

## Benthic status of near-shore fishing grounds in the central Philippines and associated seahorse densities

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### Abstract

Benthic status of 28 near-shore, artisanal, coral reef fishing grounds in the central Philippines was assessed (2000–2002) together with surveys of the seahorse, *Hippocampus comes*. Our measures of benthic quality and seahorse densities reveal some of the most degraded coral reefs in the world. Abiotic structure dominated the fishing grounds: 69% of the benthos comprised rubble (32%), sand/silt (28%) and dead coral (9%). Predominant biotic structure included live coral (12%) and *Sargassum* (11%). Rubble cover increased with increasing distance from municipal enforcement centers and coincided with substantial blast fishing in this region of the Philippines. Over 2 years, we measured a significant decrease in benthic ‘heterogeneity’ and a 16% increase in rubble cover. Poor benthic quality was concomitant with extremely low seahorse densities (524 fish per km<sup>2</sup>). Spatial management, such as marine reserves, may help to minimize habitat damage and to rebuild depleted populations of seahorses and other reef fauna.

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### 1. Introduction

Widespread deterioration of coral reefs (Bellwood et al., 2004; Wilkinson, 2004), and the significant contribution of reef fisheries to the nutrition and livelihoods of coastal communities in many developing countries (Polunin and Roberts, 1996; Burke et al., 2002), have created a need to document coral reef status and understand its impact on the associated fish assemblages. The status or “quality” of coral reefs is typically measured in terms of attributes that are widely acknowledged as desirable, such as high live coral cover, low dead coral and rubble cover, low macroalgal cover and high structural complexity (e.g. Gomez et al., 1994; DeVantier et al., 1998; Jameson et al., 1999). Reefs influence associated species through a host of mechanisms,

such as the creation of space and attachment sites, the enhancement of food supply and the provision of refuges from predation (Bruno and Bertness, 2001). There is abundant evidence that reef fish are affected by reef quality: a positive correlation between the percentage of hard coral cover and/or the complexity of the benthic substratum and the diversity and abundance of reef fishes is frequently reported (e.g. Hiatt and Strasburg, 1960; Reese, 1977; Talbot et al., 1978; Hixon, 1993; Syms and Jones, 2000; McClanahan and Arthur, 2001; Jones et al., 2004), though the relationships are complex (Roberts and Ormond, 1987; Hourigan et al., 1988).

The many natural and anthropogenic factors contributing to degradation of coral reefs include destructive storms, disease, bleaching events, sedimentation, mining and poor fishing practices. Storms can reduce hard coral cover (Gardner et al., 2005) and diseases can be important causes of reef decline (Weil et al., 2006). Bleaching events are

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predicted to become a more chronic stress on reefs with the current warming trend of sea surface temperatures (McWilliams et al., 2005), and higher levels of siltation due to land clearing and coastal erosion threaten many reefs, particularly those in sheltered, wave-protected lagoons and bays (Fabricius, 2005). Local impacts from coral-mining and land-filling practices can also significantly modify reefs (Guzmán et al., 2003).

Destructive fishing and overfishing contribute to declines in coral reef quality in many parts of the world (Wilkinson, 2004), but particularly in developing countries where high biodiversity often collides with burgeoning human populations along coastlines, open access fisheries and the absence of alternative livelihoods (Pauly et al., 1989; McManus et al., 2000). The relative impacts of benthic degradation and fishing on populations of locally exploited species are difficult to disentangle (Russ and Alcala, 1989), but poor fishing practices can directly damage primary habitat-structuring organisms (Pet-Soede and Erdmann, 1998) and also disrupt community interactions. Destructive fishing may, for example, reduce substratum complexity, with the damaged reefs rendered more susceptible to algal proliferation (McManus and Polsenberg, 2004). Harmful exploitation on reefs includes the use of explosives, trawling, drive netting, and/or poisons (Jennings and Lock, 1996; McManus, 1997; Pet-Soede and Erdmann, 1998; Mak et al., 2005). Dynamite or blast fishing is particularly pervasive in many reef fisheries in Southeast Asia, and results in indiscriminate fish mortality as well as localized patches of broken or crushed corals or rubble fields in areas of chronic blasting (Alcala and Gomez, 1987; McManus, 1997; Fox and Caldwell, 2006).

The coral reefs of Southeast Asia are in very poor shape, yet continue to be heavily exploited. An estimated 88% of reefs in this region are at risk (Burke et al., 2002), with Philippines' reefs ranking among the most vulnerable (Tun et al., 2004). Almost 40% of Philippine reefs are in 'poor' condition (<25% coral cover) and more than 50% of reef sites are estimated to be overfished (Tun et al., 2004). Nonetheless, small-scale subsistence reef fisheries continue to be crucial to local communities for direct food consumption, particularly in areas of extreme poverty where dependence on inexpensive fish for protein is high (e.g. central regions of the Philippines, Green et al., 2004). Destructive fishing and poverty-driven overfishing are now considered amongst the most urgent coastal management issues in the Philippines (Green et al., 2000; White and Vogt, 2000), and destructive fishing practices may be the largest single contributor to reef degradation (Burke et al., 2002). Illegal blast fishing is typically cited as the leading destructive fishing method (Gomez et al., 1994; White and Vogt, 2000; Green et al., 2004) and is partly responsible for the steady decline in coral cover reported over the past few decades (Tun et al., 2004).

In this study, we characterized the benthic composition of fishing grounds in the vicinity of Danajon Bank, a dou-

ble barrier reef in the central Philippines (Pichon, 1977). These fishing grounds were near-shore and fished by multiple gears for multiple species, as is typical of small-scale artisanal reef fisheries (Munro and Williams, 1985; Barut et al., 2003). Deterioration of the Danajon Bank appears to date back to the 1950s when illegal fishing by blasting and other methods became rampant (Aumentado, 2001). Blast fishing and the use of illegal active gears continues to be common in this area and are considered priority issues by local fishers (Green et al., 2000, 2004; Christie et al., 2006). Coral reefs in this region are also exposed to low water quality due to a high rate of sedimentation, fishing with poisons, bleaching events, and seaweed farming (Christie et al., 2006).

Benthic characteristics of fishing grounds were also investigated for their relationship with the distribution and abundance of the reef fish, *Hippocampus comes*. This seahorse species inhabits coral reefs and is the most common of nine *Hippocampus* species known from the Philippines (Lourie et al., 1999). Interviews indicate recent decadal-scale declines in the populations of *H. comes* in the central Philippines (Vincent, 1996; A. Maypa, unpublished data) apparently because of overexploitation and habitat degradation. *H. comes* is listed as Vulnerable on the IUCN Red List (IUCN, 2006) and its international trade is regulated under CITES (CITES, 2003). Similar to most seahorses, *H. comes* is associated with benthic structural relief and has high site fidelity, usually maintaining a home range within a few meters of a specific holdfast (Perante et al., 2002). We chose *H. comes* for monitoring to understand its habitat associations in order to support management decisions. In addition, we hypothesized that the attributes of this reef fish – it is associated with branching structures, has a small home range and its adults are sedentary – might render *H. comes* particularly responsive to local habitat conditions. We thus predicted that the distribution and abundance of *H. comes* would be positively correlated with fishing ground habitat quality, measured by the percentage cover of abiotic and biotic benthic categories and indices of benthic complexity.

