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Restoration of Marine Coastal Ecosystem Health as a New Goal for Integrated Catchment Management in Tolo Harbor, Hong Kong, China

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ABSTRACT / This article demonstrates why it is necessary to have the restoration of marine coastal ecosystem health as a new goal for integrated catchment management in the coastal area of Tolo Harbor. The present goal of integrated catchment management (ICM) in the Tolo Harbor is based on water quality objectives. The performance of the ICM plan, the Tolo Harbor Action Plan (THAP), was evaluated using marine coastal ecosystem health indicators including both stress and response indicators. Since the implementation of THAP in 1988, some significant reductions in pollution loading have been observed: reduction of 83% of biological oxygen demand load and 82% of total nitrogen between 1988 and 1999. There has also been an improvement in the health of Tolo Harbor's marine coastal ecosystem as evidenced by trends in physical, chemical, and biological indicators, although reverse fluctuations in some periods exist. However, such improvement can only be considered as the first sign of complete ecosystem health restoration, because ecosystem health covers not only physical, chemical, and biological aspects of an ecosystem, but also ecosystem service functions. The findings support the need to take the restoration and protection of marine coastal ecosystem health as a new goal rather than using water quality objectives. Steps necessary to further improve Tolo Harbor's marine coastal ecosystem health are also discussed.

The medical notion of ''health'' was extended to ecosystems in the mid-1980s in response to accumulating evidence suggesting that human-dominated ecosystems had become highly dysfunctional (Rapport 1995). Since that time, the term ''ecosystem health'' has been used with increasing frequency in all types of governmental, academic, and popular media publications (see Xu and others 1999, 2001 for review). At the same time, environmental managers began to embrace the new concept as a valuable focal point around which to characterize more specific goals within the field of environmental management (e.g., Schaeffer and others 1988, Costanza and others 1992, Rapport 1995, Rapport and others 1998a, 1998b). For instance, in the United States, ecosystem health is used as one of the goals in long-range environmental protection policy documents (Haskell and others 1992).

KEY WORDS: Marine coastal ecosystem health; Integrated catchment management; Pollution loading; Comprehensive indicator; Tolo Harbor Action Plan

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Tolo Harbor is a nearly land-locked water body located to the northeast of Hong Kong with only one narrow exit open to the sea at Mirs Bay (Figure 1). The harbor is about 15 km long with a surface area of 52 km^2 and an average depth that varies from less than 10 m in the inner harbor to more than 20 m in the main channel near the harbor's mouth. In addition, the velocity of the harbor's current is relatively weak, varying from 0.04 m s^{-1} in the inner harbor to 0.08 m s^{-1} as one reaches the channel (EPD 1987a). This weak circulation function, together with pronounced density stratification from May to September and prevailing northeasterly winds, prevents the effective transport of pollutants out of Tolo Harbor. As such, the harbor has only a limited capacity to assimilate pollutants and shows signs of progressive pollution.

Several studies undertaken in the early 1970s showed that dissolved oxygen concentrations in the inner harbor fell during the summer (Watson and Watson 1971, Okaley and Cripps 1972, Trott 1972), and that concentrations of nitrate and phosphate as

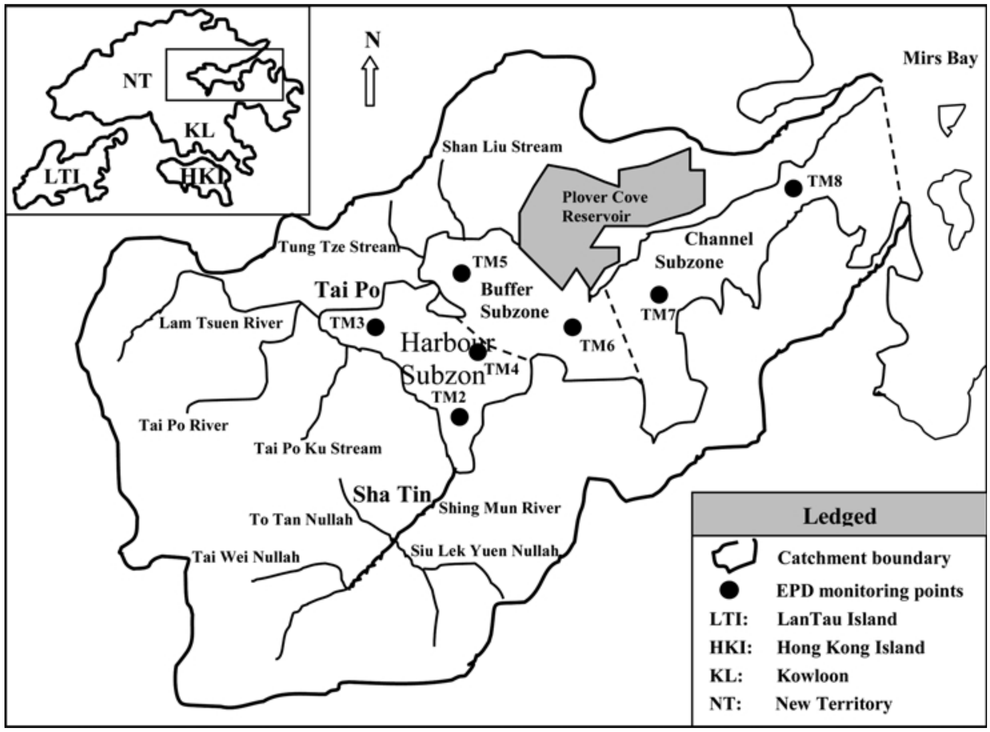

Figure 1. Sketch map of Tolo Harbor catchment showing its location, new towns, major rivers, three subzones, and EPD monitoring points.

