

Spatial and temporal distribution of the invasive lionfish *Pterois volitans* in coral reefs of Tayrona National Natural Park, Colombian Caribbean

The lionfish *Pterois volitans* is an invasive species throughout the Western Atlantic that disturbs functioning of local ecosystems such as coral reefs via fast and intense consumption of small fish and invertebrates. In 2009, lionfish populated the bays of Tayrona National Natural Park (TNNP), a biodiversity hotspot in the Colombian Caribbean that is strongly influenced by changing environmental conditions due to a rainy and dry season. So far, the spatial and temporal distribution of *P. volitans* in the bays of TNNP is unknown. Therefore, this study assessed the abundance and body lengths of *P. volitans* during monthly surveys throughout the year 2012 in four bays (thereof two bays where lionfish removals were undertaken) of TNNP at 10 m water depth in coral reefs using transect tools. Findings revealed lionfish abundances of 2.9 ± 0.9 individuals ha^{-1} with lengths of 20 - 25 cm for TNNP, hinting to an established, mostly adult local population. Actual TNNP lionfish abundances are thereby very similar to those at Indo-Pacific reef locations where the invasive lionfish formerly originated from. Significant spatial differences for lionfish abundances and body lengths between different bays in TNNP suggest habitat preferences of *P. volitans* depending on age. Lionfish abundances were highly variable over time, but without significant differences between seasons. Removals could not reduce lionfish abundances significantly during the period of study. This study therefore recommends improved management actions in order to control the already established invasive lionfish population in TNNP.

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34 **Introduction**

35 The Indo-Pacific lionfish *Pterois volitans* belongs to the family Scorpaenidae and is an invasive
36 marine fish that got introduced in the Western Atlantic during the 80's (Whitfield et al. 2002;
37 Morris and Whitfield 2009; Schofield 2010; Albins and Hixon 2011; Arias-González et al. 2011).
38 Lionfish in invaded areas have many advantages over native fauna e.g. due to their high fecundity
39 (Morris 2009; Morris and Whitfield 2009), generalist diet on a variety of smaller fishes, shrimps
40 and small mobile invertebrates (Morris and Akins 2009), effective larval dispersal mechanisms
41 (Morris and Whitfield 2009), defensive venomous spines (Morris and Whitfield 2009; Albins and
42 Hixon 2011), efficient predation (Albins and Hixon 2008; 2011; Côté and Maljković 2010), rapid
43 growth (Albins and Hixon 2011), low parasite load (Morris 2009), and habitat generality
44 (Barbour et al. 2010; Albins and Hixon 2011). These characteristics make lionfish succeed over
45 native fishes and/or dramatically decrease local populations in invaded areas (Albins and Hixon
46 2008; Arias-González et al. 2011) with strong implications for the trophic web structures of the
47 marine ecosystem (Mack et al. 2000).

48 In Colombia, lionfish arrived to the oceanic islands of San Andrés and Providencia in 2008
49 and invaded the entire continental coast of the country in the course of the following year. For the
50 Tayrona National Natural Park (TNNP) in the Northeast Colombian coast, the presence of *P.*
51 *volitans* was first recorded in May - July 2009 at water depths between 12 – 20 m over coral

52 patches (González et al. 2009). In 2010, juvenile *P. volitans* (3 – 10 cm lengths) were observed in
53 the mangrove ecosystem of Chengue Bay (Arbeláez and Acero P. 2011). The ecological
54 consequences of lionfish are of particular interest for the TNNP area due to its major coastal
55 biodiversity (Garzón-Ferreira and Cano 1991).

56 So far, little is known about the spatial and temporal distribution of lionfish in TNNP.
57 Therefore, the aim of the present study was to assess monthly *P. volitans* abundances and
58 estimated body lengths throughout one year for four bays within TNNP. The first objective was to
59 compare lionfish data from TNNP with other invaded areas and also with its native locations in
60 the Indo-Pacific. The second objective was to determine whether lionfish abundances change
61 over time and if differences between a rainy and dry season, coinciding with a seasonal
62 upwelling, exist. This objective focused on possible effects of strong seasonal variation in
63 physicochemical parameters (temperature, salinity, wind, water currents, surplus of inorganic
64 nutrients; Bayraktarov 2013, 2014) during seasonal upwelling on lionfish distribution as shown
65 for temperature by Kimball et al. 2004. The third objective addressed the efficiency of
66 management actions that started in May 2012 in two TNNP bays by comparing lionfish
67 abundances before removals with data collected after removals for two of the four bays. The
68 present study provides recent and comprehensive lionfish distribution data and establishes an
69 actual baseline with high temporal and spatial resolution for TNNP reefs in the Colombian
70 Caribbean. Further needs of management actions to control the already established invasive
71 lionfish population in TNNP are discussed.

