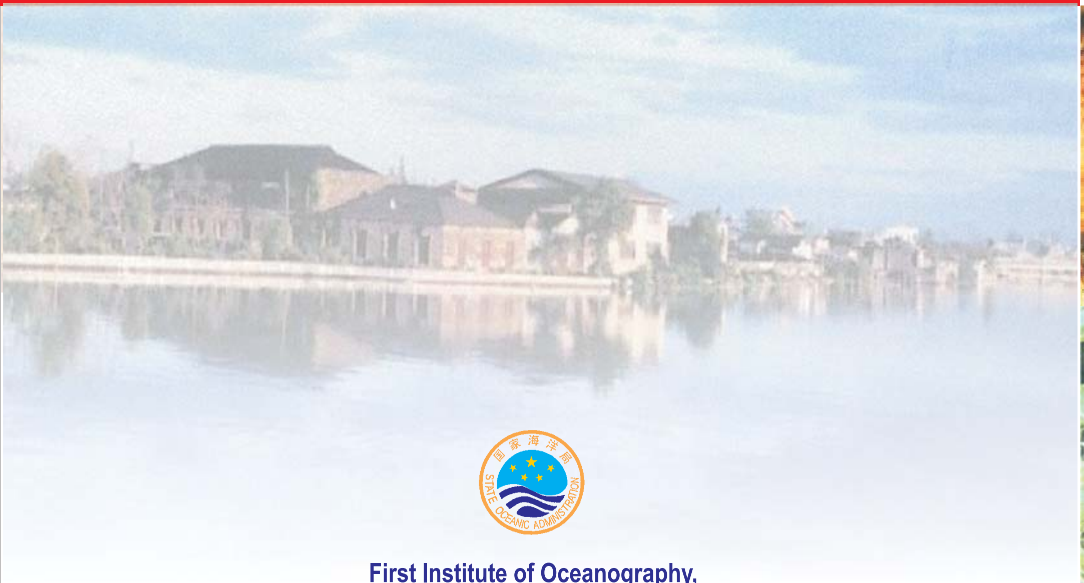
Bohai Sea

Environmental Risk Assessment



First Institute of Oceanography,
State Oceanic Administration, China

Bohai Sea Environmental Management Project
People's Republic of China

GEF/UNDP/IMO Regional Programme on
Partnerships in Environmental Management
for the Seas of East Asia

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Management for the Seas of East Asia

BOHAI SEA ENVIRONMENTAL RISK ASSESSMENT

January 2005

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> "The resource systems of the Seas of East Asia are a natural heritage, safeguarding sustainable and healthy food supplies, livelihood, properties and investments, and social, cultural and ecological values for the people of the region, while contributing to economic prosperity and global markets through safe and efficient maritime trade, thereby promoting a peaceful and harmonious co-existence for present and future generations."

PEMSEA focuses on building intergovernmental, interagency and intersectoral partnerships to strengthen environmental management capabilities at the local, national and regional levels, and develop the collective capacity to implement appropriate strategies and environmental action programs on self-reliant basis. Specifically, PEMSEA will carry out the following:

- build national and regional capacity to implement integrated coastal management programs;
- promote multi-country initiatives in addressing priority transboundary environment issues in sub-regional sea areas and pollution hotspots;
- reinforce and establish a range of functional networks to support environmental management;
- identify environmental investment and financing opportunities and promote mechanisms, such as public-private partnerships, environmental projects for financing and other forms of developmental assistance;
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The twelve participating countries are: Brunei Darussalam, Cambodia, Democratic People's Republic of Korea, Indonesia, Japan, Malaysia, People's Republic of China, Philippines, Republic of Korea, Singapore, Thailand and Vietnam. The collective efforts of these countries in implementing the strategies and activities will result in effective policy and management interventions, and in cumulative global environmental benefits, thereby contributing towards the achievement of the ultimate goal of protecting and sustaining the life-support systems in the coastal and international waters over the long term.

Dr. Chua Thia-Eng
Regional Programme Director
PEMSEA

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List of Abbreviations and Acronyms

666 – Benzene Hexachloride
ACCPMS – ASEAN – Canada Cooperative Programme on Marine Science
ADB – Asian Development Bank
ASEAN – Association of Southeast Asian Nations
ASP – Amnestic shellfish poisoning
BOD – Biochemical oxygen demand
BSEMP – Bohai Sea Environmental Management Project
CN – Cyanide
CNSN – Center of National Science and Nature
COD – Chemical oxygen demand
CPUE – Catch per unit of effort
CR – Consumption rate
DAO – DENR Administrative Order
DDT – Dichlorodiphenyltrichloroethane
DFB – Biomass of demersal fish (ton)
DIN – Dissolved inorganic nitrogen
DIP – Dissolved inorganic phosphate
DO – Dissolved oxygen
DSP – Diarrhetic shellfish poisoning
EIA – Environmental Impact Assessment
ERA – Environmental Risk Assessment
GDP – Gross Domestic Product
GEF – Global Environmental Facility
Gm – Geometric mean/Geomean
HAB – Harmful algal bloom
HP – Horsepower
IRA – Initial risk assessment
ISQV – Interim sediment quality values of Hong Kong
ICM – Integrated Coastal Management
IMO – International Maritime Organization
LC_{50} – Lethal concentration that causes death in 50 percent of an exposed population
LOC – Level of concern
MoA – Ministry of Agriculture
MEC – Measured environmental concentration
MEL – Measured environmental levels
MEY – Maximum efficiency yield
MPN – Most probable number
MPP-EAS – GEF/UNDP/IMO Regional Programme for the Prevention and Management of Marine Pollution in the East Asian Seas

MSY – Maximum sustainable yield
NH_3 – Ammonia
NH_4 – Ammonium
NH_4-N – Nitrogen in the form of ammonium
NO_2 – Nitrite
NO_2-N – Nitrogen in the form of nitrite
NO_3 – Nitrate
NO_3-N – Nitrogen in the form of nitrate
NOAEL – No observed adverse effect level
NSP – Neurologic shellfish poisoning
OA/g – Okadaic acid (OA) per gram (of sample, e.g., hepatopancreas); OA is a toxin
PAHs – Polyaromatic hydrocarbons
PCBs – Polychlorinated biphenyls
PEC – Predicted environmental concentration
PEL – Predicted environmental levels
PEMSEA – GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia
PFB – Biomass of pelagic fish (ton)
PMO – Project Management Office
PNEC – Predicted no-effect concentration
PNEL – Predicted no-effect level
PO_4 – Phosphate
PO_4-P – Phosporus in the form of phosphate (orthophosphate)
ppm – parts per million or mg/l
ppt – parts per thousand or μg/l
PSP – Paralytic shellfish poisoning
QA/QC – Quality Assurance/Quality Control
RA – Risk assessment
RDA – Recommended daily allowances
RMB – Renminbi, the unit of China Yuan (CNY)
RPO – Regional Programme Office
RQ – Risk quotient: MEC (or PEC)/PNEC (or Threshold)
RQ_{Ave} – Average risk quotient: MEC (or $PEC)_{Ave}$/PNEC
RQ_{Max} – Maximum risk quotient: MEC (or $PEC)_{Max}$/PNEC (or Threshold)
RQ_{Min} – Minimum risk quotient: MEC (or $PEC)_{Min}$/PNEC
RRA – Refined Risk Assessment
SEAFDEC – Southeast Asian Fisheries Development Center
SEPA – State Environment Protection Administration
SOA – State Oceanic Administration

STXeq/kg – Saxitoxin (STX) equivalent per kilogram
TDI – Tolerable daily intake
TOC – Total organic carbon
TSS – Total suspended solids
URENCO – Urban Environmental Company
UNDP – United Nations Development Program
UNEP – United Nations Environment Program
UNEP-IE – United Nations Environment Program – Industry and Environment
UNEP-IETC– United Nations Environment Program – International Environmental Technology Center
USD – United States Dollar
U.S. EPA – United States Environmental Protection Agency
U.S. FDA – United States Food and Drugs Administration
VNS – Vietnam National Standards
WBSA – Wider Bohai Sea Area
WWF – World Wide Fund for Nature

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This risk assessment report was supervised by Prof. Zhu Mingyuan, with the assistance of Dr. Wang Hong and Mr. Shi Honghua of the China Ocean University who provided many good suggestions. We are grateful for their efforts for this report.

On behalf of the team members, I would like to extend our appreciation to the Bohai Sea Environmental Management Project (BSEMP) and PEMSEA, for providing technical support and devoting their time and effort to revise the initial and refined risk assessment reports. Their wisdom and hardworking spirits have encouraged all of us to make this report as perfect as possible. We would like to thank Regional Programme Director Dr. Chua Thia-Eng and Senior Programme Officers Dr. Huming Yu and Mr. S. Adrian Ross of the Regional Programme Office of PEMSEA. We gratefully acknowledge Ms. Maria Teresita G. Lacerna for her good organizing and coordinating skills between us and PEMSEA and Ms. Cristine Ingrid S. Narcise for the technical refinements on the draft document. Our appreciation is also given to Ms. Maria Corazon Ebarvia for her impressive training workshop on Natural Resource Damage Assessment held in October 2003 in Qingdao, P.R. China.

We hope this report would provide the necessary information and profile of the Bohai Sea environment that would be useful in pursuing the sustainable management and development of Bohai Sea.

Dr. Zhang Zhaohui
Qingdao, P.R. China

Executive Summary

The potential harm to human and environmental targets may arise from exposure to contaminants in the environment. These contaminants come from activities that bring economic growth and contribute benefits to society. The potential harm to environmental targets may also arise from indiscriminate extraction of resources and physical destruction of habitats. The environmental impacts of these activities stem from the loss of ecological functions and the consequent disruption of the ecological balance. The impacts may not be as evident as impacts from pollutants but could be irreversible and may lead to greater losses.

An environmental risk assessment estimates the likelihood of harm being done to the identified targets because of factors emanating from human activities but which reach the targets through the environment. This combines knowledge about the factors that bring about hazards, their levels in the environment, and the pathways to the targets.

There can be two approaches to protecting the environment and human health. The first approach is to eliminate the contaminant or stop the activities that produce it. Another approach is to prevent the contaminant level from exceeding an allowable level that presents acceptable risk. The elimination of contamination to zero concentrations may require large investments and discontinuing economic activities may hinder the delivery of goods and services that contribute to human welfare and economic development.

The second approach, the risk-based methodology, presumes that there are contaminant levels in the environment that present low or acceptable risks to human health and the environment, and that there is not always a need for zero emission levels. Scientific studies have specified threshold values below which adverse effects are not likely to occur. This implies that economic development activities can be managed at levels that promote human health and environmental protection, yet maintain activities that produce economic benefits. This emphasizes the importance of cost-benefit analyses in sustainable development initiatives.

The risk assessment attempted to answer two questions: “What evidence is there for harm being done to targets in the coastal area?” (referred to as a retrospective risk assessment) and “What problems might occur as a consequence of conditions known to exist, or possibly exist in the future?” (referred to as a prospective risk assessment).

This report, implemented as part of the Global Environment Facility/United Nations Development Programme/International Maritime Organization Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), aimed to address these two questions and give the necessary information about the risks in the Bohai ecosystem and human health. This report provides information on the rationale of the environmental risk assessment, the methodology developed and applied in the Bohai Sea initiative, the results of the work and recommendations for improving the risk assessment as a management tool in Bohai Sea. The report provides basis for the risk management and interventions in Bohai Sea.

The Bohai Sea risk assessment was conducted in three stages. First, an initial risk assessment (IRA) was implemented as a screening mechanism for identifying priority environmental concerns on a sea-wide basis and the related data gaps and uncertainties. Second, the targets of interest were re-focused to human health, habitats and commercial and non-commercial marine species. In addition, the refined risk assessment was conducted at two levels. Risks to Bohai Sea as a whole were considered, in which the sea was treated as a single compartment and a single average exposure concentration was estimated. For selected contaminants, risks to the four parts of the Bohai Sea (Liaodong Bay, Bohai Bay, Laizhou Bay and the central region) were estimated, by calculating local exposure concentrations in the vicinity of specific human activities or natural resources. And lastly, the final report verified the data for each step of the assessment and further tidied up the calculation and identification of the environmental concerns. Sources of uncertainties in the risk assessment for some contaminants were also identified.

The results from the retrospective risk assessment in Bohai Sea showed a significant decline in natural resources and habitats particularly in capture fisheries and natural wetlands. For fisheries, the decline in both quantity and quality was confirmed. A manifestation of decline in the quantity of fisheries is the decline in trawl catch per unit of effort (CPUE) from 138.8 kg/net.hr to 11.2 kg/net.hr during the period 1959-1998. Evidence of the deterioration in quality include: 1) the change in trawl catch composition from economically valuable to less valuable species; 2) disappearance/near-absence of some dominant species; and 3) fish sizes are becoming smaller. The identified primary agent for the significant decline in fisheries is overfishing. Other factors such as waste discharges from land- and sea-based activities cannot be excluded. For the wetlands, the evidence of decline in the total area was found only in Liaohe River Delta Wetland. Although the total area of Yellow River Delta Wetland did not decline, the area of natural wetlands has declined and is seriously damaged. Oil exploitation is the primary reason for the decrease of natural wetlands. The secondary reason may be attributed to land reclamation for conversion into farming lands, reservoirs, ponds, salt-fields and paddy fields. These two damaged wetlands have caused the following consequences: 1) the service function of damaged wetland ecosystems has decreased and now supports less food for other living organisms; 2) the fragmented wetlands provide easily vulnerable and unsafe habitats and/or refuge for waterfowls and other species (local and alien) and birds such as the red-crowned crane, white crane and others often wintering in the wetlands around Bohai Sea may be exposed to their predators; 3) the degradation of wetlands has decreased its biodiversity and aesthetic function; and 4) the damaged wetland ecosystem has decreased its ability to treat waste discharges.

The results from the prospective risk assessment in Bohai Sea showed various risks to the ecosystem and human health. The prioritization of risks was based on the estimated magnitude and spatial extent of risk (i.e., area-wide vs. localized). Priority human health risks that need urgent management are the fecal coliform in the waters of Beidaihe and estuary of Yellow River, fecal coliform in shellfish tissue, lead (Pb) in seaweed samples, and toxins in shellfish, consequent to harmful algal blooms (HABs), that can cause diarrhetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP). Localized risks from fecal coliform in Laizhou Bay waters and Pb and dichlorodiphenyltrichloroethane (DDT) in shellfish tissue were also identified. On the other hand, the level of concern was low with regard to fecal coliform in Panjin seawater; mercury (Hg), copper (Cu), cadmium (Cd) and arsenic (As) in shellfish and fish tissue; and Hg, Cu and Cd in seaweed.

Ecologically, in seawater, total suspended solids (TSS), Pb, and oil need urgent management in Bohai Sea while dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chemical oxygen demand (COD) and Cd need management in particular areas. Current levels of Hg and Cu in seawater present a lesser concern ecologically. In the sediment, the pesticides DDT and benzene hexachloride (666) should be the top priorities for management followed by Hg, Cu, Cd, and polycyclic aromatic hydrocarbons (PAHs) in some hotspot areas. Ecological risk from oil in the sediments was acceptable. Another persistent problem in Bohai Sea is the occurrence of HABs, with increasing frequency in the past decade. HABs, which may be associated with nutrient enrichment, present ecological risks from anoxic conditions that may lead to death of aquatic organisms and human health risks from DSP and PSP. Separate area-specific assessments showed that Liaodong Bay and Bohai Bay contribute more significantly to pollution/enrichment in Bohai Sea than Laizhou Bay. Important data gaps with regard to environmental levels of contaminants and standards that need to be addressed were also identified.

The risk assessment has shown that in order to protect natural resources and habitats, some management programs should be considered, such as prolonging the fishing ban period, reducing the number of fishing boats, increasing the fishing fries by artificial methods, the setting up of more nature reserves, limiting exploitation, build more waste treatment factories, and reducing the discharge amounts. But all these management actions should be beneficial and profitable for the society; all these management initiatives should be good for the sustainable economic development in the Wider Bohai Sea Area (WBSA); and all these management initiatives should be undertaken with minimal investment costs.

For natural hazards like sea ice and windstorms, simulation and forecasting tools are available to predict their occurrences and potential impacts. These natural hazards could not be prevented from occurring but the extent of their impacts could be managed or mitigated through effective monitoring, assessment, forecasting and warning systems, and well-coordinated disaster prevention and management plans.

Chinese Summary

中文摘要

人类和环境目标会由于暴露在致染物中而存在一定的潜在危害，这些致染物主要来自于社会经济活动。对环境目标的潜在危害也可能来自于对资源的过度利用及对生境的物理破坏，这些活动对于环境的影响主要表现在生态系统服务功能丧失和生态失衡，但这种影响可能不像污染那样引人关注，通常是不可逆的并且可能导致更大的经济损失。

环境风险评估是用来评估特定目标所受危害的可能性，这些危害通常是人类活动造成的，并通过环境来危害目标。风险评估主要考虑风险因子、在环境中水平以及风险作用路径。

对于保护环境和人类健康的方法主要有二种：一是去除环境中的污染物或停止产生污染的活动；二是防止污染物超出允许的限度，将风险控制在一个可接受的水平。但要去除污染物将需要巨大的投资，而且将限制相关的经济活动，阻碍社会经济的发展。第二种方法则是基于风险学的方法，如果环境中的致污物水平比较低或对人类健康及环境处于可接受的风险水平，我们则无需关注。这种方法并不要求零排放，环境中的致污物水平低于特定值时，危害就不太可能发生。在这种情况下，既可以对经济活动进行管理以保护环境和人类健康，又可以保证经济的可持续发展。

环境风险评估主要是用来解释 2 个问题：有什么证据说明保护目标已经受到了危害（对应于回顾性风险评估）？目前的状况将会导致什么样的问题发生（对应于预期性风险评估）？本报告试图来回答上述的 2 个问题，并就渤海中生态风险与健康风险给出必要的描述。

本报告是 GEF/UNDP/IMO 东亚海洋环境管理伙伴计划(PEMSEA)中“渤海环境风险评估与管理”的中期报告。本报告提供了环境风险的基本原理、相关的方法、及在渤海中的应用，目的是为改善渤海的环境提供相关信息及建议，并作为风险管理的科学工具，为渤海的风险管理提供基本科学依据。

渤海的风险评估主要分为 3 个阶段：首先是初步评估，主要用来反映整个区域的环境问题、确定相关数据的收集及数据质量、确定重点保护目标（如人类健康、生境、经济及非经济物种）；第二阶段是高级评估，主要对渤海的风险及暴露

主要对渤海的风险及暴露水平进行确认、对于特定的致污物在不同区域的风险分别进行评估、对特定资源及生境受人类活动的影响进行了分析；最后是本报告，进一步确认了在各分析过程中的数据、归纳出了应关注的环境风险、对于结果的不确定性也进行了确定、分析和归纳。

对渤海的回顾性风险评估结果显示，渤海的自然资源及生境都有明显的下降或恶化，特别是渔业资源和湿地生境处于较高的风险之中。对于渔业资源而言，无论资源数量还是质量都有所下降，比如，主要经济渔获种类的 CPUE 从 1959 年的 138.8kg/net.hr 下降到 1998 年的 11.2kg/net.hr；品质的下降主要表现在渔获物组成中经济种类的减少、重要优势种的消失以及渔获物体型变小等。渔业资源的下降主要原因是过度捕捞，当然其它环境污染因素也不能排除。对于湿地生境，目前的资料显示只有辽河三角洲湿地的总面积有所减少，尽管黄河三角洲湿地的总面积并没有减少，但是自然湿地的面积有所下降并受到一定程度的破坏。湿地面积下降及破碎化的主要原因是由于石油开采、土地开发及转成其它用地（如养虾池、鱼塘、农田、盐田等）。湿地受损的后果主要表现在：生态系统的服务功能下降、减少了对其它生物的食物供应、栖息地功能减弱、生物多样性下降及美学价值降低等。

渤海的预期性风险评估结果表明，对于生态系统和人类健康都存在着一定的风险。根据风险的等级和范围，对于人类健康而言，风险较高的因子为贝类体中的 DSP 毒素、PSP 毒素、粪大肠杆菌（北戴河及黄河口地区）以及海藻中的铅；局部风险因子有莱州湾中的粪大肠杆菌，贝类体中的铅和 DDT；在贝类及藻类组织中可接受的因子有汞、铜、镉、砷等，鱼类组织中的风险因子均处于可接受水平，无需关注。对于生态系统而言，海水中对生态系统风险较高的主要因子有 TSS、铅和石油，对这些因子需要进行管理以降低风险；海水中局部风险因子有 DIN、DIP、COD、以及镉，这些因子需要一定的关注并在热点地区实施管理；海水中的 DO、汞、铜等因子目前还处于可接受水平。沉积物中的 DDT、666 风险水平很高，该当采取一定的措施来缓解；汞、铜、镉及 PAH 属于局部风险因子；石油为可接受水平，目前无需关注。

此外，近十年来不断发生的赤潮也是需要关注问题之一。赤潮的发生与海水的富营养化有一定关系，并导致相当的生态风险（如由于缺氧而引起水生生物的死亡）与健康风险（如 DSP 和 PSP 引起的中毒）。从空间分布来看，辽东湾和渤海湾所带来的污染和富营养化风险要明显高于莱州湾，相关的资料差距、污染水平及标准等也在本部分进行了探讨和分析。

为了保护渤海的自然资源和生境，应当考虑实施进一步的管理措施，如延长禁渔期、减少渔船数量、增加人工增殖苗种、建立保护区、限制开发活动、修建更多的污水处理厂、减少污水排放量等。但这些管理措施应当充分考虑整个社会效益，应当以最小的投资进行，应当有益于环渤海地区的经济可持续发展。

而对于发生在渤海中的海冰、风暴潮等自然灾害，已经有了相当多的模拟和预测方法来进行影响分析。这些自然灾害是无法避免发生的，但是，它们的影响范围和强度都是可以通过有效的监测、评估、预报、预警、协调及管理等手段来降到最低。

Background

INTRODUCTION

Bohai Sea is a semi-enclosed sea located in northern China, which has unique advantages in both geology and resources. It is an important receiving water body that captures the downstream impact from the surrounding Wider Bohai Sea Area (WBSA) and supports the economic system.