well as coliform bacteria were at already high levels in the harbor's surface waters (Watson and Watson 1971, Trott and Fung 1973; Trott 1973; Kuth 1974; Kuth and Trott 1974; Gordon 1975; Kuth and Chan 1975; Preston 1975). At that time, however, waters in the main channel were generally considered free of organic pollution (Trott 1972, 1973, Kuth 1974, Kuth and Trott 1974, Kuth and Chan 1975) and thus not seriously threatened. Additional research conducted during the late 1970s and early 1980s witnessed not only a continuing decline in water quality, but also a decline in channel fauna as people progressed toward the open sea (Morton 1976, 1982, 1985, 1987, 1988, 1989, 1990, Stirling and Wormald 1977, Wong and others 1977, 1980, Wu and Richards 1979, Hodgkiss 1981, 1988, Hodgkiss and Kan 1981, Scott and Cope 1982, Scott 1990, Dudgeon and Morton 1982, Thompson and Yeung 1982, Hodgkiss and Chan 1983, 1986, Wear and others 1984, Holmes and Lam 1985, Holmes 1988, Yip 1988, Lam and Ho 1989). The situation became even more critical in the late 1980s with frequent occurrences of red tides and associated fish kills (Hodgkiss 1988; Holmes 1988; Morton 1985, 1988; Yip 1988; Lam and Ho 1989) as well as coral deaths (Scott and Cope 1982, Scott 1990; Dudgeon and Morton 1982, Wu 1982, 1988). It is at this time that Morton (1988) referred to Tolo Harbor as ''Hong Kong's First Marine Disaster'' and pointed out that the inner portions of Tolo Harbor were effectively dead. In addition, long-term monitoring data from Hong Kong's Engineering Development Department (EDD 1985) and Environmental Protection Department (EPD 1982–1999) supported these earlier findings showing increasing pollution trends both spatially and temporally from the early 1970s to the late 1980s (see Xu and others 2004a for details).

In the late 1980s, environmental degradation in Tolo Harbor reached a critical stage (Morton 1988) and an integrated action plan, the Tolo Harbor Action Plan (THAP), was developed by the Hong Kong Government in an effort to stop the disastrous trend. The present study was undertaken to examine the goals, performance, and effectiveness of the THAP with the specific purpose of answering the question ''Can THAP save Tolo Harbor?''

Methods

The performance of an integrated catchment management plan, the Tolo Harbor Action Plan (THAP), was evaluated using a series of marine coastal ecosystem health indicators including stress and response

Table 1. The indicators for assessing marine coastal ecosystem health in Tolo Harbor

Ecological indicators		Relative changes following healthy state: Good health	Relative changes following healthy state: Bad health
Stress indicators	BOD loading (kg d^{-1})	Smaller	Larger
	TN loading (kg d^{-1})	Smaller	Larger
	Heavy metal loading (kg d^{-1})	Smaller	Larger
Physical response indicators	SD (m)	Larger	Smaller
	Suspended solids (mg l^{-1})	Lower	Higher
	Turbidity (NTU)	Lower	Higher
	Dilution capacity	Larger	Smaller
Chemical response indicators	DO (bottom)	Higher	Lower
	Aggregate organics (BOD_5)	Lower	Higher
	Nutrients (TN, TP)	Lower	Higher
	Heavy metals	Lower	Higher
	Bacteria level (fecal coliform)	Lower	Higher
Biological response indicators	Mangrove biomass	Larger	Smaller
	Chl-a concentration (mg m^{-3})	Lower	Higher
	Number of red tide occurrences	Lower	Higher
	Ratio of diatoms/dinoflagellates	Higher	Lower
	Species abundance	Higher	Lower
	Species diversity	Higher	Lower
Ecosystem service function response indicators	See food productivity	Higher	Lower
	See food quality	Better	Worse
	Marine farming	Yes	No
	Primary contact recreation (bathing, diving)	Yes	No
	Aesthetic enjoyment	Yes	No
	Natural flushing & dilution waters	Yes	No

indicators (see Table 1 and Xu and others 2004b for details). Biological oxygen demand (BOD), total nitrogen (TN), and heavy metal loadings were used as stress indicators, while Secci disk depth (SD), turbidity, dissolved oxygen (DO) of bottom water, aggregate organics (BOD_5), nutrients (nitrogen and phosphorus), chlorophyll-a (Chl-a), number of red tide occurrences, and bacteria (*Escherichia coli* and fecal coliform) were applied as response indicators. It was assumed that increases in SD and bottom DO coupled with decreases in turbidity, BOD_5, nutrient concentration, Chl-a contents, number of red tide occurrences, and bacteria level were representative of improvements in ecosystem health. A detailed flow chart for the study is shown in Figure 2.

