Pergamon

PII: S0025-326X(96)00002-1

Marine Pollution Bulletin, Vol. 32, No. 10, pp. 701–710, 1996
Copyright © 1996 Elsevier Science Ltd
Printed in Great Britain. All rights reserved
0025-326X/96 $15.00+0.00

REPORTS

The Subsidiary Impacts of Dredging (and Trawling) on a Subtidal Benthic Molluscan Community in the Southern Waters of Hong Kong

BRIAN MORTON
The Swire Institute of Marine Science, The University of Hong Kong, Cape d'Aguilar, Shek O, Hong Kong

The macrobenthic fauna of the southern waters of Hong Kong were surveyed in April 1992, notably with regard to the Mollusca. Subsequently, parts of the area were extensively suction dredged for major construction projects. Commercial trawling continued alongside the dredging. In October 1994, with dredging close to finishing, six of the original 50 stations were resurveyed using the same gear, and the Mollusca again re-examined. This study demonstrates that close to dredged sites, i.e. within 2 km, species and individual numbers of both the Gastropoda and Bivalvia had declined by approximately two thirds in the intervening period. With regard to the Gastropoda, most of the species losses were of specialist neogastropod predators. Post-dredging, the gastropod fauna was virtually dominated by opportunistic scavengers, notably *Nassarius siquijorensis*, *Bursa rana* and *Murex trapa*. These, however, were also dominant pre-dredging and this lends support to an earlier argument that disturbed inshore marine sediments favour the presence of such species. The bivalve fauna was dominated by a few species that are resistant to disturbance, such as *Placamen calophylla*, *Corbula crassa* and *Minnivola pyxidatus*. These species are of no commercial value and the former two have solid shells that are resistant to trawl damage and which are, actually, adaptations to avoid predation. Possibly, *Veremolpa micra* and *Paphia undulata* are new colonizers of the perturbated sea-bed, but this remains to be substantiated. This study postulates that settling silt plumes associated with dredging activity have exacerbated the problems of a sea-bed already disturbed as a result of trawling and pollution. Copyright © 1996 Elsevier Science Ltd

Keywords: Mollusca; Gastropoda; Bivalvia; suction dredging; trawling impacts; subtidal benthos

The first survey of the subtidal benthos of Hong Kong's territorial waters was by Shin & Thompson (1982) who identified five communities which could each be named after the three most dominant species of polychaetes. That study was undertaken using a grab. More detailed and specific studies have been undertaken subsequently, e.g. Shin (1989) and Ong Che & Morton (1991). These have shown the local, unpolluted, sub-tidal benthic fauna to be diverse and not to undergo significant seasonal changes in either species abundance or community composition. Most research on the effects of disturbance on the benthos of Hong Kong's territorial waters has predominantly used beam trawl sampling. A two year trawl survey of the epibenthos of Tolo Harbour by Wu (1982) showed there to be a summer defaunation and subsequent recovery, caused by eutrophication exacerbated by the establishment of a summer thermocline/halocline in the overlying water (Morton, 1995a). Subsequently, Taylor & Shin (1990) and Taylor (1992), after analysing the results of trawl surveys conducted within Tolo Harbour at three year intervals since 1978, demonstrated a progressive decline in the gastropod fauna of the inlet. These authors recorded the decline in specialist gastropod predators in relation to pollution. Morton (1995b), however, re-analysed the data and showed that such a decline was matched by periodic surges in the incidences of a suite of scavenging gastropods. Such a picture was also demonstrated for other areas of Hong Kong and this has led Britton & Morton (1994) to postulate that marine perturbations, especially with regard to periodic mortality induced by dredging and trawling (including the act of fishing and subsequent discards), tend to favour the wide-scale presence of opportunistic scavengers of which the neogastropod Nassariidae are significant, especially in intertidal and shallow water coastal habitats.

In a study of the impacts of marine gravel extraction on the macrobenthos at a site off the east coast of England, Kenny & Rees (1994) showed that significant reductions had occurred in the variety, abundance and biomass of the benthos following suction dredging. Conversely, Poiner & Kennedy (1984) argued that although species diversity, richness and abundance all declined at a dredged site in Moreton Bay, Australia, indices of the same parameters increased in adjacent areas possibly as a response to increased nutrient resources, from settling sediment. In a review of the effects of trawling, dredging and ocean dumping on the macrobenthos of the eastern Canadian continental shelf, Messieh *et al.* (1991) reported that although there was evidence of physical damage and biological effects, results were inconclusive and some studies indicated that the effects were not significantly adverse. The area of the Canadian continental shelf is, however, large in comparison to the 1800 km^2 territorial waters of Hong Kong. Local fishing grounds, must, however, be among the most extensively exploited in the world. The Hong Kong fishing fleet, for example, comprises about 4900 vessels of which 515 are shrimp trawlers, 586 are pair trawlers and 222 are stern (otter-board) trawlers. The trawlers account for well over half of the total catch of the local fleet. Most of the large trawlers operate outside Hong Kong waters but many will, at least some of the time, operate within them. There is no information on trawler impacts in Hong Kong, but it is generally assumed that they are extensive (Selby & Evans, in prep.)

Studies of trawling impacts from elsewhere are equivocal. Brylinsky *et al.* (1994) and Van Dolah *et al.* (1991) record no significant impacts upon the benthos whereas Jones (1992) and Bergman & Hup (1992) do, i.e. the greater the frequency of fishing, the greater the likelihood of permanent change. Hall (1994) reviews the available literature on the effects of trawling and other physcial disturbances upon subtidal benthic communities.

The new Port and Airport Development Strategy (PADS) for Hong Kong is concerned with the building of a new port and airport on the largely undeveloped island of Lantau in western Hong Kong by means of coastal reclamation. Historically, coastline reclamation in Hong Kong has been achieved by the dumping of unwanted construction wastes and with fill obtained from terrestrial 'borrow' areas. So large is the PADS project, that the impact of land-based quarrying and activities upon the city, measured in terms of hillside scarring and the effects on the transport infrastructure, required that borrow areas be sought elsewhere. Dutton (1987) demonstrated the existence of large volumes of dredgeable sand in the territorial waters of Hong Kong. A Fill Management Committee of the Civil Engineering Department of the Hong Kong Government was established in 1989 and by 1990 more than 20 potential marine borrow areas had been identified as economically viable for large-scale dredging. To put the operation in perspective, it was estimated that about 500 million m^3 of marine sand would be needed for the PADS project (Morton, 1992) and that by 1993, 75% of the world's hydraulic dredging fleet was operating in Hong Kong.

