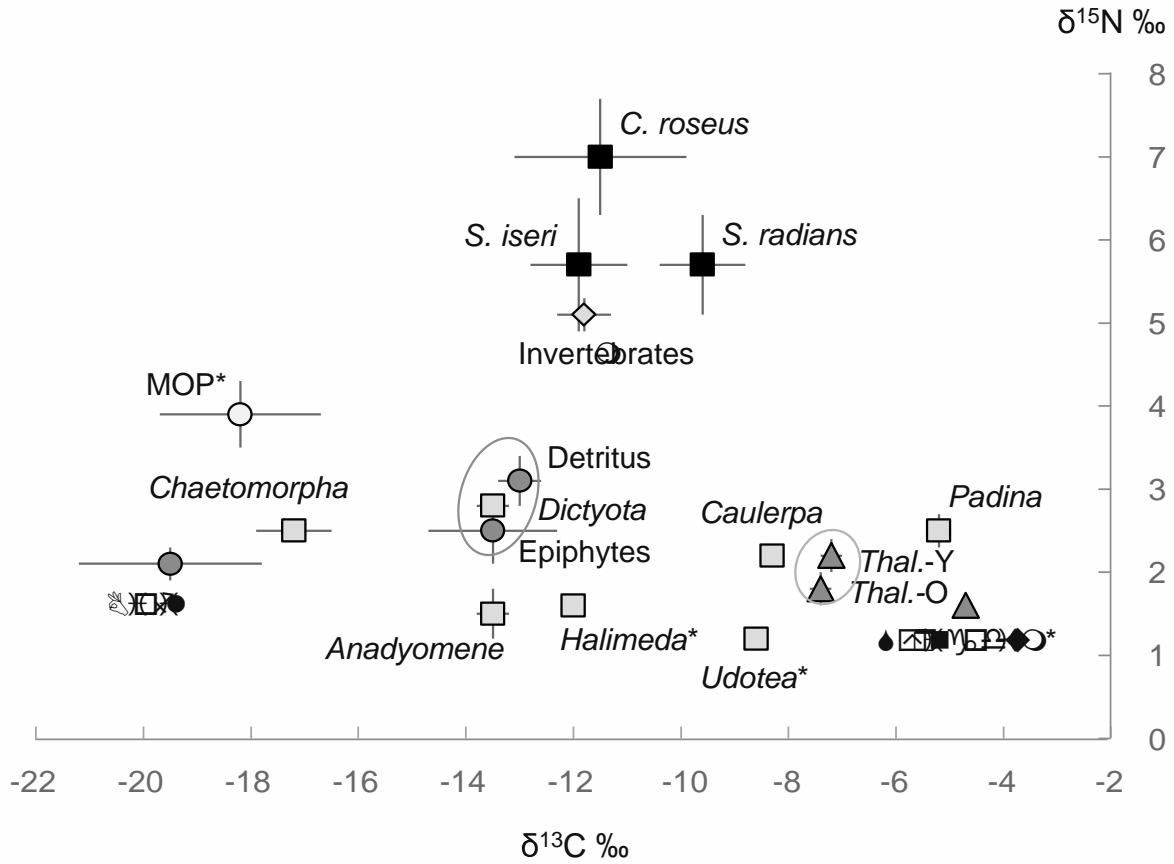
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503 Figure 1. Location of the study site in the Bay of the Grand Cul-de-Sac Marin in Guadeloupe  
504 (Lesser Antilles).



