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Population impacts of collecting sea anemones and anemonefish for the marine aquarium trade in the Philippines

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Abstract Tropical marine ornamentals comprise an increasingly important fishery worldwide. Although the potential for overexploitation of marine ornamentals is great, few studies have addressed the population-level impacts of ornamental exploitation and few ornamental fisheries are managed. Analysis of catch records obtained from collectors over a four-month period in the vicinity of Cebu, Philippines, showed that anemonefish and anemones comprised close to 60% of the total catch. Underwater visual census surveys revealed that both anemone and anemonefish densities were significantly lower in exploited areas than in protected areas. The low density of anemones on exploited reefs accounted for over 80% of the reduced density of anemonefish at those sites. There were similar numbers of anemonefish per unit area of anemone in protected and exploited sites; however, biomass of anemonefish per unit area of anemone was lower in exploited areas. Reduction of anemone removals is recommended to support the sustainable harvest of anemonefish from this region.

Keywords Aquarium trade · Anemones · Anemonefish · Fisheries management · Marine ornamentals · Philippines

Introduction

Global trade in marine ornamentals is a rapidly expanding industry involving numerous countries around the world. In the early 1980s, the import value of marine fish and invertebrates for the aquarium trade was estimated to be US \$24–40 million annually (Wood 1985). Current estimates place the worldwide import value of marine ornamentals at US \$200–330 million annually (Chapman et al. 1997; Forum Secretariat 1999; Larkin and Degner 2001), with imports to the USA representing 80% of the trade (Larkin and Degner 2001). The proportion of marine organisms in the ornamental trade rapidly increased in the 1980s (Andrews 1990). Marine species comprised only 1% of the world trade in 1975, while currently an estimated 10% of the 350 million aquarium fish traded annually are marine species (Forum Secretariat 1999).

Despite the rapid expansion of aquaculture (Kaiser et al. 1997; Ignatius et al. 2001) and post-larval capture and rearing (Bell et al. 1999; Dufour 2002), the majority of marine ornamental species are collected in the wild as juveniles or adults. Although much effort has focused on the assessment of the level of international trade in marine ornamentals (Lubbock and Polunin 1975; Wood 1985; Andrews 1990; Forum Secretariat 1999; Wood 2001; Wabnitz et al. 2003) and the potential impact of the trade on marine fishes in Australia (Whitehead et al. 1986), Hawaii (Randall 1987), Florida (Adams et al. 2001), Sri Lanka (Wood 1985; Wijesekara and Yakupitiyage 2001), the Philippines (Albaladejo and Corpuz 1981), Puerto Rico (Sadovy 1992), Eritrea (Daw et al. 2001) and the Maldives (Edwards and Shepherd 1992; Adam 1997), little effort has been given to the design of appropriate management plans (Butler 1991; Tissot and Hallacher 1999; Tissot et al. 2002).

The relationship between anemonefish and anemones has received much attention in ecological literature

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(e.g., Fautin 1991). Patterns of fine scale distribution (Fautin 1986; Srinivasan et al. 1999), growth (Ochi 1986; Ross 1990; Hattori 1991), reproduction (Ross 1978; Ochi 1989; Hattori 1994; Hirose 1995; Richardson et al. 1997; Hattori 2000), and recruitment (Bell et al. 1982; Fautin 1992; Schmitt and Holbrook 1996, 1999) of anemonefish have been extensively studied.

With the exception of *Dascyllus trimaculatus*, all anemonefish (Pomacentridae: *Amphiprion* spp. and *Premnas biaculeatus*) are obligate symbionts with a variety of host anemone species. This symbiotic relationship with a sedentary actinian host has permitted extensive research into the complex social structure that characterizes these species as well as the roles of stochastic and deterministic processes governing larval recruitment and survivorship. Marine aquarists have desired these species for both their longevity in captivity and their exotic symbiotic relationship with host actinians (Butler 1991). Unfortunately, the same physical processes that permit the ease of study of these organisms similarly permits the ease of commercial harvesting for marine aquaria. In addition, anemonefish may be exceptionally vulnerable to over-exploitation because they settle exclusively, and are restricted, to host anemones, which are also subject to harvesting and may be especially susceptible to over-exploitation due to their longer life span, slower relative growth rates, and lower reproductive rates than their resident fish.

