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Cumulative environmental impacts and integrated coastal management: the case of Xiamen, China

Xiongzhi Xue[a,*], Huasheng Hong[a], Anthony T. Charles[b]

[a]Marine Environmental Lab, Ministry of Education, Environmental Science Research Center, Xiamen University, Xiamen, China
[b]Management Science/Environmental Studies, Saint Mary's University, Halifax, Canada

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Abstract

This paper examines the assessment of cumulative environmental impacts and the implementation of integrated coastal management within the harbour of Xiamen, China, an urban region in which the coastal zone is under increasing pressure as a result of very rapid economic growth. The first stage of analysis incorporates components of a cumulative effects assessment, including (a) identification of sources of environmental impacts, notably industrial expansion, port development, shipping, waste disposal, aquaculture and coastal construction, (b) selection of a set of valued ecosystem components, focusing on circulation and siltation, water quality, sediment, the benthic community, and mangrove forests, and (c) use of a set of key indicators to examine cumulative impacts arising from the aggregate of human activities. In the second stage of analysis, the paper describes and assesses the development of an institutional framework for integrated coastal management in Xiamen, one that combines policy and planning (including legislative and enforcement mechanisms) with scientific and monitoring mechanisms (including an innovative 'marine functional zoning' system). The paper concludes that the integrated coastal management framework in Xiamen has met all relevant requirements for 'integration' as laid out in the literature, and has explicitly incorporated consideration of cumulative impacts within its management and monitoring processes.

Keywords: Integrated coastal management; Coastal management system; Coastal zone; Marine functional zoning; Cumulative impacts; Cumulative effects; Environmental assessment; Xiamen; China

1. Introduction

The majority of the world's population lives in coastal zones, combined terrestrial-aquatic areas revolving around a land-sea interface. Such areas face many environmental and management challenges, due to a combination of environmental impacts that arise in terrestrial locations, those that tend to arise in open ocean areas, and those inherent to coastlines, such as the impacts of 'land-based sources of marine pollution'. The high degree of complexity in the coastal zone has led to an emphasis on integrated coastal management (ICM) as a governance mechanism for taking into account the various aspects of human activities and their management (FAO, 1998).

From a practical perspective, successful 'integrated' management in a coastal area requires an understanding of the environmental impacts arising from each of the relevant coastal activities (shipping, port development, waste disposal, fishing, aquaculture, etc.). This may well be accomplished through Environmental Impact Assessments (EIAs) for the respective projects or activities. However, (1) some individual activities, seen as too small to justify their own EIAs, may fail to be considered, and (2) project-by-project EIAs may indicate impacts that are minor in themselves, yet the totality of these impacts could be significant, even unacceptable (especially if the impacts accumulate nonlinearly). For these reasons, ICM needs to incorporate a process to monitor and assess cumulative impacts—to address the impacts of interactions among activities, and the accumulation of impacts over time (Clark, 1996). As the Ramsar Convention on Wetlands (2002) notes, "sustainable use of coastal resources can be seriously affected by both human-made and natural perturbation of

* Corresponding author. Tel.: +86-592-2184161; fax: +86-592-2181875.

E-mail addresses: xzxue@jingxian.xmu.edu.cn (X. Xue); hshong@xmu.edu.cn (H. Hong); t.charles@smu.ca (A.T. Charles).

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coastal processes, including cumulative impacts generated by both large and small development projects…".

This paper examines how cumulative environmental impacts have been considered in the context of integrated coastal management, within a particularly challenging context—that of the rapidly-growing city of Xiamen, China. The paper also explores the lessons that might be drawn for such endeavours elsewhere in the world.

Xiamen, located on the south-east coast of China, is famous both for its history as one of the country's earliest international trade ports (Amoy) after the Opium War, and for its subtropical scenery—the 'Garden in the Sea'. A special economic zone of China, Xiamen has many of the characteristics of a free port and is becoming an attractive site for foreign investment. Xiamen's coastal zone is under increasing pressure as a result of rapid socio-economic growth and the expanding use of coastal resources. Indeed, Xiamen's coastal waters—the Jiulong River Estuary, the Western Seas, the Southern Seas, the Eastern Seas and the Tong'an Bay (Fig. 1)—have changed physically over time, especially following construction of the Gaoqi-Jimei dike in 1956, when Xiamen Island became a peninsula connected to the mainland, with Xiamen Western Sea and Tong'an Bay becoming semi-enclosed bays. Furthermore, coastal ecosystem degradation has been driven not only by physical and economic forces, but also by inadequate planning and management.

Xiamen has experienced a range of environmental impacts arising from the rapid development of its harbour and the multiple uses of that harbour, compounded by (a) the coastal/aquatic nature of the situation, which implies the relevance of water-based transport of the environmental impacts, and (b) the strongly multi-jurisdictional nature of the impacts. These realities are by no means unique to Xiamen, but the combination of these is bound to create a particular challenge. This paper examines how this challenge has been approached within a Chinese context of very rapid economic change. We begin in Section 2 with a discussion of the relevant methodologies used in the analysis.

2. Methodology: cumulative impacts and integrated coastal management

2.1. Cumulative impacts

Proposed development projects in Xiamen harbour, as elsewhere in China, have been subject (since 1979) to compulsory Environmental Impact Assessments (Editing Committee, 1994). However, as noted in the previous section, a set of project-specific EIAs may not be sufficient to deal with cumulative impacts. Accordingly, an accompanying assessment of cumulative impacts was carried out for Xiamen, in conjunction with the development of a framework for Integrated Coastal Management (ICM) supporting the sustainable development of coastal/marine areas and resources.

