

1 **Diet of the coral hawkfish *Cirrhitichthys oxycephalus* (Family: Cirrhitidae) in a fringing**
2 **coral reef of the Eastern Tropical Pacific**

3 *Coral Reefs*

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14 **Keywords:** Coral reef fishes, stomach contents, trophic interactions, Colombian Pacific.

15 **Abstract**

16 Hawkfishes are small demersal reef predators. Although their association with the coral substrate
17 has been widely documented for some species, information regarding their feeding habits is
18 limited, especially in the Eastern Tropical Pacific (ETP). We characterized the diet of the coral
19 hawkfish *Cirrhitichthys oxycephalus* in Isla Gorgona (ETP) by visually analyzing its gut contents
20 and calculating its trophic niche breadth. Crustaceans were the most important (relative
21 importance: 73%) and frequent prey found in 89% of the stomachs analyzed. Among
22 crustaceans, copepods were the most abundant prey, suggesting that *C. oxycephalus* in Isla
23 Gorgona has a specialized diet. In terms of biomass, decapods represented the highest
24 contribution to the diet. Other prey items included small mollusks and fish. This study highlights
25 the strong trophic link between coral-dwelling reef fish and mobile invertebrates that comprise
26 the coral reef cryptic fauna, and therefore the indirect benefit that live coral cover has for this
27 species.

28

29 **Introduction**

30 Hawkfishes (family Cirrhitidae) are small demersal reef predators widely distributed in tropical
31 reefs (Coker et al. 2015, 2017). These fishes are usually found on the reef substrate, which offers
32 them protection against predators and a strategic point for hunting small fish and invertebrates
33 (Schmitt et al. 2009; Leray et al. 2013; Coker et al. 2015, 2017). Hawkfishes are potential prey
34 for larger fishes, playing an important role in coral reef food webs by transferring energy to
35 larger predators (Hempson et al. 2015; Coker et al. 2017). Because most hawkfishes are strictly
36 associated with branched coral (e.g. *Pocillopora* spp.) and their movement is restricted to the

37 coral branches, these predators live in close proximity to coral-associated invertebrates that
38 comprised their main prey (Stier and Leray 2014). Mesopredators such as hawkfishes, that feed
39 upon small cryptic species, may modify the composition and abundance of cryptic fauna and key
40 mutualistic coral species, which can have significant effects on coral reef food webs (Stier and
41 Leray 2014; Leray et al. 2015; Coker et al. 2015). Cryptic invertebrates are known to perform a
42 variety of functions including positive (e.g., promote survival and growth of corals, protecting
43 corals against corallivores) or negative (e.g., parasites of corals, feed upon coral polyps)
44 interactions with corals (Stella et al. 2011; Leray et al. 2015). Therefore, the decline or loss of
45 predatory fish can trigger cascading effects on coral dynamics and throughout the coral reef
46 ecosystem (Leray et al. 2015).

47 Hawkfishes diet has been generally described by combining field observations with gut
48 content analysis (Hiatt and Strasburg 1960; Hobson 1974; DeMartini 1996; Kadota et al. 2011).
49 Studies carried out in the western and northern Pacific have shown that some cirrhitids, such as
50 *Paracirrhites arcatus* and *Cirrhitus pinnulatus*, feed mainly on crustaceans that are obligate
51 symbionts of branched corals (Hiatt and Strasburg 1960; Hobson 1974). Likewise, observations
52 of the feeding behavior of *P. arcatus* and diet analysis of *Cirrhitichthys falco* have shown that
53 planktonic organisms such as copepods also comprise the diet of these fishes (DeMartini 1996;
54 Kadota et al. 2011). More recently, molecular analysis of gut contents has provided high
55 taxonomic resolution for prey identification of *Neocirrhites armatus* and *P. arcatus*, suggesting a
56 non-random feeding behavior with a marked preference for crustaceans (Leray et al. 2013;
57 2015). Despite this, most studies on hawkfishes have focused on their reproductive behavior and
58 habitat use (Donaldson and Colin 1989; DeMartini 1996; Kadota et al. 2011; Coker et al. 2015,

59 2017). In contrast, knowledge about their feeding habits is still limited (Coker et al. 2015),
60 especially in the Eastern Tropical Pacific (ETP).

