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Balance between harvesting pressure and protection: Implications for barren ground formation in Hong Kong

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Abstract: In recent years, there is an increasing awareness of the importance of coastal communities as ecological habitats. Marine protected areas (MPA) are being established and harvesting of marine organisms within these protected areas is being regulated. MPAs provide an opportunity for dynamic regulating mechanisms within coastal community to be examined. A case in point is the Tung Ping Chau Marine Park (TPCMP) in Hong Kong established in 2001. From October 2002 to March 2004, temporal variations in algal and herbivore dynamics were observed in general monthly surveys. The density of herbivores in Lung Lok Shui (LLS), one of the sites known to support extensive bed of *Sargassum*, was low (0.76 individual/100cm^2) and herbivores did not appear to be an important factor in structuring the algal community.

In 2006 to 2007, the population of the short-spined black urchin *Anthocidaris crassispina* increased significantly, from < 1 individuals/m^2 in pre-MPA period to up to 40 individuals/m^2, likely a result of restricted harvesting of these urchins since the establishment of TPC as a marine park. One serious and unexpected consequence of this was the decimation of *Sargassum* population in LLS due to extensive urchin grazing. The cover of *Sargassum* was completely reduced, forming barren ground. Sea urchin grazing became the most important structuring force in this coastal community and was previously put under check due to harvesting by human. A question can therefore be put forward as to how important is human harvesting pressure on sea urchins, or other herbivores like fish, contributing to the dynamics of the coastal algal community. This factor may be more important than previously thought.

Introduction

Hong Kong is located in the southern part of mainland China to the east of the Pearl River, the third largest river in China. True marine environment is therefore found only along its eastern coastline whereas the western coast is highly influenced by the Pearl River outflow and hence is brackish. Rocky shores supporting marine algae are not extensive and these do not usually extend to great depth beyond 10m below the chart datum (CD). Largely because of the influence of the Pearl River, sea water around Hong Kong is highly turbid. Hong Kong has a subtropical monsoonal climate with mean sea water temperature ranging from 14℃ in winter to 28℃ in summer. More than 299 species of macroalgae (seaweeds) have been recorded within Hong Kong waters (Ang 2005). These include temperate as well as tropical species. Their abundance is highly seasonal. Many of these appear as turf that forms a thin carpet on the rocky surface especially during summer. Larger algal species appear mostly in late fall to spring. Perennial to pseudo-perennial species like *Sargassum* spp. provide the canopy to support large number of zooplankton and epiphytic flora and fauna (Ng 2009).

Changes in physical and chemical parameters in the environment, including tide, temperature

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and light are some of the forces structuring algal communities. Biological interactions, including competition and herbivory, are also important (So 2005). The level of intensity, periodicity and regularity of these interactions at the temporal and spatial scales can affect the abundances and diversities of algal populations at a particular locality. Ultimately, the characteristics of individual species or populations, including their physical form, reproductive behavior, fecundity and functional physiology could also determine their tolerance to changes in the environmental conditions.

Herbivory as a structuring force in Hong Kong algal communities is understudied. Large scale grazing by sea urchins, resulting in barren ground (isoyake) formation in many places around the world is well documented (e.g. Watanabe and Harrold 1981, Vasquez *et al.,* 1984, Himmelman & Nedelec 1990). However, this phenomenon is largely unknown in Hong Kong until recently. This study explores aspects of herbivory as a structuring force in Hong Kong algal community, with particular focus on