Unlike *Amphiprion* spp., which spend their entire lives associated with an anemone, *D. trimaculatus* reside with host anemones for approximately 6 months (4-6 cm SL), after which they become independent of anemones and have few interactions with younger fish still resident on anemones (Bolker et al., 2002). *D. trimaculatus* post-larvae preferentially recruit to anemones for added protection from predation, however, they have been observed to recruit onto branching coral or other porous substrate. This unique relationship allowed us to explore the hypothesis that the harvest of anemones limited the amount of suitable habitat for anemonefish by comparing the density of "free" to anemone-associated juvenile *D. trimaculatus*.

Here we explore the extent to which aquarium collections have impacted populations of both anemonefishes and anemones. We assess how the density of anemonefish and anemones differ in protected and exploited sites. Due to the implicit connection between the population of host anemones and anemonefish, we also explore the abundance, density, and population structure of anemonefish on individual anemones, allowing the examination of the mechanisms through which anemone and anemonefish populations respond to aquarium collections. Finally, we propose a series of management strategies to promote the sustainable harvest of anemonefish in the study region.

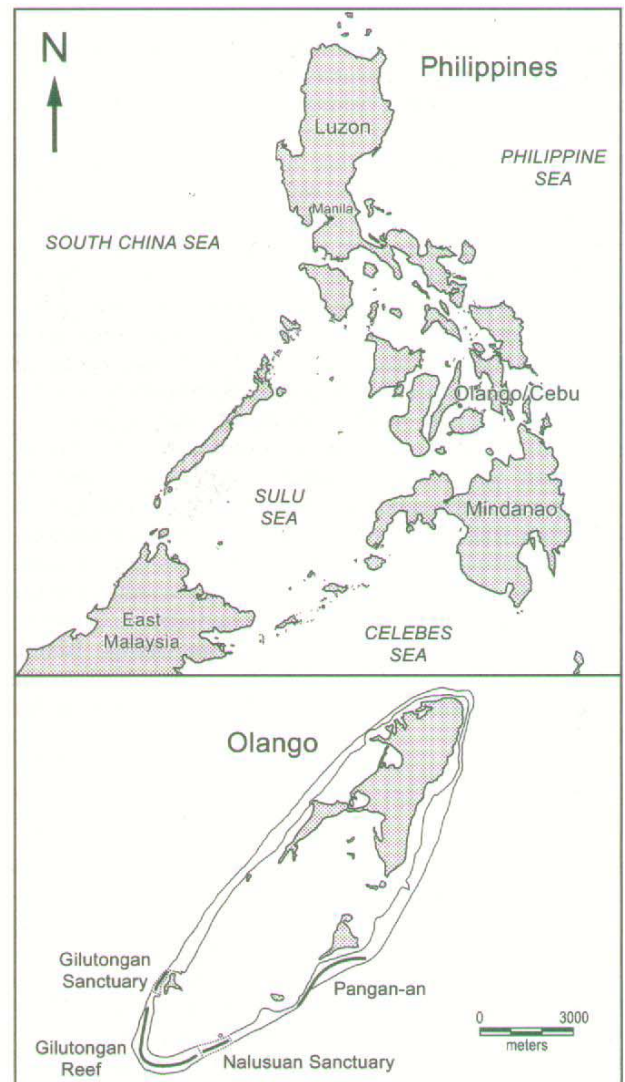


Fig. 1 Map of Philippines and Cebu/Olango region. Olango is located at approximately 124°E 11°N

Methods

Study area

The present study was conducted on a series of fringing reef slopes located in vicinity of Cebu in the Central Visayas region of the Philippines (Fig. 1). Reefs were classified as protected or unprotected according to the level of protection from fishing activities afforded to them. Surveys were made at two protected reefs, Gilutongan Sanctuary and Nalusuan Sanctuary, and three non-protected reefs, Gilutongan, Pangan-an, and Caubyan. All efforts were made to ensure that reefs were similar in exposure and habitat type.