72

73 **Materials and Methods**

74 *Study site*

75 All necessary permits were obtained for the described study by Instituto de Investigaciones
76 Marinas y Costeras (INVEMAR) in Santa Marta, Colombia which complied with all relevant
77 regulations (decree # 302 and # 309).

78 The Tayrona National Natural Park (TNNP) is located at the Northeastern coast of Colombia,
79 between 11°17' – 11°22' N and 73°53' – 74°12' W (Fig. 1). The region contains a rocky coastline
80 with capes, inlets and bays with sandy beaches covering over 40 km (Garzón-Ferreira and Cano
81 1991; Díaz et al. 2000; Martínez and Acosta 2005). The area of survey included the main TNNP

82 bays Chengue, Gayraca, Neguanje and Cinto (Fig. 1) which experience strong seasonal changes
83 due to a rainy season (> 80 % of the annual rainfall, May to November) and a dry season
84 (December to April) going along with a seasonal upwelling with strong changes in temperature
85 (decrease from 28 to 21°C), salinity (increase from 33 to 38), increased wind and water currents
86 (Salzwedel and Müller 1983; Mesa et al. 1997; Bayraktarov et al. 2013; Bayraktarov et al. 2014).
87 Reports on the increased concentration of inorganic nutrients and chlorophyll *a* characterize the
88 oligotrophic region during non-upwelling as mesotrophic in periods of upwelling (Franco-
89 Herrera et al. 2007; Arévalo-Martínez and Franco-Herrera 2008; Bayraktarov et al. 2014).

90 Coral reef formations are growing on both sides of each bay between water depths of 5 to 20
91 m (Werding and Erhardt 1976; Werding and Sánchez 1989; Garzón-Ferreira and Cano 1991) and
92 represent a habitat for over 180 reef fish species (Olaya-Restrepo et al. 2008). Additionally to
93 coral reefs, the bays harbor mangrove ecosystems and seagrass beds (Fig. 1; Garzón-Ferreira and
94 Cano 1991).

95 *Lionfish assessment in space and time*

96 In order to address the goals of the study, *P. volitans* abundances were monitored monthly in four
97 bays of TNNP. Surveys comprised monitoring along line transects of 50 m length and 5 m width
98 in triplicates that were located at the Western and at the Eastern flank of each bay (Fig. 1) in order
99 to encompass a representative area for lionfish distribution. Transects were located at water
100 depths between 9 and 11 m, parallel to the coastline. The investigated area covered 1500 m² per
101 bay and a total of 6000 m² within the TNNP. The method of visual census was applied by
102 SCUBA (English et al. 1997; Lang et al. 2010). The total number of *P. volitans* observed during a
103 time of 25 min per triplicate was counted (Morris 2009). Places where lionfish may hide such as
104 holes and cavities between rocks and coral framework were carefully examined. Estimated total
105 body lengths of lionfish were recorded *in situ* in 5 cm intervals for each localized individual from
106 the tip of the snout to the tip of the caudal fin. The surveys were performed between the second
107 and the third week of each month, between 8:00 am. and 3:00 pm.

108 Lionfish removals started in May 2012 as a joint project between Universidad Nacional de
109 Colombia, Universidad Jorge Tadeo Lozano, Universidad del Magdalena, Instituto de
110 Investigaciones Marinas y Costeras ‘José Benito Vives de Andrés’ (Invemar) and the National
111 Natural Parks of Colombia. Removals were performed monthly by spearing and nets at variable
112 depths by SCUBA diving, exclusively in the TNNP bays Chengue and Cinto. A Additional

113 unregistered removals of lionfish by dive centers or fishermen could not be considered in the
114 present survey.

115

116 *Data analysis*

117 Mean monthly abundances of *P. volitans* in the TNNP bays Chengue, Gayraca, Neguanje and
118 Cinto (Fig. 2) were calculated from data collected over 12 months with a replication of 6
119 transects per bay and month and were converted into individuals per hectare (ind ha^{-1} ; Fig. 2).
120 Monthly abundance before onset of removals in May were estimated by calculating the
121 abundance for the time period January to April, whereas lionfish data collected between May and
122 December were used to determine the monthly mean abundance after removals. For calculation
123 of the lionfish distribution with a temporal resolution, lionfish all transect data per month were
124 aggregated resulting in a replication of $n = 24$ transects (Fig. 3). Annual mean abundance was
125 determined for each bay and the whole TNNP area by pooling the data collected over 12 months
126 resulting in a transect replication of $n = 69$ transects for Chengue and Neguanje, and $n = 72$ for
127 Gayraca and Cinto (total of 282 transects).