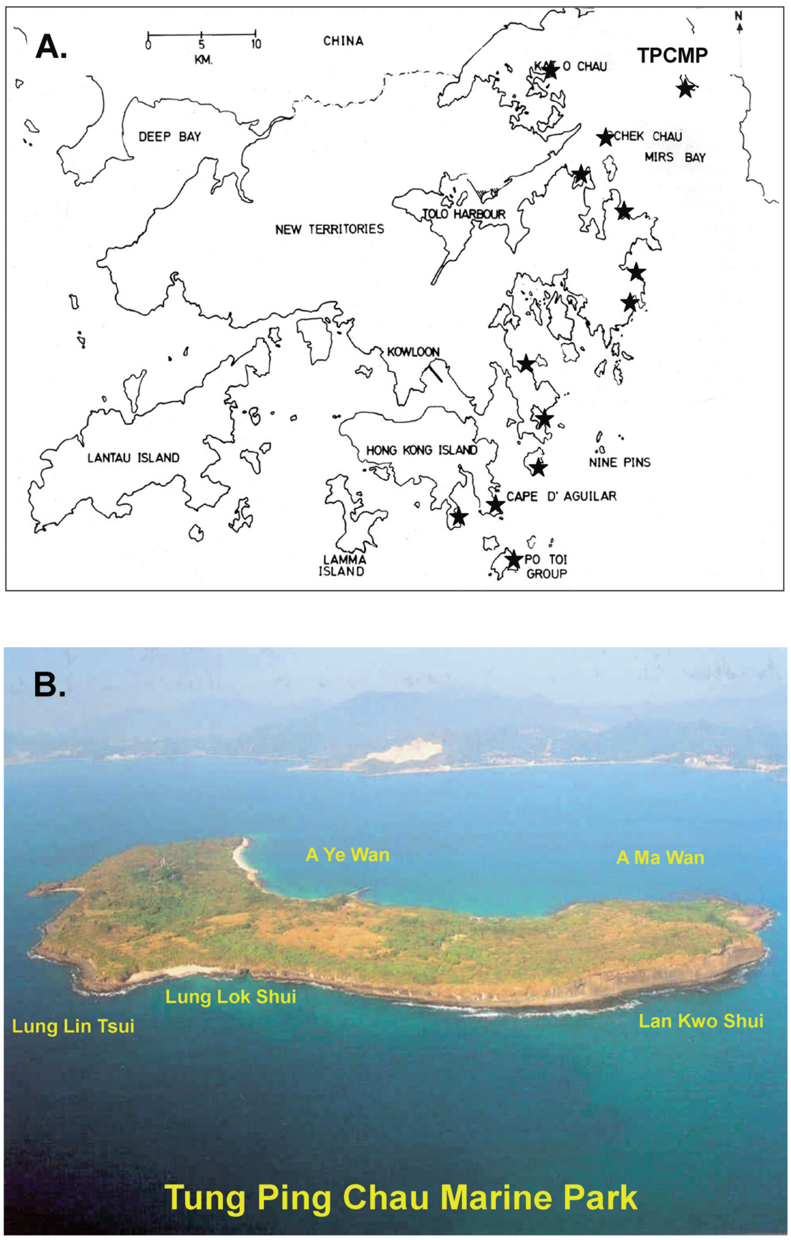

Fig. 1. Map of Hong Kong showing **A.** the location of Tung Ping Chau Marine Park (TPCMP) and other sites (marked with ★) with known abundance of *Sargassum* spp.; **B.** detailed picture of TPCMP with location of the sites mentioned in this study. (Photo Courtesy: AFCD of Hong Kong SAR Government)

sea urchin grazing in a marine protected area, the Tung Ping Chau Marine Park (TPCMP). Sea urchins, especially the short-spined black urchin *Anthocidaris crassispina*, are harvested resource in Hong Kong. They are prized for their gonads locally or are harvested for export. The earlier study on the density of *A. crassipina* in Tung Ping Chau before it was designated as a marine park in 2001 enables a comparison to be made on the density and size of this sea urchin before and after marine park designation. Furthermore, continuous monitoring of the phenology of *Sargassum siliquastrum* in the same site made possible a correlation to be made between the density of the urchins and that of the seaweed. The increase in the number of *A. crassipina*, most plausibly due to its protection after Tung Ping Chau was designated as a marine park, has brought some unexpected impact on the seaweed flora in the protected area.

