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Spatial Simulations of Hong Kong's Marine Ecosystem:
Ecological and Economic Forecasting of Marine Protected Areas with Human-Made Reefs

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Spatial Simulations of Hong Kong's Marine Ecosystem: Forecasting with MPAs and Human-Made Reefs

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Spatial Simulations of Hong Kong's Marine Ecosystem

Ecological and Economic Forecasting of Marine Protected Areas with Artificial Reefs

Table Of Contents

Annexes

Director's Foreword

Hong Kong Now and Then

Wedding Fish Procession (detail), oil painting 1815, artist unknown.
Hong Kong Museum of Art AH1964.002, with permission.

The fish in the picture were made of paper. Of realistic size for the time and carried in procession, similarly large table fish were consumed in traditional coastal wedding feasts. Such large fish, common even in the 1940s (Herklots 1940), are locally extinct in Hong Kong today (Cheung 2001), encouraging their import from throughout Southeast Asia.

This report forms part of a brave attempt to turn the tide of massive depletion of marine resources in the South China Sea, of which Hong Kong is a part (Buchary *et al.* 2002). Central to this plan is the deployment of protected human-made reefs. Although the implementation has been criticised (Sadovy 2002), the intention of the plan is to set up protected areas and replace lost reef habitat (Wilson and Cook 1998).

Previous non-spatial ecosystem modelling showed large benefits to almost all fishery sectors provided that human-made reefs are protected from fishing (Pitcher *et al.* 2000; Pitcher and Seaman 2000). The present work improves on previous forecasting using fully spatial ecosystem simulations (Pitcher *et al.* 2002), and includes scenarios with large MPAs in the South China Sea. It derives from an on-going partnership of the Fisheries Centre with the Agriculture and Fisheries Department of the Hong Kong Special Administrative Area Government and ERM (Hong Kong) Ltd.

The Fisheries Centre Research Reports series publishes results of research work carried out, or workshops held, at the UBC Fisheries Centre. The series focusses on multidisciplinary problems in fisheries management, and aims to provide a synoptic overview of the foundations, themes and prospects of current research. Fisheries Centre Research Reports are distributed to appropriate workshop participants or project partners, and are recorded in the Aquatic Sciences and Fisheries Abstracts. A full list appears on the Fisheries Centre's Web site, www.fisheries.ubc.ca. Copies are available on request for a modest cost-recovery charge.

Tony J. Pitcher
Professor of Fisheries
Director, UBC Fisheries Centre

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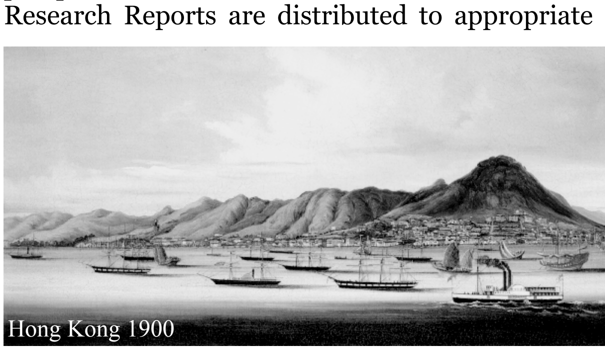


INTRODUCTION

T. J. Pitcher, E.A. Buchary, U.R. Sumaila and N. Haggan

BACKGROUND

The Hong Kong Agriculture, Fisheries and Conservation Department (AFCD) has initiated a $HK100 million Artificial Reef and Fishery Protected Area (AR/FPA) programme (Figure 1.1). The proposal builds on earlier initiatives to establish ARs in Hoi Ha Wan and Yat Chau Tong Marine Parks. The objective is to rebuild fish stocks by compensating for habitat loss and reducing fishing pressure. An extensive consultation process conducted by ERM-HK Ltd., under contract to AFCD, identified five priority deployment areas. The University of British Columbia Fisheries Centre (UBC-FC) advised on Phase I consultations with fishing communities and conducted extensive ecosystem (ECOPATH and ECOSIM) and bio-economic modelling to determine the effectiveness of different sizes of FPAs around AR complexes. The earlier results indicated that a potential for substantial gains in the value of Hong Kong fisheries resources.

This study is the first application of spatial (ECOSPACE) modelling to Hong Kong and adjacent PRC inshore waters and evaluates the effectiveness of different FPA configurations in the Tap Mun/Tolo Harbour and Outer Port Shelter FPAs shown below. The overall modelling also evaluates the benefits of recent AR/FPA initiatives in banning trawling at FPAs, Marine Parks and at the newly established Marine Exclusion Zone at Chek Lap Kok. Lastly, the study assesses the implication of a 2-month trawl moratorium in adjacent PRC inshore waters.

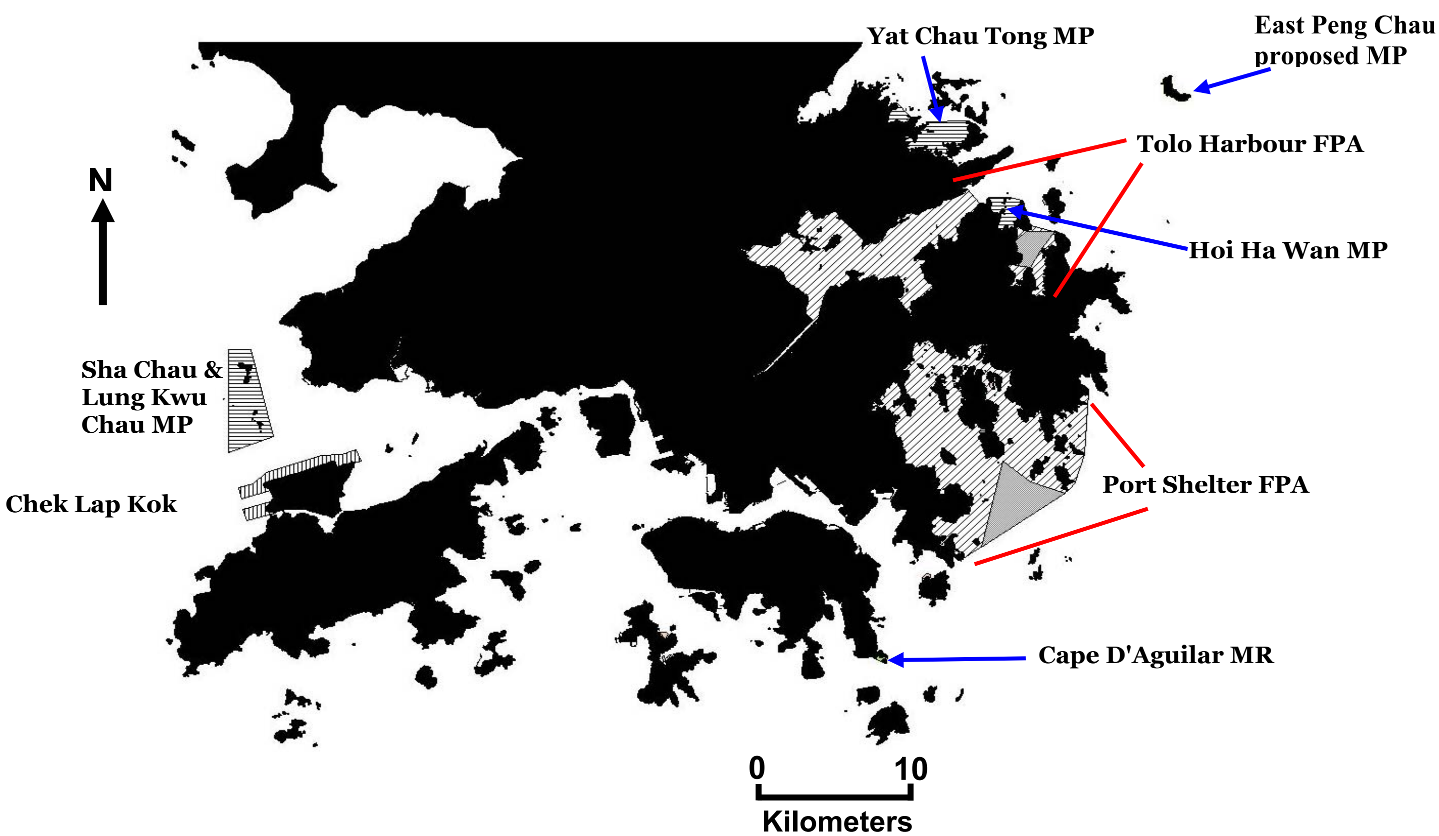


Figure 1.0 Priority areas for AR/FPA deployment. Horizontal hatched areas indicate marine parks (MP)/reserve (MR), diagonal hatched areas indicate FPA no-trawl area, vertical hatched area indicates Chek Lap Kok Marine Exclusion Zone (MEZ), and shaded areas indicate FPA no-take zones. See Table 5.1 for details of management area. Map courtesy of AFCD Hong Kong Special Administration Region (SAR).

STUDY OBJECTIVES

The objectives and terms of reference are as follows:

(a) Quantify the contribution of ARs plus Fisheries Protection Areas (FPAs) to Hong Kong fisheries resources; and

(b) Quantify the benefits of banning trawling in recently-established ARs/MPAs initiatives and more extensively throughout Hong Kong and adjacent PRC inshore waters.

Chapter 2. New Ecopath Model of Hong Kong marine ecosystem

E.A. Buchary, T.J. Pitcher, W.L. Cheung and T. Hutton

2.1 Defining and parameterizing the model

The model described is an improved and updated version of the ECOPATH model for Hong Kong marine ecosystem (Pitcher *et al.* 1998). The new version includes: reef association characteristics for demersal fish, 141 new fish species, modification of trophic relationship, new functional groups, revised landing data, and incorporation of discards. In the present model, Ecopath with Ecosim (EwE) version 4.0 (April 6, 2001 release) was used (see www.ecopath.org) which, among others, allow division of landing data into appropriate fleet and incorporation of discards information.

Model components, in general, were allocated into functional groups based on similarity in size, growth, mortality rates and diet (Christensen and Pauly 1992). Fish were allocated first by habitat preference, then by body size, and finally by reef-association attribute where applicable.

Size ranges for fish were set so that fish with an average or maximum body length of less than 30 cm, were considered to be ‘small’. Fish with an average or maximum body length between 30 to 50 cm were considered as ‘medium’; those that were greater than 50 cm were considered to be ‘large’. Sharks less than 100 cm were categorized as 'small sharks', while over 100 cm were categorized as 'large sharks'. Trophic ontogeny and other parameters related to age classes of fish populations in the ecosystem (Walters *et al.*, 1997) were represented by establishing juvenile and adult biomass pools in some functional groups (see Annex 1).

Reef association attributes were defined by taking into account the relationship of the organisms to reefs throughout their life history. This includes six life history and behavioral attributes, *i.e.*, home range, fidelity to reefs, spawning, nurseries, feeding and refuge (Pitcher *et al.* 2000). Reef association attributes are defined using the Reef Response Index (RRI) estimated by coral reef fish experts (Pitcher *et al.* 2000). Demersal fish with an RRI between 12 and 24 are considered to be "reef associated". Those that have an RRI less than 12 are allocated as "non-reef associated". In the case of new demersal fish species that may not necessarily have their RRI calculated, we used ecological and biological information provided in FishBase Online (Froese and Pauly 2001) to allocate them to appropriate functional groups. Fish assigned as "reef associated" by FishBase were given 24 points. Fish assigned as "non reef-associated" by FishBase were given a RRI score of zero.

The resulting model (Table 2.3) has 37 functional groups (Annex 1), comprised of: two primary producer groups, twelve invertebrate groups, one marine reptile group (turtles), fourteen fish groups, four elasmobranch groups, two seabirds groups, one marine mammal group and one detritus group. These groups are exploited by seven fishery sectors (Table 2.1 and 2.2) , namely, stern, hang, pair and shrimp trawlers, purse seiners, and two small-scale artisanal sectors identified as 'P4/7' vessels (i.e., vessels that are less than 5 m in length) and 'Miscellaneous', small boats that employ a wide range of lines, nets, traps and hook gears. In a trophic model such as the one that is constructed using EwE approach, it is predation that links together the different functional groups in an ecosystem and that characters the dynamics of the modelled ecosystem. Predator-prey relationship in the model is enumerated as diet composition fractions detailed in Table 2.4. Details of model inputs are documented in Annex 1.

2.2 Landing and discards database applied

Landing data entered in the previous Ecopath model of Hong Kong waters in 1990s (Pitcher *et al.*, 1998a) were revised (Table 2.1) based on the revision of catch estimates outlined in Chapter 3. Discard data (Table 2.2) that were previously left out, were derived using information from the AFCD Inshore 1982-1983 Survey (Chong 1984) and the newly revised catch estimates.

Landing and discard records for certain functional groups not officially documented in the statistics but reported as anecdotal accounts, *e.g.* sea turtles (McGilvray and Geermans, 1997, and Guang Dong Province Natural Reserve 1997; as reported by R. Kwok, AFCD, *pers. comm.*, May 26, 2000) and dolphins (Jefferson and Leatherwood 1997; and Jefferson 2000; as reported by S. Hung, Ocean Park Conservation Foundation, *pers. comm.*, June 28, 2000) caught in the nets, were also taken into account.

Table 2.1 Landing input data (t/km²/year) in the new Ecopath model of Hong Kong marine ecosystem in the 1990s. Landing data were taken from ERM Interview Program (ERM 1998a; Pitcher *et al.*, 1998) and revised based on methods described in Chapter 3.

No.	Group name	ST	SHT	PT	PS	P4/7	Misc.	HT	Total
1	Benthic Producers	0	0	0	0	0	0	0	0
2	Phytoplankton	0	0	0	0	0	0	0	0
3	Corals	0	0	0.01	0	0	0	0	0.01
4	Zooplankton	0	0.01938	0	0.02836	0	0.11076	0	0.1585
5	Sea Turtles	0	0.000012	0	0	0	0	0	0.00001
6	Jellyfish	0	0	0	0	0	0	0	0
7	LBS	0	0	0	0	0	0	0	0
8	Sm. zoobenthos	0	0	0	0	0	0	0	0
9	Macrozoobenthos	0	0.00258	0	0	0.01048	0.00136	0	0.01442
10	Bent. Crus. NRA	0.01144	0.20155	0	0	0.02418	0.0299	0	0.26707
11	Bent. Crus. RA	0.00508	0.01809	0	0	0.16362	0.0496	0	0.23639
12	Pen. prawns NRA	0	0.04393	0	0	0.00403	0	0	0.04796
13	Pen. prawns RA	0.00127	0.11111	0	0	0.00403	0.00476	0	0.12117
14	Cephalopods NRA	0.03432	0.00388	0.01039	0.21881	0.10478	0.01359	0.01333	0.3991
15	Cephalopods RA	0	0.00258	0	0	0.03788	0.00544	0	0.0459
16	LBS-assoc. fish Juv	0	0	0.00416	0	0.00484	0.00815	0.00121	0.01836
17	LBS-assoc. fish Ad	0.00055	0.00046	0.00055	0	0.00188	0.00201	0	0.00545
18	Sm. Dem. RA	0.00127	0.02842	0.17459	0.1945	0.54405	0.1128	0.01091	1.06654
19	Sm. Dem. NRA	0.11439	0.13824	0.01455	0.52068	0.40058	0.27927	0.09938	1.56709
20	Med. Dem. RA	0.03305	0.01034	0.05612	0.07294	0.1072	0.06455	0.14544	0.48964
21	Med. Dem. NRA	0.03559	0.00388	0.10808	0.37684	0.03305	0.04145	0.02909	0.62798
22	Lg. Dem. RA. Juv	0.00381	0	0.06852	0.48778	0.08777	0.0353	0	0.68318
23	Lg. Dem. RA. Ad	0.00001	0.00002	0.00006	0.00049	0.00015	0.00004	0	0.00077
24	Lg. Dem. NRA. Juv	0.01508	0.11326	0.0111	0.18104	0.12645	0.17599	0.00242	0.62534
25	Lg. Dem. NRA. Ad	0.00412	0.00658	0.00455	0.00001	0.01225	0.01271	0.00011	0.04033
26	Sm. Pelagics	0.061	0.009	1.247	2.204	0.218	0.04	0.528	4.307
27	Med. Pelagics	0.07118	0.00129	0.03949	0.08104	0.01934	0.0333	0.09211	0.33775
28	Lg. Pelagics Juv	0.02923	0.00129	0.1351	0.01216	0.00322	0.00612	0.12241	0.30953
29	Lg. Pelagics Ad	0.00381	0	0.01455	0.00203	0	0.00068	0.01333	0.0344
30	Rays and Skates	0	0	0	0	0	0	0	0
31	Small Sharks	0	0	0	0	0	0	0	0
32	Large Sharks Juv.	0	0	0	0	0	0	0	0
33	Large Sharks Ad.	0	0	0	0	0	0	0	0

Table 2.1 Landing input data (t/km²/year) in the new Ecopath model of Hong Kong marine ecosystem in the 1990s. Landing data were taken from ERM Interview Program (ERM 1998a; Pitcher *et al.*, 1998) and revised based on methods described in Chapter 3.

No.	Group name	ST	SHT	PT	PS	P4/7	Misc.	HT	Total
34	Fish-eating Seabirds	0	0	0	0	0	0	0	0
35	Invertebrate-eating Seabirds	0	0	0	0	0	0	0	0
36	Marine Mammals	0	0	0	0	0	0	0	0
37	Detritus	0	0	0	0	0	0	0	0
	Sum	0.4252	0.71589	1.89881	4.38068	1.90778	1.02778	1.05774	11.41388

Note: ST = stern trawlers; SHT = shrimp trawlers; PT = pair trawlers; PS = purse seines; P4/7 = vessels that are less than 5 m in length; Misc. = small boats that employ a wide range of lines, nets, traps and hook gears; HT = hang trawlers; LBS = living bottom structures; Sm. = small; Bent. Crus. = benthic crustaceans; NRA = non-reef associated; RA = reef associated; Pen. = penaeid; LBS-assoc. = LBS-associated; Juv = juvenile; Ad = adult; Dem. = demersal; Med. = medium; Lg. = large.

Table 2.2 Input data for discards (t/km²/year) in the new Ecopath model of Hong Kong marine ecosystem in 1990s. See text for source of data.

No.	Group name	ST	SHT	PT	PS	P4/7	Misc.	HT	Total
1	Benthic Producers	0	0	0	0	0	0	0	0
2	Phytoplankton	0	0	0	0	0	0	0	0
3	Corals	0.01	0.01	0.0102	0	0.005	0.005	0	0.0402
4	Zooplankton	0	0	0	0	0	0	0	0
5	Sea Turtles	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000007
6	Jellyfish	0.05443	0.0824	0.14866	0	0	0	0	0.28549
7	LBS	0.00016	0.00022	0.00028	0	0	0	0	0.00066
8	Sm. zoobenthos	0.00053	0.0008	0.00145	0	0	0	0	0.00278
9	Macrozoobenthos	0.003	0.005	0.00343	0	0	0	0	0.01143
10	Bent. Crus. NRA	0.00007	0.0001	0.00018	0	0	0	0	0.00035
11	Bent. Crus. RA	0.00004	0.00005	0.0001	0	0	0	0	0.00019
12	Pen. prawns NRA	0	0	0	0	0	0	0	0
13	Pen. prawns RA	0	0	0	0	0	0	0	0
14	Cephalopods NRA	0	0	0	0	0	0	0	0
15	Cephalopods RA	0	0	0	0	0	0	0	0
16	LBS-assoc. fish Juv	0	0	0	0	0	0	0	0
17	LBS-assoc. fish Ad	0	0	0	0	0	0	0	0
18	Sm. Dem. RA	0	0	0	0	0	0	0	0
19	Sm. Dem. NRA	0	0	0	0	0	0	0	0
20	Med. Dem. RA	0	0	0	0	0	0	0	0
21	Med. Dem. NRA	0	0	0	0	0	0	0	0
22	Lg. Dem. RA. Juv	0	0	0	0	0	0	0	0
23	Lg. Dem. RA. Ad	0	0	0	0	0	0	0	0
24	Lg. Dem. NRA. Juv	0	0	0	0	0	0	0	0
25	Lg. Dem. NRA. Ad	0	0	0	0	0	0	0	0
26	Sm. Pelagics	0	0	0	0	0	0	0	0
27	Med. Pelagics	0	0	0	0	0	0	0	0
28	Lg. Pelagics Juv	0	0	0	0	0	0	0	0

Table 2.2 Input data for discards (t/km²/year) in the new Ecopath model of Hong Kong marine ecosystem in 1990s. See text for source of data.

No.	Group name	ST	SHT	PT	PS	P4/7	Misc.	HT	Total
29	Lg. Pelagics Ad	0	0	0	0	0	0	0	0
30	Rays and Skates	0	0	0	0	0	0	0	0
31	Small Sharks	0	0	0	0	0	0	0	0
32	Large Sharks Juv.	0	0	0	0	0	0	0	0
33	Large Sharks Ad.	0	0	0	0	0	0	0	0
34	Fish-eating Seabirds	0	0	0	0	0	0	0	0
35	Invertebrate-eating Seabirds	0	0	0	0	0	0	0	0
36	Marine Mammals	0	0.00004	0.00002	0.00004	0.00004	0.00004	0	0.00018
37	Detritus	0	0	0	0	0	0	0	0
	Sum	0.06823	0.09861	0.16432	0.00004	0.00504	0.00504	0	0.34128

Note: ST = stern trawlers; SHT = shrimp trawlers; PT = pair trawlers; PS = purse seines; P4/7 = vessels that are less than 5 m in length; Misc. = small boats that employ a wide range of lines, nets, traps and hook gears; HT = hang trawlers; LBS = living bottom structures; Sm. = small; Bent. Crus. = benthic crustaceans; NRA = non-reef associated; RA = reef associated; Pen. = penaeid; LBS-assoc. = LBS-associated; Juv = juvenile; Ad = adult; Dem. = demersal; Med. = medium; Lg. = large.

2.3 Results

Table 2.3 Input and output (in brackets) parameters of the new Ecopath model of Hong Kong marine ecosystem in 1990s.

No.	Group name	Trophic level	Biomass (t/km²)	P/B (year⁻¹)	Q/B (year⁻¹)	EE	P/Q
1	Benthic Producers	(1)	153	11.885	-	(0.00855)	-
2	Phytoplankton	(1)	13	231	-	(0.76861)	-
3	Corals	(1.5)	(0.33993)	1.09	9	0.99	(0.12111)
4	Zooplankton	(2)	14.7	32	192	(0.16749)	(0.16667)
5	Sea Turtles	(2.5)	0.0002	0.1	2.5	(0.95072)	(0.04)
6	Jellyfish	(3)	1.52879	5.011	25.05	(0.25716)	(0.20004)
7	LBS	(2.1)	0.0042	0.25	0.5	(0.77896)	(0.5)
8	Sm. zoobenthos	(2.1)	70.37	6.57	27.4	(0.41763)	(0.23978)
9	Macrozoobenthos	(2.4)	(1.76869)	3	12.5	0.95	(0.24)
10	Bent. Crus. NRA	(3.2)	0.35813	5.65	26.9	(0.69435)	(0.21004)
11	Bent. Crus. RA	(3)	0.8036	1.85	8.35	(0.77353)	(0.22156)
12	Pen. prawns NRA	(2.7)	0.06126	4.8	16.352	(0.94872)	(0.29354)
13	Pen. prawns RA	(2.5)	0.33181	7.6	41.537	(0.9028)	(0.18297)
14	Cephalopods NRA	(3.8)	0.39529	3.1	11.97	(0.65109)	(0.25898)
15	Cephalopods RA	(3.6)	0.18669	3.1	11.97	(0.2188)	(0.25898)
16	LBS-assoc. fish Juv	(3.1)	0.0953	2.5	10.89	(0.9171)	(0.22957)
17	LBS-assoc. fish Ad	(4.1)	0.00762	1.5	6.64	(0.93306)	(0.2259)
18	Sm. Dem. RA	(2.7)	0.96475	3	10.47	(0.94776)	(0.28653)
19	Sm. Dem. NRA	(2.9)	2.49592	3	10.89	(0.98118)	(0.27548)
20	Med. Dem. RA	(3.2)	0.31412	2	8.63	(0.84526)	(0.23175)

Table 2.3 Input and output (in brackets) parameters of the new Ecopath model of Hong Kong marine ecosystem in 1990s.

No.	Group name	Trophic level	Biomass (t/km^2)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q
21	Med. Dem. NRA	(3.3)	0.34583	2.2	8.63	(0.9693)	(0.25492)
22	Lg. Dem. RA. Juv	(2.7)	0.18308	4.18	15	(0.996)	(0.27867)
23	Lg. Dem. RA. Ad	(3.6)	0.00578	0.6	5.11	(0.99801)	(0.11742)
24	Lg. Dem. NRA. Juv	(2.9)	0.327	3	10.89	(0.99577)	(0.27548)
25	Lg. Dem. NRA. Ad	(3.5)	0.05	0.92	4.53	(0.9798)	(0.20309)
26	Sm. Pelagics	(2.9)	2.09076	4	11	(0.89123)	(0.36364)
27	Med. Pelagics	(3.3)	0.21449	2	7.59	(0.98126)	(0.2635)
28	Lg. Pelagics Juv	(2.9)	0.21195	3	10.81	(0.88698)	(0.27752)
29	Lg. Pelagics Ad	(3.9)	0.04579	1.2	5.9	(0.78447)	(0.20339)
30	Rays and Skates	(3.8)	0.12649	0.5	6.35	(0.00834)	(0.07874)
31	Small Sharks	(3.9)	0.12742	0.4	6.83	(0.0126)	(0.05857)
32	Large Sharks Juv.	(3.9)	0.05	0.4	6.83	(0.03212)	(0.05857)
33	Large Sharks Ad.	(4.3)	0.005	0.2	4.13	(0.1147)	(0.04843)
34	Fish-eating Seabirds	(3.9)	0.00076	0.06	61.28029	(0)	(0.00098)
35	Invertebrate-eating Seabirds	(3.2)	0.00229	0.06	72.76378	(0)	(0.00082)
36	Marine Mammals	(4.1)	0.009	0.045	14.7682	(0.96845)	(0.00305)
37	Detritus	(1)	200	-	-	(0.49014)	-

Note: P/B = production/biomass ratio; Q/B = consumption/biomass ratio; EE = ecotrophic efficiency; P/Q = production/consumption ratio; trophic levels (TL) estimated herein were assigned as fractional numbers based on the suggestion made by Odum and Heald (1975):

$$TL_i = 1 + \sum_{j=1}^{n} DC_{ij} \, TL_j$$

where i is the predator, j the nth prey, and DC_{ij} is the diet composition, expressing the fractions of each j in the diet of i.

LBS = living bottom structures; Sm. = small; Bent. Crus. = benthic crustaceans; NRA = non-reef associated; RA = reef associated; Pen. = penaeid; LBS-assoc. = LBS-associated; Juv = juvenile; Ad = adult; Dem. = demersal; Med. = medium; Lg. = large.

Table 2.4 Diet composition matrix for all functional groups of the Hong Kong marine ecosystem model in the 1990s. Values represent the proportion (on a weight or volume basis) each prey contributes to the diet of predator. All diet proportions sum to 1 for each predator. See notes below the table for explanation on the acronyms.

No.	Prey \ Predator	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Benthic Producers			0.66667		0.1		0.17112	0.09631	0.31848	0.11457	0.26199					0.24234	0.04086	0.12129
2	Phytoplankton		0.7			0.04	0.17	0.0656									0.02684	0.02309	0.03585
3	Corals							0.0101				0.00502					0.001		0.0025
4	Zooplankton	0.6		0.11905	1.0	0.06		0.04307			0.399	0.331	0.14842		0.928		0.35073	0.12344	0.113
5	Sea Turtles																		
6	Jellyfish			0.11905													0.00142	0.00644	0.00064
7	LBS			0.04762				0.00001							0.000001	0.00001			
8	Sm. zoobenthos						0.08	0.29361	0.55486	0.00142	0.2	0.127				0.01779	0.27024	0.64093	0.12741
9	Macrozoobenthos			0.04762				0.00504	0.00512	0.47945	0.08241	0.014		0.39925		0.00838	0.00531	0.00048	0.02087
10	Bent. Crus. NRA							0.00147	0.02774							0.17701		0.00444	
11	Bent. Crus. RA							0.00243		0.05733				0.13656			0.0005		0.00051
12	Pen. prawns NRA												0.00062			0.12485		0.00045	
13	Pen. prawns RA							0.001		0.14332				0.35348			0.00488		0.11623
14	Cephalopods NRA												0.01592			0.09284		0.00225	
15	Cephalopods RA													0.01199			0.00102		0.00516
16	LBS-assoc. fish Juv												0.00001		0.024	0.10758		0.0001	
17	LBS-assoc. fish Ad															0.0108			
18	Sm. Dem. RA											0.001		0.09673			0.01538		0.40468
19	Sm. Dem. NRA								0.26202		0.00201		0.33466		0.024	0.20589		0.02313	
20	Med. Dem. RA																		
21	Med. Dem. NRA															0.0914			
22	Lg. Dem. RA. Juv											0.001		0.002			0.001		0.002
23	Lg. Dem. RA. Ad																		
24	Lg. Dem. NRA. Juv										0.00201		0.00053		0.024	0.09805		0.00512	
25	Lg. Dem. NRA. Ad															0.06541			
26	Sm. Pelagics												0.49985					0.0093	
27	Med. Pelagics																		
28	Lg. Pelagics Juv																		
29	Lg. Pelagics Ad																		
30	Rays and Skates																		
31	Small Sharks																		
32	Large Sharks Juv.																		
33	Large Sharks Ad.																		
34	Fish-eating Seabirds																		
35	Invertebrate-eating Seabirds																		
36	Marine Mammals																		
37	Detritus	0.4	0.3			0.8	0.75	0.40656	0.05395		0.2	0.259					0.07933	0.11997	0.04986
	Import																		
	Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 2.4 Continued

No.	Prey \ Predator	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	Benthic Producers	0.06822	0.24198	0.0196	0.04086	0.09985	0.00056	0.00013	0.00056							0.1702	
2	Phytoplanktons	0.00274	0.0268		0.02309		0.07816	0.04536	0.07816	0.00244							
3	Corals		0.0025	0.01007													
4	Zooplanktons	0.06361	0.35021	0.02194	0.12344	0.03455	0.83463	0.57956	0.83463	0.1986						0.04776	
5	Sea Turtles													0.0000007			
6	Jellyfish	0.02061	0.00142	0.00005	0.00644	0.00119	0.0532	0.03337	0.0532	0.0185							
7	LBS																
8	Sm. zoobenthos	0.39457	0.26984	0.06634	0.64093	0.27117					0.11672	0.13678	0.03179		0.00805	0.28559	
9	Macrozoobenthos	0.0005	0.0053	0.19904	0.00048	0.00005					0.22574	0.08248	0.10534	0.01111	0.00805	0.19443	
10	Bent. Crus. NRA	0.11829			0.00444	0.16424					0.13382	0.16971	0.08602	0.04777	0.00805	0.09722	
11	Bent. Crus. RA		0.0005	0.11096							0.0171	0.0451	0.30668	0.04666	0.00005		
12	Pen. prawns NRA	0.00503			0.00045	0.04258	0.00055	0.02841	0.00055		0.05226	0.04923	0.07924	0.04555	0.00805	0.05711	0.003
13	Pen. prawns RA		0.00488	0.12323								0.00049					
14	Cephalopods NRA	0.00649			0.00225	0.04657	0.00001	0.00446	0.00001	0.04849	0.06028	0.12476	0.03304	0.09998	0.02146	0.03115	0.16921
15	Cephalopods RA		0.00101	0.0053								0.00875	0.03304	0.07221			0.04788
16	LBS-assoc. fish Juv	0.0001		0.0001	0.0001	0.00133					0.13382	0.0608	0.01558	0.01666			
17	LBS-assoc. fish Ad	0.0001		0.0001		0.00061					0.00254	0.00006	0.00526	0.01666			
18	Sm. Dem. RA		0.01536	0.26049							0.0171	0.0791	0.1002	0.07665			0.19565
19	Sm. Dem. NRA	0.20818			0.02313	0.12593		0.00601		0.05796	0.13382	0.12014	0.0081	0.0411	0.0053		0.24456
20	Med. Dem. RA			0.16644									0.1002	0.08887			0.00324
21	Med. Dem. NRA	0.01226				0.06601		0.0006		0.01288	0.01539	0.04104		0.02666			0.00191
22	Lg. Dem. RA. Juv		0.001	0.00201							0.01994	0.01971	0.02512	0.03031			0.001
23	Lg. Dem. RA. Ad			0.001							0.0005	0.00098	0.003	0.00612			0.002
24	Lg. Dem. NRA. Juv	0.00542			0.00512	0.03007					0.07097	0.0608	0.02743	0.01666	0.29681	0.01972	
25	Lg. Dem. NRA. Ad					0.0001						0.00005	0.00005	0.00012			0.01011
26	Sm. Pelagics	0.02022			0.0093	0.04354		0.16528		0.36537			0.03179	0.07332	0.32208	0.02796	0.19124
27	Med. Pelagics					0.00871		0.01181		0.18267				0.07776			0.08305
28	Lg. Pelagics Juv					0.04354		0.1179		0.11308			0.00405	0.0511	0.32208	0.02796	
29	Lg. Pelagics Ad												0.00405	0.0511			0.04714
30	Rays and Skates													0.02555			
31	Small Sharks													0.03111			
32	Large Sharks Juv.													0.03111			
33	Large Sharks Ad.													0.00555			
34	Fish-eating Seabirds																
35	Invertebrate-eating Seabirds																
36	Marine Mammals													0.01028			
37	Detritus	0.07366	0.07921	0.01334	0.11997	0.01998	0.03288	0.00711	0.03288							0.0409	
	Import																
	Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Note: LBS = living bottom structure; Sm = small; Bent. = benthic; Crus. = crustaceans; NRA = non-reef associated; RA = reef associated; Pen. = penaeid; Juv. = juvenile; Ad. = adult; Dem. = demersal; Med. = medium; Lg. = large.