The only study to date of the biological impacts of such concentrated dredging upon Hong Kong's marine environment is by Hodgson (1994) who showed that in the 'overflowing' process of dredging, sediment plumes had settled onto corals in two inlets of North Ninepin Island in the eastern waters of Hong Kong and caused a 40% decrease in live coral cover, as could have been predicted given that the dredgers were allowed to operate so close to shore in coral areas.

In April 1992, the Swire Institute of Marine Science organized an international research workshop. One of the objectives of the workshop was to design and implement a trawl survey of the southern and southeastern waters of Hong Kong, prior to the commencement of dredging. Fifty stations were established (Fig. 1) and, to date, two sets of data have been published with regard to the epibenthic penaeid prawns (Leung, 1995) and Gastropoda (Taylor, 1994) of the area.

A similar repeat survey of the same stations was organized in April 1995 and, as a reconnaissance for that event, an opportunity was taken in October 1994 to retrawl six of the original 50 stations and obtain a preliminary assessment of any possible impacts that had taken place in areas adjacent to dredged sites after April 1992.

This paper presents the findings from a survey of the subtidal Mollusca in the southern waters of Hong Kong in October 1994. The present data are compared with that obtained by Taylor (1994) on the epibenthic Gastropoda and unpublished data on the epi- and endobenthic Bivalvia obtained in April 1992.

Materials and Methods

For the April 1992 survey, 50 stations were established in the southern and southeastern waters of Hong Kong at a variety of depths and in locations at which dredging was either planned for or not. The location of the 50 stations and the areas where suction dredging was scheduled to take place are shown in Fig. 1. A few stations were trawled twice and some were unsuccessfully trawled because of illegally dumped spoil. At each station, a pair of beam trawls, of 2.35 m width and 25 mm cod-end mesh, were hauled at an average speed of 2.25 knots for 10 min bottom time. For each haul, depth, duration and course were recorded. Details of the trawling stations are given by Leung (1995) and Taylor (1994).

In October 1994, only six stations were sampled using the same vessel and crew, but these were chosen deliberately as follows and with reference to Fig. 1.

- Station 3: Identified in 1992 as of average species richness and individual abundance and located >3 km away from dredging sites (depth 16 m).
- Station 9: Identified in 1992 as of poor species richness and individual abundance and undredgeable (depth 47 m).
- Station 4: Identified in 1992 as of average species richness and individual abundance and closer (2 km) to nearest dredging sites (depth 27 m).
- Stations 8, 17 and 45: Identified in 1992 as of high species richness and individual abundance and all approximately 1 km from the nearest dredging site (depths 37, 30 and 25 m, respectively).

It was assumed that Stations 3, 9 and 4 would serve as controls with regard to the efficacy of the trawling gear, its operation and station location. Stations 3 and 4 also served as sites where it was thought that dredging

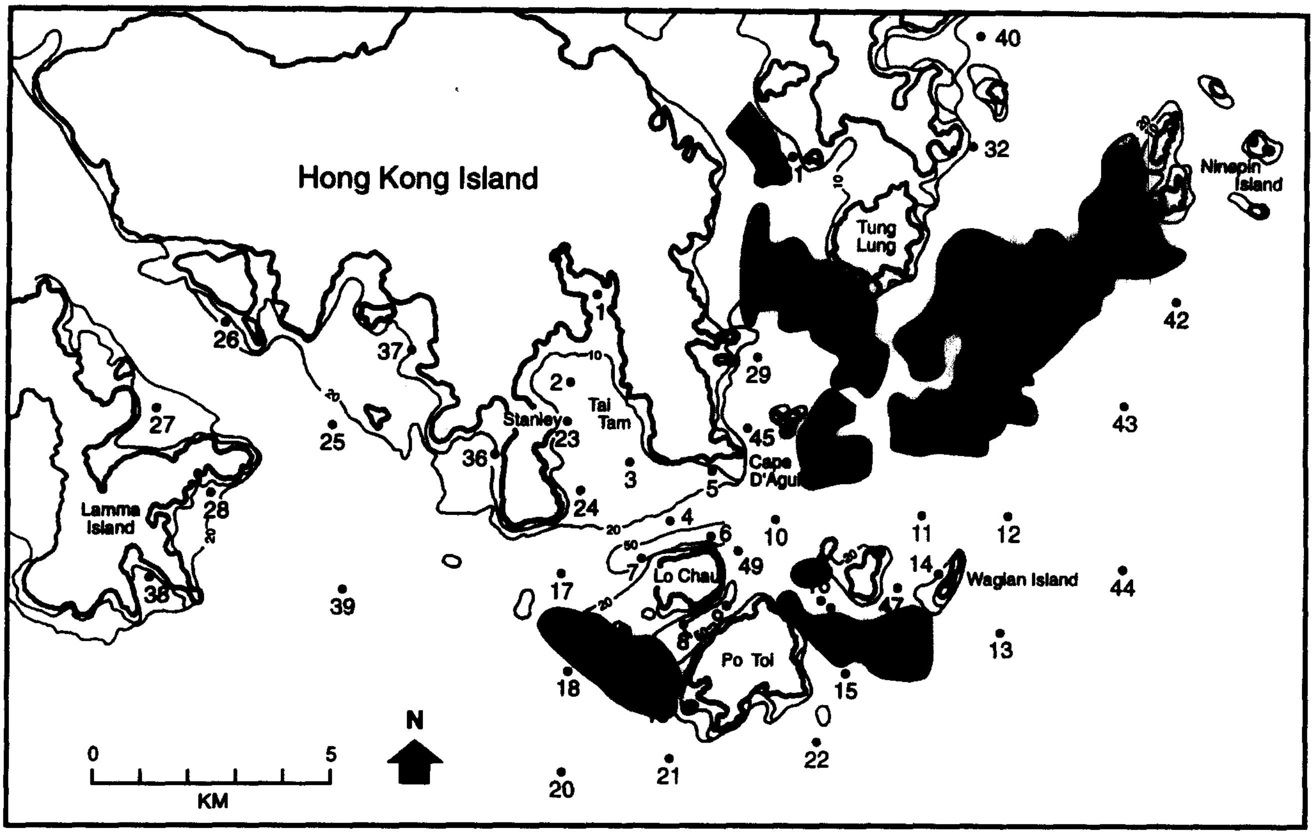

Fig. 1 A map of Hong Kong Island and the southern waters of Hong Kong showing the trawl stations surveyed in 1992. Superimposed upon the map are the areas gazetted for dredging subsequently.