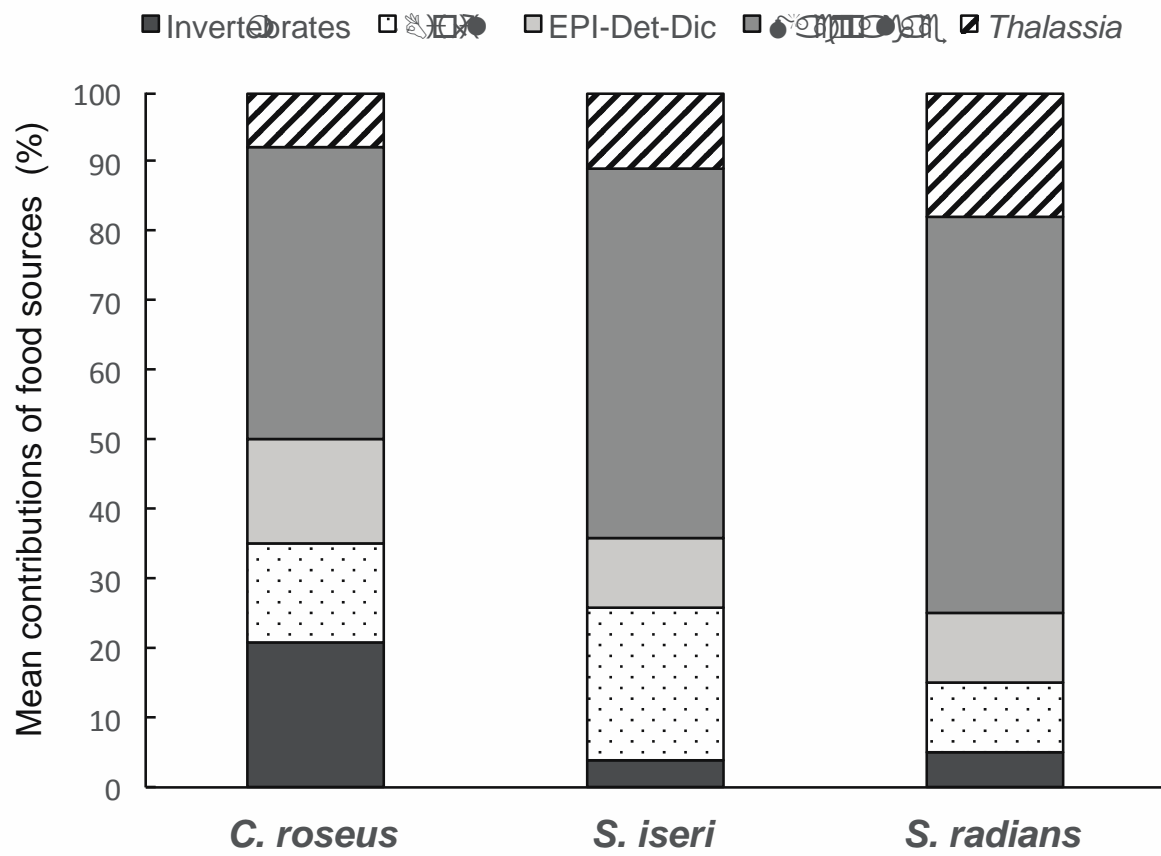
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506 Figure 2. Mean isotopic signatures of carbon ( $\delta^{13}\text{C} \pm \text{SD}$ ) and nitrogen ( $\delta^{15}\text{N} \pm \text{SD}$ ) of the  
 507 three juvenile fish species and their potential food sources in Guadeloupean seagrass beds.  
 508 *Thal.-O*: *Thalassia*-old leaves; *Thal.-Y*: *Thalassia*- young leaves; \* indicates sources not  
 509 taken into account in the mixing models.



510  
 511 Figure 3. Mean contribution of food sources to the diet of fishes calculated with SIAR mixing  
 512 models. 95% Bayesian Credibility Intervals of these values are given in Table 3. Fleshy  
 513 macroalgae: *Anadyomene stellata*, *Caulerpa cupressoides*, *Chaetomorpha* sp. and *Padina* sp.  
 514 EPI-Det-Dic: epiphytes, detritus and *Dictyota* sp.





515

516 **Tables**

517

518 Table 1. Mean  $\pm$  SD values of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  signatures and C/N ratio of juvenile scarids and

519 organic matter sources collected in Guadeloupe seagrass beds. N: number of samples. \*

520 Sources not taken into account in mixing models

<b>Sample types</b>	<b>N</b>	<b><math>\delta^{13}\text{C}</math> ‰ <math>\pm</math> SD</b>	<b><math>\delta^{15}\text{N}</math> ‰ <math>\pm</math> SD</b>	<b>C/N</b>
Fish species				
<i>Cryptotomus roseus</i>	13	-11.5 $\pm$ 1.6	7.0 $\pm$ 0.7	3.3 $\pm$ 0.1
<i>Scarus iseri</i>	11	-11.9 $\pm$ 0.9	5.7 $\pm$ 0.8	3.3 $\pm$ 0.03
<i>Sparisoma radians</i>	13	-9.6 $\pm$ 0.8	5.7 $\pm$ 0.6	3.1 $\pm$ 0.02
Invertebrates	5	-11.8 $\pm$ 0.5	5.1 $\pm$ 0.2	5.6 $\pm$ 0.5
MOP*	9	-18.2 $\pm$ 1.5	3.9 $\pm$ 0.4	7.1 $\pm$ 1.2
Biofilm	6	-19.5 $\pm$ 1.7	2.1 $\pm$ 0.2	9.4 $\pm$ 0.2
Detritus	5	-13.0 $\pm$ 0.04	3.3 $\pm$ 0.03	8.6 $\pm$ 0.1
Fleshy macroalgae				
<i>Anadyomene stellata</i>	3	-13.5 $\pm$ 0.3	1.5 $\pm$ 0.3	20.0 $\pm$ 0.4
<i>Caulerpa cupressoides</i>	3	-8.3 $\pm$ 0.1	2.2 $\pm$ 0.03	13.5 $\pm$ 0.2
<i>Chaetomorpha</i> sp.	3	-17.2 $\pm$ 0.7	2.5 $\pm$ 0.03	19.5 $\pm$ 0.7
<i>Dictyota</i> cf <i>pulchella</i>	3	-13.5 $\pm$ 0.3	2.8 $\pm$ 0.1	23.8 $\pm$ 0.5
<i>Halimeda incrassata</i> *	3	-12.0 $\pm$ 0.04	1.6 $\pm$ 0.04	9.9 $\pm$ 0.1
<i>Padina</i> sp.	3	-5.2 $\pm$ 0.1	2.5 $\pm$ 0.2	38.0 $\pm$ 0.9
<i>Udotea flabellum</i> *	3	-8.6 $\pm$ 0.03	1.2 $\pm$ 0.1	10.8 $\pm$ 0.1
Epiphytes ( <i>Thalassia</i> )	6	-13.5 $\pm$ 1.2	2.5 $\pm$ 0.4	11.8 $\pm$ 2.9
Seagrass				
<i>Thalassia testudinum</i> (old)	10	-7.4 $\pm$ 0.1	1.8 $\pm$ 0.2	23.8 $\pm$ 2.1
<i>Thalassia testudinum</i> (young)	5	-7.2 $\pm$ 0.1	2.2 $\pm$ 0.1	19.7 $\pm$ 0.2
<i>Syringodium filiforme</i> *	5	-4.7 $\pm$ 0.1	1.6 $\pm$ 0.07	23.0 $\pm$ 0.3