Unprotected coral reefs in this region are heavily exploited by fishermen using a variety of artisanal gear types. In addition, destructive fishing practices such as dynamite and cyanide fishing for both subsistence food fishing and commercial aquarium fishing are widespread (Sotto et al. 2001). Despite the heavy exploitation of coral reef resources in the region, there are some protected areas. Gilutongan Sanctuary was established in 1991 as a 10 ha reserve on the west coast of Gilutongan Island, then reestablished in 1999 and enlarged to nearly 15 ha (Cordova Municipality 2001). Managed and maintained by the local community, Gilutongan Sanctuary has been actively protected full time since its reestablishment in 1999. Nalusuan Sanctuary is a 10 ha privately declared marine sanctuary dedicated exclusively to tourism. Similar to Gilutongan Sanctuary, Nalusuan Sanctuary is actively protected to prevent fishing within the sanctuary boundaries and has been in operation since 1997 (S. Green, personal communication). Gilutongan and Pangan-an reefs are located adjacent to the marine sanctuaries and are subject to the extensive resource utilization described above. Caubyan is located approximately 15 km east of Olango Island. The reefs adjacent to this small island are subject to the same fishing pressure as the unprotected reefs in the Olango region.

Catch records

Fishers' logbooks can be a very useful tool to determine catch composition and volume (e.g., Jennings and Polunin 1995). Logbooks were obtained from fishers residing in the Olango region providing catch composition information from January through April 2002. Logbooks detailed the catch of over 40 collectors representing the collection of over 40,000 fish and invertebrates. These records were analyzed to determine the relative contribution of different taxonomic families to the total catch to estimate the relative intensity of harvesting of specific species. In addition, prices paid to fishers for their catch were studied to determine how economic incentives may have influenced resource exploitation. Mean prices were used when inconsistent prices were encountered during analysis of the collector records. Catch records did not classify anemones to species level, although anemones were divided into long

tentacle (e.g., *Heteractis* spp.) and flat/carpet (e.g., *Stichodactyla* spp.) anemones.

Fish and anemone surveys

Due to the low abundance of anemones in the study areas, free swims were used to census the populations of target species, since free swims can cover much larger areas than surveys utilizing standard transect lines. Free swims have shortcomings, however, in that replication is limited and the estimate of the size of the area surveyed can be less accurate than estimates of area based on transect lines. Rather than artificially fragment the free swims in each site, all analyses were based on the assumption that sites were equivalent, with each free swim representing a replicate observation in the two differing treatment types ($n=2$ for protected, $n=3$ for exploited). Free swims consisted of the observer swimming along a compass heading while recording target epifauna in a swath approximately 5 m wide. Surface GPS coordinates were used to estimate the distance of each survey. After taking an initial GPS point, the support boat would meet the surveyor at frequent intervals during the survey to record additional coordinates to ensure the distance of each survey was accurately calculated. When a target organism was encountered, the surveyor would record the species and size of target organisms (standard length for fish, longest length and perpendicular width for anemones). All surveys were conducted at a depth of 2–3 m, the observed depth of most free diving collections.

The length of the free swim was limited in the protected sites by the size of the protected areas. Consequently, a greater distance was covered in the exploited sites than in the protected sites (Table 1). Densities were used to standardize population estimates from unequal sampling areas.

Biomass estimates

Biomass estimates used length–weight relationships obtained from FishBase (Froese and Pauly 2003). Length–weight relationships, however, were not available for *Amphiprion clarkii*, *A. percula*, and *A. perideraion*. Consequently, length–weight relationships for

Table 1 Characteristics of protected and exploited sites and summary of results of free swims

Site	Protection	Survey area (m ²)	Anemones counted	Fish counted	Hard coral (%)	Sand (%)
Gilutongan sanctuary	1999	2,945	18	159	35	35
Nalusuan sanctuary	1997	3,940	34	173	26	53
Gilutongan	–	13,630	3	17	23	40
Pangan-an	–	12,935	16	69	20	45
Caubyan	–	16,890	27	59	–	–

Substrate cover estimated from point contact sampling detailed in Shuman (2003). Substrate composition data was unavailable for Caubyan

other similarly sized species of *Amphiprion* were applied to length data of these species to generate biomass estimates. To control for any bias introduced by the use of inappropriate length–weight relationships, a variety of relationships were tested to determine if similar results were achieved. Biomass estimates for *A. clarkii* were generated from length–weight constants for *A. akindynos*, *A. bicinctus*, and *A. chrysopetrus* (Froese and Pauly 2003). For smaller species such as *A. percula* and *A. perideraion*, two different length–weight constants of *A. melanopus* were used (Froese and Pauly 2003). The various constants were tested to ensure that no bias was introduced into the analyses from the use of improper length–weight relationships. Similar results were obtained from the use of the varying length–weight relationships. Although we recognize the limitations of using length–weight relationships for small or juvenile fish, we present this analysis because of the importance of assessing the relationship between available anemone area and its interaction with the biomass as well as the number of resident fishes.