## 2. Material and methods

### 2.1. Study sites

Twenty eight fishing grounds were selected for study on Danajon Bank. This reef system stretches approximately 145 km along the northern coastline of Bohol Island (Fig. 1). The inshore waters are shallow (approximately  $\leq 10$  m), silty and composed of scattered and patchy coral reefs interspersed with *Sargassum* and seagrass (Meeuwig et al., 2003). Study sites were situated between the northern coast of Bohol Island and the outer reef of Danajon Bank, with many sites located directly on the inner Calituban reef (Fig. 1). Sites were located within four municipalities (Getafe, Talibon, Bien Unido and Pres. Carlos P. Garcia) and were selected from a larger group of fishing grounds

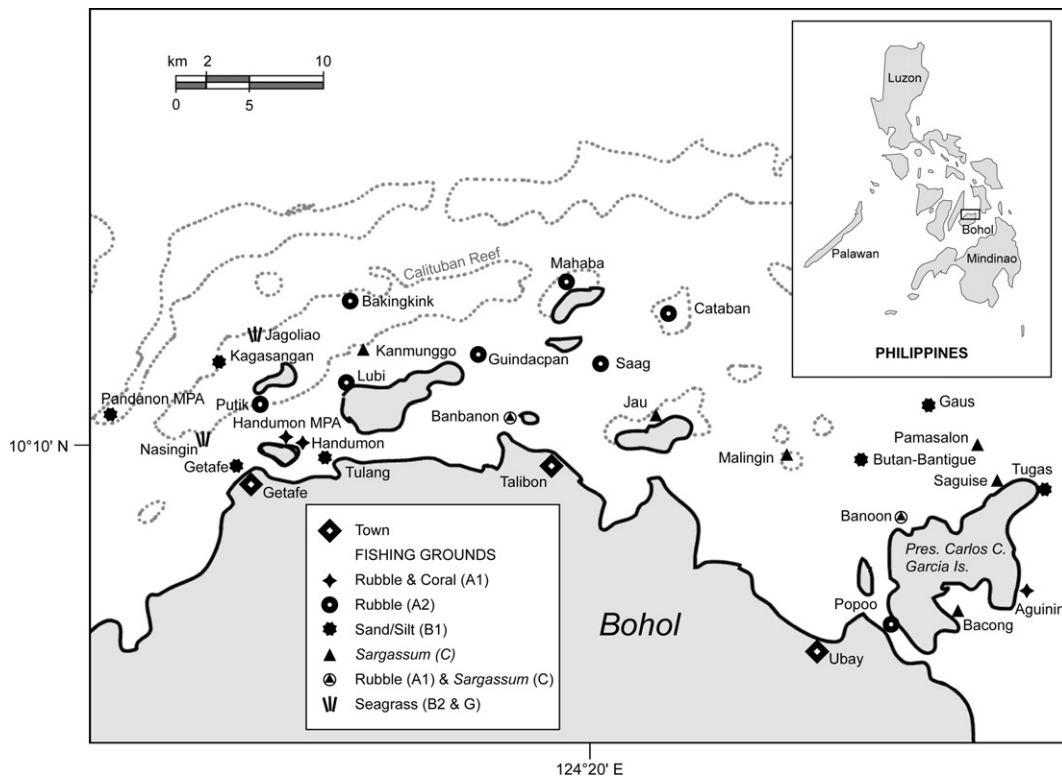


Fig. 1. Map of Danajon Bank with fishing ground locations. Fishing grounds are labeled by their most dominant substratum feature: rubble & coral ( $n = 3$ ), rubble ( $n = 8$ ), sand/silt ( $n = 7$ ), *Sargassum* ( $n = 6$ ), rubble and *Sargassum* ( $n = 2$ ) and seagrass ( $n = 2$ ). See Table 1 for a characterization of benthic types.

determined by a previous study (Meeuwig et al., 2003). Sites were mapped in April–June 2000, with help from lantern fishers familiar with the fishing grounds, using a Global Positioning System (GPS). Fishing grounds were all less than  $1 \text{ km}^2$  in area (average size of  $0.33 \text{ km}^2$ ).

## 2.2. Benthic and seahorse surveys

Bohol experiences a typical tropical monsoonal climate, with the dry season characterized by North-east trade winds from February to May, and the wet season characterized by South-west trade winds from August to November (Green et al., 2000). Surveys were conducted over 2 years in four time periods: the wet season of 2000, the dry and wet seasons of 2001, and the dry season of 2002.

Within each fishing ground, three to six 50 m transects were laid to survey benthic cover and *H. comes* density. The number of replicate transects depended on the size of the fishing ground, and transect locations were chosen by randomly selecting grids identified from the fishing ground maps. Grids were large enough to ensure non-overlapping transects, and transect tapes were positioned based on GPS fixes of grid locations. All 28 fishing grounds were surveyed in each sampling period, except for three sites in the dry season of 2001 (Malinguin, Butan-Bantigue, Aguinin; Fig. 1) which could not be visited for logistic reasons. Across all sampling periods, 487 transects were surveyed

with a mean of 4.5 transects per fishing ground. The fishing grounds were shallow; transect depths ranged from 0.1 to 6.3 m, with an average minimum depth of  $2.3 \pm 0.7 \text{ m}$  and an average maximum depth of  $3.1 \pm 0.7 \text{ m}$ .

Benthic cover was recorded during the day from a randomly selected 20 m section of each 50 m transect, using the line intercept method (English et al., 1997). Percentage cover of the following 14 ‘benthic categories’ were recorded to within 1 cm: live coral (six forms: branching and digitate, encrusting, foliose, mushroom, massive and submassive, tabular; after English et al., 1997), dead coral, soft coral, rubble, sand/silt, *Sargassum*, other algae, seagrass and sponge. The total survey area for benthic cover was 9740 m.

Seahorses were surveyed at night (between 20:00 and 24:00 h) along the entire length of the 50 m transect, with transect width delimited by the light cast by the kerosene lantern mounted on the prow of the survey boat (estimated to be 4 m). Two observers, an experienced seahorse fisher and a biologist, swam along the transect for 30 min towing the paddleboat. The fisher searched for seahorses and when one was sighted, the fisher signaled to the biologist who then recorded species, length, holdfast type, and depth. Seahorse length was measured using the straight height (HT) method (Lourie et al., 1999). The seahorse was returned to the same location where it was found. The total area surveyed for seahorses was 97,400 m<sup>2</sup>.