9, two 10 min hauls were undertaken as in 1992. Stations 8, 17 and 45 were all located within approximately 1 km of dredging sites and Station 8 was also retrawled for 10 min. They were all, however, for reasons which will soon become clear, subsequently retrawled two more times, but for 20 min each. As in 1992, specimens obtained by each of the paired trawls were pooled, but specimens from each single trawling period were isolated, obtained species identified and numbers recorded. Trawling in the dredge 'holes' themselves was not possible because of the dramtic increases in depth that have been achieved i.e. up to 30 m.

Results

Data on the Mollusca present at Stations 3, 9, 4, 8, 17 and 45 in 1992 and 1994 are contained in Table 1 (Gastropoda) and Table 2 (Bivalvia).

Gastropoda

At Station 3 in 1992, six species and 11 individuals were obtained from two 10 min hauls. From the same station in 1994, six species and 12 individuals were obtained. In both 1992 and 1994, *Nassarius siquijorensis* was dominant. At Station 9 in 1992, no gastropods were obtained. From the same station in 1994, one individual each of *Nassarius siquijorensis* and *Gemula deshayesi* were obtained.

At Stations 8, 17 and 45 in 1992, 14, 17 and 17 species were obtained, respectively, and 21, 33 and 93 individuals, again respectively. From Station 8 in 1994, one individual of *N. siquijorensis* (2 × 10 min hauls), one individual of *N. siquijorensis* (2 × 20 min hauls) and one individual each of *N. siquijorensis*, *Murex trapa* and *Lataxiena fimbriata* (2 × 20 min hauls) were obtained. From Station 17 in 1994, two individuals of *Murex trapa* and one individual each of *Bursa rana* and *M. aduncospinosus* (2 × 20 min hauls) and one individual each of *Calyptraea extinctorum*, *Distorsio reticulata*, *M. trapa* and *Bursa rana* (2 × 20 min hauls) were obtained. From Station 45 in 1994, eight individuals of *N. siquijorensis*, one of *M. trapa*, one of *Funa jeffreysii*, two of *Bursa rana* and two of *F. spectrum* (2 × 20 min hauls) and one *Polinices melanostomus*, one *Distorsio reticulata*, eight *N. siquijorensis* and three *Bursa rana* (2 × 20 min hauls) were obtained.

Table 1 summarizes all 1992 and 1994 data for Stations 3, 9, 4, 8, 17 and 45 and concludes that from only Stations 8, 17 and 45 in 1992, 147 individuals of 33 species of gastropods were obtained. In 1994 from the same three stations but using repeat, paired, 20 min hauls, 40 individuals of 11 species were obtained. That is, there was a 73% and 67% decrease in species numbers and individual abundance, respectively, but that this estimate had been obtained by a doubling in trawling effort between the two sampling years. Truer comparisons are given by the differences obtained between 1992 and 1994 for Stations 4 and 8 when during the latter sampling date only one individual was obtained from each station as compared to 14 individuals of 9 species (Station 4) and 21 individuals of 14 species (Station 8) during the former sampling date for the same trawling effort, i.e. 2 × 10 min hauls.

Bivalvia (Table 2)

At Station 3 in 1992, three individuals of three species were obtained from two 10 min hauls. From the same station in 1994, two individuals of two species were obtained. From Station 9 in both 1992 and 1994, no bivalves were obtained. At Station 4 in 1992, seven individuals of three species, i.e. *Minnivola pyxidatus* (5), *Anomia chinensis* (1) and *Paphia gallus* (1) were obtained. From the same station in 1994, three individuals of two species, i.e. *Mactrinula reevesii* (2) and *Tellina pallidula* (1) were obtained.

At Stations 8, 17 and 45 in 1992, 16, 10 and 10 species, respectively, and 50, 69 and 48 individuals, again respectively, were obtained. At Station 8 in 1992, *Pinctada martensii* was the dominant species (15 individuals). From Station 8 in 1994, one individual of *Placamen calophylla* (2 × 10 min hauls), seven individuals of *Placamen calophylla* (4), *Paphia undulata* (2) and *Mactrinula reevesii* (1; 2 × 20 min hauls) and twelve individuals of eight species of which *Veremolpa micra* was the most abundant (4), all other species being represented by either two (*Minnivola pyxidatus*) or one individual (2 × 20 min hauls), were obtained. From Station 17 in 1994, six individuals of *Placamen calophylla* and one individual each of *Anadara ferruginea*, *Paphia undulata* and *Tellina pallidula* (2 × 20 min hauls) and six individuals of *Minnivola pyxidatus* and nine individuals of *Veremolpa micra* (2 × 20 min hauls) were obtained. From Station 45 in 1994, one individual each of *Placamen calophylla* and *Corbula crassa* (2 × 20 min hauls) and one individual of *Placamen calophylla* (2 × 20 min hauls) were obtained.

Table 2 summarizes all the 1992 and 1994 data for Stations 3, 9, 4, 8, 17 and 45 and shows that from Stations 8, 17 and 45 alone in 1992 were obtained 167 individuals of 24 species of bivalves. In 1994, from the same three stations but using repeat, paired, 20 min trawls were obtained 49 individuals of 11 species. That is, there was a 70% decrease in the numbers of individuals obtained and a 54% decrease in species numbers but that this estimate had been obtained by a doubling in trawling effort between the two sampling years. Truer comparisons are given between 1992 and 1994 for Stations 4 and 8 when during the latter sampling date only three individuals of two species and one individual of one species were obtained, respectively, as compared with seven individuals of three species and 50 individuals of 16 species, again respectively, for the same trawling effort (2 × 10 min) in 1992.