Analyses

A. clarkii and *D. trimaculatus* were the most abundant fish species. Consequently, most analyses were focused exclusively on these two species. To explore population parameters, the standard length of the two fish species as well as the elliptical area of *Heteractis crispa* and the other species of anemones were assessed to determine if the size frequency distributions differed between protected and exploited sites. To control for food fishing pressure on adult *D. trimaculatus*, we excluded individuals not associated with anemones from these analyses.

Amphiprion spp. exclusively, and *D. trimaculatus* preferentially, settle and reside on a variety of species of host anemones, and competition among anemonefish for space on host anemones is intense (Fautin and Allen 1992). Therefore, we assessed the populations of fish on each anemone to detect trends in protected and exploited sites. These censuses allowed us to determine whether the difference in densities of fish in protected and exploited sites was primarily due to limited habitat availability resulting from anemone harvesting or directly from collections of fish. In addition, the density of anemones without resident fish was assessed to determine if the direct removal of anemonefish resulted in a “surplus” of habitable space.

All data met assumptions of normality and homogeneity of variances except for the elliptical size of anemones and the number and biomass of fish per anemone and unit area of anemone. These data were log transformed to approximate these assumptions. *t*-Tests were performed to determine the statistical significance

of all comparisons except for the comparisons of size frequency distributions, which utilized the Kolmogorov–Smirnov two-sample test. All statistics were performed using SYSTAT 9 (SPSS 1998).

Results

Catch records

Catch records revealed that over 57% of all organisms collected in the Cebu/Olango region were anemonefish, representing slightly under 33% of the total monetary value of the catch during the sampling period (Table 2). *D. trimaculatus* was captured in the highest numbers, followed by *A. clarkii*, representing 31.3 and 17.2% of the total catch, respectively. Approximately 9% of the total catch was distributed among the five other anemonefish species. All anemonefish captured in the Cebu/Olango region were of relatively low value. Fishermen received values ranging from US \$0.03 to 0.12 per fish.

Long tentacle anemones made up approximately 1.5 and 4.1% of the total abundance and total value of the catch, respectively. Flat/carpet anemones represented approximately 0.2 and 1.2% of the total abundance and total value of the catch, respectively. The average value of anemones was estimated to be US \$0.35, which is an order of magnitude higher than the price obtained for the most abundant anemonefish.

Field surveys

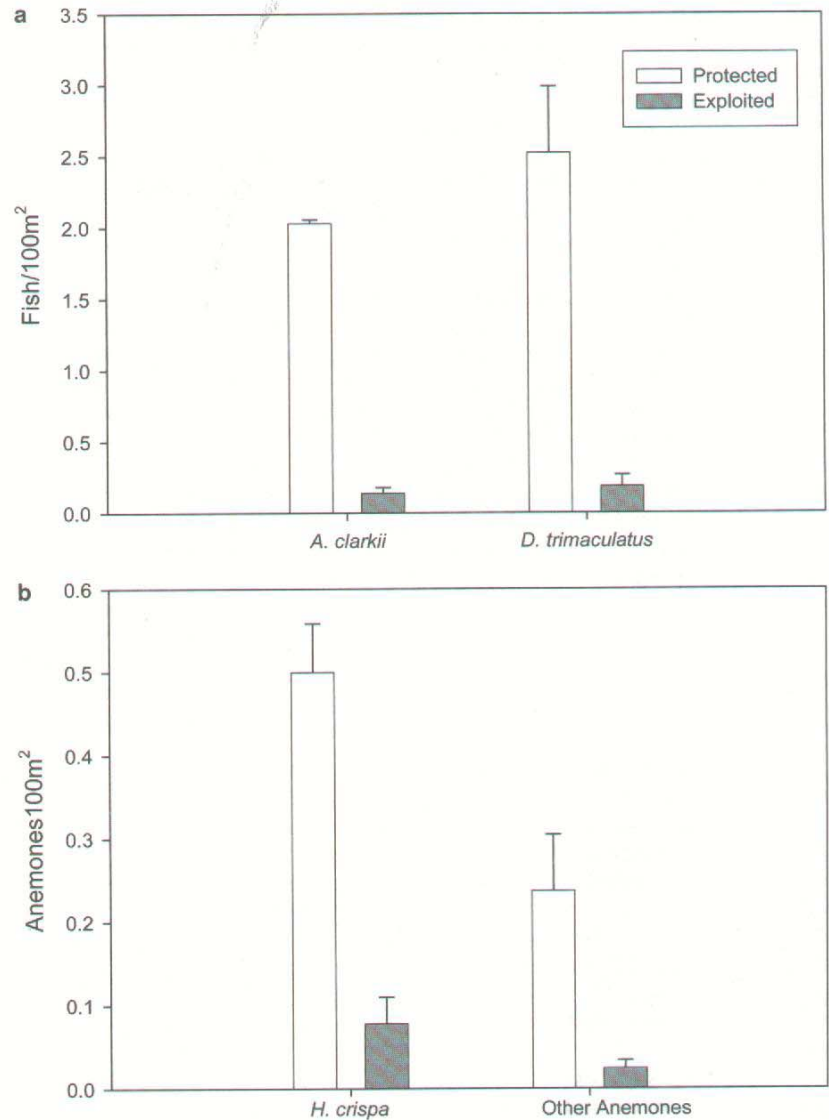
A. clarkii and *D. trimaculatus* were the most abundant species, together representing 93 and 95% of the total number of anemonefish surveyed in protected and exploited sites, respectively. Densities of *A. clarkii* and *D. trimaculatus* were significantly higher in protected areas than in exploited areas (*t*-test: $t=34.51$, d.f. = 3, $P < 0.01$; $t=6.44$, d.f. = 3, $P < 0.01$, respectively; Fig. 2a). Of the anemones surveyed during the timed swims, 67