61 Of the three hawkfish species registered in the ETP (*Cirrhitichthys oxycephalus*,
62 *Oxycirrhites typus*, and *Cirrhites rivulathus*) and that are present in Isla Gorgona (Colombian
63 Pacific), only *C. oxycephalus* has been recorded in the coral reefs of the island (Zapata and
64 Morales 1997; Alzate et al. 2014). In this study, we investigate the feeding habits of *C.*
65 *oxycephalus* in La Azufrada coral reef (Isla Gorgona, ETP) by visually analyzing its gut
66 contents, and calculating its trophic niche breadth. We hypothesize that out of the high diversity
67 of food resources available in the coral reef, *C. oxycephalus* mainly feeds on crustaceans, as has
68 been documented for other cirrhitids in coral reefs in the central and western Pacific (Hiatt and
69 Strasburg 1960; Hobson 1974; Kadota et al. 2011; Leray et al. 2015).

70

71 **Materials and Methods**

72 **Study area**

73 La Azufrada coral reef is the largest (length: 780 m, width: 80 – 180 m) and most continuous
74 fringing reef of Isla Gorgona (2°58'10"N and 78°11'05"W), a continental island 35 km from the
75 Pacific coast of Colombia (Glynn et al. 1982; Muñoz and Zapata 2013). This study was
76 conducted on La Azufrada's reef flat, which is the shallowest and largest zone and presents the
77 highest live coral cover (up to 70%) dominated by *Pocillopora damicornis* (Zapata and Vargas-
78 Ángel 2003; Muñoz and Zapata 2013).

79

80 **Fish community survey**

81 Underwater visual censuses were conducted on the reef's flat to estimate the density of
82 *Cirrhitichthys oxycephalus* on La Azufrada coral reef throughout September 2019 (ESM Table
83 2). Richness and abundance of the fish community was estimated on the reef's flat along six
84 transects of 20 x 2 m (40 m² survey area), randomly distributed parallel to the shore line. Two
85 runs per transect were conducted to reduce observer biases (Palacios and Zapata 2011). In the
86 first run, mobile and conspicuous species were registered, and then the small-bodied and cryptic
87 species that are more closely associated with the reef substrate (e.g., *C. oxycephalus*).

88

89 **Fish collection and gut content analysis**

90 Fifty *C. oxycephalus* (TL: 45.7 – 71.5 mm) were collected using a 50 cm hand-propelled spear
91 between 0900-1300 hrs throughout September 2019. Fish were euthanized by puncturing the
92 brain with a diving knife and were placed in 70% ethanol after returning to shore. Once in the
93 laboratory, total and standard length as well as total and eviscerated weight were registered for
94 each individual (ESM Table 1). Then, each individual's gut was dissected and preserved in 70%
95 ethanol.

96 To characterize the diet of *C. oxycephalus* and the relative importance of each prey item,
97 the stomach content including the pyloric caecum and anterior portion of the intestine of each
98 individual was analyzed (see ESM methods). All prey or distinguishable fragments of prey were
99 identified to the lowest taxonomic level possible, counted, and weighed on an analytical balance
100 (dry weight: 60°C x 24 h) (Hyslop 1980; Cortés 1997; Mar-Silva et al. 2014). Digested material
101 with no distinguishable fragments was also sorted and weighed. The vacuity coefficient (V) was

102 calculated based on the number of empty stomachs (Hyslop 1980). Likewise, the frequency of
103 occurrence (F), percentage by number (N), percentage by weight (W), and the index of relative
104 importance (RI) were calculated for each prey (George and Hadley 1979; Hyslop 1980; Fabi et
105 al. 2006) (see ESM methods). To describe the trophic niche breadth, Levin's index (B_i) and its
106 standardized form (B_A) were calculated (Krebs 1999).