Results

Implementation of Integrated Catchment Management

Major factors in the integrated Tolo Harbor catchment water management plan include (1) strengthening legislation and implementation, (2) intensifying treatment of various pollution sources by a number of actions including upgrading treatment facilities, and (3) tightening administrative management through establishment of a licensing system and by enforcement of the ''Polluter Pays Policy.''

Legislation and enforcement. Two pieces of legislation, the Water Pollution Control Ordinance (WPCO) and the Waste Disposal Ordinance (WDO), play crucial roles in enforcing the integrated basin management plan for the Tolo Harbor catchment. The WPCO, enacted in 1980 (Pearce 1980), is the principal piece of legislation controlling water pollution in Hong Kong. The ordinance and its subsidiary legislation allows the government to set up 10 water control zones (WCZs) in which regulations are applied to control effluent discharges aimed at achieving specific water quality objectives (WQOs) in each zone. The Tolo Zone (WCZ1), declared on April 1, 1987, was the first WCZ in Hong Kong. The WPCO was amended in 1990 to expand the scope and allow for tighter controls on effluent discharge. Further amendments were made in

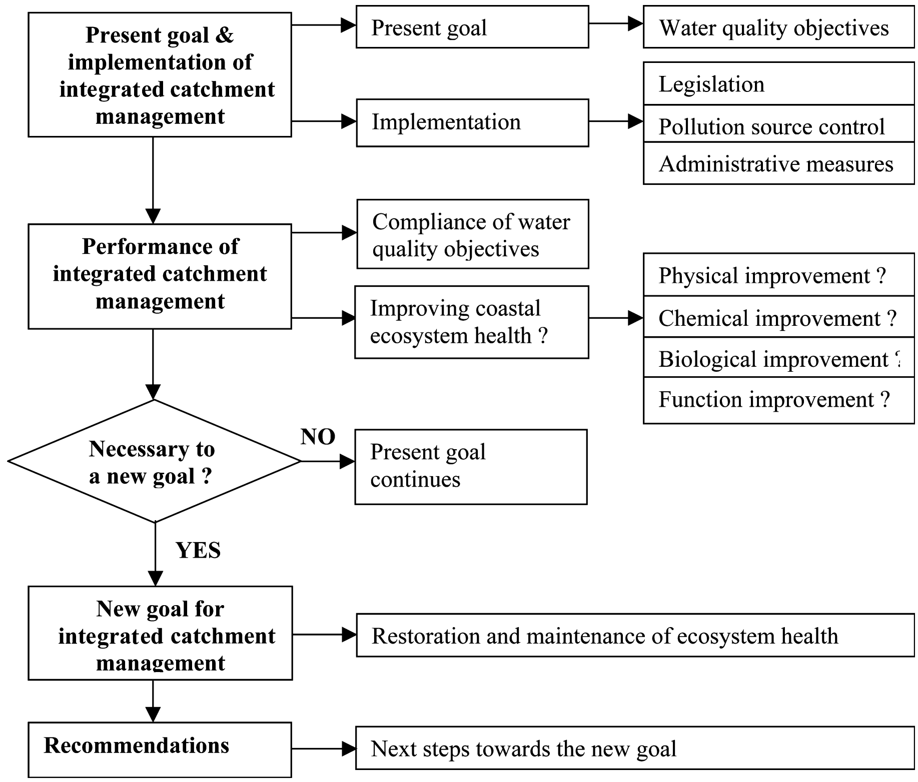

Figure 2. The flow chart for the study of new goals for integrated catchment management.

1993 to impose controls on the connection of wastewater to the public sewerage system and the proper operation and maintenance of private communal sewage treatment plants. With the last amendment of WPCO, the Tolo Harbor Supplementary Water Control Zone (SWCZ) was further designated as a new water control zone beginning 1 June 1993.

WDO is the principal waste management law in Hong Kong. The Waste Disposal Regulation concerning Chemical Waste made under the WDO was enacted in January 1992 to control chemical waste including toxic industrial effluents (EPD 1992), while the Waste Disposal Livestock Waste Regulation imposed a ban on keeping livestock in designated urban areas. With implementation of these regulations, disposal of wastes directly into receiving waters has been theoretically eliminated. Under the Waste Disposal Ordinance Amendment effective July 1994, Livestock Waste Prohibition Areas were extended in coverage and additional Restriction Areas were introduced. Furthermore, no new livestock farms were allowed in the designated Restriction Areas.