128 Differences in *P. volitans* abundances between bays and months were tested by a Generalized
129 Linear Model (GLM) for Poisson-distributed data and the software R (R Development Core
130 Team 2008). Multiple comparisons between bays (Chengue, Gayraca, Neguanje and Cinto) and
131 months were performed by a Tukey's Honestly Significant Difference (HSD) *post hoc* test on
132 data before (January – April; 93 transects) and after onset of removal (May – December; 189
133 transects). For a quantification of possible removal effects, GLMs for Poisson-distributed data
134 and Tukey's HSD *post hoc* tests were performed for lionfish data before and after removal and
135 the bays Chengue and Cinto, individually. The graphical representation of data was performed by
136 the software SigmaPlot 10.0 (Systat Software, Inc).

137

138 **Results**

139 *Spatial distribution of lionfish in TNNP*

140 Throughout the year 2012, 123 individuals of *Pterois volitans* were counted during 12 months in
141 4 bays over a total monitored area of 6000 m^2 . Before removals, lowest mean monthly lionfish

142 abundance was found in Chengue Bay with 1.7 ± 1.0 ind ha⁻¹ (monthly mean \pm SE for the months
143 January - April), followed by Cinto with 2.5 ± 0.3 , and Neguanje with 3.9 ± 1.0 ind ha⁻¹. Highest
144 numbers of monthly lionfish were present in Gayraca with 5.8 ± 3.6 ind ha⁻¹. Significant
145 differences in lionfish abundances for the registered individuals during the months before
146 removal were present between the bays Chengue and Gayraca (GLM, Tukey's HSD *post hoc*, $p =$
147 0.033) with higher lionfish abundance in Gayraca. After onset of monthly removal in May, lowest
148 monthly lionfish abundance was observed in Neguanje with 0.8 ± 0.5 ind ha⁻¹, followed by
149 Chengue with 1.3 ± 0.6 and Cinto with 3.9 ± 2.0 ind ha⁻¹. Highest monthly lionfish abundance
150 was still observed in Gayraca Bay with 4.4 ± 1.7 ind ha⁻¹. After removal, significant differences
151 were found between Chengue and Cinto ($p = 0.017$), Chengue and Gayraca ($p = 0.004$), Gayraca
152 and Neguanje ($p < 0.001$) and Neguanje and Cinto ($p = 0.003$).

153

154 Monthly lionfish abundances for the TNNP bays were between 0 and 16.7 ind ha⁻¹ (Fig. 2). In
155 Chengue, lionfish abundances were below 5 ind ha⁻¹ (monthly mean \pm SE) until July and
156 disappeared thereafter completely until December, where 1.1 ± 1.1 ind ha⁻¹ were registered.
157 Highest abundances were observed in Gayraca during January with 16.7 ± 10.3 ind ha⁻¹ and
158 August with 12.2 ± 4.6 ind ha⁻¹, while intermediate abundances were present during September
159 with 10.0 ± 5.6 ind ha⁻¹ and December with 7.8 ± 6.5 ind ha⁻¹ in this bay. In Neguanje, highest
160 lionfish abundances were recorded in January with 5.6 ± 5.6 ind ha⁻¹ and February with 5.6 ± 3.6
161 ind ha⁻¹. Here, no lionfish were observed between July and December, except for September
162 where 2.2 ± 2.2 ind ha⁻¹ were registered. In Cinto, lionfish abundances peaked during September
163 with 16.7 ± 5.6 ind ha⁻¹ and June with 6.7 ± 2.4 ind ha⁻¹, but were otherwise below 5 ind ha⁻¹.

164 Largest estimated lionfish body lengths of 40 cm were registered for Cinto in January and
165 August, and Neguanje in September. Largest body lengths were present in Gayraca and Cinto
166 with sizes of 20 – 25 cm, followed by Neguanje with 15 – 20 cm, and smallest in Chengue with
167 10 – 15 cm fishes. A total of 75 % of all registered lionfish individuals had a body length larger
168 than 17 cm (20 – 25 cm) representing the size of mature females (Morris 2009). The total
169 percentage of adults was distributed as 8 % in Chengue, 50 % in Gayraca, 13 % in Neguanje and
170 29 % in Cinto.