Pre- and Post-Dredging Molluscan Communities

Gastropoda

Taylor (1994) produced a table of the ranked abundance of all species of gastropods obtained from all 50 stations trawled in the southern waters of Hong Kong in April 1992. Table 3 has been constructed for the gastropods obtained from that longer data set but pertaining only to Stations 4, 8, 17 and 45. Specific attention is drawn to the first four important species identified by Taylor (1994; Tables 3 and 4) and in this study for the four stations sampled. In 1992 and 1994, the same four species were dominant, i.e. *N. siquijorensis*, *B. rana*, *Murex trapa* and *Distorsio reticulata*. Both in 1992 and 1994, the same four species were followed by suites of, mostly, neogastropod predators. Taylor (1994) identified a total of 69 species. This study only identified 11 species and it is clear that other than the top ranked four, no specific comparisons with the 1992 data of Taylor (1994) are possible (because of the restricted nature of the 1994 survey), except that the majority of such predators were largely absent in 1994. For example, Taylor (1994) collected representatives of 28 families, this study only nine. Taylor (1994) identified 11 species of the exclusively polychaete feeding Turridae, this study only seven. Taylor (1994) collected eight species of Muricidae and six species of Nassariidae, this study only three and three, respectively. Between 1992 and 1994, therefore, the soft subtidal gastropod epibenthos of the southern waters of Hong Kong within 2 km of dredged sites had been reduced not only in terms of species richness but also diversity at the species, generic and family levels. Particularly important is that, just as with Tolo Harbour (Taylor & Shin, 1990; Taylor, 1992), perturbation had removed most of the specialist predators from the community. Whether this is because of the indirect impacts of dredging, probably sediment plumes, or trawling with resuspension of silt and direct damage, or because of the simultaneous loss of the favoured prey is unknown. It can also be seen from Table 3, however, that the same four dominant species in 1992 have survived the indirect impacts of dredging and are still dominant, albeit less numerous.

Table 4 examines the known diets of the eleven commonest gastropods in the southern waters of Hong Kong, data on which are summarized in Taylor (1982, 1994) and supplemented by other specific references below. *Nassarius siquijorensis* is a scavenger (Liu & Morton, 1994). Nothing is know of *B. rana* other than that reported upon by Taylor from stomach contents analyses. Species of *Murex* reportedly feed on bivalves (Coleman, 1975). *Murex trapa* also probably feeds on carrion, based on an analysis of stomach contents (Table 4). *Distorsio reticulata* feeds exclusively upon chaetopterid polychaetes (Taylor, 1994). The three turrids, *Funa jeffreysii*, *Cheungbeia robusta* and *Gemmula deshayesi* feed an polychaetes (Taylor, 1994). Nothing is known about the diet of the muricid *Lataxiena fimbriata*. *Rapana bezoar* feeds on bivalves (Morton, 1994). *Nassarius livescens* is probably a scavenger, as is *Babylonia lutosa* (Morton, 1990a).

This study concludes that of the 11 top-ranked species of Gastropoda in the southern waters of Hong Kong in 1992, five of them are known to consume carrion. Three of the dominant four in 1992, i.e. *N. siquijorensis*, *B. rana* and *M. trapa* were still dominant in 1994 and I believe that they are, at least, opportunistic scavengers. It is thus here contended, as argued earlier (Morton,

TABLE 1

The species and numbers of individuals of Gastropoda recovered from either 10 or 20 min pair trawls at stations 3, 4, 8, 9, 17 and 45 in the southern waters of Hong Kong in 1992 and 1994.

	Station 3 (10 min) 1992	Station 3 (10 min) 1994	Station 9 (10 min) 1992	Station 9 (20 min) 1994	Station 4 (10 min) 1992	Station 4 (10 min) 1994	Station 8 (10 min) 1992	Station 8/1 (20 min) 1994	Station 8/2 (20 min) 1994	Station 8/3 (20 min) 1994	Station 17 (10 min) 1992	Station 17/1 (20 min) 1994	Station 17/2 (20 min) 1994	Station 45 (10 min) 1992	Station 45/1 (20 min) 1994	Station 45/2 (20 min) 1994
Calyptraea extinctorum	1												1	2		
Polinices melanostomus	1													1		1
Distorsio reticulata	2				2		3				4		1	5		1
Babylonia lutosa	2													3		
Nassarius siquijorensis	4	7		1	1			1	1	1	3			29	8	8
Turricula nelliae spurius	1													2		
Murex trapa		1					1			1	1	2	1	19	1	
Turritella bacillium		1														
Latexiena fimbriata		1					4			1	3					
Funa latisinuata		1												1		
Funa jeffreysii		1			1						3			5	1	
Bursa rana					2		1				4	1	1	16	2	3
Babylonia areolata					1						1					
Nassaria acuminata					1						1			1		
Scalptia costifera					1											
Gemmula deshayesi				1	1						4			4		
Cheungbeia robusta					4						1			1		
Conus sulcatus						1										
Scutus unguis							1									
Diodora sp.							2									
Phenacovolva birostris							2									
Rapana bezoar							1				1			1		
Ergalatax contracta							1									
Chicoreus asianus							1									
Chicoreus brunneus							1									
Cantharus cecillii							1									
Nassarius livescens							1				2					
Hemifusus ternatana							1									
Siphopatella walshi											1					
Sinum haliotoideum											1			1		
Architectonica perspectiva											1					
Pleurobranchaea brockii											1					
Euselenops luniceps											1					
Murex aduncospinosus												1				
Strombus vittatus														1		
Turricula javana														1		
Funa spectrum															2	
Number of species	6	6	0	2	9	1	14	1	1	3	17	3	4	17	5	4
Number of individuals	11	12	0	2	14	1	21	1	1	3	33	4	4	93	14	13
Total no. of species (Stations 8, 17 & 45)	1992 33	1994 11														

TABLE 2

The species and numbers of individuals of Bivalvia recovered from either 10 or 20 min pair trawls at stations 3, 4, 8, 9 17 and 45 in the southern waters off Hong Kong in 1992 and 1994.