Tolo Harbor Action Plan. Using these two legislatively based regulations as a base, a comprehensive water pollution control plan, the THAP, was implemented in 1988. THAP consists of a number of component actions whose main objective was the development of sewerage and sewage treatment works (Table 2). As indicated in Table 2, controls on livestock waste and urban and rural sewage are key components in the THAP. In order to combat the increasing seriousness of pollution from livestock waste, a 10-year livestock waste control scheme was put into place in 1988 (actions (1) and (2)). The Tolo Harbor Sewerage Master Plan (THSMP) implemented in 1993 was designed to solve problems associated with unsewered village sewage within the catchment area (actions (5a), (5b)). The THSMP provides the sewerage infrastructure for approximately 165 villages that are now required to collect sewage and direct it to treatment facilities. Upon completion of the THSMP, an estimated 88,500 inhabitants in the Tolo Harbor area will be provided with proper sewerage (EPD 2000b). To eliminate nutrient loading from domestic sewage, the Sewage Treatment Works (STW) Process Modifications (action (4)) for Shatin and Tai Po STWs were implemented in 1992 and the treated sewage diverted by Effluent Export Schemes (actions (7a), (7b) and (7c)). The pollution loadings from other sources, such as industrial and commercial effluents, have been reduced following the implementation of WPCO's action (3).

Table 2. Component actions of Tolo Harbor Action Plan (data from EPD 2000b)

Number	Action	Enactive date
(1)	Livestock Waste Disposal Control in Tolo Harbor catchment	1988
(2)	Livestock Ban in urban areas and new towns	1988
(3)	Implementation of Water Pollution Control Ordinance (WPCO)	1990
(4)	Sewage Treatment Works (STW) Process Modification	1992
(5a)	Sewerage Master Plan Stage I—Sewage First-aid Measures	1993
(5b)	Sewerage Master Plan Stage I—Village Sewage Scheme	1998
(6)	Landfill Restoration	1994
(7a)	Effluent Export Scheme (Shatin)—Partial Diversion	1995
(7b)	Effluent Export Scheme (Tai Po)—Partial Diversion	1996
(7c)	Effluent Export Scheme—Full Diversion	1998

Administrative Measures

In order to control pollution loading and to achieve and maintain water quality objectives in the Tolo Harbor WCZ, a Licensing System and a ‘‘polluter pays policy’’ have been implemented as major administrative controls for the enforcement of various actions and legislations. The license system includes both industrial discharge licenses and livestock-keeping licenses. Each industrial discharge license specifies the permitted volume or rate of discharge and the permitted quality of effluent. A scheme for licensing livestock farms has been introduced to regulate livestock keeping and to ensure effective on-site controls over livestock waste. Farms are able to receive livestock-keeping licenses only after the installation of appropriate waste treatment systems (EPD 2000b).

The ‘‘Polluter Pays Policy,’’ as part of the wastewater management strategy, was proposed in a 1989 White Paper on pollution management in Hong Kong (Planning, Environment and Lands Branch 1993). Charges for domestic polluters consists of two parts: a fixed charge that is based on the capacity of the water meter in each household, and a variable charge that is based on the volume of sewage produced by each water consumer and calculated according to the volume of water consumed. For heavier industrial and commercial polluters, there is an additional trade effluent surcharge based on the additional operating costs of providing treatment for excess pollutant loads when the effluents are above the average strength of domestic sewage. The policy also provides incentives for both minimizing wastewater generation and for adoption of cleaner production techniques by installing on-site wastewater pretreatment facilities.

The Present Goal of the Integrated Catchment Management

The establishment of the WCZ in 1987 and the SWCZ in 1993 with a view toward integrated catchment management marked a new beginning for management practices in the Tolo Harbor. WQOs were first established after the formal declaration of the Tolo Harbor WCZ in 1987 (Table 3) and since then, WQOs have served as the primary goal for Tolo Harbor's integrated catchment management scheme.

Performance of the Integrated Catchment Management Plan

Since the implementation of the THAP in 1988, industrial and livestock pollution within the catchment has been largely eliminated. Implementation of THAP has led to reductions in a number of WQOs including BOD, TN, and heavy metal loadings as well as in the percentages of compliance with key water quality objectives in the Harbor Subzone, as well as improvement in long-term trends in physical, chemical, and biological aspects of marine coastal ecosystem health as measured by ecosystem health indicators (Figures 3–7). BOD, TN, and heavy metal loadings to the Tolo Harbor are considerably reduced, especially pollution loads from industrial wastewater and livestock wastes. By the end of 1999, a total of 12,345 kg BOD d^{-1} (83% of 1986 load) had been effectively removed from the Shing Mun River, Lam Tsuen, and Tai Po River catchments (EPD 1999). Total TN load from point sources in the Tolo Harbor catchment also decreased significantly, falling from $\sim$6000 kg/d in 1986 (EPD 1987b) to about 1100 kg/d in 1999 (EPD 2000b). In addition, toxic metal concentrations in the Fo Tan Nullah, which was heavily polluted by industrial discharge, has declined steadily since 1987. The yearly mean concentrations of Cu, Ni and Cr have also dropped from 3589, 546.8 and 589.6 μg/L in 1987 to 3.8, 2.4 and 1.24 μg/L in 1999, respectively (EPD 2000).