107

108 **Results and Discussion**

109 Thirty-one fish species from 18 families were recorded during our surveys in La Azufrada reef's
110 flat (ESM Table 2). The most abundant fish were *Thalassoma lucassanum* (mean density $\times 40 \text{ m}^2$
111 \pm SD: 54.00 ± 16.50), *Chromis atrilobata* (49.17 ± 36.56), *Stegastes acapulcoensis* ($9.17 \pm$
112 4.40), *Scarus ghobban* (5.67 ± 7.15), *Cephalopholis colonus* (5.17 ± 4.17), and *Cirrhitichthys*
113 *oxycephalus* (3.7 ± 3.01). This result suggests that *C. oxycephalus* is one of the most abundant
114 species on the reef's flat, as has been reported in La Azufrada (Zapata and Morales 1997; Alzate
115 et al. 2014). Therefore, characterizing the diet of *C. oxycephalus* is an important step to better
116 understanding the trophic dynamics of coral reef systems in the Eastern Tropical Pacific (ETP).

117 From the fifty *C. oxycephalus* analyzed, 47 contained prey items in their guts (stomachs
118 and/or intestines) and were considered for the diet analysis (i.e., %F, %N, %W, %RI). However,
119 from these 47 individuals, only 42 contained prey items in their stomachs and therefore, the
120 vacuity coefficient was 16%. We registered 61 prey items in the gut contents of *C. oxycephalus*.
121 Because most prey items were highly digested, only five were identified to species level, five to
122 genus level, and seven to family level (Table 1). The remaining prey items were classified to
123 higher taxonomic levels. From the unidentified prey, 24 were classified as morphospecies (four

124 ostracods, four bivalves, and 16 gastropods), but due to their small size, their individual weight
125 could not be quantified.

126 Our results show that *C. oxycephalus* mainly feeds on small invertebrates, including
127 crustaceans such as decapods, copepods, and isopods, mollusks such as bivalves and gastropods,
128 and echinoderms such as ophiuroids (ESM Figs. 1-6). Crustaceans were the most frequent prey
129 (89.4%) and also the most important dietary component (%RI: 73.3) (Table 1, ESM Table 3).
130 Among crustaceans, copepods were the most frequent (53.2%) and abundant (84.4%) prey,
131 followed by decapods (%F: 46.8%) and isopods (%F: 44.7%) (ESM Table 3). However, in terms
132 of biomass, the contribution of copepods was the lowest among all crustaceans consumed (<1%,
133 Table 1). In contrast, other small crustaceans such as isopods, amphipods, ostracods, and
134 tanaidaceans comprised 14.4% of the total diet weight (Table 1).

135 At a lower taxonomic level, females and juveniles of *Gnathia* sp. (Isopoda) were the most
136 frequent crustaceans found in the diet of *C. oxycephalus* (36.2%), followed by the decapods
137 *Fennera chacei* (10.6%), *Trapezia* spp. (4.3%), and *Alpheus lottini* (4.3%) (Table 1). Crabs of
138 the genus *Trapezia* are obligate symbionts of corals of the genera *Pocillopora* (Coles 1980;
139 Castro 1982), and have also been found in the diet of other cirrhitids. For example, Hiatt and
140 Strasburg (1960) found fragments of *Trapezia* in *Paracirrhites arcatus*, and Hobson (1974)
141 found that *Trapezia* represented most of the crabs present in the stomach contents of *Cirrhites*
142 *pinnulatus*. In our study, fragments of the crab *Teleophrys cristulipes* were also found in the
143 stomach contents of *C. oxycephalus* (F: 2.1%, Table 1). According to Gotelli et al. (1985), *T.*
144 *cristulipes* and *Trapezia* are both commonly found in pocilloporid corals in the Pacific of
145 Panama (frequency: 82%). Likewise, shrimps such as *F. chacei*, *A. lottini*, and *Synalpheus* spp.
146 that were found in the diet of *C. oxycephalus* (Table 1), have also been reported as dominant

147 crustaceans inhabiting *P. damicornis* in Costa Rica (Alvarado and Vargas-Castillo 2012) and in
148 Isla Gorgona (von Prael et al. 1978; Castro 1982).

