

1 **Influence of coral cover and structural complexity on the accuracy of visual**
2 **surveys of coral-reef fish communities**

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24 Visual surveys are an integral tool for evaluating ecologically and commercially relevant
25 fishes within coral reef ecosystems; however, whether and how accuracy is influenced by
26 habitat condition remains poorly understood. Using manipulated patch reefs with
27 combinations of varying live coral cover (low, medium, and high) and structural
28 complexity (low, high), we compare common community-metrics (abundance, diversity,
29 richness, and community composition) collected through standard underwater visual
30 census techniques to exhaustive collections with a fish anesthetic (clove oil). This study
31 showed that reef condition did not influence UVC estimates at a community level;
32 however, reef condition can influence reliable detectability of some small and cryptic
33 species, and this may be exacerbated if surveys are conducted on a larger scale.

34

35 Visual surveys are a fundamental part of any effort to document abundance, distribution,
36 and community composition of organisms in coral reef ecosystems. Underwater visual
37 census (UVC) has been used extensively over the past few decades as a basis to most
38 impact assessments, experimental, and monitoring research (Harmelin-Vivien *et al.*,
39 1985; Bortone & Kimmel, 1991; Medley *et al.*, 1993; Cinner *et al.*, 2016). UVCs provide
40 quick, non-destructive, and cost-effective estimates of targeted fish communities,
41 particularly over large areas. UVCs have been particularly instrumental for examining the
42 response of coral reef fishes to changing habitat conditions (Jones *et al.*, 2004; Graham *et*
43 *al.*, 2015).

44 Disturbances impact benthic condition through the loss of live coral cover (e.g.,
45 bleaching, disease, and crown of thorns starfish), and physical degradation (e.g., tropical
46 storms) (Gardner *et al.*, 2003; Hughes *et al.*, 2003; De'ath *et al.*, 2012). Live coral cover

47 and structural complexity of reefs are both recognized as important components for many
48 coral reefs fishes, although their influence may vary among different fish assemblages
49 (Graham *et al.*, 2006; Wilson *et al.*, 2006; Graham & Nash, 2013). Live coral and the
50 structure it provides not only afford essential food and habitat for reef fishes (Cole *et al.*,
51 2009; Coker *et al.*, 2013), but also influences recruitment and post-settlement
52 survivorship (Beukers & Jones, 1998; Ohman *et al.*, 1998; Coker *et al.*, 2012). However,
53 these two habitat factors are not mutually exclusive and are often in varying
54 combinations as a result of disturbance and recovery.

55 Despite the wide spread use of UVCs for documenting reef communities, few
56 studies have validated their ability to reliably estimate ecologically relevant aspects of
57 reef fish communities (but see: Sale & Douglas, 1981; Brock, 1982; John *et al.*, 1990;
58 Kulbicki, 1990; Ackerman & Bellwood, 2000; Willis, 2001). Moreover, the influence of
59 habitat condition on the reliability of UVC estimates remains wholly unknown. This is
60 problematic, because the shelter provided by live corals and the increased refuge spaces
61 within structurally complex reefs, for example, may make it difficult to accurately assess
62 entire fish communities (Brock, 1982). Clove oil has become an effective tool for
63 anaesthetizing fishes for collection and experimental purposes (Munday & Wilson, 1997;
64 Ackerman & Bellwood, 2000; Goatley *et al.*, 2016). Given the efficiency of this method,
65 it can further be utilized to validate UVC estimate on small spatial scales.

66 Small, discrete, artificially constructed patch reefs provide a good opportunity to
67 empirically test the influence of habitat condition on the reliability of UVC estimates.
68 They can be easily manipulated or purposefully constructed in suitable locations and
69 environments to control for or include specific environmental variables. This provides a

70 replicable and standardized frame-work for drawing relationships between changes in
71 substrate (e.g., degradation, composition, and location) and associated reef fish
72 communities (e.g., Almany, 2004; Bonin *et al.*, 2011; Messmer *et al.*, 2011; Coker *et al.*,
73 2012). Using manipulated patch reefs, the objective of this study was to determine
74 whether and how habitat condition affects the accuracy of UVC measurements of
75 abundance, richness, diversity, and species composition of associated fish communities.
76 This was achieved by comparing UVC estimates to exhaustive collections of reef fish
77 communities using clove oil on small isolated patch reefs with alternating combinations
78 of coral cover and structural complexity.