Study Site

Tung Ping Chau Marine Park (TPCMP) is located on the northeastern corner of Hong Kong territorial water (Fig. 1). Because of its relative remoteness to the highly urbanized Hong Kong, it still enjoys a relative protection from many human disturbances that are characteristics of many other coastal areas in Hong Kong. A Ye Wan (AYW) and A Man Wan (AMW), on the north to northeastern side of the island (Fig. 1), support a high cover (>50%) of hard corals. But high diversity of algae can also be found in their shallower rocky shores especially in winter. Lung Lok Shui (LLS), on the other hand, is located on the south to southwestern side of the island. It is exposed to strong waves especially in summer. It supported extensive beds of *Sargassum*, mainly *S. hemiphyllum* in the lower intertidal and *S. henslowianum* and *S. siliquastrum* in the subtidal. Population of *S. siliquastrum* extended all the way to 10m depth below CD, forming one of the largest seaweed beds in Hong Kong. The presence of this extensive seaweed bed, together with high covers of corals in AYW and AMW, were the reasons behind the designation of Tung Ping Chau as a marine park in November 2001. Changes in algal and herbivore densities in LLS are the focus of this study.

Materials and Methods

Measurement of Algal Percentage Cover

Algal percentage cover in LLS was examined monthly from December 2002 to March 2004. Seven 5m transects were laid parallel to the shore haphazardly. Four quadrats were placed on each transect which was marked with random points. The random point quadrat was 25cm x 25cm in dimensions, with 100 random points represented by intersections of cross strings. Algae underneath every random point were identified to the species level as much as possible. The percentage cover of each algal species was recorded by counting the number of random points that it covered. At times when there was more than one layer of algae under one point, the algae in the upper layer were recorded first, and were then pushed to one side to expose and count the algae in the lower layer.

Some algae were difficult to identify *in situ*. Filamentous algae less than 1cm in length were grouped as turf algae. Encrusting algae were also identified as a group. No attempt was made to examine the detailed species composition of the turf or encrusting algae.

Measurement of Herbivore Density

The position and number of quadrats were the same as those used in the measurement of algal percentage cover described above. The number of individuals of each herbivore species within the 25cm x 25cm quadrat was counted and identified to the lowest taxonomic level as much as possible. The sampling method for fishes was different. The observer would stay at 2m away from the plot and would count the number of fishes hitting the plot for two minutes. After recording, the number of individuals for each herbivorous species per quadrat, including fishes, was standardized and expressed as number of individuals/100 cm^2 in the analyses.

Density and size of *Anthocidaris crassispina*

Other than the density of herbivores measured above, the density of the sea urchin *Anthocidaris crassispina* and its sizes in LLS were separately measured *in situ* on a monthly basis in 2000, then in 2006-07 and 2008-09. Eight transect lines, each

20m long, were laid out haphazardly, in a direction perpendicular to the shoreline. A cave in LLS was used as a reference point to allow rough estimation of the position of the study site. All transect lines were set at the shallow water region with depth between −3 to −5 m CD. A 0.25 m^2 quadrat was placed at 2m interval on the left side along each transect and all individuals of *A. crassispina* found inside the quadrat were counted. At the same time, the test diameter of each of these individuals of *A. crassispina* was measured with a vernier caliper to the nearest millimeter.

Phenology of *Sargassum siliquastrum*

Monthly monitoring for the growth and reproduction of *Sargassum siliquastrum* in LLS has been on going since 1996. In each month, 100 individuals of *S. siliquastrum* were haphazardly selected and its maximum length from the base of the holdfast to the tip of the longest lateral was measured to the nearest millimeter using a meter stick. The number of individuals that became reproductive was also counted.