However, with the spate of economic development activities in the area, Bohai Sea is confronted with serious challenges. Bohai Sea has been under considerable stress because of the loss of its service functions and sustaining capacities.

Recognizing the importance and urgency of protecting Bohai Sea's environment and resources, the government of China has decided to take effective measures to improve and sustainably manage the Bohai Sea environment. One of such concerted efforts is the Bohai Sea Environmental Management Project (BSEMP), implemented by the State Oceanic Administration (SOA) with technical support and assistance from PEMSEA. The risk assessment of Bohai Sea, one of the indispensable components of BSEMP, is focused on the impact of land-based and sea-based activities and the contaminants derived from them, on living and non-living resources of Bohai Sea, including ecology, people and society.

This report's chapters are Background, Description of Bohai Sea, the Risk Assessment Approach, Retrospective Risk Assessment, Prospective Risk Assessment, Comparative Risk Assessment, and Conclusions and Recommendations.

OBJECTIVES

The following are the objectives of the Risk Assessment:

- To establish a team to serve as a resource base for local/national risk assessment projects and future risk assessment programs;
- To enhance the capacity of scientists and professionals around the WBSA in conducting environmental risk assessment of trans-provincial boundary sea areas/pollution hotspots;
- To examine and analyze the damaged status of the environment and natural resources of Bohai Sea;
- To identify and prioritize inter-provincial environmental issues around Bohai Sea; and
- To recommend immediate management actions to improve the environmental quality of Bohai Sea.

SOURCES AND QUALITY OF INFORMATION

In this risk assessment report, the data used in the initial risk assessment (IRA) and refined risk assessment (RRA) were verified and updated. The quality of data used in the retrospective and prospective risk assessment was assessed through a scoring system to reduce uncertainties. The scoring system was based on the documentation of procedures and adoption of quality assurance/quality control (QA/QC) procedures in sampling and laboratory analysis and was the same as that adopted by the ASEAN-Canada Cooperative Programme on Marine Science (ACCPMS) — Environmental Criteria Component. Data quality score is from 1 to 3, where 1 denotes data with well-documented QA/QC procedures adopted in sample collection and analysis. A score of 2 denotes data generated from where employed procedures were generally satisfactory, some information, such as exact location of sampling station, analyzing method is not confirmed. A score of 3 denotes data generated where procedures were poorly documented or where the values were cited without proper documentation or explanation.

The primary sources of information for the risk assessment were the Report of the Bohai Sea Coastal Resource Conservation and Environmental Management Project (Agriculture Department and ADB, 2000). Other references that were used include the Monitoring Report for Land-based Pollution and its Effects on the Coastal Waters and Resources in China. A detailed list of the sources for each parameter is given in Table 1. The sampling stations are shown in Figure 1.

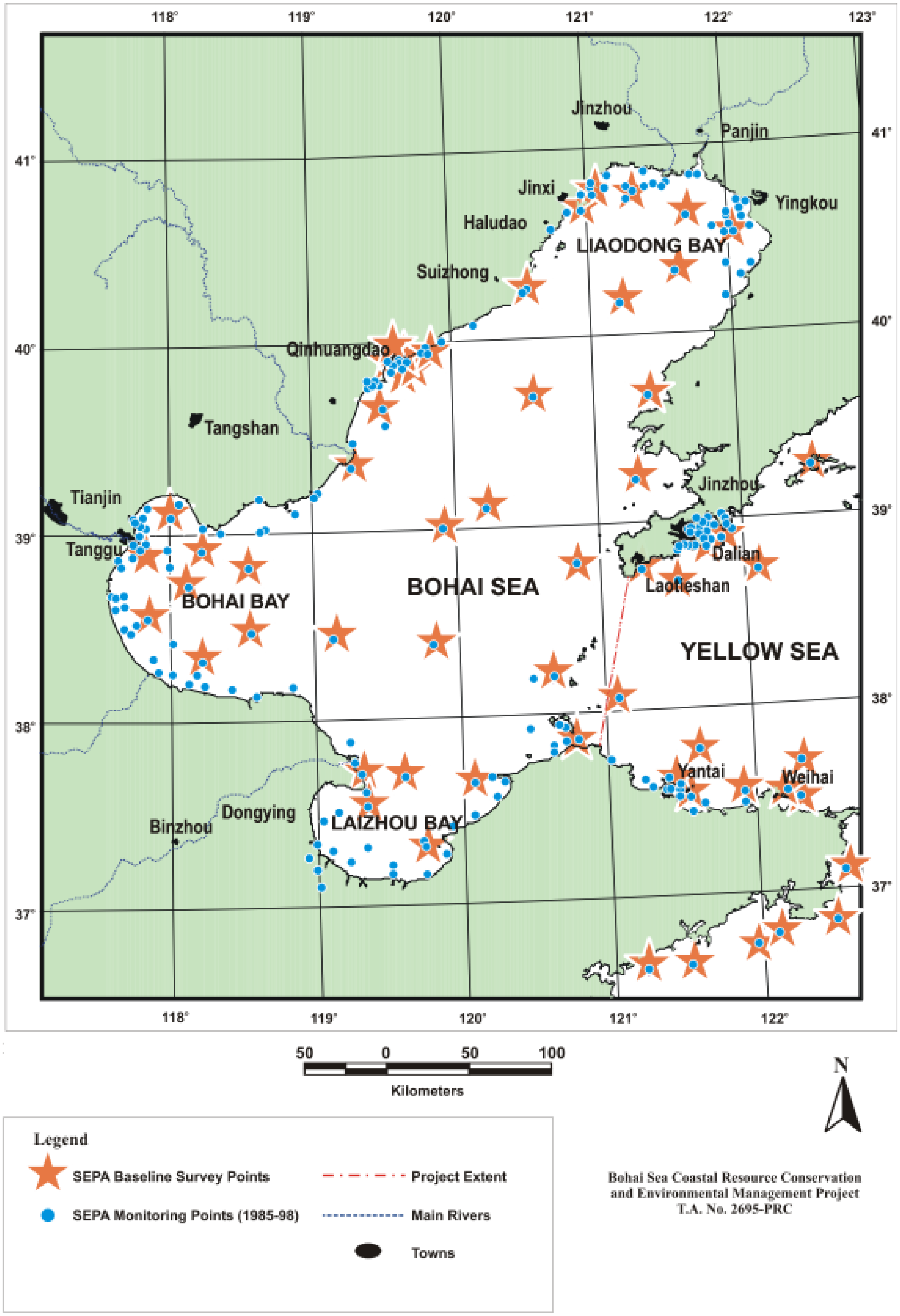
Table 1. Sources of Information for the Risk Assessment.

Parameters	Description of Data	Location	References	Data Quality Score
Fisheries	1949–1998 statistics, and 1982, 1989, 1992, 1998 fishery resource investigation (station unknown)	Entire Bohai Sea	MoA, 1949–1998; Agriculture Department and ADB, 2000	2
Maricultural Species	1949–1998 statistics, 1988–1998 marine culture statistics (unknown station)	Entire Bohai Sea	MoA, 1949–1998; Agriculture Department and ADB, 2000	2
Benthos	1982, 1992, 1998 investigation (unknown stations)	Entire Bohai Sea	Agriculture Department and ADB, 2000	2
Phytoplankton	1982, 1992, 1998 investigation (unknown stations)	Entire Bohai Sea	Agriculture Department and ADB, 2000	2
Zooplankton	1982, 1992, 1998 investigation (unknown stations)	Entire Bohai Sea	Agriculture Department and ADB, 2000	2
Wetland	1981–1998 Research articles	Entire Bohai Sea	Liu Hongyu, et al., 2001	2
Beach	1993	Entire Bohai Sea	Some research articles	3
Coast	1949–1990	Entire Bohai Sea	Recent Marine Erosion along the Coast of the Bohai Sea (Li Fenglin, 1994)	2
Nutrients	1998, station and depth unknown	Entire Sea	Ocean Environment Bulletin, 1998;	2
	1985–1998 station & depth unknown	Entire Sea	Agriculture Department and ADB, 2000	2
COD	1985–1998 station & depth unknown	Entire Sea	Agriculture Department and ADB, 2000	2
DO	Raw data: March 1995, 8 stations	Jinzhou Bay	Monitoring Report for Land-based Pollution and its Effects on the Coastal Waters and Resources in China	1

Table 1. Sources of Information for Risk Assessment (continuation).

Parameters	Description of Data	Location	References	Data Quality Score
Coliform Water Column	13 stations, surface, May-June & August-September 1998	Laizhou Bay	Office of Ocean and Fishery, 2001	1
Tissue	7 stations, shellfish, October-November 1997	Beidaihe	He Jie, et al., 2002	1
TSS Water column	Raw data: March 1995, 8 stations	Jinzhou Bay	Monitoring Report for Land-based Pollution and its Effects on the Coastal Waters and Resources in China	1
Heavy Metals Water column and Sediment	1985-1998, station & depth unknown	Entire Sea	Agriculture Department and ADB, 2000	2
Tissue	1997, station & depth unknown	Tianjin Dalian Yantai		
	1993, station & depth unknown	Tianjin Laizhou Bay		
As in tissue	station & depth unknown	Entire Sea		
Pesticides Water column DDT and 666	1997, station & depth unknown	Entire Sea	Agriculture Department and ADB, 2000	2
DDT	1996, time, station & depth unknown	Entire Sea	Bohai Sea Comprehensive Improvement Plan (SOA, 2000)	3
Oil Water column and Sediment	1985-1998, station & depth unknown	Entire Sea	Agriculture Department and ADB, 2000;	2
	1993, 14 stations, 1 m water column	Laizhou Bay	Xie Xudong,1993;	1
Tissue	time, station & depth unknown	Entire Sea	SOA, 2000	3
PAHs	time, station & depth unknown	Entire Sea	SOA, 2000	3
Oil spills	1979-1998	Entire Sea	Agriculture Department and ADB, 2000	2
HABs **Toxic algae**	1952-1998	Entire Sea	Agriculture Department and ADB, 2000	2
Sea Ice	1969-2000	Entire Sea	SOA, 2000	2
Windstorm	1964-1987	Entire Sea	Bohai Sea Ecology Comprehensive Improvement Technique (First Institute of Oceanography, 2003)	2

Figure 1. Sampling Stations in Bohai Sea.



Data Source: State Environment Protection Administration (SEPA)
Source: Agriculture Department and ADB, 2000

DEFINITION OF TERMS

The key terms used in this report are defined below.

Effects assessment. The component of a risk analysis concerned with quantifying the manner in which the frequency and intensity of effects increase with the increasing exposure to a substance.

Exposure assessment. The component of a risk analysis that estimates the emissions, pathways and rates of movement of a chemical in the environment, and its transformation or degradation, in order to estimate the concentrations/doses to which the system of interest maybe exposed.

Hazard assessment. Comparison of the intrinsic ability of a substance to cause harm (i.e., to have adverse effects for humans or the environment) with its expected environmental concentration, often a comparison of predicted environmental concentration (PEC) and predicted no-effects concentration (PNEC). Sometimes referred to as risk assessment.

Hazard identification. Identification of the adverse effects, which a substance has an inherent capacity to cause, or in certain cases, the assessment of a particular effect. It includes the identification of target populations and conditions of exposure.

Risk. The probability of adverse effects on humans or the environment resulting from a given exposure to a substance. It is usually expressed as the probability of an adverse effect occurring, e.g., the expected ratio between the number of individuals that would experience an adverse effect in a given time and the total number of individuals exposed to the risk factor.

Risk assessment. A process which entails some or all of the following elements: hazard identification effects assessment, exposure assessment and risk characterization. It is identification and quantification of the risk resulting from a specific use or occurrence of a chemical including the determination of exposure/dose-response relationships and the identification of target populations. It may range from largely qualitative (for situations in which data are limited) to fully quantitative (when enough information is available so that probabilities can be calculated).

Risk characterization. The step in the risk assessment process where the results of the exposure assessment (e.g., PEC, daily intakes) and the effects assessment (e.g., PNEC, no observed adverse effect level or NOAEL) are compared. If possible, an uncertainty analysis is carried out, which, if it results in a quantifiable overall uncertainty, produces an estimation of the risk.

Risk classification. The weighing of risks in order to decide whether reduction is required. It includes the study of risk perception and the balancing of perceived risks and perceived benefits. The general term “risk assessment” is used throughout this document while others might have used “characterization” or “classification.”

Description of Bohai Sea

Bohai Sea covers an area of 77,284 km^2. It is an important receiving water body that captures the downstream impacts from the surrounding WBSA, which includes Bohai Sea and its adjacent provinces and municipalities, namely, the Liaoning, Hebei and Shandong Provinces and the municipality of Tianjin. There are more than 40 rivers flowing into it, among which Yellow River, Haihe River, Liaohe River and Luanhe River are the major ones. Average run-off is 7.2×10^8 million m^3/a and more than 1.3×10^8 tons of sand and mud flow into Bohai Sea annually (Li Shuyuan, 1996).

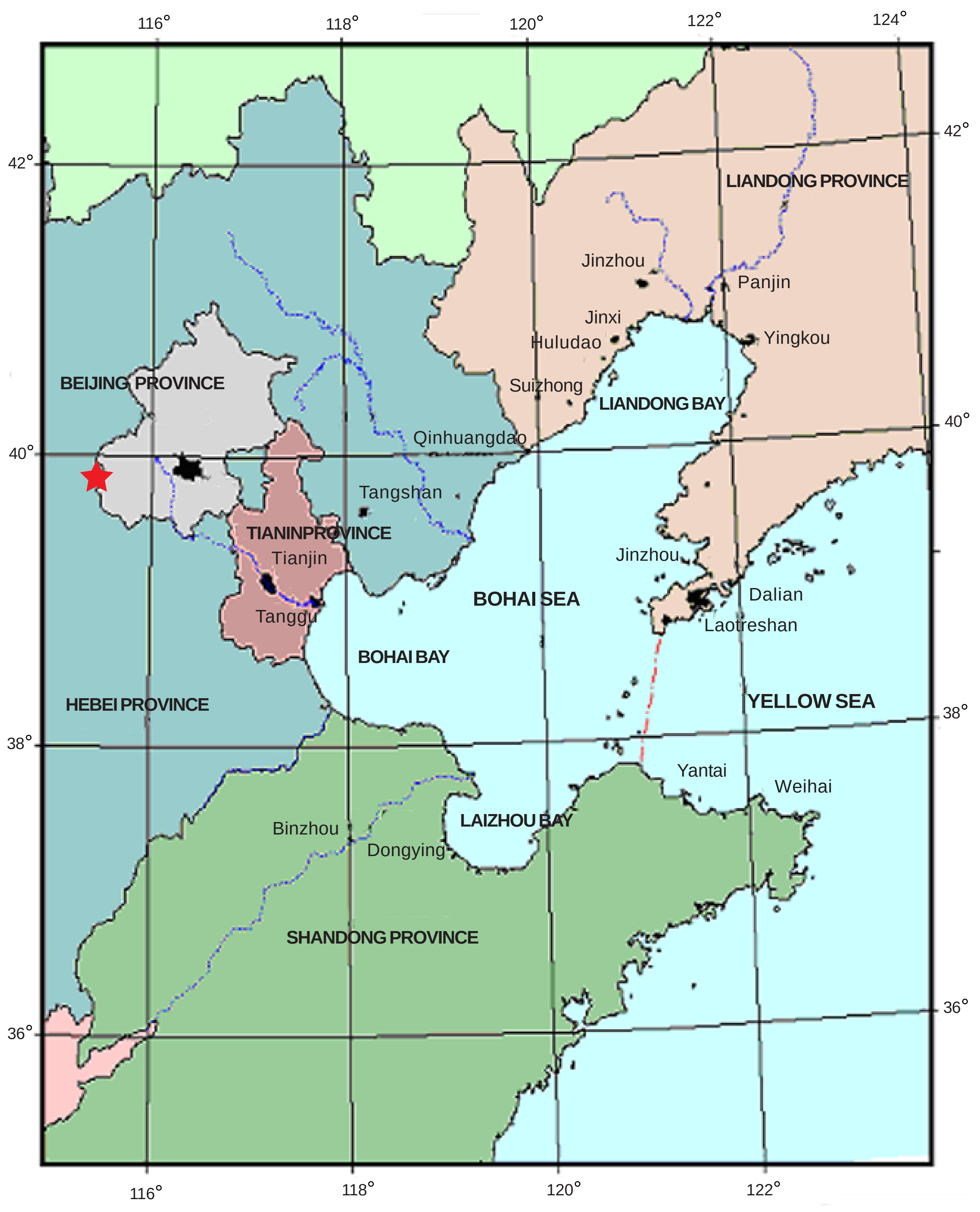
Bohai Sea is a unique shallow marine ecosystem with a strong pelagic–benthic coupling process. Bohai Sea consists of three bays — Liaodong Bay, Bohai Bay and Laizhou Bay and the central region. Huge mud and sand loading in the river water has formed two wide and plain delta wetlands — the Liaohe River estuary and the Yellow River estuary. The latter is the biggest wetland in Asia. There are about 150 kinds of birds wintering in Yellow River estuary. These estuaries also provide grounds for fish, shrimp and crab to spawn, nurse and feed. These halobios are very rich in Bohai Sea, and include such main species as the yellow croaker, clam, scallop, abalone, and Chinese shrimp. The mariculture industry is highly developed in Bohai Sea, and has made the area into the most important center of shellfish aquaculture in China. Bohai Sea is also rich in oil, salt, chemicals and other resources and has adequate ports and tourism facilities. The main environmental disasters are harmful algal blooms (HABs), oil spills, coastal erosion, intrusion of seawater, windstorms, and sea ice.

Figure 2. Location of Bohai Sea in China.

WBSA is recognized as one of the major centers of economic development in China. In 1999, the WBSA accounted for some 22 percent of the nation's Gross Domestic Product (GDP) and 16 percent of the nation's population. The area serves as an important maritime outlet for the country's landlocked Great West and Northeast Provinces and a Euro-Asian transportation linkage as well.

The rapid economic and industrial development in the WBSA in recent years resulted in tremendous amounts of land-based pollutants being discharged into Bohai Sea, exerting enormous pollution pressure to its environment. The continued degradation of the Bohai Sea environment has damaged the resources and led to the sharp decline of their service functions, and undermined Bohai Sea's capacity to sustain the needs of the present and future generation.

Figure 3. Map of Wider Bohai Sea Region.



The Risk Assessment Approach

An environmental risk assessment involves estimating the likelihood of harm being done to human health and/or ecosystems through factors emanating from human activities that reach their targets via the natural environment. Hence, it usually combines an understanding of factors that may cause harm (hazard identification) with an understanding of the likely levels of exposure in targets (exposure assessment). The basic principles and techniques for risk assessment (both retrospective and prospective risk assessment) are described in the *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (MPP-EAS 1999a).