The methodology for analysing such cumulative environmental impacts is known as Cumulative Effects Assessment (CEA), or equivalently Cumulative Impact

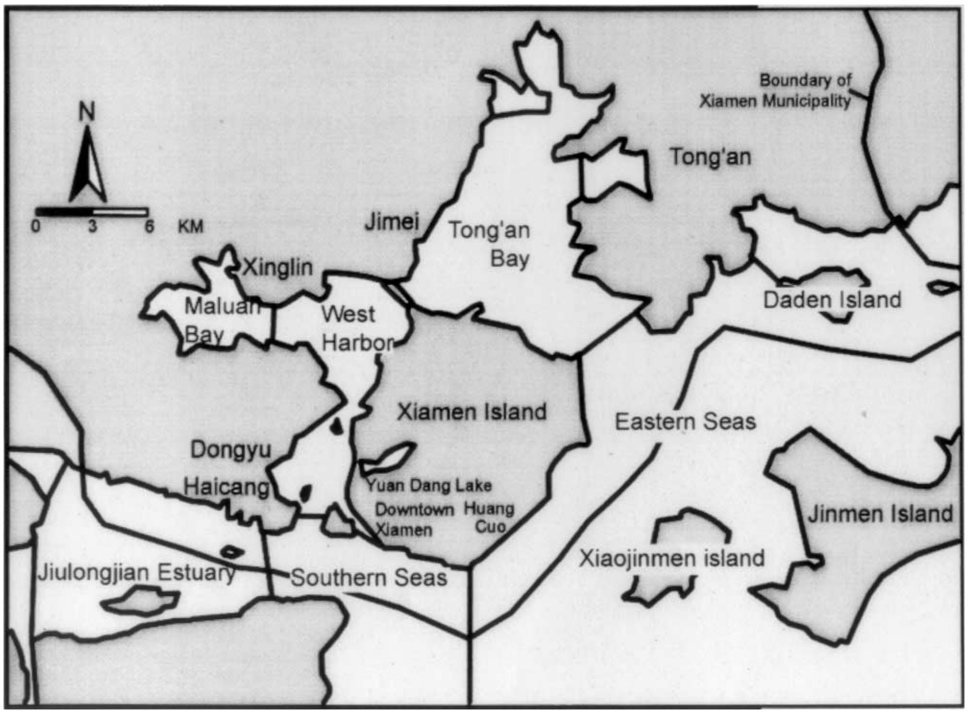

Fig. 1. Division map of Xiamen Municipality.

Assessment (CIA). The goal of this approach—referred to as CEA from here on—is to broaden the single-project environmental impact assessment (EIA) to examine 'the accumulation of human-induced changes in valued environmental components over time and across space in an additive or interactive manner' (Spaling, 1997). CEA has evolved largely over the 1980s and 1990s, with contributions to the field including the work of Beanlands et al. (1986), Burris and Canter (1997), Canter (2002), Contant and Wiggins (1991), Cooper and Canter (1997), Damman et al. (1995), Sadar (1997) and Spaling (1994, 1997). Coastal areas and wetlands have received some attention in CEA analyses—see, e.g. Brinson (1988), Childers and Gosselink (1990), Clark and Zinn (1978), Dickert and Tuttle (1985), Risser (1988) and Vestal et al. (1995).

While there is no universally accepted approach to CEA, components may include (Parr, 1999) an initial scoping stage, the setting of spatial and temporal boundaries for the analysis, the identification of 'valued ecosystem components' (VECs) and indicators, the identification of the sources of impacts and the pathways through which impacts are likely to occur, and the assessment and/or prediction of impacts on the VECs arising through the identified pathways. In addition, any EIA may eventually lead to (a) recommendations on acceptability of an activity and minimising, eliminating or offsetting adverse effects, (b) a management plan to accomplish these measures, and (c) a monitoring program.

The examination of cumulative impacts reported on in this paper included initial scoping and boundary-setting, and then focused on certain of the components noted above:

1. Identification of the underlying sources of environmental impacts (i.e. the various economic sectors and human actions causing impacts) emphasized overall growth, the changing typology of industry, the changing spatial distribution of industry, ports and shipping, land reclamation, aquaculture and waste disposal, along with other smaller sources. It was recognized that cumulative impacts from these sources could arise through varying pathways (see Vestal and Rieser, 1995, p. 21), notably by 'persistent additions from one process' (i.e. accumulated impacts from a single source) or 'compounding effects involving two or more processes' (i.e. the effect of impacts from multiple sources).
2. Identification of the major categories of impacts (which may be seen as proxies for the 'valued ecosystem components') was carried out using an ecological approach, in the sense that the major environmental disturbances, caused by economic development impacting on Xiamen's coastal waters, were assumed to be reflected in the ecological elements of the system, notably physical, chemical and biological aspects (Hong and Xue, 1996). Specifically, the analysis identified five major biophysical or ecological categories: (1) circulation and siltation, (2) water quality, (3) sediment, (4) the benthic community, and (5) the state of mangrove forests.
3. Assessment of the anthropocentrically-induced impacts themselves (using the set of categories above) included both the aggregate impacts of relevant activities that occur simultaneously in the system, and the accumulation of impacts over time (i.e. those cumulative impacts that are temporally-oriented). These aspects were assessed using certain key indicators—e.g. various chemical parameters were included, relating to water quality and the state of the ocean bed and of marine organisms. In addition to generally-applicable indicators, some indicators of special interest were included in the analysis, such as those relating to the particular species *Sousa chinensis*, *Egret*, *Lancelet* and mangroves (although not all of these are discussed in the present paper). The various indicators were analysed with allowance for delays in the appearance of cumulative effects, depending on the levels of resistance, inertia, adaptability and response to environmental change of the relevant organisms.

The analysis was based on a compilation of historical (secondary) socio-economic and ecological data (Hong and Xue, 1996) rather than ecological, causal or predictive modelling. Accordingly, the identification of major categories of ecological impacts, the choice of indicators and the reporting on changes in those indicators over time were based not on model outputs but rather on more informal analyses. Furthermore, while certain pathways for impacts were apparent from a close examination of the Xiamen context, rigorous analysis of the causal connections between sources and impacts was not undertaken. In particular, the analysis did not indicate which impacts were 'additive' and which involved 'interactive' (magnifying and/or synergistic) accumulation, recognizing that cumulative impacts may be due simply to the sum of many impacts, or to the more complex nonlinear interaction among those impacts. Finally, in terms of what was not included in the examination of cumulative impacts, the EIA components noted earlier (providing recommendations, developing management plans and implementing monitoring) were left to later in the paper, where they arise in the Integrated Coastal Management framework (see below).