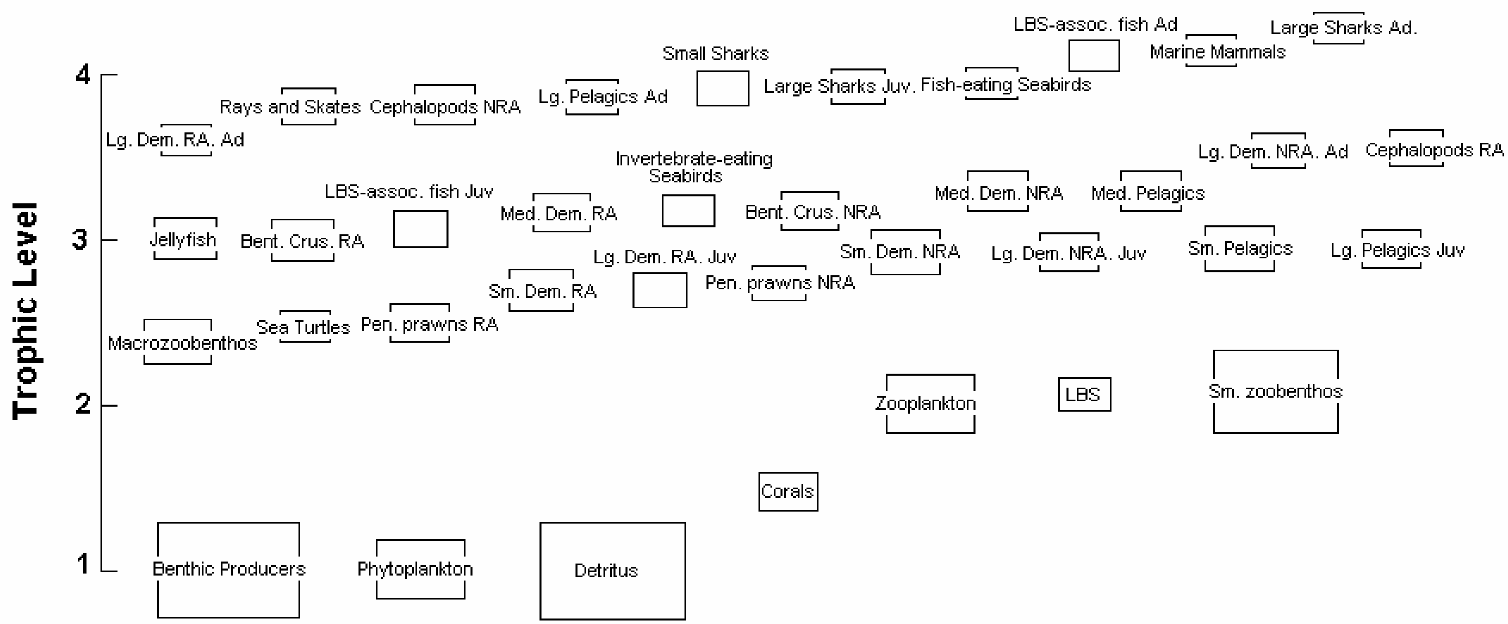


Figure 2.1 Simplified trophic flow diagram of the Hong Kong marine ecosystem in the 1990s, all arranged by their trophic levels. For reason of clarity, fluxes flow lines, numerical labeling of flows, and symbols for harvest, other export, flows to detritus, cannibalism and respiration were omitted. The modelled area is 1,680 km².

2.4 Revised Ecopath model representing the system after 5 years of closure

Table 2.5 Input and output (in brackets) parameters of the revised Ecopath model of Hong Kong marine ecosystem in 1990s, after 5 years of closure (*vide* Scenario 6 in simulations for Hong Kong and Scenario 2 in simulation for PRC inshore waters).

No.	Group name	Trophic level	Biomass (t/km²)	P/B (year⁻¹)	Q/B (year⁻¹)	EE	P/Q
1	Benthic Producers	(1)	152.2371	11.885	-	(0.02037)	-
2	Phytoplankton	(1)	13.20054	231	-	(0.74664)	-
3	Corals	(1.5)	(0.46666)	1.09	9	0.99	(0.12111)
4	Zooplankton	(2)	14.50554	32	192	(0.26058)	(0.16667)
5	Sea Turtles	(2.5)	0.00023	0.1	2.5	(0.82088)	(0.04)
6	Jellyfish	(3)	1.07467	5.011	25.05	(0.60237)	(0.20004)
7	LBS	(2.1)	0.0096	0.25	0.5	(0.35006)	(0.5)
8	Sm. zoobenthos	(2.1)	68.404	6.57	27.4	(0.49763)	(0.23978)
9	Macrozoobenthos	(2.4)	(1.95583)	3	12.5	0.95	(0.24)
10	Bent. Crus. NRA	(3.0)	0.25393	5.65	26.9	(0.85872)	(0.21004)
11	Bent. Crus. RA	(2.9)	0.4479	1.85	8.35	(0.85277)	(0.22156)
12	Pen. prawns NRA	(2.7)	0.09791	4.8	16.352	(0.86421)	(0.29354)
13	Pen. prawns RA	(2.5)	0.26843	7.6	41.537	(0.87167)	(0.18297)
14	Cephalopods NRA	(3.5)	1.47404	3.1	11.97	(0.48082)	(0.25898)
15	Cephalopods RA	(3.5)	0.06339	3.1	11.97	(0.90366)	(0.25898)
16	LBS-assoc. fish Juv	(3.1)	0.16983	2.5	10.89	(0.82774)	(0.22957)
17	LBS-assoc. fish Ad	(4.1)	0.03204	1.5	6.64	(0.47182)	(0.2259)
18	Sm. Dem. RA	(2.7)	0.87156	3	10.47	(0.96668)	(0.28653)
19	Sm. Dem. NRA	(2.9)	2.49563	3	10.89	(0.94958)	(0.27548)
20	Med. Dem. RA	(2.8)	0.49975	2	8.63	(0.91096)	(0.23175)
21	Med. Dem. NRA	(3.0)	1.3876	2.2	8.63	(0.37408)	(0.25492)
22	Lg. Dem. RA. Juv	(2.7)	5.77038	4.18	15	(0.03792)	(0.27867)
23	Lg. Dem. RA. Ad	(3.4)	0.66977	0.6	5.11	(0.03405)	(0.11742)
24	Lg. Dem. NRA. Juv	(2.9)	1.00372	3	10.89	(0.45641)	(0.27548)
25	Lg. Dem. NRA. Ad	(3.3)	0.34164	0.92	4.53	(0.21002)	(0.20309)
26	Sm. Pelagics	(2.9)	2.99239	4	11	(0.88334)	(0.36364)
27	Med. Pelagics	(3.1)	0.83169	2	7.59	(0.61397)	(0.2635)
28	Lg. Pelagics Juv	(2.9)	0.28176	3	10.81	(0.92876)	(0.27752)
29	Lg. Pelagics Ad	(3.7)	0.31111	1.2	5.9	(0.14331)	(0.20339)
30	Rays and Skates	(3.7)	0.18722	0.5	6.35	(0.00962)	(0.07874)
31	Small Sharks	(3.8)	0.1719	0.4	6.83	(0.01594)	(0.05857)
32	Large Sharks Juv.	(3.8)	0.05996	0.4	6.83	(0.0457)	(0.05857)
33	Large Sharks Ad.	(4.3)	0.00538	0.2	4.13	(0.18181)	(0.04843)
34	Fish-eating Seabirds	(3.9)	0.00082	0.06	61.28029	(0)	(0.00098)
35	Invertebrate-eating Seabirds	(3.0)	0.00236	0.06	72.76378	(0)	(0.00082)
36	Marine Mammals	(4.3)	0.00873	0.045	14.7682	(0.9281)	(0.00305)
37	Detritus	(1)	201.0629	-	-	(0.4834)	-

Note: P/B = production/biomass ratio; Q/B = consumption/biomass ratio; EE = ecotrophic efficiency; P/Q = production/consumption ratio; trophic levels (TL) estimated herein were assigned as fractional numbers based on the suggestion made by Odum and Heald (1975):

$$TL_i = 1 + \sum_{j=1}^{n} DC_{ij}\ TL_j$$

where i is the predator, j the nth prey, and DC_{ij} is the diet composition, expressing the fractions of each j in the diet of i.

Table 2.6 Diet composition matrix for all functional groups of the revised Hong Kong marine ecosystem model in the 1990s, after 5 years of closure. Values represent the proportion (on a weight or volume basis) each prey contributes to the diet of predator. All diet proportions sum to 1 for each predator. See notes below the table for explanation on the acronyms.

No.	Prey \ Predator	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Benthic Producers			0.66667		0.1		0.17208	0.12154	0.34742	0.11473	0.26253					0.24559	0.04188	0.19764
2	Phytoplankton		0.7			0.04	0.17	0.06596									0.0272	0.02367	0.05843
3	Corals							0.00736				0.00368					0.00074		0.00221
4	Zooplankton	0.6		0.11905	1.0	0.06		0.04331			0.39954	0.33168	0.46392		0.94465		0.35544	0.12653	0.18413
5	Sea Turtles																		
6	Jellyfish			0.11905													0.00144	0.0066	0.00103
7	LBS			0.04762				0.00001							0.000001	0.00001			
8	Sm. zoobenthos						0.08	0.29524	0.70021	0.00155	0.20027	0.12726				0.0287	0.27386	0.65699	0.20761
9	Macrozoobenthos			0.04762				0.00506	0.00646	0.52301	0.08252	0.01403		0.6104		0.01351	0.00538	0.00049	0.03401
10	Bent. Crus. NRA							0.00037	0.01053							0.07371		0.00149	
11	Bent. Crus. RA							0.00109		0.02566				0.06189			0.00022		0.00023
12	Pen. prawns NRA												0.00037			0.09431		0.00027	
13	Pen. prawns RA							0.0007		0.10235				0.28263			0.0034		0.08694
14	Cephalopods NRA												0.04976			0.14977		0.00231	
15	Cephalopods RA													0.00872			0.00073		0.0037
16	LBS-assoc. fish Juv												0.00001		0.02307	0.12134		0.0001	
17	LBS-assoc. fish Ad															0.01742			
18	Sm. Dem. RA											0.0003		0.03331			0.00459		0.13957
19	Sm. Dem. NRA								0.09317		0.00066		0.19088		0.00784	0.09007		0.00759	
20	Med. Dem. RA																		
21	Med. Dem. NRA															0.14746			
22	Lg. Dem. RA. Juv											0.001		0.00306			0.00102		0.00326
23	Lg. Dem. RA. Ad																		
24	Lg. Dem. NRA. Juv										0.00201		0.00166		0.02443	0.15819		0.00525	
25	Lg. Dem. NRA. Ad															0.10552			
26	Sm. Pelagics												0.2934					0.00385	
27	Med. Pelagics																		
28	Lg. Pelagics Juv																		
29	Lg. Pelagics Ad																		
30	Rays and Skates																		
31	Small Sharks																		
32	Large Sharks Juv.																		
33	Large Sharks Ad.																		
34	Fish-eating Seabirds																		
35	Invertebrate-eating Seabirds																		
36	Marine Mammals																		
37	Detritus	0.4	0.3			0.8	0.75	0.40882	0.06809		0.20027	0.25953					0.08039	0.12298	0.08125
	Import																		
	Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 2.6 Continued

No.	Prey \ Predator	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	Benthic Producers	0.09084	0.24523	0.03812	0.04188	0.14001	0.00056	0.00016	0.00056							0.19407	
2	Phytoplankton	0.00365	0.02716		0.02367		0.07818	0.0569	0.07818	0.00396							
3	Corals		0.00221	0.0074													
4	Zooplankton	0.0847	0.35491	0.04268	0.12653	0.04845	0.83482	0.72694	0.83482	0.32271						0.05446	
5	Sea Turtles																
6	Jellyfish	0.02744	0.00144	0.0001	0.0066	0.00167	0.05321	0.04185	0.05321	0.03006							
7	LBS																
8	Sm. zoobenthos	0.5254	0.27346	0.12906	0.65699	0.38025					0.15918	0.21089	0.07526		0.01618	0.32565	
9	Macrozoobenthos	0.00067	0.00537	0.38721	0.00049	0.00007					0.30786	0.12717	0.24939	0.01761	0.01618	0.22171	
10	Bent. Crus. NRA	0.04544			0.00149	0.06417					0.05382	0.06924	0.03719	0.0186	0.003	0.03688	
11	Bent. Crus. RA		0.00022	0.05125							0.00861	0.02313	0.15837	0.02182	0.00003		
12	Pen. prawns NRA	0.00329			0.00027	0.02926	0.00033	0.01704	0.00033		0.03625	0.03551	0.06094	0.03052	0.00486	0.03666	0.00188
13	Pen. prawns RA		0.0034	0.09985								0.00042					
14	Cephalopods NRA	0.00864			0.00231	0.0653	0.00001	0.0056	0.00001	0.07879	0.08221	0.19236	0.07821	0.15848	0.04311	0.03552	0.37248
15	Cephalopods RA		0.00072	0.00392								0.00746	0.02903	0.05653			0.03588
16	LBS-assoc. fish Juv	0.00011		0.0001	0.0001	0.00141					0.14455	0.0666	0.01606	0.0166			
17	LBS-assoc. fish Ad	0.00013		0.0002		0.00086					0.00347	0.00009	0.01246	0.02641			
18	Sm. Dem. RA		0.00458	0.09525							0.00594	0.02884	0.03929	0.02612			0.06617
19	Sm. Dem. NRA	0.07887			0.00759	0.05012		0.00214		0.02317	0.05246	0.0493	0.0039	0.01704	0.00249		0.10644
20	Med. Dem. RA			0.11305									0.07893	0.06205			0.00215
21	Med. Dem. NRA	0.01632				0.09256		0.00075		0.02093	0.02099	0.06328		0.04226			0.0042
22	Lg. Dem. RA. Juv		0.00101	0.00391							0.0272	0.03038	0.05948	0.04804			0.0022
23	Lg. Dem. RA. Ad			0.00194							0.00068	0.00152	0.00711	0.0097			0.0044
24	Lg. Dem. NRA. Juv	0.00722			0.00525	0.04216					0.09679	0.09375	0.06493	0.02641	0.59627	0.02249	
25	Lg. Dem. NRA. Ad					0.00014						0.00008	0.00012	0.00018			0.02225
26	Sm. Pelagics	0.00919			0.00385	0.02095		0.0717		0.17263			0.01742	0.03546	0.16346	0.0125	0.09536
27	Med. Pelagics					0.01221		0.01481		0.29682				0.12326			0.18281
28	Lg. Pelagics Juv					0.0224		0.0532		0.05092			0.00234	0.02569	0.1544	0.01341	
29	Lg. Pelagics Ad												0.00959	0.081			0.10378
30	Rays and Skates													0.0405			
31	Small Sharks													0.04931			
32	Large Sharks Juv.													0.04931			
33	Large Sharks Ad.													0.0088			
34	Fish-eating Seabirds																
35	Invertebrate-eating Seabirds																
36	Marine Mammals													0.0083			
37	Detritus	0.09809	0.08027	0.02594	0.12298	0.02801	0.03289	0.00891	0.03289							0.04663	
	Import																
	Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Note: LBS = living bottom structure; Sm = small; Bent. = benthic; Crus. = crustaceans; NRA = non-reef associated; RA = reef associated; Pen. = penaeid; Juv. = juvenile; Ad. = adult; Dem. = demersal; Med. = medium; Lg. = large

Chapter 3. Revision of the Hong Kong Catch Estimates

T.J. Pitcher

3.1 Methods applied in revising the catch estimates

The revision uses new method based on integrating across the log normal distributions fitted to the individual vessel catches, each multiplied by the estimated number of vessels in Hong Kong. Previous method, *i.e.*, performed in HK1 Project and used in HK2 Project (ERM 1998a; Pitcher *et al.*, 1998) was based on the mean of the fitted log normal distributions. This new method is more precise, but the uncertainty in the original database – based on interviews of Hong Kong vessels - is such that it is not really justified. Note that the log normal has been re-fitted to the purse seine data.

	SHT	HT	ST	P4/7	Misc.	PT	PS	Totals
Total # interviewed	272	22	71	873	458	149	85	1930
# interviewed fishing HK	113	22	13	562	207	4	85	1006
est. proportion fishing HK	0.42	1.00	0.18	0.64	0.45	0.03	1.00	0.52
# vessels from AFD survey	460	36	179	2610	891	546	135	4857
est # vessels fish in HK	**191**	**36**	**33**	**1680**	**403**	**15**	**135**	**2492**
mean log t per year per vessel	4.9	38.8	17.6	2.0	6.3	170.4	33.1	3.0
lo95CL from log normal	*1.3*	*14.8*	*3.9*	*0.4*	*1.3*	*31.7*	*4.2*	*1.7*
up95CL from log normal	*18*	*102*	*80*	*6*	*7*	*917*	*262*	*119463*
CATCHES								
A. estimated by individual vessel catch								
estimate of catch	945	1398	577	3318	2551	2498	4468	15754
lower 95% CL	*255*	*531*	*127*	*657*	*505*	*464*	*564*	*3104*
upper 95% CL	*3502*	*3677*	*2626*	*9576*	*2944*	*13439*	*35365*	*71129*
B. estimated by species and ind. vessel								
estimate of catch	879	1293	572	3964	2842	1563	3633	14747
lower 95% CL	*245*	*440*	*178*	*909*	*748*	*985*	*630*	*4134*
upper 95% CL	*3930*	*5276*	*3388*	*23903*	*17157*	*260512*	*48556*	*362722*
C. estimated by integrating log normal								
	1118	**1560**	**727**	**3162**	**1842**	**3222**	**7351**	**18982**

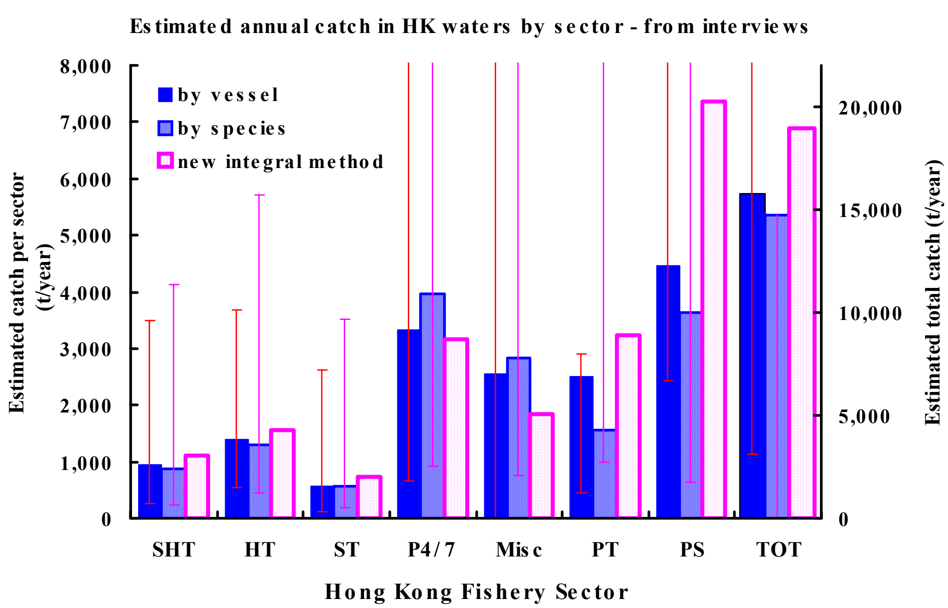
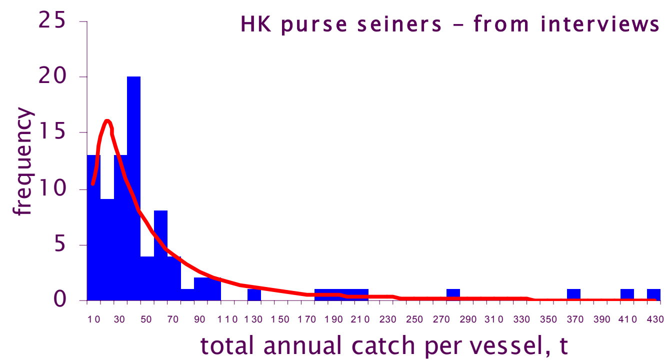
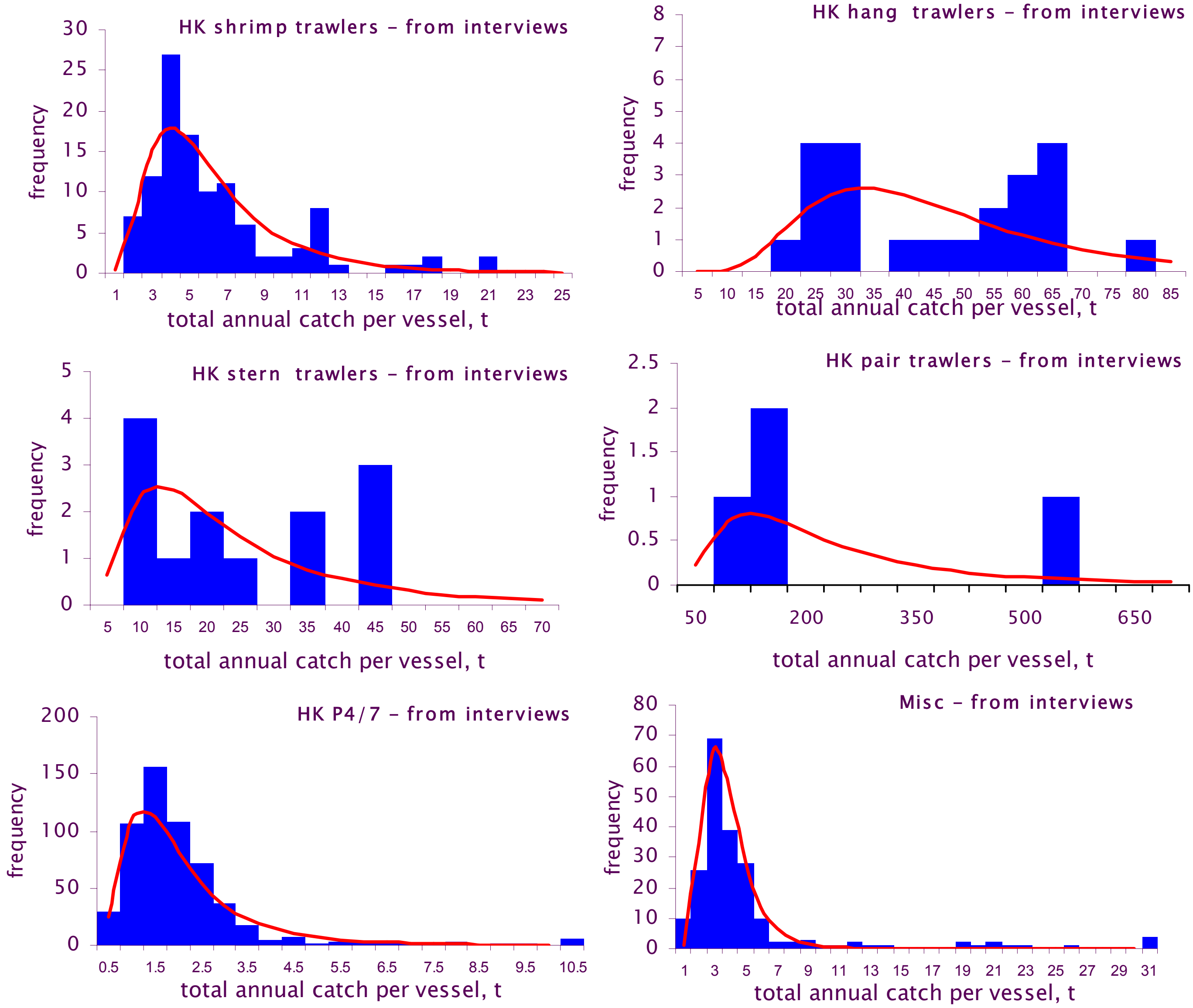


Figure 3.1 Estimated catch by fishery sector in Hong Kong. Estimation of catch by vessel type and species are as in HK1. New method as described in the text (confidence limits only available for previous methods).

3.2 Results

Figure 3.2 Log normal distributions (red lines) fitted to reported daily catches (blue histograms) from the interview database compiled by ERM Ltd. (ERM 1998a). The seven sectors of the Hong Kong fishery are shown. Catches are in tons per year. Fitting was by least squares with adjustment for catch bin size and truncation of exceptionally very high reported catches.





Chapter 4. Temporal Simulation using ECOSIM

E.A. Buchary and T.J. Pitcher

4.1 Setting up ECOSIM simulation routine

The only parameter altered in the ECOSIM set-up table was the duration of the simulation which was set to 25 years. Other parameters were set to default values.

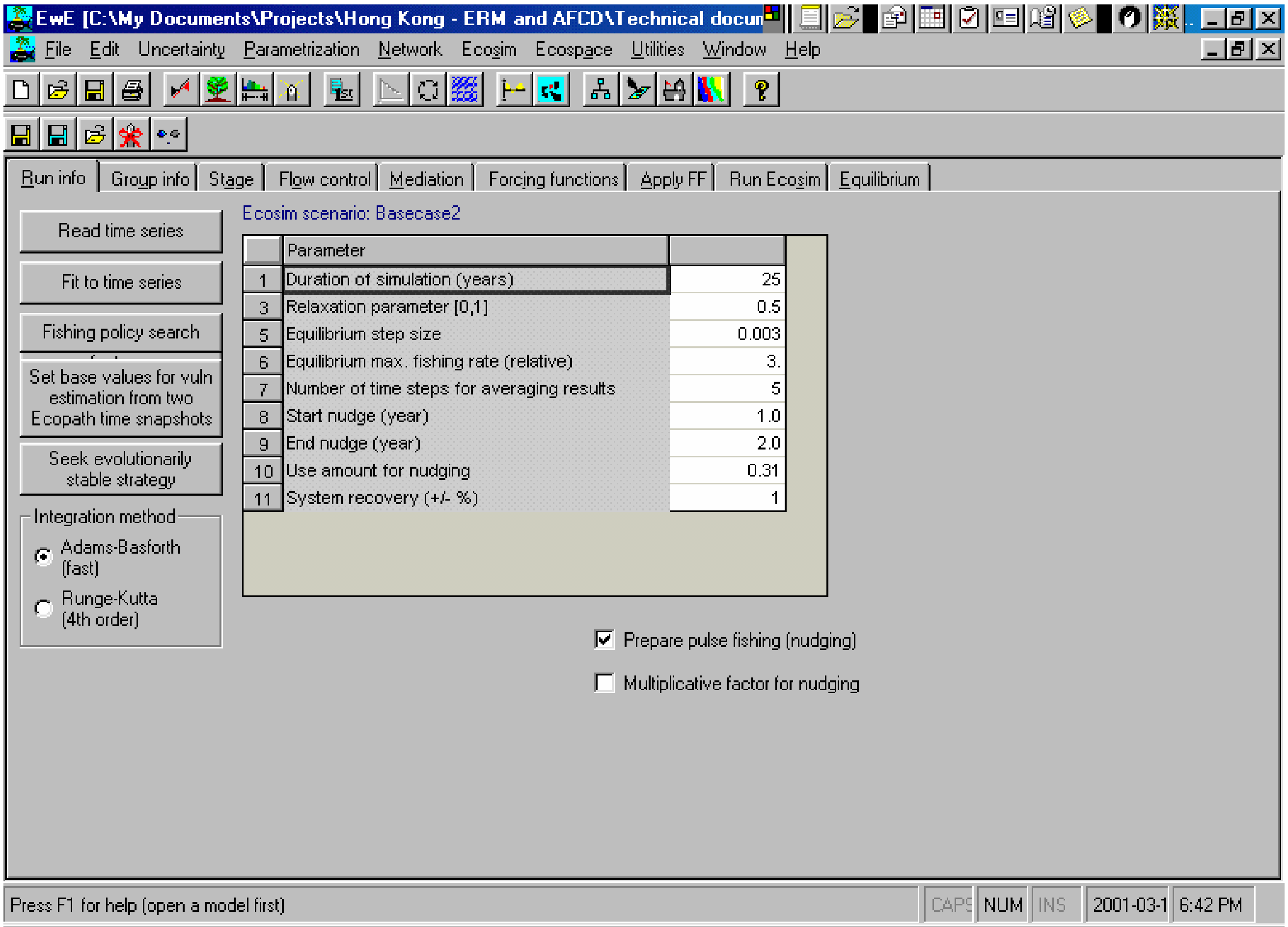


Figure 4.1 ECOSIM set-up table.

4.2 Feeding behavior parameters

Parameter adjustments (Table 4.1) were made to stabilize the dynamic simulation of the Hong Kong marine ecosystem models because previous models (Pitcher *et al.*, 2001, *in press*) generated unrealistic structural changes in the ecosystem after 10 years. This is because groups that were split into juvenile and adult pools set up cyclic predator-prey oscillations which limited model simulation to 10 years only. Adjustment to feeding behavior parameters (see Christensen *et al.*, 2000 for detailed explanation) allowed simulations without violent structural changes, *viz.*:

(1) For sessile organisms such as Corals and LBS (= living bottom structures), their 'maximum relative feeding time' was defined as half the default amount set for other groups.

(2) 'Feeding time adjustment rate factors' for all adult and juvenile split pools were set to 0 and 1.0, respectively. RA and NRA invertebrates had their feeding time factors set to 1.0 and 0.5, respectively. For sessile organisms and invertebrates with very little movement, zooplankton, and marine mammals, their feeding time factors were adjusted to 0. Other groups had their feeding time factors adjusted to 0.5, except for small demersal RA, which was adjusted to 0.75.

(3) The 'fraction of unexplained predation' for all adult pools, marine mammals, fish-eating seabirds, and medium demersal RA and NRA were set to 1.0. Other groups had their fractions of unexplained predation set to 0, except for small sharks, which was set to 0.5.