171

172 *Temporal distribution of lionfish in TNNP*

173 On the temporal scale, highest abundance of lionfish was observed in September with 7.2 ± 2.4
174 ind ha⁻¹ (monthly TNNP mean \pm SE; Fig. 3) and January with 6.4 ± 3.0 ind ha⁻¹; lowest during
175 November with 0.3 ± 0.3 ind ha⁻¹ and July with 0.8 ± 0.6 individuals ha⁻¹ ind ha⁻¹. Significant
176 differences between months were present between September and April (GLM, Tukey's HSD
177 *post hoc*, $p = 0.05$), July and January ($p = 0.04$), September and July ($p = 0.02$), September and
178 May ($p = 0.03$), and between September and October ($p = 0.03$). However, lionfish abundances
179 were not significantly different between rainy (May – November) and dry season (December –
180 April).

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182

183 *The effect of fish removal*

184 Individual GLM analyses showed no significant differences in lionfish abundance before
185 (January – April) and after removal (May – December) for both controlled bays, Chengue (GLM,
186 Tukey's HSD *post hoc*, $p = 0.53$) and Cinto ($p = 0.25$). Since no significant differences were
187 observed between the abundance data before and after removal, transect data collected over 12
188 months of monitoring and 4 bays with a total of $n = 282$ transect replicates were pooled to
189 calculate an annual mean of 2.9 ± 0.9 ind ha⁻¹ (annual mean \pm SE) for the TNNP region. The
190 annual mean for Chengue was 1.4 ± 1.3 ind ha⁻¹, 4.9 ± 1.3 ind ha⁻¹ for Gayraca, 1.8 ± 0.6 ind ha⁻¹
191 for Neguanje, and 3.4 ± 0.8 ind ha⁻¹ for Cinto, respectively (Table 1).

192

193 **Discussion**

194 *Spatial and temporal distribution of *P. volitans**

195 Our data on *P. volitans* distribution in TNNP (Colombian Caribbean) show that a local population
196 with mean body length of 20 – 25 cm has developed in the bays Chengue, Gayraca, Neguanje and
197 Cinto. These lionfish body lengths hint to a population mostly dominated by adult fishes that are
198 able to recruit sexually. This assumption is confirmed by the study of Morris (2009) who reported
199 17 cm as the size of mature females.

200 With an annual mean of 2.9 ind ha⁻¹, lionfish abundance in TNNP was similar to some
201 locations in the Indo-Pacific where it originated from, e.g. Palau Archipelago with 2.2 ind ha⁻¹
202 (Grubich et al. 2009), but below ~80 ind ha⁻¹ reported for the Gulf of Aqaba/ Red Sea (Fishelson
203 1997). Table 1 shows a comparison of lionfish abundance in TNNP to other invaded and native
204 habitats worldwide, however data should be considered as estimates as methods of monitoring
205 were not always comparable (e.g. rotenone-sampling over small areas; Fishelson 1997). Lionfish
206 abundances in TNNP were below the values reported for other invaded areas of the Western
207 Atlantic such as the Bahamas with 393 (Green and Côté 2009) or the coast off North Carolina/
208 USA with 150 ind ha⁻¹ (Morris and Whitfield 2009) which may be due to the relatively recent
209 invasion of TNNP in 2009 (González et al. 2009) vs. an invasion of the Bahamas in 2004
210 (Schofield 2009). High abundances of lionfish in invaded areas are likely the result of unlimited
211 growth and reproduction due to the availability of food sources and lack of natural predators.
212 Some predators obviously learned to target lionfish as potential prey (Bernadsky and Goulet
213 1991; Maljković et al. 2008). So far, two Caribbean large-bodied grouper species, *Epinephelus*
214 *striatus* and *Mycteroperca tigris*, were observed to successfully ingest lionfish (Maljković et al.
215 2008). However, *E. striatus* is one of the species categorized as endangered in the Colombian
216 Caribbean red list of marine fishes (Mejía and Acero P. 2002). Mumby et al. (2011) presented
217 data on the reduction of lionfish biomass by groupers which may thus serve as natural biocontrol
218 of growing lionfish populations. However, the lack of these natural lionfish predators in TNNP
219 (Olaya-Restrepo et al. 2008) and the wider Caribbean (Sadovy 2005) is alarming. In contrast to
220 Mumby et al. (2011), the study of Hackerott et al. (2013) concluded that the success of lionfish
221 population was not influenced by interaction with native predators in 71 reefs and different
222 biogeographic regions in the Caribbean. These conflicting results once more stress the necessity
223 of immediate management actions to control further lionfish reproduction and invasion.

224 Our monthly *P. volitans* distribution data over four bays in TNNP showed no seasonal pattern
225 between a rainy and a dry season, going along with seasonal upwelling Seasonal upwelling and
226 the consequently altered environmental conditions (temperature, salinity, water currents, and
227 surplus of inorganic nutrients; Salzwedel and Müller 1983; Bayraktarov et al. 2014) did not affect
228 the established lionfish population. The decrease in seawater temperature from 28 to 21 °C had
229 no effect on lionfish distribution within the area as the critical temperature at which lionfish
230 ceases feeding was reported to be 16 °C with lethal consequences at 10 °C (Kimball et al. 2004).