Trends in average compliance percentage for bottom DO and Chl-a within the Harbor subzone are presented in Figure 4. Average compliance percentages for bottom DO increased from 75% in 1988 to 93% in 1990, although this was followed by decreases during 1991

Table 3. Water quality objectives (WQO) for Tolo Harbor and channel

Water quality parameters	Harbor subzones	Buffer subzones	Channel subzone
E. coli (no./100 ml) (annual geometric mean)	<610	<610	<610
Chlorophyll-a (mg m^{-3}) (5 days running mean)	<20	<10	<6
DO within 2 m of bottom (mg L^{-1})	>2	>3	>4
DO in rest of water column (mg L^{-1})	>4	>4	>4
Light penetration reduction (%)	<20% of normal level	<15% of normal level	<10% of normal level
pH value	<0.5	<0.3	<0.1
Salinity change (ppt)	<3	<3	<3
Temperature change (°C)	<1	<1	<1

Data from EPD 1986.

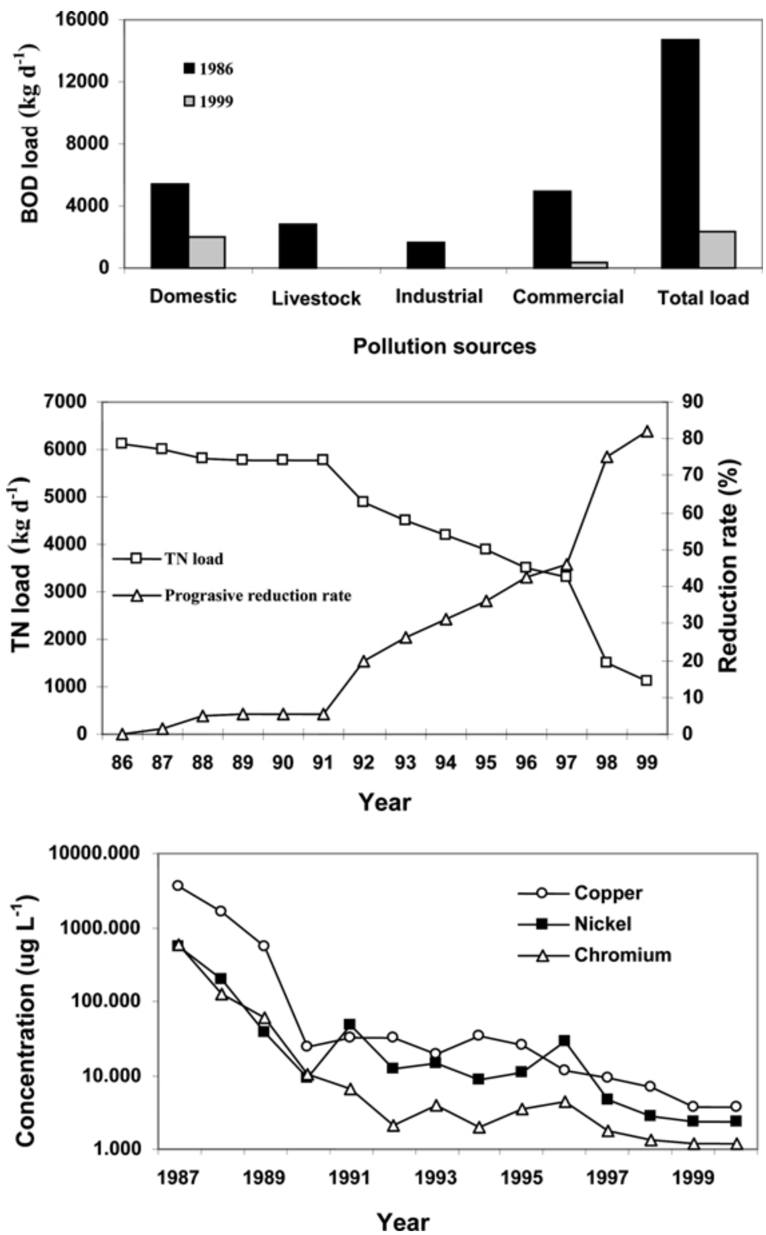

Figure 3. Reduction of (a) BOD load, (b) TN load, and (c) heavy metal concentrations in Fo Tan Nullah (drawn from EPD, 1994, 1999, 2000a).