### 2.3. Data analyses

#### 2.3.1. Characterization of fishing ground benthos

To determine the overall composition of the fishing ground benthos, we combined data from all sampling periods and calculated the mean percent cover ( $\pm 1$  standard error) of each benthic category. To distinguish common substratum characteristics of the fishing grounds, we conducted a hierarchical cluster analysis using all transects and all benthic categories. We chose a 55% similarity level to differentiate clusters and interpreted these clusters as specific ‘benthic types’. Clustering was based on the Bray–Curtis similarity coefficient and the group average method. The cluster result was supported with a multidimensional scaling (nMDS) analysis applied to the same data set (Legendre and Legendre, 1998). For each benthic type, we also report (1) the number of transects in the group with live and/or dead coral cover (to indicate present and/or past coralline habitat), (2) mean live coral cover and (3) the ‘coral mortality index’ (CMI), calculated as the ratio of dead coral cover to the sum of dead and live hard coral cover; rubble was not included in the dead coral category. Gomez et al. (1994) argue that the CMI is a better index of coral health than live coral cover since it accounts for areas of the reef that may be unsuitable for coral growth. Multivariate analyses were implemented in PRIMERv5 (Clarke and Warwick, 2001).

#### 2.3.2. Spatio-temporal patterns of fishing ground benthos

We examined how the benthic characteristics of the fishing grounds varied across the Danajon Bank and over 2 years. Longitudinal and inshore–offshore gradients in benthic structure were explored with linear regressions based on the percent cover (arcsin transformed) of each benthic category. Significant longitudinal trends were further examined by sampling period to determine if spatial pattern differed over time. Inshore–offshore gradients were assessed using the distance between each fishing ground and its corresponding municipal city hall, which is the site of governance (local government unit, LGU) responsible since 1991 for management and enforcement of municipal waters (to 15 km offshore, White et al., 2006). We chose this distance metric since the potential for LGUs to monitor illegal destructive fishing practices may decrease with increasing distance of the fishing ground from enforcement centres. In addition, as these practices may be chosen as methods of last resort when poverty and highly depleted fish populations combine to make other means of extraction less attractive (e.g. Pauly et al., 1989), we hypothesized that the extent of rubble cover at a fishing ground would partly determine its future rubble cover as destructive practices would continue in depleted sites. To examine this, we used the mean rubble cover per fishing ground in sampling period 1 (Wet 2000) and the distance from city hall as two independent variables in a multiple regression to predict the mean rubble cover per fishing ground in sampling periods 2–4 inclusive (Dry 2001–Dry 2002).

Temporal trends in benthic structure were examined by calculating the mean percent cover of each benthic category per sampling period and testing for a significant difference among periods with a Kruskal–Wallis one-way analysis of variance. To test for a temporal difference in the multivariate structure of the benthic transects, we used a two-way crossed analysis of similarity (ANOSIM) to test the hypothesis that there were no temporal effects, allowing for possible site effects. A SIMPER analysis determined which benthic categories were driving the differences among sampling periods (subroutines offered in PRIMERv5, Clarke and Warwick, 2001). A two-way ANOSIM was selected due to identified geographic trends in benthic composition. Temporal changes in benthic composition were also assessed by calculating for each sampling period: (1) the mean Bray–Curtis similarity among transects (‘benthic heterogeneity’) and (2) the mean number of benthic categories, total and only biotic, recorded per transect (‘benthic diversity’) and comparing among the four periods with a Kruskal–Wallis test. If a significant difference was detected with any of the Kruskal–Wallis tests, differences among paired sampling periods were examined with Mann–Whitney *U* tests.

#### 2.3.3. Seahorse density and habitat associations

Seahorse occurrence, density and holdfast use were calculated for each sampling period and we related seahorse distribution and abundance to various habitat measures. Potential habitat associations were examined in two ways using combined data from all sampling periods by: (1) comparing univariate measures of benthic composition (the percent cover of each benthic category, total percent biotic cover), habitat (transect depth), and benthic diversity (number of benthic categories, total and only biotic, per transect) between transects used and not used by seahorses (Mann–Whitney *U* test); and (2) performing logistic regressions of seahorse presence/absence against the percent cover of each benthic category. Seahorse numbers were too few to compare seahorse presence and density among cluster-defined benthic types.

## 3. Results

### 3.1. Characterization of fishing ground benthos

Living structure (hence excluding dead corals) covered on average 31% of the substrata of these Danajon Bank fishing grounds. The mean percent cover of benthic categories in decreasing order were (Fig. 2): rubble ( $32\% \pm 1.1$  SE), sand/silt ( $28\% \pm 1.1$  SE), live coral ( $12\% \pm 0.6$  SE), *Sargassum* ( $11\% \pm 0.9$  SE) and dead coral ( $9\% \pm 0.4$  SE). Variability among transects was high; for example, rubble cover ranged from 0% to 100% and live coral cover ranged from 0% to 82%. Seagrass, sponge, other algae and soft coral combined contributed less than 8% to total benthic cover (Fig. 2). The mean coral mortality index was



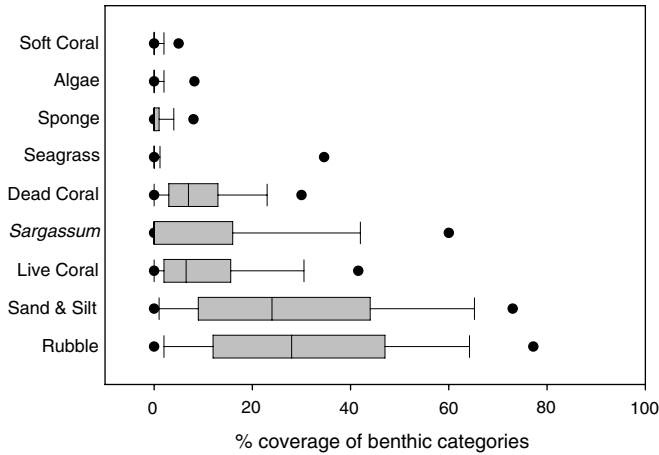


Fig. 2. Overall benthic composition of Danajon Bank fishing grounds. Box plots indicate variation in percent cover of benthic categories across habitat transects ( $n = 487$ ). Lines are median values, with boxes containing 50% of values, intervals containing 75% of values and dots are the 5th and 95th percentiles. Live coral is the sum of all six coral forms.

$0.50 \pm 0.01$ , indicating that half of the area with coral accretion was dead.