	Station 3 (10 min) 1992	Station 3 (10 min) 1994	Station 9 (10 min) 1992	Station 9 (20 min) 1994	Station 4 (10 min) 1992	Station 4 (10 min) 1994	Station 8 (10 min) 1992	Station 8/1 (10 min) 1994	Station 8/2 (20 min) 1994	Station 8/3 (20 min) 1994	Station 17 (10 min) 1992	Station 17/1 (20 min) 1994	Station 17/2 (20 min) 1994	Station 45 (10 min) 1992	Station 45/1 (20 min) 1994	Station 45/2 (20 min) 1994
Nuculana mauritiana							1									
Anadara ferruginea		1					1					1		3		
Scapharca disparilis											1					
Trisidos semitorta											1					
Barbatia							3									
Striarca tenebrica							1									
Pteria brevialata							5									
Malleus albus							2									
Pinctada martensii							15			1	3			2		
Ostrea pestigris	1															
Hyotissa sinensis							3									
Minnivola pyxidatus					5		7			2	19		6	4		
Amusium pleuronectes							1									
Anomia chinensis					1		2									
Musculus sp.							3									
Galeomma takii							3									
Bucardium fimbriatum							1				3			1		
Vepricardium sinense											3			3		
Placamen calophylla								1	4		11	6		18	1	2
Dosinia nanus										1	25			10		
Paphia gallus					1		1				1					
Paphia undulata							1		2	1		1				
Circe scripta														1		
Tellina vestalis	1													1		
Corbula crassa	1									1	2			5	1	
Dosinorbis exasperata		1														
Mactrinula reevesii						1			1							
Tellina pallidula						2						1	9			
Veremolpa scabra										4						
Paphia euglypta										1						
Callocardia hungerfordi										1						
Number of species	3	2	0	0	3	2	16	1	3	8	10	4	2	10	2	1
Number of individuals	3	2	0	0	7	3	50	1	7	12	69	9	15	48	2	2
Total no. of species (Stations 8, 17 & 45)	1992	1994														
	24	11														

TABLE 3

The most numerous species of Gastropoda at Stations 4, 8, 17 and 45 in the southern waters of Hong Kong found during the trawling surveys of 1992 (prior to dredging) and 1994 (post dredging).

1992	1994
Nassarius siquijorensis (33)	*Nassarius siquijorensis* (19)
Bursa rana (23)	*Bursa rana* (7)
Murex trapa (21)	*Murex trapa* (5)
Distorsio reticulata (14)	*Distorsio reticulata* (2)
Funa jeffreysii (9)	*Funa spectrum* (2)
Gemmula deshayesi (9)	
Lataxiena fimbriata (7)	
Cheungbeia robusta (6)	
Rapana bezoar (3)	
Nassarius livescens (3)	
Babylonia lutosa (3)	

1995b), that this now badly perturbated habitat is dominated by scavenging gastropods. Interestingly, however, it was also in 1992, prior to dredging.

Bivalvia

Nothing is published on the bivalve communities of the southern waters of Hong Kong, although unpublished data are available and this study abstracts some of that information obtained during the 1992 survey for Stations 4, 8, 17 and 45 and which are within 2 km of dredging sites (Table 5).

In 1992, *Minnivola pyxidatus*, a swimming pectinid scallop and *Dosinia nanus* dominated the bivalve epi- and endobenthos, respectively. *Placamen calophylla* and *Corbula crassa* were also dominant and it is significant that both species have remarkable shell adaptations that make them virtually unassailable as prey for predatory gastropods (Ansell & Morton, 1985; Morton, 1990b). *Pinctada martensii* byssally attaches to any hard substratum while *Pteria brevialata* is typically associated with gorgonians (Morton, 1995c), but can also attach to other hard substrata. *Vepricardium sinense* (Cardiidae) and *Anadara ferruginea* (Arcidae) are shallow burrowers.

In 1994, *Minnivola pyxidatus* was still among the dominant six bivalves, possibly because of its swimming abilities which enable it to escape predators. *Placamen calophylla* and *Corbula crassa*, also with known anti-predator qualities, i.e. thick shells, which would also protect them from trawler damage, have also survived. *Paphia undulata* (Veneridae) and *Mactrinula reevesi*

TABLE 5

The most numerous species of Bivalvia at Stations 4, 8, 17 and 45 in the southern waters of Hong Kong found during the trawling surveys of 1992 (prior to dredging) and 1994 (post dredging).

1992	1994
Minnivola pyxidatus (35)	*Placamen calophylla* (14)
Dosinia nanus (35)	*Veremolpa micra* (13)
Placamen calophylla (29)	*Minnivola pyxidatus* (8)
Pinctada martensii (20)	*Paphia undulata* (4)
Corbula crassa (7)	*Corbula crassa* (2)
Vepricadium sinense (5)	*Mactrinula reevesii* (2)
Pteria brevialata (5)	
Anadara ferruginea (5)	

(Mactridae) were all collected from stations other than 4, 8, 17 and 45 in 1992 and their occurrence in 1994 is either a case of chance sampling by the trawls or of recolonization of a perturbated habitat. *Veremolpa micra* (Veneridae) was not recorded from any station in 1992 and is now rare elsewhere in Hong Kong. In the year prior to 1977, however, *Veremolpa micra* was the dominant bivalve of the clean subtidal sands of Tolo Harbour and Channel, Hong Kong (Horikoshi & Thompson, 1980) and was one of the first species to disappear when the harbour became polluted (Shin, 1985; Morton, 1985). Is it, therefore, possible that *V. micra* has colonized the possibly cleaner, reworked, sediments of the southern waters of Hong Kong? This could also be the case with the few individuals (all of shell lengths <10 mm and, therefore, juveniles) of *Paphia undulata* recovered from the 1994 stations (which it was not recorded from in 1992), because this species also naturally inhabits cleaner sediments and also disappeared quickly from Tolo Harbour when pollution impacts began to be recorded there (Horikoshi & Thompson, 1980; Shin, 1985; Morton, 1985).

Discussion

The impacts of dredging (and trawling) upon benthic subtidal communities are extremely difficult to assess because of the need for repeated sampling of the originally perturbated areas. Although the use of grab sampling of dredged ('treatment') and non-dredged ('reference') sites has been used with success (Van Dolah *et al.*, 1991; Kenny & Rees, 1994) to obtain information on the impacts and recovery rates of the

TABLE 4

Diets of the most abundant species of subtidal gastropods in the southern waters of Hong Kong (after Taylor, 1982, 1994).

Species	Food items
Nassarius siquijorensis	Unidentified tissue, fish bones and scales, polychaetes
Bursa rana	Sediment, ophiuroids, fish scales and bones, polychaetes
Murex trapa	Unidentified tissue (probably molluscan), crustacean fragments, fish scales, polychaetes
Distorsio reticulata	Chaetopterid polychaetes
Funa jeffreysii	Polychaetes, nemerteans
Gemmula deshayesi	Polychaetes
Lataxiena fimbriata	?
Cheungbeia robusta	Polychaetes
Rapana bezoar	Bivalves
Nassarius livescens	Carrion
Babylonia lutosa	Fish bones and scales, crustacean fragments, unidentified tissues polychaetaes

macrobenthos, repeat trawling would introduce the confounding effect of repeating a bioturbation. Suction dredging at the level recently undertaken in Hong Kong must have an adverse, both direct and indirect, effect on the benthic community. Hodgson (1994) has shown how silt plumes from the suction dredgers at work in Hong Kong have killed shallow subtidal corals, notably the plateforming *Acropora candelabrum* although the same author also noted that winter storm waves had removed much of the smothering silt, depositing it back offshore and that there was thus the potential for recovery.