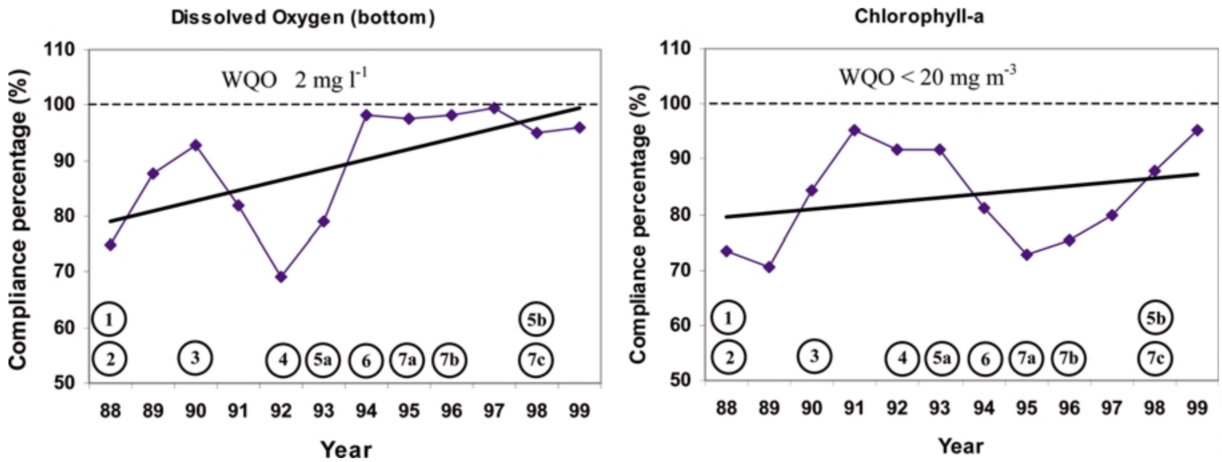

Figure 4. Percentages of compliance with key water quality objectives in Harbor subzone from 1988 to 1999 (average of TM2, TM3, and TM4; calculated and drawn from EPD 1996, 1999).

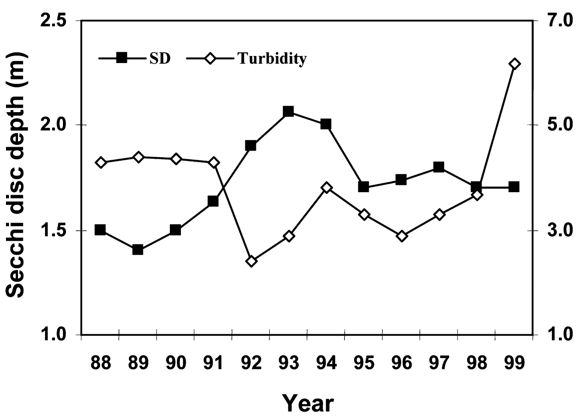

Figure 5. Long-term trends of ecosystem health indicators in Tolo Harbor subzone after THAP (calculated and drawn from EPD 1988–1999; average of T2, TM3, and TM4; (1)-(7c): THAP actions).

and 1992. Since then, average compliance percentages have remained above 95%. For Chl-a, the average compliance percentage increased from less than 75% in 1988 and 1989 to more than 85% between 1990 and 1993. After decreases in 1994 and 1995, the average compliance percentage has increased progressively.

Figure 5 shows the general trend for SD levels, with decreases occurring between 1994–1995 and 1997–1999. However, there was no general trend observed for turbidity. Figure 6 shows the generally increasing trend for bottom DO (Figure 6a) and fecal coliform (Figure 6b), whereas BOD_5 in Figure 6a, *Escherichia coli* in Figure 6b, TN and TIN in Figure 6c, and TP and PO_4-P in Figure 6d show general declines. However, there were decreases in compliance percentages for bottom DO during 1996–1999 (Figure 6a), as well as some increases for BOD_5 between 1994 and 1996 (Figure 6a), for *E. coli* between 1989 and 1992 (Figure 6d), for Chl-a between 1993 and 1995 (Figure 6b), for TN between 1996 and 1998, and TIN between 1989 and 1994 and 1996 and 1998 (Figure 6c), for TP between 1989 and 1991 and 1995 and 1996, and for PO_4-P between 1989 and 1994 (Figure 6d). The decreasing trend in Chl-a concentration and the number of red tide occurrences can be seen in Figure 7.

These overall trends suggest that the general health state of Tolo Harbor's marine coastal ecosystem has improved. However, the reverse fluctuations observed in some periods are not yet fully understood and thus there is no clear picture of the plan's long-term effective capability. A better understanding of these reverse fluctuations will be necessary before a final assessment of THAP's effectiveness can be clearly established.

A New Goal for Integrated Catchment Management

For most contemporary investigators, ecosystem health is a holistic concept covering both the biophysical and socioeconomic aspects of ecosystems, e.g., Rapport (1989), Kay (1991), Costanza (1992), Jϕrgensen (1995), Rapport and others (1998a, 1998b), and Xu and others (1999, 2001, 2004b). Assuming this to be true, then the use of key water quality objectives along with improvements in certain physical, chemical, and biological features represents only one aspect of ecosystem health and as such, should be thought of as a first step in the restoration process. Complete restoration will require not only measures necessary to address the regulation of ecological structure, but also the restoration and maintenance of important ecosystem service functions as well. This suggests that the integrated catchment management plan should take the ''restoration and protection'' of marine coastal