Table 2 Catch record data from January to April 2002 in the Cebu/Olango region of the Philippines describing the catch of over 40 collectors comprising 40,000 organisms

Species	Unit price ^a (US \$)	Total catch number (%)	Total catch value (%)
<i>D. trimaculatus</i>	0.03	31.3	15.6
<i>A. clarkii</i>	0.03	17.2	8.6
<i>A. frenatus</i>	0.12	2.7	2.7
<i>A. percula</i>	0.06	2.2	2.2
<i>A. perideraion</i>	0.04	2.0	1.3
<i>A. polymnus</i>	0.10	1.0	1.7
<i>P. biaculeatus</i>	0.06	0.8	0.8
Fish total		57.2	32.9
Long tentacle anemone	0.30	1.5	4.1
Flat/carpet anemone	0.40	0.2	1.2
Grand total		58.9	38.2

^aPrice paid to fishermen by middlemen

Fig. 2 Density (mean \pm SE) of (a) anemonefish, $n=448$ (*A. clarkii* and *D. trimaculatus*) and (b) anemones, $n=98$ (*H. crispa* and other anemone species) in protected ($n=2$) and exploited ($n=3$) sites



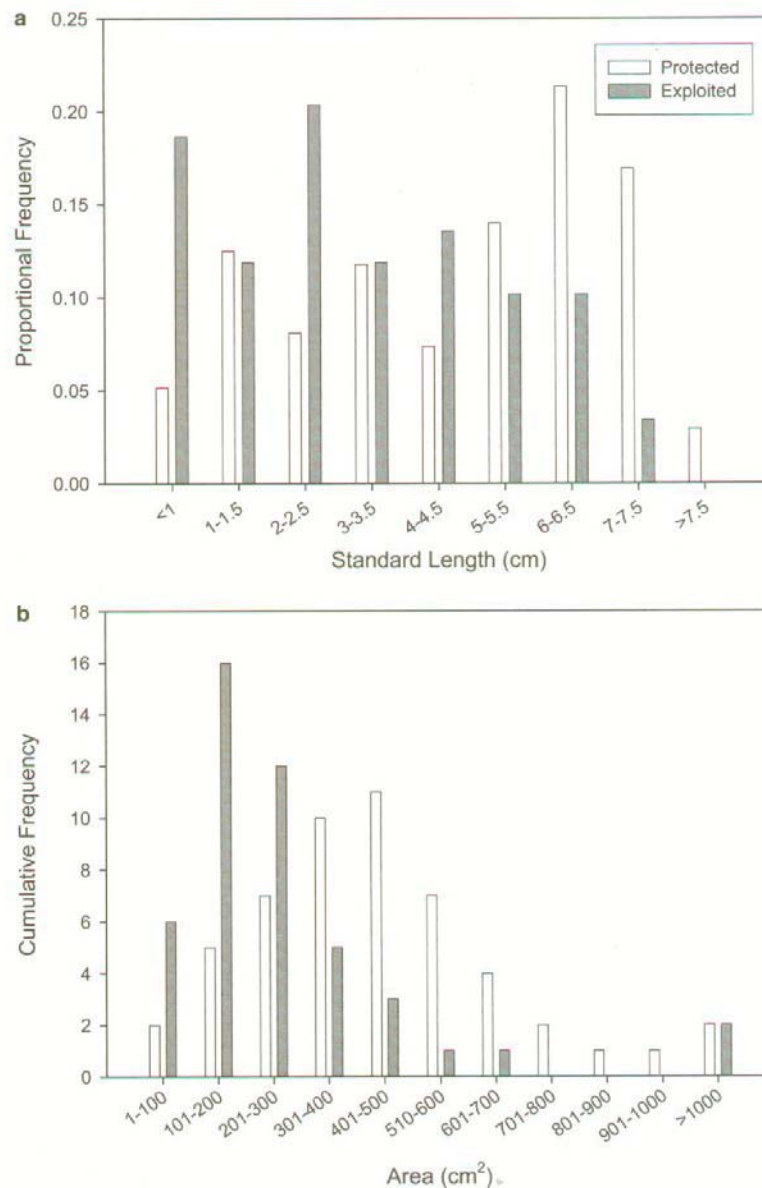
and 78% were *H. crispa* in protected and exploited areas, respectively. As a result, this species was separated from the other seven anemone species for analysis to control for size differences between individual anemones and habitat selection by target fish species. The density of *H. crispa* alone and other anemone species together were significantly higher in protected sites (t -test: $t=7.03$, d.f. = 3, $P < 0.01$; $t=4.11$, d.f. = 3, $P=0.03$, respectively, Fig. 2b).

Analysis of the size frequency distribution indicated that *A. clarkii* were significantly larger in protected sites (K-S, $P < 0.01$; Fig. 3a). This assessment was not performed for *D. trimaculatus* because adult *D. trimaculatus* were not counted because they are collected for food, and only small fish inhabit anemones; therefore, we would not expect to detect a size difference between

individuals in protected and exploited sites despite heavy collection pressure. The size frequency distribution of both *H. crispa* alone and all anemones combined indicated that anemones were significantly larger in protected sites (K-S, $P < 0.01$; Fig. 3b).