2.2. Integrated coastal management

The World Bank (2002) views Integrated Coastal Management (ICM) as seeking to "maximize the benefits provided by the coastal zone and to minimize the conflicts and harmful effects of activities on social, cultural and environmental resources" through "…an interdisciplinary and intersectoral approach to problem definition and solutions" involving "a process of governance that consists of the legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental and social goals, and are developed with the participation of those affected."

Cicin-Sain and Knecht (1998) focus on ICM as "a continuous process by which decisions are made within a suitable coastal management system", one that involves "blending together science, social science and technological studies, on the one hand, with development of suitable policies, planning and programs, on the other hand" The latter emphasizes that ICM specifically incorporates an information and analytical stage (through "science, social science and technological studies") with a policy-oriented stage. In this light, assessment of cumulative impacts fits well within the philosophy of ICM, providing the required factual and analytical foundation for evaluating implications of alternative decisions.

In examining Xiamen's approach to ICM, this paper uses a methodological framework based on Cicin-Sain and Knecht's (1998) conception of the practice of ICM as involving five forms of 'integration':

- *Intersectoral integration* is fundamental to the nature of ICM, involving coordinated management of the various sectors of coastal activity, such as fisheries, aquaculture, shipping, ports, tourism, etc.;
- *Intergovernmental integration* implies attention to the various levels of government, from local/municipal to provincial to national;
- *Spatial integration* involves in particular the many connections between land-based and sea-based activities and institutions;
- *Science-management integration* deals with the multiple disciplines required to understand coastal issues, and linkages between science and management itself;
- *International integration* arises when coastal problems—such as those relating to pollution, fishing, shipping, etc.—cross national boundaries.

Specifically, we examine to what extent the Xiamen case study incorporates these five forms of integration. (Note that both vertical and horizontal integration are included in the above, e.g. within the intergovernmental and intersectoral forms, respectively.) Within this context, we also explore inter-relationships between cumulative impacts and ICM. Incorporation of cumulative impacts within an integrated management process provides critical input by identifying and quantifying major impacts to be taken into account in the management endeavour. At the same time, ICM itself can be an effective managing tool for dealing with cumulative impacts. The paper explores these inter-relationships in the context of the coastal areas of Xiamen, China, examining the manner by which the existence of cumulative impacts has influenced ICM arrangements, as well as the role of an ICM process in actually preventing or mitigating those cumulative impacts.

3. Sources of cumulative environmental impacts in Xiamen's harbour

This section briefly surveys seven major sources of anthropogenic impacts on Xiamen's harbour area: overall population and economic growth, the changing composition of industrial activity, the changing spatial distribution of industry, ports and shipping, land reclamation, waste disposal and aquaculture. All data described here are drawn from Hong and Xue (1996).

3.1. Overall growth

Since 1980, and especially in the 1990s, Xiamen has developed rapidly, with an *annual* growth rate of more than 20% in both the GDP and the total population. Between 1990 and 1995, the population of traditional residents increased slowly, rising from 1.1 to 1.2 million (an annual growth rate of 1%) but the immigrant population from other cities or rural areas of China increased rapidly from 100,000 to 290,000, driven by job creation and needs for additional manpower. On Xiamen island, such immigrants now constitute almost 40% of the total population.

3.2. Changing nature of industry

One feature of economic development is the changing contribution to the GDP of the primary, secondary and tertiary industrial sectors. Light and heavy industries in the secondary sector are the major contributors to the GDP, but tertiary industries—including commercial activities, communication and tourism—are developing more rapidly. It is predicted that the mechanical, electronic, petro-chemical and construction industries will develop especially rapidly, and that increasing numbers of tourists and passengers will visit Xiamen in the future.

3.3. Changing spatial distribution of industry

Another feature of development is the density distribution of industrial production and population: the highest industrial production and population density are distributed in the old urban areas of the Xiamen Island, especially along the east coast of Xiamen's Western Seas. Haicang, situated across from the old urban district (Fig. 1), is planned for development into a new modern urban area and a large industrial investment area. Most new development projects are located along the coast of Xiamen's Western Seas, which will be the focus of this paper.

3.4. Ports and shipping

Port and shipping industries contribute significantly to Xiamen's economy. As an important foreign trade centre of China, Xiamen's port hosts shipping to more than 60 ports in over 40 countries and regions. Xiamen Harbour is envisioned as a multi-function comprehensive port engaged in both passenger and cargo transportation. The handling capacity of the port has increased greatly since 1990—from 1.68 million tons cargo and 45.4 thousand containers in 1990 to 11.4 million tons cargo and 224.7 thousand containers in 1994, to 16.4 million tons of cargo and 654,000 containers in 1998. This reflects a growth rate of around 10% for cargo and more than 30% for containers annually over the period 1994–1998. There are 77 berths constructed or under construction, of which 11 berths are capable of handling vessels of between 10 thousand and 50,000 tons. Notably, most of the berths are located along the coast line in the Western Seas, where the priority economic function has been designated as port development and transportation.

3.5. Land reclamation

In Xiamen, a series of projects has taken place—notably in the Western Seas—involving reclamation of coastal areas, by filling in wetlands, diking, and building dams and other barriers to exclude coastal waters. This reclamation occurred largely in the 1950s, 1960s and 1970s, with the Gao-Ji, Ji-Xing and Maluan dikes constructed and large areas reclaimed to meet requirements for transportation and land use (Table 1).

Reclamation activities demonstrate well the nature of cumulative effects: the various reclamations have had a cumulative impact over time, which has led to potentially detrimental effects, e.g. accelerated erosion, unacceptable siltation patterns, siltation of drainage outlets, loss of fish spawning grounds, and hindrance of commercial activities dependent on navigation.