231 The reported critical temperature for lionfish distribution of 16 °C lies below the lowest seawater
232 temperature that can be expected for the TNNP region.

233

234 *Effect of lionfish removal*

235 Abundances and body lengths of *P. volitans* for Chengue Bay, in which removals were
236 performed, were smaller than for the uncontrolled Gayraca and Neguanje. However, removals
237 could not effectively reduce lionfish abundances in Cinto which were lower than abundances in
238 Gayraca but higher than in Neguanje. Body lengths found in Cinto corresponded to those in
239 Gayraca. The smallest body lengths observed in Chengue indicate that a mostly juvenile
240 population may have developed in this bay and thereby indicates a habitat preference dependent
241 on age. However, it cannot be excluded that the smaller body lengths of lionfish in Chengue are a
242 consequence of removal during management actions targeting predominantly larger adult
243 individuals which are easier to observe and catch. Smaller juveniles may hide between the roots
244 of mangroves (Arbeláez and Acero P. 2011) or in crevices and holes of the reef framework.
245 Additionally, Chengue Bay comprises a highly developed mangrove ecosystem (Garzón-Ferreira
246 and Cano 1991) which may serve as nursery for lionfish larvae and juveniles. This is further
247 supported by the study of Arbeláez and Acero P. (2011), who found lionfish juveniles of 3 – 10
248 cm lengths at the submerged roots of the mangroves bordering the entrance to the southern
249 lagoon in Chengue Bay.

250 Factors affecting fish populations that cannot be excluded are the differences in coral reef
251 complexity between the bays and the potential food sources for lionfish. These important points
252 need to be addressed in further studies.

253 Our study suggests that management actions for the TNNP require further improvement in
254 terms of removal frequencies and a larger control area in order to significantly reduce the
255 established lionfish population. The implementation and improvement of management actions in
256 order to preserve the condition of Caribbean coral reef ecosystems during *P. volitans* invasion are
257 crucially essential. The national plan to control and manage lionfish invasion in Colombia is
258 focused on three focal strategy points: 1.) realization of fundamental research, 2.) implementation
259 of management actions and 3.) focus on education and control (MADS et al. 2013). Whereas the
260 first two points are addressed by research groups of universities and institutes, the third point is

261 coordinated by the National Natural Parks of Colombia dealing with all territories of marine
262 parks and reserves. The removal of lionfish outside the marine parks territories lies in the hands
263 of regional environmental officers.

264

265 *Recommendations*

266 Considering the national plan to control and manage lionfish invasion, potential management
267 actions required for the Colombian Caribbean region may further focus on raising the
268 community's awareness by introducing the lionfish problem and the consequences of its invasion.
269 Removals on a wider scale can be promoted by consumption of lionfish on a local and
270 commercial scale as suggested by Morris et al. (2011). Lionfish meat proved to be a good
271 candidate for human nutrition due to its relatively high content of fillet yield (30.5 %)
272 comparable to groupers, graysbys, and coneys (Morris et al. 2011). Lionfish meat had also higher
273 content of essential n-3 fatty acids and a relatively low amount of saturated fatty acids as
274 compared to other marine reef fish species (e.g. red snapper, dolphinfish, blue fin tuna,
275 triggerfish, grouper and tilapia; Morris et al. 2011). The authors suggested that public outreach
276 should especially focus on education about lionfish invasion, handling and cleaning of *P. volitans*
277 in order to minimize risks for envenomation (Morris et al. 2011).

278 The establishment of marine reserves can effectively protect larger fishes (Halpern 2003) such
279 as groupers that could prey on lionfish as reported for the fishing-restricted Exuma Cays Land
280 and Sea Park / Bahamas by Mumby et al. 2011. Further controlled fishing restrictions especially
281 on native apex predator populations will become imperative for lionfish invasion control.

282 The invasion of *P. volitans* in the Western Atlantic and the Caribbean is considered as one of
283 the top global threats to conservation of biodiversity (Sutherland et al. 2010). Local lionfish
284 populations may disturb functioning of coral reefs through high consumption of small
285 herbivorous fishes, including parrotfishes (Albins and Hixon, 2008; Morris and Akins 2009), thus
286 indirectly promote the outcompeting of corals by naturally uncontrolled growth of seaweeds
287 (Mumby et al. 2006; Mumby and Steneck 2008). Combined with a decrease in live coral cover
288 due to overfishing of herbivores by humans and lionfish (Albins and Hixon 2011), consequences
289 of global climate change (Hoegh-Guldberg et al. 2011), and environmental degradations, the

290 future of coral ecosystems is severely endangered (Jackson 2010) in the Western Atlantic and
291 Caribbean.