79 Existing patch reefs (see Coker *et al.*, 2012) situated within the shallow lagoon at
80 Lizard Island (Great Barrier Reef, Australia) were first visually surveyed and then all fish
81 collected for comparisons and additional analysis. A total of 28 small (1m²), isolated
82 patch reefs were used, consisting of six treatments: high (H), medium (M), and low (L)
83 coral cover (approx. 55%, 35%, 10%, respectively), crossed with high (H) and low (L)
84 structural complexity. Each treatment was replicated five times, except for medium coral
85 cover high complexity (MH) and high coral cover low complexity (HL), which were
86 replicated four times due to damage. All reefs comprised equal volumes of substrate and
87 coral species composition (Coker *et al.*, 2012).

88 All visual surveys were conducted by a single observer (DJC) and executed in a
89 three-stage approach in an attempt to document all species present. First, the observer
90 recorded from a distance of approximately 3m to survey larger, flighty, and shy species.
91 Next, the patch reef was surveyed from the perimeter until the observer was confident
92 that all individuals were recorded. Finally, the internal structure (refuge spaces and holes)

93 was searched with the aid of an underwater torch to capture cryptic species. The survey
94 ended when the observer was confident that all fishes had been documented.

95 Clove oil collections were conducted by two divers. A small mesh barrier net was
96 placed around each patch reef to prevent the escape of larger mobile individuals. With the
97 use of clove oil, all fish were anesthetized and collected. Patch reefs were separated by >
98 10 m of open sand, and no individuals were observed to escape collection. In order to
99 collect small and cryptic species, most of the reef was dismantled and exhaustively
100 searched. Following collection, fish were placed in ice slurry and later identified to
101 species.

102 A total of 773 fishes, comprising 50 species were, recorded by UVC, in
103 comparison to 918 fishes and 62 species through clove oil collections. Hence, UVC
104 detected 16% fewer individuals and 21% fewer species, revealing that even at the
105 relatively small scale of the study, overall species abundance and richness was under-
106 estimated using UVC methods. This pattern is consistent with studies that have tested
107 direct comparisons between survey methods (e.g., via rotenone, clove oil, quinaldine),
108 however these do not take into account habitat condition (Brock, 1982; Kubicki, 1990;
109 Ackerman & Bellwood, 2000; Willis, 2001). There is, however, a considerable trade off
110 in time, equipment, and sacrifice of individuals associated with collections. In addition,
111 reefs generally need to be physically manipulated in order to obtain small and cryptic
112 individuals, potentially damaging organisms. Only 39 species were recorded by both
113 methods, with 10 species (7%) recorded by UVC but not clove oil, and 23 species (31%)
114 collected using clove oil, but not observed with UVC. A total of 72 species were
115 identified on the reefs through both sampling methods; revealing that UVC potentially

116 captured 68% of species present, whereas collection captured 86%. Overall, this suggests
117 that while UVCs are negligibly less capable of capturing true species richness relative to
118 exhaustive collection, both approaches entail biases and limitations, and the most
119 appropriate method will depend on the specific aims of each study (see Sale & Douglas,
120 1981).

121 Differences in substrate composition and structural complexity may not only
122 influence fish communities (Wilson *et al.*, 2006; Coker *et al.*, 2012; Graham & Nash,
123 2013), but also their visual detectability. Structurally complex corals (e.g., Acroporidae,
124 Pocilloporidae) and the underlying reef matrix (e.g., rubble, holes) provide habitat
125 structure that can assist species in remaining cryptic through camouflage and the
126 provision of refuge spaces. We found that the difference between UVC and collection
127 measurements of abundance, richness, and diversity did not vary between different
128 combinations of coral cover and structural complexity (Fig. 1). Differences between
129 UVC and collection measurements were slightly more under-estimated at the two habitat
130 condition extremes (HH and LL) (Fig. 1); however, this was not statistically significant.
131 Taken together, these findings suggest that habitat condition did not affect the reliability
132 of UVC estimates of species abundance, richness, or diversity.