Statistical Analysis

Relationships between the abundance of algae and herbivores were tested by Pair-wise Pearson Correlation. The percentage cover of algae and the density of herbivores, including herbivorous fishes, were correlated. Furthermore, Canonical Correlation was used to relate the abundance of the algal species and the density of herbivorous species in the whole community. Variables used in the analysis were defined as the variables measured in the study, such as the percentage cover of *Lobophora variegata*. Canonical variates were the linear combinations of these variables (Tabachnick & Fidell 1989). Two linear combinations of variables were employed in this study, representing the algal species and the herbivorous species. Each species was tested as one variable, unless the parametric assumptions of the analysis had been violated. In the latter case, the algal species *Amphiroa ephedraea, Caulerpa racemosa, Ceramium* spp., *Ceratodictyon spongiosum, Colpomenia sinuosa, Dictyosphaeria cavernosa, Dictyota dichotoma, Gracilaria verrucosa, Hydroclathrus clathratus, Hypnea japonica, Laurencia japonica,* and *Ulva lactuca* were grouped as others.

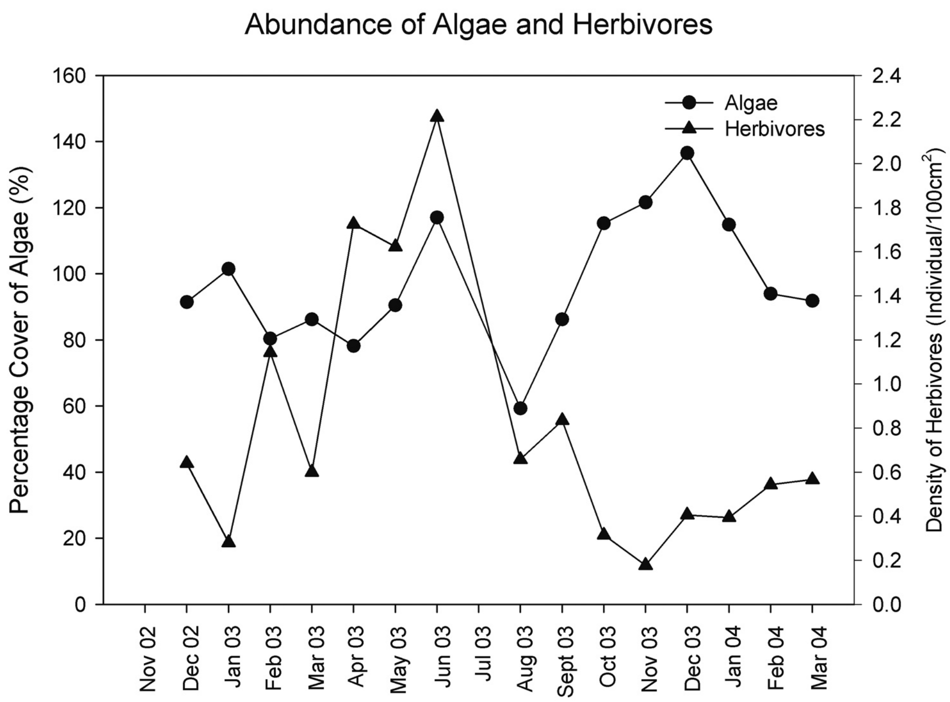

Fig. 2. Mean percentage cover (%) of algae and mean density of herbivores (Individuals/100cm^2) recorded in the general surveys from November 2002 to March 2004 in Lung Lok Shui. SD not shown.

Herbivores like *Epitonium perplexa*, *Signus japonica*, *Menaethius monoceros*, *Nerita albicilla*, *Flabellina ornate* and other small crabs were grouped as small herbivores. The significance of each canonical correlation was noted. For significant correlations, their canonical loadings with values that were <0.3 were not interpreted as they explained <10% of the variance (Tabachnick & Fidell 1989).

Results

Seasonal Variation in Algal Diversity and Cover

A total of 23 algal species were recorded in LLS. The species richness of algae was highest around February to April 2003 and the maximum number of species found in any single month was 16. Diversity of the algae remained high throughout the survey period with a peak shown in March 2003. *Sargassum* spp. were always the most dominant species recorded.