(4) All other feeding behavior parameters were accepted as suggested by the default values.

Table 4.1 Adjusted feeding behavior parameters in ECOSIM routine

	Group	Max rel. P/B	Max rel. feeding time	Feeding time adjust rate [0,1]	Fraction of 'other' mortality sens. to changes in feeding time	Predator effect on feeding time [0,1]	Density-dep. catchability: Qmax/Qo [>=1]	QBmax/QBo (for handling time) [>1]
1	Benthic Producers	2.0						
2	Phytoplanktons	2.0						
3	Corals	2.0	1.0	0.0	0.00	0.00	1.00	1000.00
4	Zooplanktons	2.0	2.0	0.0	0.00	0.00	1.00	1000.00
5	Sea Turtles	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
6	Jellyfish	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
7	LBS	2.0	1.0	0.0	0.00	0.00	1.00	1000.00
8	Sm. zoobenthos	2.0	2.0	0.0	0.00	0.00	1.00	1000.00
9	Macrozoobenthos	2.0	2.0	0.0	0.00	0.00	1.00	1000.00
10	Bent. Crus. NRA	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
11	Bent. Crus. RA	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
12	Pen. prawns NRA	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
13	Pen. prawns RA	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
14	Cephalopods NRA	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
15	Cephalopods RA	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
16	LBS-assoc. fish Juv	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
17	LBS-assoc. fish Ad	2.0	2.0	0.0	1.00	0.00	1.00	1000.00
18	Sm. Dem. RA	2.0	2.0	0.75	0.00	0.00	1.00	1000.00
19	Sm. Dem. NRA	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
20	Med. Dem. RA	2.0	2.0	0.5	1.00	0.00	1.00	1000.00
21	Med. Dem. NRA	2.0	2.0	0.5	1.00	0.00	1.00	1000.00
22	Lg. Dem. RA. Juv	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
23	Lg. Dem. RA. Ad	2.0	2.0	0.1	1.00	0.00	1.00	1000.00
24	Lg. Dem. NRA. Juv	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
25	Lg. Dem. NRA. Ad	2.0	2.0	0.0	1.00	0.00	1.00	1000.00
26	Sm. Pelagics	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
27	Med. Pelagics	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
28	Lg. Pelagics Juv	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
29	Lg. Pelagics Ad	2.0	2.0	0.0	1.00	0.00	1.00	1000.00
30	Rays and Skates	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
31	Small Sharks	2.0	2.0	0.5	0.50	0.00	1.00	1000.00
32	Large Sharks Juv.	2.0	2.0	1.0	0.00	0.00	1.00	1000.00
33	Large Sharks Ad.	2.0	2.0	0.0	1.00	0.00	1.00	1000.00
34	Fish-eating Seabirds	2.0	2.0	0.5	1.00	0.00	1.00	1000.00
35	Invertebrate-eating S	2.0	2.0	0.5	0.00	0.00	1.00	1000.00
36	Marine Mammals	2.0	2.0	0.0	1.00	0.00	1.00	1000.00

4.3 Trophic Ontogeny

Trophic ontogeny and other parameters related to age classes of fish populations in the ecosystem (Walters *et al.*, 1997) were represented by establishing juvenile and adult biomass pools in some functional groups (Table 4.2).

Table 4.2 Recruitment linkages between split juvenile and adult biomass pools in new ECOSIM simulations of the Hong Kong ecosystem model in the 1990s.

Juvenile (J) group: Adult (A) group:	LBS-assoc. fish J LBS-assoc. fish A	Lg. Dem. RA. J Lg. Dem. RA. A	Lg. Dem. NRA. J Lg. Dem. NRA. A	Lg. Pel. J Lg. Pel. A	Lg. Sharks J Lg. Sharks A
Min. time as juv. (rel. to orig. setting) *	1	1	1	1	1
Max. time as juv. (rel. to orig. setting) *	1.0001	1.0001	1.0001	1	1.0001
Recruitment power parameter *	1	1	1	1	1
Age (year) at transition to adult group (t_k)	3	3	3	2.5	3
W_{avg} / W_k (Av. adult weight / weight at transition)	6	6	5	7	6
K of the VBGF (/year)	0.16	0.16	0.3	0.25	0.16
Base fraction of food intake used for reproduction *	0.3	0.3	0.3	0.3	0.3
Fraction of increase in food intake used for growth *	0.8	0.8	0.8	0.8	0.8

Note: Parameters marked with * are default values, other parameters were entered based on information from FishBase Online (Froese and Pauly 2001).

4.4 Flow Control Assumption

To mimic a more realistic bottom-up donor control and top-down predator control in the trophic control of the ecosystem, the vulnerability parameter of each functional group was adjusted to be proportional (Table 4.3) to their Ecopath estimated trophic level (Cheung *et al.,* 2001, *in prep*.). Therefore, the relationship between vulnerability and trophic level becomes linear (Figure 4.2).

Table 4.3 Adjustment of trophic flow control (vulnerability parameters) that is proportional to each trophic level (TL) of the functional groups (Cheung *et al.,* 2001, *in prep*.).

Functional Groups	TL	Vulnerability
Benthic Producers, Detritus, Phytoplankton	1	0.2000
Corals	1.5	0.2758
Zooplankton	2	0.3515
LBS, Sm. Zoobenthos	2.1	0.3667
Sea turtles	2.3	0.3970
Macrozoobenthos	2.4	0.4121
Pen. prawns RA	2.5	0.4273
Pen. prawns NRA, Sm. Dem. RA and Lg. Dem RA Juv	2.7	0.4576

Table 4.3 Adjustment of trophic flow control (vulnerability parameters) that is proportional to each trophic level (TL) of the functional groups (Cheung *et al.,* 2001, *in prep*.).

Functional Groups	TL	Vulnerability
Sm. Dem. NRA, Lg. Dem NRA Juv, Sm. Pelagics and Lg. Pelagic Juv	2.9	0.4879
Jellyfish and Bent. Crust. RA	3	0.5030
LBS-assoc. fish Juv	3.1	0.5182
Bent. Crus. NRA, Invertebrate-eating Seabirds and Med. Dem. RA	3.2	0.5333
Med. Dem. NRA and Med. Pelagics	3.3	0.5485
Cephalopods RA and Lg. Dem. NRA Ad.	3.5	0.5788
Lg. Dem. RA. Ad	3.6	0.5939
Cephalopods NRA and Rays & Skates	3.8	0.6242
Lg. Pelagics Ad., Sm. Sharks, Lg. Sharks Juv & Fish-eating Seabirds	3.9	0.6394
LBS-assoc. fish Ad and Marine Mammals	4.1	0.6697
Large Sharks Ad	4.3	0.7000

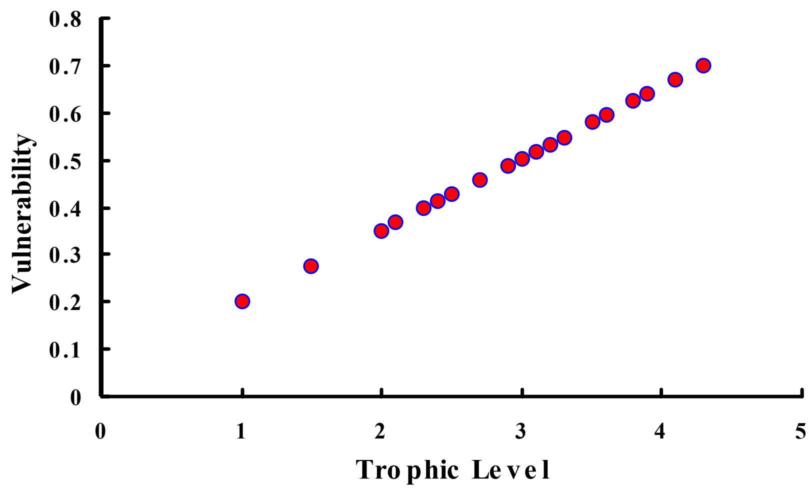


Figure 4.2 Relationship between trophic levels and vulnerability parameters as outlined in Cheung et al. (2001, in prep.).

4.5 Mediation Factor

In Ecosim simulations, we also represent a non-feeding interaction (*i.e.*, mediation) of protection effects (Christensen *et al.*, 2000), between corals and reef-associated groups and between LBS and LBS-associated fish.

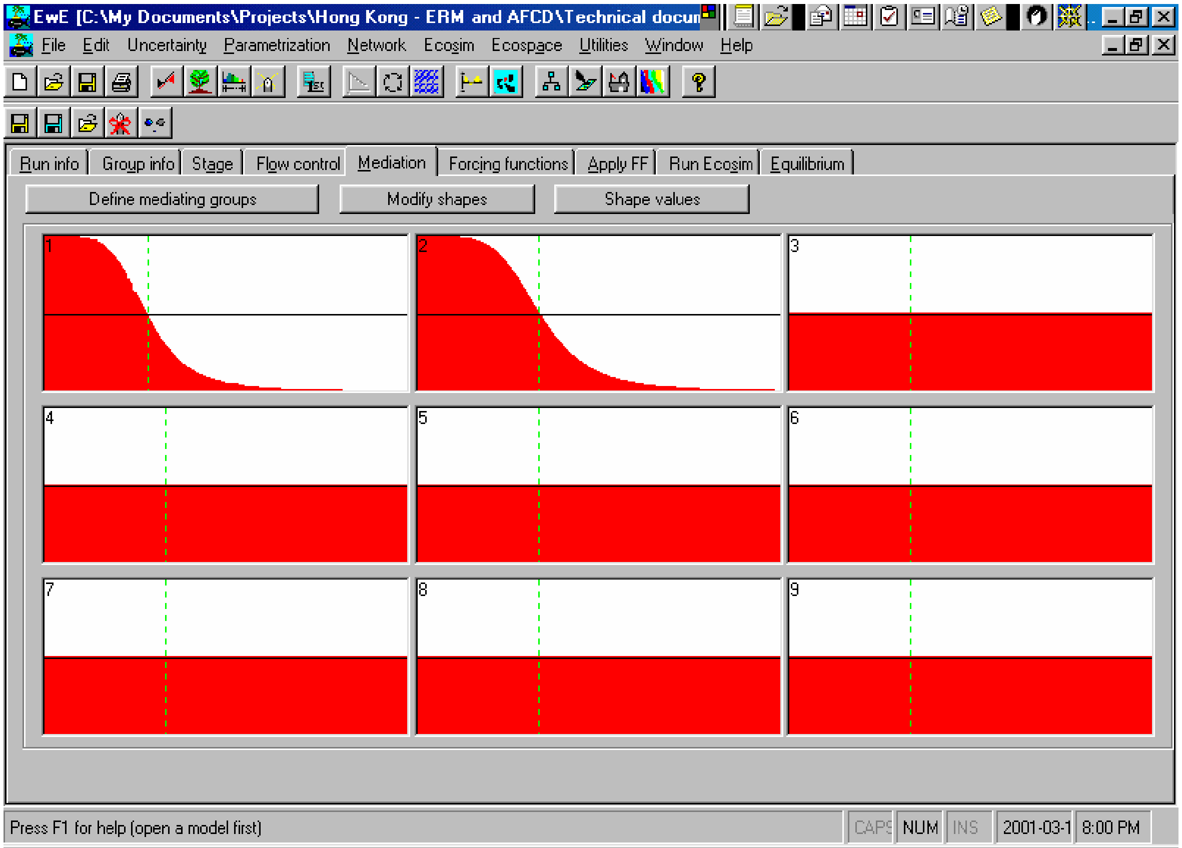


Figure 4.3 Mediating LBS with LBS-fish (panel 1) and corals with reef-associated fish (panel 2) in ECOSIM. The mediation relation was set as sigmoid for both of them, at Y_{zero} = 1, Y_{base} = 0.5, Y_{end} = 0 and steep = 5.

4.6 Fishing Effort Trajectory and Assumption

The baseline temporal simulations (Ecosim, Walters *et al.*, 1997) were run using an assumption of a 3% annually compounded increase in relative fishing power for all seven fishing fleets in the present-day model (Pitcher *et al.*, 2001, *in press*.).

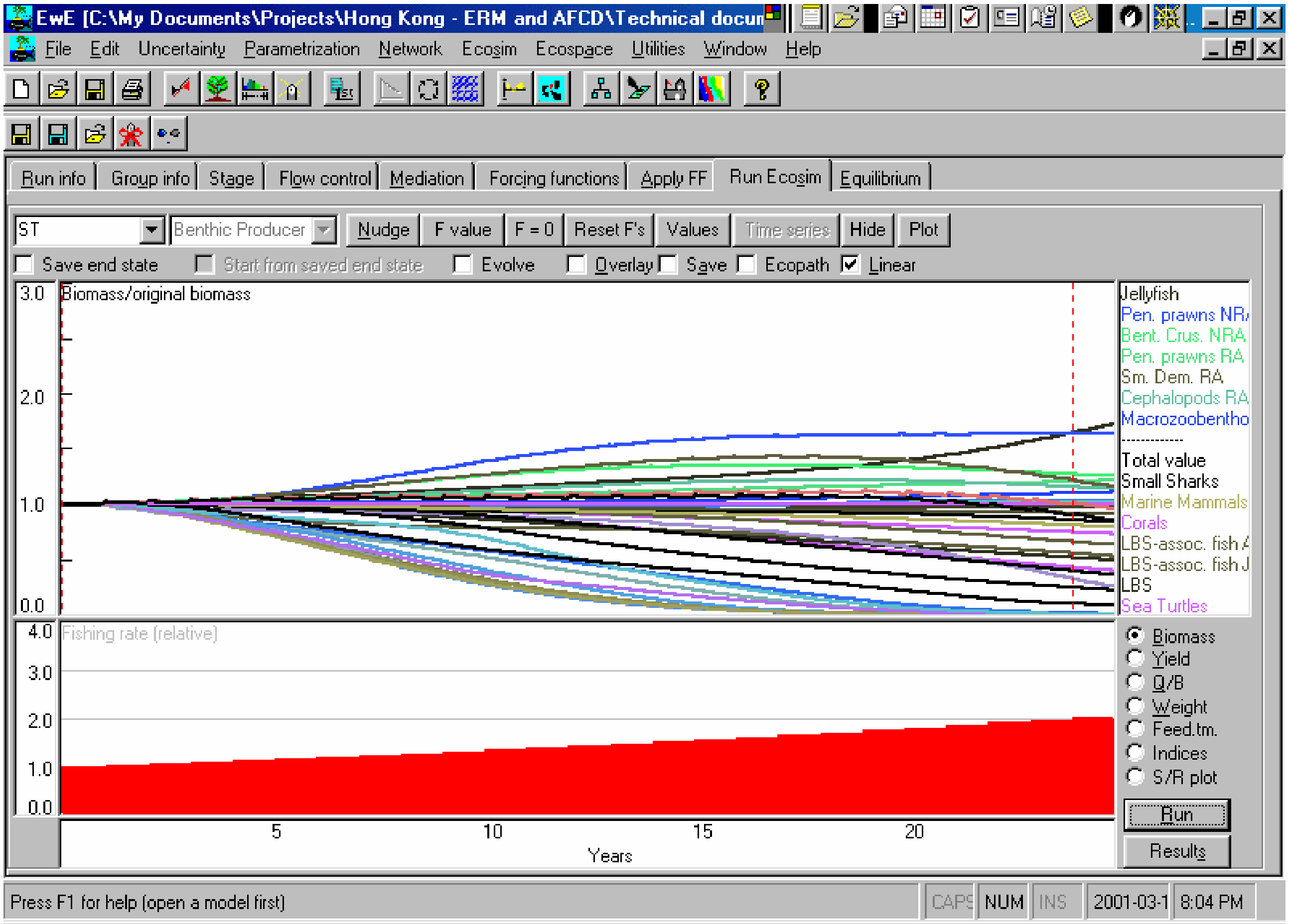


Figure 4.4 Baseline Ecosim run trajectories of all relative biomass responses (upper panel) in the present-day model over 25 years (horizontal axis). Each coloured line indicates relative biomass response of a particular functional group listed in the right panel. Lower panel represents a sketching pad for the relative fishing rate. Note in the right panel that by the end of the simulation, small and low trophic level species (such as jellyfish, prawns and benthic crustaceans) dominate.

4.7 Biomasses Depleted Under Baseline Assumption

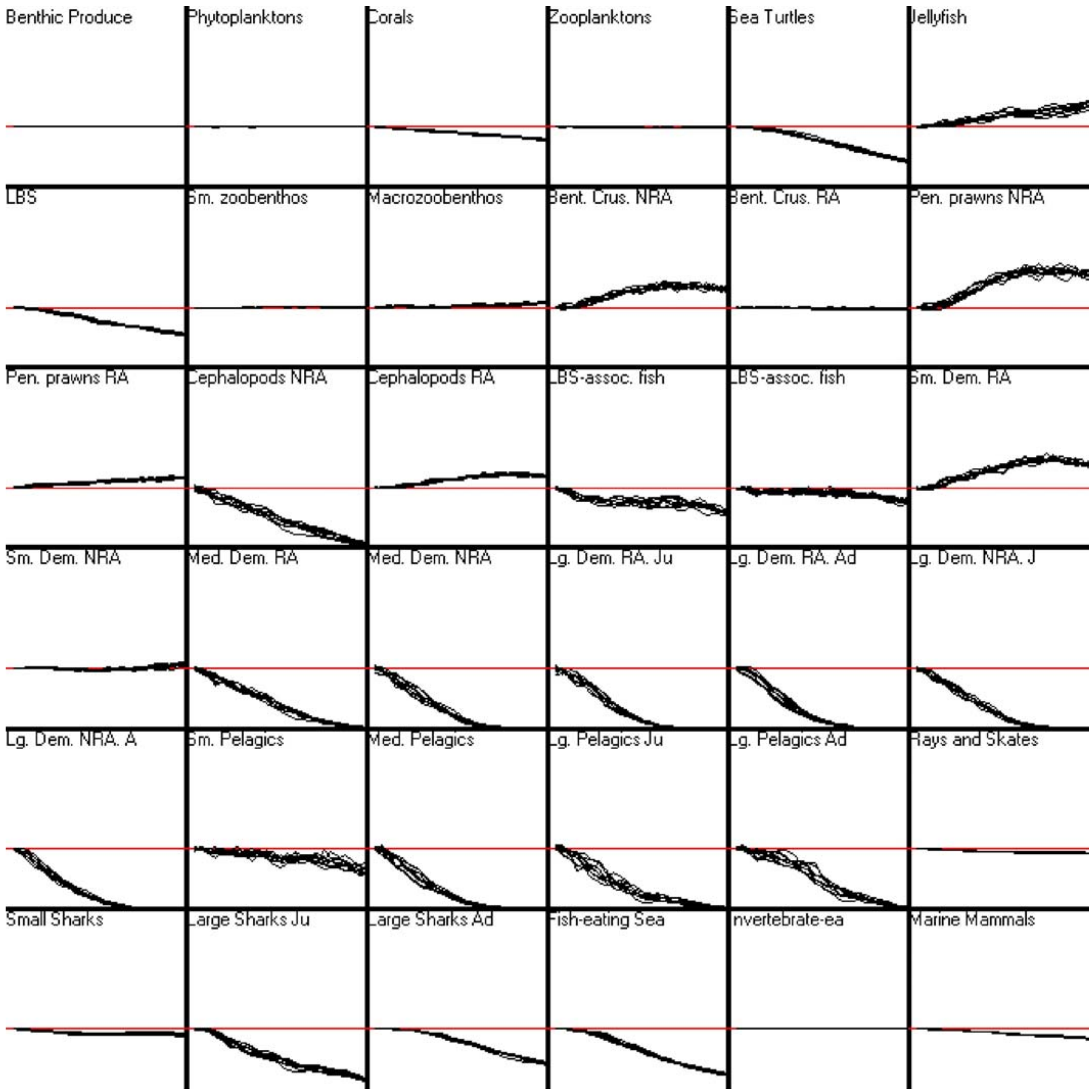


Figure 4.5 Simulated depletion of the Hong Kong ecosystem over 25 years (horizontal axis), as shown by ECOSIM. Fishing effort is increased 3% per annum. Panels represent each group in the ECOPATH model. Red lines indicate no change. Black lines show 20 simulated Monte Carlo runs of the model with 20% CVs on all population parameters.

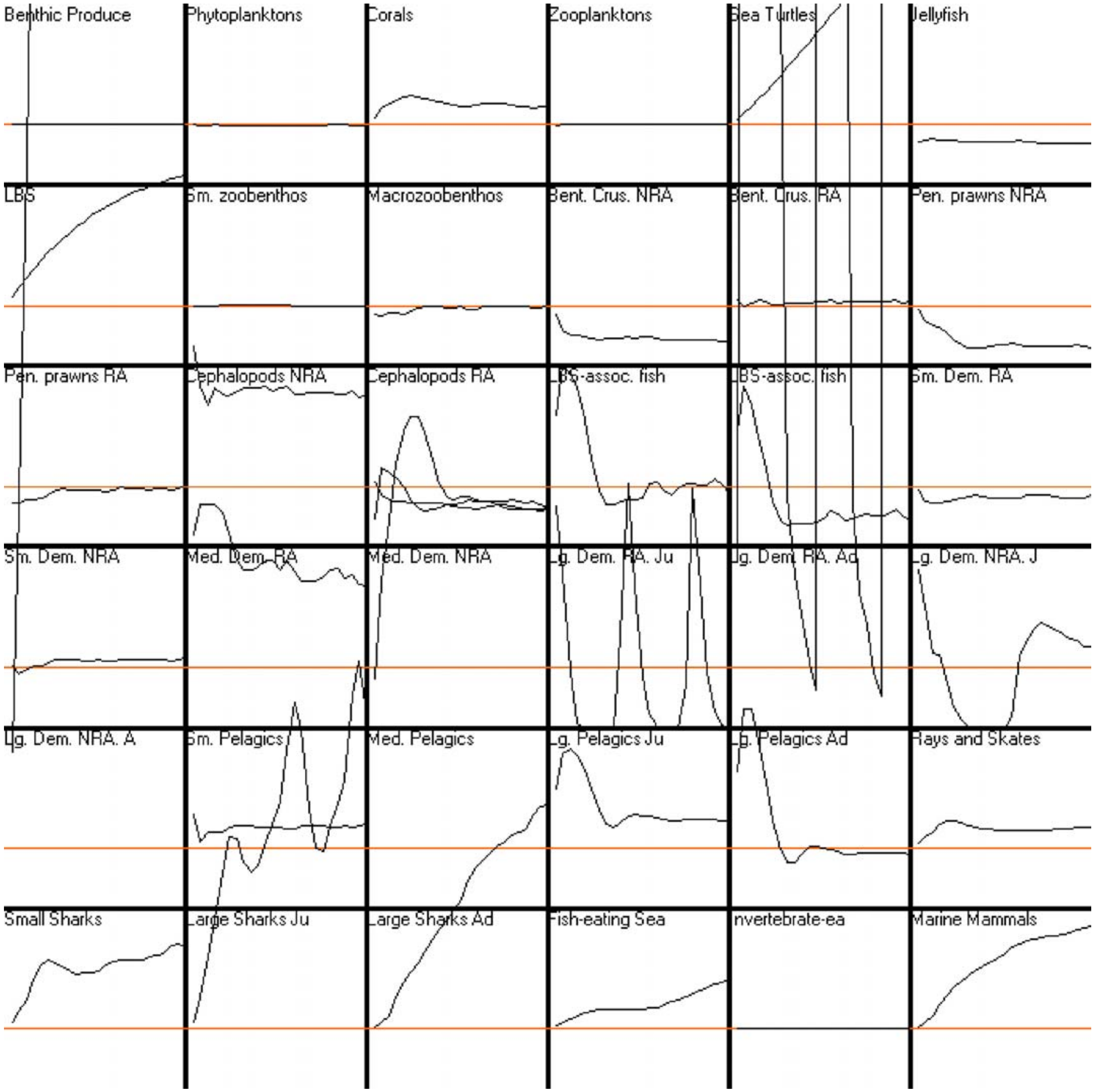


Figure 4.6 Simulated depletion of the Hong Kong ecosystem over 25 years (horizontal axis), as shown by ECOSIM. All fishing effort is halted. Panels represent each group in the ECOPATH model. Red lines indicate no change. Black lines show one runs of the model. After very large increases or decreases in biomass, some groups exhibit oscillations caused by the integration algorithm. Contrast with Figure 4.5.

Chapter 5. ECOSPACE Simulations for Hong Kong waters

T.J. Pitcher and E.A. Buchary

The Hong Kong map used for ECOSPACE simulations is loosely based on the survey data used to plan the deployment sites for artificial reefs complexes (ERM 1997, 1999). The Ecospace map is drawn on a grid of 25 by 25 cells (Figure 5.1 through 5.3). Hong Kong marine waters (area = 1,680 km^2; K. Wilson, *pers. comm.*, October 27, 2000) were represented by 351 cells, each approximately 5 km^2.

ECOSPACE is structured on biomass pools, linked by trophic (*i.e.*, predator-prey) relationships, which migrate among grids of cells. Movements of functional groups are driven by parameters such as foraging behavior, avoidance of predation, and dispersal rates that are linked to a range of defined habitats preferred by each functional group. Robust default estimation for these parameters based on life histories is built into ECOSPACE (Walters *et al.*, 1999). We only adjusted these values for strongly reef-associated groups, sessile organisms such as the Corals and LBS, and LBS-associated fish.

In the ECOSPACE simulations, all functional groups were caught by the seven fishery sectors according to the amount set initially in the landing and discard components of the ECOPATH model. Distribution of fishing effort among grid cells during simulations is predicted using a 'gravity model' where fishing effort is proportional to the biomass of the target species and the profitability of fishing it (Caddy 1975; Hilborn and Walters 1987). Each fishery sector was allowed to fish only in specific grids of the map related to spatial management scenarios. Results express average spatial responses to fishing and protected reefs.

5.1 Management area designation

Table 5.1 List of existing and proposed marine parks and marine reserve in Hong Kong waters and proposed management control and restoration measures of the Hong Kong SAR Government, as implemented in Scenario 2a. See Annex 2 for details on management control. Data source: R. Kwok (AFCD, *pers. comm.*, September 14, 2000).

No.	Location	Category	Area (km^2)	% Area [c]	Permitted Fishing [d]
Existing and proposed marine parks and marine reserve [a]:					
1	Sha Chau & Lung Kwu Chau	Marine Park	12.8	0.76	Licensed Misc., P4/7 and PS vessels
2	Hoi Ha Wan	Marine Park	2.5	0.15	Licensed Misc., P4/7 and PS vessels
3	Yat Chau Tong	Marine Park	6.6	0.39	Licensed Misc., P4/7 and PS vessels
4	Cape D'Aguilar	Marine Reserve	0.2	0.01	None
5	East Peng Chau	Proposed Marine Park	2.7	0.16	Licensed Misc., P4/7 and PS vessels
Proposed management control and restoration measures [b]:					
1	Tolo Harbour	FPA, no-take	3.3	0.19	None, AR are deployed
2	Tolo Harbour	FPA, no-trawl	53	3.16	Licensed Misc., P4/7 and PS vessels
3	Port Shelter	FPA, no-take	11.2	0.67	None, AR are deployed
4	Port Shelter	FPA, no-trawl	70.1	4.17	Licensed Misc., P4/7 and PS vessels
5	Chek Lap Kok	MEZ, no-take	6.3	0.37	None, AR are deployed

Note:

a) Designated under the 1995 Marine Parks Ordinance (Chapter 476).

b) Planned to be designated under the Fisheries Protection Ordinance (Chapter 171). However, this ordinance (*i.e.* Fisheries Protection Ordinance, FPO) has to be revised to give AFCD statutory power to designate the FPA. The revision was still under way at the time of this study.

c) The percent area values were estimated using a total Hong Kong marine areal extent of 1,680 km^2 (K. Wilson, *pers. comm.* October 27, 2000).

d) Misc. = miscellaneous small boats that employ a wide range of lines, nets, traps and hook gears, P4/7 = vessels that are less than 5 m in length, PS = purse seiners, FPA = fishery protection area, MEZ = marine exclusion zone, and AR = artificial reefs.

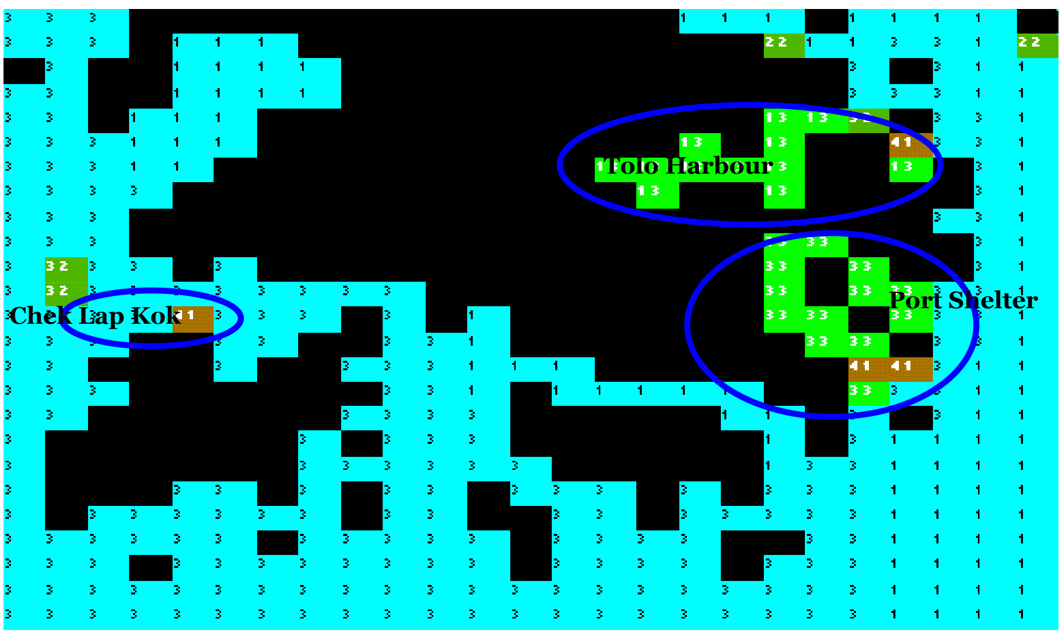


Figure 5.1 Distribution of 2 FPA management areas as implemented in Scenario 2 through Scenario 8. See Annex 2 for colour-coded keys to management areas and descriptions on management control, and Table 5.1 for list of management areas. Note the dark green cells representing existing marine parks and reserve, as also depicted in Figure 1.1.

In addition to the currently planned 2 FPA (*i.e.*, Tolo Harbour and Port Shelter) with deployed artificial reefs (AR) that are simulated in Scenario 2a, in this ECOSPACE simulation the original 5 FPA (ERM 1999) with no-take zones were also simulated. These are Tolo Harbour and Port Shelter plus the three originally planned, Sokos (63.39 km^2, 3.77% of total Hong Kong waters[1]), Po Toi (14.46 km^2, 0.86%[1]) and Ninepins (27.99 km^2, 1.67%[1]). The 5 FPA simulation (Figure 5.2) is implemented in Scenario 9.

[1] As estimated by R. Kwok, AFCD, *pers. comm.*, March 2001.