Of anemones with resident fish, the number and biomass of fish per anemone was higher in protected sites (t -test: $t=4.43$, d.f. = 97, $P < 0.01$; $t=7.56$, d.f. = 97, $P < 0.01$). When these values were scaled to individual anemone size, fish biomass per cm² of anemone remained significantly higher in protected sites (t -test: $t=3.49$, d.f. = 97, $P < 0.01$) while fish number per cm² of anemone was similar in protected and exploited sites (Fig. 4). A similar trend was observed when *H. crispa* was assessed separately. Despite the high volume of collections, it is apparent that the direct removal of

Fig. 3 Size frequency distribution of (a) *A. clarkii* and (b) all anemones combined



anemonefish by collectors did not significantly affect the number of fish utilizing anemone space as there appears to be sufficient larval delivery to “fill” empty anemones. In contrast, anemonefish removals may have resulted in the observed decreased biomass of anemonefish per unit area of anemone. There was no significant difference between the density of unoccupied anemones in protected and exploited sites.

Survey results revealed that 82 and 80% of the sampled population of *D. trimaculatus* in protected and exploited sites, respectively were not associated with anemones. Due to the absence of the practice of

catching the larger size classes of *D. trimaculatus* in exploited sites for food fishing activities, we restricted the following analyses to individuals less than 2 cm (SL). The proportion of free (non-anemone-associated) *D. trimaculatus* < 2 cm (SL) was calculated to determine the ratio of free to total *D. trimaculatus* in this size class (Fig. 5). Although not statistically significant, the proportion of free *D. trimaculatus* < 2 cm was nominally higher in exploited sites than protected sites (0.74 and 0.23, respectively) suggesting that anemones may indeed be limiting, resulting in the selection of non-preferential habitat by smaller size classes of *D.*

Fig. 4 Number and biomass (Mean \pm SE) of anemonefish per square centimeter of *H. crispa* ($n = 70$)