The yearly mean percentage cover (±SD) of algae was 93.6 ± 26.5%, ranging from 59% in August 2003 to 136% in December 2003 (Fig. 2). The peaks of algal coverage were in June 2003 and December 2003. Although there was a significant drop in algal cover in August 2003, the cover rebounded quickly. The results of Kruskal-Wallis one-way ANOVA indicate that the algal percentage cover was significantly different ($p < 0.05$, df = 14) among months.

Seasonal Variation in Herbivore Abundance and Diversity

Seasonal variations of herbivore density were observed in LLS. The densities of all herbivores, including fishes, increased in March 2003 and leveled off in May 2003. The density of the herbivores ranged from 0.18 – 1.14 individual/100cm^2 (Fig. 2) with a mean of 0.76 individual/100cm^2. Eighteen species of herbivores were recorded, with the highest diversity recorded in February 2003 and March 2004. The gastropod *Chlorostoma rustica* was the dominant herbivore within the period surveyed with the highest density of 0.95 to 1.17 individual/100cm^2 recorded in April to June 2003. The density of the sea urchin *Anthocidaris crassipina* was very small and except for June 2003, was always less than 0.1 individual/100cm^2. In June 2003, its density was 0.14 individual/100cm^2. All the other herbivores were also low in density at <0.3 individual/100cm^2 all throughout the surveyed period.

Interactions between Algae & Herbivores

Results of Pair-wise Pearson Correlation showed that the cover of algae was not significantly correlated with the density of the herbivores (r = −0.112, $p > 0.05$, n = 15). For the results of Canonical Correlation, the first set was significant (p = 0.005) between the two pairs of canonical variates with encrusting algae having negative relationships with hermit crabs, the rock fish *Sebastiscus marmoratus* and small herbivores. The alga *Galaxaura oblongata*, in contrast, had positive relationship with these three types of herbivores. The contributions from *Galaxaura oblongata* and hermit crabs were more important than those from the other variables. The contribution from the sea urchin *Anthocidaris crassipina* was negligible.

Density and size of *Anthocidaris crassipina*

Comparing the density of *Anthocidaris crassipina* sampled over the years, albeit at times using slightly different methods, it can be observed that the number of these sea urchins was very low in 2000, ranging from 1.3 to 5.3 individuals/m^2, and remained low throughout 2003 to early 2004 (Fig. 3). The density, however, increased significantly by 2006. The mean density of *A. crassispina* increased from 5.5 individuals/m^2 in September 2006 to 10.23 individuals/m^2 in March 2007. In some quadrats, the density could be as high as 40 individuals/m^2. This increase in March 2007 was a result of recruitment of young urchins during winter (February and March). This is reflected in the population structures of *A. crassispina* shown in Fig. 4. In October 2006, 39 – 52% of the sea urchins were in the size range of 35 – 45 mm. In early 2007, the number of individuals having test diameter < 15mm increased to 21% in January and eventually to 32% in March (not all data shown). A more detailed analysis on changes in the size structure of *A. crassipina* in LLS, TPCMP is given in Li (2007). The mean density of *A. crassipina* remained high (> 5 individuals/m^2) in 2008–2009 (Fig. 3) with maximum density at 20 individuals/m^2

recorded in some quadrats.

Phenology of *Sargassum siliquastrum*

As typical for many *Sargassum* species. *siliquastrum* exhibits an annual cycle of growth and die-back. It has a slow growth period in spring to summer, a rapid growth period in the fall, cumulating in the peak reproductive period in early winter (December to January) before dying back in February to March. Over the years, this pattern has been consistent although the peak period of growth and reproduction may differ slightly from year to year (Fig. 3). Starting from September to October 2006, however, the population of *S. siliquastrum* failed to attain a rapid increase in length. By December 2006, the mean maximum length remained at only 13.4 ± 3.6 cm. In January and February 2007, only few reproductive plants were found. Although some increase in length was apparent in March to June 2007, this was largely due to development of the new shoots from the perennating holdfast. Thereafter, the population completely disappeared and in 2008 to 2009, no individual of *S. siliquastrum* was found in the same site (Fig. 3). The cover of *Sargassum* was reduced to 0%.