Although fishing grounds encompassed a variety of benthic structures, from rubble and coral to *Sargassum* and seagrass, abiotic substrata dominated more than 60% of all transects (Table 1). Clustering delineated nine groups or ‘benthic types’ at the 55% similarity level and groupings were supported by the MDS analysis (Fig. 3). Most transects (92%) belonged to three large clusters (containing five groups: A–C) dominated by rubble, sand/silt or *Sargassum* (Fig. 3a and b; Table 1). **Group A1** ( $n = 50$ ) had medium cover by rubble ( $34\% \pm 0.3$  SE), live coral ( $29\% \pm 0.1$  SE), dead coral ( $22\% \pm 0.2$  SE) and sand/silt ( $11\% \pm 0.2$  SE). **Group A2** ( $n = 156$ ) was characterized by high rubble

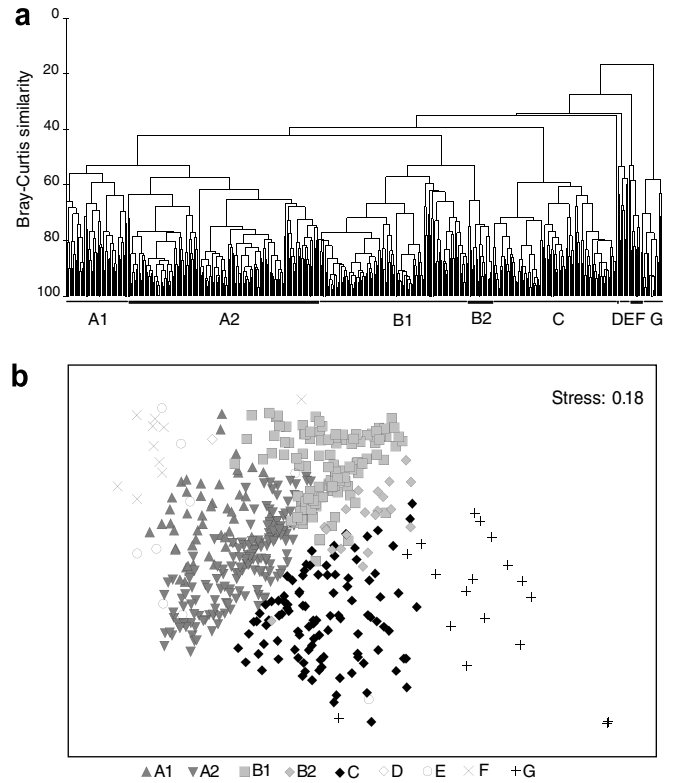


Fig. 3. Characterization of benthic types common to Danajon Bank fishing grounds. (a) Cluster analysis of all benthic transects identified nine benthic types at the 55% Bray–Curtis similarity level: A1, rubble and coral; A2, rubble; B1, sand/silt; B2, sand/silt and seagrass; C, *Sargassum*; D, sponge; E, other algae; F, branching coral; G, seagrass. See Table 1 for a description of the benthic types. (b) MDS ordination of all benthic transects coded by cluster-defined benthic types.

cover ( $55\% \pm 1.5$  SE) and medium to low cover by sand/silt ( $21\% \pm 1.2$  SE), live coral ( $10\% \pm 0.2$  SE) and dead coral ( $7\% \pm 0.5$  SE). **Group B1** ( $n = 122$ ) was dominated by

Table 1  
Cluster-defined substratum groups (see Fig. 3) characterized by mean percent cover of benthic categories

Group	Benthic type	n	Benthic cover			Corals			Seahorses	
			High (>35%)	Medium (11–35%)	Low (5–10%)	LC/DC pres.	LC (%)	CMI	% pres.	Mean density
A1	Rubble and Coral	50	–	R, DC, CBCD, CM, SASI	–	50	28.6	0.45	8.0	0.2
A2	Rubble	156	R	SASI	DC, CM	154	10.4	0.45	7.1	0.3
B1	Sand/Silt	122	SASI	R, DC	CM	120	10.0	0.53	7.4	0.2
B2	Sand/Silt and Seagrass	20	SASI	SG, R	–	18	2.7	0.57	5.0	0.1
C	<i>Sargassum</i>	101	SAR	R, SASI	DC	95	4.9	0.56	6.9	0.2
D	Sponge	1	SP	R, SASI	SAR, CM, CBCD	1	12.4	0.28	0.0	0.0
E	Other algae	9	AL	R, DC	SASI, SAR, CM	9	8.1	0.72	22.2	1.1
F	Branching coral	10	CBCD	DC, R	SASI	10	63.5	0.18	20.0	1.0
G	Seagrass	18	SG	SASI	–	10	2.5	0.49	5.6	0.1

AL = other algae, CBCD = branching and digitate coral, CM = massive and submassive coral, DC = dead coral, R = rubble, SAR = *Sargassum*, SASI = sand/silt, SG = seagrass, SP = sponge. For each group, we also list the: number of transects per group ( $n$ ), number of transects with live coral (LC) and/or DC present, mean percent LC cover, mean coral mortality index (CMI), percent of transects with a seahorse (% pres.) and the mean seahorse density per 500 m<sup>2</sup>.

See Fig. 1 for fishing grounds labeled by their most common substratum feature.

sand/silt ( $59\% \pm 1.6$  SE), with medium cover by rubble ( $14\% \pm 1.1$  SE), dead coral ( $11\% \pm 0.9$  SE) and live coral ( $10\% \pm 0.2$  SE). **Group B2** ( $n = 20$ ) also had high sand/silt cover ( $42\% \pm 3.1$  SE), but fell out separately due to medium-high cover by seagrass ( $30\% \pm 1.9$  SE). **Group C** ( $n = 101$ ) was defined by high *Sargassum* cover ( $45\% \pm 1.7$  SE), followed by rubble ( $25\% \pm 1.6$  SE) and sand/silt ( $16.5\% \pm 1.3$  SE). **Groups D–F** represented 4% ( $n = 20$ ) of all transects and were dominated by high cover of typically rare benthic types: sponge, other algae and branching coral. **Group G** ( $n = 18$ ) was dominated by sea-grass ( $75\% \pm 4.1$  SE).

Fishing grounds were labeled by their most dominant substratum feature, defined by the benthic type(s) which accounted for the largest proportion of transects from that site (Fig. 1). Most benthic transects contained live coral (89%,  $n = 433$ ) and dead coral (89%,  $n = 433$ ), while live and/or dead coral occurred in 96% of the transects ( $n = 467$ ). Rubble was reported from 94% ( $n = 458$ ) of all transects and all fishing grounds had a portion of their benthos represented by the ‘rubble’ benthic type. Only 70% of the fishing grounds ( $n = 20$ ) had transects categorized as the ‘rubble and coral’ type.