292

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- 458

Figure 1

Area of survey in the Tayrona National Natural Park (TNNP)

The points indicate the sampling locations at the western and eastern flank of each bay.

Source: Invemar 2014

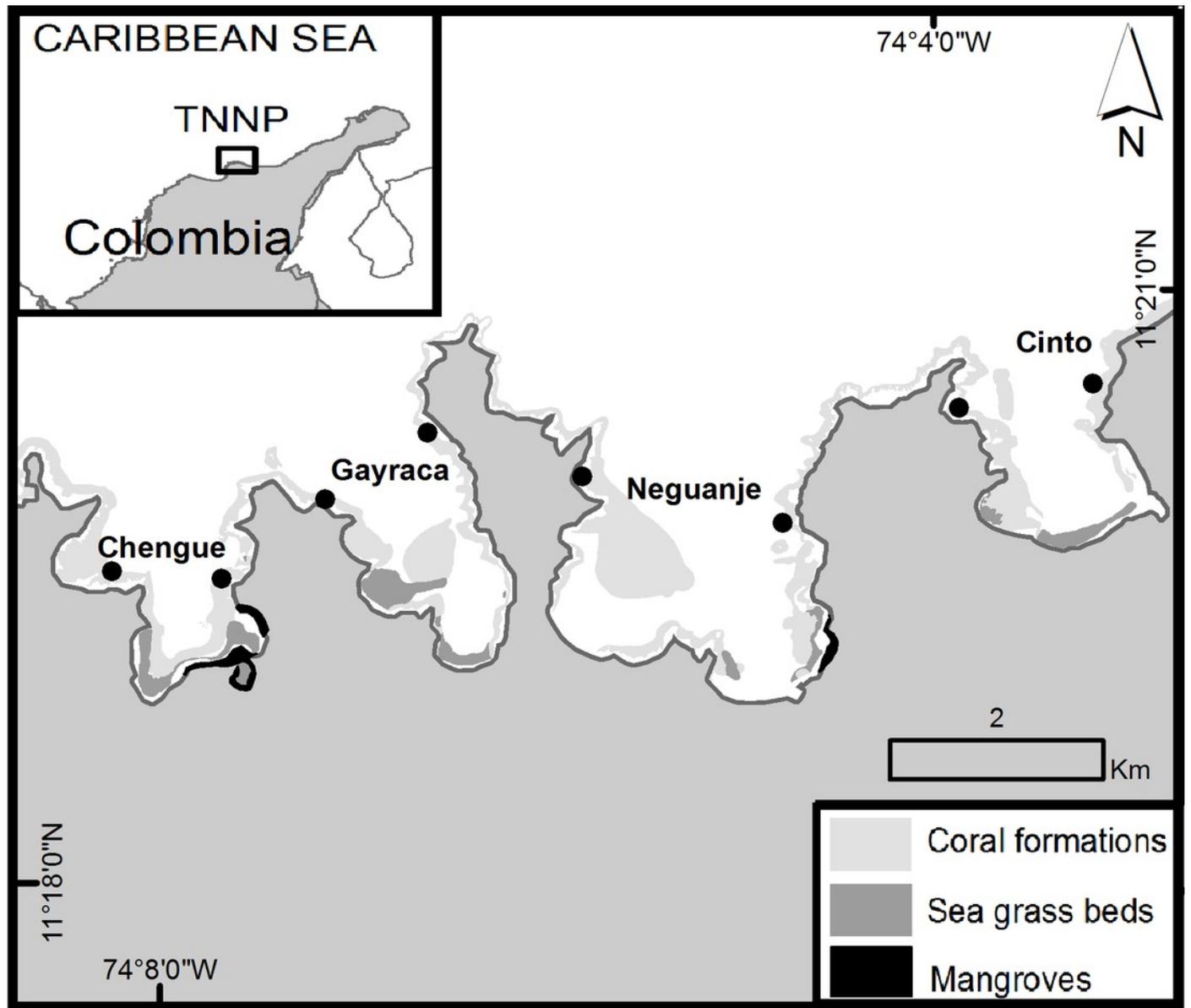


Figure 2

Abundances (monthly mean \pm SE) of *Pterois volitans* in the Tayrona National Natural Park bays Chengue, Gayraca, Neguanje and Cinto throughout the months of 2012

The red line indicates the starting period of monthly removals (May 2012) from the bays Chengue and Cinto