Discussion

Since our monitoring of the ecological condition of Tung Ping Chau in 1996, the presence of a large seaweed bed in LLS was a prominent feature. Although measurements of changes in the length of the *Sargassum* spp. in this bed were not carried out every year, their presence could not be missed. Our earlier data indicated that the growth cycles of the seaweeds, including the large *Sargassum* spp. were very regular for many years and herbivores were not an important structuring force in this seaweed bed. This situation, however, had changed dramatically since 2006.

Anthocidaris crassipina is a well known herbivore. Its grazing effect and changes in its population structure have been reported in other parts of Hong Kong (Chiu 1988) as well as in other parts of the Asia Pacific (Yoo *et al.,* 1982, Yatsuya & Nakahara 2004). It is a harvested resource in Hong Kong. Local villagers would collect these urchins in late winter for their gonads. Even small sizes of these urchins are collected, especially by fishers from mainland China, and grown in cages until a suitable marketable size for export (pers. com. with local villagers). This situation was also true in Tung Ping Chau in earlier years. On several occasions, we had directly observed the collection of these sea urchins by these fishers underwater as well as by the local villagers. Each time, the collection was very extensive and almost no urchin was left untouched.

Since Tung Ping Chau was designated as a marine park in November 2001, all forms of plant and animal collection are prohibited except with permission. Hook and line fishing is allowed but only in two designated sites. While local villagers could still collect the urchins for their local consumption, the large scale collection by other fishers is banned. Our pre-marine park data on sea urchin density clearly showed that the density was very low, and this density remained low in a few years (2003-2004) immediately after large scale collection of the sea urchins was banned. This low density population was likely maintained by harvesting pressure and it took a few years for the population to increase in size after harvesting was discontinued.

While no detailed monitoring on the density and sizes of *A. crassipina* was carried out between 2004 and 2006, our regular monitoring of the *Sargassum* bed within the same period did not find them to be prominent. This situation changed in 2006 when visual inspection of the seaweed bed showed the presence of many sea urchins. Our subsequent monitoring of their density confirmed our suspicion of the dramatic increase in their number. It is apparent that the banning of larger scale sea urchin collection after Tung Ping Chau was designated as a marine protected area may have contributed to the dramatic increase in the sea urchin populations. As observed, this high density of sea urchins grazed directly on *Sargassum* and was responsible for the decimation of the *Sargassum* bed.

The presence of this large *Sargassum* bed itself could have provided the food needed by the urchins for rapid population growth. The large recruitment in winter is timed with the presence of highest amount of seaweed biomass. The impact of sea urchin grazing actually started in the shallower area of LLS. While individuals of *S. siliquastrum* could still be found in slightly deeper (-3 to -6 m CD) subtidal area, albeit in a much reduced size, individuals of *S. hemiphyllum* and *S. henslowianum* in lower intertidal and shallow subtidal were all gone as of October 2006. In other parts of TPCMP, like Lan Kwo Shui (LKS) and Lung Lin Tsui (LLT)