### 3.2. Spatio-temporal patterns of fishing ground benthos

Benthic condition showed trends with longitude and fishing ground distance from municipal city halls. Rubble cover was significantly higher in western fishing grounds ( $F = 12.99$ ,  $p < 0.001$ ) over all years, and an analysis by sampling period revealed that rubble was higher in western fishing grounds in the first and the last sampling periods, but cover did not vary significantly with longitude in the two intervening seasons (Fig. 4). *Sargassum* and dead coral cover were higher in eastern fishing grounds (respectively:  $F = 68.95$ ,  $p < 0.001$  and  $F = 6.49$ ,  $p = 0.011$ ), but the relationship between longitude and dead coral was driven by three sites in the west with unusually low dead coral cover (Nasingin, Jagoliao, Tulang). *Sargassum* and dead coral did not show geographic shifts in percent cover over time; cover was significantly higher in eastern fishing grounds in each sampling period. Rubble was also significantly higher in fishing grounds more distant from their respective mainland municipal city halls (Fig. 5), and both distance from city hall and initial rubble were significant explicative variables for predicting mean fishing ground rubble cover (Table 2). No other benthic category had a significant trend with longitude or distance.

There was an overall decrease in benthic quality over the 2 years. Rubble cover increased monotonically with time ( $p < 0.001$ ), from a mean cover of 24.6% ( $\pm 2.7$  SE) in the wet season of 2000 to 40.6% ( $\pm 1.9$  SE) in the dry season of 2002 (Fig. 6). In contrast, sponge cover decreased steadily with time ( $p < 0.001$ ), but the total change was  $< 2.5\%$  due to low overall cover. Cover by live coral, soft coral, seagrass and other algae were significantly different in at least one sampling period ( $p < 0.05$  in all cases), but

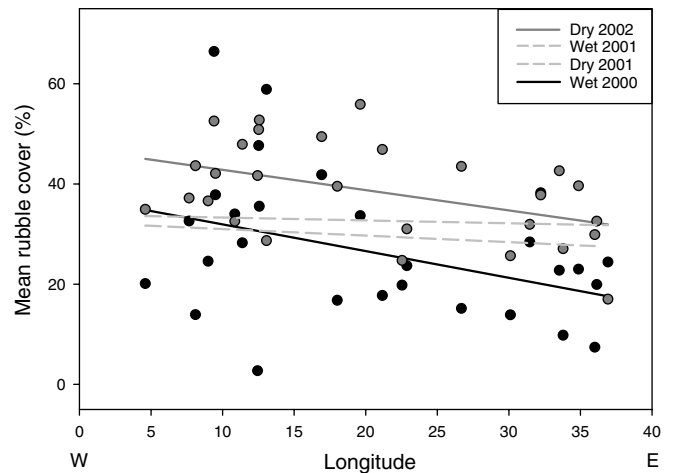


Fig. 4. Temporal relationships of percent rubble cover (arcsin transformed) to longitude ( $124^\circ$  East, minutes given in figure). Western fishing grounds had significantly more rubble cover than eastern fishing grounds in Wet 2000 (black circles;  $F = 7.83$ ,  $p = 0.006$ ) and Dry 2002 (grey circles;  $F = 12.27$ ,  $p = 0.001$ ), while rubble cover did not vary significantly across the Danajon Bank in the two intervening seasons (data not shown). Regression lines are shown for all seasons; line order in the legend corresponds to line order in the figure.

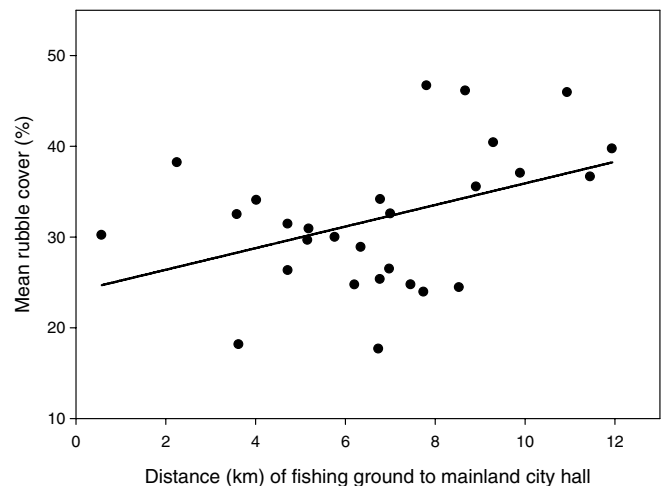


Fig. 5. Relationship between mean rubble cover (arcsin transformed) of fishing grounds (all seasons combined) and the distance of each fishing ground to its respective municipal city hall. Distant fishing grounds have higher rubble cover than inshore sites ( $F = 18.48$ ,  $p < 0.001$ ).

differences were not associated with consistent temporal trends or seasonal patterns (Fig. 6). No difference was detected across the sampling periods in the percent cover of dead coral ( $p = 0.617$ ), sand/silt ( $p = 0.303$ ) and *Sargassum* ( $p = 0.108$ ). In addition to changes in the percent cover of some of the benthic categories over time, the multivariate structure of the benthic transects differed among sampling periods ( $p = 0.001$ , Global  $R = 0.322$ , ANOSIM test). All paired sampling periods were significantly different ( $p \leq 0.001$ ), with rubble, sand/silt and *Sargassum* contributing most to dissimilarities among seasons (SIMPER

Table 2

Results of a linear multiple regression between mean rubble cover of fishing grounds in sampling periods 2–4 (dependent variable), and two independent variables: distance between the fishing grounds and their respective municipal city halls (distance from city hall) and mean rubble cover of fishing grounds in sampling period 1 (initial rubble)

Variable	Coefficient	Standard error	<i>p</i>
Distance from city hall	1.117	0.435	0.017
Initial rubble	0.204	0.080	0.018

The overall model was significant ( $F = 7.77$ ,  $p = 0.002$ ) with an  $R^2 = 0.383$ .

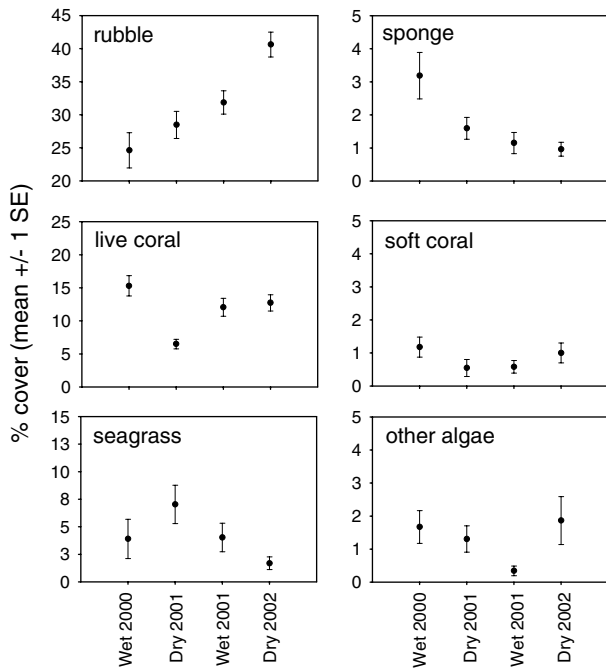


Fig. 6. The percent cover of six benthic categories varied significantly across the four sampling periods: rubble ( $p < 0.001$ ), sponge ( $p < 0.001$ ), live coral ( $p < 0.001$ ), soft coral ( $p = 0.046$ ), seagrass ( $p = 0.025$ ) and other algae ( $p < 0.001$ ) (Kruskal–Wallis tests). Note that the range in percent cover differs among graphs. The number of benthic transects per sampling period was Wet 2000 ( $n = 101$ ), Dry 2001 ( $n = 125$ ), Wet 2001 ( $n = 135$ ) and Dry 2002 ( $n = 124$ ).

analysis, average contribution across all six comparisons: rubble 24%, sand 24% and *Sargassum* 15%).