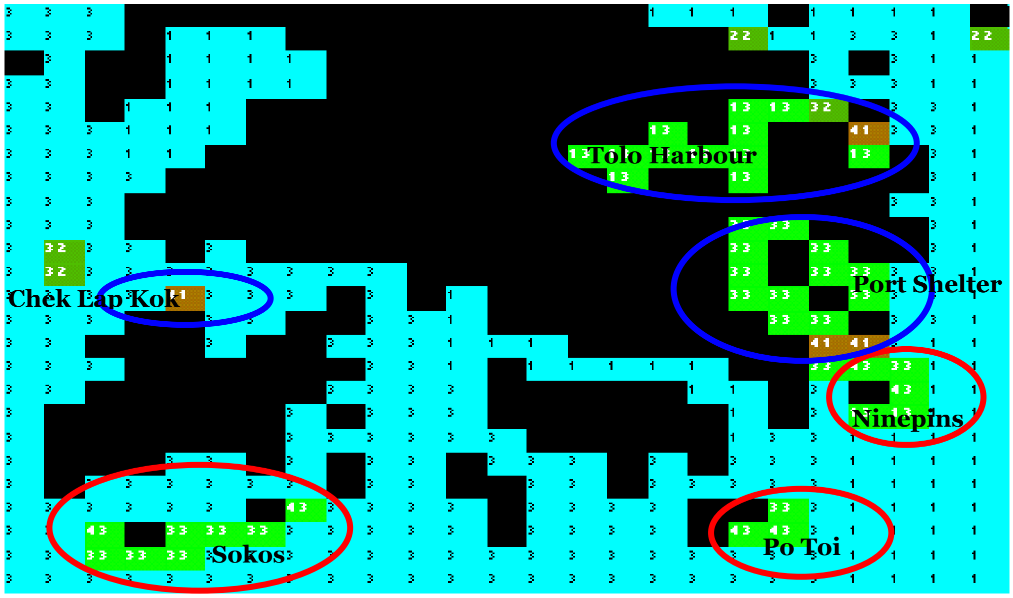


Figure 5.2 Distribution of 5 FPA management areas implemented in Scenario 9. See Annex 2 for colour-coded keys to management areas and descriptions on management control. Note the dark green cells representing existing marine parks and reserve (see Figure 1.1).

5.2 Habitat area designation and assignation of functional groups into different habitats

Four habitat types (Figure 5.3) were defined for the ECOSPACE simulations, *viz.*, 'non-reef', 'natural reefs' (which includes coral and rocky reefs), 'marine mammal' and 'artificial reefs' habitats.

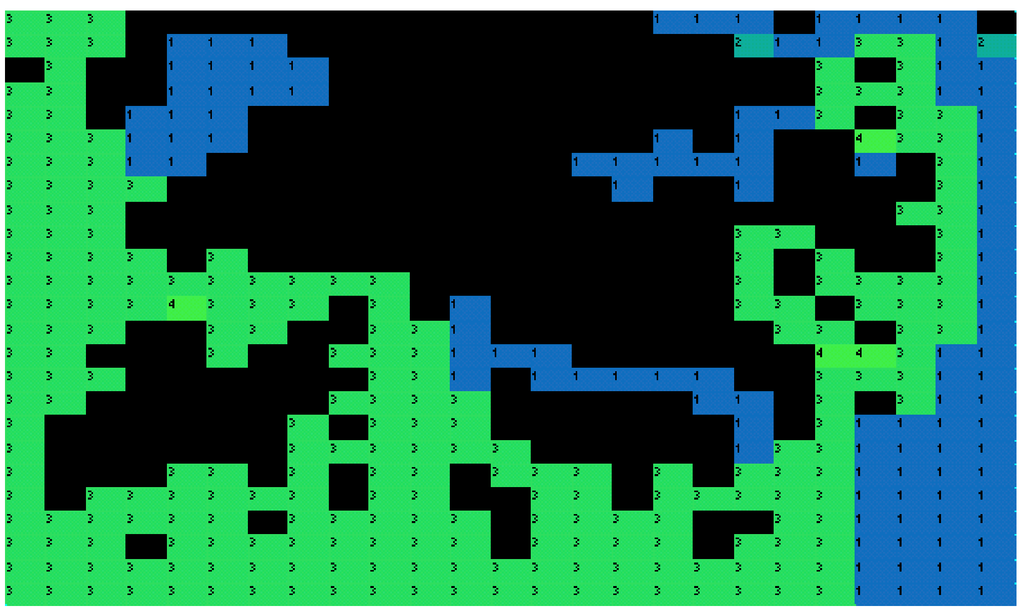


Figure 5.3 Distribution of four habitat types (*i.e*, habitat 1 = non-reef; habitat 2 = natural reefs; habitat 3 = marine mammals; habitat 4 = artificial reefs) modelled in the ECOSPACE simulation, drawn on a grid of 25 by 25 cells. The natural reef distribution (represented by only 2 cells in this model) was based on McCorry (2000), while the marine mammal habitat distribution was based on Parsons (1997). AR distribution was based on information from AFCD, as summarized in Table 5.1 and depicted in Figures 5.1 and 5.2 as brown cells.

Habitat preference of each functional group (Table 5.2) for reef, non-reefs or marine mammal habitat were assigned as follows: corals and RA groups were assigned to reef habitat only, LBS and NRA groups were assigned to both non-reefs and marine mammal habitats, the marine mammal group was assigned to reefs and mammal habitats. Other groups were assigned to all habitats.

Table 5.2 Habitat assignations to each functional group in ECOSPACE.

Group \ Habitat #	All habitats	Non-reefs	Natural Reefs	Mammals	Artificial Reefs	Ecospace area	Ecopath area
Benthic Producers	+					1	1
Phytoplankton	+					1	1
Corals			+		+	0.01709	1
Zooplankton	+					1	1
Sea Turtles	+					1	1
Jellyfish	+					1	1
LBS		+		+		0.98291	1
Sm. zoobenthos	+					1	1
Macrozoobenthos	+					1	1
Bent. Crus. NRA		+		+		0.98291	1
Bent. Crus. RA			+		+	0.01709	1
Pen. prawns NRA		+		+		0.98291	1
Pen. prawns RA			+		+	0.01709	1
Cephalopods NRA		+		+		0.98291	1
Cephalopods RA			+		+	0.01709	1
LBS-assoc. fish Juv		+		+		0.98291	1
LBS-assoc. fish Ad		+		+		0.98291	1
Sm. Dem. RA			+		+	0.01709	1
Sm. Dem. NRA		+		+		0.98291	1
Med. Dem. RA			+		+	0.01709	1
Med. Dem. NRA		+		+		0.98291	1
Lg. Dem. RA. Juv			+		+	0.01709	1
Lg. Dem. RA. Ad			+		+	0.01709	1
Lg. Dem. NRA. Juv		+		+		0.98291	1
Lg. Dem. NRA. Ad		+		+		0.98291	1
Sm. Pelagics	+					1	1
Med. Pelagics	+					1	1
Lg. Pelagics Juv	+					1	1
Lg. Pelagics Ad	+					1	1
Rays and Skates	+					1	1
Small Sharks	+					1	1
Large Sharks Juv.	+					1	1
Large Sharks Ad.	+					1	1
Fish-eating Seabirds	+					1	1
Invertebrate-eating Seabirds	+					1	1
Marine Mammals			+	+	+	0.69231	1
Detritus	+					1	1
Habitat area	1	0.30769	0.0057	0.67521	0.0114	-	-

5.3 Dispersal rate, predation and foraging parameters

Dispersal rate, predation and foraging outside preferred habitats were adjusted as shown in Table 5.3.

Table 5.3 Adjustments made to the dispersal, predation and foraging parameters in the ECOSPACE simulation of the Hong Kong model. Explanation of these parameters is detailed in Christensen *et al*. (2000).

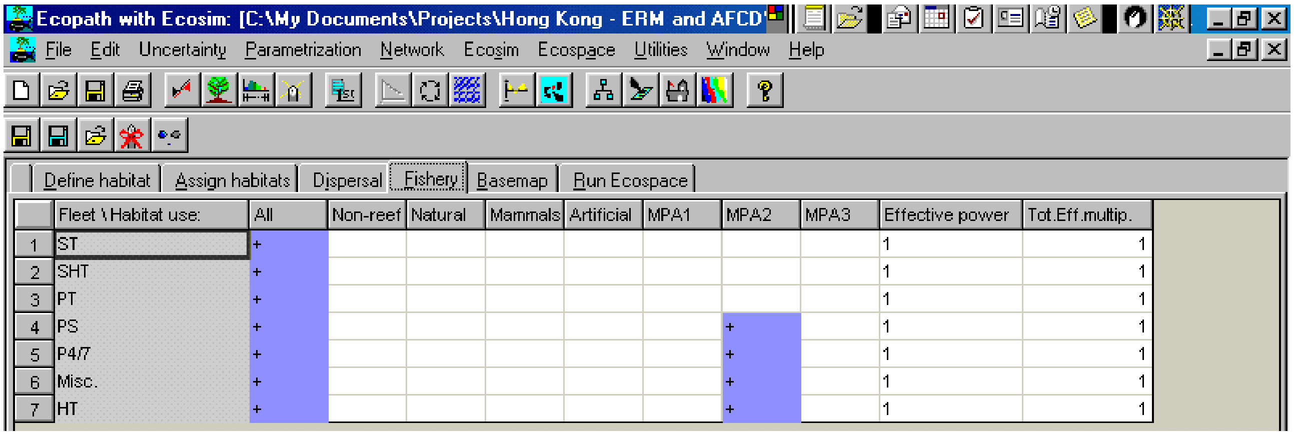
No.	Group name	Base Dispersal rate (km/year) [a]	Relative dispersal in bad habitat [b]	Relative vulnerability to predation in bad habitat [c]	Relative feeding rate in bad habitat [d]
1	Bent. producers	0.1	5	2	0.5
2	Phytoplankton	1	5	2	0.5
3	Corals	0.2	10	50	0.02
4	Zooplankton	1	5	2	0.5
5	Sea turtles	100	5	2	0.5
6	Jellyfish	60	5	2	0.5
7	LBS	10	10	50	0.1
8	Sm. zoobenthos	34	5	2	0.5
9	Macrozoobenthos	41	5	2	0.5
10	Bent. Crust. NRA	47	5	2	0.5
11	Bent. Crust. RA	62	7	10	0.1
12	Pen. prawns NRA	53	5	2	0.5
13	Pen. prawns RA	10	0.1	100	0.01
14	Cephalopods NRA	80	5	2	0.5
15	Cephalopods RA	78	7	5	0.1
16	LBS-A fish Juv	58	5	10	0.05
17	LBS-A fish Ad	81	5	10	0.05
18	Sm. Dem. RA	60	7	5	0.1
19	Sm. Dem. NRA	65	5	2	0.5
20	Med. Dem. RA	73	7	5	0.1
21	Med. Dem. NRA	76	5	2	0.5
22	Lg. Dem. RA Juv	20	2	200	0.01
23	Lg. Dem. RA Ad	0.7	0.1	200	0.01
24	Lg. Dem. NRA Juv	62	5	2	0.5
25	Lg. Dem. NRA Ad	83	5	2	0.5
26	Sm. Pelagics	63	5	2	0.5
27	Med. Pelagics	81	5	2	0.5
28	Lg. Pelagics Juv	67	5	2	0.5
29	Lg. Pelagics Ad	93	5	2	0.5
30	Rays and Skates	88	5	2	0.5
31	Small Sharks	100	5	2	0.5
32	Large Sharks Juv	100	5	2	0.5
33	Large Sharks Ad	300	5	2	0.5
34	Fish-eating seabirds	91	5	2	0.5
35	Invert.-eating seabirds	91	5	2	0.5
36	Mar. Mammals	300	2	2	0.5
37	Detritus	1	5	2	0.5

Note:
a) See explanation in Christensen *et al*. (2000).
b) Default value is 2 and upper limit is 10.
c) Default value is 2 and upper limit is 100. A value of 1 will make this function inoperative.
d) Default value is 0.5 and it can be reduced down to 0.01. A value of 1 (unity) will make this function inoperative.

5.4 Assignation of fisheries sectors into different habitats

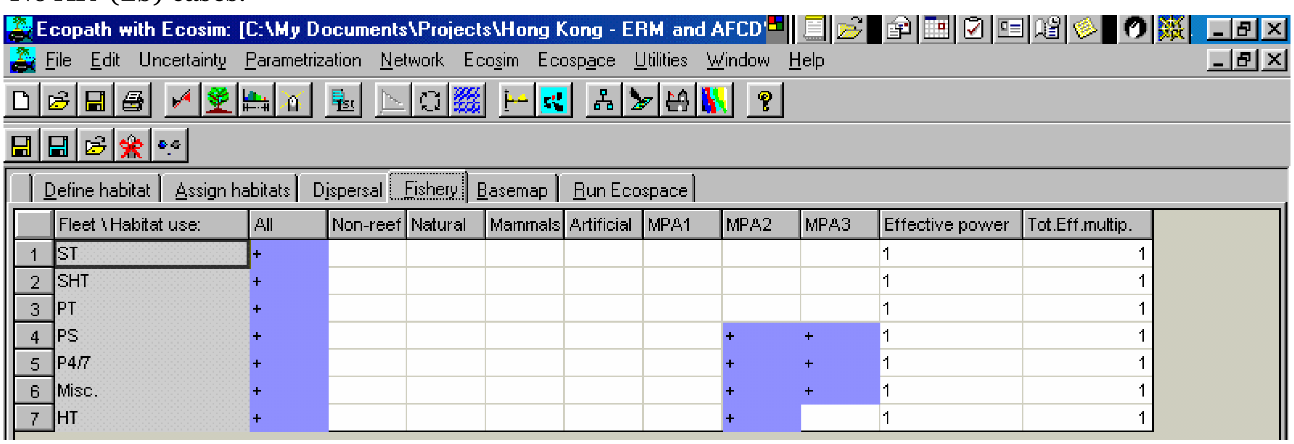
Each fishery sector was allowed to fish only in specific grids of the map delimited by the spatial management scenarios tested. Each scenario tests the effect of artificial reefs by running the scenario both under the 'AR' (denoted by an 'a' suffix) and 'No AR' (denoted by a 'b' suffix) cases. In the simulations, three management zones are defined, *i.e.*, 'MPA1' signifies FPA no-take areas/no-take MEZ, 'MPA2' signifies existing marine parks and reserve, while 'MPA3' signifies FPA no-trawl areas. See Chapter 8 for detail description on each of the management scenario.

Scenario 1a and 1b:
Do nothing, no plan and baseline scenario, under 'AR' (1a) and 'No AR' (1b) cases. In here, MPA1 and MPA3 are non-existent.



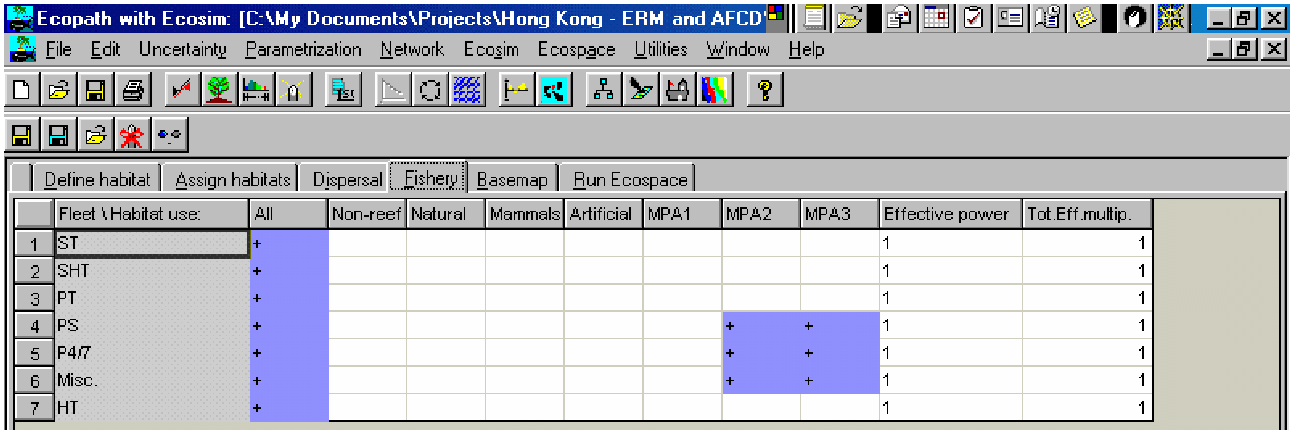
	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST	+								1	1
2	SHT	+								1	1
3	PT	+								1	1
4	PS	+						+		1	1
5	P4/7	+						+		1	1
6	Misc.	+						+		1	1
7	HT	+						+		1	1

Scenario 2a and 2b:
The current 2FPA program, which comprised of existing marine parks and reserve (*viz.*, MPA2), plus two FPA no-take zones (*viz.*, MPA1), two FPA no-trawl zones (*viz.*, MPA3) and one MEZ no-take zone (*viz.*, MPA1). Here, the effect of artificial reefs is tested both under the 'AR' (2a) and 'No AR' (2b) cases.



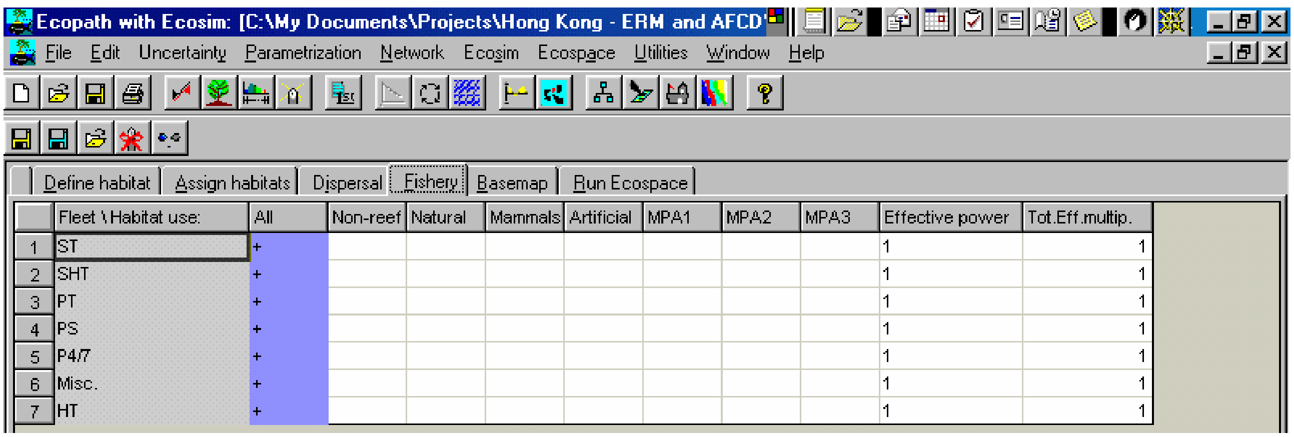
	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST	+								1	1
2	SHT	+								1	1
3	PT	+								1	1
4	PS	+						+	+	1	1
5	P4/7	+						+	+	1	1
6	Misc.	+						+	+	1	1
7	HT	+						+		1	1

Scenario 3a and 3b:
No trawling in all of the 3 planned management zones (*i.e.*, MPA1, MPA2 and MPA3), with 'AR' (3a) and 'No AR' (3b). All other fishing sectors fish as in Scenario 2.



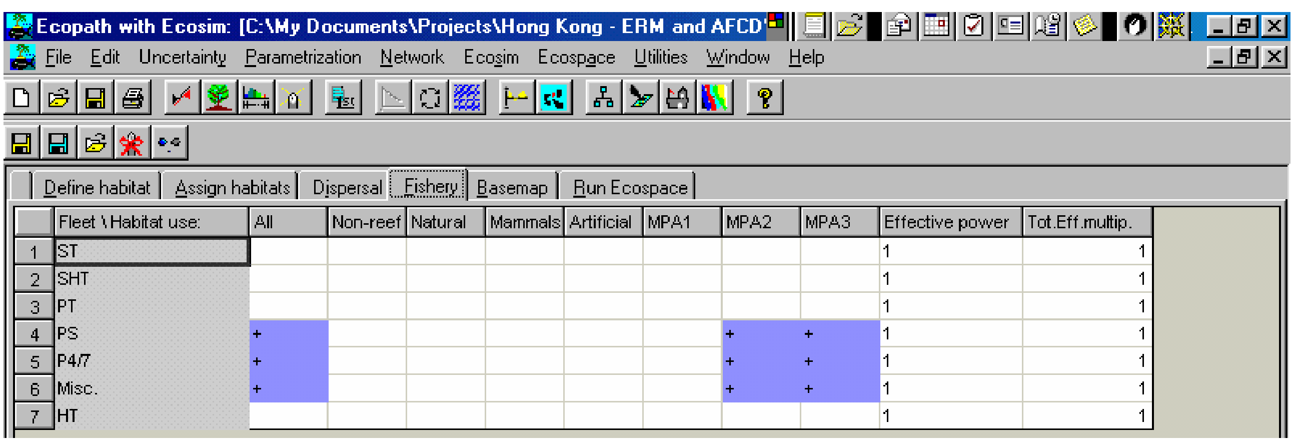
	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST	+								1	1
2	SHT	+								1	1
3	PT	+								1	1
4	PS	+						+	+	1	1
5	P4/7	+						+	+	1	1
6	Misc.	+						+	+	1	1
7	HT	+								1	1

Scenario 4a and 4b:
No-take in all of the 3 planned management zones (*i.e.*, MPA1, MPA2 and MPA3), with 'AR' (4a) and 'No AR' (4b).



	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST	+								1	1
2	SHT	+								1	1
3	PT	+								1	1
4	PS	+								1	1
5	P4/7	+								1	1
6	Misc.	+								1	1
7	HT	+								1	1

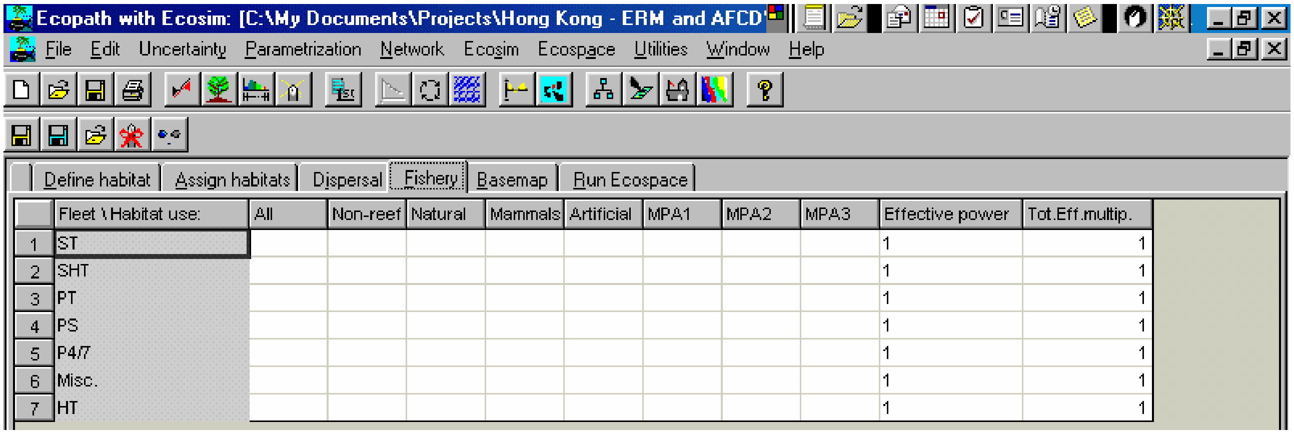
Scenario 5a and 5b:
No trawling everywhere within Hong Kong waters, with 'AR' (5a) and 'No AR' (5b). All other sectors fish as in Scenario 2.



	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST									1	1
2	SHT									1	1
3	PT									1	1
4	PS	+						+	+	1	1
5	P4/7	+						+	+	1	1
6	Misc.	+						+	+	1	1
7	HT									1	1

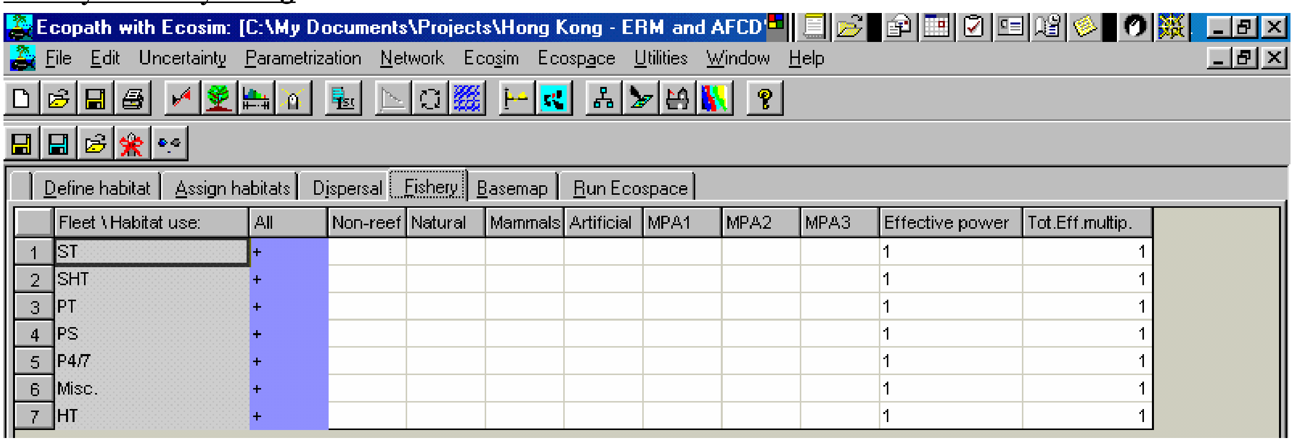
Scenario 6a and 6b:
No take everywhere within Hong Kong waters with a resumption of fishing after 5 years (maintaining no-take in the planned management zones), with 'AR' (6a) and 'No AR' (6b). After 5 years of complete no-take closure, all sectors fish as outlined in Scenario 4.

<u>During the first 5 years</u>:



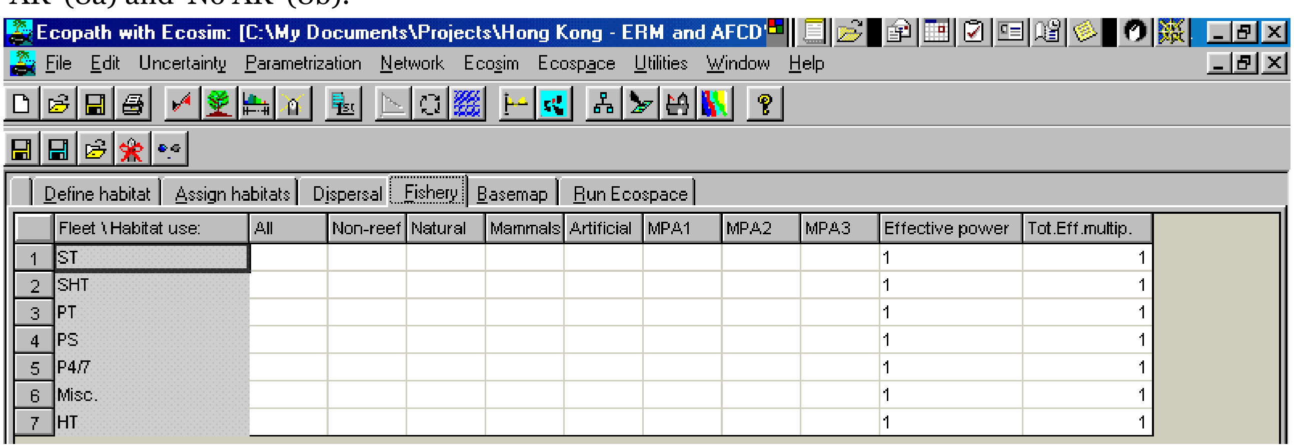
	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST									1	1
2	SHT									1	1
3	PT									1	1
4	PS									1	1
5	P4/7									1	1
6	Misc.									1	1
7	HT									1	1

<u>From year 6 to year 25</u>:



	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST	+								1	1
2	SHT	+								1	1
3	PT	+								1	1
4	PS	+								1	1
5	P4/7	+								1	1
6	Misc.	+								1	1
7	HT	+								1	1

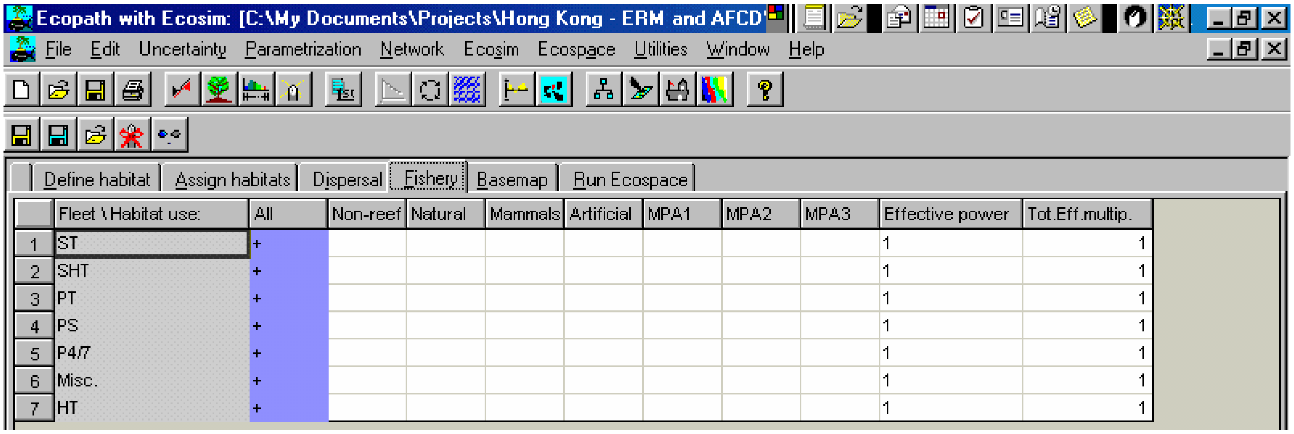
Scenario 8a and 8b:
No take everywhere within Hong Kong waters (for the entire 25 years modelling period), with 'AR' (8a) and 'No AR' (8b).



	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST									1	1
2	SHT									1	1
3	PT									1	1
4	PS									1	1
5	P4/7									1	1
6	Misc.									1	1
7	HT									1	1

Scenario 9a and 9b:

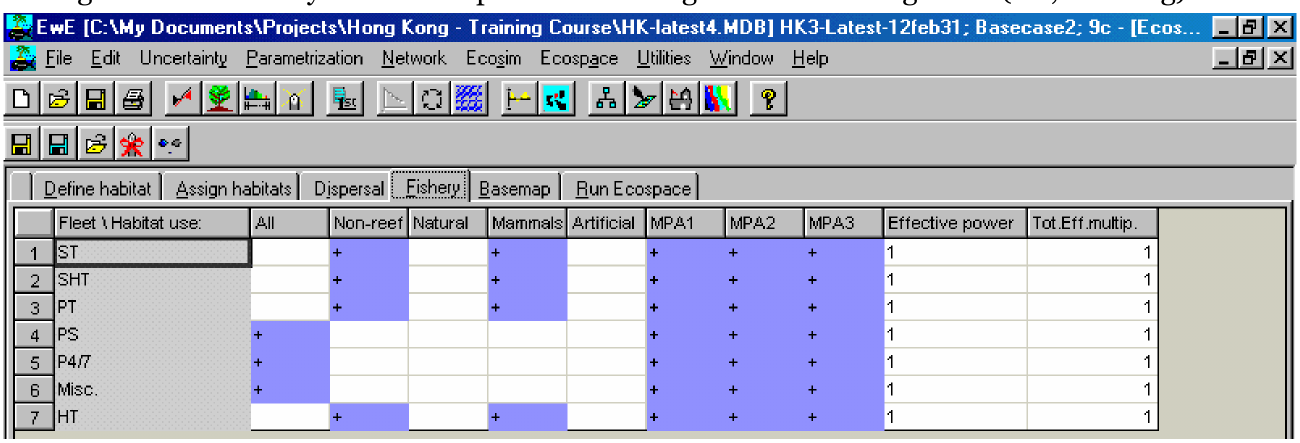
Original 5 FPA with no-take zones, under 'AR' (9a) and 'No AR' (9b) cases. Management of these areas is all completely no-take. In the simulation, the extra three management areas (*i.e.*, Sokos, Po Toi and Ninepins) are categorized as MPA3.