3.6. Waste disposal

The harbour, particularly the Western Seas, provides an important sink for waste disposal. Accompanying the region's high level of economic development has been an increase in land-based industry and domestic waste water discharge to the sea, from 49 million tons in 1985 to 90 million tons in 1994. With enforcement of waste treatment and recycling within industry, the rate of increase in industrial waste discharge slowed or even reversed with the growing GDP, but there has been an increase in domestic waste, with higher contents of nutrients and organic matter. About 80% of the waste was discharged into the Western Seas. In 1996, sewage treatment capacity was about 100,000 tons/day, and only 40% of land-based waste was treated before discharge into the Western Seas. More sewage treatment plants are planned, and the treatment capacity could reach 350,000 tons/day in 2005, at which time more than 80% of sewage will be treated before being discharged into the Western Seas. The most important pollution sources at sea are (a) oil and garbage discharged from docks and vessels, and (b) organic pollution from aquaculture activity. Oil pollution increased from 275 tons in 1990 to 325 tons in 1994, of which 55% was produced in the Western Seas. The waste is flushed out by the tidal current, which is semi-diurnal.

Table 1
Reclamation of Xiamen's Western Seas

Years	Project name	Site	Construction		Reclamation area	
			Begun	Finished	ha.	Acre
1955–1979	Xinglin Bay reclamation	Jimei-Xinglin	1955	1956	2000	30,000
	Malun Bay reclamation	Malun	1958	1960	2093	31,400
	Yuandang Lake reclamation	Dongdu	1970	1972	672	10,080
	Dongdu fishing dock	Dongdu	1972	1976	30	450
	Jingkou Bay reclamation	Jingkou-Dongyu		1979	400	6000
	Dongyu reclamation	Dongyu-Jingkou		1978	90	1350
	Gaopu reclamation	Gaopu-Ningbaoshan		1979	77	1150
	Zengying reclamation	Wuzaiwei-Houwei		1970	19	280
	Shitang reclamation		1964	1979	77	1158
	Gaodian reclamation	Gaoqi-Dianqi			72	1080
	Shuimenjiao reclamation	Shuimenjiao-Chang'an			48	720
	Cailing reclamation	Shanwei-Paitou			21	315
	Paitou reclamation	Paitou-Shuitou			6	90
	Subtotal	13			5605	84070
1980–1994	Huoshaoyu reclamation	Huoshaoyu west	1982	1983	6	90
	Dongdu dock Project 1	Dongdu	1976	1984	30	450
	Dongdu dock Project 2	Xiangyu	1989	1993	62	930
	Bonded area dock Project 1	Huyu-Zhouyu	1993	1994	60	900
	Coastal road	Outside Yuandang dam		1993	28	428
	Subtotal	*5*			*186*	*2790*
	Total	*18*			*5791*	*86860*

From: Hong and Xue (1996).

3.7. Aquaculture

Marine aquaculture in Xiamen developed relatively rapidly, and by 1994, aquaculture activities occupied 18.28 km^2, including shallow seas, inter-tidal flats and reclaimed areas, accounting for 77.38% of the total area available for utilization. The level of aquaculture production was 29,120 tons in 1994, out of a total aquatic production of 69,030 tons. A variety of environmental impacts can be attributed to aquaculture, largely as a result of high breeding densities and poor distribution of the farming activity. First, waste water from shrimp ponds along the coast has been discharged directly into seas, affecting water quality. Second, when fish are reared through cage culture in shallow seas, the combination of residual fish food (dropping to the ocean bottom when feeding levels are excessive) and fish excrement produces sulfides which can not only directly poison fish but also consume large amounts of oxygen in the water, which also causes fish mortality. Third, underneath aquaculture cages, there can be a relative abundance of Fe–Mn oxide; heavy metals deposit in the sediment, of organic material and clay, to pollute the benthic material.

4. Assessment of cumulative impacts

As noted earlier, the analysis of cumulative impacts took an ecological approach, focusing on the physical, chemical and biological elements of the coastal ecosystem, specifically relating to:

1. circulation and siltation;
2. water quality;
3. sediment;
4. benthic communities;
5. mangrove forests.

These categories of cumulative impacts were assessed through key indicators, arising either from a set of multiple activities or from a specific activity continued over time. In the following, the relevant indicators are described under each of the five headings above.

4.1. Cumulative impacts on circulation and siltation

The reclamation activities described earlier produced direct impacts on geomorphology and reductions in water surface area. In particular, the tidal flushing area declined greatly; since 1955, Xiamen's Western Seas declined in area by 57.9 km^2, or 53.7% compared to its former state. The tidal influx volume was reduced by 120 million cubic metres. In 1996, the water surface area of the Western Sea, at low tide, was only 22.5 km^2, subsequent planned reclamation is expected to reduce this area by an additional 2.6 km^2.

Since the direction and velocity of the tidal current are controlled by geomorphology, indirect impacts occurred in terms of changes in the hydrological circulation pattern and siltation velocity. As the tidal influx volume was reduced significantly, the tidal flushing capacity was weakened and sedimentation processes were accelerated in the Western Seas. From a ^{210}Pb study in 1985, the sedimentation rate at both sites of the Gao-Ji dike increased between two- and six-fold, and the areas were seriously silted. Siltation occurred rapidly and the channel shoaled up, becoming an obstacle to navigation. As shown in Fig. 2, comparing water depth in 1934 and in 1976, the Songyu-Gulangyu channel water depth was reduced by 10 m near the Gulangyu side. In order to maintain the depth of the channel for navigation, the frequency and cost of dredging increased. In 1984, 150,000 m^3 of deposits were dredged from the channel for the first time. In 1993, 190,000 m^3 were dredged, but 2 years later, 160,000 m^3 needed to be dredged again. In other words, dredging of 80,000 m^3 was needed annually, on average. It should be pointed out that the increasing sedimentation rate in recent years was also caused by improper coastal construction, such as reclamation without cofferdam. The reduction in tidal flushing capacity and the increasing sedimentation rate represent limitations on development of the port and the shipping industry.