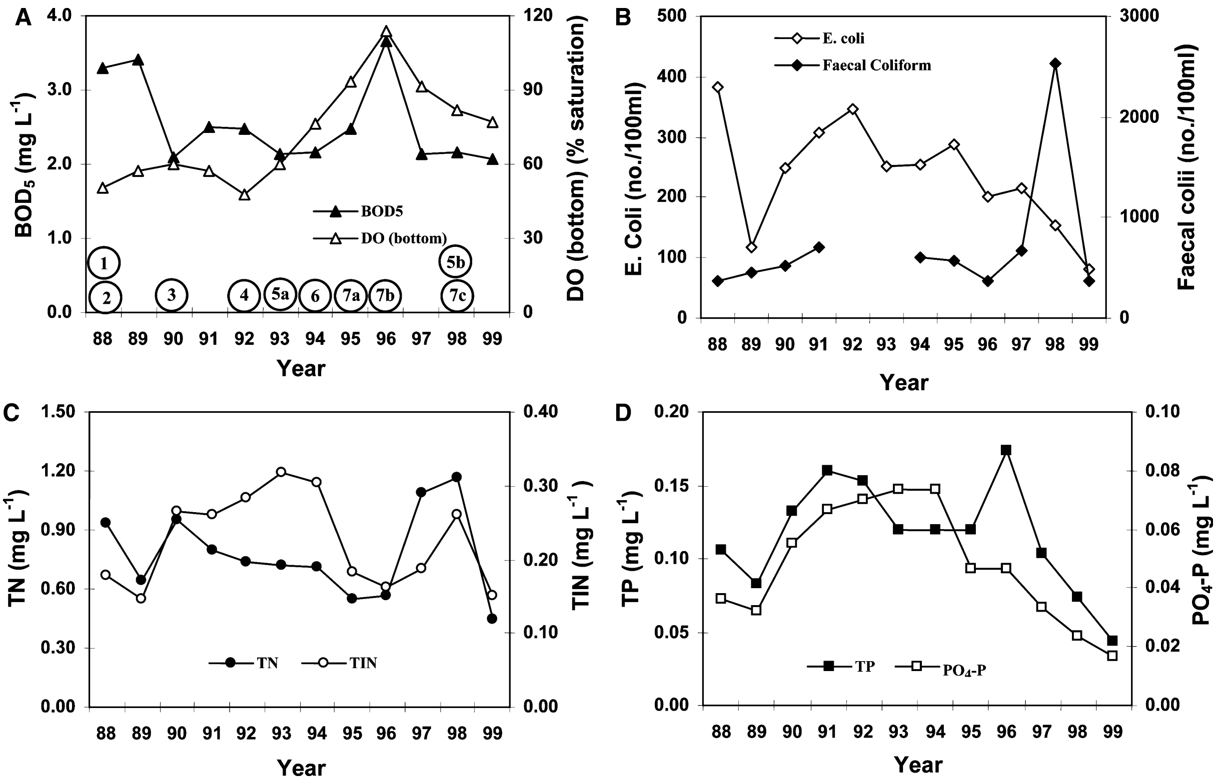

Figure 6. Long-term trends of ecosystem health indicators in Tolo Harbor subzone after THAP (calculated and drawn from EPD 1988–1999; average of T2, TM3, and TM4; (1)-(7c): THAP actions).

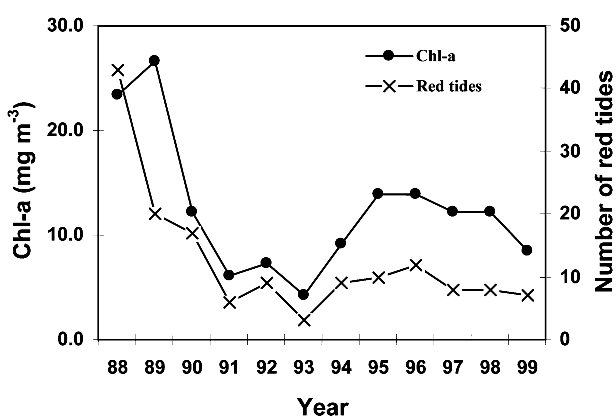

Figure 7. Long-term trends of ecosystem health indicators in Tolo Harbor subzone after THAP (calculated and drawn from EPD 1988–1999; average of T2, TM3, and TM4; (1)-(7c): THAP actions).

ecosystem health as a new goal for Tolo Harbor, with water quality objectives internal to the plan rather than the sole objective of the management approach. Thus, improvements in water quality including physical, chemical, and biological aspects may be treated as the first step towards this new goal, while the restoration and maintenance of ecosystem service functions provide the final step.

Research during the early 1970s on the inner portion of Tolo Harbor even went so far as to suggest that with high biodiversity the area could serve as the paradise for harvestable sea life (fish, shellfish, crustaceans), marine farming, and primary contact recreation such as swimming and diving (e.g., Morton 1988). Unfortunately, the majority of these functions has been completely or partly lost due to significant increases in organic pollution and eutrophication (e.g., EPD 1987b, Morton 1988) (Table 4).