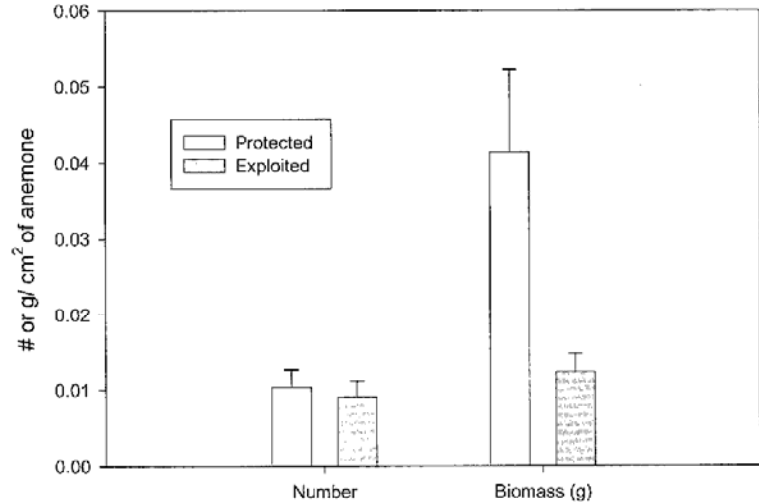
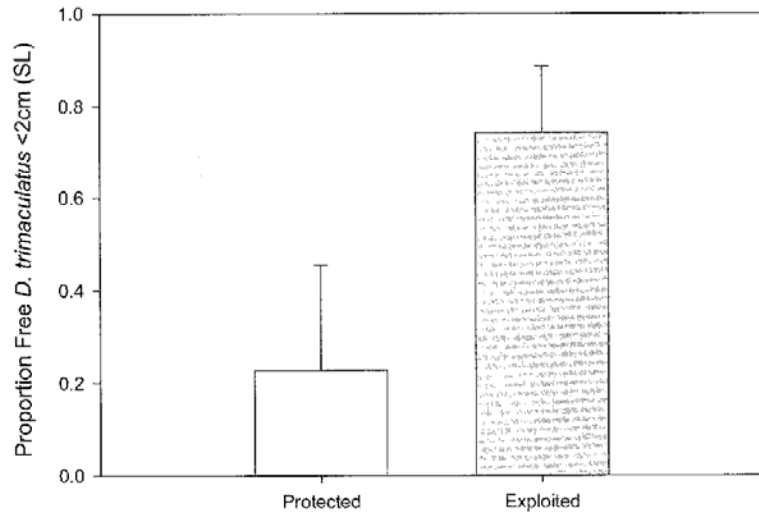


Fig. 5 Proportion *D. trimaculatus* (Mean \pm SE) < 2 cm not associated with anemones in protected ($n = 2$) and exploited ($n = 3$) sites



trimaculatus. Competition for space by both conspecifics and other species, however, may confound these results.

Discussion

Contrary to the findings of Butler (1991) that there were no significant differences between the densities of either anemones or anemonefish on protected and unprotected reefs on the Great Barrier Reef, we determined that aquarium fishing activities significantly impacted the populations of both anemones and anemonefish in the study region. The lack of harvesting of all anemonefish for food except for adult *D. trimaculatus*,

coupled with the high exploitation rates indicated by catch records, provide evidence that ornamental fishing was responsible for the reduced densities of anemones and anemonefish in exploited sites. The symbiotic relationship between the anemonefish and their host anemones provided a unique opportunity to explore the mechanisms through which the exploited species responded to fishing pressure. The higher proportion of free *D. trimaculatus* < 2 cm in exploited sites indicate that anemones may indeed be limiting, resulting in the selection of non-preferential habitat by smaller size classes of *D. trimaculatus*. In addition, the similar densities of unoccupied anemones as well as the number of fish per unit area of anemone in protected and exploited sites indicates that the densities of ane-

anemonefish may be primarily limited by available anemone space.

Previous research has indicated that the spatial distribution and variation of reef fish populations may be dictated by the amount of suitable habitat rather than larval supply (Holbrook et al. 2000; Schmitt and Holbrook 2000). This trend may be further enhanced by the dependence of anemonefish on a specific habitat type (i.e., anemones) for both settlement and adult habitat, although Richardson (1999) concluded that environmental variables, along with sea anemone cover, played a role in the spatial distribution of anemonefish. In addition, Fautin (1991) determined that anemonefish other than *D. trimaculatus* cannot survive and reproduce without being associated with anemones further demonstrating the importance of indirect impacts of anemone removals on anemonefish populations.