RISK ASSESSMENT APPROACHES

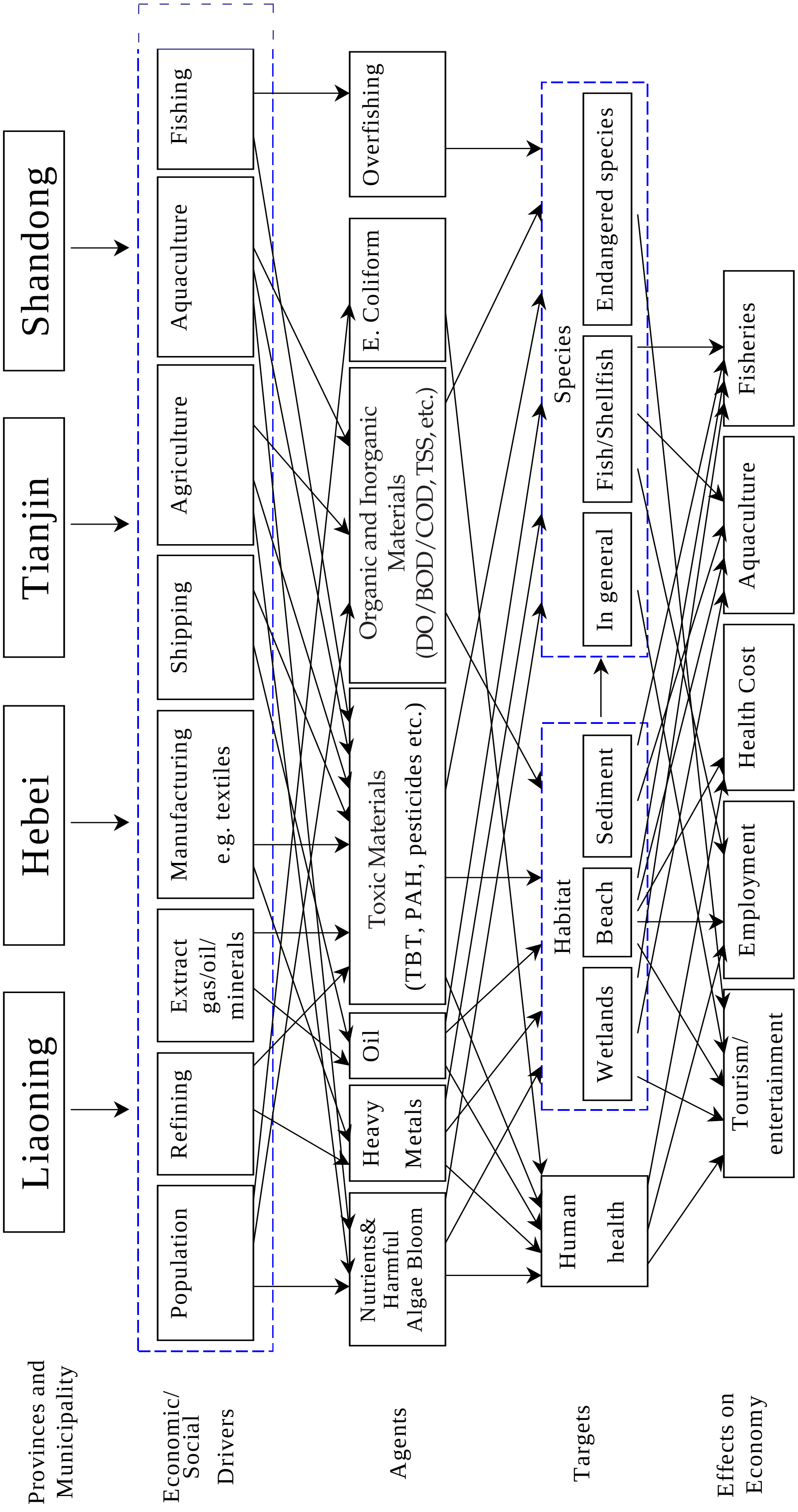
The following is a summary of risk assessment approaches applied. Based on available data, Bohai Sea is divided into four parts: Liaodong Bay, Bohai Bay, Laizhou Bay and the central region

Considering the conditions around Bohai Sea, the main economic and social drivers include: population, refining, extracting oil/gas/minerals, manufacturing, shipping, agriculture, aquaculture and fishing.

The main agents are nutrients and HABs, heavy metals, oil, chemical organics, other chemicals, *E. coli* and overfishing. While the main categories of the targets are human health, habitats, i.e., wetlands, beaches (swimming beach, muddy beach etc.) and sediment, and species, i.e., commercial and non-commercial marine species.

Risk represents the likelihood that conditions will lead to harmful effects in targets that involve human health and/or ecological quality. Assessment of risks can be carried out in terms of historical conditions as a retrospective risk assessment, where the fundamental question concerns the extent to which these conditions are likely to have caused adverse effects observed in specific targets. The alternative approach is to consider the extent to which current conditions and/or those likely to pertain to the future due to new developments are likely to cause harm. This is the prospective risk assessment approach. Both can be used as basis for environmental management and imply the desire to control activities and conditions to levels that will not cause harm and which are likely to be non-zero. In comprehensive environmental management programs, such as the one being implemented in Bohai Sea, a combination of retrospective and prospective approaches is applied. Thus a retrospective approach is applied to explain observed deterioration in ecological targets and/or the occurrence of human health problems in the light of likely levels of exposure and their causes. A prospective approach is applied to consider and compare the likely adverse effects emanating from observed environmental concentrations of chemicals. Both these approaches ought to be converged. The approach also ought to indicate the relative importance of different adverse effects and their causes and suggest appropriate, cost-effective management programs.

The fundamental feature of both retrospective and prospective risk assessments is the identification of problems and their causes on the basis of systematic and transparent principles that can be justified in public and can be revisited when more information and understanding become available. The key concept for risk assessment is


Provinces and Municipality
Liaoning
Hebei
Tianjin
Shandong
Economic/Social Drivers
Population
Refining
Extract gas/oil/minerals
Manufacturing e.g. textiles
Shipping
Agriculture
Aquaculture
Fishing
Agents
Nutrients& Harmful Algae Bloom
Heavy Metals
Oil
Toxic Materials (TBT, PAH, pesticides etc.)
Organic and Inorganic Materials (DO/BOD/COD, TSS, etc.)
E. Coliform
Overfishing
Targets
Human health
Habitat
Wetlands
Beach
Sediment
Species
In general
Fish/Shellfish
Endangered species
Effects on Economy
Tourism/ entertainment
Employment
Health Cost
Aquaculture
Fisheries

the comparison between environmental conditions (e.g., environmental concentrations of chemicals) and threshold values likely to cause adverse effects in the targets under consideration. In the prospective risk assessment, this is made explicitly as a risk quotient (RQ) that is the ratio of an environmental concentration which can be either predicted (PEC) or measured (MEC) with a predicted no-effect concentration (PNEC) for the target of concern ($RQ = P(M)EC/PNEC$), such that an $RQ < 1$ indicates a low, and thus acceptable risk and an $RQ > 1$ indicates a level of concern and possibly the deployment of management programs. PNECs have been derived from standards obtained from various sources.

RISK PATHWAYS OF BOHAI SEA

The conduct of risk assessment began with a qualitative indication of risk pathways to draw attention to the key issues. Figure 4 shows the main risk agents, targets and their consequences in/around Bohai Sea. The sources of agents are ultimately related to economic and other social drivers that are distributed among Liaoning, Hebei, Tianjin and Shandong. The consequences of pollution will have knock-on effects on the economy, although differently, among the littoral provinces and municipality; but any control would likely have impact on the economies within and outside the littoral community. These considerations ought not to influence the way the risk assessment is carried out, but they may influence judgments about priorities for actions and hence at which issues the risk assessment is directed. Ultimately they will influence what management actions are taken, when it will be important to weigh benefits to human health and the environment with costs to the economy. Involving a range of social, national, governmental, and commercial interests, these considerations will never be far from an analysis of complex risk pathways of high economic importance.

Retrospective Risk Assessment

INTRODUCTION

Retrospective risk assessment is an evaluation of the causal linkages between observed ecological effects and stressor(s) in the marine environment. It addresses risks from actions that began in the past and can therefore be assessed based on measurements of the state of the environment (Suter, 1998). It attempts to answer the question: "What evidence is there for harm being done to targets in the Bay?" (MPP-EAS, 1999a). In retrospective studies, it is important to identify significant effects (targets and endpoints) and ascribe causation. The approach involves making inferences about the causes of observed effects (Suter, 1998), and this often requires temporal and spatial series of data for comparative purposes. Comparison facilitates the ascribing of risks to a particular source.

The retrospective approach employed for Bohai Bay was of the "effects-driven assessment" type that addresses apparent ecological effects that have uncertain magnitudes and causes (Suter, 1998). Under this perspective, risk is viewed as the likelihood that current impacts are occurring and that demonstrating these existing impacts confirms that a risk exists. It is important to note that impacts have primary or secondary effects — as these may cause direct or indirect changes in identified targets. These impacts range from those occurring inland and near the coast to those occurring in the Bay itself as consequences of developments and ecosystem exploitation.

METHODOLOGY

A considerable volume of materials on Bohai Bay from various studies, reports, and projects were reviewed and relevant data on identified targets (habitats and resources) in the bay were put together for the retrospective risk assessment. Steps prescribed in MPP-EAS (1999a) were likewise applied.

Problem Formulation

The problem formulation phase involved defining the target and the way it is impaired by recognizing that an undesirable effect on an ecological system or human population has already occurred, identifying suspected (or known) agents, and considering the links between the agents and the adverse effects on the targets with an aim to eventually manage these agents in order to reduce harm.

Identification of Assessment and Measurement Endpoints in the Targets

It is important to determine the assessment and measurement endpoints in the targets. Assessment endpoints are features related to the continued existence and functioning of the identified targets (e.g., production, density changes and mortality), which may not be easy or would take much time to measure. Hence, measurement endpoints, which are features related to the assessment endpoints but are easier to measure, are used instead, such as biomass (for production), abundance (for density changes) and LC_{50} or biomarkers (for mortality).

To elaborate on the interrelation of agents and targets in Bohai Sea, a simplified risk pathway (Figure 4) was used.

The identified targets for resources in Bohai Sea are classified into five groups:

a. Fisheries;
b. Maricultured species;
c. Benthos;
d. Phytoplankton; and
e. Zooplankton.

The identified targets for habitats in Bohai Sea cover:

a. Wetland;
b. Beach; and
c. Coast.

The suspected agents for the different resources and habitats in Bohai Sea includes:

1. Overfishing (over-collection/over-harvesting);
2. Destructive and illegal fishing;
3. Physical disturbance;
4. Physical removal/clearance;
5. Sedimentation;
6. Diseases;
7. Freshwater run-off;
8. Oil exploitation;
9. Over-reclamation;
10. Dam building;
11. Tourist trampling;

Table 2. Details of Retrospective Risk Assessment.

Resource/Habitat
1. Is the target exposed to the agent? **Note:** Answer YES if actual data (or visual observations of solid wastes, oil and grease, physical removal) show the presence of that particular agent in the study area (whatever the level might be); also if activities that are potential sources of these agents are present in the area.
2. a. Was/Were there any loss/es that occurred following exposure? **Note:** Answer YES if data is available to show correlation between observed decline and exposure to the agents. b. Was there any loss/es correlated through space? **Note**: This asks if in places where exposure levels were higher, the impacts/losses were also greater.
3. Does the exposure concentration exceed the threshold where adverse effects start to happen? **Note:** Please refer to the results of the prospective RA, especially if there are data available on contaminant levels within the period when decline was observed or area where decline was observed.
4. a. Do the results from controlled exposure in laboratory or field experiments lead to the same effect? **Note:** For agents for which controlled experiments in laboratories do not need to be conducted (e.g., collection, clearance, reclamation, etc.), answer should be NR (not relevant); for other agents, answer YES only if experiments have really shown that exposure to the agent has led to the decline of the particular resource or habitat. b. Will removal of the agent lead to amelioration? **Note:** Although in theory removal of agent will lead to amelioration, recovery might not come easily for some targets, or some might not recover at all (e.g., for agents like physical removal, reclamation, land conversion).
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)? **Note:** The **observed effect** should be specifically caused only by the identified agent and cannot be attributed to any other agent. An example of specific evidence is the deformity observed in the reproductive organs of mollusks as a result of exposure to TBT. If you answer YES to this question, please provide information in the discussion on what specific evidences were observed that will link that particular agent to the decline (cite studies). The observed effect can also be a physical observation such as tainting by oil.
6. Does it make sense? Logically and Scientifically **Note:** Does it make sense for the agent to have caused the observed effect on the basis of scientific principles or as established through simulation? (Is cause-effect relationship known to be possible, in principle?)
7. Try to determine likelihood (VL = Very Likely, L = Likely, P = Possibly, U = Unlikely, ? = Don’t Know **Note:** In deciding the likelihood, please use the decision criteria, Table 3, (although the cases included in the table are not comprehensive; other combinations of answers are possible); for cases that cannot be found in the table, decide on the likelihood to be assigned then update the decision criteria table (include the new case(s) and likelihood and provide explanation.)

12. Windstorm;
13. Seawater intrusion;
14. Underground water exploitation;
15. Sand excavation;
16. Dissolved oxygen (DO);
17. Biochemical oxygen demand (BOD);
18. Chemical oxygen demand (COD);
19. Nutrients;
20. Coliform;
21. Harmful algal blooms (HABs);
22. Heavy metals;
23. Pesticides;
24. Total suspended solids (TSS);
25. Total organic carbon (TOC);
26. Oil and grease;
27. Polyaromatic hydrocarbons (PAHs);
28. Polychlorinated biphenyls (PCBs) and other organics;
29. Oil spills; and
30. Zooplankton.

In addition, changes in the physical feature of Bohai Sea particularly, bathymetric and shoreline changes, and their concomitant effects on habitats and resources, were also examined.

Determination of Likelihood of Harm on the Identified Target by the Suspected Agent

Under the retrospective risk assessment phase, a set of questions, answerable by yes (Y), no (N), maybe (M), no data, (ND) do not know (?) and/or not relevant (NR), was formulated in order to establish evidences of decline, causes of the decline, and consequences of the decline. The following questions and steps (Table 2) were adapted from MPP-EAS (1999a). The decision criteria for determining the different categories of likelihood of harm for specific agents are listed in Table 3.

Table 3. Decision Criteria for Determining the Likelihood of Harm.

Case	Result Decision Tables	Conclusion
A	No 1 & 2 = unlikely (U)	No correlation
B	Yes 1 & 2, ND for 3 – 6 = possibly (P)	Just correlation
C	Yes 1 & 2, but no 3 = unlikely (U)	Correlation but negative evidence for cause-effect
D	Yes 1 & 2, but no 6 = unlikely (U)	Spurious correlation
E	Yes 1, 2, & 3 = likely (L)	Correlation with some evidence of cause-effect
F	Yes 1, 2, & 3, but no 4a = unlikely/possibly (U/P)	Correlation but negative evidence for cause-effect; if good experimental design (e.g., low Type II error = unlikely), with poor experimental design (e.g., high Type II error) = possibly.
G	Yes 1, 2, & 3, ND for 4a, but no 4b = possibly (P)	Correlation but lack of evidence for cause-effect
H	Yes, 1, 2, 3, & 4a, but no 4b = likely (L)	Correlation with evidence for cause-effect and recovery does not always occur
I	Yes, 1, 2, 3, 4a, & 5 = very likely (VL)	Correlation with strong evidence for cause-effect
J	Yes, 1, 2, 3, & 4a, but no 5 = likely (L)	Correlation with evidence for cause-effect (a lack of biomarker response is inconclusive evidence)
K	Yes, 1, 2, 3, 4a, 5, & 6 = very likely (VL)	Correlation with very strong evidence for cause-effect
L	Yes, 1, 2, 3, but maybe 6 = possibly (P)	Correlation but scientific/logical justification lacking
M	Yes 6 but no data for 1 & 2 = unknown (?)	Cause-effect relationship known to be possible in principle, but no evidence in this case
N	Yes 1, but no 2	Target is exposed but there is no evidence for decline; if there is good evidence for no decline then there is no need to take the risk assessment further; if evidence for no decline is weak or questionable, seek more evidence.

In order to facilitate the assessment, all the above-mentioned questions were tabulated in a matrix where each of the targets was subjected to the series of questions. The answers to the questions were based on available information on the targets and agents. The matrices are termed here as Decision Tables. Using these tables, agents that were likely to have caused adverse effects have been systematically screened.

Upon screening, summaries of likelihood of some identified agents causing decline in resources and habitats were prepared and were made part of the basis for the results of the retrospective risk assessment. It is important to note that the summaries of likelihood were established on the basis of the retrospective analyses (Decision Tables) and on the prospective risk assessments for different agents summarized in the Comparative Risk Assessment section.

The results of the retrospective analysis of each resource or habitat (identified target) in terms of spatial extent, changes observed and the identified agents for these changes, and the ecological and socioeconomic consequences of these changes is summarized in tabulated form for each resource or habitat assessed.

RESOURCES

Fisheries

The total area of Bohai Sea is around 77,284 km^2, almost all of which is set as fishing areas. The total production value from all marine-related industries in Bohai Sea was 90.7 billion RMB (about US$10.8 billion) in 1997, of which 62.29 billion RMB (about US$7.4 billion) came from marine fisheries (including mariculture). More than 800,000 persons were involved in this field (SOA report, 1998). The fishing production increased rapidly in the past decades by the introduction of modern fishing methods. The production grew five times more in 1998 (1618x10^3 tons) compared to the production in 1979 (322x10^3 tons). Figure 5 shows the catch production in Bohai Sea from 1979 to 1998, Table 4 shows the data on fisheries production in Bohai Sea in recent years (MoA, 1949–1998).

Evidence of Decline

The following evidence is based on data generated by the Agriculture Department and ADB (2000) and the *Blue Sea Action Program in Bohai Sea (SEPA, 2001).* Table 6 summarizes the retrospective analysis for fisheries in Bohai Sea.

Catch per unit of effort (CPUE) is the number or weight of fish caught per unit of fishing effort, e.g., weight in kilograms (kg) per fishing hour (H) or per horsepower (HP). It is often used as a measure of fish abundance or fishing gear efficiency.

Figure 6 shows the CPUE of Yellow Sea and Bohai Sea from 1949 to 1993. The CPUE dropped in the 1960s and remained in low level after 1980s,

Table 4. The Total Catch Production in Bohai Sea.

Year	1994	1995	1996	1997	1998
Catch (x1000 MT)	905	954	1,271	1,290	1,618

and fishing gear efficiency could not sustain the declining fisheries production. The only reason for CPUE decline is the depletion of resources. The yield of small yellow croaker, which was the main fishing species between the 1960s and 1970s, shows the same trend with the CPUE. The CPUE of small yellow croaker in a Qingdao fishing company (Figure 7) clearly shows that the volume of this resource declined to a very low level after the 1960s with the use of motorized fishing boats and the high efficiency of fishing gears. The CPUE for Bohai Sea was 1.33 T/HP in 1995, while it rapidly declined to 0.33 T/HP in 1997. The decline in the CPUEs could be a very clear evidence for resource volume decline.

The CPUE for valuable species (Table 5) also shows a clear decline. It was 138.8 kg/net.hr in 1959, declining to 50.4 kg/net.hr in 1982, and then to 11.18 kg/net.hr in 1998.

Figure 5. The Fisheries Catch Production of Bohai Sea in the Past Decades.

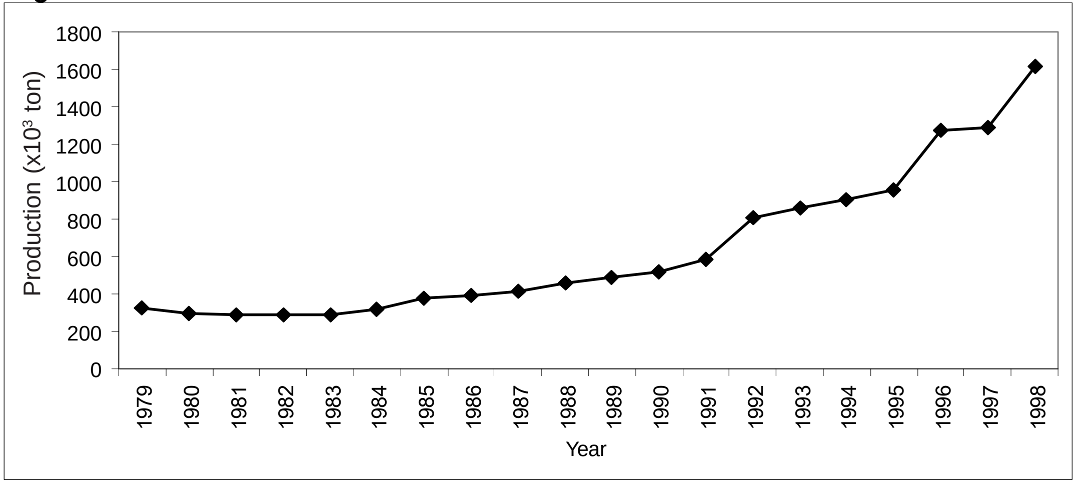


Figure 6. The CPUE and Production of Main Fish Species in Yellow Sea from 1949-1993.

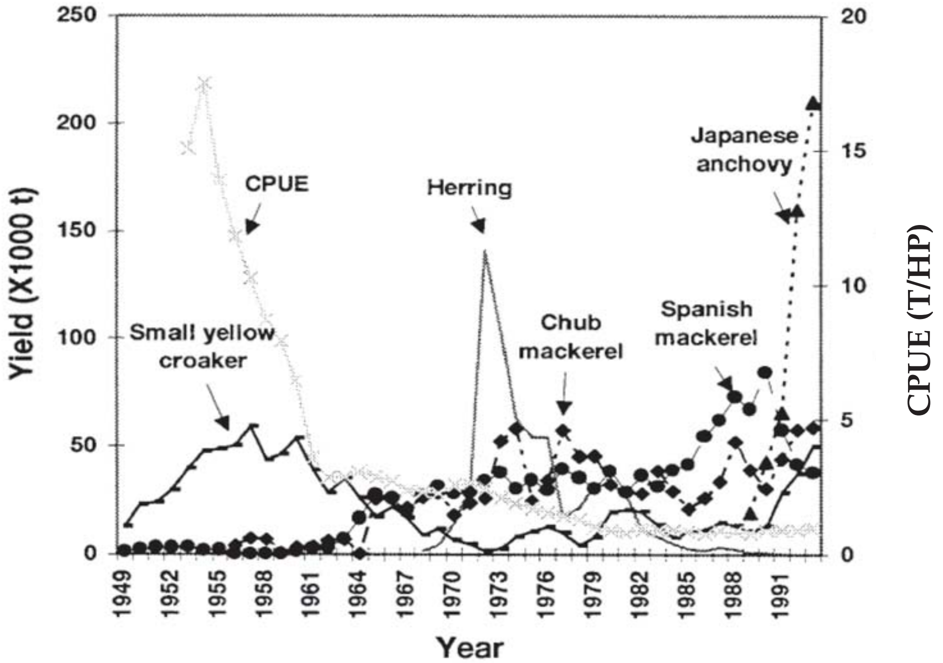


Table 5. Changes of CPUE for Valuable Species in Bohai Sea (1959-1998, kg/net.hr).