	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST	+								1	1
2	SHT	+								1	1
3	PT	+								1	1
4	PS	+								1	1
5	P4/7	+								1	1
6	Misc.	+								1	1
7	HT	+								1	1

Scenario 9c and 9d:

Cheating scenario with original 5 FPA, with 'AR' (9c) and 'No AR' (9d). All trawlers fish everywhere, except at areas where there are natural reefs and at areas where artificial reefs were deployed. Herein, AR act as 'sleeping police officers' that physically prevent trawling. All other fishing sectors fish everywhere. Compliance to management zones is ignored (*i.e.*, cheating).



	Fleet \ Habitat use:	All	Non-reef	Natural	Mammals	Artificial	MPA1	MPA2	MPA3	Effective power	Tot.Eff.multip.
1	ST		+		+		+	+	+	1	1
2	SHT		+		+		+	+	+	1	1
3	PT		+		+		+	+	+	1	1
4	PS	+					+	+	+	1	1
5	P4/7	+					+	+	+	1	1
6	Misc.	+					+	+	+	1	1
7	HT		+		+		+	+	+	1	1

Chapter 6. ECOSPACE simulations for the People's Republic of China (PRC) inshore waters

T.J. Pitcher and E.A. Buchary

6.1 Underlying assumptions

The ECOPATH model for the PRC inshore waters (*viz*., South China Sea area) is an extension of the present-day ECOPATH model of Hong Kong waters, with the following assumptions:

(a) The area of the South China Sea modelled is approximately 15 times that of HK waters, extending south of HK to at least one cell beyond the boundary of the 'no-trawl' zone, which approximates to the 40 m depth contour.

(b) The PRC simulations employ an extension of the HK ecosystem model with the same ECOPATH trophic structure, and the same ECOSIM feeding behavior, trophic ontogeny, flow control, mediation and baseline fishing effort parameters. Similar ECOSPACE habitat properties apply, except that a few groups, such as small pelagics, seabirds and prawns are confined to water < 40m deep. Similar ECOSPACE dispersal rate, predation and foraging rate parameters of the HK model are also applied in the PRC model.

(c) Three cells of natural reefs have been assumed in PRC waters, based on anecdotal information.

(d) In the PRC model, Hong Kong's jurisdiction is represented at grid cells of 'habitat' and 'management zone'. All seven fishing sectors of Hong Kong fish all the time in all 'Hong Kong' grid cells.

(e) The PRC fishing fleet structure is the same as that of the Hong Kong fishing fleets.

(f) In all scenarios, no hang trawlers (HT), stern trawlers (ST) or pair trawlers (PT) fish in PRC water depth < 40 m.

(g) Meanwhile, shrimp trawlers (SHT) only fish in PRC waters < 40 m, and are simulated as: (1) fishing fully (*vide* 'SHT' in Table 8.3) and (2) not fishing at all (*vide* 'No SHT' in Table 8.3).

(h) AFCD requested that we simulate a one sixth reduction of shrimp trawling (SHT) in the PRC model to reflect the 2-month (June and July) annual shrimp trawl ban in PRC waters < 40 m. However, ECOSPACE cannot yet accommodate a temporal fishing reduction on a single fleet. Therefore, in our simulation the one sixth reduction (*vide* '5/6' in Table 8.3) applied to all fishing sectors that operate in PRC waters < 40 m.

(i) 'P4/7' and 'Misc.' sector vessels do not fish within the PRC waters > 40 m deep. Purse seiners (PS) operate in both PRC waters < 40 m and > 40 m.

(j) Modelling time is 25 years.

(k) There are no AR in the PRC Model.

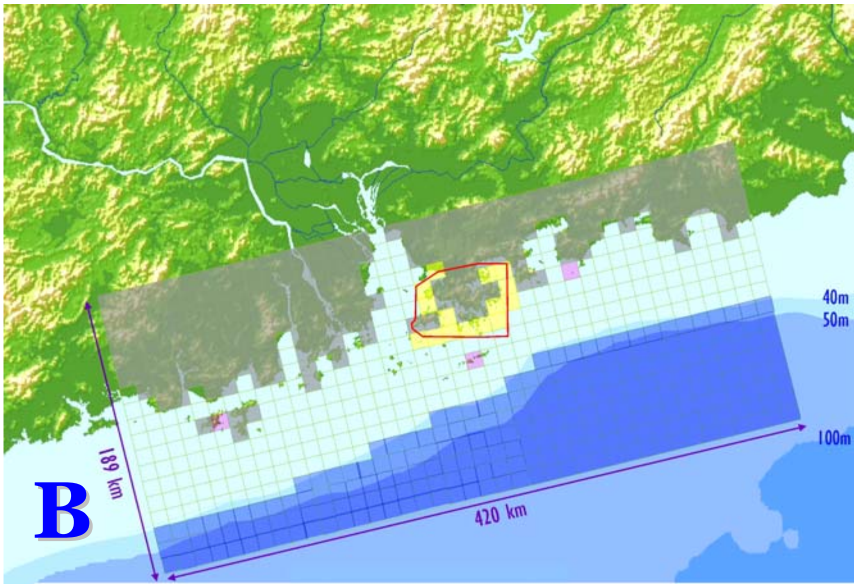
(l) No bio-economic nor game theoretic analysis were requested for the PRC simulations.

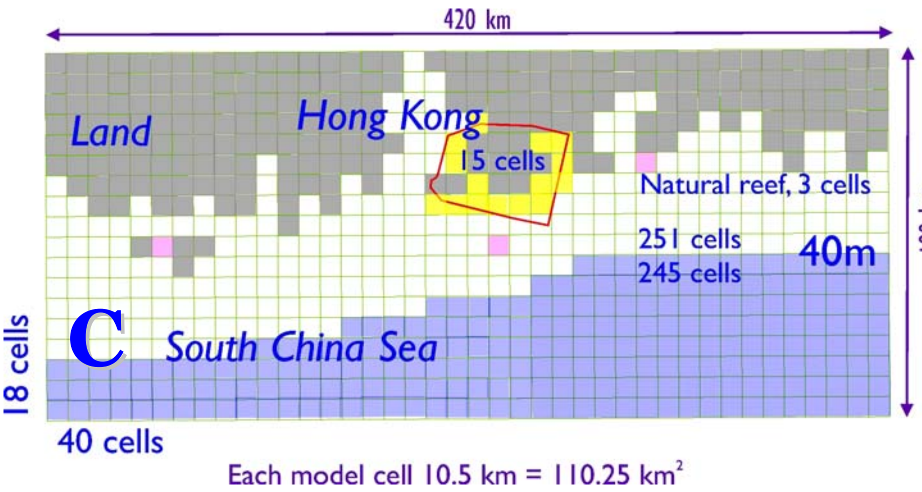
6.2 Management area designation and mapping

Maps illustrating construction of an Ecospace model for simulated fishery zones in the South China Sea

A. Map showing approximately 50,000 km² area of the South China Sea. Red line shows approximate boundary of Hong Kong jurisdiction. Sea depth contours drawn at 100m, 50m and 40m. Grid of 18 x 40 cells (green) indicates area and orientation for ecosystem simulation model.

B. Construction of map cells for the PRC ecosystem simulation model. Grey shaded cells in grid = land boundary. Pink shaded cells in grid (3) = remaining natural reef areas. Blue shaded cells (245) = water >40m deep. Unshaded cells (251) = waters < 40m deep, subject to a trawl ban and seasonal prawn trawl closure in the PRC. Yellow shaded cells (15) = waters under Hong Kong jurisdiction.





C. Final grid map of cells used in the ecosystem simulations. Each model cell is 10.5 km square = 110.25 km² . Hong Kong area (15 cells) = approx 1654 km² ; PRC waters < 40m deep = 27,673 km² ; PRC waters > 40m deep = 27,011 km² .

6.3 Habitat and management area designation and assignation of functional groups into different habitats

In the PRC modelling, four habitat types were modelled (Figure 6.1). These are 'PRC waters < 40m', 'PRC waters > 40 m', 'natural reefs' and 'HK waters'.

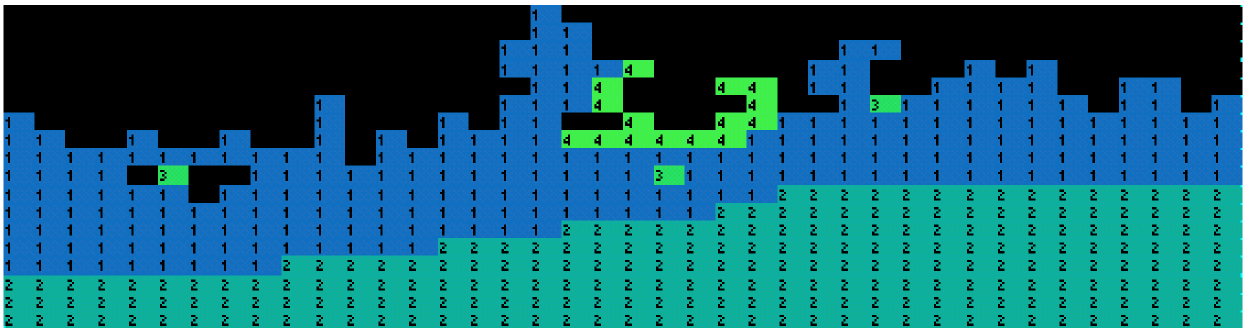


Figure 6.1 Distribution of four habitat types (*i.e*, habitat 1 = PRC waters < 40 m; habitat 2 = PRC waters > 40 m; habitat 3 = natural reefs; habitat 4 = HK waters) modelled in the ECOSPACE simulation, drawn on a grid of 18 by 40 cells of the PRC inshore waters map.

Management scenarios tested are based on three spatial zones (Figure 6.2 and Figure 6.3), *i.e.*, 'HK zone', 'PRC waters < 40 m' and 'no-take PRC' which are applied in Scenario PRC 5. In PRC 0 through PRC 4 scenarios, only 'HK zone' and 'PRC waters < 40 m' are implemented. Note that both 'HK zone' as a management zone (Figure 6.2) and 'HK waters' (Figure 6.1) as a habitat overlap.

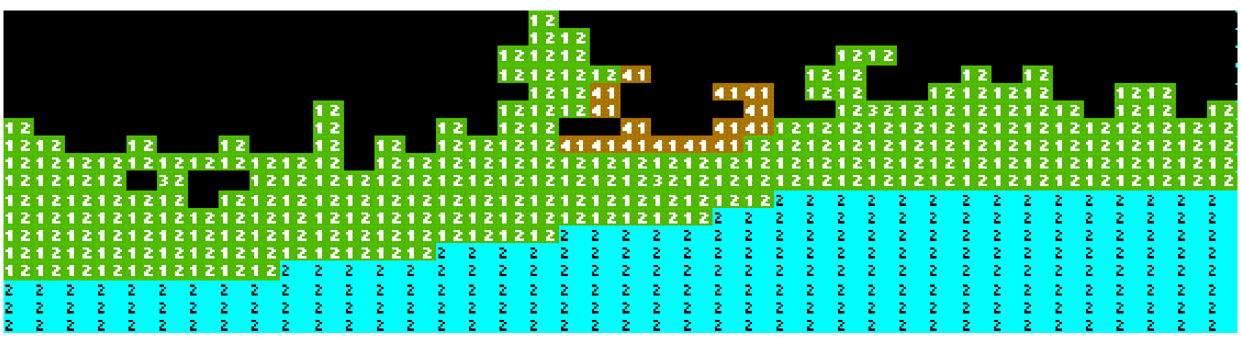


Figure 6.2 Distribution of management areas in the ECOSPACE simulation of the PRC model as implemented in Scenarios PRC 0 through PRC 4 drawn on a grid of 18 by 40 cells. Brown denotes 'HK zone', while green color denotes 'PRC < 40 m '. Blue color denotes 'PRC waters > 40 m' habitat (see Figure 6.1).

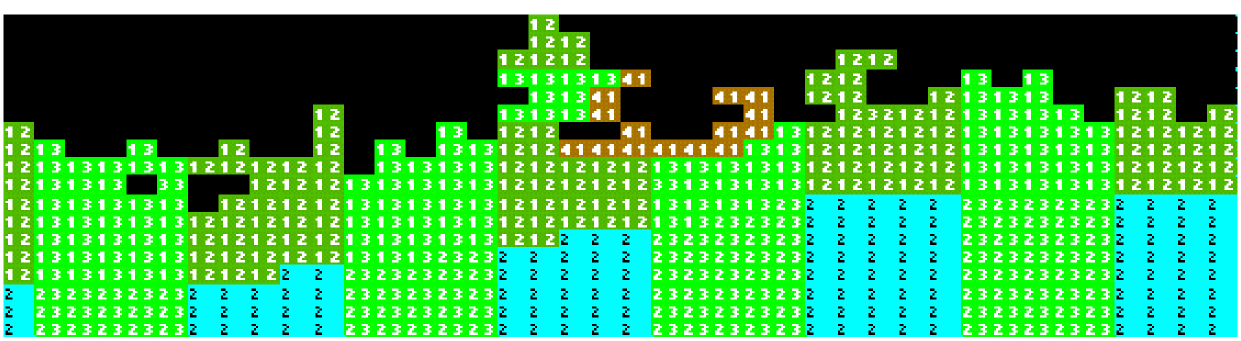


Figure 6.2 Distribution of management areas in the ECOSPACE simulation of the PRC model as implemented in Scenario PRC 5 drawn on a grid of 18 by 40 cells. Brown denotes 'HK zone', dark green denotes 'PRC < 40 m ', light green denotes 'no-take PRC' which amounts to 50% of total PRC waters. Blue denotes 'PRC waters > 40 m' habitat (see Figure 6.1).

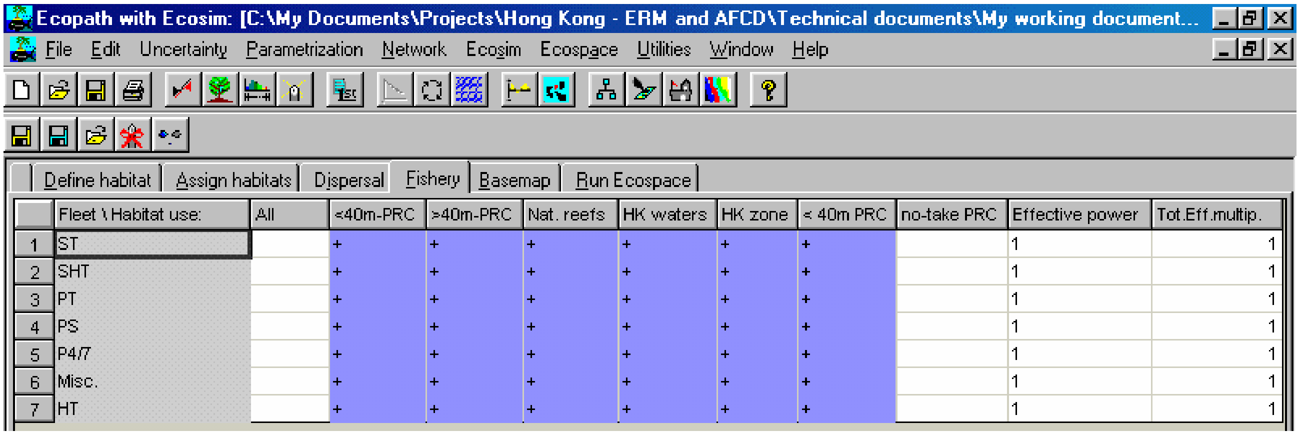
As mentioned earlier, the habitat preference of each functional group in ECOSPACE are similar to those in the Hong Kong model, except for some groups (*i.e.*, small pelagics, prawns and seabirds which are confined to PRC waters < 40 m and HK waters only) as noted in the Table 6.1 below:

Table 6.1 Habitat assignation to each functional group in ECOSPACE for the PRC model.

Group \ Habitat #	All habitats	PRC waters < 40 m	PRC waters > 40 m	Natural Reefs	HK waters	Ecospace area	Ecopath area
Benthic Producers	+					1	1
Phytoplankton	+					1	1
Corals				+		0.00604	1
Zooplankton	+					1	1
Sea Turtles	+					1	1
Jellyfish	+					1	1
LBS		+	+		+	0.99396	1
Sm. zoobenthos	+					1	1
Macrozoobenthos	+					1	1
Bent. Crus. NRA		+	+		+	0.99396	1
Bent. Crus. RA				+		0.00604	1
Pen. prawns NRA		+			+	0.52918	1
Pen. prawns RA				+		0.00604	1
Cephalopods NRA		+	+		+	0.99396	1
Cephalopods RA				+		0.00604	1
LBS-assoc. fish Juv		+	+		+	0.99396	1
LBS-assoc. fish Ad		+	+		+	0.99396	1
Sm. Dem. RA				+		0.00604	1
Sm. Dem. NRA		+			+	0.52918	1
Med. Dem. RA				+		0.00604	1
Med. Dem. NRA		+	+		+	0.99396	1
Lg. Dem. RA. Juv				+		0.00604	1
Lg. Dem. RA. Ad				+		0.00604	1
Lg. Dem. NRA. Juv		+	+		+	0.99396	1
Lg. Dem. NRA. Ad		+	+		+	0.99396	1
Sm. Pelagics		+			+	0.52918	1
Med. Pelagics		+	+		+	0.99396	1
Lg. Pelagics Juv		+	+		+	0.99396	1
Lg. Pelagics Ad	+					1	1
Rays and Skates	+					1	1
Small Sharks	+					1	1
Large Sharks Juv.	+					1	1
Large Sharks Ad.	+					1	1
Fish-eating Seabirds		+			+	0.52918	1
Invertebrate-eating Seabirds		+			+	0.52918	1
Marine Mammals		+		+	+	0.53521	1
Detritus	+					1	1
Habitat area	1	0.49899	0.46479	0.00604	0.03018	-	-

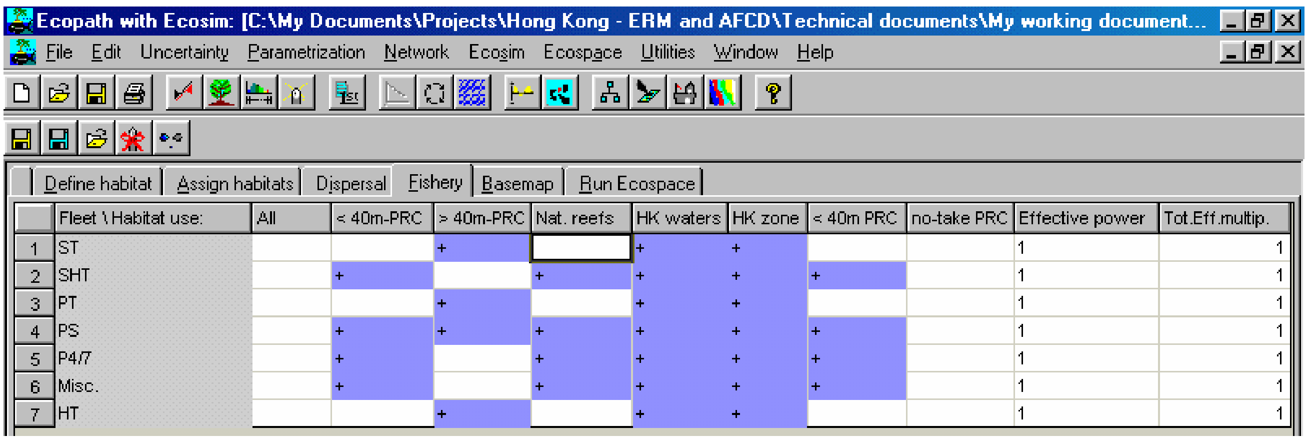
6.4 Assignation of fisheries sectors into different habitats and management areas

Scenario PRC 0:
All sectors fish everywhere all year.



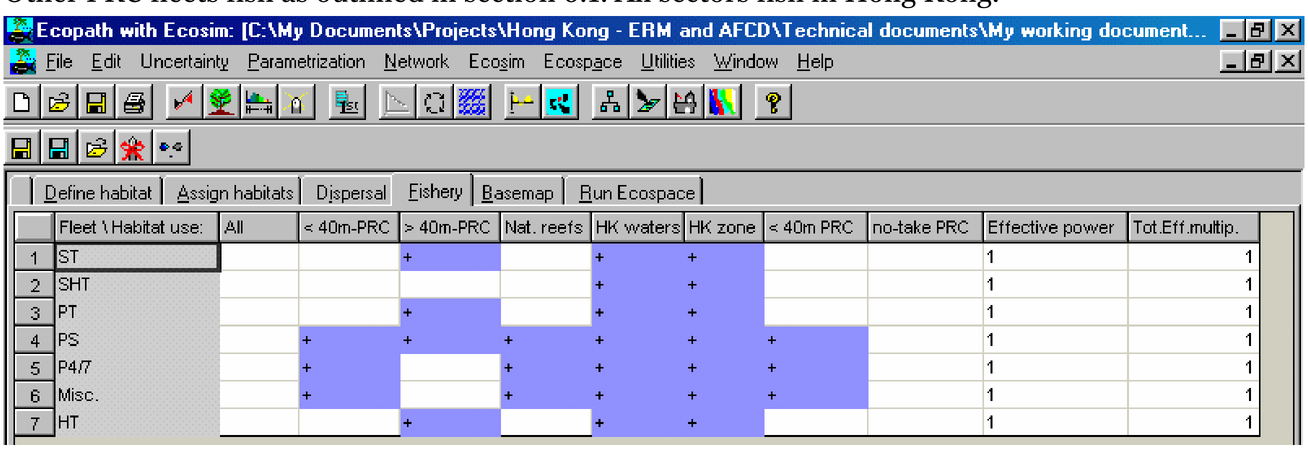
	Fleet \ Habitat use:	All	<40m-PRC	>40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST		+	+	+	+	+	+		1	1
2	SHT		+	+	+	+	+	+		1	1
3	PT		+	+	+	+	+	+		1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+	+	+	+	+	+		1	1
6	Misc.		+	+	+	+	+	+		1	1
7	HT		+	+	+	+	+	+		1	1

Scenario PRC 1a:
SHT operate in PRC waters <40m, no other trawling in PRC waters <40m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.



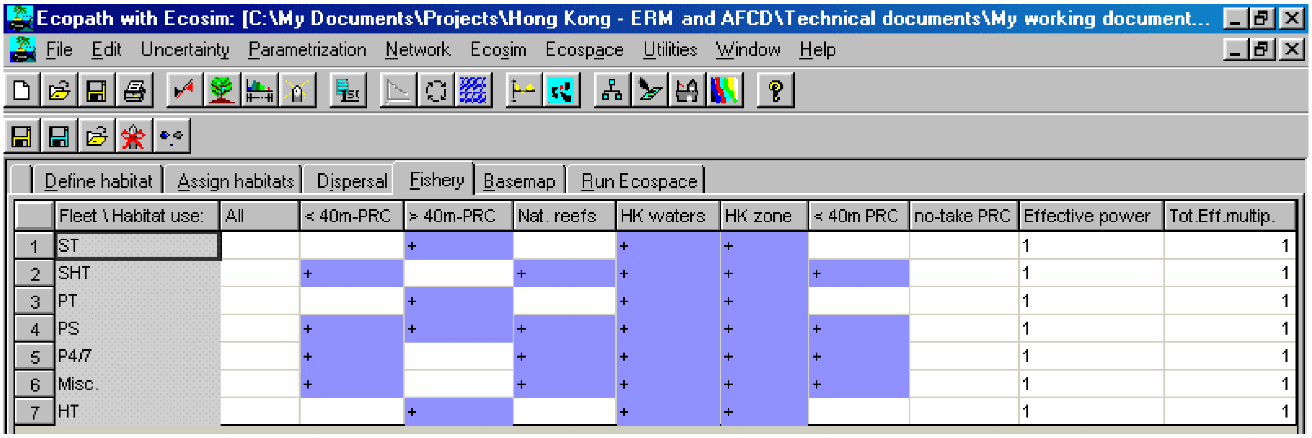
	Fleet \ Habitat use:	All	< 40m-PRC	> 40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT		+		+	+	+	+		1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

Scenario PRC 1b:
No SHT in PRC waters <40m (except in Hong Kong), no other trawling in PRC waters <40m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.

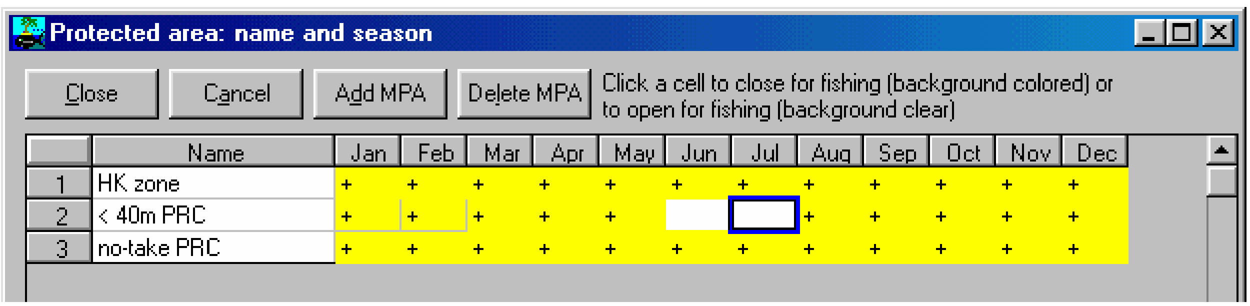


	Fleet \ Habitat use:	All	< 40m-PRC	> 40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT					+	+			1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

Scenario PRC 1c:
All fisheries are reduced by one sixth (*vide* '5/6' in Table 8.3) in PRC waters <40 m. SHT operate in PRC waters <40m, no other trawling in PRC waters <40m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.

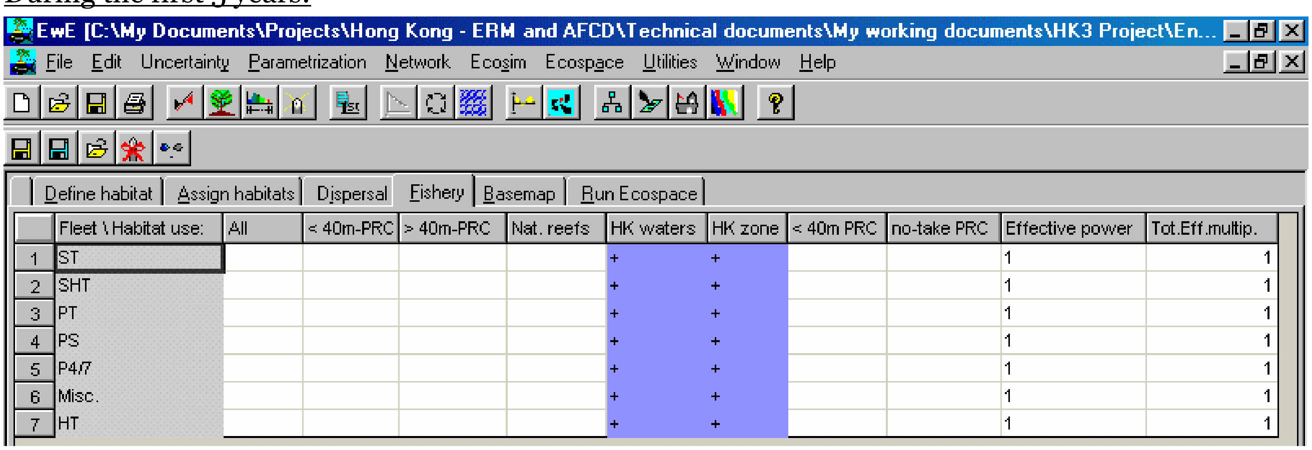


Reduction of all fishing effort by one sixth (*vide* '5/6' in Table 8.3) in PRC waters <40 m is set in the ECOSPACE routine. This one-sixth reduction also applies to scenarios PRC 2c and PRC 5c.

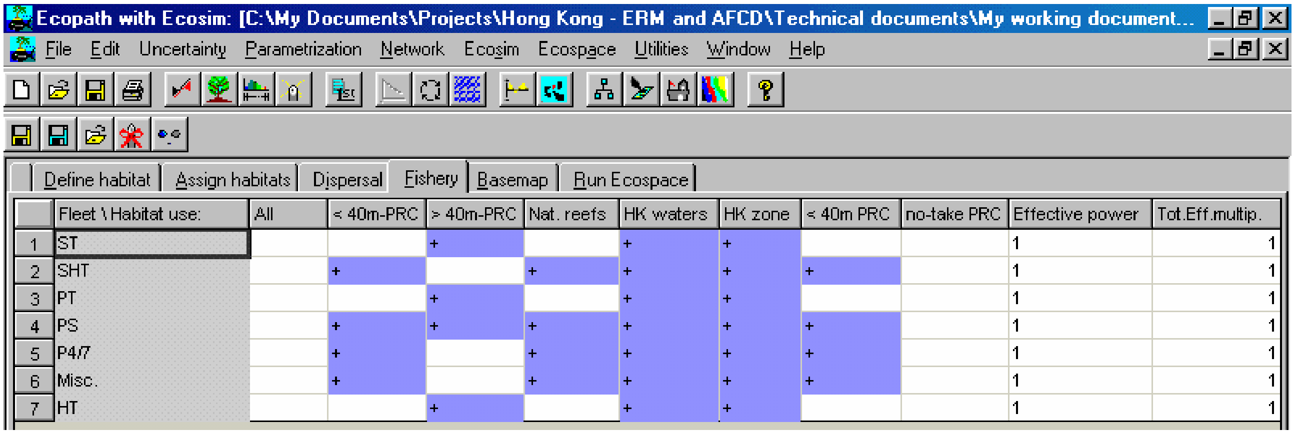


Scenario PRC 2a:
Total ban on all fishing in PRC waters (except in Hong Kong) with a resumption of fishing after 5 years (as in scenario PRC 1a, with SHT in PRC waters < 40 m).

<u>During the first 5 years:</u>



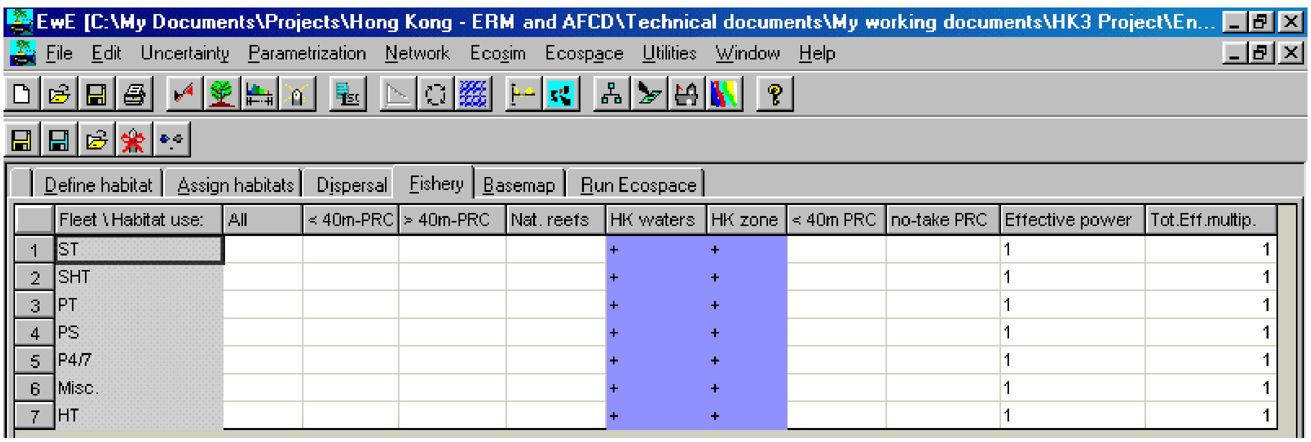
From year 6 to year 25:



	Fleet \ Habitat use:	All	< 40m-PRC	> 40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT		+		+	+	+	+		1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

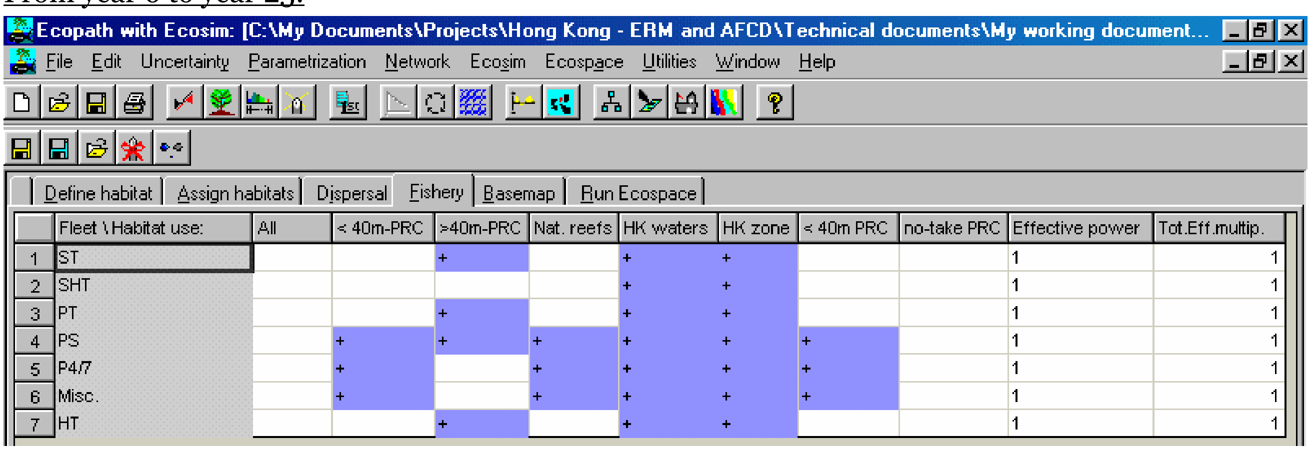
Scenario PRC 2b:
Total ban on all fishing in all PRC waters (except in Hong Kong) with a resumption of fishing after 5 years (as in scenario PRC 1b, with no SHT in PRC waters < 40 m).

