Losing 'Nemo': bleaching and collection appear to reduce inshore populations of anemonefish

A. M. JONES*[†], S. GARDNER[§] and W. SINCLAIR*

* Marine Molecular Genetics Group, Department of Biosystems and Resources, Central Queensland University, Rockhampton, Queensland 4702, Australia; [§] Ferguson Street, Emu Park, Queensland, Australia; [‡] Department of Biosystems and Resources, Central Queensland University, Rockhampton, Queensland 4702, Australia

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Running headline: Loss of anemonefish on bleached reefs.

[†] Author to whom correspondence should be addressed: Tel.: 61 7 49309945, Fax: 60 7 49309209, Email: a.jones@cqu.edu.au

Abstract

Surveys of anemonefish were conducted on reefs in two regions of the Great Barrier Reef Marine Park with contrasting history of disturbance to determine the degree to which spatial variation might be explained by bleaching or management status. Densities of anemonefish were lower on reefs in the bleaching-impacted Keppel Islands than on reefs in Far North Queensland. No anemonefish or anemones were found on or near bleached corals in the Keppel Islands. Furthermore, the highest densities of fish were found on reefs closed to fishing and aquarium collecting in both the Keppel Islands and Far North Queensland which suggests that collecting is compounding the effects of bleaching. These results emphasise the importance of understanding the interaction between bleaching events and anthropogenic disturbance upon commercially exploited species.

Keywords: anemonefish, anemone, bleaching, aquarium, harvesting, clownfish

Anemonefish and their obligate, protective symbiotic hosts, the sea anemones (*Actinaria*) occur in relatively low densities throughout the Indo-Pacific predominantly on coral reefs between 3 m and 20 m (Mariscal, 1970; Sale *et al.*, 1986). The association between fish, anemone and zooxanthellae (*Symbiodinium*) succeeds because the zooxanthellae, via photosynthesis, supply nutrients to the sea anemone for their metabolism (Bachar *et al.*, 2007). The anemone provides a predator-free habitat for the fish which, in turn, defends the host anemone from predators (Fautin, 1991). However, symbiosis between anemones and zooxanthellae makes them vulnerable to environmental stressors such as warmer waters and high irradiance which can cause expulsion of the algae or ‘bleaching’. The fish are also targeted by marine aquarists because of their bright coloration and enigmatic association with sea anemones. Since bleaching is predicted to become more frequent due to global warming (Wilkinson, 2004; Hoegh-Guldberg *et al.*, 2007), determining the status of the distribution and abundance of anemonefish and their host anemones on different reef habitats is vital to understanding how such confounding pressures may affect these iconic species in the longer term.

Anemonefish populations are entirely dependent on the availability of suitable host anemones for habitat and protection. Both anemones and anemonefish spawn irregularly (usually only once or twice a year) and are subject to commercial harvesting for sale or export to the aquarium industry which makes them makes more them vulnerable to localized stock depletion than other species (Shuman *et al.*, 2006). Although adult anemonefish live for up to 30 years (Buston and Garcia, 2007) they rarely migrate further than a few hundred metres (Hattori, 2004) whilst the larvae of both anemonefish and anemones have a relatively short life span (4 days for anemones and 8-12 days for anemonefish) (Almany *et al.*, 2007; Scott and Harrison, 2007). Spawning success is rare for anemones and the mortality of anemonefish larvae is extremely high (~50%). Even if anemonefish spawning and recruitment are successful, the unusual social structure results in high mortality of juveniles. The recruitment rate of the twin-barred anemonefish *Amphiprion akindynos* (Allen, 1972) has been shown to be quite low, around the order of 0.37 ± 0. 0.27 (mean ± S.D.) fish $100m^{-2}$ (Capricorn Bunker reefs over 3 years) and the presence of an anemone may be required to provide the necessary cue for the settlement of anemonefish larvae (Sale *et al.*, 1986). Unfortunately very little is known about anemone and anemonefish population dynamics, especially in conjunction with other species harvested by the marine aquarium trade. Management authorities rely almost exclusively on fisheries logbook data for information about stock depletion of targeted species (Turton and Otomo, 2007) and the industry is otherwise almost entirely self-regulating. Logbooks provide relatively crude information about the catch per unit effort (CPUE) which is notoriously unreliable for assessing stock levels. Because of this information gap, localised depletion is a recognised threat to heavily targeted species such as the anemonefish (Ecological Assessment of the Queensland Marine Aquarium Industry, Department of Environment and Heritage, Canberra 2005).

Reefs in the Great Barrier Reef (GBR) Marine Park are classified as open or closed to recreational and commercial aquarium harvesting by zoning under the auspices of the Great Barrier Reef Marine Park Authority (GBRMPA). Nine licensed marine aquarium collectors in Queensland work in the Keppel Islands (KI) region, and up to 15 in the Far North Queensland (FNQ) region under licences managed by the Department of Primary Industries and Fisheries. Harvest occurs all year round with peaks in February/March, July and October/November. Normally, a breeding pair of adults or sub-adults is removed, leaving at least one anemonefish behind. Unlike commercial harvest, recreational harvesting is largely controlled by legislative restrictions on both gear and bag limits (and the recreational take of anemones is prohibited), but the extent of recreational collection for domestic aquaria or black market resale is not known. The available fisheries logbook data for the entire KI region indicates that catch-rates of anemonefish per year per vessel has declined by almost 50% from an approximate average of 84 to 45 fish per year per vessel (Data from Department of Primary Industries and Fisheries, Queensland 2000-2003). The only fisheries data available on combined anemone and corallimorph collection (both which are listed under 'Actinaria' in the logbooks) indicates a substantial decline in take in the KI region: from 1060 specimens caught per vessel in 2004 to 407 in 2005 and a further decline to 96-per vessel in 2006.