Valuable species	1959	1982	1992	1998
Small yellow croaker *(Pseudosciaena polyactis)*	51.0	7.2	5.7	0.4
Tail fish (*Trichiurus muticus)*	50.7	0.8	0.1	0.08
Half-fin anchovy (*Setipinna taty)*	8.2	18.0	8.0	
Japanese anchovy (*Engraulis sp)*		6.8	25.0	0.2
Spotted sardine *(Clupanodon punctatus)*			6.5	1.6
Madura anchovy *(Thrissa kammalensis)*			2.6	7.2
Spanish mackerel (*Scomberomorus niphonius)*		3.8	0.2	0.8
Prawn (*Penaeus orientalis)*	25.2	0.9	0.4	
Squilla (*Oratosquilla oratoria)*		3.7	4.8	0.5
Swimming crab (*Portunus trituberculatus)*	3.7	9.2	2.9	0.4
Total	138.8	50.4	56.2	11.18

Source: SEPA, 2001

Table 6. Summary of Information for the Retrospective Risk Assessment for Fisheries.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Fisheries	Large (all of Bohai Sea)	1. CPUE: 1.33 T/hp in 1995 and 0.33 T/hp in 1997. 2. CPUE for valuable species: 138.8 kg/ net.hr in 1959, only 11.18 kg/net.hr in 1998. 3. Diversity index: 3.61 in 1983 and 2.52 in 1993. 4. Abundance: 85 species in 1983 reduced to 74 species in 1993. 5. Resource for demersal fisheries: 3.36 T/ km^2 in 1930, 1.22 T/km^2 in 1950, 0.89 T/ km^2 in 1982, 0.696 T/km^2 in 1992. 6. Fishing boat: total HP of fish boat increased 3 folds in 1960s; increased 10 times in 1970s, and 25 times in 1980s. 7. Fish length: small yellow croaker, 221 mm in 1950s, 179 mm in 1970s, and 123 in 1988. 8. Economically valuable species: high value species occupied 69.6 percent in the total catch in 1959, decreased 58.3 percent in 1982, and 18.9 percent in 1992. 9. Low value small fish: 12.3 percent of the total catch in 1959 increased to 19.8 percent and 53.4 percent in 1982 and 1992. 10. Dominant species: small yellow croaker in 1950s, herring and chub mackerel in 1970s, Spanish mackerel in 1980s, Japanese anchovy in 1990s.	**Very likely:** 1. Recruitment overfishing and growth overfishing; 2. Destructive and illegal fishing; 3. HABs; 4. Heavy metals; 5. Pesticides; 6. Oil and grease; 7. PAHs; and 8. Oil spills. **Likely:** Freshwater run-off decreased **Possible:** 1. Oil exploitation 2.TSS/TOC **Unlikely:** DO	• Decrease in mature individuals • Reduced demersal fishery production • Increased production from pelagic fisheries • Less production of eggs and larvae • Loss of economically important species • Reduced economic value due to decrease in average sizes of fish • Decrease in sustainable net income

The "Diversity Index (Shannon-Weaver Index)" is an indicator of ecological structure and function of a resource community. From 3.61 in 1983, it decreased to 2.52 in 1993 in the Bohai Sea, which means the ecological structure had a big change within the 10-year period. The main commercial catchable fish species also decreased from 85 to 74 during the 10-year period.

There were 156 species of fish in Bohai Sea and 70 of these species have high economical values for catching, such as *Pseudosciaena polyactis, Trichiurus muticus, Pagrosomus spp., Sparus sp., Pneumatophorus japonicus, Bothus sp, Gadus sp, Engraulis sp, Mugil sp.* and *Nibea sp.* More than 20 species of shrimp, particularly, *Acetes chinensis*, and about 10 species of crabs especially *Portunus trituberculatus* and *Charybdis japonica* are catchable and economically valuable. Cephalopods, such as *Loligo japonicus* and *Sepia esculenta, Rhopilema esculenta* are also catchable. But of all the catchable and economically valuable species, only the *Rhopilema,* crabs, *Logigo, Engraulis* and *Acetes* can be caught in Bohai Sea at present.

Figure 7. CPUE of Small Yellow Croaker Provided by a Fishing Company.

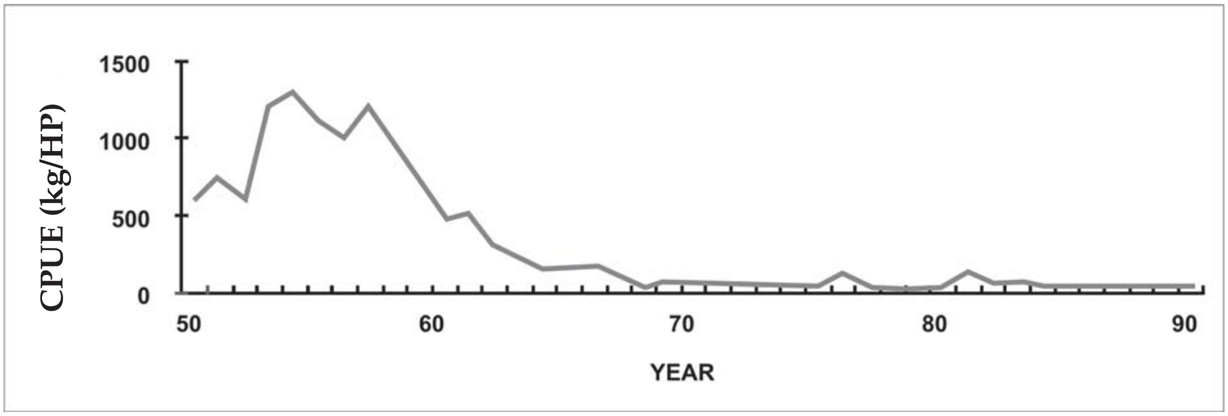
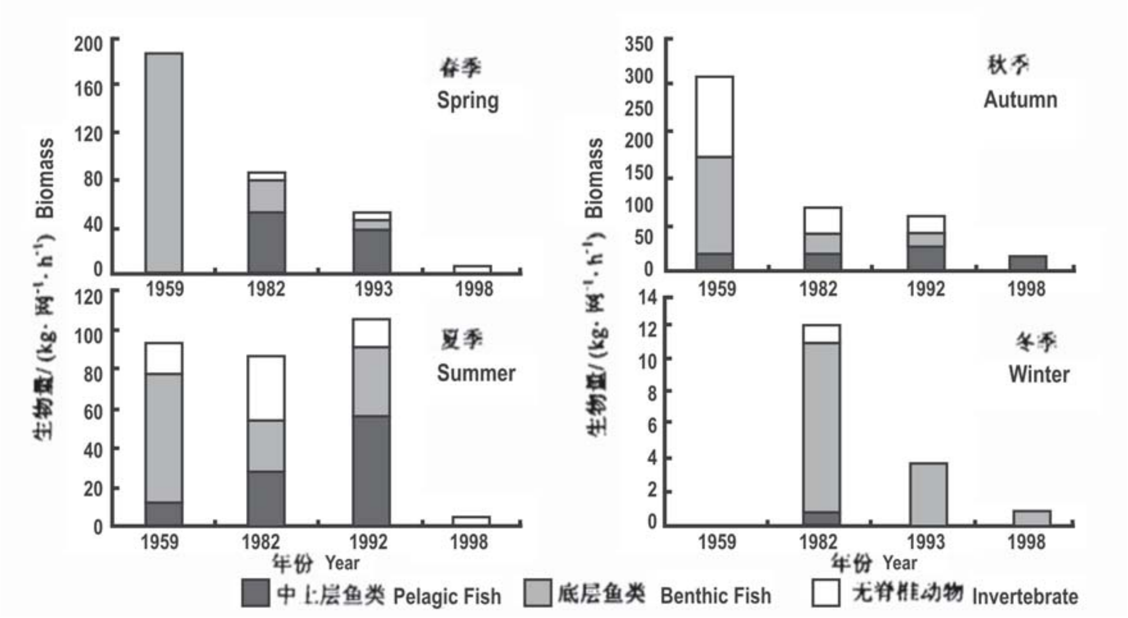


Figure 8. Variations of Fishery Resource Biomass in Bohai Sea.



Demersal catchable biomass of fish also declined. From 3.36 T/km^2 in 1930, this was reduced to 1.22 T/km^2 in 1950, then 0.89 T/km^2 in 1982, and only 0.696 T/km^2 in 1992, based on the investigation carried out in 1982–1983 and 1992–1993. In general, the demersal biomass of fish was low in winter and high in spring, which was 3,000 T and 122,776 T respectively in the whole Bohai Sea (Figure 8). The highest biomass could reach 123,824 T and per statistical data, the average biomass was 55,662 T annually. However, in the 1990s, biomass was only 0.696 T/km^2/yr, a mere 20 percent that of 1930. Figure 8 presents the fishery resource biomass changes in 1959, 1982, 1992 and 1998 (Jin Xianshi, 2001), showing a significant decline in all the seasons.

Fish species and diversity declined in Bohai Sea. Table 7 shows the data results from the investigation in 1982–1983 and 1992–1993. The average fish species was 52.5 in 1982–1983 and 44.25 in 1992–1993, which declined around 20

Figure 9. Number of Fishing Boats from 1989-1997.

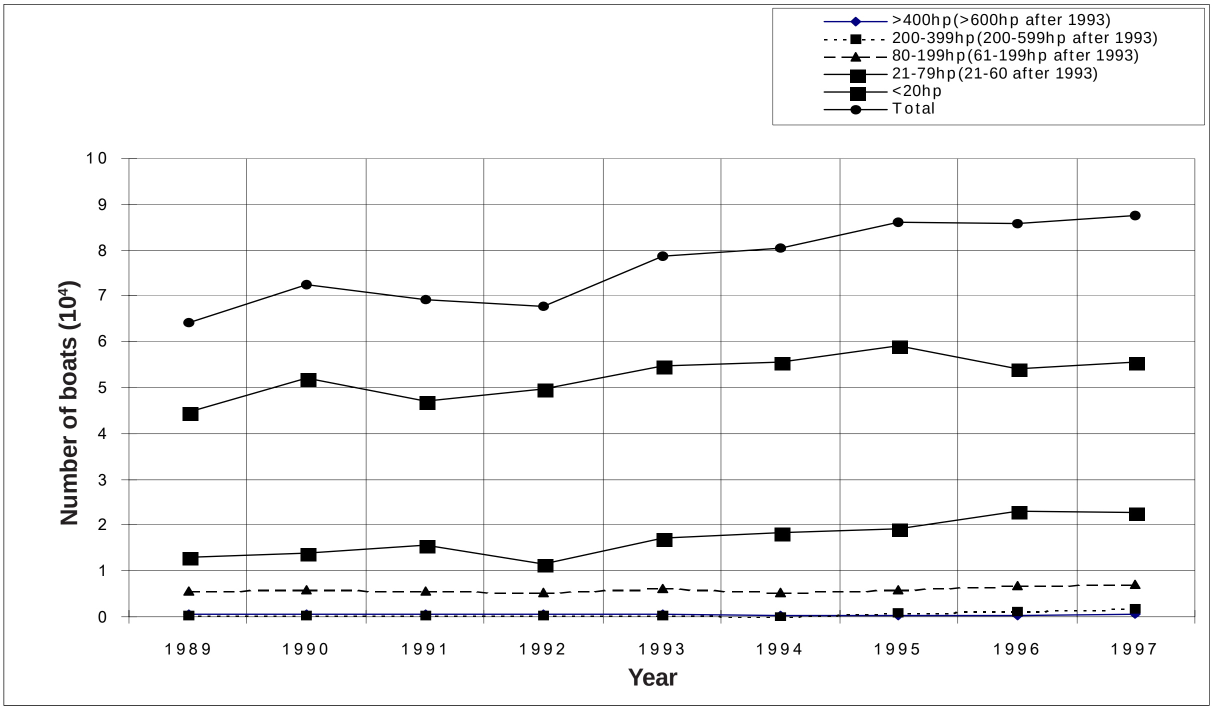


Table 7. Diversity and Biomass of Fish in the Bohai Sea in 1982–1983 and 1992–1993.

Items	1982/83 spring	1992/93 spring	1982/83 summer	1992/93 summer	1982/83 fall	1992/93 fall	1982/83 winter	1992/93 winter	Average 1982/3	Average 1992/3
N	61.00	43.00	61.00	54.00	64.00	61.00	24.00	19.00	52.50	44.25
H’	2.14	1.16	2.56	2.40	2.98	2.43	2.22	1.47	2.48	1.87
E	0.52	0.31	0.62	0.60	0.72	0.59	0.70	0.50	0.64	0.50
T	11.50	10.30	22.70	21.90	20.10	18.00	1.00	1.90	13.83	13.03
PFB	94,006.00	81,520.00	53,634.00	78,655.00	53,844.00	70,210.00	1,996.00	23.00	50,870.00	57,602.00
DFB	28,770.00	5,599.00	37,379.00	30,722.00	38,801.00	18,755.00	15,865.00	2,994.00	30,204.00	14,518.00
Total	122,776.00	87,119.00	91,013.00	109,377.00	92,645.00	88,965.00	17,861.00	3,017.00	81,074.00	72,120.00
Ratio	3.26	14.50	1.43	2.60	1.30	3.80	0.90	0.10	1.72	5.25

N = Species number, H’ = Shannon index, E = Even index, T = Demersal temperature, PFB = Biomass of pelagic fish (ton), DFB = Biomass of demersal fish (ton), Total biomass = PFB + DFB, Ratio = PFB/DFB percent. The diversity dropped from 2.48 to 1.87. The ratio of pelagic fish and demersal fish biomass increased from 1.72 to 5.25, which means the valuable demersal fish resource declined and low value pelagic fish occupied most of the catch.

Table 7 shows that the fishery resource decreased in the whole Bohai Sea. While the number of fishing boats had largely increased, total HP of fishing boats increased 3 times in the 1960s; 10 times in the 1970s, and 25 times in the 1980s. Figure 9 gives some idea of fishing boat increments from 1989 to 1997. There were 64,100 boats in 1989, 78,500 boats in 1993, and 87,300 boats in 1997. The number of boats increased by 36 percent in 10 years. Since some boats did not operate in Bohai Sea, there was no calculation for fishing boat numbers per square kilometer or per length of coastline. However, the data clearly establishes that the fishing efforts increased in the past years, which could aggravate the depletion of fishery resources in Bohai Sea.

The size of the fish species have become smaller in the past few years. For example, the average length of a small yellow croaker was 221 mm in the 1950s, 179 mm in the 1970s, and 123 mm in 1988. Table 8 illustrates the decreasing trend in length, weight and age of the small yellow croaker since the 1950s. Figure 10 gives annual changes in average length of the small yellow croaker. By 1988, the average length of the yellow croaker was only half of what it was in the 1950s, and about one-seventh of the body weight and age in that period. Sexual maturity of the fish became one year old from being two years old in the 1950s. Unfortunately, these adaptations were unsuccessful for its survival in Bohai Sea; the small yellow croaker still disappeared in the 1990s because of overfishing.

More economically valuable species have disappeared. High value species accounted for 69.6 percent of the total catch in 1959, which decreased to 58.3 percent in 1982 and to 18.9 percent in 1992. Low value small fish accounted for 12.3 percent of the total catch in 1959, which increased to 19.8 percent in 1982 and to 53.4 percent in 1992. The *Engraulis* was regarded as a low value species before the 1980s and a huge amount of *Engraulis* eggs were found during the field survey. During the late 1980s, fishers switched to catching *Engraulis*

Figure 10. Average Length of the Small Yellow Croaker.

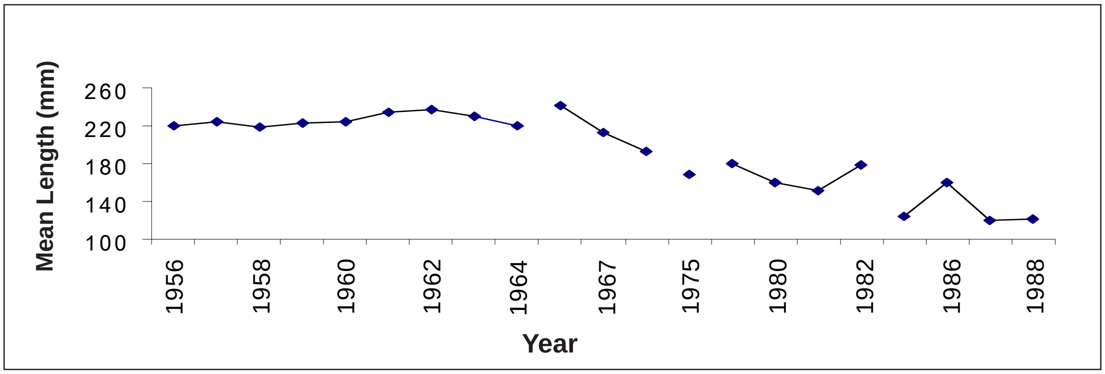


Table 8. The Average Length, Weight and Age of the Small Yellow Croaker from the 1950s to 1988.

Year	1950s	1960s	1970s	1980	1985	1986	1987	1988
Length (mm)	221.0	227.0	179.0	164.0	127.0	159.0	121.0	123.0
Weight (g)	203.0	218.0	102.0	77.0	35.0	70.0	30.0	31.0
Age (yr)	5.3	5.2	2.4	1.5	0.8	1.4	0.6	0.7

Figure 11. Percentage of *Engraulis japonicus* in the Total Catch (percentage of wet weight).

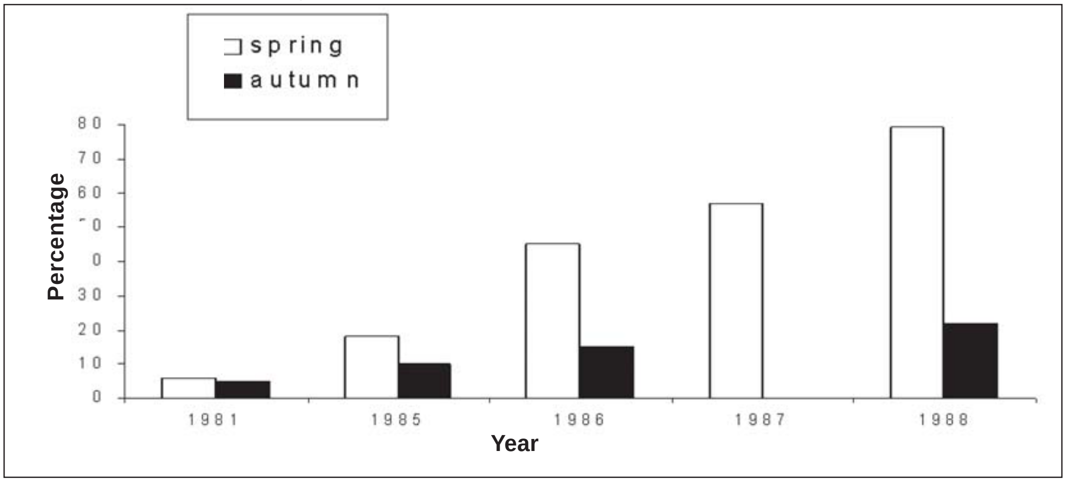
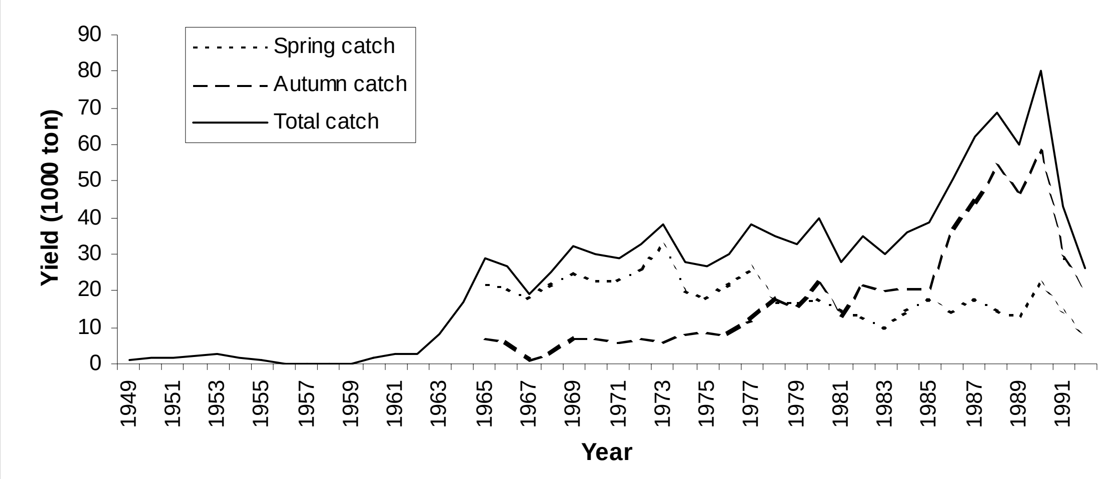


Figure 12. *Scomberomorus niphonius* Catch from 1949 to 1992.



after realizing that no other fish could be caught. Hence, the production of the *Engraulis* increased rapidly since 1981. The standing stock of the *Engraulis* in 1998 was only one percent of what it was in 1993. Figure 11 illustrates the percentage of *Engraulis* to the total catch production from 1981 to 1988. This low value species was less than 7 percent of the total catch in 1981, which became around 80 percent in 1988.