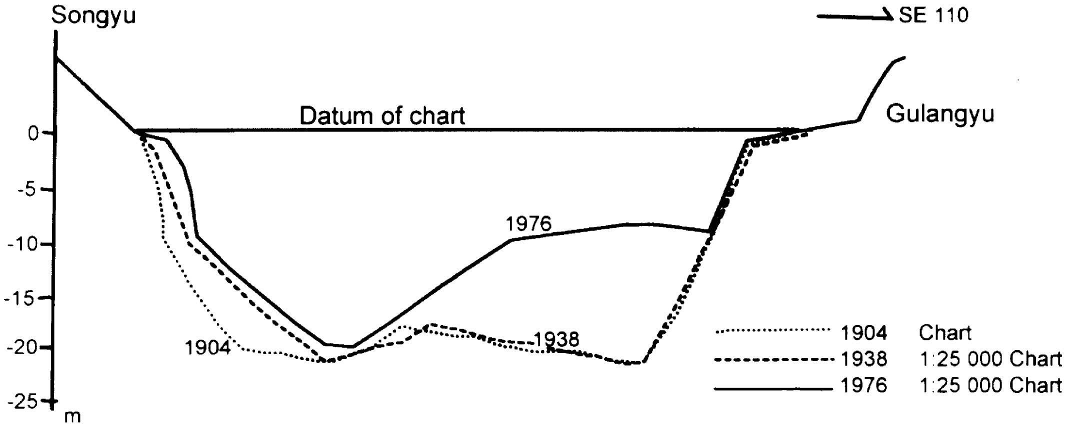

Fig. 2. Depth variations in Song Gu Channel.

Table 2
Changes in water quality in Xiamen Western Seas (unit: mg/l)

Year		DO	CODMn	Oil	Inorganic-N	Inorganic-P	S.S.
1990	Range	5.20–7.23	0.46–2.98	0.025–0.24	0.234–0.575	0.006–0.046	30–174
	Average	6.10	1.04	0.09	0.358	0.017	70
1993–1994	Range	4.98–8.07	0.62–3.30	0.025–0.26	0.137–0.818	0.006–0.069	98–409
	Average	6.55	1.22	0.04	0.378	0.027	188
1996	Range	7.70–8.08	1.87–2.38	0.002–0.003	0.368–0.539	0.032–0.048	
	Average	7.88	2.04	0.003	0.452	0.038	

From: Hong and Xue (1996). DO: dissolved oxygen; CODMn: Chemical Oxygen Demand by Permanganate; S.S.: suspended solids.

4.2. Cumulative impacts on water quality

As noted above, Xiamen's Western Seas receive 80% of the total land-based waste. The amount of waste discharged, especially domestic waste, is increasing. Although water quality in the Western Seas still meets China's 'class 2 seawater quality standard', quality declines might be accelerated as tidal flushing velocity and water carrying capacity are reduced. In fact, such deterioration seems indicated in the increases that have occurred in the level of COD_{Mn} (Chemical Oxygen Demand by Permanganate) nutrients and total suspended particles (Hong and Xue, 1996). In comparison with surrounding water bodies, available data indicates that the Western Seas were at a higher level of COD, nitrate and phosphate (Table 2).

4.3. Cumulative impacts on sediment

Cumulative impacts can be manifested in declining quality of marine sediment, which can be a sink for pollutants, thus representing an historical record of pollution. While recent studies show that environmental regulation in Xiamen, leading to reduction of waste loading into the seawater, has resulted in improved coastal water quality, it is possible for contaminated sediment to act as a non-point source, with the potential to release 'in place pollutants', such as nutrients, impacting the corresponding water column.

A study in 1993 (Hong and Xue, 1996) showed that the general distribution pattern of organic pollutants in the sediment in the Xiamen Seas reflects the level of pollutant discharge from industrial and urban sources (Table 3). The highest concentration of DDT in sediment was found in the Western Seas between Xiamen and Gulangyu Island, where the population density is highest. The highest concentration of polychlorinated biphenyls (PCBs) is near the discharge point for municipal sewage in Yuandang Lake. Finally, the highest concentration of polycyclic aromatic hydrocarbons (PAHs) in sediment was found near the Dongdu Harbor and the navigation channel. Results showed that PAHs in sediment are relatively low, but tend to increase as a result of port activities and the increasing number of vessels in the area. The general distribution pattern of pollutants in the sediment corresponds with pollutant discharge sources, and indicates the accumulation of pollutants in the sediment.

Bacterial pollution, indicated by coliform levels, is serious in the Western Seas, and reflects the large amounts of domestic waste the water receives. With the construction of sewage treatment plants and regulation of waste discharge, the total bacteria and total coliform counts in the water showed a slight decrease, but still exceed the standard values for coastal water. In sediment, the highest counts of coliform are in the samples collected closest to the urban sewage discharge sites.

4.4. Cumulative impacts on the benthic community

Cumulative impacts that lead to deterioration of water and sediment quality may also affect the flora and fauna of

Table 3
Pollutants in Xiamen Seas (mg/kg)

		Western Seas	Estuary	Southern Seas	Tong'an Bay	Eastern Seas
Organic matter	Range	0.83–4.88	0.15–2.86	0.65–2.10	0.11–1.57	–
	Average	1.90	1.88	1.26	0.99	–
Sulfur compounds	Range	5.69–883	3.0–553	3.8–162	3.4–53.8	–
	Average	175	187	78	31.3	–
Oil	Range	22–40	3.9–11.4	1.2–13.8	1.1–2.4	1.6-2.8
	Average	30	7.6	8.1	1.9	2.1
HCH	Range	0.0001–0.001	0.00002–0.0009	0.00006–0.0005	0.00006–0.0005	0.00003-0.0008
	Average	0.0004	0.0005	0.0002	0.0003	0.0003
DDT	Range	0.004–0.311	0.003–0.019	0.003–0.011	0.002–0.004	0.002-0.008
	Average	0.05	0.011	0.006	0.003	0.005

From: Hong and Xue (1996). HCH: hexachlorocyclohexane, DDT: dichlorodiphenyltrichloroethane.