During the first 5 years:



	Fleet \ Habitat use:	All	< 40m-PRC	> 40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST					+	+			1	1
2	SHT					+	+			1	1
3	PT					+	+			1	1
4	PS					+	+			1	1
5	P4/7					+	+			1	1
6	Misc.					+	+			1	1
7	HT					+	+			1	1

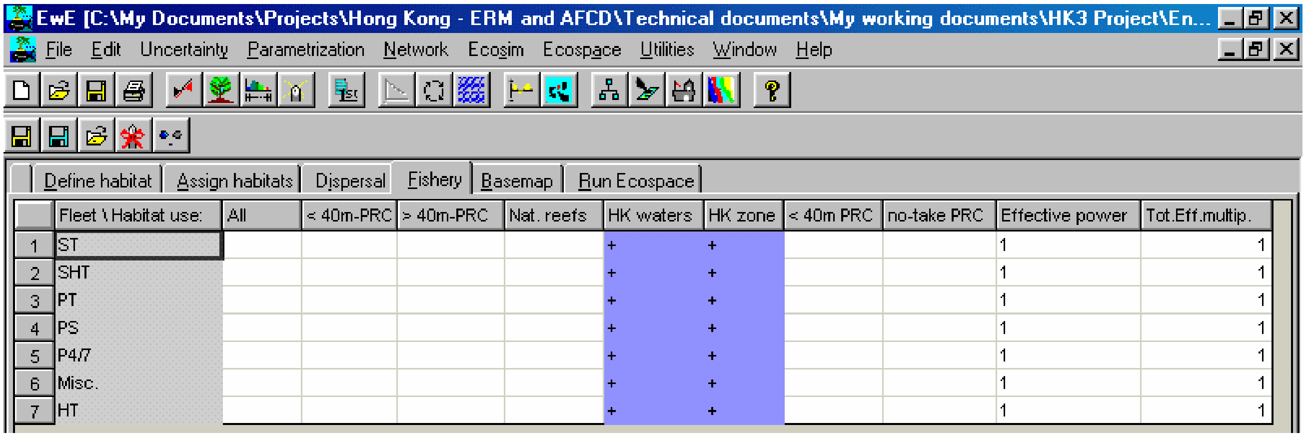
From year 6 to year 25:



	Fleet \ Habitat use:	All	< 40m-PRC	>40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT					+	+			1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

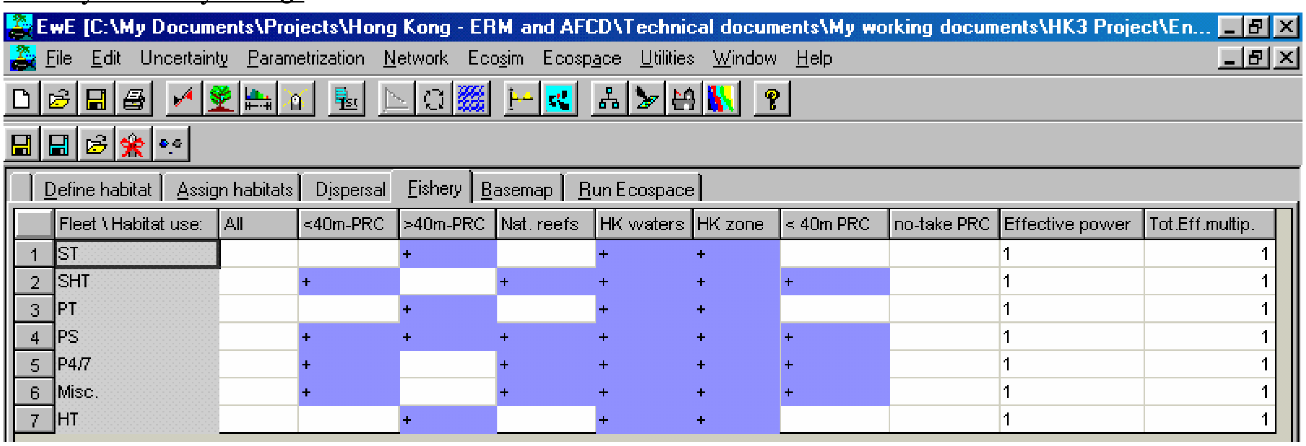
Scenario PRC 2c:
Total ban on all fishing in all PRC waters (except in Hong Kong) with a resumption of fishing after 5 years as in scenario PRC 1c. After 5 years, all fisheries are reduced by one sixth in PRC waters <40 m, (*vide* '5/6' in Table 8.3, and see the ECOSPACE routine in scenario PRC 1c above). SHT operate in PRC waters <40m, no other trawling in PRC waters <40m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.

<u>During the first 5 years:</u>



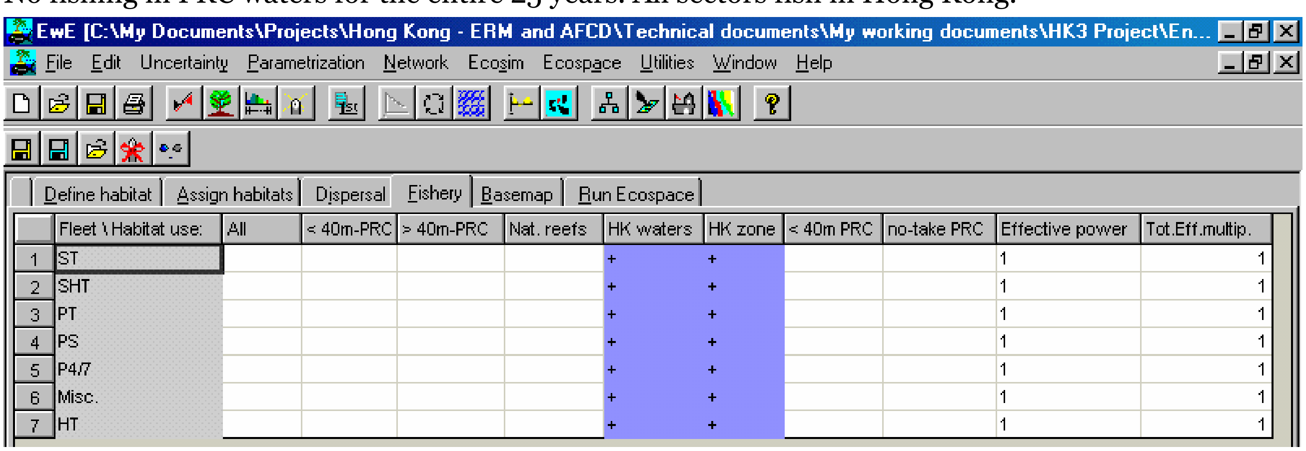
	Fleet \ Habitat use:	All	< 40m-PRC	> 40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST					+	+			1	1
2	SHT					+	+			1	1
3	PT					+	+			1	1
4	PS					+	+			1	1
5	P4/7					+	+			1	1
6	Misc.					+	+			1	1
7	HT					+	+			1	1

<u>From year 6 to year 25:</u>



	Fleet \ Habitat use:	All	<40m-PRC	>40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT		+		+	+	+	+		1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

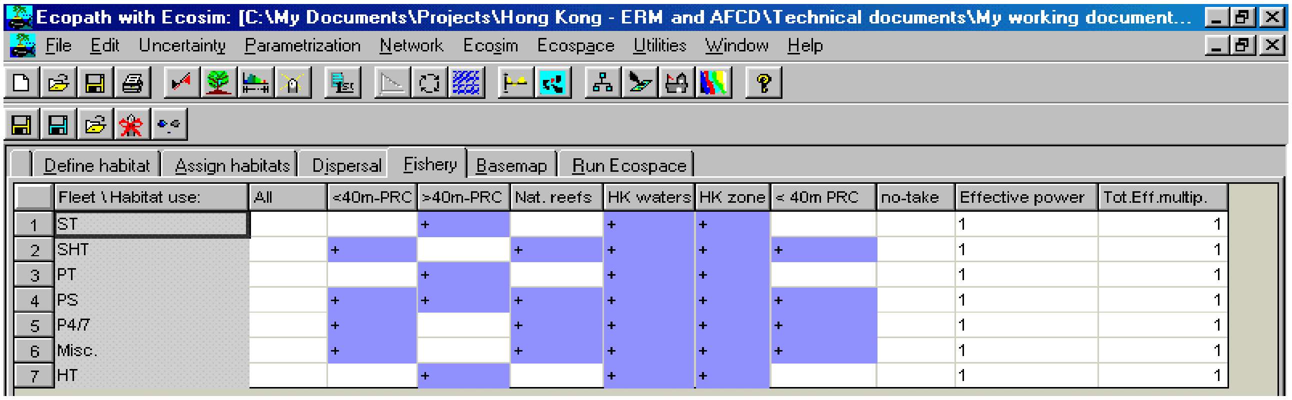
Scenario PRC 4:
No fishing in PRC waters for the entire 25 years. All sectors fish in Hong Kong.



	Fleet \ Habitat use:	All	< 40m-PRC	> 40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST					+	+			1	1
2	SHT					+	+			1	1
3	PT					+	+			1	1
4	PS					+	+			1	1
5	P4/7					+	+			1	1
6	Misc.					+	+			1	1
7	HT					+	+			1	1

Scenario PRC 5a:

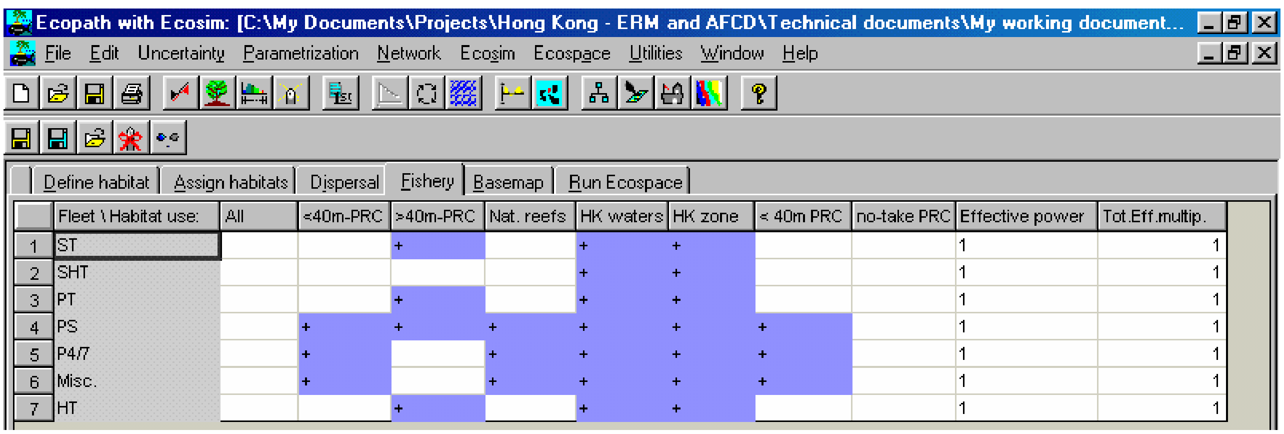
Half of PRC waters is designated as no-take area (see Figure 6.2). SHT operate in PRC waters < 40 m, no other trawling in PRC waters < 40m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.



	Fleet \ Habitat use:	All	<40m-PRC	>40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT		+		+	+	+	+		1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

Scenario PRC 5b:

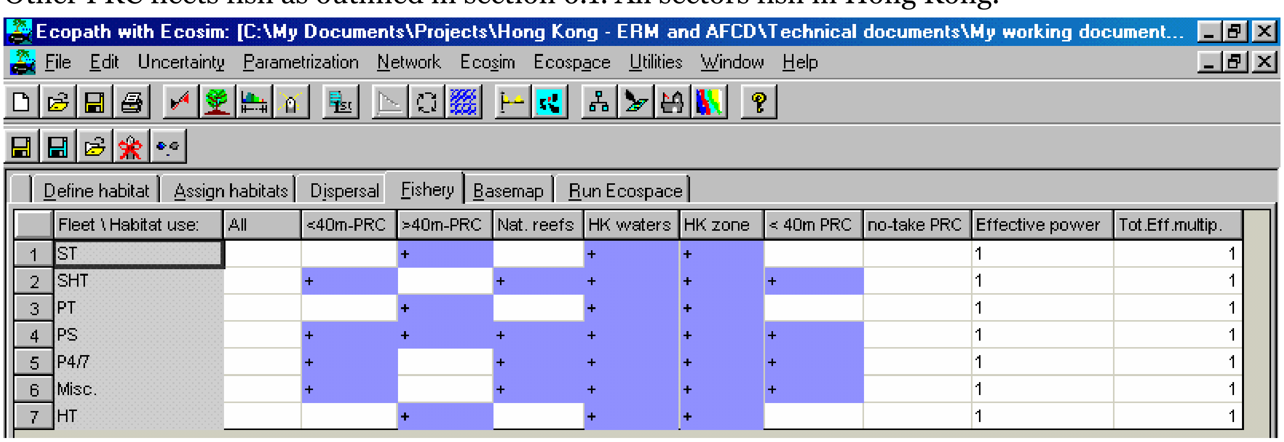
Half of PRC waters are designated as a ‘no-take’ area (see Figure 6.2). No SHT except in Hong Kong, no other trawling in PRC waters < 40 m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.



	Fleet \ Habitat use:	All	<40m-PRC	>40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT					+	+			1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

Scenario PRC 5c:

Half of PRC waters are designated as a ‘no-take’ area (see Figure 6.2). All fisheries in PRC waters <40 m are reduced by one sixth (*vide* '5/6' in Table 8.3, see the ECOSPACE routine in scenario PRC 1c above). SHT operate in PRC waters <40 m, no other trawling in PRC waters <40 m. Other PRC fleets fish as outlined in section 6.1. All sectors fish in Hong Kong.



	Fleet \ Habitat use:	All	<40m-PRC	>40m-PRC	Nat. reefs	HK waters	HK zone	< 40m PRC	no-take PRC	Effective power	Tot.Eff.multip.
1	ST			+		+	+			1	1
2	SHT		+		+	+	+	+		1	1
3	PT			+		+	+			1	1
4	PS		+	+	+	+	+	+		1	1
5	P4/7		+		+	+	+	+		1	1
6	Misc.		+		+	+	+	+		1	1
7	HT			+		+	+			1	1

Chapter 7. Assumptions of ECOPATH, ECOSIM and ECOSPACE in this Study

E.A. Buchary and T.J. Pitcher

The simulations rely mainly on the feeding interactions between the predators and their preys in the underlying ECOPATH model. The diet matrix of our ECOPATH models represent the 'best available knowledge' extracted from available stomach content studies from the study area and other similar systems. The annual averages used in ECOPATH ignore competitive interactions in feeding and the fact that the prevalence of diet items may change on a seasonal basis.

Environmentally driven factors such as seasonal change in abundance and reproduction, and decadal fluctuations of primary productivity in the study area have not been incorporated into our ECOSIM model due to lack of information. For a similar reason, physical transports through advection processes have also not been incorporated in our simulations. We also assume that all protected areas (*i.e.*, marine parks, marine reserve, FPA and MEZ) in our simulations are 'equal' in biological quality and that compliance to the control and restoration measures in all scenarios tested are adhered to by all fishing fleets. We further assume that the only non-feeding interaction (*i.e.*, mediation) in the system occurred between coral reefs and reef associated (RA) fish and between LBS (Living Bottom Structure) and LBS-associated fish. Trophic flow control (i.e., vulnerability parameters, *v*) for all functional groups in the system is also assumed to be in inverse relationship with their respective trophic levels.

We also made assumptions for reef habitat. The majority of reef habitat in the Hong Kong marine ecosystem is rocky reef, which runs all along the seashore in Hong Kong (A. Cornish, University of Hong Kong, pers. comm.). Consequently, some of these rocky reefs are protected under the existing and proposed management control measures, and some are not. However, it is not technically feasible to model this rocky reef in our Ecospace simulations because the width of the rocky reefs band along the shores is too narrow to be represented by the model cells (i.e., each model cell in Hong Kong model represents approximately 5 km2). Therefore, in our Ecospace simulations we lumped all existing reef habitats (both coral and rocky reefs) into the areas of marine parks, FPA and MEZ. Ecospace does not take into account ecological succession processes in its simulation, therefore, in our simulations, all biomass pools recover simultaneously.

Chapter 8. Management Scenarios Tested and Analyzed

E.A. Buchary and T.J. Pitcher

8.1 Ecosystem model of Hong Kong waters

Modelling scenarios for the ecological and economic analyses for Hong Kong FPA zones with ('AR') and without ('No AR') artificial reefs are as in the following table:

Table 8.1 List of modelling scenarios for the Hong Kong model.

No.	Scenario Description	Ecological Analysis		Bio-economic Analysis	
		'AR'	'No AR'	'AR'	'No AR'
1	***Do nothing, baseline scenario:*** Translates into 1.46% of Hong Kong waters as a no-trawl area in the existing Marine Parks. The parks include Hoi Ha Wan (represented by 1 cell), Yat Chau Tong (represented by 1 cell), Sha Chau/Lung Kwu Chau (represented by 2 cells) and the proposed East Peng Chau (represented by 1 cell). In total, all of these occupy 5 grid cells in ECOSPACE . Licensed miscellaneous, P4/7, and purse seine fishing fleets were allowed to fish in these marine parks. Hang trawlers, however, are allowed to fish in Sha Chau/Lung Kwu Chau Marine Park only. The no-take effect in Cape D'Aguilar (0.19 km^2) Marine Reserve was too small to be taken into account in ECOSPACE. ECOSIM relative fishing power increase by 3% annually compounded (Pitcher *et al*., 2001, *in press*).	Sce1a Same as 10a	Sce1b Same as 10b	Sce1a Same as 10a	Sce1b Same as 10b
2	***The planned deployment and 2 FPA program:*** In addition to marine parks from Scenario1, Scenario 2 adds a further 7.33% of Hong Kong waters as no-trawl and 0.86% as a 'no-take' FPA (see Table 5.1). Two FPA are proposed, one in Tolo Harbour (56.3 km^2) , and another in Port Shelter (81.3 km^2). Each FPA is divided into 'no-take' areas that contain deployed AR and 'no-trawl' areas. No fleets are allowed to fish in 'no-take' areas, represented by 1 cell in Tolo Harbour FPA and 2 cells in Port Shelter FPA. The remainder of the FPA (25 cells) is a 'no-trawl' area where misc., P4/7 and purse seines vessels are allowed to fish. The MEZ (6.28 km^2, 0.37%) in Chek Lap Kok (1 cell in the model), is off-limits for all fishing fleets and contains deployed AR, *i.e.* a 'no-take' area. In areas outside these zones, all seven fishery sectors were simulated as fishing.	Sce2a	Sce2b	Sce2a	Sce2b

Table 8.1 List of modelling scenarios for the Hong Kong model.

No.	Scenario Description	Ecological Analysis		Bio-economic Analysis	
		'AR'	'No AR'	'AR'	'No AR'
3	***No trawling in all of the 3 planned management zones for the entire simulation period:*** These three management zones are: (a) Marine Parks, (b) FPA no-take/MEZ no-take and (c) FPA no-trawl. All other sectors fish as in Scenario 2.	Sce3a	Sce3b	Sce3a	Sce3b
4	***No take in all of the 3 planned management zones for the entire simulation period:*** These three management zones are: (a) Marine Parks, (b) FPA no-take/MEZ no-take and (c) FPA no-trawl, all now set as complete no-take areas. All fishing sectors operate outside these three management zones.	Sce4a	Sce4b	Sce4a	Sce4b
5	***No trawling everywhere within Hong Kong waters for the entire simulation period:*** All other sectors fish as in Scenario 2.	Sce5a	Sce5b	Sce5a	Sce5b
6	***No take everywhere within Hong Kong waters with a resumption of fishing after 5 years (maintaining no-take in the three planned management zones):*** After 5 years complete 'no-take' closure, all sectors fish as outlined in Scenario 4. We ran 5 years no-take in ECOSPACE, then took the recovered biomasses and set up a new re-balanced ECOPATH model (see Table 2.5). This new model was then employed as the basis of the remaining 20 of the 25 year simulation. Fishing resumed as prior to the closures, with all three management zones set as no-take as in Scenario 4.	Sce6a	Sce6b	Sce6a	Sce6b
7	***No take everywhere within Hong Kong waters with a resumption of fishing after 10 years (maintaining no-take in the three planned management zones):*** After 10 years, all fishing sectors will fish as outlined in scenario 2. Dropped – see 10.	Dropped – see 10	Dropped –see 10	Dropped –see 10	Dropped –see 10
8	***No take everywhere within Hong Kong waters (for the entire 25 years modelling period)*** Simulated biomass only as all fishing is halted with no resumption after year 5.	Sce8a	Sce8b	(No catch)	(No catch)

Table 8.1 List of modelling scenarios for the Hong Kong model.

No.	Scenario Description	Ecological Analysis		Bio-economic Analysis	
		'AR'	**'No AR'**	**'AR'**	**'No AR'**
9	***Original 5 FPA areas with no-take zones*** The original 5 FPA include the 2 FPA mentioned above (*viz.*, Tolo Harbour and Port Shelter), plus 3 originally planned sites, *i.e.*, Sokos (63.39 km^2, 3.77%), Po Toi (14.46 km^2, 0.86%) and Ninepins (27.99 km^2, 1.67%), as proposed in the ERM Final Report (ERM 1999; also see Figure 5.2). Management of these 5 FPA in the simulation are all complete no-take.	Sce9a	Sce9b	Sce9a	Sce9b
9 extra	***Original 5 FPA areas with no-take zones*** Cheating scenario with original 5 FPA areas, with 'AR' (9c) and 'No AR' (9d). All trawlers fish everywhere, except at areas where there are natural reefs and at areas where artificial reefs were deployed. Herein, AR act as 'sleeping police officers' that physically prevent trawling. All other sectors fish everywhere. Compliance to management zones is ignored (*i.e.*, cheating).	Sce9c	Sce9d	Not analyzed	Not analyzed
10	***AR without FPA modelled. If necessary, drop item (vii) to accommodate*** This is scenario 1a.	See 1a	See 1b	See 1a	See 1b

Other analysis in the Hong Kong model:

(a) Food web recovery analysis, emphasizing the small pelagic species; and
(b) Game theoretic analysis.

8.2 Ecosystem model of PRC inshore waters: an extension of HK model

As detailed in Chapter 6, the ECOPATH model of the People's Republic of China (PRC) inshore waters is an extension of the present-day ECOPATH model of Hong Kong waters. Modelling scenarios for the ecological analyses of the ECOPATH model of the PRC inshore waters are as in the following tables:

Table 8.2 Six modelling scenarios for the PRC model.

No.	Scenario Description
PRC 0	All fishing everywhere (an addition to contract deliverables)
PRC 1	Total ban on trawling in PRC waters < 40 m
PRC 2	Total ban on all fishing with a resumption of fishing (as in PRC1) after 5 years
PRC3 *	Total ban on all fishing with a resumption of fishing (as in PRC1) after 10 years
PRC 4	Total ban on all fishing everywhere (except in Hong Kong) for the entire 25 years
PRC 5	Closure of 50% of the PRC fishery area

* not completed for same reasons as HK scenario 7.

Table 8.3 Distribution of modelling scenarios for the PRC model with respect to simulation on the shrimp trawlers (SHT) and one-sixth reduction to all fishing fleet in PRC waters < 40 m.

No.	Scenario	Simulation of SHT and fishing reduction			
		SHT	No SHT	5/6 **	other
PRC 0	All fishing everywhere	PRC 0			
PRC 1	No trawling in PRC < 40m	PRC 1a	PRC 1b (SHT fish in HK)	PRC 1c	
PRC 2	close 5 years then as PRC 1	PRC 2a	PRC 2b	PRC 2c	
PRC 3 *	close 10 years then as PRC1				
PRC 4	No fishing anywhere				PRC 4
PRC 5	Half PRC in no-take MPA	PRC 5a	PRC 5b	PRC 5c	

* not completed for same reasons as HK scenario 7

** denotes one-sixth reduction to all fishing fleet in PRC waters < 40 m, to represent 2 months

Chapter 9. Economic analysis and simulations of Hong Kong fisheries

U.R. Sumalia

9.1 Introduction

The purpose of this analysis is twofold. First, we estimate and compare the potential annual net economic gains to be derived from Hong Kong's fisheries under a number of management scenarios. Second, we undertake a simple game theoretic analysis to project possible economic benefits to be derived from the fisheries if fishers work cooperatively or non-cooperatively.

The scenarios to be analyzed (see Chapter 8) are:

Scenario 1: Do nothing, baseline scenario (status quo)
Scenario 2: Planned deployment and FPA Program
Scenario 3: No trawling in all of the 3 planned management zones
Scenario 4: No take in all of the 3 planned management zones
Scenario 5: No trawling everywhere within Hong Kong waters
Scenario 6: No take everywhere within Hong Kong waters with a resumption of fishing after 5 years (maintaining no-take in the planned management zones)
Scenario 9: Original 5 FPA areas with no-take zones (i.e., increase in no-take zones by 5/2 = 2.5x)

For all of the above, two different simulations were carried out, one 'with' and the other 'without' artificial reef deployment (AR). It should be noted that Scenario 1 with AR (= Scenario 1a) is the same as Scenario 10 with AR (= Scenario 10a), as described in Chapter 8. Scenario 8 is not analyzed because no fishing is allowed, while Scenario 7 has not been separately modelled ecologically, so there is no basis for an economic analysis.

It is assumed in this study that all the potential economic benefits resulting from one of the above scenarios translate into potential high future yields/harvests. Hence, given the projected future yields from major Hong Kong fish stocks determined using ECOPATH, ECOSIM and ECOSPACE, we combine economic information (*i.e.*, prices, costs, and discount rates) to carry out a cost benefit analysis (CBA) of the management scenarios listed above.

9.2 General outline of the approach used for the analysis

The major steps taken in the present analysis are:

1. Identify the effects of a given management scenario on the biomass and yield (harvest) of the major fish stocks in Hong Kong waters.
2. Quantify in physical terms the changes in biomass and harvest.
3. Value changes in harvest.
4. Determine the cost of implementing the AR/FPA Project and harvesting the resource.
5. Discount the stream of costs and benefits

Steps 1 and 2 are the concerns of the biologist: these are carried out with the aid of ECOPATH, ECOSIM and ECOSPACE (see earlier sections of the report). Steps 3 -5 are the economist's concern, further explanations of which are given in the next few paragraphs.

9.3 Valuation of changes in quantity harvested

This involves putting prices or social values on the physical changes in the quantity of fish harvested, which can be directly linked to the kind of management scenario in place. The prices used in an economic analysis are termed *shadow prices*, that is, prices that reflect the marginal effects on social welfare of a unit change in the quantity of harvest. Shadow prices can be viewed from the demand side, where they reflect people's marginal valuation of fish, or they may be viewed from the cost side, where they denote the total cost of producing a unit of harvest: In a perfect world these two views give the same shadow price. For the present analysis, market price is assumed to be a good proxy for the shadow price of fish because the market for fish products is well developed in Hong Kong.

9.4 Determining artificial reef deployment and fish harvesting costs

All the costs to be incurred in implementing the project must be identified and counted. In this particular project the major costs are: (1) artificial reef deployment cost, (2) enforcement /patrolling cost where applicable, and (3) fish harvesting cost.

9.5 Weighting present and future streams of income

To facilitate appropriate comparison of present and future net incomes under a given management scenario, streams of cost and benefits are discounted using an appropriately determined social discount rate for Hong Kong. Discounting is the device employed by economists to internalize the "cost of waiting", thereby adjusting for the fact that "a dollar today is not the same as a dollar tomorrow". AFCD suggest a social discount rate of 7% as reasonable for Hong Kong at the moment (Hong Kong Monetary Authority, unpublished data).

9.6 The analysis

9.6.1 Project benefits

The benefits to be derived under the management scenarios listed above are assumed to come in the form of increased potential harvest from the fisheries of Hong Kong. Estimates of changes in harvest under the various scenarios for the major fish stocks are determined using the ECOPATH, ECOSIM and ECOSPACE modeling frameworks (see Christensen and Pauly 1992, Walters et al., 1997, 1999). These changes are valued using 1997 price data (see Annex 4) obtained from the AFCD, Hong Kong.

9.6.2 Project costs

Cost of deployment

The AFCD has provided cost data regarding the deployment of artificial reefs (AR) from which we determine the deployment cost applied in this analysis. Four different types of AR components will be deployed: (1) boats, (2) tire modules, (3) concrete structures, and (4) quarry rock. These will be deployed at an estimated total cost of HK$ 24.13 million for all Hong Kong waters in each of the first 2 years of the project. This works out at HK$14,365 per km^2 per year (see Annex 4, Table C).

Cost of enforcement/patrolling

Using data from AFCD, it is estimated that the annual cost of patrolling two FPA by two teams in Hong Kong waters is about HK$ 2.93 million. This works out at about HK$ 1,742 per km². It should be noted that this includes the annual cost of borrowing to purchase patrol vessels. Under scenario 1 (no plan) no patrolling/enforcement cost is involved. Scenarios 2 to 8 all have two FPA, so the cost of patrolling is HK$ 1,742. Scenario 9 has five FPA. Assuming some economies of scale, we estimate patrolling can be adequately carried out by 4 teams. Hence, the cost of patrolling is assumed to be HK$ 3,484 (see Annex 4, Table C) for this scenario.

Harvesting costs

Taking as point of departure data provided by the AFCD on the annual catch capacity, and cost of employing (capital and operating) the seven major vessels used in the seven major fishery sectors, we derive the cost (and hence the profitability levels) incurred to land a unit of fish under the different management scenarios analyzed (see Annex 4, Table B).

9.6.3 Analysis and comparison of annual benefits

From the ecological modeling (see earlier chapters in this report), estimates of the annual harvests that can be sustainably taken from Hong Kong waters under the various scenarios are derived. These harvests are then valued, as explained above, to obtain the estimated annual net economic benefits that can be obtained under the different management scenarios. Since these are only a year's net benefit, we include only harvesting: in other words, we assume AR deployment costs to be 'sunk'. The results obtained are presented in Chapter 10 of this report.