Another example is the *Scomberomorus niphonius*, which was abundant in Bohai Sea and Yellow Sea. It spawns from April to June in Bohai Sea then moves on to grow in the Yellow Sea. Figure 12 shows the production of the *Scomberomorus niphonius* from 1949 to 1992. The yield used to rapidly increase after each new fishing technique renovation. With the use of the motorized fishing boats in the beginning of the 1960s, production peaked in 1965 at $2.83x10^4$ tons. The second production peak ($7.95x10^4$ tons) was in 1990, resulting from the introduction of the fast-moving trawls technique. After, the production went down rapidly due to high fishing pressure. The production of the *Scomberomorus niphonius* in 1992 returned to its level in the 1960s at $25.9x10^3$ tons.

Dominant species have bigger changes in the fisheries structure of Bohai Sea since the 1960s.

Upper trophic and highly valuable species got lesser, with their ages and individual sizes becoming smaller in the catch composition. At the same time, the percentage of lower trophic and low valuable species rose up. For example, some highly valuable species, such as *Pseudosciaena polyactis, Trichiuris haumela,* and *Penaeus chinensis*, accounted for 69.6 percent in 1959, 58.3 percent in 1982, and 18.9 percent in 1992. However some low value species, such as the *Engraulis japonicus,* account for a significant portion of the total catch before extinction, at 12.3 percent in 1959, 19.8 percent in 1982, and 53.4 percent in 1992.

Investigations show that *Setipinna taty* was the dominant species in 1982, its biomass reaching 10,500 T/yr and holding 19 percent of the total biomass of Bohai Sea. Other important species were *Pseudosciaena polyactis, Scomberomorus niphonius, Engraulis japonicus, Raja porposa, Collichthys lucidus, Lateolobrax japonicus, Raja pulchra, Stromateodes argenteus, Cynoglossus semilaevis, Coilia mystus* and *Navodon modestus*. The CPUE for *Trichiuris haumela* is 11 g/hr, and 73 g/hr for *Ilisha elongata*. The results showed that those two dominant species in the 1960s almost disappeared in Bohai Sea in the 1980s. The biomass for commercial fishing species declined by about 40 percent in 1982 compared to that in the 1960s. However, *Engraulis* accounted for 88.4 percent of the total catch during the 1992 investigation (spring). The biomass of *Setipinna taty* declined by 50 percent in the summer investigation. Moreover, no *Scomberomorus niphonius* was caught in 1992.

Attributed Causes

Table 9 presents the detailed retrospective risk assessment for fisheries. The most likely reasons for fishery decline were overfishing (both growth and recruitment overfishing), destructive and illegal fishing gears, freshwater run-off, oil exploitation, DO, HABs, heavy metals, pesticides, TSS/TOC, oil and grease, PAHs and oil spills.

Table 9. Detailed Retrospective Risk Assessment for Fisheries.

Fisheries	Overfishing	Destructive and Illegal Fishing	Freshwater Run-off	Oil Exploitation	DO	HABs	Oil Spills	Heavy Metals	Pesticides	TSS/TOC	Oil and Grease	PAHs
1. Is the target exposed to the agent?	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	M	N	Y	Y	Y	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	ND	N	Y	Y	Y	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	?	N	Y	Y	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	ND	ND	Y	Y	Y	Y	Y	ND	Y	Y
4b. Will removal of the agent lead to amelioration?	Y	Y	N	M	ND	Y	Y	Y	Y	?	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	Y	ND	M	Y	Y	Y	Y	ND	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	?	NR	Y	Y	Y	Y	Y	Y	Y
Likelihood	**VL**	**VL**	**L**	**P**	**U**	**VL**	**VL**	**VL**	**VL**	**P**	**VL**	**VL**

Legend: Y – Yes, N – No, M – Maybe, ND – No Data, ? – Don't Know, NR – Not Relevant,VL – Very Likely; L – Likely, P – Possibly, U – Unlikely

Overfishing is a very important factor in the decline of fishery resources. The use of motorized fishing boats and new high efficiency fishing techniques facilitated fishing with ease in Bohai Sea. This could be proven by the yearly catch increase. Overfishing would not only impact on the stock biomass of high value species, but also on the recruitment of new resources. In the meantime, some destructive and illegal fishing gears were used in some fishing boats to get more production. On another hand, the number of fishing boats increased in the past ten years. According to the incomplete statistical data, the number of motorized fishing boats in Bohai Sea and Yellow Sea increased from 18,499 boats (total power 702,657 kW) in 1981 to 69,330 (1,667,195 kW) in 1991 and 86,577 (2,156,583 kW) in 1997. All these overfishing activities will give high stress on fishery resource restoration.

Environmental pollution is another very important reason for the decline of fishery resources in Bohai Sea. Bohai Sea receives the riverine run-off, agricultural run-off, industrial run-off, and city sewage, which occupies 32 percent of the whole nation's city sewage. Bohai Sea receives 47 percent of the whole nation's pollution amount with 1.6 percent area of the China seas. Based on the investigation (1997), 2.99 billion tons of industrial and city sewage, which was 34 percent of the nation's total discharge, were annually discharged in WBSA. These sewage contained 6.99x10^5 tons of pollutants, which was 47.74 percent of the nation's amount. 2.15x10^4 tons of pollutants were discharged into Bohai Sea through the riverine systems every year, representing 72 percent of nation's pollutants from the rivers to the sea.

There are 32 large rivers that empty into Bohai Sea, with an annual average freshwater run-off of 854.76x10^8 tons (Data from MoA, 1997). These freshwater run-offs could also bring pollutants into Bohai Sea. For example, the estuary of Wulihe River, a river into Liaodong Bay, was covered by 2–4 mm of oil and the oil silt was 30–40 cm. The concentration of lead, cadmium, and mercury exceeded the standard by 300, 200, and 150 times respectively. The river became a drainage of industrial sewage discharge.

All these environmental pollution must have affected the survival, growth, and spawning of halobios. The results of the prospective risk assessment that showed ecological risks associated with oil, heavy metals, pesticides, PAHs, nutrients and organic load in various environmental compartments in Bohai Sea support this assessment.

Table 10. Annual Freshwater Run-off of Yellow River (1997–2001).

Year	1997	1998	1999	2000	2001
Run-off (x10^8 ton)	18.61	106.1	68.36	48.59	46.51

Table 11. The Salinity of Laizhou Bay for Selected Years (%).

Year	**May**		**August**		**October**	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
1959	27.96	28.23	29.64	29.99	27.02	27.20
1982	29.52	29.80	28.45	30.78	28.08	29.13
1992	29.77	29.76	30.46	30.54	28.66	28.70
1998	31.37	31.35	30.04	31.14	29.28	29.50
2002	32.26					

HABs that occur in Bohai Sea with increasing frequency have also been linked to fish kills.

Freshwater run-off could be a factor that would impact on the fishery resource, especially on the fishery resource recruitment. A stable freshwater run-off is the key to keeping salinity and a hydrodynamic environment, which are very important for spawning activities and the survival of juveniles of halobios. Yellow River is the biggest river in Bohai Sea, with an average run-off of about 57.63x10^8 tons annually. However, its freshwater run-off has grown lesser recently. Table 10 gives the figures for the run-offs of the Yellow River in the past five years, and Table 11 shows the salinity of Laizhou Bay. These two tables show the correlation between Yellow River and the salinity of Laizhou Bay. The high salinity could restrain the spawning activities of most halobios in the sea. Therefore, the freshwater run-off reduction will affect the recruitment of fishery resources, then result in the decline of the fishery biomass.

Consequences

The decrease in fishery resources has caused the following consequences as described in Table 6:

- The degradation of the Bohai Sea ecosystem and destruction of its health;
- Decrease in mature individuals;
- Reduced demersal fishery production;
- Increased production from pelagic fisheries;
- Less production of eggs and larvae;
- Loss of economically important species;
- Reduced economic value due to decrease in average sizes of fish;
- Decrease in sustainable net income; and
- Destruction of the stable development of fishery and related industries.

Maricultured Species

There are more than 20 species of marine organisms which can be farmed in Bohai Sea. Most of the species are economically valuable species,

Table 12. Main Maricultured Species.

Scientific Name	Common Name	Economic Value
Fish		
Pagrosomus major	red sea bream	high
Sparus macrocephalus	black sea bream	high
Lateolobrax japonicus	sea perch	high
Fugu rubripes	red fugu	low
F. pseudommus	black fugu	low
Mugil soiny	barracuda	medium
Paralichthys olivaceous	Japanese flounder	low
Solea solea	sole	low
Sebastodes fuscescens	monk fish	medium
Oreochromus spp.	African crucian	low
Hexagrammos spp.	yellow fish	low
Crustacean		
Penaeus chinensis	Chinese prawn	high
P. japonicus	Japanese prawn	medium
P. monodon	grass shrimp	medium
Portunus spp.	crab	low
Mollusca		
Mytilus edulis	green mussel	medium
Chlamys farreri	Chinees scallop	high
Argopecten irradians	Mexico scallop	high
Patinopectin yessoensis	Japanese scallop	high
Haliotis discus	abalone	medium
Meretrix meretrix	hard clam	high
Ruditapes philippinarum	clam	high
Cyclina sinensis	green clam	low
Scapharca granosa	blood mussel	medium
Sinonvacula constricta	knife mussel	low
Crassostrea gigas	Pacific oyster	high
Ostrea edulis	oyster	low
Seaweed		
Laminaria japonica	kelp	high
Porphyra tenera	purple laver	high
Undaria pinnatifida	skirt kelp	high
Gracilaria verrucosa	gracilar	high
Echinoderm		
Apbistichopus japonicus	sea cucumber	medium
Hemicentrotus pulcherrimus	sea urchin	medium
Anthocidaris crassispina	sea urchin	low

which include fish, shellfish, crustacean, and kelp. The list of farmed species is provided in Table 12. The important species include prawns and shrimps, oysters, clams, scallops, mussels, abalone, kelp, and sea urchins.

The production from marine cultivation in Bohai Sea increased from 1,236x10^3 T in 1991 to 3,780x10^3 T in 1996. Shellfish contributed 85 percent of the total production (in weight) and 10 percent for seaweed, 3 percent for fish, and 2 percent for both crab and shrimp.

Evidence of Decline

Table 13 summarizes the retrospective analysis for marine cultivation in Bohai Sea based on data generated by the Agriculture Department and ADB (2000).

Marine cultivation developed very rapidly in the 1980s after fishermen and fishing companies realized that natural fishery resources have been in short supply. The government also encouraged them to shift to mariculture to protect the natural resources. More fishermen switched to marine farming of kelps, mollusks, fish, sea urchins, sea cucumbers and other possible species. The production from total marine cultivation increased three times from 1991 to 1996, and reached 3.78 million tons. Figure 13 shows the production of various mariculture types. Such rapid growth in mariculture brought heavy environmental problems as discussed in the Prospective Risk Assessment.

The cultivation area increased three times from 1.64´10^5 ha in 1989 to 4.65´10^5 ha in 1998. Figure 14 shows the increase in mariculture area and the

Table 13. Retrospective Analysis for Mariculture Species.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Marine cultivation	Medium	1. The production of marine cultivation was increased from 1.236 million tons in 1991 to 3.78 million tons in 1996. 2. Cultivation area increased from 1.64´10^5 ha in 1989 to 4.65´10^5 ha in 1998. 3. Production of farmed fish increased from 0.98x10^3 T in 1989 to 4.12x10^4 T in 1998. 4. Production of shellfish increased from 6.74x10^5 T in 1989 to 2.86x10^6 T in 1998. 5. Prawn and crab production decreased from 1.4x10^5T in 1991 to 5.25x10^4 T in 1998. 6. Production of kelp increased from 2.13x10^5 T to 6.77x10^5 T from 1989 to 1998.	Very Likely: 1. HABs 2. Disease 3. DO 4. Heavy Metals Likely: 1. Pesticides 2. Oil and grease 3. PAHs 4. Oil spills Possible: TSS/TOC	For fast development of mariculture: 1. Destroying the normal energy flow of ecosystem; 2. Harmful to health of ecosystem; 3. Change in species replacement; 4. Shortening the food chain; 5. Simplification of food web; 6. Heavy self pollution; and 7. Worsening in water quality declined. For decline in prawn and crab production: 1. Decreasing the maximum sustainable income; and 2. Destroying stable development of maricultural and related industries.

Figure 13. The Production of Different Types of Mariculture from 1989 to 1998.

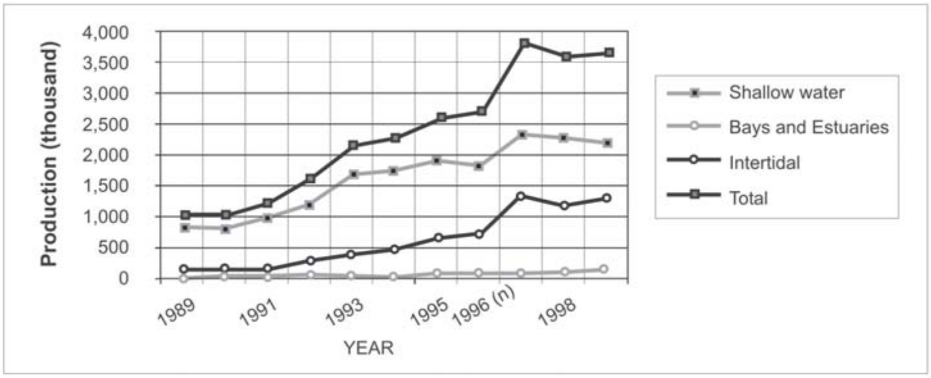


Figure 14. Areas of Different Mariculture Types.

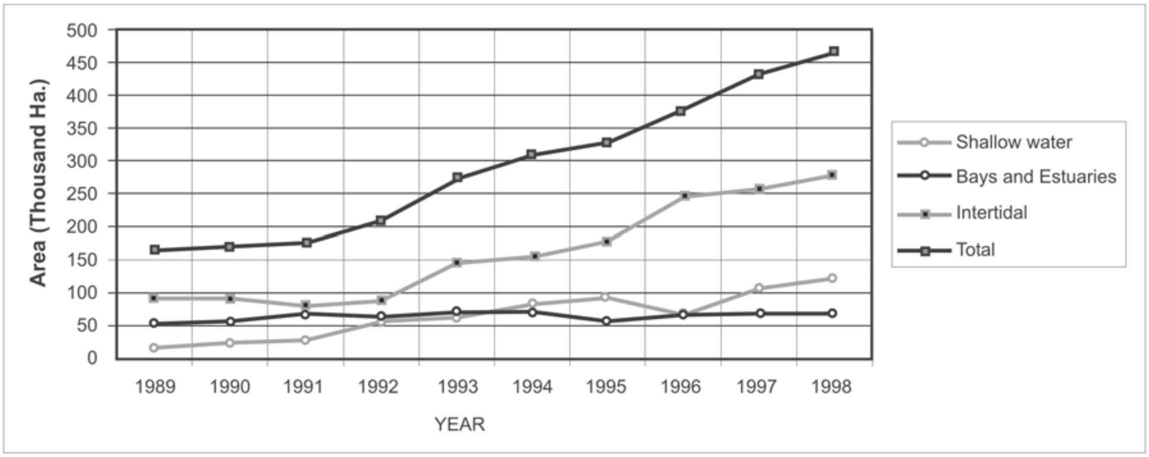
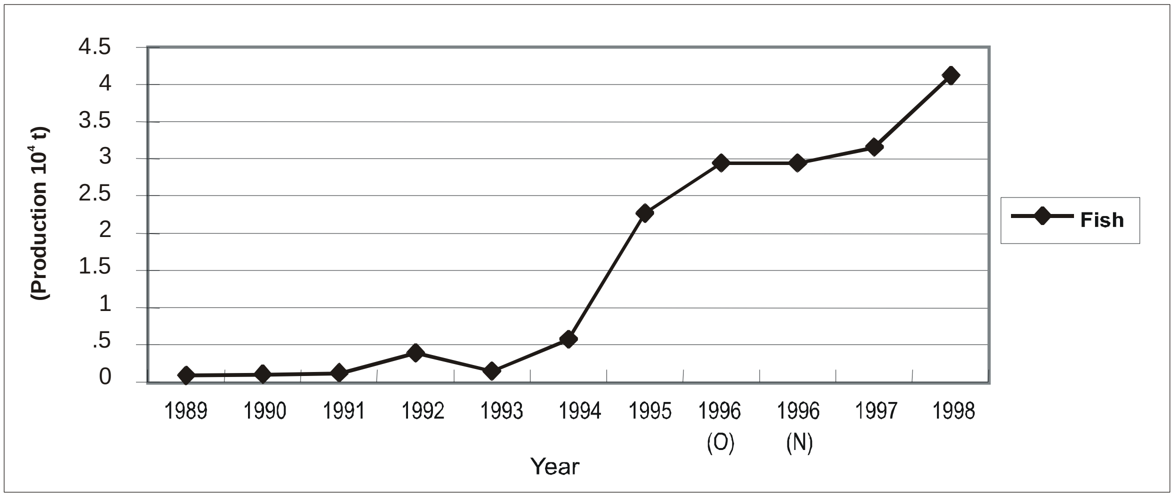


Figure 15. Production of Farmed Marine Fish from 1989 to 1998.



** Note: The statistic method was changed in 1996; hereby two figures for 1996 are given to show the difference between the new and old method. O—old method, N—new method.*

rapid increase in inter-tidal farming area. This means that the inter-tidal area was totally disturbed by farming activities. The natural habitat and environment were largely changed as many inter-tidal areas were converted into farming ponds for shrimps.

Fish production, as shown in Figure 15, increased 41 times from 0.98x10^3 tons in 1989 to 4.12x10^4 tons in 1998.

The shellfish production increased 4.2 times from 6.74x10^5 tons in 1989 to 2.86x10^6 tons in 1998; and kelp production increased 3.2 times from 2.13x10^5 to 6.77x10^5 tons (Figure 16 and Figure 18).

However, shrimp and crab farming production have reached their apex in 1991 with 1.4x10^5 tons. Production went down drastically after 1992 as a viral disease spread through Bohai Sea. Around 80 percent of the shrimp farming factories were affected by the disease. Production in 1994 was only 21.4 percent that of 1991 and production in 1998 only 5.25x10^4 tons, which is 40 percent that of 1989 (Figure 17).

Attributed Causes

The above figures show that the production of most maricultured species, except for prawns and crabs, have increased. The main reason for

Figure 16. Production of Farmed Shellfish from 1989 to 1998.

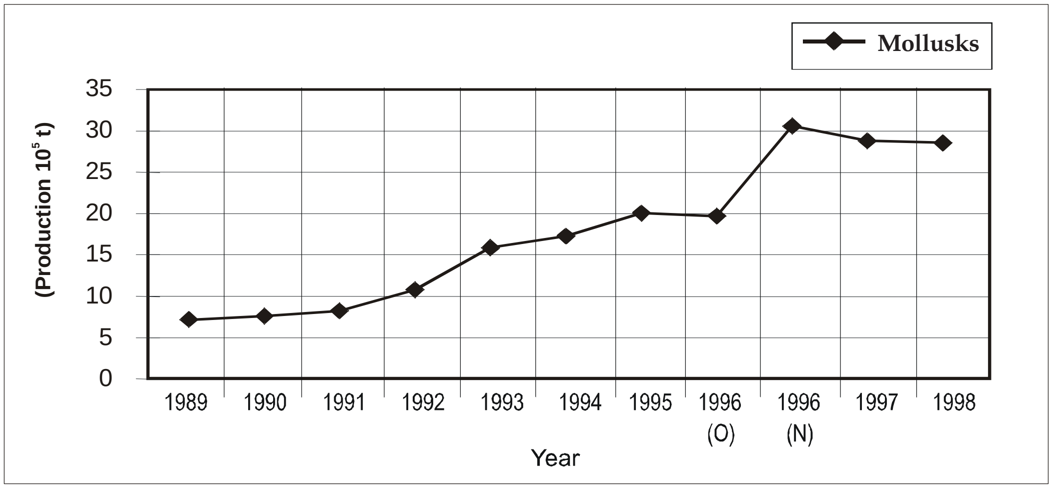
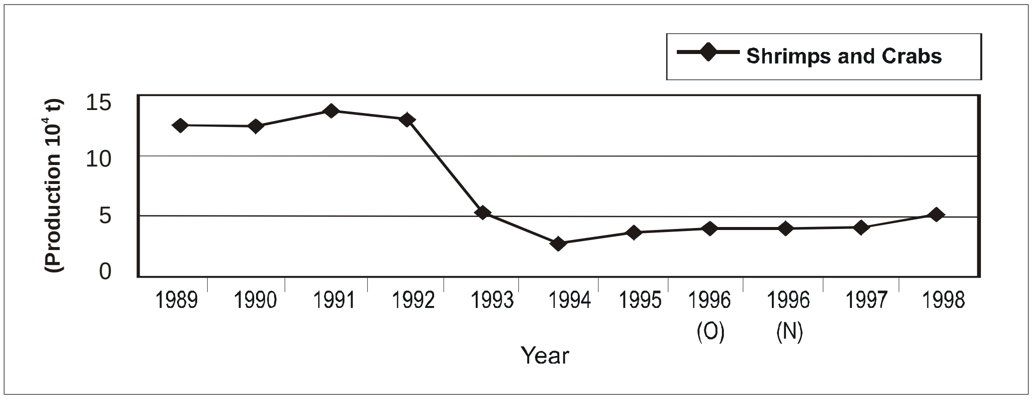


Figure 17. Production of Farmed Shrimps and Crabs from 1989 to 1998.



the increased production of most species was the increasing shift to marine farming. Mariculture, however, is still growing in Bohai Sea.