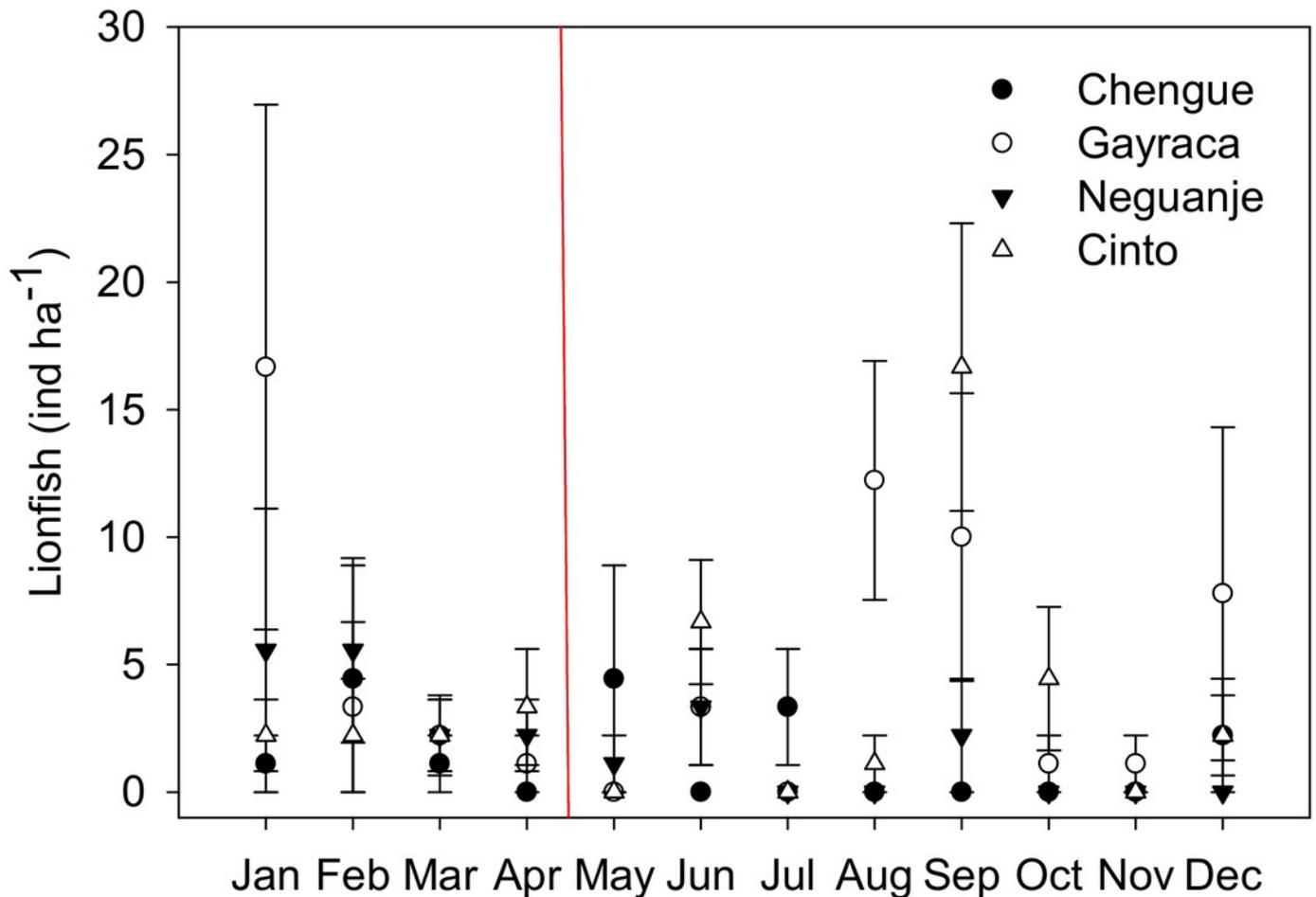


Figure 3

Monthly abundances of *Pterois volitans* (monthly mean \pm SE) for Tayrona National Natural Park