9.6.4 Game theoretic analysis

Here, projections of the potential discounted stream of net benefits under the different scenarios are calculated depending on whether fishers work together in a cooperative way or not. A few words on game theory are in order here. Game theory is a mathematical tool for analyzing interactions between economic agents. For example, suppose a few firms dominate a market, or a few group of individuals or entities have fishing rights to a common property resource, or countries have to make an agreement on trade or environmental policy. Then each agent in question has to consider the other agent's reactions and expectations regarding their own decisions. This exemplifies what is termed strategic interaction in game theory. Games are classified in a number of ways (see Binmore 1982); one of these is the distinction between cooperative and non-cooperative games. The latter are games in which there is no credible communication between players, and no binding agreements are feasible. On the other hand, under cooperative management, binding agreements are feasible and fishers act according to group decision – that is, they do not cheat the system. In this section, simple versions of cooperative and non-cooperative games are set up to analyze the potential economic results under these two types of game for each of the management scenarios analyzed.

It has been shown by several authors that the economic outcome under a non-cooperative exploitation regime generally results in both economic and biological waste (see for instance, Munro 1979, Levhari and Mirman 1980 and Sumaila 1997). At the worst, when non-cooperative behaviour degenerates to open access, all the potential economic rent can be dissipated (Clark 1990). For the purposes of this report, we define cooperative behaviour as fishers working together to control and keep their total fishing effort at levels that would maximize their joint benefits from the fisheries of Hong Kong. On the other hand, in a non-cooperative situation, the fishers go about doing their own fishing without due regard to the consequences of their actions on other fishers. In addition, the fishers are assumed to believe that other fishers are acting in exactly the same manner as them.

In practical terms, some form of regulation is needed to stop the waste that is bound to happen when fishers behave in a non-cooperative manner. This, in fact, is one reason why government agencies such as the AFCD are set up – they are expected to put in place a system to inform, educate, patrol and monitor the use of the marine resources in a manner that mitigates the negative impacts of non-cooperative behaviour by fishers. All these of course, come at a cost. In the cooperative management regime, because fishers work together to maximize their joint benefits under a binding contract, which includes an accepted formula for sharing benefits of cooperation, the need for the regulatory function of control and monitoring is no more necessary. Hence, cost of patrol and monitoring of the fisheries is assumed to be zero under cooperative management. The results of analysis are presented in Chapter 10 of this report.

Chapter 10. Discussion and Concluding Remarks

T.J. Pitcher, U.R. Sumalia, E.A. Buchary and N. Haggan

10.1 Main Ecological Results and Discussion

10.1.1 Comparison of Reef Resources Across Scenarios

Comparisons between the 'AR' and 'no AR' across scenario for reef fish resources are depicted in Figures 10.1 through 10.3. Given the assumptions used in our models, our simulations suggest that the effect of closure outweighs the effect of artificial reefs. Nevertheless, the combination of closure and artificial reefs greatly outweighs the 'no plan' option (*viz.*, Scenario 1). The trawl ban also leads to important gains in biomass of certain resource groups and important economic gains in selected component of Hong Kong fishing fleets (see Annex 2).

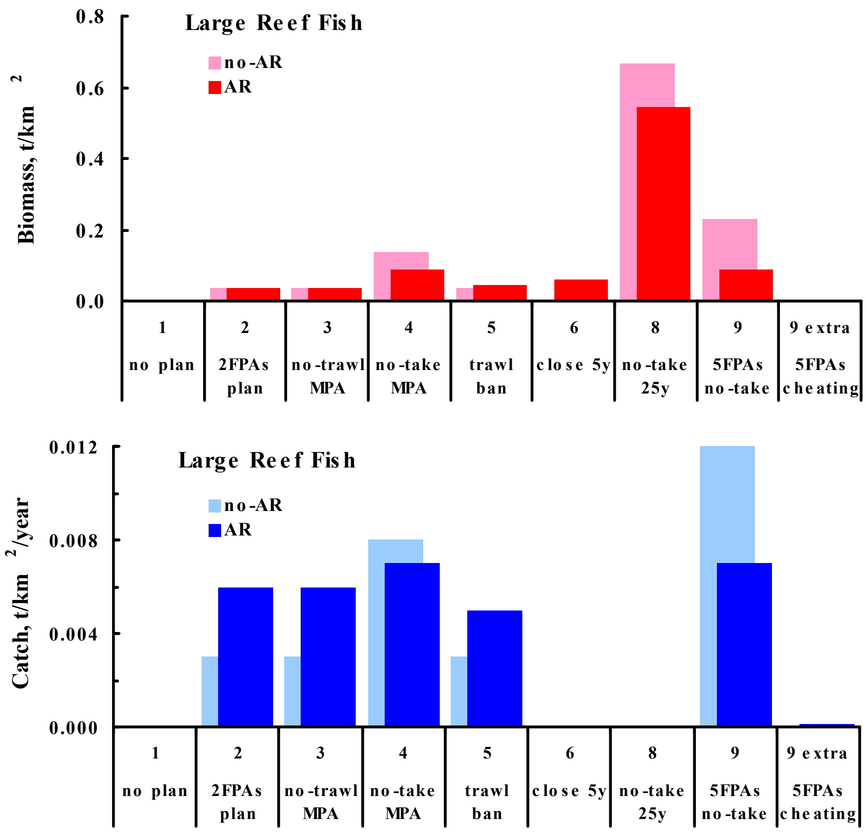


Figure 10.1 Biomass and catch of large reef fishes on year 25 by simulation scenario.

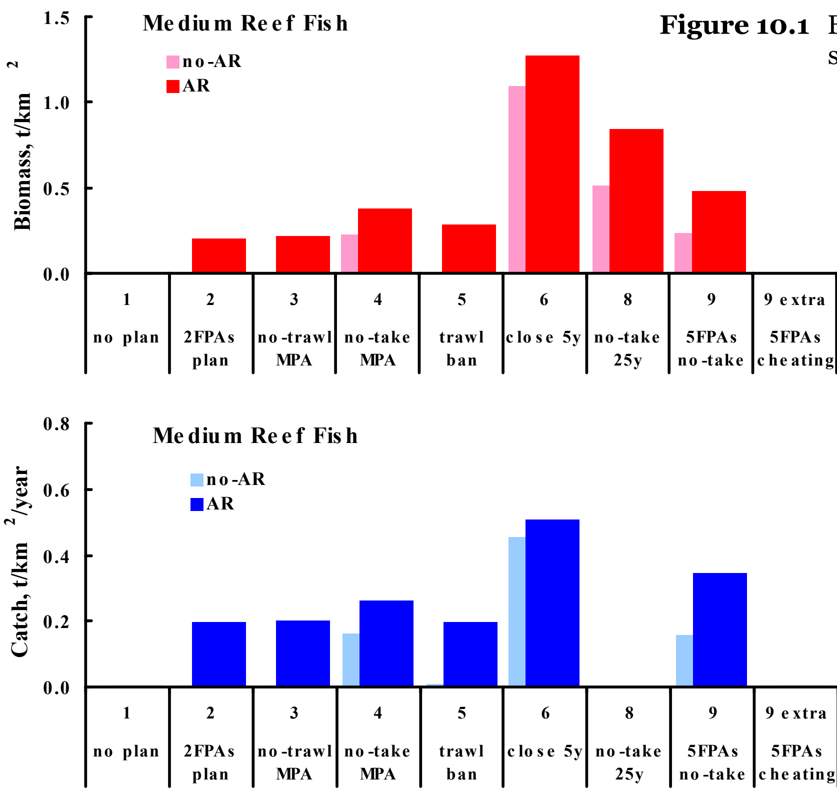


Figure 10.2 Biomass and catch of medium reef fishes on year 25 by simulation scenario.

Comparison between the 'AR' and 'no AR' options also indicated that small reef fishes benefit more from AR Deployment than medium and large reef fishes.

Non-compliance with the management regime – as shown in Scenario 9 extra (*i.e.*, 5 FPA, cheating; as described in Chapter 8) will negate any benefits. Despite the deployed AR and larger no-take area, cheating simulated in Scenario 9 extra leads to biomass and catches similar to those in Scenario 1 (*i.e.*, no protected area plan) as shown in Figure 10.1 through 10.3, and detailed in Annex 2.

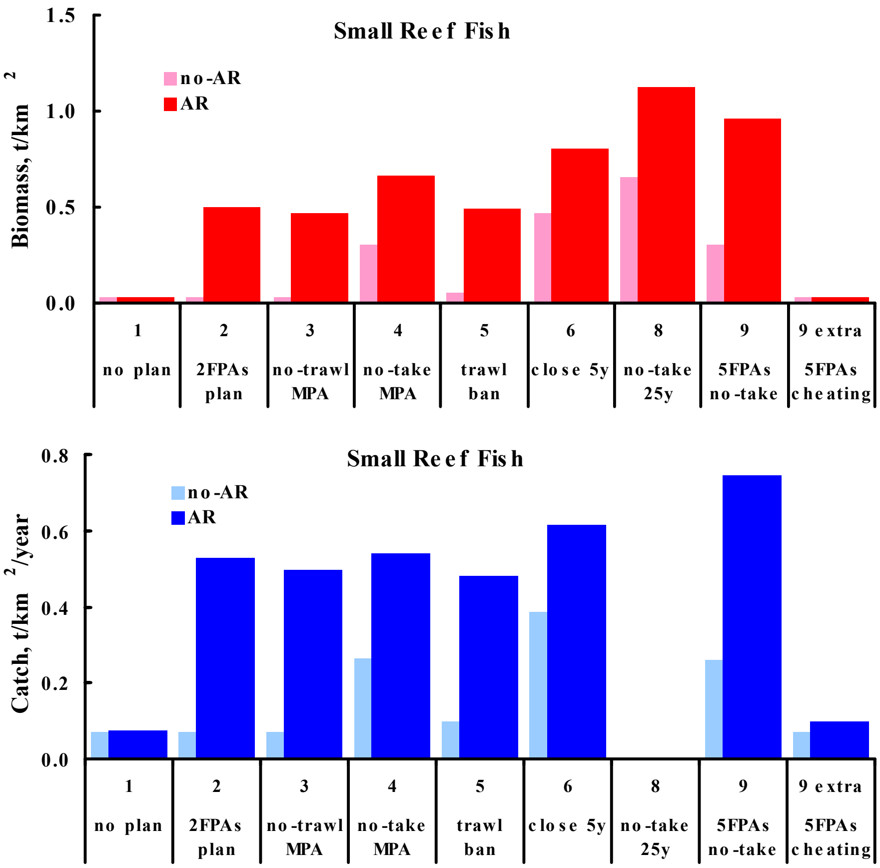


Figure 10.3 Biomass and catch of small reef fishes on year 25 by simulation scenario.

10.1.2 Comparison of Indicator Species Across Scenarios

Indicator species such as jellyfish and small pelagic fish (Figure 10.4 and 10.5) also do not differ greatly across scenarios, except in Scenario 5 and 8 for jellyfish and Scenario 5, 6 and 8 for small pelagic fish; where there is enough reduction in fishing effort to allow larger fish (who prey on jellyfish and small pelagic fish) to recover and replace jellyfish and small pelagic fish.

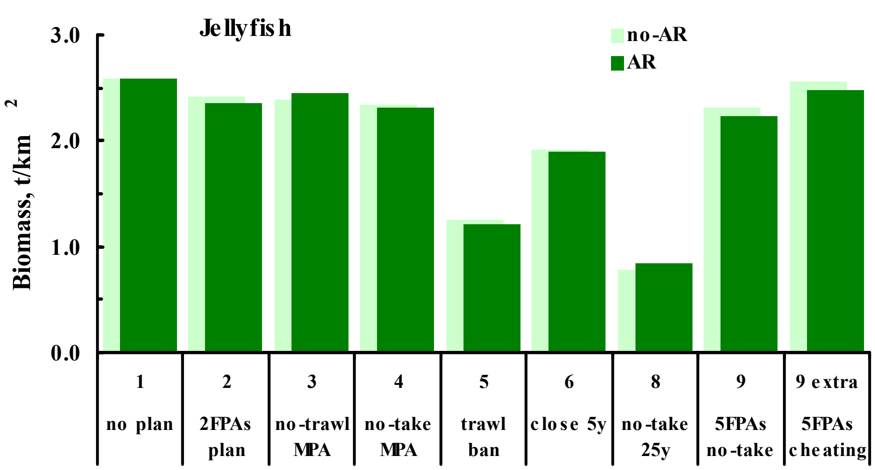


Figure 10.4 Biomass of jellyfish on year 25 by simulation scenario.

The 25 year simulation in Scenario 1b (*i.e.*, no protected area plan and no AR) indicates large increases in the biomass of jellyfish, small benthos, and small sharks (Figure 10.6). Increases in prawn biomass (which has high current market price) contribute to a valuable fishery, even though most of the large fish species are depleted. This point will be discussed later in section 10.2.4. On the other hand, corals and most large fish groups show large declines – an example of fishing down marine food webs (Pauly *et al.* 1998).

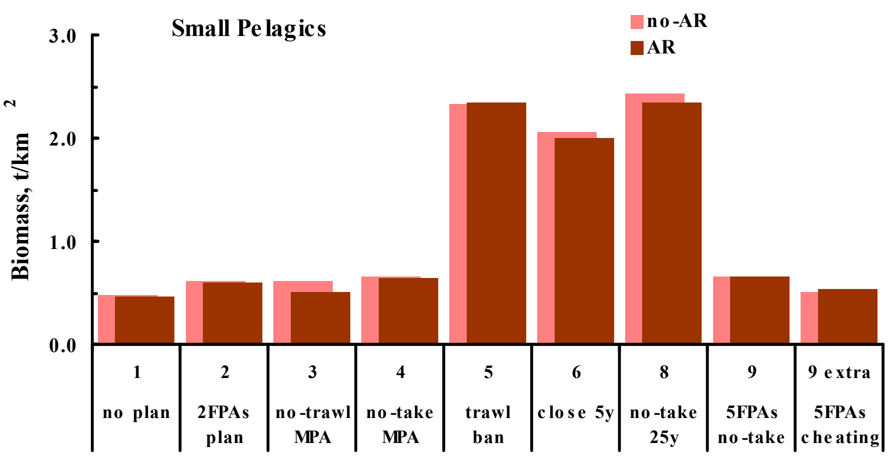


Figure 10.5 Biomass of small pelagic fish on year 25 by simulation scenario.

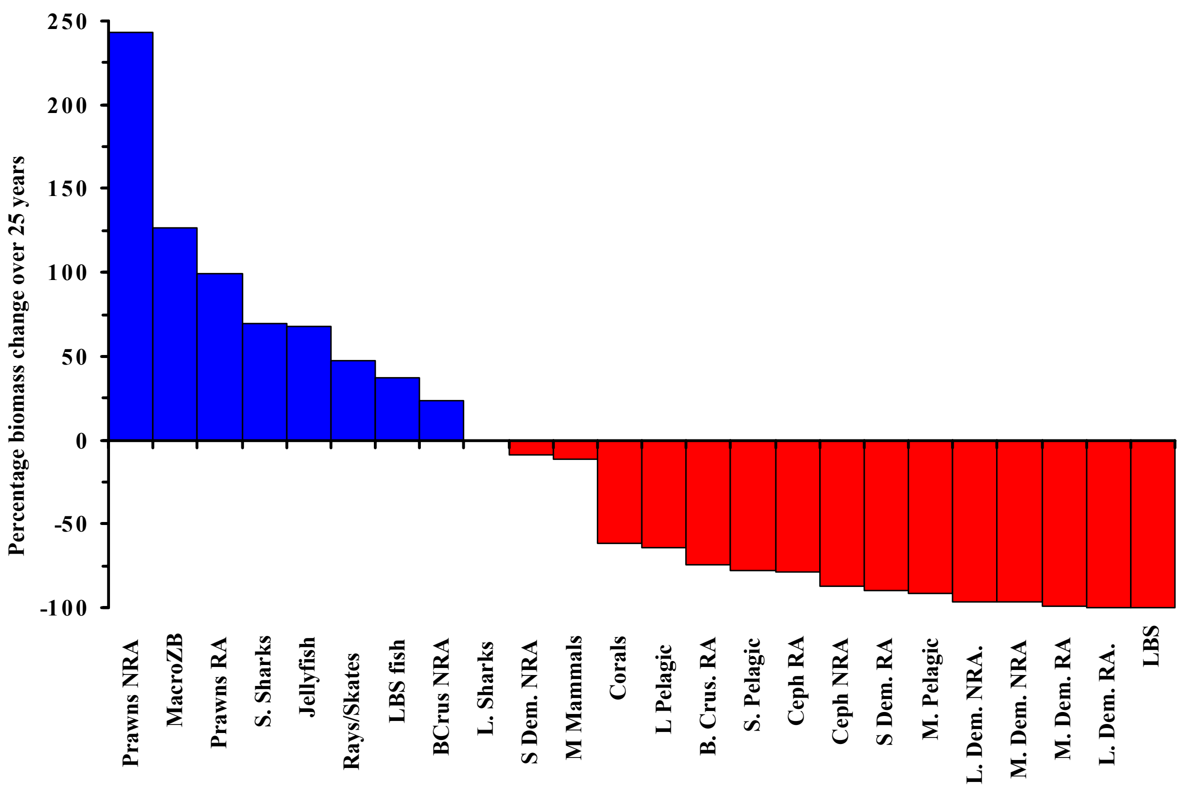


Figure 10.6 Estimates of the percentage change in biomass (*i.e.*, 'starting biomass' at year-1 versus 'end biomass' at year-25) for the principal marine ecosystem groups in Hong Kong over 25 years simulation in Scenario 1b (*viz.*, no protected area plan and no AR deployed). Note: NRA = non-reef associated, MacroZB = macrozoobenthos, RA = reef associated, S = small, LBS = living bottom structures, BCrus = benthic crustaceans, L = large, Dem = demersal, M Mammals = marine mammals, Ceph = cephalopods, M. Pelagic = medium pelagic fish, M. Dem. = medium demersal.

10.2 Main Economic Results and Discussion

10.2.1 Potential benefits from the different scenarios analyzed

Table 10.1 presents the overall annual economic results from the different scenarios at the end of 25-year simulations. Observations that can be made from the table include:

- The trawl ban scenario (#5) delivers the best economic outcome under both 'AR' and 'No AR'.
- The next best is achieved under Scenario 6, both under the 'AR' and 'No AR' simulation runs.
- Compared to the 'no plan' scenario (#1), the trawl ban scenario (#5) produces 46% and 54% more benefits per square km of habitat area, under 'AR' and 'No AR', respectively.
- Deployment of AR appears to increase benefits from the 'no plan' scenario by about 13%.
- One may wonder why the economic benefits obtained under Scenario 1b (or the *status quo*) are not much lower than those under Scenario 2a (the current 2 FPA plan). This is because the market price for penaeid prawns (and other invertebrates) is very high relative to finfish (see economic data in Annex 4), and in this scenario, large high trophic level finfish get replaced by small, low trophic level species. Species such as penaeid prawns are abundant under this scenario (see Figure 10.6; and also results of Scenario 1 in Annex 2) resulting in high catches. The large catches of penaeid prawns (and the like) under this scenario coupled with the relatively high prices led to the high economic benefits (see Figure 10.8).

Table 10.1 Net overall economic benefits (HK$/km^2/year) for each management scenario with and without artificial reefs.

Management Scenario	No AR	AR
1: no plan	43,341	48,878
2: 2 FPA plan	47,800	48,700
3: no trawl MPA	48,180	46,618
4: no-take MPA	45,608	46,447
5: trawl ban	66,553	71,148
6: Close 5 yr	61,410	62,611
9: 5FPA plan	47,293	49,034

10.2.2 Reef fish benefits

The economic outcomes under the different scenarios for large, medium and small size reef fishes are given in Figure 10.7 below. We see from these figures that:

- Gains from large reef fishes are higher in three of the seven AR scenarios analyzed, implying that other efforts at enhancing large reef fish population have significant impacts over and above deployment of AR *per se* (see Figure 10.7, upper panel).

- The highest benefits from large reef fish is obtained under Scenario 9, in the 'No AR' case.

- The second best outcome for large reef fish is achieved under Scenario 4. Here, too, the 'No AR' scenario does better than the 'AR' scenario.

- Compared to Scenario 1 (*i.e.*, no plan), Scenarios 9, 4, 5, 2 and 3 all result in significant gains in benefits from large reef fishes. Note that under Scenario 1, no economic benefits are derived from large reef fishes due to the dramatic decline of their biomass.

- .e case of medium sized reef fishes (Figure 10.7, middle panel), AR appear to have a significant positive economic impact. In fact, in all scenarios, except in Scenario 1, more gains are obtained in the 'AR' simulations.
- The highest economic benefit from medium sized reef fishes is obtained under Scenario 6 in the 'AR' case.
- The next best outcome for medium reef fish is achieved under Scenario 9, again in the 'AR' simulation runs.
- Compared to Scenario 1, all other scenarios result in significant gains in benefits from medium reef fishes (see Figure 10.7, middle panel).
- Results from small reef fishes (Figure 10.7, lower panel) are similar in many ways to those for medium sized reef fishes. Deploying artificial reefs make sense under all the scenarios.
- The highest economic benefit from small sized reef fishes (Figure 10.7, lower panel) is obtained under Scenario 9 in the 'AR' case.
- The second best outcome is achieved under Scenario 6, again in the 'AR' simulations.
- Scenario 1 produces the lowest economic benefit in almost all situations.

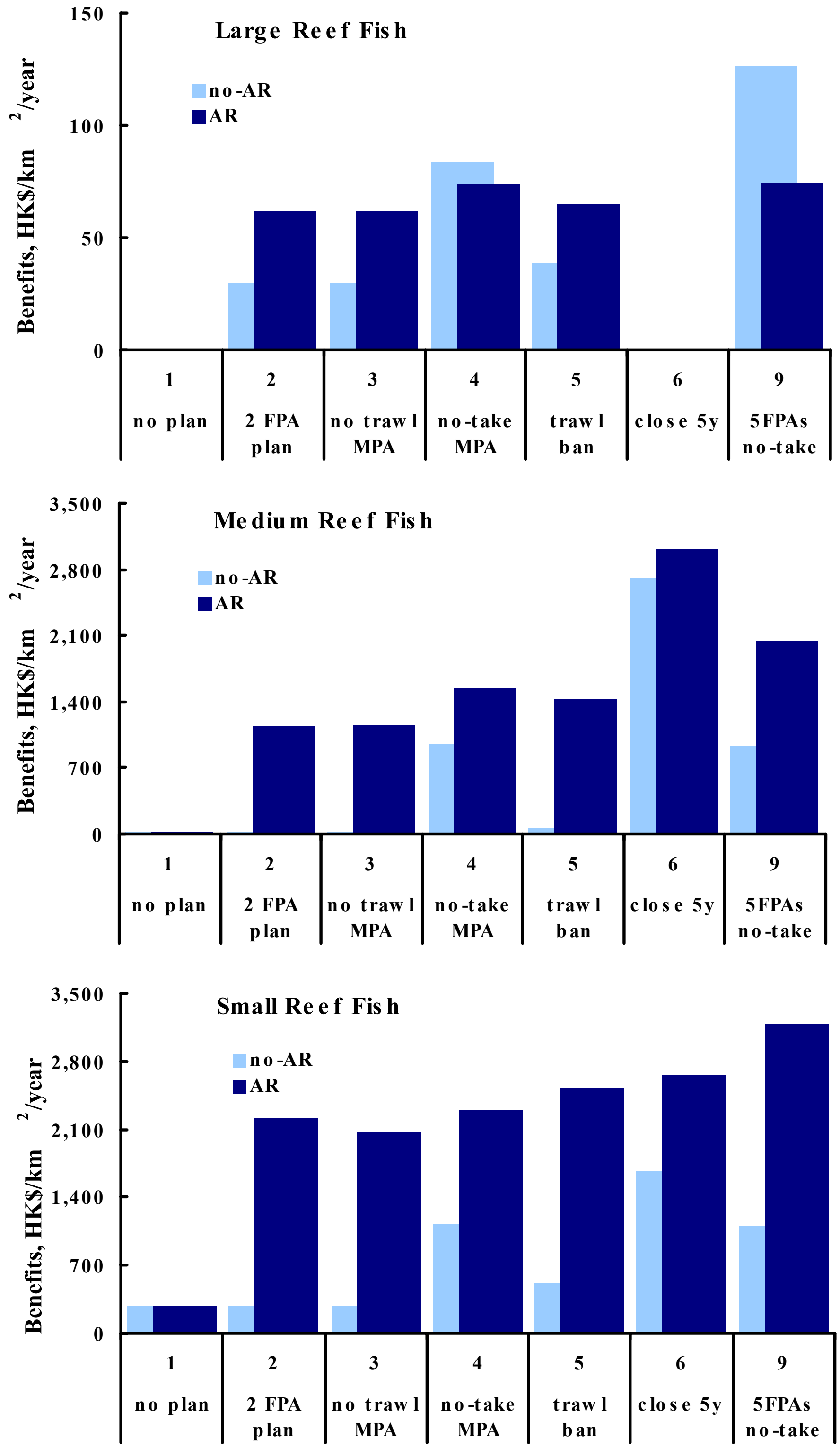


Figure 10.7 Net economic benefits of reef fishes on year 25 by simulation scenario.

10.2.3 Benefits from key commercial resources

The economic results from the eight key species groups in Hong Kong waters (see Annex 4, Table D), benthic crustaceans NRA, prawns NRA, cephalopods NRA, small pelagic fish, adult large pelagic fish, adult LBS-associated fish, adult large demersal NRA and adult large reef fishes show that:

- Relatively more economic benefits are derived from large fish groups under virtually all scenarios compared to the *status quo* (Scenario 1).
- In almost all scenarios, most economic benefits come from benthic crustaceans, penaeid prawns and small pelagic fishes (see Annex 4, Table D; and bar charts of each scenario in Annex 2).
- Small pelagic fishes are the biggest beneficiaries of AR deployment in all scenarios (except #1) (see Annex 4, Table D). This is due to trophic interactions across the food web combined with fishing effort patterns.

10.2.4 Comparison of ecological and economic outcomes

A comparison of the ecological and economic outcomes under the different scenarios reveals the following:

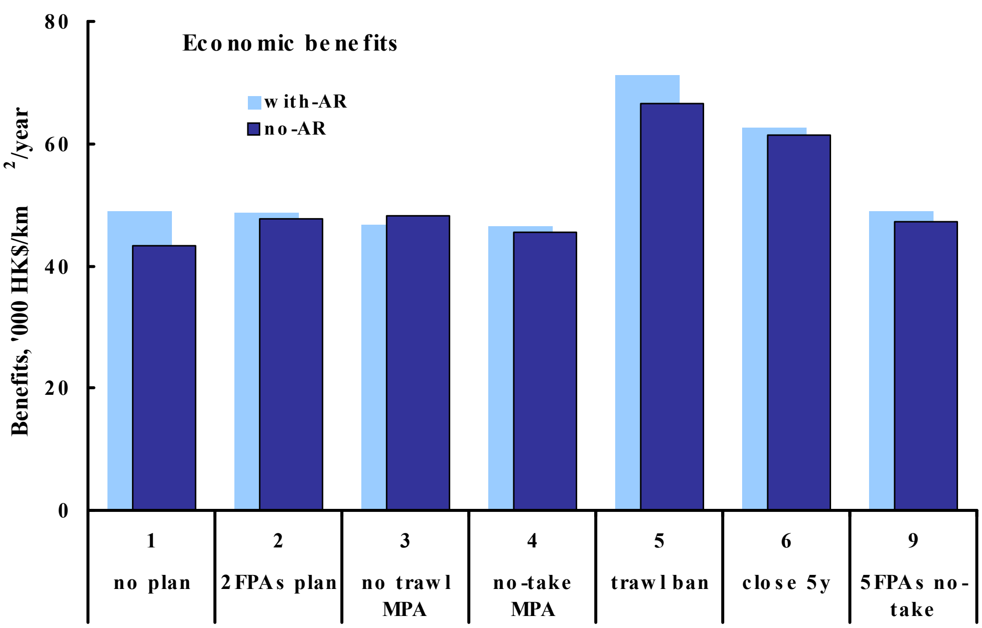
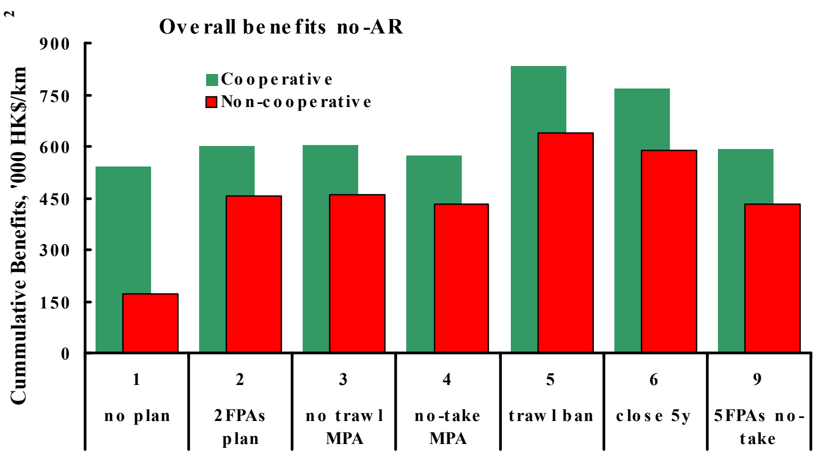


Figure 10.8 Economic benefit comparisons on year 25 by simulation scenario for all commercial species in the marine ecosystem of Hong Kong.

- Scenario 8, no take everywhere within Hong Kong waters for 25 years, results in the highest level of biomass for large adult reef fish (Figure 10.1) Not surprisingly this scenario gives no catch (Figure 10.1) and thus, no economic benefits.
- For medium reef fish, the highest biomass (Figure 10.2) and economic gains (Figure 10.7, middle panel) benefits are obtained under Scenario 6.
- For small reef fish (Figure 10.3), Scenario 8 produces the best ecological outcome with the highest biomass recorded, while Scenario 9 gives the highest economic benefits.

10.2.5 Cooperative and non-cooperative outcomes

The main results of the game theoretic analysis are presented in Figures 10.9 and 10.10. We see from Figure 10.9 that when fishers behave in a non-cooperative manner, net economic benefits are lost under all management scenarios of 'No AR'. This result is repeated even when AR are deployed as depicted in Figure 10.10.



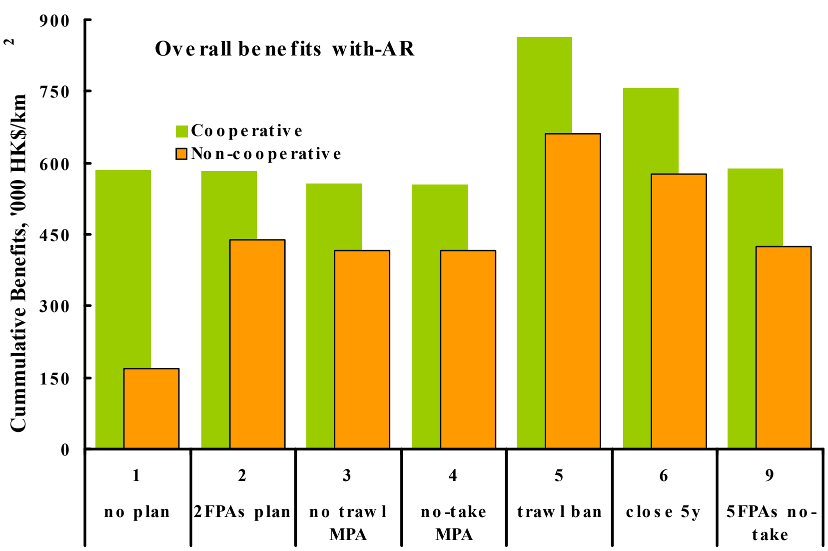


Figure 10.9 (top) and 10.10 (lower) Results from game theoretic analysis, with and without artificial reefs.