Table 4
Levels of pollution and major dominant species in the Zoobenthos Community of the Western Seas in Xiamen

Location	Year	Diversity (H)	Uniformity (J)	Level of pollution	Top three dominant species
Near Baozhuyu	1980	3.68	0.82	Medium	*Paxalacydonia paradoxa*, *Poecilochaetus paratropicus*, *Haploscoloplos sp.*
	1988	2.67	0.94	Medium	*Poecilochaetus paratropicus*, *Haploscoloplos* sp., *Aglaophamus dibranchis*
Discharge site of Yuandang lake	1980	2.56	0.56	Medium	*Saccella cuspidata*, *Haploscoloplos* sp., *Episiphon kiaochowwanense*
	1988	3.16	0.82	Medium	*Nucula kawamurai*, *Trigonothracia jinxingaeRange*, *Aglaophamus dibranchis*
Songgu channel	1980	3.31	0.86	Balanced State	*Saccella cuspidata*, *Aglaophamus dibranchis*, *Nassarus variciferus*
	1988	3.25	0.83	Balanced State	*Neoxenophthalmus obscurus*, *Amphioplus laevis*, *Amphioplus impressus*

From: Hong and Xue (1996).

Xiamen's coastal area, with impacts in the benthic community (as well as mangrove habitat, discussed in Section 4.5). In Xiamen's Western Seas, the bottom configuration has changed over time, with coarse sand being replaced by fine mud, enriched with organic matter. The composition of benthic species has changed accordingly, with increasing dominance of polychete worms (Table 4). High levels of organic matter in the sediment, and the abundance of polychete worms, are usually indicative of organic pollution. The *rate* of change in the benthic community of the Western Seas is suggested in the substantial change in diversity and uniformity indices over the period 1980–1988 (Table 4), compared with index levels for the Song Gu Channel, on the edge of the Western Seas.

4.5. Cumulative impacts on mangroves

A clear impact of human activities in coastal areas of Xiamen is the large-scale destruction of mangrove forests. Historically, Xiamen had a vast area of such forests, which had both direct utilisation value in forestry and fisheries production, and the potential to protect coastlines and provide a variety of ecological services. However, rapid development in the mangrove environment has led directly or indirectly to their almost complete destruction. By comparing remote-sensing images from 1987 and 1995 (Table 5), it can be estimated that 88% of mangrove forests present in 1987 within the Xiamen area were gone eight years later (reflecting a decline from 179.3 to 20.8 km^2). Indeed, mangroves in some locations were 100% destroyed; for example, those in Dongdu were lost to construction of the harbour while those in the Yuandang lake area were removed for human settlement.

5. Mitigating cumulative impacts through integrated coastal management

The extent of cumulative impacts arising from Xiamen's coastal development are clear from the above discussion. Although understanding and assessing cumulative impacts is a challenge, mitigating such cumulative impacts may be even more so. In seeking to address these impacts, it is important to note that they arise not only through the over-exploitation of natural resources, increasing population and pollutant discharges, but also through coastal resource use conflicts between sectors and inadequate management measures (Chua et al., 1997).

In Xiamen, the capacity for managing such impacts has been enhanced by Integrated Coastal Management initiatives launched in 1994. These were implemented as part of the Regional Programme for the Prevention and Management of Marine Pollution in the East Asian Seas (MPP-EAS), executed by the International Maritime Organisation (IMO) and supported by the Global Environmental Facility (GEF) and the United Nations Development Programme (UNDP). One of the main efforts of the Programme is to demonstrate the applicability of the ICM approach in addressing marine pollution problems through two demonstration sites, one being Xiamen, and the other Batangas Bay in the Philippines (Chua, 1998).

The Xiamen Demonstration Project is the first internationally funded pilot project for the application of integrated coastal management in China. It has sought to use ICM to avoid the old, costly model of 'pollution first, management second' by treating economic development and environmental protection as simultaneous tasks. This approach has had some success. As GESAMP (1998) notes: "Improved environmental quality in the River Thames in

Table 5
Changes in Mangrove areas in Xizmen

	1987 areas (km^2)	1995 areas (km^2)	% Decline
WuzaiWei	9.9	0.4	96
Dongyu	110.8	14.3	87
Haicang	3.3	1	70
Qingjiao-Haicang	2	1.1	45
Haicang-Houjing	8.2	1	88
Qianyu	10.9	0	100
Dongdu-Xianyu	16.5	0	100
Yuandang huxiditou	3.3	0	100
Eyuyu	4.5	0.8	82
Jiyu	9.9	2.2	78
Total	179.3	20.8	88

England, Boston Harbour in the United States, and Xiamen in China show that determined, co-ordinated action can produce benefits even in large urban areas, where development and population pressures are concentrated". Four key components of Xiamen's ICM framework, contributing to the prevention and mitigation of cumulative impacts, are briefly discussed below.

5.1. Co-ordinating mechanism for ICM

With guidance from the MPP-EAS Programme, Xiamen's Municipal Government established (in 1995) an inter-agency, multi-sectoral coordinating mechanism for integrated coastal management, as well as operational offices to implement ICM programs. The integrated management framework is illustrated in Fig. 3. Note that the Xiamen Marine Management and Coordination Committee involves the municipal government at a high level, with the first deputy mayor serving as director, and the other four deputy mayors (in charge of transportation, agriculture, science and city construction) serving as deputy directors. Committee members include the heads of bureaus for city construction, science, environment protection, fisheries, etc. Within this framework, Xiamen has established priorities, undertaken capacity building to strengthen planning and management capabilities, developed a sustained environmental quality monitoring program and a financial mechanism to mobilise pubic and private financial resources,