Benthic “heterogeneity” of the fishing grounds decreased over the 2 years as the benthos became more homogenous: with each consecutive sampling period, the average Bray–Curtis similarity between pairs of benthic transects increased steadily (Fig. 7,  $p < 0.001$ , Kruskal–Wallis test) and similarity values were significantly different between all pairs of seasons ( $p < 0.001$  in all cases, Mann–Whitney *U* test). This increase in benthic similarity was also evident in the MDS plot when coded by sampling period (not shown). Benthic “diversity”, calculated as the total number of benthic categories recorded per transect, did not differ across the four sampling periods ( $p = 0.270$ , Kruskal–Wallis test).

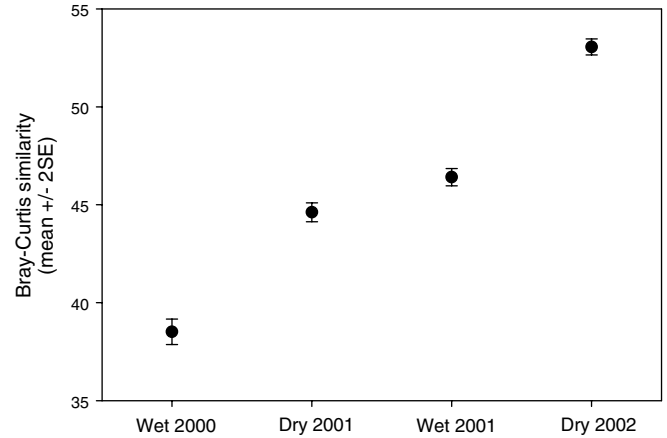


Fig. 7. The mean Bray–Curtis similarity among all pairs of benthic transects per sampling period increased steadily from Wet 2000 to Dry 2002 ( $p < 0.001$ : Kruskal–Wallis test;  $p < 0.001$ : Mann–Whitney *U* tests comparing all pairs of sampling periods). This indicates an overall decrease in variation in the composition of benthic transects with time.

### 3.3. Seahorse density and habitat associations

Seahorse population densities were extremely low. Of the 487 transects, only 37 (7.6%) contained seahorses, and where seahorses were present densities ranged from 1 to 3 fish per transect. A total of 51 seahorses were recorded, equivalent to an overall density of 0.262 fish per 500 m<sup>2</sup> or 524 fish per km<sup>2</sup>. Although, seahorse densities appeared to decline over the 2 years of this study (Fig. 8), the change was not significant ( $p = 0.304$ , Kruskal–Wallis test). The seahorse populations comprised juveniles (8%) and adults (92%), ranging in height from 6.5 cm to 17.0 cm.

Seahorse presence and density varied significantly with benthic diversity. The number of benthic categories (all and only biotic) was higher in transects with seahorses versus without seahorses (Fig. 9,  $p = 0.014$  for all and  $p = 0.035$  for biotic, Mann–Whitney *U* test). Seahorse density was also positively correlated with both measures of

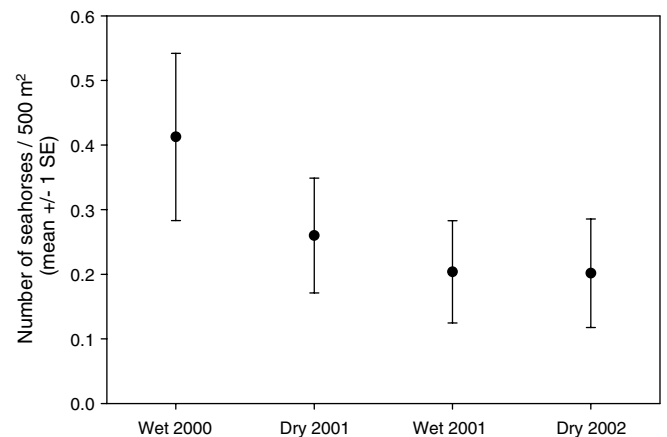


Fig. 8. The mean number of seahorses (*H. comes*) per 500 m<sup>2</sup> in each sampling period. Seahorse density did not differ over the 2 years of this study ( $p = 0.304$ : Kruskal–Wallis test).

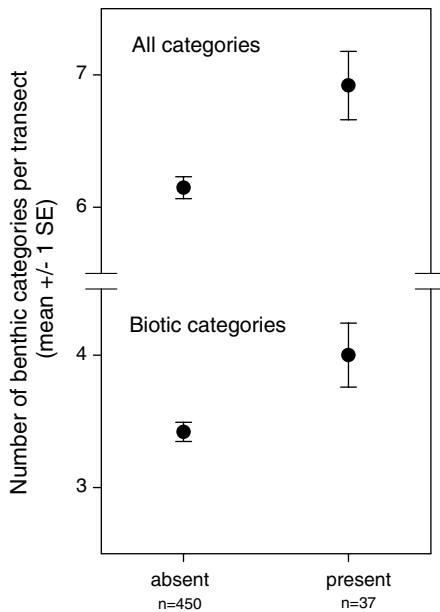


Fig. 9. Transects with *H. comes* present ( $n = 37$ ) had a higher number of benthic categories (upper panel,  $p = 0.014$ ), and a higher number of biotic benthic categories (lower panel:  $p = 0.035$ ), than transects with seahorses absent ( $n = 250$ ) (Mann–Whitney  $U$  tests).

benthic diversity ( $p = 0.013$  for all and  $p = 0.033$  for biotic, Kendall's Tau). All other comparisons between univariate benthic descriptors (percent cover of each of the 14 benthic categories, percent biotic cover, coral mortality index and maximum transect depth) and seahorse presence and density were not significant, although transects with seahorses present had marginally higher cover by sponges ( $p = 0.059$ ) and branching/digitate coral ( $p = 0.15$ ). Logistic regressions detected no significant relationships between the percent cover of any benthic category and seahorse presence. Similarly, there was no clear pattern of association between seahorse presence or density and cluster-defined benthic types. Seahorses occurred across all benthic types (except 'sponge' which was represented by one transect, Table 1), and although the frequency of seahorse occurrence and density were higher in transects dominated by 'other algae' and 'branching coral', numbers were too low to assess significance (Table 1).