Implications of cooperative behavior over time are presented in Figure 10.11, where the trajectories of net discounted benefits for Scenarios 1, 2, 5 and 9 are plotted. This figure shows that:

- Non-cooperative behavior results in low total net economic benefits from the fisheries of Hong Kong. The outcome is worst under the 'no plan' scenario, for obvious reasons.
- Apart from the initial dip in benefits due to the cost of AR deployment, AR appear to increase the flow of discounted net benefits under cooperative management for scenarios 1 and 5. However, under scenarios 2 and 9, the flow of net benefits is about the same for the 'AR' and 'No AR' scenarios.
- Artificial reef deployment appears to improve the flow of net benefits under non-cooperation only for scenario 5. For the other scenarios, the differences are little or non-existent.

One important implication is that community outreach activities can promote cooperative behavior by fishers. Earlier work by UBCFC on the AR/FPA program recommended that the enforcement program be complemented by a substantial community outreach program (ERM 1998b). Simulations indicate that while short-term costs are increased, government cost is reduced over time as communities develop a sense of ownership and begin to self-police (ERM 1999). As noted by AFCD, NGOs can play an important role in the transition. While consultations show that Hong Kong fishing communities are not yet prepared to take a role in enforcement, experience elsewhere shows that involvement in scientific monitoring is the first step on a continuum leading to full cooperative management.

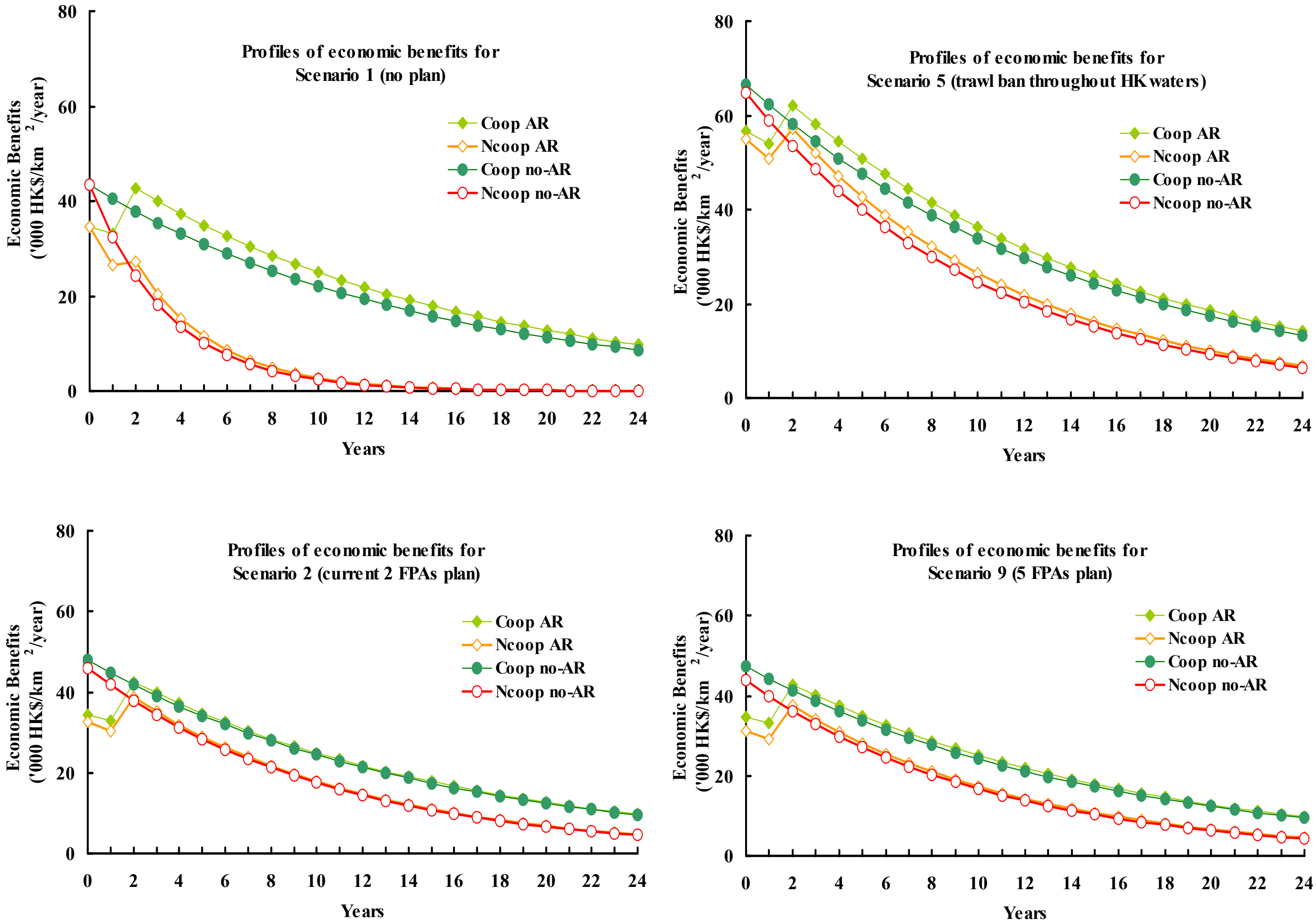


Figure 10.11 Results from game theoretic analysis, with and without artificial reefs, in Scenario 1, 2, 5 and 9. Key for colors is the same as in Figure 10.9 and 10.10. Open symbols: non-cooperative scenarios. Note: Coop = cooperative, Ncoop = non-cooperative, AR = artificial reefs, FPA = fishery protection area (see Chapter 5 for details on FPA), HK = Hong Kong.

10.3 Resumption of Fishing after Closure in Hong Kong and PRC inshore waters

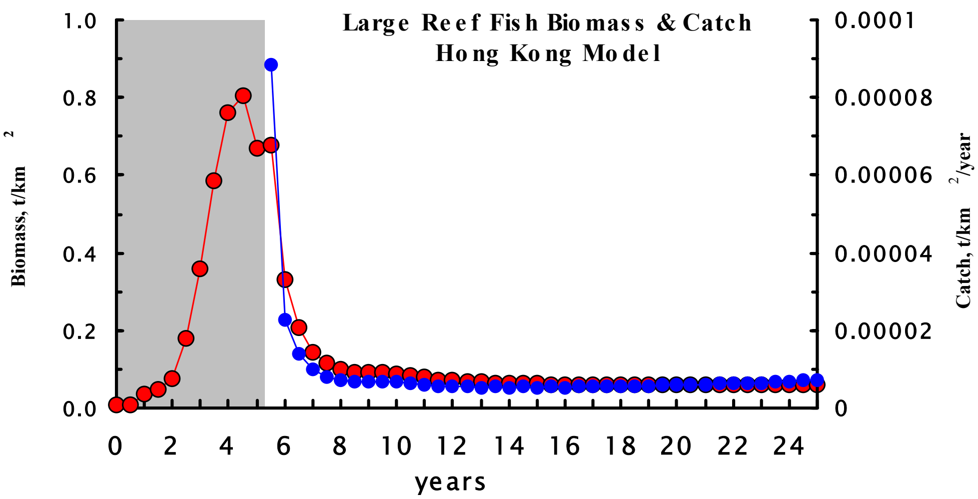


Figure 10.12 Biomass (red) and catch (blue) trajectories for large reef fish over 25 simulated years in Hong Kong, obtained under Scenario 6a. Years 1-5 (shading): all fisheries closed. Years 6 to 25: fisheries opened, with no-take zones in the two FPA, MEZ and Marine Parks. Artificial reefs were present in this scenario. See Annex 2 for details of simulation profile and results..

The effect of the closure of all fishing activities in Hong Kong (*viz.*, Scenario 6, see Chapter 8) and adjacent PRC inshore waters (*viz.*, Scenario 2, see Chapter 8) over a certain period of time was tested. Detail results are given in Annex 2 and 3 for Hong Kong and PRC models, respectively.

As outlined in Chapter 8, fishing closure for both models in this scenario was set only for the first five years. All fishing resumed in year 6.

In Figure 10.12 and 10.13, the biomass and catch trajectories of large reef fishes in both models were plotted. In these simulations deployment of AR was factored in.

The five year closure of all fishing activities allowed the biomass of large reef fishes to increase dramatically. However, resumption of fishing in year 6 led to high catches of large reef fishes only during the first 18 months of reopening. This was followed by a precipitous decline of both catches and biomass of large reef fishes.

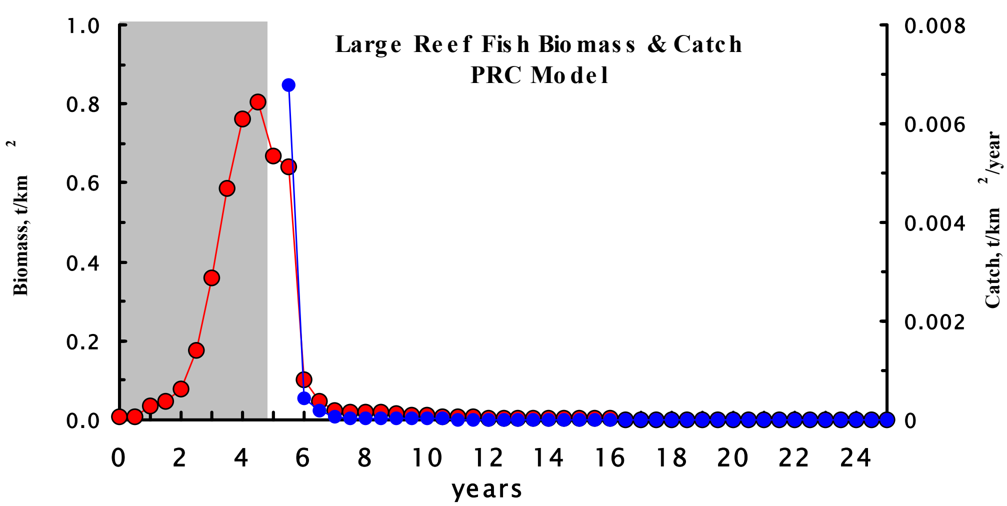


Figure 10.13 Biomass (red) and catch (blue) trajectories for large reef fish over 25 simulated years in the PRC model, obtained under Scenario 2a. Years 1-5 (shading): all fisheries closed. Years 6 to 25: fisheries opened. Artificial reefs were present in this scenario. See Annex 3 for details of simulation profile and results.

10.4 Management policy implications of the current AR/FPA plans in Hong Kong

To provide some insights on how each fisheries management policy will impact various fishing sectors in Hong Kong fisheries, a sectoral comparison on selected management scenarios is presented in Figure 10.14 and 10.15 as requested by AFCD. Details of these sectoral comparisons are documented in Annex 2.

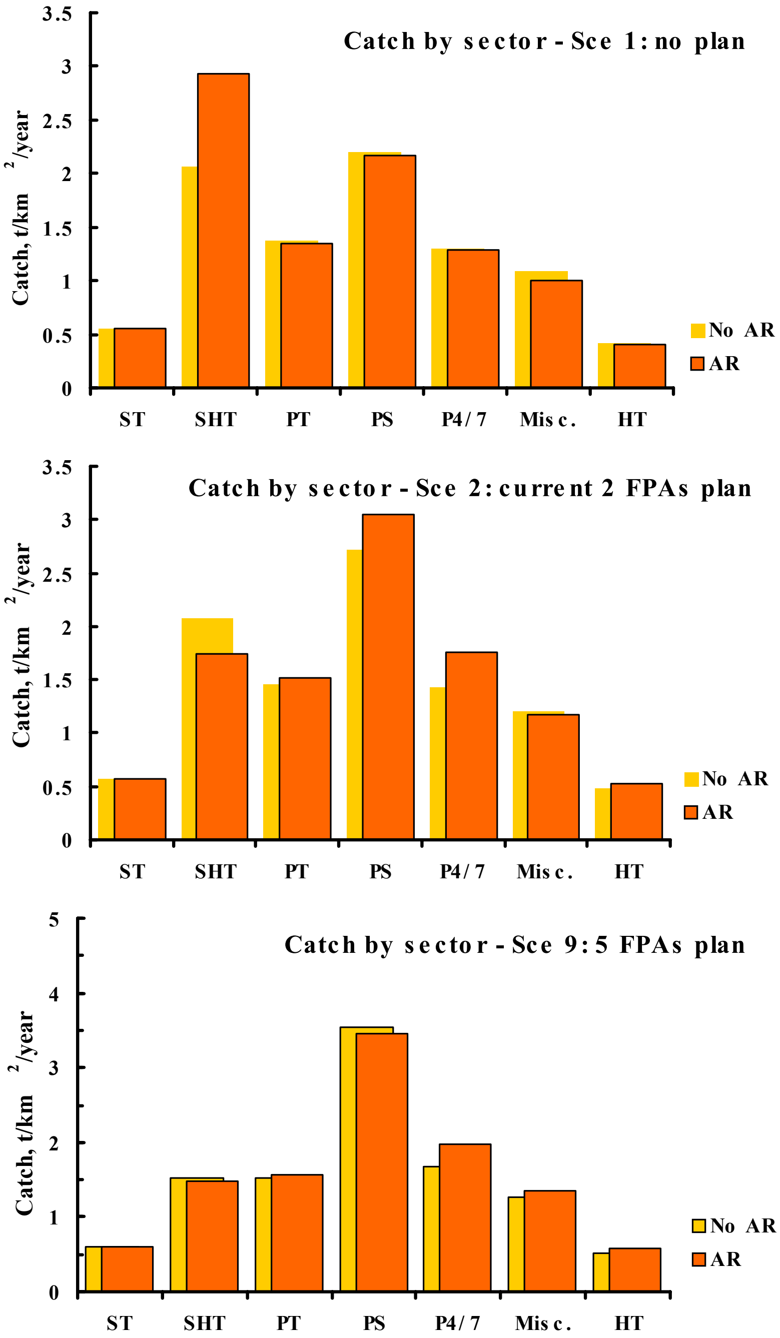


Figure 10.14 Sectoral comparison (predicted catch in t/km²/year on year 25 of the simulation) of all fishing sectors in Hong Kong for Scenario 1, 2 and 9. Note: ST = stern trawlers; SHT = shrimp trawlers; PT = pair trawlers; PS = purse seines; P4/7 = vessels that are less than 5 m in length; Misc. = small boats that employ a wide range of lines, nets, traps and hook gears; HT = hang trawlers.

Of all fishing sectors, the shrimp trawlers (SHT) would be the ones to suffer from any management policy selected from the two management options (other than the *status quo*) presented in Figures 10.14 and 10.15 and Table 10.2 (*i.e.*, scenarios 2 and 9). On the contrary, in both management options the purse seiners (PS) are predicted to be the biggest beneficiaries gaining 19% to 38% in their predicted catch (see Table 10.2). The next sector that would benefit from these two fisheries management options is the P4/7 fleets (14% to 34% gain), followed by the hang trawlers (HT) earning 8% to 30% gain.

One thing that is interesting to note in both Figure 10.14 and 10.15, and Table 10.2, is that should AFCD proceed with the artificial reef deployment program with no protected area (*viz.*, Scenario 1a), the shrimp trawlers will attain the highest gain in their predicted catches, a 30% increase compared to what they presently take. In contrast, other sectors would suffer from catch reduction, ranging from 1% to 10%.

Table 10.2 outlines the predicted catches by fishing sector per analyzed scenario. The current 2FPA plan with AR deployment (*viz.*, Scenario 2a) will cause the shrimp trawlers to lose approximately 19% of their current catches (in Scenario 1b). A further increase in the size of the protected area (*viz.*, Scenario 9) will cause them about 39% ('AR' case) and 36% ('No AR' case) loss in their catches compared to what they presently take.

Table 10.2 Predicted catches (t/km²/year) by fishing sector per analyzed scenario. The suffix 'a' at the end of each scenario number denotes 'AR' case, while 'b' denotes 'No AR' case. See Chapter 8 for detail descriptions on each scenario.

Fleets	Predicted Catches (t/km²/year)					
	Sce1a	**Sce1b**	**Sce2a**	**Sce2b**	**Sce9a**	**Sce9b**
ST	0.551	0.556	0.568	0.567	0.606	0.595
SHT	2.938	2.064	1.735	2.067	1.482	1.515
PT	1.351	1.371	1.521	1.451	1.577	1.515
PS	2.162	2.206	3.046	2.717	3.448	3.532
P4/7	1.284	1.305	1.756	1.42	1.983	1.678
Misc.	1.001	1.099	1.171	1.199	1.348	1.26
HT	0.406	0.414	0.526	0.482	0.589	0.522

Note: ST = stern trawlers; SHT = shrimp trawlers; PT = pair trawlers; PS = purse seines; P4/7 = vessels that are less than 5 m in length; Misc. = small boats that employ a wide range of lines, nets, traps and hook gears; HT = hang trawlers.

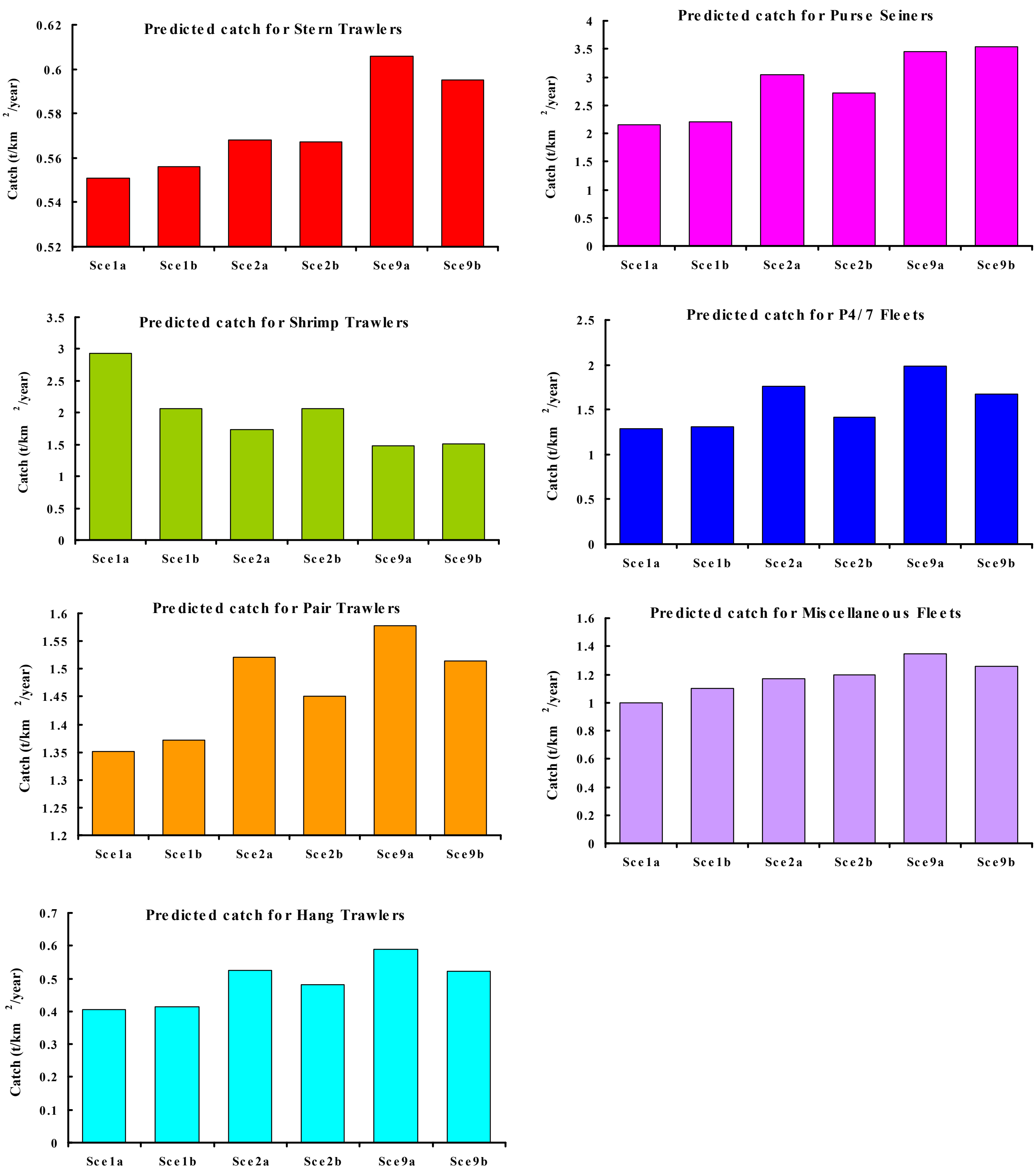


Figure 10.15 Sectoral comparison (predicted catch in t/km^2/year on year 25 of the simulation) of all fishing sectors across Scenario 1, 2 and 9. Note: The suffix 'a' at the end of each scenario number denotes 'AR' case, while 'b' denotes 'No AR' case. See Chapter 8 for detail descriptions on each scenario.

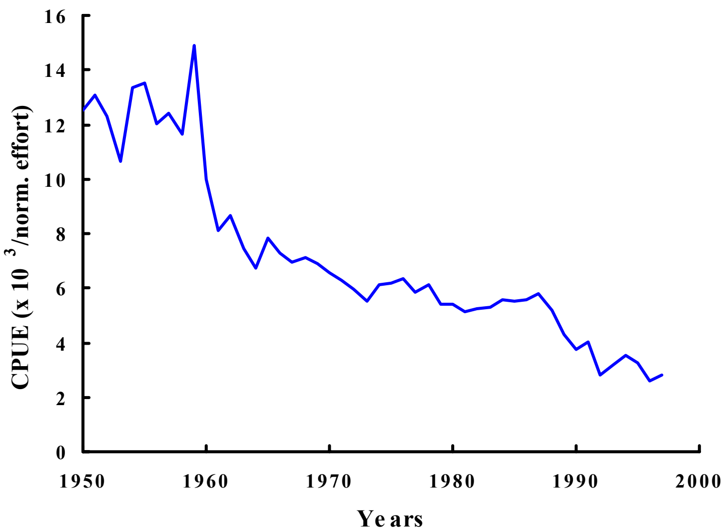


Figure 10.16 Declining catch per unit effort (CPUE) in Hong Kong fisheries from 1950 to 1997. Reproduced from Cheung (2001) with permission.

Cheung (2001) reconstructed the Hong Kong marine ecosystem as it might have been in the 1950s. Ecopath with Ecosim (EwE) was used to demonstrate the loss of biodiversity and abundance from the marine ecosystem of Hong Kong in the past four decades.

Continuously increasing fishing effort in Hong Kong fisheries had led to a precipitous decline in the catch per unit effort (Figure 10.16). Mean trophic level of the overall catch has also declined in the last decade (Figure 10.17).

It appears that unless a restoration plan is put in place, further fishing down the marine food web and shifts in ecosystem structure could lead to ecosystem collapse, and the attendant loss of economic and social benefits.

Figure 10.18 presents ecological comparisons between the past marine ecosystem of Hong Kong in the 1950s and the present-day ecosystem (*i.e.*, 1990s) under scenarios 1b, 2a, 5b and 9a. These scenarios were simulated for 25 years. Clearly, larger no-take areas as depicted in Scenario 9a (Figure 10.18, upper panel) will bring us much closer, in ecological terms, to what Hong Kong's marine ecosystem looked like in the 1950s. The predicted total biomass (Table 10.3) for all reef fish, non-reef demersal fish, all reef resources and pelagic fish attained under Scenario 9a is about 52% of what it was in 1950s for similar resources. The second best outcome is attained under Scenario 5b (37%), followed by Scenario 2a (30%).

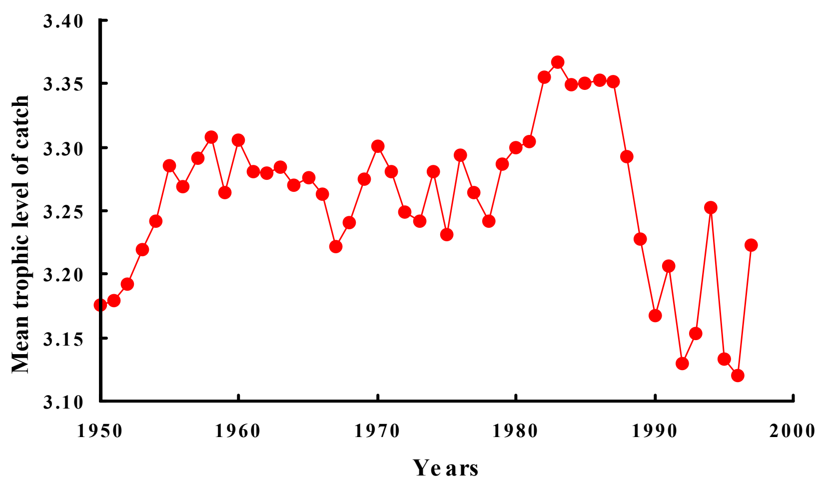


Figure 10.17 Profile of mean trophic level of the catch from Hong Kong fisheries from 1950 to 1997. Reproduced from Cheung (2001) with permission.

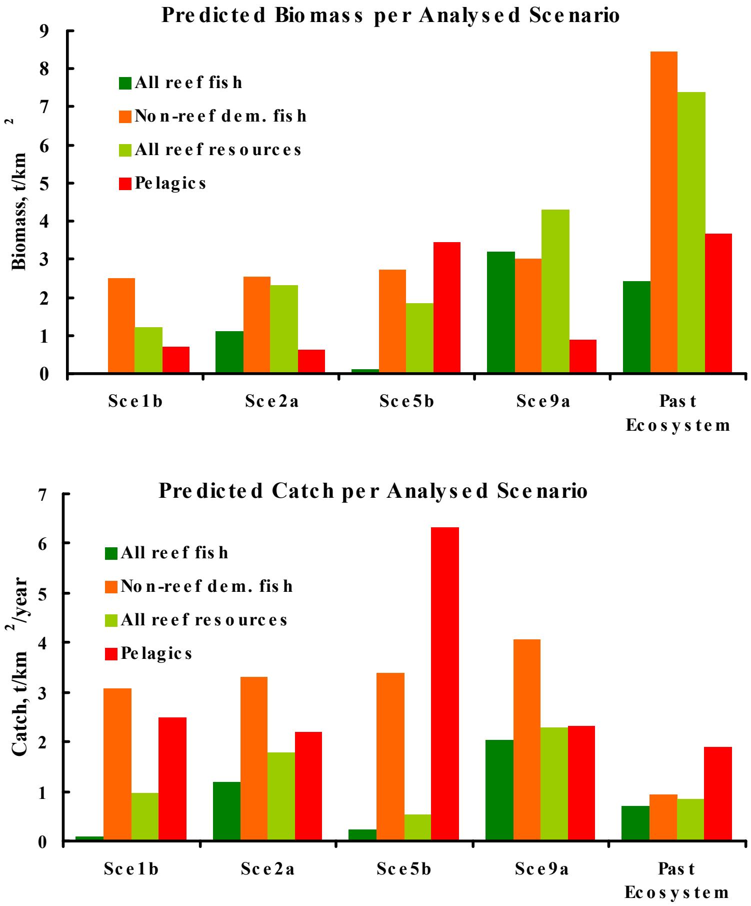


Figure 10.18 Comparison between the past (*i.e.*, 1950s) model and the present-day model of Hong Kong marine ecosystem under selected fisheries management scenarios simulated for 25 years period. Biomass profile of the past ecosystem model was reproduced from Cheung (2001) with permission. Note: the suffix 'a' at the end of each scenario number denotes 'AR' case, while 'b' denotes 'No AR' case.

Table 10.3 Comparing the predicted biomass (t/km^2) of selected resource groups in the past marine ecosystem of Hong Kong in the 1950s (Cheung 2001) with those of the present-day ecosystem (*i.e.*, 1990s) under selected fisheries management scenarios. The suffix 'a' at the end of each scenario number denotes the 'AR' case, while 'b' denotes the 'No AR' case. See Chapter 8 for detail descriptions on each scenario.

Resource Group	Predicted biomass (t/km^2)				
	Present-day Ecosystem				Past Ecosystem
	Sce1b	Sce2a	Sce5b	Sce9a	
All reef fish	0.03	1.10	0.11	3.19	2.44
Non-reef demersal fish	2.48	2.55	2.73	3.03	8.46
All reef resources	1.20	2.30	1.83	4.31	7.38
Pelagic fish	0.69	0.62	3.45	0.89	3.67
TOTAL	4.40	6.57	8.13	11.42	21.96

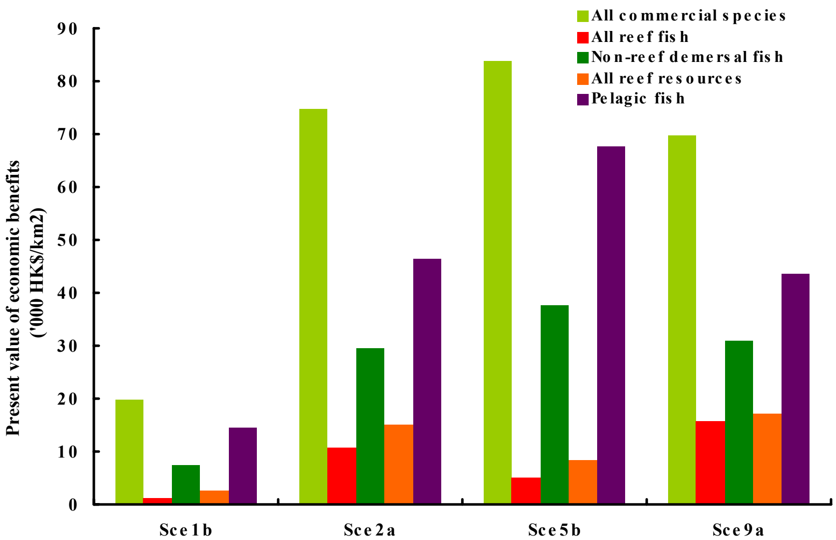


Figure 10.19 Present value ('000 HK$/km²) of economic benefits obtained under selected fisheries management scenarios.

In terms of economics (Figure 10.19), the 'no plan' scenarios (*viz.*, Scenario 1b) does very poorly compared to the other scenarios mainly because the economic rent gets dissipated due to the 'race for the fish' that occurs under this scenario.

Unlike in the case of ecology, where Scenario 9a does best, followed by scenarios 5b and 2a; economically, Scenario 5b does best, while Scenario 9a and Scenario 2a produced similar results in our simulations.

10.5 Conclusions and Recommendations

Subject to the assumptions within our modelling system, we conclude:

1. That current biomass, species composition and economic returns compare very unfavorably with the 1950s model of Hong Kong marine ecosystem (Cheung 2001)
2. Continuation of the *status quo* without mitigation measures will lead to further fishing down the marine food web and shifts in ecosystem structure with a high probability of ecosystem collapse and attendant loss of economic and social benefits.
3. Complete closure of Hong Kong waters to all fishing leads to rapid rebuilding of the marine ecosystem, however resumption of fishing at current fleet and effort levels negates these benefits in about 2 years.
4. The benefits of large 'no-take' areas outweigh AR placement, however, AR are beneficial in the 'no-plan' or *status quo* scenario.
5. The combination of AR and 'no-take' FPA confers significant ecological and economic benefits.
6. A trawl ban in Hong Kong waters would lead to important gains in biomass, benefits to remaining fishing sectors and substantial long-term economic gains.
7. A trawl ban in coterminous PRC waters combined with 50% 'no-take' areas sees very substantial gains in all sectors including prawn fisheries.
8. It appears AR would improve economic gains from the marine ecosystem of Hong Kong in the 'no plan scenario'.
9. Cross sectoral comparisons indicate that prawn fishers are the only losers from AR/FPA implementation, all other sectors benefit.

The above conclusions are based on the assumption that fishers comply with management regimes. In order to maximize the chance of compliance we recommend:

1. Simulations of the interaction between other measures contemplated by AFCD, *e.g.* licensing, with the AR/FPA program to determine the most beneficial combination.
2. Implementation of a substantial community outreach program with the active participation of NGOs as recommended in the HK2 Project (ERM 1999).
3. More detailed analysis of fishing sector net economic benefit analysis is needed to support future negotiations (between AFCD and fishing sectors) that may lead to reduction of fishing effort in order to get a given management policy scenario implemented.
4. That fishing communities be fully integrated into the monitoring and assessment of ecological and economic changes attributable to the AR/FPA program.

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