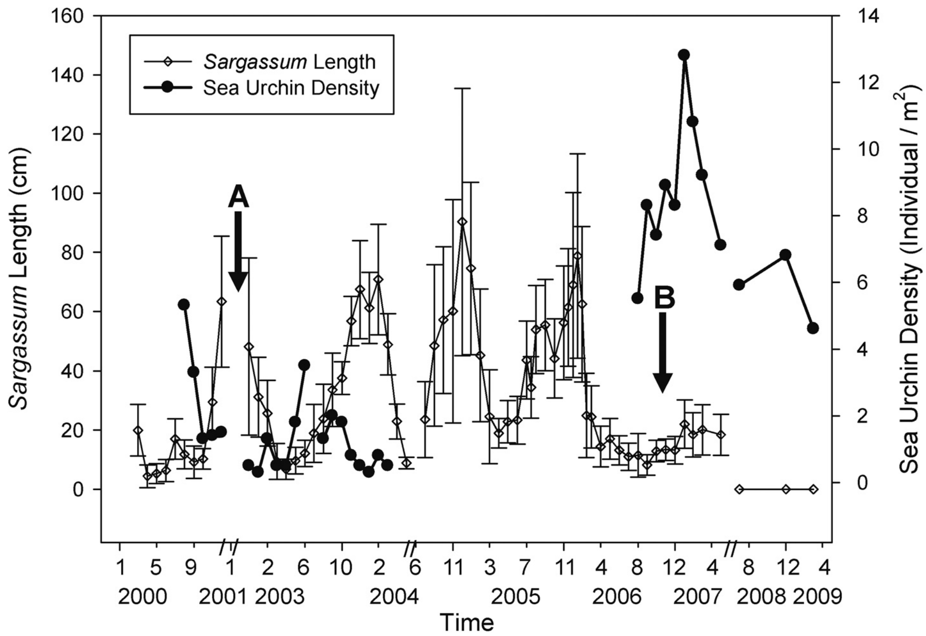

Fig. 3. Monthly mean length (± SD) of *Sargassum siliquastrum* from Lung Lok Shui, Tung Ping Chau Marine Park over a 10 year period from 2000 to 2009. Data on the density of the sea urchins *Anthocidaris crassipina*, when available, are also shown. Arrow A, time (Nov 21, 2001) when Tung Ping Chau was designated as a marine park. Arrow B, time (Nov/Dec 2006) when decimation of the *Sargassum* population started to become clear. Note time gaps in the X axis.

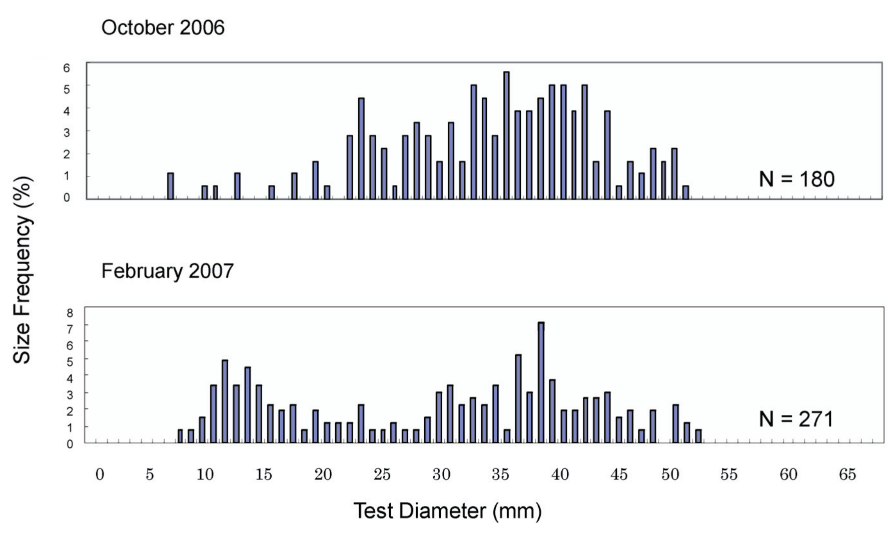

Fig. 4. Size frequency (%) of the test diameters of the sea urchins *Anthocidaris crassipina* in Tung Ping Chau Marine Park. Only data for October 2006 and February 2007 are shown to illustrate the increase in the number of small urchins in winter.