The absence of an accessible research vessel in Hong Kong, however, has meant that no studies on either the direct or indirect impacts of such widescale dredging, or, for that matter, trawling, have been undertaken. This study, as explained, was a reconnaissance of a few stations examined in 1992 as part of a much wider survey of the waters of Hong Kong prior to their being dredged. It is unfortunate that more taxa cannot be reported upon, but the Mollusca at least have one positive advantage as monitors which is that they have a greater potential to survive trawl sampling and are, thus, easily distinguishable dead from alive. Sampling of control sites, i.e. Stations 3 and 9, first surveyed in 1992, confirmed that the gear was operating now as then and that similar species and individual numbers were obtained at both times. The re-survey of stations within <2 km of the dredging sites documents an approximate two thirds decline in both species richness and individual numbers of both gastropods and bivalves and which in view of the scale of the dredging can only be accounted for in terms of secondary impacts. That is, between April 1992 and October 1994, no other perturbation occurred in the southern waters of Hong Kong which are locally regarded as our cleanest (Environmental Protection Department, 1994). The benthos of these waters does not experience widescale seasonal fluctuations in species abundance and community change (Shin, 1989; Ong Che & Morton, 1991). Local fishermen have argued that dredging in these waters has destroyed the fishing but there is no evidence in support of such a claim. This study is, therefore, the only information available and in the absence of any other evidence that there have been other perturbations in the area sampled, it is concluded that the impacts documented here upon the benthic molluscan community are the secondary result of dredging. Specifically, the sediment plumes that overflow from the suction dredgers as they work (Fig. 2). It is, however, possible that trawling has exacerbated the problem in that turbulence created in the wake of trawl doors can generate large and highly turbid clouds of suspended sediment (Churchill, 1992). Trawlers operating close to dredgers producing large clouds of sediment would further disturb an already impacted environment. Selby & Evans (in prep.) argue that sea bed disruption in the southern waters of Hong Kong is caused by trawling and localized dredged sediment replacement. In the absence of any continuous monitoring of the impacts of the dredging fleet, it is unknown if that which is reported upon here represents the situation prevailing at the termination of dredging which occurred towards the end of 1994 or represents an initial step towards recovery. The more comprehensive survey conducted in April 1995 may help elucidate this.

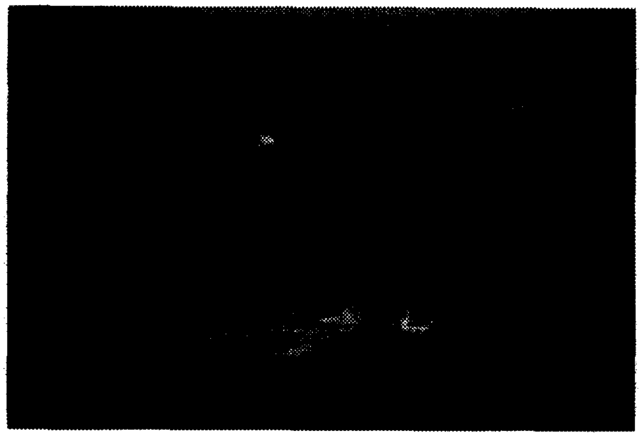

Fig. 2 Suction dredgers operating in the southern waters of Hong Kong in 1993. (Photo: M. Pitts.)

By analysing trawl samples collected over many years, but typically at three year intervals, from one of Hong Kong's progressively most polluted bodies of water, i.e. Tolo Harbour (Morton, 1985), a local *cause celebre* (Morton, 1988; Taylor & Shin, 1990; Taylor, 1992; Morton, 1995a) have demonstrated progressive, long-term, changes in the macrobenthic fauna, particularly the Mollusca. Essentially, two of the three axioms of a community's response to a stressor (Gray, 1989) were held to be true, i.e. a reduction in diversity and a retrogression to dominance by opportunist species. The third, i.e. a reduction in the mean size of the dominating species is possibly also true, in view of the fact that, on the whole, the replacement of large specialized predatory gastropods is by smaller 'generalists' (Taylor, 1992). The results of this survey also support the axioms of Gray's hypothesis, but with one important qualification. The top four dominant gastropods present in 1994 had not been replaced by other species present in 1992, indeed they were the same, albeit in reduced numbers. It has been argued (Britton & Morton, 1994; Morton, 1995a) that with regard to Hong Kong's now dominant epibenthic gastropods, the term scavenger should apply since such animals, though possibly more generalist predators are, naturally, capable of opportunistically exploiting the ephemeral resource of carrion that trawling and pollution must engender. Kaiser & Spencer (1994) similarly showed for the epibenthos of the Irish Sea, that trawling increases the abundance of scavengers. Britton & Morton (1994) define marine carrion as 'freshly dead metazoan soft tissue at the microcarrion size scale ($\sim > 0.01$ kg) or greater that, because it has not achieved an advanced stage of saprophytic digestion, attracts a variety of consumers which derive significant sustenance from it'. The important word in this definition is 'freshly' dead because it suggests that a community of opportunistic scavengers can only be maintained if there is a continual supply of carrion. Although settling sediment plumes might, therefore, suffocate the benthic fauna, trawling would effect its continued resuspension and, moreover, keep on providing carrion through injury and death.

Nassarius siquijorensis (Liu & Morton, 1994) is a scavenger. There is also some evidence to suggest that although *B. rana* and *M. trapa* may feed naturally on ophiuroids and bivalves, respectively, they also exploit carrion (Table 4). The fact, therefore, that such animals were dominant in the southern waters of Hong Kong in 1994, but also in 1992, suggests that the sea bed was already perturbated even then, probably from intense trawling. Essentially, therefore, this study supports an earlier contention (Morton, 1995a) that virtually all, if not all, of Hong Kong's 1800 km^2 of sea bed is perturbated: from *1.* pollution; *2.* trawling; and now *3.* direct and indirect (sediment plumes) dredging impacts, and that the epibenthic community is dominated by scavengers of the so engendered carrion. That *Babylonia lutosa*, another known scavenger (Morton, 1990a), is not high on the list of dominant species is because it is a fishery resource, like *Buccinum undatum* in the Atlantic.