On the other hand, the main cause of the decline in the production of prawns and crabs was the fast spread of viral diseases since 1991, which were difficult to control. To date, farmers still could not control these diseases and could only take preventive measures. A detailed analysis is shown in Table 14.

Environmental pollution is regarded as another important reason for the production decline of prawn and crabs. Normally, shrimp ponds are close to the seashore, which means they could be easily influenced by water pollution. Water in shrimp ponds tend to stagnate, which could lead

Figure 18. Production of Seaweeds from 1989 to 1998.

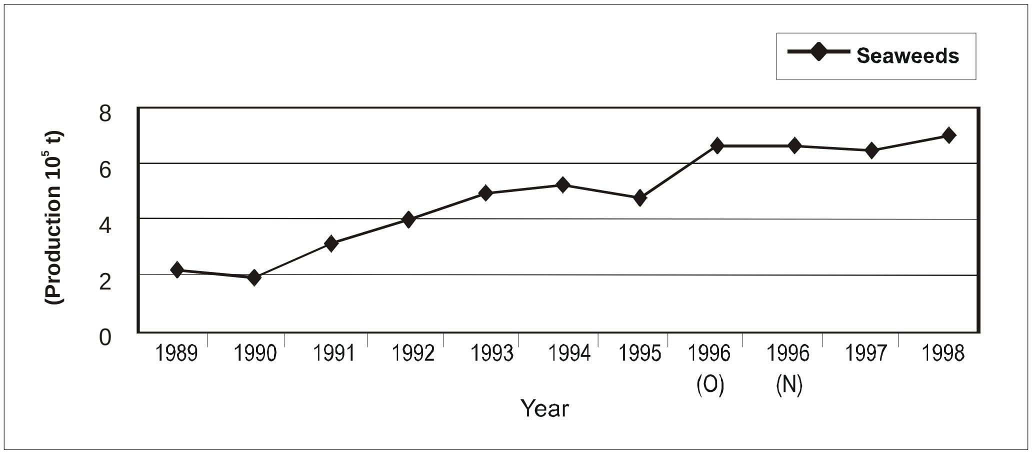


Table 14. Detailed Retrospective Risk Assessment for Maricultured Species.

Mariculture Species	HABs	Heavy Metals	Pesticides	TSS/TOC	Oil and Grease	PAHs	Oil Spills	Disease	DO
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	ND	Y	ND	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	ND	Y	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	ND	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	ND	ND	ND	ND	ND	Y	Y
4b. Will removal of the agent lead to amelioration?	Y	Y	Y	ND	Y	ND	Y	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	Y	ND	Y	ND	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	M	Y	Y	Y	Y	Y
Likelihood	**VL**	**VL**	**L**	**P**	**L**	**L**	**L**	**VL**	**VL**

Legend: Y – Yes, M – Maybe, ND – No Data, VL – Very Likely, L – Likely, P – Possibly to high COD/BOD by feeding and excretion of shrimps. Oxygen depletion resulting from high COD/BOD, could kill the shrimps. At the same time, feeding in ponds always makes the seawater more eutrophic, which could lead to HABs and oxygen depletion. Another problem in pond farming was the fluctuating water temperature, which make the shrimps and crabs vulnerable to viral infections. Pond farming technology is obviously affected by environmental changes, which bring higher risks than farming fishes in cages, and mollusks and kelps in the sea.

Figure 19. Shrimp Ponds Located in the Inter-tidal Area.

Consequences

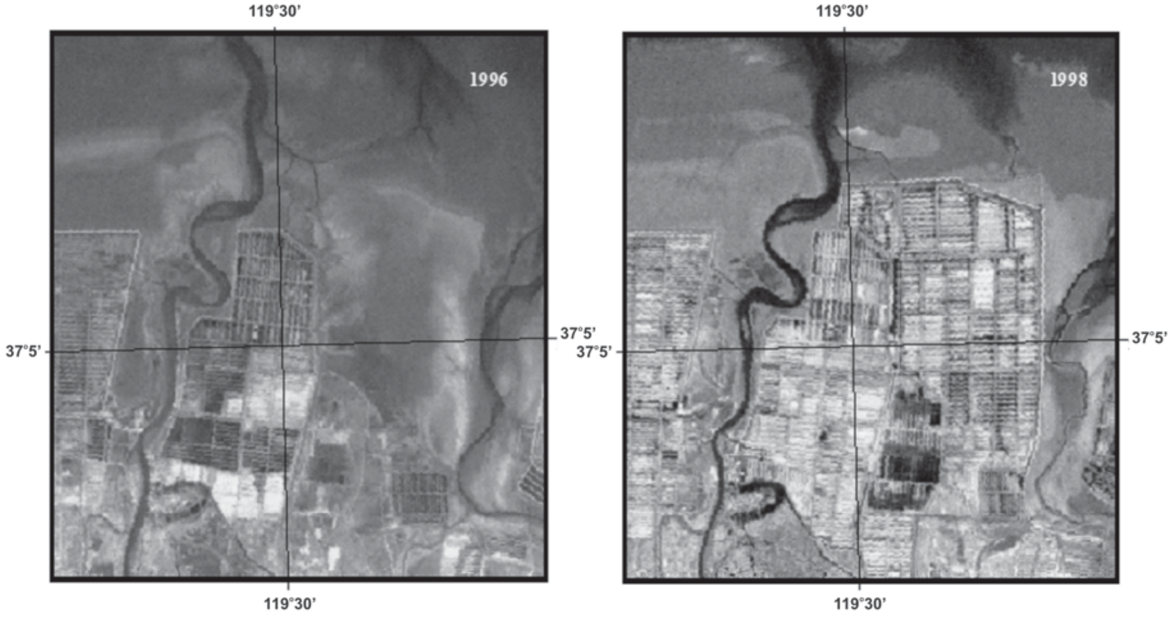
The fast development of mariculture had brought many serious consequences to the Bohai Sea environment, including:

- Destruction of normal energy flow of the ecosystem;
- Shortening of the food chain and simplifying the food webs;
- Production of heavy pollution and worsening of water quality;
- Occupation of more land and/or inter-tidal area to be farming ponds (Figure 19 and Figure 20);
- Destruction of natural habitats and resources in the inter-tidal area.

Production decline of prawns and crabs could result in the following:

- Decrease in the maximum sustainable income for fishermen; and
- Destruction of the stable development of mariculture and related industries.

Figure 20. Satellite Pictures of the Development of Farming Lands in Hebei Province.



A. 1996

B. 1998

Benthos

Evidence of Decline

The seasonal pattern of the benthic community varied greatly from 1982 to 1992. In summer, the dominance of crustaceans in 1992 reached 83.7 percent, 45.9 percent higher than the same period in 1982 (37.8 percent); while the dominance of mollusks decreased from 58 percent in 1982 to 8.1 percent in 1992. The results of the retrospective analysis are shown in Table 15.

Table 16 shows the details of changes of species composition in the Bohai Sea benthic ecosystem. The dominant compositions were the same between 1982 and 1993 except during the summer season. The mollusk was dominant in the summer of 1982, while the crustacean was dominant in that of 1992.

Both mean number per haul and mean catch per haul of benthos decreased largely from 1982 to 1992. The mean catch in 1992 was 13.99 kg/net.hr, 38.9 percent less than in 1982, which was 22.91 kg/net.hr, while the mean number per haul was 1,428 ind./net.hr, just 53.2 percent of that in 1982 which was 2,683 ind./net.hr (Cheng and Guo, 1998).

Table 17 shows the changes in dominant species, with the probable same trend as the general species. The table shows an obvious replacement of dominant species between 1982 and 1993. In 1982, Loligo beka was the absolutely dominant species, followed by *Loligo japonica, Trachypenaues spp., Oratosquilla oratoria* and *Portunus trituberculatus.* In 1993, *Loligo beka* was still the first dominant species but *Oratosquilla oratoria* climbed to the second, and *Loligo japonica* became fifth in the dominant species list. Figure 21 shows the

Table 15. Retrospective Analysis for Benthos.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Benthos	Medium	The dominance of crustacean is 83.7 percent in 1992, 45.9 percent higher than 1982. The dominance of mollusk is 58 percent in 1982, 8.1 percent in 1992. Mean number of • *Loligo beka* per haul is 1032 in 1982, which declined to 877 in 1992. • *Loligo japonica* was 801 in 1982, which declined to 27 in 1992. • *Trachypenaues spp* was 298 in 1982, while only 77 in 1992. • *Portunus trituberculatus* was 59 in 1982, while 33 in 1992.	**Very likely:** 1. Overfishing 2. Destructive and illegal fishing 3. Physical disturbance 4. Sedimentation 5. Over-reclamation 6. Sand excavation 7. Heavy metal 8. Pesticides 9. Oil and grease 10. PAHs 11. Oil spills **Likely:** 1. DO **Possible:** 1. Oil exploitation 2. HABs 3. TSS/TOC	• Degradation of benthic ecosystem; • Lower the biodiversity and stability of the marine ecosystem; • Reducing the food support of fishery resources; and • Loss of fisherman's income.

distribution of benthos between 1982–1983 and 1992–1993 (Cheng and Guo, 1998), exhibiting a decline during all the seasons.

Attributed Causes

Human activities are the main reasons for the decline of the benthic biomass. First, overfishing and illegal fishing are identified as the most likely causes for the evident decline in benthic stock and recruitment. Since the 1980s, the number of fishing boats has doubled and illegal trawling nets have been used in some regions in Bohai Sea, which could cause very high fishing stress on the benthos and reduce the benthic biomass. Overfishing also resulted in the replacement of dominant species and decline of the high-value species. Hauling has destroyed benthic habitats, making them unsuitable for the benthic organisms' growth and reproduction in return.

Physical disturbances mainly come from excavating farming ponds, which would totally destroy the habitats for benthos. This situation has become more serious with the development of marine cultivation. The benthos biomass would be reduced by habitat disturbance, especially in the inter-tidal areas, the satellite photos (Figure 20) clearly shows the changes from natural habitats to the farming ponds.

Sedimentation could also influence the benthic biomass by habitat changes. The main cause of sedimentation was silt from rivers in Bohai Sea. As shown in Table 8, the freshwater run-off declined largely in recent years, which could affect the sedimentation dynamics. This will also result in habitat change, which could be unsuitable for benthos.

The pollution in sediment could be another possible agent for the decline of benthic biomass. As discussed in the Prospective Risk Assessment section, heavy metals and oil were over the criteria level in some areas. The pollution could have very serious adverse effects to the benthic growth and reproduction.

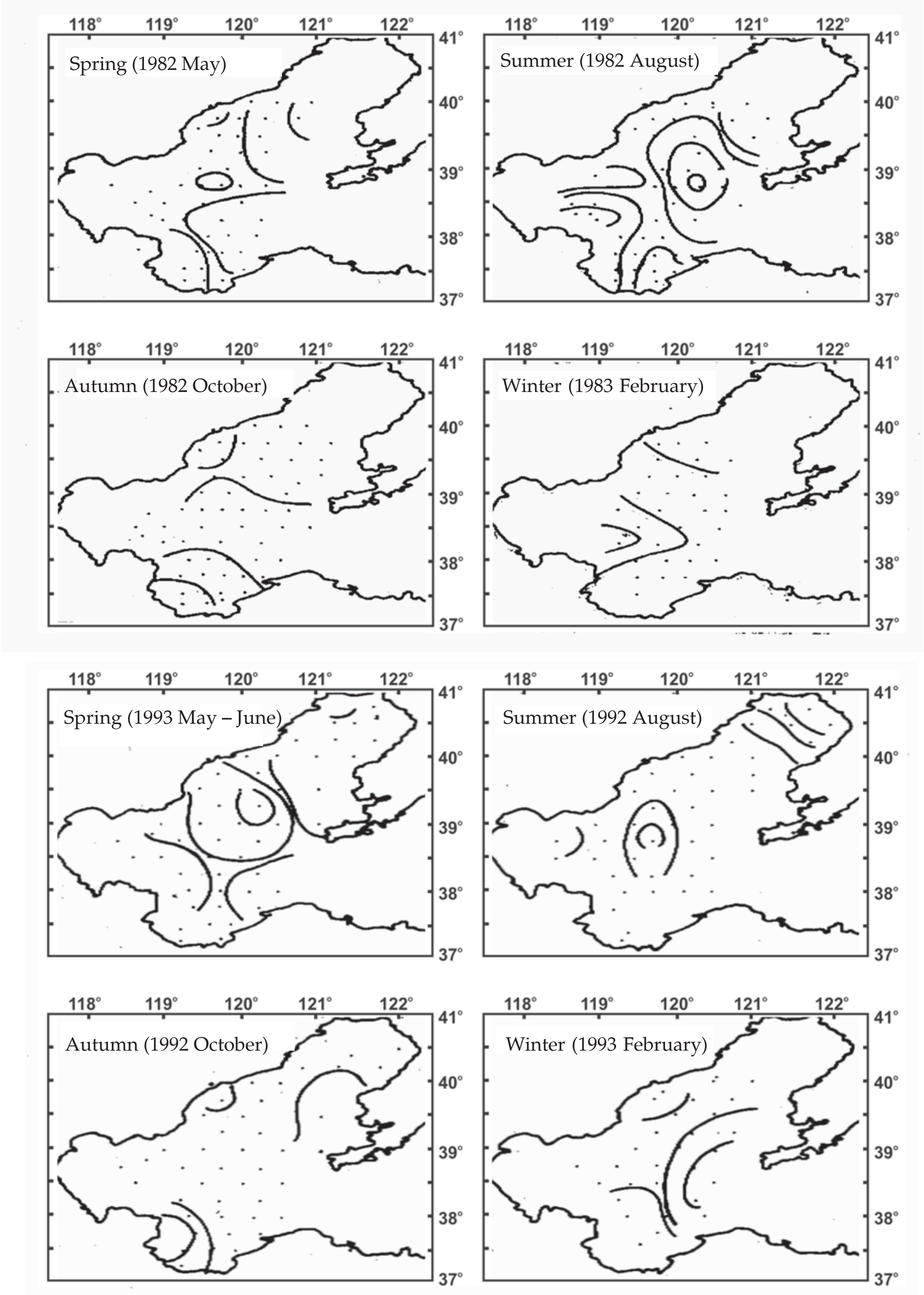
Table 16. Inter-decadal Change of Species Composition in the Bohai Sea Benthic Ecosystem (Based on Mean Catch per Haul).

Seasons	Survey time	Crustacean (%)	Mollusk (%)	Echinoderm (%)	Other (%)
Spring	May 1982	34.5	61.0	4.2	0.3
	May 1993	31.2	65.8	2.5	0.5
Summer	August 1982	37.8	58.0	4.0	0.2
	August 1992	83.7	8.1	8.1	0.1
Fall	October 1982	68.9	27.4	3.4	0.3
	October 1992	58.8	38.9	2.2	0.1
Winter	February 1983	46.3	10.1	42.9	0.7
	February 1993	13.0	3.6	76.8	7.3

Table 17. Decadal Change of Dominant Species in the Bohai Sea Benthic Ecosystem.

Dominant species	Mean number per haul (kg/net.hr)		Mean catch per haul (kg/net. hr)	
	1982–1983	1992–1993	1982–1983	1992–1993
Loligo beka	1,032	877	4.104	4.111
Loligo japonica	801	27	3.788	0.184
Trachypenaues spp.	298	77	0.993	0.336
Oratosquilla oratoria	129	180	2.407	3.979
Portunus trituberculatus	59	33	7.564	2.364

Figure 21. Distribution of Benthos by Trawling between 1982–1983 and 1992–1993 (kg/h).



Consequences

The decline of benthic biomass could have the following impacts:

- Degradation of benthic ecosystem and lower benthic biodiversity;
- Reduction of food support for fishery resources, and some benthos were fishery species themselves, like most mollusks;
- Decrease the sustainable income for fishers and the stable development of fisheries and related industries.

Phytoplankton

Marine phytoplankton is not only the primary producer of organic compounds and the major generator of chemical energy; it is also a fundamental level in the marine food chain. It provides food for fish, shellfish, shrimp, crab and other marine lifeforms. Phytoplankton performs many important roles in the nutrients recirculation in the marine ecosystem.

Evidence for Decline

The results of the retrospective analysis for phytoplankton are shown in Table 19.

Table 20 (Wang, 1998) shows the variation of phytoplanktons. There were 31 genera and 70 species of phytoplankton identified in Bohai Sea. Diatom is absolutely dominant with 27 genera and 63 species, followed by dinoflagellate (4 genera, 7 species). Compared with 1982, there was a big

Table 18. Detailed Risk Assessment for Benthos.

Benthos	Overfishing	Destructive and Illegal Fishing	Physical Disturbance	Sedimentation	Oil Exploitation	Over-Reclamation	Sand Excavation	DO	Heavy Metals	Pesticides	TSS/TOC	Oil and Grease	PAHs	HABs	Oil Spills
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y	ND	Y	Y	Y	Y	Y	ND	Y	Y	ND	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	Y	ND	Y	Y	N	Y	Y	M	Y	Y	?	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	Y	ND	Y	Y	ND	Y	Y	ND	Y	Y	ND	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4b. Will removal of the agent lead to amelioration?															
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y Y	Y Y	Y Y	Y Y	Y ND	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y	Y Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Likelihood	**VL**	**VL**	**VL**	**VL**	**P**	**VL**	**VL**	**L**	**VL**	**VL**	**P**	**VL**	**VL**	**P**	**VL**

Legend: Y – Yes, N – No, M – Maybe, ND – No Data, VL – Very Likely, L – Likely, P – Possibly reduction in phytoplankton abundance in 1992. The density of phytoplankton was only 99×104 cells/m^3 in 1992, which is only 35 percent that of 1982 (Figure 22). The density of phytoplankton was relatively higher in Laizhou Bay than the other bays. For the whole Bohai Sea, the first most dominant species of phytoplankton in 1982 was the *Chaetoceros spp*. However, this species decreased in 1992 and tied with *Coscinodiscus spp.* for the most dominant species. The distribution of phytoplankton in 1982 and 1992 is shown in Figure 23 and Figure 24, which clearly describes the phytoplankton biomass decline in the whole Bohai Sea.

Figure 22. Phytoplankton Abundance in Bohai Sea (×10^4 cell/m^3).

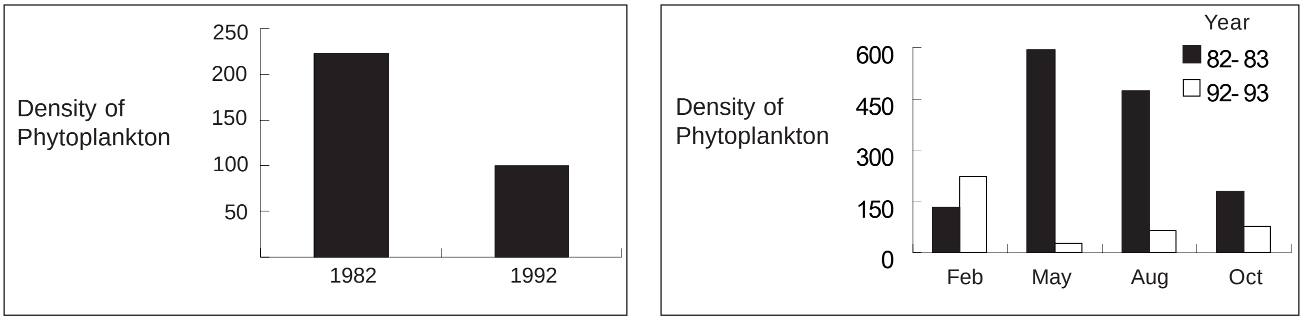


Table 19. Retrospective Analysis for Phytoplankton.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	**Identified Agents**	
Phytoplankton	Large (all the Bohai Sea)	The density of phytoplankton in 1992 is only 35 percent of 1982. Dominant species changed from *Chaetoceros spp*. in 1982 to *Coscinodiscus spp.* in 1992.	**Very Likely:** 1. Shellfish culture 2. Heavy metals 3. Pesticides, 4. Oil spills 5. Zooplankton **Likely:** 1. TSS/TOC **Possibly:** 1. Oil and grease, 2. PAHs	Reduce the food supply for shellfish and other living organisms Decline the shellfisheries resource Loss of income for fishers

Table 20. Decadal Change in Phytoplankton and Its Dominant Species (×10^4 cell/m^3).

Species	Year	Whole Bohai Sea	Laizhou Bay	Bohai Bay	Liaodong Bay	Central Waters
Phytoplankton	1992–1993	99	321	20	44	51
	1982–1983	222	693	39	100	109
Coscinodiscus spp.	1992–1993	9	27	3	5	5
	1982–1983	20	56	16	5	7
Chaetoceros spp.	1992–1993	8	29	0.2	7	4
	1982–1983	90	378	2	10	6

Figure 23. Distribution of Phytoplankton from 1982–1983 (x10^4 cell/m^3).