(see Fig. 1 for their locations in TPCMP), which are only a few hundred meters from LLS, large number of *Sargassum* spp. remained during this same period. A scenario could therefore be projected that this bloom of sea urchin population most likely started in the shallow area of LLS in 2006. There could be other environmental conditions that contributed to this bloom, e.g. warmer sea water temperature (?). But the most likely scenario would have been that the release of sea urchins from harvesting pressure, coupled with the absence of any large predators like fish and the presence of large amount of food in the seaweed bed, provided the impetus for its population expansion. This hypothesis could further be confirmed with other developments observed since 2006. The density of sea urchins remained high and in 2007 to 2008, these urchins had moved on to decimate deeper populations of *S. siliquastrum* in LLS, as well as populations of other *Sargassum* spp. in LKS and LLT. Extensive barren grounds can now be observed throughout the west and southwestern shore of Tung Ping Chau where large beds of *Sargassum* spp. used to stand. As of April 2009, pockets of *S. siliquastrum* could still be found in LLT. These populations are currently being monitored as they could serve as the source of recruits to the barren grounds should the population of *A. crassipina* decline in the near future.

Hong Kong fisheries are heavily overexploited so the absence of any large predatory fish is not a surprise. Elsewhere outside TPCMP (or in the earlier years in TPCMP), harvesting pressure itself serves as a top down control on the population of sea urchins, and indirectly on the seaweed populations. The question now is after the decimation of the seaweed bed in TPCMP, would the absence of food resource then provide a bottom up control that would eventually lead to the decline of the sea urchin population? Or would the persistence of sea urchins lead to a phase shift in the community structure such that barren grounds would become the norm rather than the exception?

One other indirect consequence of the formation of barren ground is the recruitment of other invertebrates, notably barnacles, on the newly opened space. The open areas cleared of *Sargassum* spp. in LLS are now all covered with barnacles. Would the dominance of barnacles prevent the coming back of the algae, and lead to further persistence of the barren ground even after the population of sea urchins has declined?

The formation of barren ground is an unexpected result of the protection of Tung Ping Chau as a marine park. This ran contrary to the very objective of the marine park designation, which is to preserve and protect the existing biodiversity, including the extensive *Sargassum* beds. Successful marine parks are expected to serve the functions of increasing the biodiversity and abundance of protected species, preservation of genetic pools, and eventual spill of individuals (adults, juveniles or propagules) to surrounding areas (Russ 2002). Our own studies, providing both temporal and spatial comparisons of the mean density and diversity of fish before and after Tung Ping Chau was designated as a marine park, indicated that there were increases in the fishery target species like the seagrass rabbitfish *Siganus canaliculatus*, as well as other species like the yellowstripe scad *Selaroides leptolepsis* and the silver sweeper *Pempheris schwenkii* (Tam & Ang in prep., Lam *et al.,* in prep.). None of these, however, are the predatory fish that could prey on the sea urchins.

In our survey of LLS in December 2008, some *Sargassum* individuals belonging to *S. hemiphyllum* and *S. henslowianum* had come back, mainly in the lower intertidal and shallow subtidal areas. However, the deeper areas remained barren with no sign of *S. siliquastrum*. Nonetheless, the return of *S. hemiphyllum* and *S. henslowianum*, albeit very few of them, may provide some hope on the potential of natural recovery of the *Sargassum* bed.

The unexpected formation of barren ground has implications for future management of TPCMP. Several critical management questions need to be addressed. In spite of the formation of barren grounds, should the system be left alone? Would large predators eventually appear in the marine park to initiate a top down control on the population of the sea urchins that would eventually lead to the recovery of the *Sargassum* bed? Or should human step in to act as the "top predator" under the unlikely scenario of natural appearance of other top predators? Finally, larger scale harvesting of sea urchin is a more recent activity that probably started only in the last 20 or 30 years. There was no record of what the environment was like prior to that. Is it therefore likely that barren ground was actually the "natural" situation and seaweed beds appeared only because of the removal of these major grazers by human? How important is human harvesting pressure on sea urchins, or other herbivores like fish, contributing to the dynamics of the coastal algal community. What would be the other implications of this observed impact, i.e. on the role of seaweed bed as a nursery and breeding ground for other fish and invertebrates? All these questions inevitably point to the utility of setting up of the marine park itself and would need to be examined more carefully!

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