The extensive body of knowledge surrounding the life history characteristics of anemonefish allows extrapolation of our results to a broader management context. Although detailed site-specific studies must be made on the population dynamics of anemonefish targeted for collection, previous research can be used to gain insight into the mechanisms at work in a given system. The socially controlled protandrous nature (Hattori 1991, 1994) and recruitment patterns (Fautin 1992; Elliot and Mariscal 2001) of anemonefish may actually render anemonefish more amenable to sustainable regular harvest than other species. In addition, intensive competition for space coupled with conspecific facilitated settlement may provide a built-in mechanism promoting restrained local exploitation (Bolker et al. 2002).

A distinct social hierarchy has been observed within the anemonefish population on each anemone or colony of anemones in which a dominant breeding pair of adults restricts both the settlement of new recruits to the anemone and the growth of juvenile residents (Hattori 1991; Srinivasan et al. 1999; Elliott and Mariscal 2001). Although Hattori (1991) found that it took as long as 1.5 years for the second largest fish on the anemone (functional male) to attain female breeding size, Fautin (1992) provided evidence that post larvae rapidly (~30 days) settle onto anemones after the removal of some or all residents. In addition, Yanagisawa and Ochi (1986) found that two-thirds of removed breeding males were replaced by foreign males that assumed almost full responsibility of care for the eggs. Therefore, a sensible management strategy may be to leave the largest breeding female on each anemone and remove all other individuals, periodically allowing one small individual to grow into the breeding male partner if there does not appear to be sufficient immigration of adult males to resume reproductive activity. This is similar to the harvest practice employed in Australia where anemone collections are not permitted and at least one anemonefish is left on each anemone to enable new recruits to use odor to locate and join groups of similar species (QFMA 1999). The selective harvest of juvenile ane-

mones may actually increase the productivity of the system by creating "space" on anemones to which new recruits can settle, thus maintaining a sustainable source of income for local ornamental fishermen. This management strategy, however, is contingent on the retention of anemones to serve as habitat for new recruits as well as healthy stocks of breeding adults to provide ample reproductive output of new recruits. Further research is needed to determine the nature of recruitment suppression by the dominant female and associated population dynamics to quantify the efficacy of such management strategies.

Results from the present study indicate that there may be sufficient larval delivery and settlement onto exploited anemones to maintain similar densities of anemonefish on anemones in protected and exploited sites. However, the reduced biomass of anemonefish per unit area of anemone in exploited sites and the lower size frequency distribution of *A. clarkii* indicates that adults were not present in comparable numbers, potentially negatively impacting reproductive output in exploited areas. The close proximity of protected areas to exploited regions may have resulted in the distribution of abundant larvae into exploited regions, as Fautin (1992) found the number of anemones colonized by fish was proportional to the "local" breeding population. If it is found that larval dispersal from protected sites is indeed seeding exploited sites, then it may not be critical to maintain a breeding pair on each anemone in exploited sites. The presence of adult anemonefish may decrease an anemone's susceptibility to predation (Fautin 1986) and the presence of conspecifics may enhance the ability of settlers to find host anemones efficiently.

Results of the present study reveal that the cessation of anemone removals would not only greatly reduce the direct impacts to anemone populations, but also reduce the indirect effects on anemonefish populations. Given the relatively high value of anemones, preventing over-exploitation would be difficult unless it could be clearly shown that the harvest of anemonefish could be sustainable indefinitely, thus providing a consistent source of income to local fishers. Although it may be possible to sustainably harvest anemones at low levels, current harvest rates are clearly exceeding the ability of anemones to repopulate impacted regions.

Socio-economic forces coupled with the lack of a strong enforcement body encourage overexploitation of the resource in most regions of the world where aquarium fishing takes place. The findings of the present study and proposed management strategies provide rationale that intermediate catch of anemonefish can be sustainable and may even increase productivity of the system. Dissemination of these findings to the local collectors may lead to a self-regulating system where management is performed on a local level by collectors rather than by a regulatory agency (Hilborn et al. 1995). Further field studies and population dynamics models (e.g., Bolker et al. 2002) are needed to provide additional information on how best to harvest the population of each area to

maximize yield and subsequent livelihood opportunities for impoverished communities. Until such empirically validated models become available, we must use best available knowledge to devise reasonable management strategies that will work within the socio-economic framework of developing world fisheries.

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