149 The presence of planktonic organisms like calanoid copepods and early life-stages of
150 crustaceans (e.g., zoea and nauplii) in the diet of *C. oxycephalus* suggests that these fish also
151 obtain their food from the water column (Table 1). This result is consistent with the finding of
152 DeMartini (1996) for cirrhitids in Hawaii, who found that 60% of fish predation attacks were
153 directed towards the benthic substrate whereas 40% were directed towards prey in the water
154 column at shorter distances 3 m away the reef substrate. Similarly, Hobson (1974) documented
155 calanoid and cyclopid copepods in the diet of other cirrhitids, and Kadota et al. (2011) reported
156 that harpacticoid copepods were one of the most frequent preys in *Cirrhitichthys falco*.

157 Our results show that the diet of *C. oxycephalus* in La Azufrada coral reef mostly
158 comprises invertebrates, mainly crustaceans that are associated with the reef substrate dominated
159 by *Pocillopora* spp. This result is expected considering that species in the family Cirrhitidae
160 show a strong association with branched corals (e.g., corals of the genera *Acropora* and
161 *Pocillopora*), and these corals constitute an important habitat for potential preys like crustaceans
162 (Coles 1980; Coker et al. 2015). Due to its high preference for crustaceans, *C. oxycephalus*'
163 trophic niche breadth is narrow (B_i : 1.42, B_A : 0.01), suggesting that this coral-dwelling predator
164 has a specialized diet (Krebs 1999). Leray et al. (2013, 2015) documented a similar result for
165 other cirrhitids (*Neocirrhites armatus* and *P. arcatus*) that also inhabit pocilloporid reefs; both
166 species showed a marked preference for crustaceans, occurring in 75% and 68% of the gut
167 contents, respectively. Another similarity between our results and those by Leray et al. (2015)
168 was the low frequency of occurrence of mutualistic coral-dwelling decapods in the diet of
169 cirrhitids, even though these decapods are often dominant components in the coral branches.

170 Instead, in Leray's and our study, copepods were the most frequent and abundant prey,
171 suggesting that *C. oxycephalus* also presents a specialized diet with a non-random feeding
172 behavior. However, despite the low frequency of occurrence of coral-dwelling decapods (e.g.,
173 *Trapezia* spp. and *A. lottini*) in the diet of *C. oxycephalus*, they represented an important
174 contribution in terms of biomass (Table 1).

175 Mollusks and fish were other groups frequently found in the diet of *C. oxycephalus* (ESM
176 Figs. 4-6). Mollusks, represented by bivalves and microgastropods, were found in 55.3% of the
177 gut contents; however, their contribution to the diet in terms of biomass was minimal (1.1%,
178 Table 1). Fish were mostly represented by scales that were found in 91.5% of the stomachs
179 analyzed, and also by the presence of a fish larvae of the family Gobiidae (Table 1). The high
180 frequency of occurrence of fish scales and fish bones in the gut contents of *C. oxycephalus*
181 suggests that small fishes strongly associated with the coral substrate also represent an important
182 dietary component (Table 1). Because only fish remains were found in the gut contents, their
183 biomass could not be quantified, and it is likely that the contribution of fish to the diet of *C.*
184 *oxycephalus* was underestimated. Complementary approaches to morphological methods (e.g.,
185 DNA metabarcoding) could provide a more robust analysis of highly degraded prey that cannot
186 be visually identified (Amundsen and Sánchez-Hernández 2019). The preference to prey upon
187 small fishes (e.g., family Pomacentridae) has been documented for other cirrhitids such as *C.*
188 *falco* and *Paracirrhites forsteri* (Hiatt and Strasburg 1960; Hobson 1974; Kadota et al. 2011).
189 Branched corals such as *Pocillopora* spp. offer hiding and stalking sites to hawkfishes (Kane et
190 al. 2009; Schmitt et al. 2009), while also offering microhabitats for other small fishes and refuge
191 against predators for juvenile-stage species (Alvarez-Filip et al. 2011; Coker et al. 2013; Wilson

192 et al. 2016). All these habitat uses increase the prey availability to small predators such as *C.*
193 *oxycephalus*.