Discussion

Results from the integrated catchment management scheme outlined above show signs of effective progress in delimiting pollutant loadings from point sources (Figure 3) and in improving the general health state of Tolo Harbor's marine coastal ecosystem as evidenced by the trends of the physical, chemical, and biological indicators (Figures 5–7). However, the trends observed to date are somewhat unstable as indicated by the number of reverse fluctuations in performance witnessed thus far (Figures 5–7). In addition, there have been no signs of improvement in the ecosystem's service functions, further suggesting that a great deal of

Table 4. Changes in marine coastal ecosystem service functions of Harbor subzone

Ecosystem service functions	Period to 1970s	1970s	1980s	1990s
Maintenance of natural aquatic ecosystems	+	+	+	+
Sea food (fish, shellfish, crustaceans)	+	±	−	−
Mariculture	+	±	−	−
Primary contact recreation (bathing, diving)	+	±	−	−
Secondary contact recreation (boating, fishing)	+	+	+	+
Aesthetic enjoyment	+	±	−	−
Shipping & marine traffic	+	+	+	+
Industrial & domestic salt water supply	+	+	+	+
Natural flushing & dilution waters	+	±	−	−

''+'': Yes; ''−'': No.

work remains before Tolo Harbor's restoration is complete.

If ecosystem health is to be used effectively as a management objective, then THAP should be revised to achieve the following objectives: (1) to reflect a shift from water quality objectives (WQOs) to an ecosystem health objective (EHO) that is composed of a set of subgoals including physical, chemical, biological, and ecosystem-serving functions and where the restoration and maintenance of ecosystem service functions are thought of as the final goal; (2) new monitoring items including physical, chemical, biological and ecosystem-serving function aspects should be added in the revised THAP; and (3) strategies for this new management goal should emphasize both ''reducing pressures'' (decreasing the adverse influences of various pollutions, resource uses, and ecological damage caused by human activities) and ''increasing buffering capacity'' (increase the capacity of the ecosystem to counteract adverse pressures).

There is also the need for comprehensive policies and countermeasures that can integrate a full array of market-based incentives (fees, fines, permits, emissions trading, and green taxes) with other instruments (legal, administrative, technical, and educational) in order to promote cleaner behaviors throughout the economic sector and provide clearly stated controls for the various pressures that adversely affect ecosystem health.

Eutrophication and heavy metal pollution in sediment may be two of the factors needing immediate attention. Although 82% of the TN load from point sources has been removed (Figure 3), a great deal of work remains because the nutrients necessary for algal blooms may also be found in internal sources (Perking and Underwood 2001). Recent research suggests that a large amount of the nutrients discharged into natural aquatic ecosystems can accumulate in sediments in both organic and inorganic forms and be released into the water column at a later time under certain environmental conditions (see Evans 2001 for review). Van der Molen and Boers (1994) even found that a reduction in the external supply through management can increase the importance of internal nutrient loading from the sediment. For Tolo Harbor, the results from N and P release experiments performed by Hu and others (2001) showed that the sediments released a significant amount of nutrients, especially orthophosphates and ammonia nitrogen, with maximum release rates on the order of 15.0 to 206.0 mg m^{-2} d^{-1}. Although the external nutrient loading has been reduced, nutrients could gradually be released back into the water column from the contaminated sediments, delaying any improvements in water quality and ecosystem health.

In terms of heavy metal pollution (Cd, Cr, Cu, Fe, Mn, Pb, and Zn), routine measurements of Tolo Harbor's sediments have been carried out by Hong Kong's Environmental Protection Department since the 1980s in addition to numerous outside studies (Wong and others 1980, Wong and Au 1984, Chu and others 1990, Cheung and Wong 1992, Tam and Wong 1994, 1995). Blackmore (1998) conducted an excellent review of heavy metal pollution in Tolo Harbor and concluded that heavy metal pollution was serious, as reflected by the elevated levels measured in sediments and biomonitors (barnacles, mussels, and algae) through the 1980s and early 1990s (Blackmore 1998).

In order to determine the potential for and influence of internal loading, a detailed site study should be carried out. Laboratory approaches are also necessary to examine the sediment responses to different nutrient and heavy metal loads. In addition, efforts should continue to be made to control pollutant loadings from various point sources, especially untreated village sewage. The Hong Kong EPD annual report for 2000 shows there were still about 90,000 villagers without sewage systems. At the same time, the license system for farms should continue to be enforced to control livestock wastes, because there is evidence suggesting an increasing trend in pig and poultry populations in the New Territories including portions of the Tolo Harbor catchment since 1993 (see Xu and others 2004a for details).

Conclusions

The performance of the Action Plan has been evaluated in the present study. Assessment results of an integrated catchment management plan for Tolo Harbor using marine coastal ecosystem health as an indicator reveal that implementation of THAP has been particularly effective in eliminating pollutant loadings from point source. Also, there has been a general improvement in the harbor's health state as evidenced by trends in several physical, chemical, and biological indicators, although the present results indicate that the trends are unstable with some reverse fluctuations. By introducing the restoration of marine coastal ecosystem health as a new goal for the integrated catchment management of Tolo Harbor, improvements in physical, chemical, and biological aspects of ecosystem health can be considered only a first step toward the new goal. To achieve this new goal, managers and planners should place increased emphasis on cutting down internal nutrient loads as well as eliminating sewage loads from the nearly 90,000 small villages without treatment facilities. This is in addition to continuously controlling point sources including those from industrial, agricultural, and commercial sources.

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