With regard to the Bivalvia, *Placamen calophylla, Corbula crassa* and *Minnivola pyxidatus* have known anti-predation devices, i.e. the shell in terms of the former two (Ansell & Morton, 1985; Morton, 1990b) and an ability to swim in the case of the latter (Morton, 1994). This would enable it to escape from settling sediment (Morton, 1996). *Corbula crassa*, at least, is also known to be tolerant of sea-bed anoxia (Morton, 1990b) while the scallop, *M. pyxidatus*, is epibenthic. Either a tolerance of perturbations on the part of these species or, more likely, a thick shell highly resistant to trawler damage, and evolved as an anti-predation adaptation against, notably, gastropod predators has allowed them to survive in Hong Kong's southern waters and now, because they are not a fishery resource, to dominate, albeit in reduced numbers, the bivalve fauna of the sea-bed. Rumohr & Krost (1991) record that thick-shell bivalves such as *Astarte borealis* and *Corbula gibba* are resistant to trawl damage, as are species of *Spisula, Mactra, Venus* and *Cardium* (de Groot, 1984). Although silt (and trawling) has killed most of the earlier recorded members of the bivalve endobenthos, *Veremolpa micra* and *Paphia undulata*, known to be restricted to clean sands (Horikoshi & Thompson, 1980) and among the first to disappear with sea-bed pollution, have been recorded from the new sea-bed created by the settlement of silt.

It is, finally, significant that the reductions in gastropod species richness and abundance match those which have also occurred with the Bivalvia, i.e, approximately by two thirds, confirming the scale of sedimentation impacts close to the dredge sites.

I am especially grateful to Dr J. D. Taylor, the Natural History Museum, London, for the provision of unpublished data on the bivalves collected from the southern waters of Hong Kong during the 1992 survey and for encourging me to re-assemble and re-analyse this and the 1992 gastropod data for comparison with the 1994 survey. I also thank other colleagues, particularly Y. S. Leung, S. F. Leung and P. H. Scott (1992) and Y. S. Leung and K. F. Leung (1994), for their hard work on the trawl surveys.

Ansell, A. D. & Morton, B. (1985). Aspects of naticid predation in Hong Kong with special reference to the defensive adaptations of *Bassina (Callanaitis) calophylla*. In *The Malacofauna of Hong Kong and Southern China II* (B. Morton & D. Dudgeon, eds), pp. 635–660. Proceedings of the Second International Workshop on the Malacofauna of Hong Kong and southern China, Hong Kong 1983. Hong Kong, Hong Kong University Press.

Bergman, M. J. N. & Hup, M. (1992). Direct effects of beam trawling on macrofauna in a sandy sediment in the southern North Sea. *ICES J. Mar. Sci.* **49**, 5–11.

Britton, J. C. & Morton, B. (1994). Marine carrion and scavengers. *Oceanog. Mar. Biol. Ann. Rev.* **32**, 369–434.

Brylinsky, M., Gibson, J. & Gordon, D. C. Jr. (1994). Impacts of Flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. *Canad. J. Fish. Aquat. Sci.* **51**, 650–651.

Churchill, J. H. (1992). The effect of commercial trawling on sediment resuspension and transport over the Middle Atlantic Bight continental shelf. *Cont. Shelf Res.* **9**, 841–864.

Coleman, N. (1975). *What Shell is that?* Paul Hamlyn, Sydney, Australia.

Van Dolah, R. F., Webdt, P. H. & Levisen, M. V. (1991). A study of the effects of shrimp trawling on benthic communities in two South Carolina Sounds. *Fish. Res.* **12**, 139–156.

de Groot, S. J. (1984). The impact of bottom trawling on benthic fauna in the North Sea. *Ocean Management* **9**, 177–190.

Dutton, C. (1987). Marine fill investigation for site formation at Tin Shui Wai in Hong Kong. *Hong Kong Engineer* **8**, 29–38.

Environmental Protection Department (1994). *Marine water quality in Hong Kong*. Monitoring Section, Water Services Group, Environmental Protection Department, Hong Kong Government.

Gray, J. S. (1989). Effects of environmental stress on species rich assemblages. *Biol. J. Linnean Soc. Lond.* **37**, 19–32.

Hall, S. J. (1994). Physical disturbance and marine benthic communities: life in unconsolidated sediments. *Oceanog. Mar. Biol. Ann. Rev.* **32**, 179–239.

Hodgson, G. (1994). The environmental impact of marine dredging in Hong Kong. *Coast. Manag. Trop. Asia* **2**, 1–8.

Horikoshi, M. & Thompson, G. B. (1980). Distribution of subtidal molluscs collected by trawling in Tolo Harbour and Tolo Channel, Hong Kong, with special reference to habitat segregation in two venerid bivalves. In. *The Malacofauna of Hong Kong and Southern China* (B. Morton, ed.), pp. 149–162. Proceedings of the First International Workshop on the Malacofauna of Hong Kong and southern China, Hong Kong, 1977. Hong Kong University Press.

Jones, J. B. (1992). Enviromental impact of trawling on the sea bed: a review. *N. Z. J. Mar. Freshwat. Res.* **26**, 59-67.

Kaiser, M. J. & Spencer, B. E. (1994). Estimates of scavenging behaviour in recently trawled areas. In *Environmental Impact of Bottom Gears on Benthic Fauna in relation to Natural Resources Management and Protection of the North Sea* (S. J. de Groot & H. J. Lindeboom, eds), pp. 87–94 NI02- RAPPORT 1994-11: RIVO — DLO REPORT C026/94.

Kenny, A. J. & Rees, H. L. (1994). The effects of marine gravel extraction on the macrobenthos: early post-dredging recolonization. *Mar. Pollut. Bull.* **28**, 442–447.

Leung, S. F. (1995). The species composition and distribution of penaeid prawns in the southern waters of Hong Kong. In *The Marine Biology of the South China Sea II.* (B. Morton, Xu Gongzhao, Zou Renlin, Pan Jinpei & Cai Guoxiong, eds), pp. 59–69. Proceedings of the Second International Conference on the Marine Biology of the South China Sea, Guangzhou, China, 1993. World Publishing Corporation, Beijing, China.