Analysis of smaller-scale habitat use showed that seahorses used sponges, dead coral, live coral and *Sargassum* as holdfasts (Fig. 10). In the sampling periods where it was recorded, all seahorses found on live coral were using branching or digitate forms. In the first year of the study, seahorses were found predominantly on sponges and live coral, while in the last year more seahorses were found using dead coral (Fig. 10).

#### 4. Discussion

Our observations of the benthic condition of coral reef fishing grounds in the Danajon Bank, central Philippines

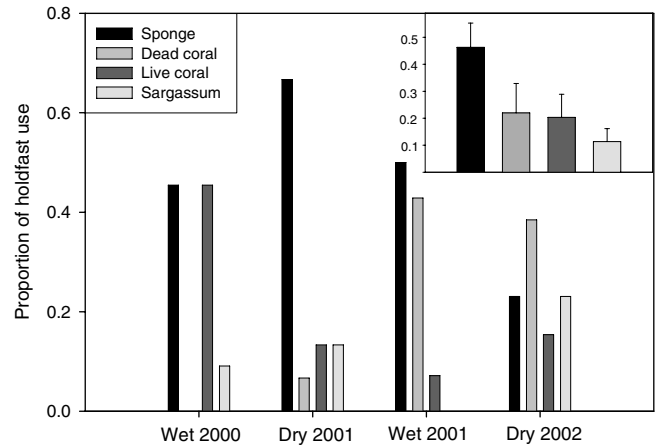


Fig. 10. *H. comes* occurred on sponges, dead corals, live corals and *Sargassum* in differing proportions across the sampling periods. Inset depicts the mean holdfast use across sampling periods; error bars represent one standard error.

provide a stark example of the extent of reef degradation often found in Southeast Asia in response to overfishing and destructive fishing practices (Tun et al., 2004). More than two-thirds of the fishing grounds on this double barrier reef system were dominated by abiotic components such as rubble, sand and silt and dead coral, while live coral cover averaged only 12% of the surveyed benthos. This depleted status may well be linked, at least in part, to the destructive extractive practices, such as blast fishing, that are prevalent in the area. In addition, benthic quality appeared to decline significantly over the course of our study. Over 24 months (2000–2002), we measured a 16% increase in average rubble cover and a commensurate decrease in benthic 'heterogeneity'. Poor benthic quality was concomitant with extremely low seahorse densities. *H. comes* presence and abundance were positively associated with benthic diversity, but were not related to any other measured habitat variables.

Baseline data on Danajon Bank benthic condition are sparse, but available information indicates that the near-shore areas of northern Bohol and Danajon Bank historically supported more corals and less cover by rubble and sand/silt. In 1977, Pichon reported "numerous massive coral species, polyspecific coral patches and a dense vegetation of *Sargassum*" on the back-reef slope of the inner barrier reef (Calituban). Over two decades later, Green et al. (2000) described a series of shallow habitat zones: (1) a shallow near-shore seagrass zone in the inshore waters of northwestern Bohol, followed by (2) scattered coral patches and reefs interspersed with beds of *Sargassum*, with sandy and silty substrata dominated by seagrass and degraded and dead coral colonized by *Sargassum*. A survey of the coral reefs outside of the Danajon Bank in northwestern Bohol in 1997–1998 found a mean live hard coral cover of 31%, followed by 15% cover by both rubble and sand (Green et al., 2000). The fishing grounds examined in this study, a mere 2–4 years later, were in worse overall



condition: live coral cover was less than half, rubble was double and sand/silt cover was high.

The coral-dominated areas surveyed in this study were highly degraded. Fifty percent of the substratum area deemed suitable for coral growth was covered by dead corals (using the Coral Mortality Index, Gomez et al., 1994), and despite the presence of hard corals on almost all of the benthic transects, only three of the 28 fishing grounds were characterized by moderate coral cover (the 'rubble and coral' type). Moreover, these three sites, which had the highest coral reef quality observed, would only be classified as 'fair' by Gomez et al. (1994) due to their marginal live coral cover of 29% to 43%, compared to 'excellent' Filipino reefs with >75% live coral cover. Coral status of the three other common benthic types (Groups A2, B1 and C) was also poor: approximately half of the area covered by corals was dead. Only the branching coral type, which occupied a mere 4% of the total substratum surveyed, had a mean live coral cover greater than 50% and a CMI below 0.2 (i.e. less than 20% of all coral cover was dead). In contrast, during the late 1980s over 40% of 85 reefs surveyed across 14 locations in the Philippines had a CMI equal to or less than 0.2 (Gomez et al., 1994). By the early 2000s, only 4% of Filipino reefs were classified as being in excellent condition, while over a quarter were in poor condition (<25% live coral cover; Burke et al., 2002).

The 1950s are typically regarded as the start of the demise of the Danajon Bank, with the introduction of dynamite fishing during the Second World War and other illegal practices in the subsequent decades, such as cyanide fishing and trawling (Aumentado, 2001; Green et al., 2002). In April of 2000, a survey conducted on illegal fishing in Bohol Province showed that dynamite was the most widely used of 11 outlawed fishing gears and activities (Green et al., 2002). Many of the areas examined in this study are listed as dynamite and cyanide hotspots in Bohol (Green et al., 2002): Guindacpan Island (Talibon municipality), Nasingin and Pandanon Islands (Getafe municipality) and President Carlos P. Garcia Island (CPG municipality). Furthermore, Danajon Bank fishers generally perceived that the quality of their fishing grounds was higher in the past, was currently in decline and would continue to decline in the future, and these fishers considered destructive fishing, particularly blast fishing and cyanide poisoning, as the primary cause of the poor condition of the sites (Meeuwig et al., 2003). It is of note that these fishers' relative ranking of fishing ground quality was also inversely related to the percent of rubble cover measured independently (in the Wet 2000 surveys of this study) highlighting that rubble cover is directly associated with the perceived quality of a fishing ground.

We suggest that blast fishing was the most likely reason for the poor benthic status of the fishing grounds. Blasting shatters hard corals, typically destroying the more delicate structures first, such as branching corals (Pet-Soede and Erdmann, 1998) and repeated blasting can reduce reefs to fields of rubble (Fox et al., 2005; Fox and Caldwell,

2006). Blast fishing is currently considered such a serious problem on the Danajon Bank that a Danajon-wide fisher Alliance is helping authorities track the movements and activities of fishers using dynamite (A. Blanco, pers. comm., Project Seahorse Foundation for Marine Conservation Inc., Philippines). Other destructive fishing practices common to this area such as cyanide and *tubi* (a local plant poison, Meeuwig et al., 2003) are also problematic, but they do not directly result in physical breakage of hard corals and sponges (McManus et al., 1997). Likewise, the inshore waters of Danajon Bank are well-protected from most storms and typhoons. We cannot deduce the potential impacts of a 1998 mass bleaching event on the benthic condition of the fishing grounds. Seaweed farms may also impact the reefs, but they are usually restricted to the very shallow intertidal reef flats.