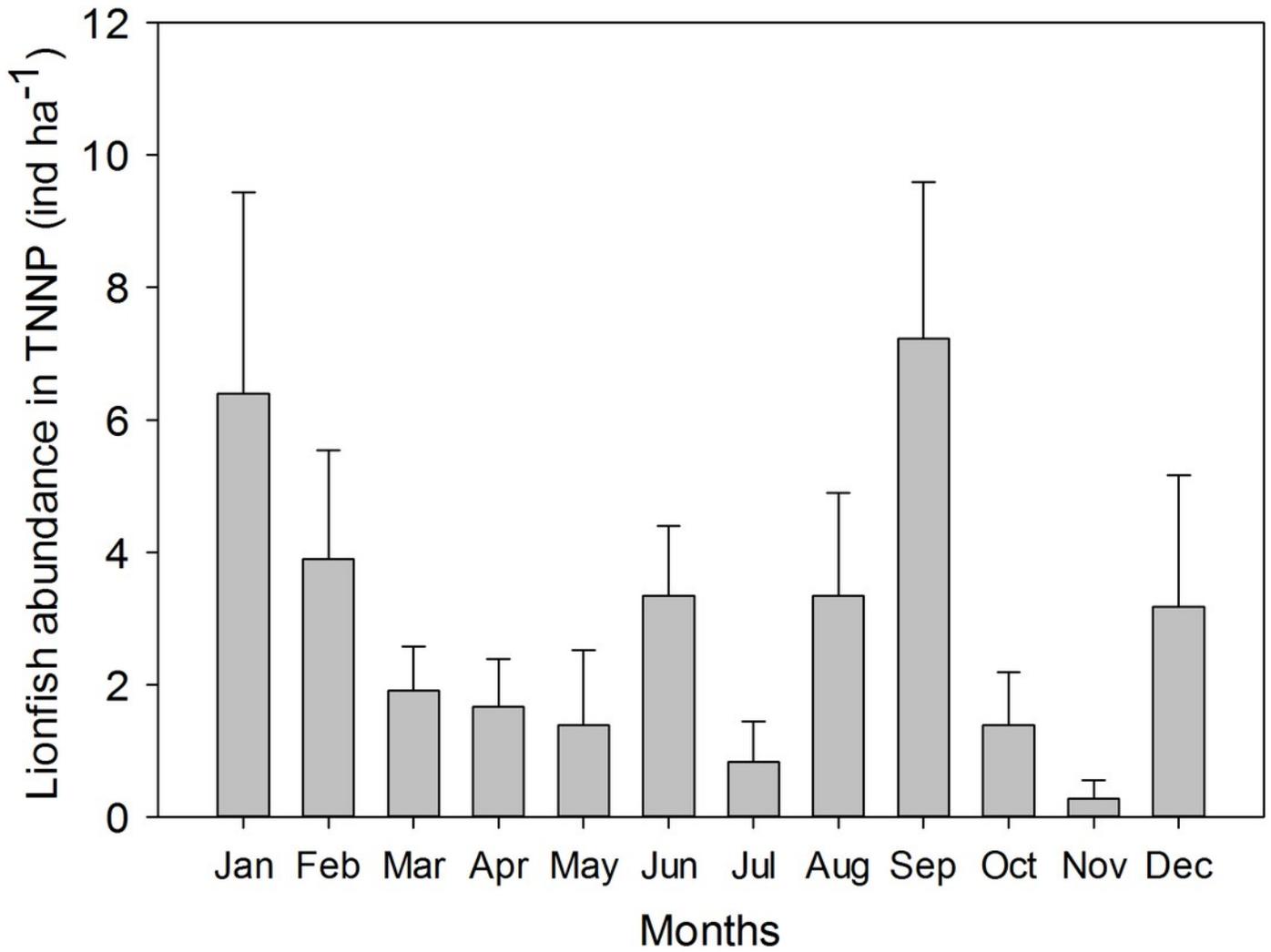


Table 1 (on next page)

Comparison of *Pterois volitans* abundance in TNNP with worldwide reports on invaded and native habitats

Region and Year	Habitat for lionfish	Reported abundance (ind ha ⁻¹)	Source
Chengue Bay (TNNP, Colombian Caribbean), 2012	invasive	1.4 ± 0.6	this study
Gayraca Bay (TNNP, Colombian Caribbean), 2012	invasive	4.9 ± 1.3	this study
Neguanje Bay (TNNP, Colombian Caribbean), 2012	invasive	1.8 ± 0.6	this study
Cinto Bay (TNNP, Colombian Caribbean), 2012	invasive	3.4 ± 0.8	this study
TNNP, Colombian Caribbean, 2012	invasive	2.9 ± 0.9	this study
New Providence, Bahamas, Western Atlantic, 2008	invasive	393.3 ± 144.4	Green and Côté (2009)
Coast off North Carolina, USA, Western Atlantic, 2004	invasive	21.2 ± 5.1	Whitfield et al. (2007)
Coast off North Carolina, USA, Western Atlantic, 2008	invasive	150	Morris and Whitfield (2009)
Palau Archipelago, Western Pacific, 2008	native	2.2	Grubich et al. (2009)
Gulf of Aqaba, Red Sea, 1997	native	~ 80	Fishelson (1997)