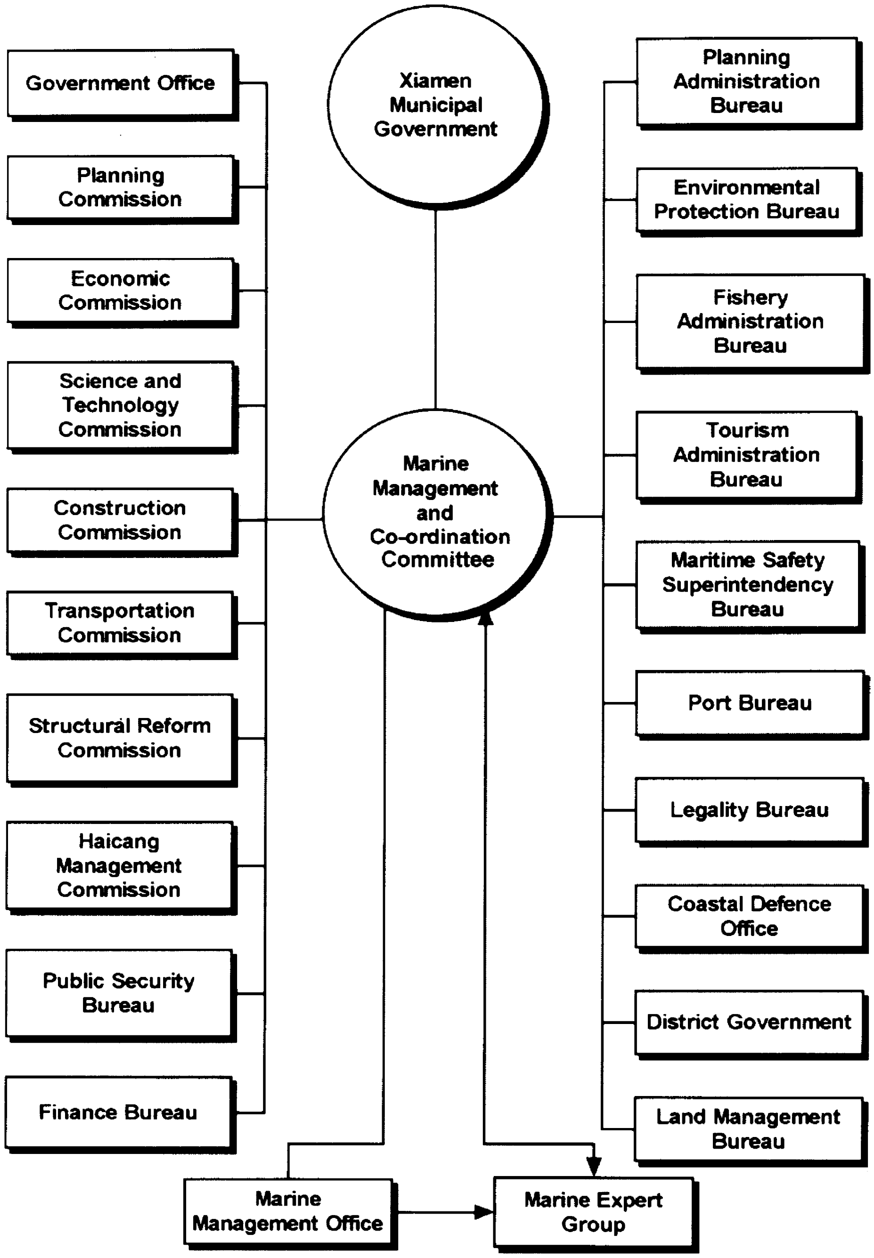

Fig. 3. Organizational structure for integrated coastal management in Xiamen.

and established the needed local ordinances to legitimise institutional arrangements and permit systems. This structure would seem to satisfy Cicin-Sain and Knecht's (1998) goal of 'intersectoral integration', providing a means for coordinated management of the various sectors of coastal activity.

5.2. Legislative framework and enforcement mechanisms

The Xiamen government implemented marine legislation, particularly the *Regulation on Management of Sea Area Use* (Li, 1999), as the legal framework for managing cumulative impacts and use conflicts. This is among the local regulations enacted concerning resource management, ecological environment protection and transportation management, to complement national laws (Table 6)—providing an illustration of Cicin-Sain and Knecht's (1998) 'intergovernmental integration' across the various levels of government (from local/municipal to provincial to national). The legal framework seeks to meet several objectives: (1) to establish a unified mechanism with coordination responsibility within the government of Xiamen, (2) to redefine the responsibilities of various government departments involved in coastal and marine management, (3) to establish licensing, charging and penalty systems for use of ocean areas, and (4) to establish an effective law enforcement mechanism. In order to strengthen integrated law enforcement, a supervisory force was formed within the marine management office, and relevant departments (e.g. harbour supervisor, fishery supervisor, water police, and environment supervisor) were organised into an integrated law enforcement group. A number of coastal use conflicts were successfully resolved by this group. For example, in dealing with interactions between aquaculture and transportation, conflicts were resolved arising from illegally-established fish farms in areas designated for harbour development, and unregulated eel fry gathering in navigational channels. Now, the navigation channel in Xiamen harbour is open 24 h daily, bringing improved maritime safety.

Table 6
Ocean-related legislation in Xiamen

Development and utilization
Regulations on land management
Regulations on city planning
Regulation on the management of sand, soil and stone
Regulation on the management of waterway transportation
Public notice on removal of households engaged in aquaculture from the location of the new shipyard
Regulation on aquaculture management in the shallow seas and intertidal zones
Regulation on the use and management of sea areas
Measures on management of charging sea area uses
Regulations on coastline planning and management
Environmental Protection
Regulations on environmental protection
Measures on the management of Yuandang lagoon region
Regulations on the Management of Nature Protected Areas for Chinese White Dolphin
Measures on the management of nature protected area for White Egret in Dayu Island
Public notice on the reinforcement of management of sea eel fishing in the Sea areas around Xiamen
Regulation on the protection and management of the marine environment measures on the management of Lancelet nature protected area

From: Li (1999).

5.3. Scientific support mechanism linking assessment and management

In implementing the coordinating mechanism described earlier, the main change from past structures was the inclusion of a Marine Expert Group, so policy and management interventions can better be based on sound scientific findings, such as cumulative impact analyses (see below). The Marine Expert Group—comprising marine scientists, legal experts and economists—was established by the Municipal Government in 1996, as a means to integrate science into policy-making and management. The responsibility of the group is to provide essential socio-economic, ecological and technical advice to policymakers and to provide the best available information that will minimise costs and maximise benefits associated with a proposed development project. The Marine Expert Group, and its role in the Xiamen ICM framework, reflect well Cicin-Sain and Knecht's (1998) goal of 'science-management integration', providing for interdisciplinary studies and for linkages between science and management itself.

Since 1996, several important accomplishments can be noted, including the following:

- enactment of the Xiamen Marine Functional Zoning Scheme (XMFZS), to be described below;
- completion of a comprehensive marine economic development plan in Xiamen;
- establishment of a marine environmental monitoring network;
- improvement of the financial mechanism for management-oriented scientific research;
- operation of the Xiamen Coastal Sustainable Development Training Center, promoting awareness and capacity building with emphasis on the policymaker and manager.