Our finding of higher rubble cover at distant fishing grounds also points to destructive practices. The near-shore waters of the Danajon Bank are typically turbid due to a high rate of sedimentation and distant clearer waters generally support higher quality coral habitat than inshore areas (Christie et al., 2006). Surprisingly, we found no trend with distance for live coral cover at the fishing grounds; rather distant sites had higher rubble cover than areas closer to mainland municipal centers. Distant grounds may thus be more vulnerable to destructive extraction, perhaps in part because monitoring and enforcement are more challenging at far-off locations. Poor enforcement of illegal fishing practices in remote areas has been noted for Indonesia (Pet-Soede et al., 1999). In addition, the result that prior rubble cover partly explains future rubble cover suggests that fishers may increasingly turn to destructive gears like blasting as a method of last resort in degraded sites.

The intensity or frequency of the factor(s) responsible for the increase in rubble cover may have spatially shifted over very short time scales (months). Although, the data were quite variable, there was an east–west gradient in rubble cover (low to high) in the first and the last sampling periods, but no gradient in the two intervening seasons. If most rubble in the fishing grounds resulted from blast fishing, our observations suggest that once an area is blasted, fishers quickly moved into adjacent sites. Continued monitoring of Danajon Bank fishing grounds is needed to corroborate the current findings, to further track changes in benthic quality and to assess the causes of such change. Continued physical degradation of the reefs may be linked to increases in sand/silt and *Sargassum*, the latter being a well-known colonizer of damaged reefs (McCook, 1999). Benthic types identified in this study can be used to implement random stratified sampling of Danajon Bank sites. To determine the causes of benthic degradation, the frequency and intensity of possible driving factors such as blast fishing, trawling and storms should be concomitantly sampled.

Habitat degradation and fishing pressure are currently considered the leading causes of the depleted status of

Table 3  
Average densities reported for the seahorse *H. comes* from various studies in the central Philippines

Site	Methodology	Density (500 m <sup>2</sup> )	Fishing pressure	References
Handumon MPA, Bohol Is.	Focus study grid, MPA, targeted area of high seahorse density	10	no	Perante et al. (2002)
Jagoliao Island, Bohol, a seagrass MPA	Focus study grid, MPA, targeted area of high seahorse density	10–20	no	Anticamara and Giles (unpublished data)
Danajon Bank, 9 MPA sites	50 m strip transects, MPAs, haphazard sampling	0.6	no	McCorry et al. (unpublished data)
Danajon Bank, 5 'control' sites	50 m transects, seahorse fishing grounds, haphazard sampling	0.2	yes	McCorry et al. (unpublished data)
Central Philippines: 27 sites across 5 provinces	50 m strip transects, seahorse fishing grounds and MPAs, stratified sampling design <sup>a</sup>	0.6	yes <sup>b</sup>	Maypa et al. (unpublished data)
Danajon Bank, 4 islands	100 m transects, seahorse fishing grounds, stratified sampling design targeting recruitment months	0.7	yes	Morgan and Vincent (unpublished data)
Danajon Bank, 28 fishing grounds	50 m strip transects, seahorse fishing grounds, random sampling	0.3	yes	This study

MPA = no take marine protected area.

<sup>a</sup> Density for the "hard coral community".

<sup>b</sup> Study did not report densities separately for MPAs and fishing grounds, but most sites (77%) were fishing grounds and the MPAs were variably enforced.

*H. comes* populations (Martin-Smith et al., 2004; IUCN, 2006), but the extent of their relative impact is unknown, a feature typical of other near-shore fisheries in the Philippines (Russ and Alcala, 1989). The prevalence of low-complexity, non-living structure in Danajon Bank fishing grounds may partly explain the paucity of seahorses, as *H. comes* typically relies on seabed habitats with some degree of benthic structure for holdfasts (Perante et al., 2002). The density estimate from this study is amongst the lowest ever recorded for this species: over 90% of the surveyed transects contained no seahorses and the average density was 0.262 fish per 500 m<sup>2</sup> (equivalent to 524 fish per 1 km<sup>2</sup>). Other density estimates from recent studies suggest that *H. comes* is an order of magnitude more abundant in areas protected from fishing (Table 3). Future studies should investigate the relative influence of habitat and fishing on *H. comes* populations, as population status is likely affected by their combined effects.

The positive association identified between *H. comes* presence and density and substratum diversity suggests that activities which reduce the variety of benthic forms may negatively affect this species. Within a given benthic zone, adult *H. comes* often prefer to use large structures that are unique from the predominant substratum, rather than using a specific holdfast type (S. Morgan, pers. comm.). Contrary to expectation, the seasonal surveys showed no significant decrease in seahorse abundance over 2 years coincident with benthic decline, and the distribution and abundance of *H. comes* were not associated with most measures of benthic composition. The lack of *H. comes* association with specific habitat types and benthic categories may reflect measurement of habitat use at inappropriate scales and/or the severely depleted status of this species. In Bohol Province, seahorses were historically much more abundant. In Handumon village (Bohol

Island) seahorse catch declined by 70% from 1985 to 1995 (Vincent, 1996), and Bohol seahorse fishers reported a 67% decline in catch per unit effort from the 1980s to the early 2000s for *H. comes* (Maypa et al., unpublished data). Assessing habitat associations for species at risk, as are *Hippocampus* spp. (Vincent, 1996; CITES, 2003; IUCN, 2006), is a challenge since densities and hence sample sizes are so low.

Habitat is considered vitally important to fishery production (Dayton et al., 1995), but the direct impacts of benthic degradation on fisheries are not well studied (Turner et al., 1999; Rodwell et al., 2003). Marine protect areas (MPAs) are often heralded as a management tool for protecting fish from direct exploitation and for safeguarding habitat from further deterioration. MPAs are thus regarded by some as a tool to mitigate both overfishing and habitat degradation (Russ, 2002; Roberts et al., 2005). Fish communities positively responded to strictly enforced MPAs in the central Philippines (Samoilys et al., 2007). MPAs may also best protect and possibly restore benthic quality when degradation is predominantly caused by local forces. In areas like Danajon Bank, where destructive fishing practices may have greatly contributed to benthic damage, well-enforced MPAs may be one useful management tool and may also allow analysis of the relative importance of benthic quality to fisheries.

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