The aim of this study was to estimate densities of anemones and anemonefish in two separate regions of the GBR to determine the degree to which spatial variation might be explained by bleaching or management status. The Keppel Island (KI Mackay/Capricorn Management Area, Fig 1, Inset A) and Far North Queensland (FNQ and Cairns/Cooktown Management Areas, Fig 1, Inset B) regions of the Great Barrier Reef were chosen because of their different histories of disturbance. The reefs of the KI have been subjected to disturbance within the past 17 years, including a major flood in 1991, a number of minor floods (Furnas, 2003), two moderate to severe summer bleaching events in 2002 and 2006 (Berkelmans and Jones, unpublished data, Berkelmans *et al.*, 2004) and a minor salinity bleaching in October 2006 (A. Jones, personal observation). Photographs taken by local KI residents in 2002 and 2006 clearly show bleached anemones. In contrast, the FNQ reefs have been relatively unaffected by disturbance during this time.

Because of the typical low abundance of anemonefish, visual census surveys using free swims along 5 m wide transects were used in place of set transects to census the populations of anemones and anemonefish (Shuman *et al.*, 2006). A towed GPS recorded the survey track and longitude coordinates (± 1m) were recorded every 10 s, saved and later used to estimate the area of each survey. When an anemone was encountered, the number of fish and the diameter of the anemone colony were noted. The total length of survey transects in the KI and FNQ reefs were 21.9 km and 19.0 km respectively. Forty four transects were conducted at 12 reef sites in the KI region and 66 transects were conducted at 10 reef sites in FNQ. Fish densities were highly variable among transects at both locations (± 111 fish.100m^{-2}) and subsequently, an overall density (total fish or anemones ÷ total sum of all transects) was calculated for each reef. Transects were classified as either 'bleached' or 'unbleached' using the BleachWatch survey method (Anonymous, 2007) of visually assessing percentage coral cover loss, because the loss of > 50% of live coral cover have been shown to impact habitat-specialist fish species (Dennis, 2002; Pratchett *et al.*, 2006; Wilson *et al.*, 2006; Wilson *et al.*, 2008). The presence or absence of anemones and anemonefish along 110 transects on 29 reefs were analysed using a 2 × 2 Pearson chi-square contingency table (SPSS, Version 15.0).

Anemones and anemonefish were found on all reef habitat types: reef slopes, reef flats, inter-reefal areas and particularly on reefs near sand patches; and at all depths between 2 m and 17 m. No anemones were found without fish present. The mean depth in KI (8 ± 2.9 m) was similar to FNQ (6 ± 3.4 m) and deeper sites did not necessarily have the highest densities. Fifty five percent of transects in the KI had no anemones or anemonefish compared to 8% in FNQ. Densities of anemonefish ranged from 0.4 to 221 100 m^{-2} on reefs in the KI (TABLE I) and from 15 to 370 100m^{-2} in FNQ (TABLE II). Reefs on which no anemones or anemonefish were found are not listed in the tables.

In the Keppel Islands region the twin-barred anemonefish, *A. akindynos*, the red and black anemonefish, *A. melanopus* (Bleeker 1852) and the black-spot or humbug damselfish, *Dascyllus auranus* (Linnaeus, 1758) were found predominantly on the sea anemone *Entacmaea quadricolour* (Rüppell, Leuckart, 1828). There was only one occurrence of *Heteractis crispa* (Ehrenberg, 1834) at Middle Island in spite of anecdotal evidence to suggest its previous presence at Passage Rocks. The highest densities of anemonefish were found at Man and Wife rocks (19 100 m^{-2}) and at Egg rocks (221 100 m^{-2}) which are relatively unaffected by bleaching. Only two occurrences of *D. aruanus* were recorded, both on relatively unbleached sections of reef: at Shelving reef (protected by GBRMPA zoning) adjacent to Great Keppel Island, and at Egg rock, which has been completely protected from fishing for over 30 years. There were no anemonefish or anemones on any bleached and unprotected reefs in the KI, but specimens were still found on or near unbleached corals on protected reefs (even within a metre of dead corals) at a depth of 2 m at Shelving reef and Middle Island. In fact, one of the highest densities was found in 3 m water at Shelving reef which is protected from collecting. The presence of anemones and anemonefish so close to bleached corals on this protected reef suggests that bleaching is not the only factor impacting populations.