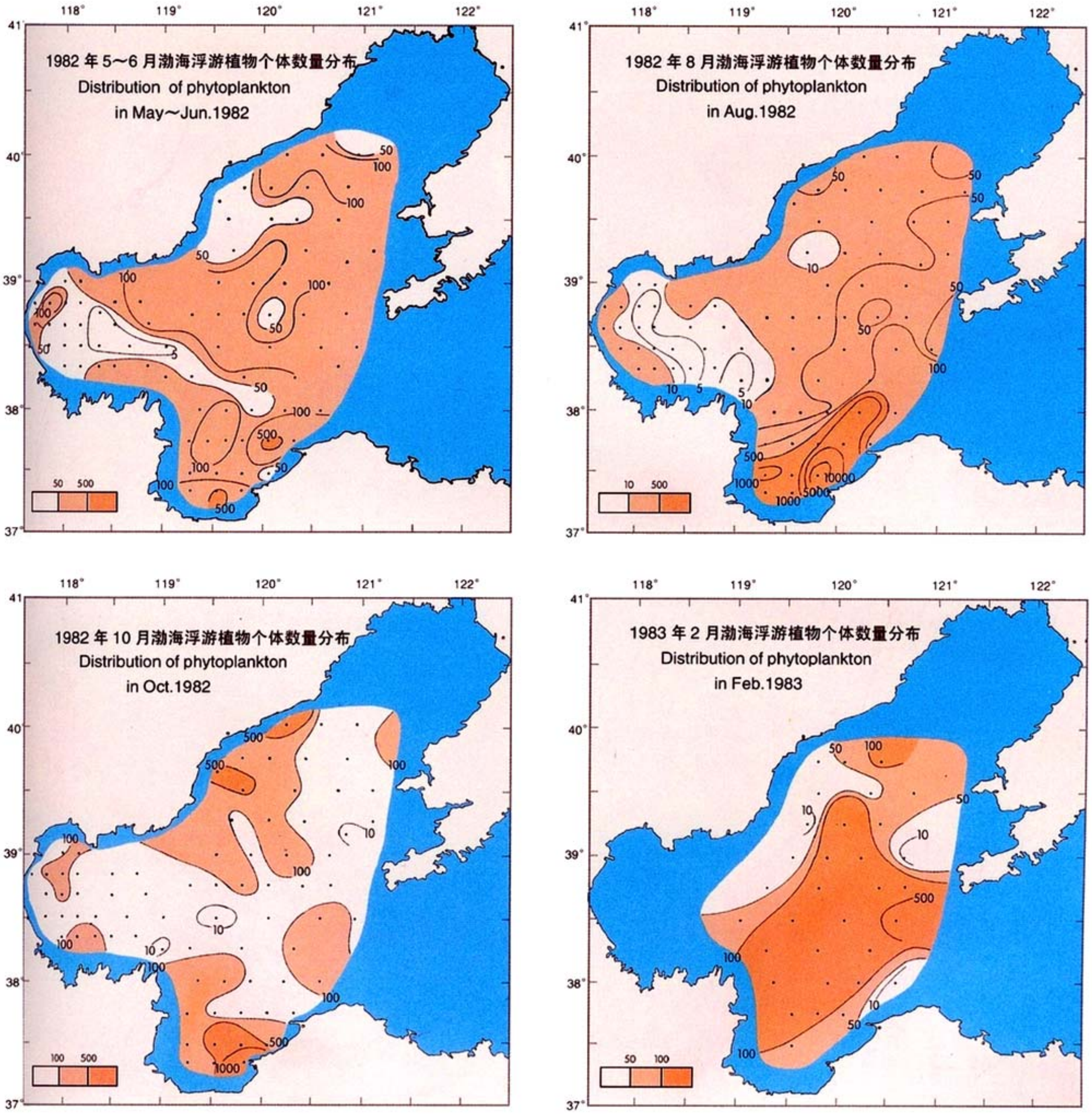
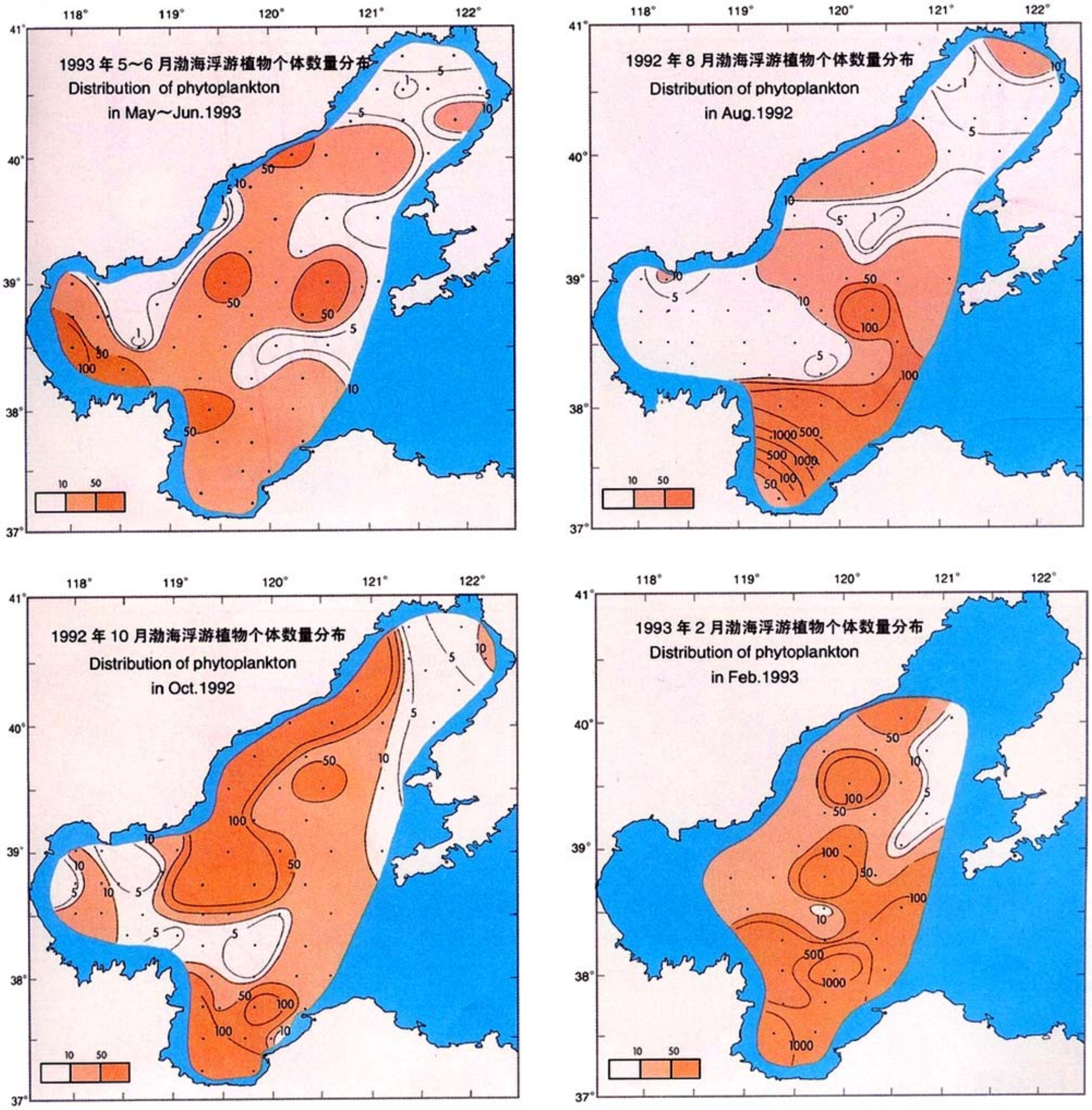


Figure 24. Distribution of Phytoplankton from 1992–1993 (x10^4 cell/m^3).



1993 年 5～6 月渤海浮游植物个体数量分布
Distribution of phytoplankton
in May～Jun.1993

1992 年 8 月渤海浮游植物个体数量分布
Distribution of phytoplankton
in Aug.1992

1992 年 10 月渤海浮游植物个体数量分布
Distribution of phytoplankton
in Oct.1992

1993 年 2 月渤海浮游植物个体数量分布
Distribution of phytoplankton
in Feb.1993

The variation of chlorophyll-a and primary productivity reflects the biomass of phytoplankton. Table 21 shows the chlorophyll-a and primary productivity of Bohai Sea between 1982 and 1992. These figures evidently show a decline in phytoplankton. The average chlorophyll-a was 0.98 mg/m^3 in 1982 and only 0.61 mg/m^3 in 1992, showing around 38 percent decrease (Li, 1999). The primary productivity was 312 mg C/(m^2.d) in 1982 and 216 mg C/(m^2.d) in 1992, which shows a 31 percent decrease.

Attributed Causes

Rapid development of marine cultivation in Bohai Sea, especially for shellfish, was the key reason for the decline of the phytoplankton biomass. Most of the farmed shellfish were filter-feeding animals, and the phytoplankton was their main food. As analyzed in maricultured species, shellfish farming developed quite fast since 1990, especially scallops and oysters. They could filter huge numbers of phytoplankton.

Environmental pollution was considered as a possible reason for the decline of phytoplankton biomass. The environment was polluted largely as a result of rapid economic development activities, and those pollutants (such as heavy metals and pesticides) could make the seawater unsuitable for reproduction of phytoplankton.

Table 21. Changes of Chl-a and Primary Productivity (1982-1992).

	Year	August	October	February	June	Mean
Chl-a (mg/m^3)	1982-1983	1.15	1.05	1.1	0.64	0.98
	1992-1993	0.67	0.58	0.73	0.44	0.61
Primary productivity mg C/(m^2.d)	1982-1983	537	297	207	208	312
	1992-1993	419	154	127	162	216

Table 22. Detailed Risk Assessment for Phytoplankton.

Phytoplankton	*Shellfish Culture*	*Heavy Metals*	*Pesticides*	*TSS/TOC*	*Oil and Grease*	*PAHs*	*Oil Spills*	*Zooplankton*
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y	ND	ND	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	ND	ND	ND	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	Y	Y	Y	Y	Y	Y
4b. Will removal of the agent lead to amelioration?	Y	Y	Y	Y	Y	Y	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	Y	ND	Y	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y	Y	Y
Likelihood	VL	VL	VL	L	P	P	VL	VL

Legend: Y – Yes, ND – No Data, VL – Very Likely, L – Likely, P – Possibly

Consequences

Decline of phytoplankton will provide less supply of food for shellfish and other marine organisms heavily impacting on the fishery resources. The catch of shellfish may decrease and lead to a decrease in the income of fishers.

Zooplankton

Zooplankton occupies a key position in the marine food chain. It not only supplies energy to upper trophic level (e.g., fish) but also controls lower trophic level (e.g., phytoplankton).

Evidence of Decline

The results of the retrospective analysis for zooplankton in Bohai Sea are shown in Table 23. There were 47 species of zooplankton recorded in Bohai Sea in 1992–1993, among which were 17 species of copepod, and 14 of hydromedusa. *Calanus sinicus, Sagita crassa* and *Labidocera euchaeta* were the dominant species. Compared with 1982, the biomass of zooplankton in 1992 declined about 30 percent from 98.0 mg/m^3 to 62.3 mg/m^3 (Table 24).

Figure 25 and 26 show the distribution of zooplankton biomass in 1982 and 1992 respectively. There was an obvious decline in the zooplankton biomass compared to the distributions between 1982 and 1992.

Attributed Causes

The biomass of zooplankton in Bohai Sea decreased by 35.7 mg/m^3 from 1982–1983 to 1992–1993. One possible reason is the decrease of phytoplankton in the same period as mentioned before. The phytoplankton provides food for zooplankton, therefore the decline of phytoplankton could cause the decline in zooplankton biomass.

Table 23. Retrospective Analysis for Zooplankton.

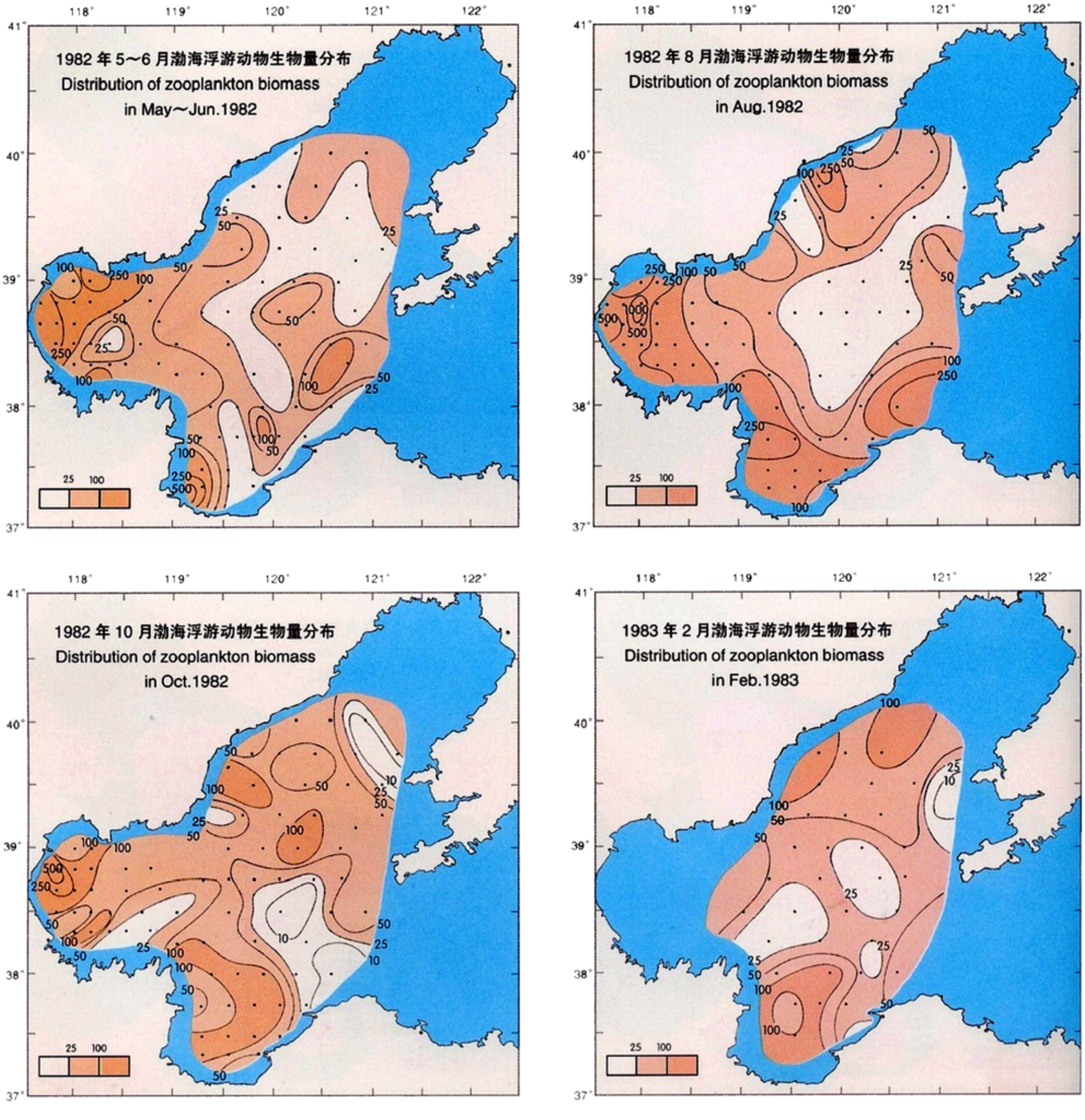
Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Zooplankton	Large (all the Bohai Sea)	The biomass of zooplankton decreased from 98.0 mg/m^3 to 62.3 mg/m^3 from 1982 to 1992, and increased to 341.9 mg/m^3 from 1992 to 1998.	**Very Likely:** 1. Shellfish culture 2. DO 3. Heavy metals 4. Pesticides **Possibly:** 1. Harmful algal bloom 2. TSS/TOC 3. Oil and grease 4. PAHs 5. Oil spills	1. Increase the possibility of HABs; 2. Less food supply to fish and shellfish; 3. Less fisheries production; and 4. Loss of income for fishermen.

Table 24. Decadal Change in Zooplankton Biomass (mg/m^3) in Bohai Sea.

Year/Month	May-Jun	August	October	Average
1982–1983	88.6	125.9	79.4	98.0
1992–1993	72.8	57.9	56.7	62.3

Source: Living Community and Environment in Coastal Bohai Sea, 2001.

Figure 25. Distribution of Zooplankton Biomass from 1982–1983.



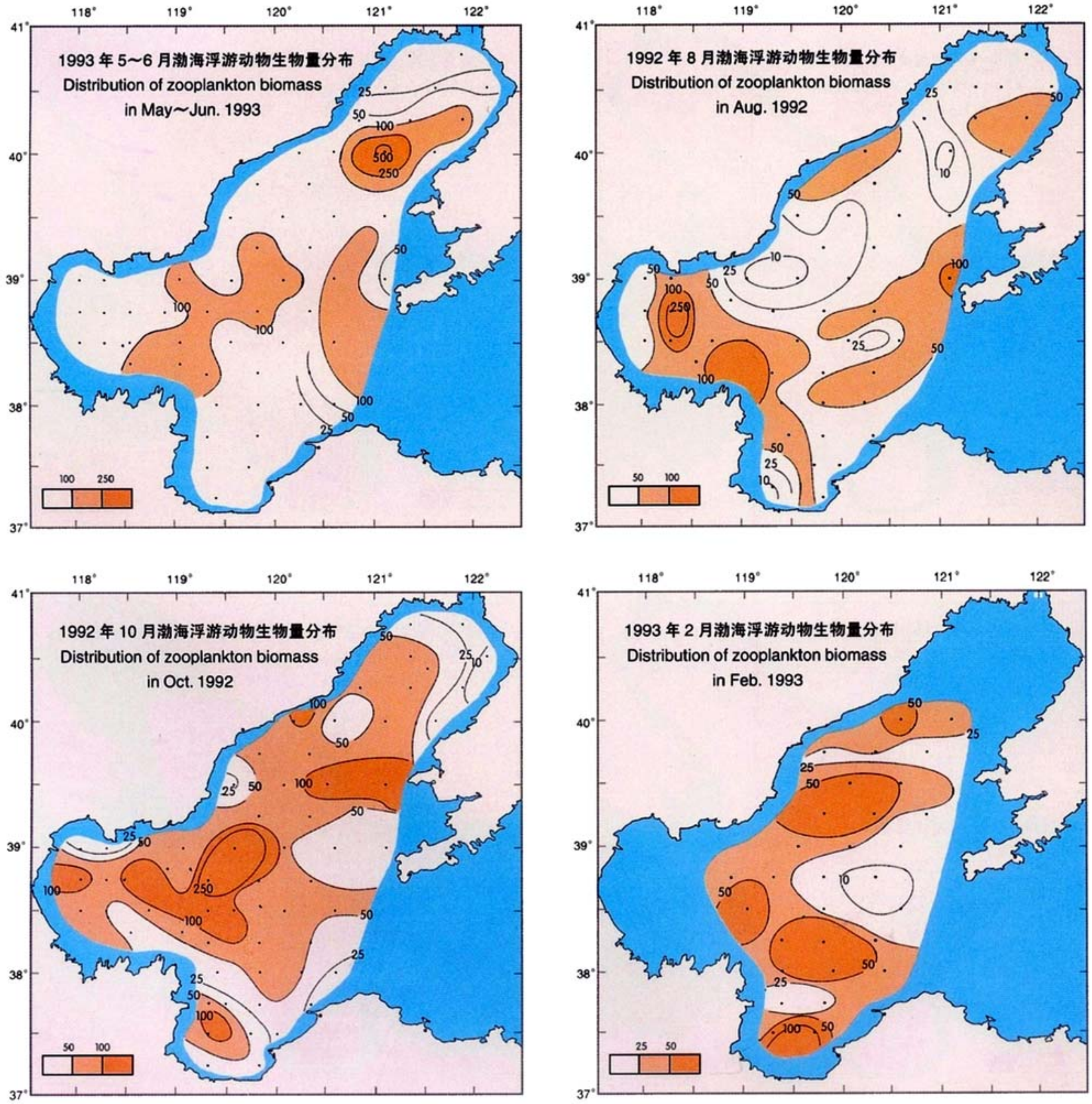
1982 年 5～6 月渤海浮游动物生物量分布
Distribution of zooplankton biomass
in May～Jun.1982

1982 年 8 月渤海浮游动物生物量分布
Distribution of zooplankton biomass
in Aug.1982

1982 年 10 月渤海浮游动物生物量分布
Distribution of zooplankton biomass
in Oct.1982

1983 年 2 月渤海浮游动物生物量分布
Distribution of zooplankton biomass
in Feb.1983

Figure 26. Distribution of Zooplankton Biomass from 1992–1993.



Another possible reason is the fast development of shellfish culture. Shellfish not only grazes zooplankton but also competes with it for food.

Environmental pollution also affects the zooplankton biomass. Pollutants, such as heavy metals, oil, pesticides and HABs, adversely impact on the zooplankton biomass in Bohai Sea.

Consequences

The decline in zooplankton will lighten the grazing pressure to phytoplankton but the probability of occurrence of HABs will increase. The decline in zooplankton results in less food supply for fish and shellfish and other living organisms. Consequently, the catch of fish and shellfish may decrease, affecting the income of fishers.

HABITATS

Wetlands

There are two big wetlands located around Bohai Sea, i.e., Yellow River Delta Wetland and Liaohe River Delta Wetland. The total area of these wetlands is 648,284 ha (1997), in which Liaohe River Delta Wetland accounts for 314,857 ha (including 159,919 ha of natural wetlands and 154,838 ha of artificial wetlands), and Yellow River Delta Wetland accounts for 333,427 ha (including 229,329 ha of natural wetlands and 104,098 ha of artificial wetlands).

