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

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

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

Disturbances impact benthic condition through the loss of live coral cover (e.g., bleaching, disease, and crown of thorns starfish), and physical degradation (e.g., tropical storms) (Gardner *et al*., 2003; Hughes *et al*., 2003; De'ath *et al.*, 2012). Live coral cover and structural complexity of reefs are both recognized as important components for many coral reefs fishes, although their influence may vary among different fish assemblages (Graham *et al.*, 2006; Wilson *et al*., 2006; Graham & Nash, 2013). Live coral and the structure it provides not only afford essential food and habitat for reef fishes (Cole *et al.*, 2009; Coker *et al.*, 2013), but also influences recruitment and post-settlement survivorship (Beukers & Jones, 1998; Ohman *et al*., 1998; Coker *et al.*, 2012). However, these two habitat factors are not mutually exclusive and are often in varying combinations as a result of disturbance and recovery.

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

Small, discrete, artificially constructed patch reefs provide a good opportunity to empirically test the influence of habitat condition on the reliability of UVC estimates. They can be easily manipulated or purposefully constructed in suitable locations and environments to control for or include specific environmental variables. This provides a replicable and standardized frame-work for drawing relationships between changes in substrate (e.g., degradation, composition, and location) and associated reef fish communities (e.g., Almany, 2004; Bonin *et al.*, 2011; Messmer *et al.*, 2011; Coker *et al.*, 2012). Using manipulated patch reefs, the objective of this study was to determine whether and how habitat condition affects the accuracy of UVC measurements of abundance, richness, diversity, and species composition of associated fish communities. This was achieved by comparing UVC estimates to exhaustive collections of reef fish communities using clove oil on small isolated patch reefs with alternating combinations of coral cover and structural complexity.

Existing patch reefs (see Coker *et al.*, 2012) situated within the shallow lagoon at Lizard Island (Great Barrier Reef, Australia) were first visually surveyed and then all fish collected for comparisons and additional analysis. A total of 28 small ($1m^2$), isolated patch reefs were used, consisting of six treatments: high (H), medium (M), and low (L) coral cover (approx. 55%, 35%, 10%, respectively), crossed with high (H) and low (L) structural complexity. Each treatment was replicated five times, except for medium coral cover high complexity (MH) and high coral cover low complexity (HL), which were replicated four times due to damage. All reefs comprised equal volumes of substrate and coral species composition (Coker *et al.*, 2012).

All visual surveys were conducted by a single observer (DJC) and executed in a three-stage approach in an attempt to document all species present. First, the observer recorded from a distance of approximately 3m to survey larger, flighty, and shy species. Next, the patch reef was surveyed from the perimeter until the observer was confident that all individuals were recorded. Finally, the internal structure (refuge spaces and holes) was searched with the aid of an underwater torch to capture cryptic species. The survey ended when the observer was confident that all fishes had been documented.

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

A total of 773 fishes, comprising 50 species were, recorded by UVC, in comparison to 918 fishes and 62 species through clove oil collections. Hence, UVC detected 16% fewer individuals and 21% fewer species, revealing that even at the relatively small scale of the study, overall species abundance and richness was under-estimated using UVC methods. This pattern is consistent with studies that have tested direct comparisons between survey methods (e.g., via rotenone, clove oil, quinaldine), however these do not take into account habitat condition (Brock, 1982; Kubicki, 1990; Ackerman & Bellwood, 2000; Willis, 2001). There is, however, a considerable trade off in time, equipment, and sacrifice of individuals associated with collections. In addition, reefs generally need to be physically manipulated in order to obtain small and cryptic individuals, potentially damaging organisms. Only 39 species were recorded by both methods, with 10 species (7%) recorded by UVC but not clove oil, and 23 species (31%) collected using clove oil, but not observed with UVC. A total of 72 species were identified on the reefs through both sampling methods; revealing that UVC potentially captured 68% of species present, whereas collection captured 86%. Overall, this suggests that while UVCs are negligibly less capable of capturing true species richness relative to exhaustive collection, both approaches entail biases and limitations, and the most appropriate method will depend on the specific aims of each study (see Sale & Douglas, 1981).

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

For the majority of patch reefs (21/28), similarity of the fish community sampled between the two survey methods was greater than among replicates from the same or different habitat treatments (Bray Curtis similarity (PRIMER-V6, Clarke, 1993)) (Fig. 2). Within the same reefs, community similarity between the different survey methods ranged from 60 to 90%, illustrating that for most reefs, community estimates were comparable between survey methods. However, for seven reefs, the composition recorded by UVC was not directly similar to the collected composition. These were from all levels of coral cover, but mostly from low complexity reefs (six out of the seven). The greatest discrepancies between UVC and collections came from low complexity reefs across a range of different coral cover levels, suggesting that physically degraded reefs are more difficult to accurately survey community composition. This is counterintuitive, as reefs with high complexity are expected to afford higher levels of shelter. It is possible that the rubbly substrate caused by the physically degradation of structure provides better refuges for some small cryptic reef fishes.

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

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

While UVCs continue to play a central role in assessing key aspects of fish communities, it is to be expected that this approach may entail some level of measurement inaccuracy, particularly among varying habitat conditions. This study corroborates previous studies, showing that compared to exhaustive fish collections, UVCs tend to under-estimate fish community measurements (Christensen & Winterbottom, 1981; Brock, 1982; Kulbicki, 1990; Ackerman & Bellwood, 2000). This was consistent among habitat treatments, with small numerous fishes over-estimated and cryptic fishes under-estimated. Importantly, most of these differences were not significant, however the low sample sizes of our treatments should be kept in mind. We further show that habitat quality has a negligible influence on the UVC measurement accuracy of species abundance, richness, and diversity; yet in low complexity environments. However, this study was conducted at a scale of 1 m^2 and differences would be expected to increase exponentially as surveying scale increases, and other community metrics may be more or less sensitive. It should also be noted that UVC is less destructive to the reef and allows repetitive sampling through time, which can be important for studies that monitor ecological processes and demographics (e.g., Almany, 2004; Coker *et al.*, 2012). Hence, overall, UVC continues to provide an important role and reliable estimates of fish community metrics, irrespective of reef condition, at least at a small patch reef level.

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