5.4. Marine functional zoning: a tool for mitigating cumulative impacts

The Xiamen Marine Functional Zoning Scheme (XMFZS) has been a crucial means for the effective mitigation of cumulative impacts. *Marine functional zoning* is defined here as the zoning of natural resource uses through an integrated approach to considering ecosystem and socio-economic factors. A zoning approach seeks to determine multi-use priorities, reduce use conflicts

Table 7
Xiamen marine uses by location and level of priority

	Dominant function	Compatible function	Restricted function
Western Seas	Shipping/port	Tourism/nature reserve	Aquaculture
Tong'an Bay	Aquaculture	Tourism/nature reserve	Waste disposal
Eastern Seas	Tourism	Shipping/engineering/nature reserve	Aquaculture
Dadeng Seas	Aquatic resource enhancement	Shipping/tourism	Waste disposal

From: Ruan and Yu (1999).

and increase the socio-economic benefits to society as a whole obtained from the various uses, while sustaining the resource base and ecosystem functions (Ruan and Yu, 1999). Marine functional zoning is an important component of ICM, providing a base for managing multiple use prioritisation and coordination, and for effectively minimising adverse environmental impacts through allocation of sea space based on functional characteristics of a given area.

Xiamen's Marine Functional Zoning Scheme was formulated by the Marine Expert Group and accepted by Xiamen Municipality in October 1996. It covers an area of 314 km^2 and a 234 km long coastline, including marine waters, islands, shorelines and the adjacent land areas under the jurisdiction of the Xiamen Municipality. Prioritisation of use functions is the key to the zoning, with priorities depending on the level of socio-economic effects and associated environmental impacts of uses. The large spatial extent of the Marine Functional Zoning Scheme, as well as its operational nature in allocating coastal uses spatially, would appear to satisfy well Cicin-Sain and Knecht's (1998) goal of 'spatial integration' (that of recognizing connections among land-based and sea-based activities and institutions).

The scientific basis for establishment of the zoning scheme lay in assessments of the cumulative effects of current and potential activities in marine areas of Xiamen. Based on this assessment, the zoning defined use priorities in terms of *dominant*, *compatible* or *restricted* functions. The 'dominant function' is assigned to uses considered high priority, while a 'compatible function' designation is for those considered to have no significant adverse effects on the priority use. Finally, a 'restricted function' applies to those that should be reduced, moved out or closed altogether due to their detrimental effects on the priority function and other functions. Zoning results for four sub-areas are outlined in Table 7.

For example, in the Western Seas, where the *dominant function* is port development, land reclamation is strictly forbidden, based on the impact analyses shown earlier relating to circulation and siltation impacts. This move will help to maintain the Western Seas in a deep enough state for navigation. To facilitate the *compatible function* of tourism (and nature reserves), there is a recognition of the importance of environmental protection, in keeping with results shown above on water quality and mangroves. Thus, as port traffic expands, conservation measures are needed, including a strict water quality standard to meet national environmental law requirements for nature reserves. Such measures mean in particular that more funding must be provided for wastewater treatment and for mangrove rehabilitation. (It is also relevant to note that in the zoning, the inter-tidal area of Haicang, on the side of the Western Seas, was designated for mangrove rehabilitation, and Dayu Island was designated as an Egret Conservation area.)

6. Conclusions

This paper has used a case study of Xiamen, China, to explore the incorporation of cumulative impact analysis within an integrated framework for coastal management. The particular motivation for the paper lay in the reality that Xiamen represents a challenging situation of very rapid economic growth and coastal change, and that even though a reasonably effective environmental impact assessment (EIA) system is in place, EIAs are unlikely to assess fully the threat to ecosystems from incremental degradation, as faced by Xiamen's Western Seas as a result of serial marine engineering projects and dramatic economic development.

The paper first provided a brief review of the relevant methodologies, Cumulative Effects Assessment (CEA) and Integrated Coastal Management (ICM), before focusing in detail on the set of cumulative environmental impacts in Xiamen's harbour. Analysis of these cumulative impacts incorporated major components of CEA—scoping, boundary-setting, identification of underlying sources of environmental impacts, identification of major categories of impacts (proxies for valued ecosystem components), and assessment of environmental impacts. On the other hand, the analysis did not focus on ecological modelling or predictive approaches to impact assessment, and in particular did not attempt to determine, through ecological or modelling studies, the causal links between specific human activities and resulting environmental impacts.

The cumulative impact studies in the Xiamen Seas reported here were used to develop a marine zoning scheme (XMFZS), and to provide guidelines for the ICM planning process. As with other CEA analyses, the results here can be used to assist regulators in deciding whether an incremental change is acceptable, and to increase the capability of regulators to control or influence small-scale activities and projects that would not be considered under the conventional EIA procedure. In this sense, one can argue that CEA is a crucial tool to be used within an ICM process. Conversely, ICM provides a co-ordinated, integrated approach to address the cumulative impacts identified through a CEA. Crucial to this is the implementation of institutional and legal arrangements for ICM (Chua, 1998). For example, in the case of Xiamen, the *Regulation of the Use and Management of Sea Area* facilitates effective marine management based on the XMFZS zoning approach.

ICM and CEA share in common an inherently integrated approach. Just as CEA seeks to build into an assessment framework all relevant impacts accumulating over time and space, whatever the source, so too does ICM attempt to integrate, within a management framework, the full range of coastal activities and institutions. Indeed, the discussion in this paper has shown that all the relevant forms of integration outlined at the outset—intersectoral, inter-governmental, spatial and science-management integration—are found within the processes and structures involved in Xiamen's ICM efforts. Furthermore, each of these forms of integration relates back to one or more elements of the cumulative impact analysis—for example, a particular impact may be related to multiple sectors, or may require multiple levels of government to resolve.

Thus, with Integrated Coastal Management having become the standard institutional and process tool for dealing with environmental and use issues in coastal areas, this paper has highlighted the role of cumulative impacts as a consideration, and perhaps even a driving force, within an ICM framework.

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