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522

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524

525 Table 2. Mean and range of fish total length (TL) and wet weight (W) of the three fish  
 526 species. Lengths at maturity (Lm) are taken from Bouchon-Navaro *et al.* (2006).  
 527

<b>Fish species</b>	<b>TL (cm)</b>	<b>W (g)</b>	<b>Lm (cm)</b>
<i>Cryptotomus roseus</i>	5.7 (4.6 – 6.8)	2.5 (1.3 – 4.2)	8.6
<i>Scarus iseri</i>	5.0 (4.5 – 5.5)	2.0 (1.5 – 2.6)	15.9
<i>Sparisoma radians</i>	6.4 (6.0 – 6.7)	5.1 (4.5 – 5.7)	12.0

528

529

530 Table 3. Mean proportion of food items ( $\pm$  SD) ingested by *Cryptotomus roseus*, *Scarus iseri*  
 531 and *Sparisoma radians*.

532

<b>Species</b>	<b>Principal food items</b>	<b>Secondary food items</b>	<b>Method</b>
<i>Cryptotomus roseus</i>	Vegetal matter (72 $\pm$ 11%)	Invertebrates (28 $\pm$ 5%)	Gravimetric
<i>Scarus iseri</i>	Vegetal matter (58 $\pm$ 10%)	Sediment (12 $\pm$ 7%) and unidentified matter (30 $\pm$ 6%)	Point-intercept
<i>Sparisoma radians</i>	Vegetal matter (60 $\pm$ 8%)	Sediment (7 $\pm$ 4%) and unidentified matter (33 $\pm$ 8%)	Point-intercept

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536

537 Table 4. Mean contribution of food sources (%) and Bayesian Credibility Interval 95% to the  
 538 diet of *Cryptotomus roseus*, *Scarus iseri* and *Sparisoma radians* calculated with SIAR mixing  
 539 models.  
 540

<b>Food sources</b>	<i>C. roseus</i>	<i>S. iseri</i>	<i>S. radians</i>
	%	%	%
Invertebrates	21.1 (7.8 - 33.9)	3.5 (0.0 - 9.9)	4.9 (0.0 - 13.5)
Biofilm	14.7 (0.1 - 26.6)	22.4 (1.0 - 33.8)	10.1 (0.0 - 21.3)
Epiphytes+Detritus+ <i>Dictyota</i>	14.7 (0.7 - 26.6)	9.8 (0.0 - 23.9)	10.4 (0.0 - 24.1)
Fleshy Macroalgae			
<i>Anadyomene stellata</i>	10.2 (0.0 - 23.0)	21.9 (0.1 - 43.0)	16.8 (0.1 - 33.1)
<i>Caulerpa cupressoides</i>	9.0 (0.0 - 20.8)	11.1 (0.0 - 25.2)	16.1 (0.0 - 31.0)
<i>Chaetomorpha</i> sp	14.8 (0.1 - 28.1)	13.3 (0.0 - 28.2)	9.2 (0.0 - 21.4)
<i>Padina</i> sp.	8.4 (0.0 - 19.0)	6.9 (0.0 - 17.1)	15.3 (0.1 - 28.1)
Seagrass			
<i>Thalassia testudinum</i>	8.4 (0.0 - 19.1)	11.1 (0.0 - 24.8)	17.2 (1.0 - 31.6)

541