194 Because invertebrate communities that live associated with coral reefs can influence the
195 distribution and abundance of fish, particularly for species that have highly specialized
196 associations (Lawton et al. 2012; Pratchett et al. 2012; Coker et al. 2017), degradation of coral
197 reef ecosystems might negatively affect hawkfishes by affecting the composition of their
198 potential prey (Pratchett et al. 2015). Fish responses to habitat degradation depend on the type of
199 disturbance and the degree of specialization in resource acquisition (Hempson et al. 2017). While
200 large mobile apex predators could respond to localized degradation by moving to healthier
201 habitats, less mobile reef-associated mesopredators will mainly depend on their habitat versatility
202 and their ability to adapt their diets (Pratchett et al. 2008; Coker et al. 2015; Hempson et al.
203 2017). In the case of *C. oxycephalus*, which has shown a high habitat versatility by increasing its
204 abundance in low-moderate coral loss events (Pratchett et al. 2008), the maintenance of its
205 population will depend on the ability to modify the prey selection to fulfil their energetic
206 requirements (Hempson et al. 2017). Because *C. oxycephalus* often feed on planktonic prey (e.g.,
207 40%), planktonic organisms could provide a food alternative to these fish under coral loss events.
208 However, *C. oxycephalus* may also switch to feed on cryptic fauna living within the algal matrix
209 that covers non-coral substrates (Pratchett et al. 2015). According to Pratchett et al. (2015), the
210 increase in the epilithic algal matrix that harbors a high density of cryptofauna would affect the
211 crypto-benthic invertebrates' composition, but not its abundance. Therefore, the decline in coral
212 cover would more likely affect specialized fish species (e.g., highly specialized invertebrate
213 feeders), that cannot adapt their diets to the changing environment, contrary to species with
214 feeding plasticity and more generalist habits (Lawton et al. 2012; Pratchett et al. 2015).

215 Our study shows that *C. oxycephalus* is a specialized predator feeding mainly upon
216 invertebrates, mostly crustaceans such as copepods and decapods, and to a lesser extent on
217 mollusks and small fishes with a strong association with the coral substrate. Therefore, our
218 results highlight the strong trophic link existing between coral-dwelling reef fishes and mobile
219 invertebrates that comprise the coral reef cryptic fauna in the ETP. Degradation of coral reef
220 ecosystems could potentially affect the populations of *C. oxycephalus* due to its high specialized
221 diet, this as a consequence of their preys' habitat loss and the change in the crypto-benthic
222 community.

223

224 **Acknowledgements**

225 We thank Diego Córdoba for his assistance in laboratory and data analyses, and Edgardo
226 Londoño and Juan Felipe Lazarus for their help with the identification of the invertebrates. We
227 especially thank Juan Pablo Erazo, Alejandro Perlaza, Kevin Steven Mendoza, and Juan José
228 Gallego for their help during the field trip. We thank Parques Nacionales Naturales, especially
229 the staff of PNN Gorgona for their logistical support. We thank Maitreyi Nagarkar and Mikaela
230 Seemann for correcting the English. This study is part of the research project “Estructura y
231 función de los invertebrados crípticos móviles en dos arrecifes coralinos del Pacífico
232 colombiano” funded by COLCIENCIAS and Universidad del Valle to BV. This study was
233 performed under the collection permit No. 20192000038341.

234

235 **Conflict of interest statement**

236 On behalf of all authors, the corresponding author states that there is no conflict of interest.

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