Liu, J. H. & Morton, B. (1994). Food choice, detection, time spent feeding, consumption and the effects of starvation on a subtidal scavenger, *Nassarius siquijorensis* (Gastropoda: Nassariidae), from Hong Kong. In *The Malacofauna of Hong Kong and Southern China III* (B. Morton, ed.), pp. 357–375. Proceedings of The Third International Workshop on the Malacofauna of Hong Kong southern China, Hong Kong, 1992. Hong Kong University Press.

Messieh, S. N., Rowell, T. W., Peer, D. L. & Cranford, P. J. (1991). The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf sea-bed. *Cont. Shelf Res.* **11**, 1237–1263.

Morton, B. (1985). Marine pollution induced enviromental changes in Hong Kong—the Tolo Harbour case study. In *Pollution in the Urban Environment* (M. W. H. Chan, R. W. M. Hoare, P. R. Holmes, R. J. S. Law & S. B. Reed, eds), pp. 548–558. Elsevier Applied Science Publishers.

Morton, B. (1988). Hong Kong's first marine ecological disaster. *Mar. Pollut. Bull.* **19**, 299–300.

Morton, B. (1990a). The physiology and feeding behaviour of two marine scavenging gastropods in Hong Kong: the subtidal *Babylonia lutosa* (Lamarck) and the intertidal *Nassarius festivus* (Powys). *J. Mollusc. Stud.* **56**, 275–288.

Morton, B. (1990b). The functional morphology of *Corbula crassa* (Bivalvia: Corbulidae) with special reference to shell structure and formation. In *The Marine Flora and Fauna of Hong Kong and Southern China II* (B. Morton, ed.), pp. 1055–1073. Proceedings of the Second International marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and southern China, Hong Kong 1986. Hong Kong University Press.

Morton, B. (1992). Hong Kong's new airport. *Mar. Pollut. Bull.* **24**, 174–175.

Morton, B. (1994). Prey preference and method of attack by *Rapana bezoar* (Gastropoda: Muricidae) from Hong Kong. In *The Malacofauna of Hong Kong and Southern China III* (B. Morton, ed.), pp. 309–325. Proceedings of the Third International Workshop on the Malacofauna of Hong Kong and southern China, Hong Kong, 1992. Hong Kong University Press.

Morton, B. (1995a). Hong Kong's corals. *Mar. Pollut. Bull.* **30**, 230–231.

Morton, B. (1995b). Perturbated soft intertidal and subtidal marine communities in Hong Kong: the significance of scavenging gastropods. In *The Marine Biology of the South China Sea II* (B. Morton, Xu Gongzhao, Zou Renlin, Pan Jinpei & Cai Guoxiong, eds), pp. 1–15. Proceedings of the Second International Conference on the Marine Biology of the South China Sea, Guangzhou, China, 1993. World Publishing Corporation, Beijing, China.

Morton, B. (1995c). The biology and functional morphology of *Pteria brevialata* (Bivalvia: Pterioidea), epizoic on gorgonians in Hong Kong. *J. Zool. Lond.* **236**, 223–241.

Morton, B. (1996). The biology and functional morphology of *Minnivola pyxidatus* (Bivalvia: Pectinoidea). *J. Zool. Lond.* **240**, (In press).

Ong Che, R. G. & Morton, B. (1991). Spatial and temporal variations in the subtidal macrobenthic community of Tai Tam Bay, Hong Kong. *Asian Mar. Biol.* **8**, 193–216.

Poiner, I. R. & Kennedy, R. (1984). Complex patterns of change in the macrobenthos of a large sandbank following dredging I. Community analysis. *Mar. Biol.* **78**, 335–352.

Rumohr, H. & Krost, P. (1991). Experimental evidence of damage to benthos by bottom trawling with special reference to *Arctica islandica*. *Meeresforsch* **33**, 340–345.

Selby, I. & Evans, N. C. (in prep). Origins of mud clasts and suspensions on the sea bed in Hong Kong.

Shin, P. K. S. (1985). A trawl survey of the subtidal Mollusca of Tolo Harbour and Mirs Bay, Hong Kong. In *The Malacofauna of Hong Kong and Southern China II* (B. Morton & D. Dudgeon, eds), pp. 439–447. Proceedings of the Second International Workshop on the Malacofauna of Hong Kong and southern China, Hong Kong, 1983. Hong Kong University Press.

Shin, P. K. S. (1989). Natural disturbance of benthic in fauna in the offshore waters of Hong Kong. *Asian Mar. Biol.* **6**, 193–207.

Shin, P. K. S. & Thompson, G. B. (1982). Spatial distribution of the infaunal benthos of Hong Kong. *Mar. Ecol. Prog. Ser.* **10**, 37–47.

Taylor, J. D. (1982). Diets of sublittoral predatory gastropods of Hong Kong In *The Marine Flora and Fauna of Hong Kong and Southern China* (B. Morton & C. K. Tseng, eds), pp. 907–920. Proceedings of the First International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and southern China, Hong Kong, 1980. Hong Kong University Press.

Taylor, J. D. (1992). Long-term changes in the gastropod fauna of Tolo Channel and Mirs Bay, Hong Kong: the 1989 survey. In *The Marine Flora and Fauna of Hong Kong and Southern China III* (B. Morton, ed.), pp. 557–573. Proceedings of the Fourth International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and southern China, Hong Kong, 1989. Hong Kong University Press.

Taylor, J. D. (1994). Sublittoral benthic gastropods from the southern waters of Hong Kong. In. *The Malacofauna of Hong Kong and Southern China, III* (B. Morton, ed.), pp. 479–495. Proceedings of the Third International Workshop on the Malacofauna of Hong Kong and southern China, Hong Kong, 1992. Hong Kong University Press.

Taylor, J. D. & Shin, P. K. S. (1990). Trawl surveys of sublittoral gastropods in Tolo channel and Mirs Bay; a record of change from 1976–1986. In *The Marine Flora and Fauna of Hong Kong and Southern China II* (B. Morton, ed.), pp. 857–881. Proceedings of the Second International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and southern China, Hong Kong, 1986. Hong Kong University Press.

Wu, R. S. S. (1982). Periodic defaunation and recovery in a subtropical epibenthic community in relation to organic pollution. *J. Exp. Mar. Biol. Ecol.* **64**, 253–269.