133 For the majority of patch reefs (21/28), similarity of the fish community sampled
134 between the two survey methods was greater than among replicates from the same or
135 different habitat treatments (Bray Curtis similarity (PRIMER-V6, Clarke, 1993)) (Fig. 2).
136 Within the same reefs, community similarity between the different survey methods
137 ranged from 60 to 90%, illustrating that for most reefs, community estimates were
138 comparable between survey methods. However, for seven reefs, the composition

139 recorded by UVC was not directly similar to the collected composition. These were from
140 all levels of coral cover, but mostly from low complexity reefs (six out of the seven). The
141 greatest discrepancies between UVC and collections came from low complexity reefs
142 across a range of different coral cover levels, suggesting that physically degraded reefs
143 are more difficult to accurately survey community composition. This is counterintuitive,
144 as reefs with high complexity are expected to afford higher levels of shelter. It is possible
145 that the rubbly substrate caused by the physical degradation of structure provides better
146 refuges for some small cryptic reef fishes.

147 For the majority of species, in all habitat treatments, discrepancies between the
148 two survey methods for species abundance measurements were minimal ($< \text{average} \pm 6$
149 individuals per treatment (mean \pm SE)). Discrepancies increased with habitat quality,
150 such that UVC tended to over-estimate species abundance in high complexity and/or
151 coral cover. However, for the majority of species, this was only to a small extent (Fig. 3).
152 This suggests that in complex habitats, some species abundances may be over-estimated,
153 presumably as a result of re-counting the same individuals. In the context of this study,
154 the error in estimating species abundance using UVCs is minor, but provides insight into
155 which species are miss-recorded, and if reef health influences this. The greatest disparity
156 between the two methods was in estimating the abundance of species from the family
157 Pomacentridae, with many species being over- and under-estimated (Fig. 3). Many of
158 these species are relatively small, remain close to the substrate, and potentially
159 experience high levels of predation. The greatest and most consistent differences among
160 reef treatment were observed for *Pomacentrus ambionensis* Bleeker 1868,
161 *Pseudochromis fuscus* Müller & Troschel 1849, and an unidentifiable species of Gobiidae

162 (Goby sp.). *Pseudochromis fuscus* is relatively common on coral reefs and regarded an
163 important reef mesopredator (McCormick & Holmes, 2006). They are small (max 100
164 mm) and cryptic in nature, remaining close to the substrate and often move within the
165 reef matrix. This emphasizes the challenges in detecting common active fishes, even on a
166 small scale.

167 While UVCs continue to play a central role in assessing key aspects of fish
168 communities, it is to be expected that this approach may entail some level of
169 measurement inaccuracy, particularly among varying habitat conditions. This study
170 corroborates previous studies, showing that compared to exhaustive fish collections,
171 UVCs tend to under-estimate fish community measurements (Christensen &
172 Winterbottom, 1981; Brock, 1982; Kulbicki, 1990; Ackerman & Bellwood, 2000). This
173 was consistent among habitat treatments, with small numerous fishes over-estimated and
174 cryptic fishes under-estimated. Importantly, most of these differences were not
175 significant, however the low sample sizes of our treatments should be kept in mind. We
176 further show that habitat quality has a negligible influence on the UVC measurement
177 accuracy of species abundance, richness, and diversity; yet in low complexity
178 environments. However, this study was conducted at a scale of 1 m² and differences
179 would be expected to increase exponentially as surveying scale increases, and other
180 community metrics may be more or less sensitive. It should also be noted that UVC is
181 less destructive to the reef and allows repetitive sampling through time, which can be
182 important for studies that monitor ecological processes and demographics (e.g., Almany,
183 2004; Coker *et al.*, 2012). Hence, overall, UVC continues to provide an important role
184 and reliable estimates of fish community metrics, irrespective of reef condition, at least at

185 a small patch reef level.

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