On the Far North Queensland reefs five species of anemonefish were found on three anemone species. These included *A. akindynos*, *A. melanopus*, the pink anemonefish, *A. perideraion* (Bleeker, 1855), the maroon or spine-cheeked anemonefish, *Premnas biaculeatus* (Bloch, 1790) and the three-spot damselfish, *A. trimaculatus* (Rüpell, 1829) on the anemones *E.*

quadricolour, *H. crispa* and *Stichodactyla mertensii* (Brandt, 1835). The highest densities of anemones and anemonefish were found at Raine Island which is completely protected from fishing (370 100 m^{-2}). Eighty six percent of anemonefish in the two study locations were found on unbleached transects (Pearson's chi-square df = 1, $p < 0.001$) and 51% on transects closed to fishing (Pearson's chi-square df = 1, $p = 0.003$). A Model II regression analysis showed that fish density increased linearly with anemone surface area (n = 22, $r^2 = 0.97$, $p < 0.001$, Fig 2). Anemonefish density became more variable with larger colonies suggesting that habitat loss from bleaching was not a limiting factor and therefore not the only cause of the low fish densities. There was no significant difference in the linear associations of fish density and anemone cover with respect to location.

The long-term effects of bleaching-induced loss of structural corals on coral-dependent fish populations are now well-documented (Pratchett *et al.*, 2004; Graham *et al.*, 2006; Pratchett *et al.*, 2006; Feary *et al.*, 2007). The absence of fish and anemones on bleached reefs around the inshore KI in contrast to the high densities on FNQ reefs strongly suggests that bleaching has reduced the distribution and abundance of anemone populations in the KI region, especially since anecdotal reports and photographs from long-term Great Keppel Island residents suggest that anemonefish were present and more abundant ten years ago on reefs that have since become bleached (Carl Svendsen, personal communication). At the same time, however, the occurrence of anemones and anemonefish on small, isolated unbleached patches at Middle Island and Shelving reefs in spite of a bleaching event in the region in 2006 indicates that bleaching effects are not straightforward. Bleaching causes the anemones to lose their symbionts after which they may shrink and eventually die due to the temporary loss of photosynthesis. The shrinkage, weakening or disappearance of the host anemone can limit the anemonefish population (Richardson, 1999), the size of the female fish (Hattori, 2004) and the potential for new recruits (Shuman *et al.*, 2006). Additionally, loss of fish can then affect the survival and growth rate of the anemone (Holbrook and Schmitt, 2005). This negative cycle of shrinkage as a result of bleaching and subsequent loss of anemonefish protection followed by further shrinkage may have led to serious declines in the anemone habitat available for new fish recruits and this may have depressed the reproductive success of the remaining fish.

The results of this study suggest that bleaching has reduced the occurrence and numbers of anemone and anemonefish on the reefs around Great Keppel Island and also that management status may have had an effect. Except for Five Reefs and Man and Wife Rocks, the highest densities of anemonefish in both the KI and FNQ occurred on closed reefs, so there is evidence to suggest that management status may be compounding the impacts of bleaching damage on anemone and anemonefish populations in both locations.

The slow reproductive rate of anemones, the minimal migration of adult and juvenile anemonefish and the absolute dependence of the fish on suitable anemone habitat means that regeneration on bleached reefs that have lost anemones and fish may take decades (Sale *et al.*, 1986). Although fish populations undergo seasonal and even yearly cycles in density, the stock level of anemonefish in the KI region is now so low that any further disturbance such as a flood or bleaching event could be catastrophic without adequate time for the levels to build up again. A suspension of commercial harvest could relieve the additional pressure that collecting places on these species. In addition, the assumption of commercial collectors that removing breeding adult anemonefish increases survivorship and growth of young recruits is contentious (Sweatman, 1983; Sale *et al.*, 1986) and contrary to the principle of sustainable harvest by removal of juveniles during the period when mortality is considered density-dependent (Holbrook and Schmitt, 2002). Removing breeding adults or even sub-adults could cause the anemone to shrink, thereby reducing the amount of space for new recruits, and it may be up to 6 months before the fish begin to breed again. The management of the fishery should not be based on these assumptions as the removal of anemonefish from anemones has, in some cases, caused a total cessation of recruitment (Sale *et al.*, 1986). Assuming that fish populations recover from areas of reef that are not prone to bleaching (marine 'refugia') then the collection of anemones and breeding pairs of adult anemonefish from these areas is also likely to prevent or at least limit repopulation of recovering reefs.

Due to its isolation from other reef systems, the KI region may be more susceptible to localised depletion of heavily targeted aquarium species. This isolation and the additional pressure of coral bleaching may confound the impacts of collecting upon inshore reefs and may even affect other non-targeted species. Because of the heavy reliance of the KI region economy on tourism, all commercial and recreational aquarium collecting should be suspended as it has been on other tourism-dependent regions of the Great Barrier Reef: the Whitsunday and Palm Islands regions. The compounding effects of climate change-driven bleaching and continued industry self-regulation without consideration for localised depletion of heavily targeted species could be devastating for local reefs in the KI region without fisheries management intervention. The impact of the marine aquarium trade in Australia, whilst still comparatively small, needs to be reassessed in the light of its compounding effects with other, more significant pressures such as climate change and human activities (Turton and Otomo, 2007 102).

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