There are 150 species of birds in the WBSA, in which 97 species of waterfowls were found in wetlands around Bohai Sea. Because of the long-term, high-intensity exploitation, the two wetlands have been greatly damaged and degraded.

Table 25. Detailed Risk Assessment for Zooplankton.

Zooplankton	**DO**	**Shellfish Culture**	**HABs**	**Heavy Metals**	**Pesticides**	**TSS/TOC**	**Oils and Grease**	**PAHs**	**Oil Spills**
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	ND	Y	Y	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	ND	Y	Y	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	?	Y	Y	?	?	?	?
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	ND	Y	Y	ND	ND	ND	ND
4b. Will removal of the agent lead to amelioration?	Y	Y	Y	Y	Y	Y	Y	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	?	Y	Y	Y	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y	Y	Y	Y
Likelihood	VL	VL	P	VL	VL	P	P	P	P

Legend: Y – Yes, ND – No Data, ? – Don't Know, VL – Very Likely, P – Possibly

Evidence of Decline

The retrospective analysis for wetlands is shown in Table 26. Changes in wetland area and landscape structure will be analyzed to show the decline in wetlands.

Area of Wetlands

Yellow River Delta Wetland has been expanding because of the long-term sedimentation of mud and sand from Yellow River. On average, Yellow River brings 10.5x10^8 tons of silt down to the delta every year. Some scientists estimated that the coastline of this delta area moves forward to Bohai Sea about 0.16 km/yr, especially in the estuary, the coastline moves forward very fast, averaging 1.8 km/yr. The newly-formed wetland grows about 21.3 km^2 annually. Around 2,535 km^2 of land have been formed from 1855 to 1984. But the area of the Yellow River Delta declined in recent years since the large decline of Yellow River freshwater run-off (Table 10).

Table 27 shows that from 1981 to 1998, the natural wetlands declined about 73,375 ha because of reclamation activities for reservoirs, ponds, salt fields and paddy fields. The area of reed fields decreased to 19,103 ha in 1998, which is only 40.1 percent of the area in 1981 while tidelands greatly

Table 26. Retrospective Analysis for Wetlands.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Wetlands	Small	**Yellow River Delta:** 1. 2,535 km^2 of land was formed from 1855 until 1984. 2. 73,375 ha natural wetland declined from 1981-1998. 3. 40.1 percent reed field was left from 1981 to 1998. 4. Tideland decreased from 69,224 ha to 24,382 ha from 1981 to 1998. 5. Artificial wetland increased 50,600.5 ha. **Liaohe Delta Wetland:** Area decreased from 366,000 ha in 1984 to 314,857 ha in 1998.	**Very likely:** 1. Oil exploitation 2. Over-reclamation 3. Physical removal/ clearance 4. Sedimentation 5. Freshwater run-off 6. Dam building 7. Seawater intrusion 8. Sand excavation	• Weakening the function of the wetland ecosystem • Less food supply for other living organisms • Less security for living organisms • Decreased biodiversity • Low aesthetic function • Less ability to treat waste discharge • Loss of tourism and other related industries

Table 27. Changes in Wetland Area of the Yellow River Delta (ha).

Types of Wetlands		1981	1990	1998
Natural Wetlands	Reed field	47,636	25,409	19,103
	Tideland	69,224	32,721	24,382
Artificial Wetlands	Paddy field	80,000.4	86,068	101,914
	Salt field	335.2	2,627.5	3,721
	Reservoir	1,954.1	12,831.6	14,410
	Pond	3,000	12,945.7	18,846

Source: Liu Honhyu, 2001.

Figure 27. The Satellite Picture of Yellow River Delta in 1996 and in 2001.

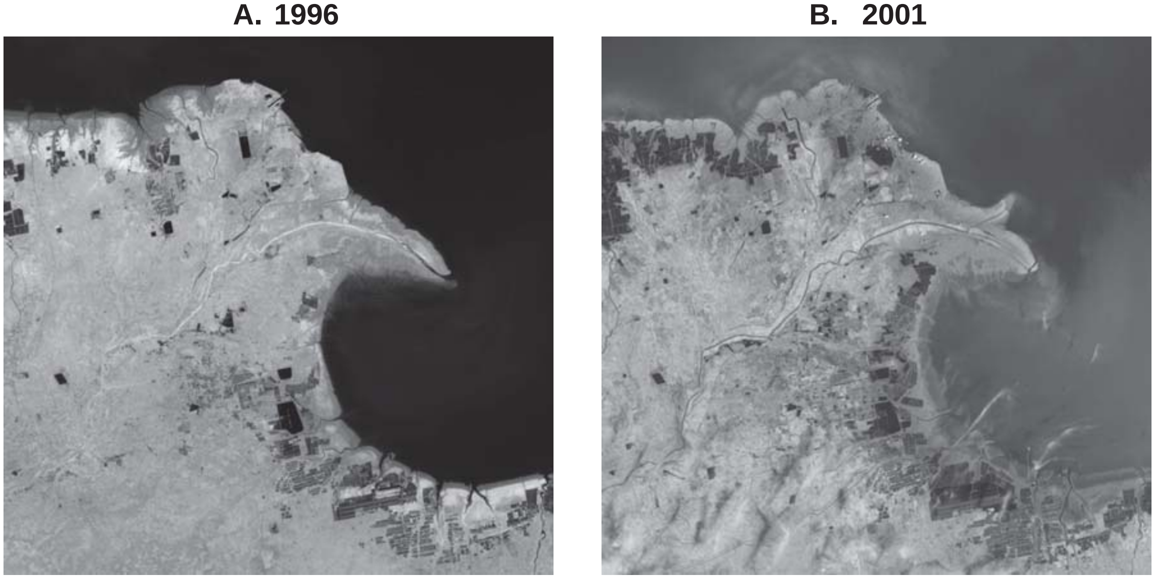


Figure 28. The Oil Drill of Shengli Oil Field in the Yellow River Delta.

decreased from 69,224 ha in 1981 to 24,382 ha in 1998. The area of artificial wetlands has increased to 50,600.5 ha. Figure 27 shows the satellite images of Yellow River Delta in 1996 and 2001 and the changes in wetland areas because of sedimentation.

For the Liaohe Delta Wetland, the area of wetland decreased from 366,000 ha in 1984 to 314,857 ha in 1998 (about 14 percent of loss), in which 31,850 ha was for exploiting oil and 13,334 ha for planting. Moreover, the natural wetlands have decreased gradually while the artificial wetlands have been increasing since the 1980s.

Landscape Structure

There are many types of landscapes in the delta wetlands. They are important habitats for many kinds of wildlife. The fragmentation of wetlands, however, is becoming more serious. Three kinds of indexes, i.e., diversity index of landscape, dominance of landscape and index of human interference, are used to measure the structure of landscape of the Liaohe River Delta Wetland (Table 28). The diversity index of landscape in Liaohe River estuary was the largest among three sampling regions; so was its dominance of landscape. The landscape of the dry land had the lowest diversity index and dominance index, and the highest index of human interference.

Attributed Causes

Both natural and human factors lead to the changes of wetlands. For the Yellow River Delta Wetland, the coastline has been expanding due to the flow of sand at 10.5×108 ton/year into Bohai Sea, around two-thirds (2/3) of which settle in the coastal area of this delta. In the middle of the wetland, its natural wetland has been fragmented, which could be attributed to the high density oil exploitation and reclamation for ponds, paddy fields, salt fields and a reservoir. Shengli Oil Field has been exploiting oil for about 50 years and extending their oil extraction activities to the shallow waters around Yellow River Delta. Figure 28 shows the oil drill located in the Yellow River Delta field.

In Liaohe River Delta, human activities are the main causes of changes. Oil exploitation is the most important reason. From 1990 to 1995, 31,850 ha natural wetlands were converted to oil fields. Reclamation is the second cause of natural wetland decline. Paddy fields increased from 69,624 ha in 1980 to 118,783 ha in 1998,

Table 28. Indexes of the Landscape in Some Regions of Liaohe River Delta Wetland.

Sampling Region	Diversity Index of Landscape	Dominance of Landscape	Index of Human Interference
Estuary	2.36	6.22	2
Paddy Field	1.20	4.01	9
Dry Land	0.68	3.49	12

Source: Liu Zhenqian, 2000.

Table 29. Detailed Risk Assessment for Wetlands.

Wetlands	Physical Removal/ Clearance	Sedimentation	Freshwater Run-off	Oil Exploitation	Over-Reclamation	Dam Building	Seawater Intrusion	Sand Excavation
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	Y	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	Y	Y	Y	Y	Y	Y
4b. Will removal of the agent lead to amelioration?	Y	Y	Y	Y	Y	Y	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	Y	Y	Y	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y	Y	Y
Likelihood	VL	VL	VL	VL	VL	VL	VL	VL

Legend: Y – Yes, VL – Very Likely

most of which are from reed fields and marshlands. It is estimated that natural reed wetlands have decreased to only 24,000 ha in 2002. About 60.3 percent of reed wetlands have been lost in the past 15 years. The development of aquaculture also destroyed natural wetlands. From 1985 to 1994, the area of aquaculture increased from 15,995 ha to 36,760 ha (Liu Honhyu, 2001).

Human activities severely affected the structure of wetland landscapes. Table 28 shows that the dry land region was the most seriously interfered because it is easier for humans to access dry land than the other regions.

Possible Consequences

The service function of damaged wetland ecosystems will decline and provide less food to support other living organisms. Fragmented wetlands provide vulnerable and unsafe habitats and/or refuge for waterfowls and other species (local and alien). Birds such as the red-crowned crane, white crane and so on, often wintering in the wetlands around Bohai Sea may be exposed to predators. The degradation of wetlands decreased its biodiversity and aesthetic functions for human entertainment. The damaged wetland ecosystem decreased its ability to treat waste discharges.

Table 30. Retrospective Analysis for Beaches.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Beaches	Small	No Data	**Possible:** 1. Physical removal/clearance 2. Dam building 3. Tourist trampling 4. Seawater intrusion 5. Underground water extraction 6. Sand excavation.	• Local species loss • Damaged natural landscape • Low aesthetic and recreational value • Loss from tourism

Table 31. Detailed Risk Assessment for Beaches.

Beaches	Physical Removal/ Clearance	Dam Building	Tourist Trampling	Underground Water Extraction	Seawater Intrusion	Sand Excavation
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	ND	ND	ND	ND	ND	ND
2b. Was there any loss/es correlated through space?	ND	ND	ND	ND	ND	ND
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	Y	Y	Y	Y
4b. Will removal of the agent lead to amelioration?	Y	Y	Y	Y	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	Y	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y
Likelihood	**P**	**P**	**P**	**P**	**P**	**P**

Legend: Y – Yes, ND – No Data, P – Possibly

Beaches

Evidence of Decline

The results of the retrospective analysis for beaches around the Bohai Sea are shown in Table 30.

The total area of beaches in Bohai Sea is 68.04 ha. The beaches are mainly located in the Liaohe River Delta and Yellow River Delta. Intertidal zones, swamps and riverside beaches accounted for 75.1 percent, 17.5 percent and 7.4 percent respectively in 1993 (He, 2002).

Attributed Causes

While there may be no concrete data to confirm the decline of beach areas, there are observations that beach areas have actually been lost due to construction of tourism facilities, ports, dams and other infrastructures.

Possible Consequences

The loss and/or damage of beaches could cause the shift and loss of local benthos species that live in sands. The natural landscape would also be adversely damaged and would further impact on the aesthetic value.

Coasts

Coastal changes in the Bohai Sea should be a special concern since coastal erosion is a regular occurrence and the intrusion of seawater has become serious especially around Laizhou Bay and Tianjing municipality.

Evidence of Decline

The results of the retrospective analysis for the coasts of Bohai Sea are shown in Table 32.

Table 32. Retrospective Analysis for Coasts.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Coasts	Small	• 75 percent of the coast has eroded. • 8.5 percent has more than 10 m/yr erosion rate. • 400 km^2 coast had been lost from 1949 to 1990.	**Very Likely:** 1. Windstorm; 2. Sand excavation; 3. Decrease in underground water; 4. Physical removal/ clearance; and 5. Dam building. **Possible:** 1. Tourist trampling; and 2. Seawater surface level.	• Damaging function of the coastal ecosystem; • Destroying coastal industrial/ aquacultural facilities; • Loss of local species; • Damaging natural landscape; • Causing groundwater salty; • Loss of land; • Loss of coastal industries; and • Human illnesses.

Table 33. Erosion Rate of Coasts along Bohai Sea.

Erosion Rate	More than 10 m/yr	5–10 m/yr	3–5 m/yr	1–3 m/yr	Less than 1 m/yr
Eroded Area	8.5 %	5.4 %	23 %	20 %	43.1 %

Source: Li Fengling, 1994.

Based on statistical data, 75 percent of the Bohai Sea coasts have eroded (Table 33). About 8.5 percent of the coasts have an erosion rate of more than 10 m/yr, and 5.4 percent have an erosion rate of 5–10 m/yr. It was estimated that about 400 km^2 of coasts have eroded from 1949 to the 1990s (Li Fenglin, 1994).

The coastal region along Laizhou Bay is the most severely intruded area around Bohai Sea. This region intruded by seawater reached 343.6 km^2 in 1991. The intrusion rate of seawater greatly increased, from 46 m/yr in 1976 to 404.5 m/yr in 1987, which increased 7.78 times (Table 34). The total intruded area amounted to 238.2 km^2 from 1976 to 1989, which is 80 percent of the total coastal plains of Laizhou Bay.

Attributed Causes

Human activities are the major reasons for coastal erosion, specifically the building of reservoirs in the upriver area and sand excavation in the coastal area. From 1950 to 1988, around 8,626 reservoirs were built in the upriver of all the rivers that flow into Bohai Sea and their total capacity reached 933 million m^3. This led to a great decline of water and sand flowing into Bohai Sea (Table 35). The influx of water and sand into Bohai Sea were 1,389 billion m^3 and 14 billion m^3 respectively

Figure 29. Coastal Erosion in the Bohai Sea.

Table 34. Changes in the Seawater Intruded Area and the Intrusion Rate of the Coast around Laizhou Bay (1976–1989).

	1976–1979	1980–1982	1983–1984	1984–1987	1987–1988	1988–1989
Intruded area	15.8 km^2	23.4 km^2	31.9 km^2	98.5 km^2	32.36 km^2	36.24 km^2
Intrusion rate	46 m/yr	92 m/yr	177 m/yr	345 m/yr	404.5 m/yr	

Source: Ji Zixiu, 1996.

Table 35. Flux of Water and Sand into Bohai Sea (100 million m^3).

	1950–1964	1965–1979
Volume of Water	13,889.90	9,158.70
Volume of Sand	139.77	108.96

Source: Li Fenglin, 1994.

from 1950 to 1964, while they decreased to 915.9 billion m^3 and 10.9 billion m^3 in from 1965 to 1979. The sharp decline of riverine sand and water destroyed the dynamic balance of coasts, particularly in the estuaries where the intrusion of seawater had become stronger.

In Jinzhou and Penglai coasts, coastal erosion is mainly attributed to illegal and over-excavation of sand. The changes in the current fields due to the dam building is also one of the main causes of coastal erosion in the specific coast. The natural causes of coastal erosion include strong windstorms and sea level rise due to climate change.

Consequences

Coastal erosion destroys the stability of coastal ecosystem and industrial/aquacultural facilities, such as oil platforms, shrimp/crab ponds, farmlands and roads, which causes economic loss. In some coasts, the natural landscapes, such as in swimming beaches, are destroyed.

Coastal erosion makes the coastal regions' groundwater salty and the coastal land unsuitable for plant, animal and human life. Therefore, it has resulted in the low yield of crops. The total output of crops around Laizhou Bay was 5,200 billion kg in 1979, and has decreased to 3,650 billion kg in 1987. In Laizhou City, around Laizhou Bay, more than 445,000 people have been facing a shortage of freshwater.

Groundwater mixed with seawater has plenty of chlorine ions, which may rust the metal equipments used in agricultural/industrial activities and lead to huge economic losses. It was estimated that about RMB 150 million (US$18 million) of industrial production value per year have been lost from 1977 to 1987 in Laizhou City.

Seawater intrusion also makes groundwater unsuitable for drinking for both humans and animals. About 15,600 people around Laizhou Bay area became ill because they drank salty water for extended periods due to freshwater shortage (Hu and Zang, 1992).

Table 36. Detailed Risk Assessment for Coasts.

Coasts	*Physical Removal/ Clearance*	*Dam Building*	*Tourist Trampling*	*Decrease in Underground Water*	*Seawater Surface Level*	*Sand Excavation*	*Windstorm*
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	ND	Y	ND	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	ND	Y	ND	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	Y	Y	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	Y	Y	Y	Y	Y	Y	Y
4b. Will removal of the agent lead to amelioration?	Y	Y	Y	Y	Y	Y	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	Y	Y	Y	Y	Y	Y	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y	Y
Likelihood	VL	VL	P	VL	P	VL	VL

Legend: Y – Yes, ND – No Data, VL – Very Likely, P – Possibly

Prospective Risk Assessment

INTRODUCTION

For the prospective risk assessment, the Risk Quotient (RQ) approach was adopted. The approach starts by using worst-case and average scenarios and progresses if the results show the need for a more refined assessment and more sophisticated ways of assessing and addressing the uncertainties associated with the RQ technique. The RQ technique can be applied to the prospective risk assessment in order to determine if measured or predicted levels of environmental parameters in Bohai Sea are likely to cause harm to environmental/human targets. It is accomplished by identifying the likely targets and comparing their measured or predicted environmental concentrations (MECs or PECs) with appropriate threshold values or predicted no-effects concentrations (PNECs) to obtain the RQs. For human health, risk in seafood ingestion is estimated by comparing the measured or predicted environment levels (MELs or PELs) with the Level of Concern (LOC), which in this case will be the tolerable daily intake (TDI) divided by the consumption rate (CR).

METHODOLOGY

For the ecological risk assessment, RQs are the ratios of MECs (or PECs) and PNECs.

$$RQ = \frac{MEC\ (or\ PEC)}{PNEC}$$

However, for human health, since almost all the toxicants have accumulative actions and accumulation of toxicant is dependent on seafood consumption, risk to human health cannot be assessed only by dividing MEC with a PNEC that is based on set tolerances or guidelines for contaminants in food. RQs are the ratios of MELs (or PELs) and LOCs. LOCs are obtained by dividing the TDIs of specific contaminants in food by the daily CR.

$$RQ = \frac{MEL\ (or\ PEL)}{LOC}$$

When the RQ is less than 1, it is presumed that the likelihood of adverse effects is low. When the RQ is greater than 1, there is a likelihood of adverse effects, the magnitude of which increases with the increase in RQ.

RQs in this environmental risk assessment are expressed as RQ_{Ave} and RQ_{Max}. The RQ_{Ave} is obtained by dividing the arithmetic mean of MECs with the PNEC. For human health, the quotient is obtained by dividing the MEC with the LOC. Though the geometric mean of environmental data would usually exhibit a less biased estimate than the average one, the geometric data cannot be obtained since the original data of the environmental parameters for each data point are not available. The data are all exhibited in average form as the Chinese scientific data are always in. Available data are mostly in average and maximum forms without the specific sampling points. RQ_{Max} gives an estimate of the worst or highest RQ based on a set of available data by selecting the highest MEC and dividing it by the PNEC or LOC.

DESCRIPTION OF DATA

In the refined risk assessment (RRA), the data used in the initial risk assessment (IRA) were verified and updated. The quality of data used in the retrospective and prospective risk assessments was assessed through a scoring system to reduce the uncertainties. The scoring system was based on the documentation of procedures and adoption of QA/QC procedures in sampling and laboratory analysis and was the same as that adopted by the ASEAN-Canada Cooperative Programme on Marine Science (ACCPMS) – Environmental Criteria Component. Data quality score is from 1 to 3, where 1 denotes data with well-documented QA/QC procedures adopted in the sample collection and analysis. A score of 2 denotes data generated where procedures employed are generally satisfactory although some information, such as the exact location of sampling stations and analytical methods are not confirmed. A score of 3 denotes data generated where procedures are poorly documented or where the values are cited without proper documentation or explanation. The data source and quality is listed in Table 1.

The primary sources of information for the prospective risk assessment were the Report of Bohai Sea Coastal Resource Conservation and Environmental Management Project (Agriculture Department and ADB, 2000). Other references that were used include Monitoring Report for Land-based Pollution and its Effects on the Coastal Waters and Resources in China. A detailed list of the sources and values for each parameter is given in Table 37.

For the ecological risk assessment, the RQ-based prospective risk assessment technique was considered adequate in determining risks posed by contaminants in the water column and sediment. In the RRA, the 12 parameters discussed include: 1. Nutrients; 2. DO/COD; 3. Coliform; 4. TSS; 5. Heavy Metals; 6. Pesticides; 7. Oil; 8. PAHs; 9. Oil spills; 10. HABs; 11. Sea Ice; and 12. Windstorms.

Table 37. Water Quality Criteria.

Agent (mg/l)	Chinese Standards for Seawater Quality (National Standards of PR China, 1995) Class II	ASEAN Marine Water Quality Criteria (ASEAN, 2003)	U.S. EPA Quality Criteria for Seawater for Regulatory Purposes (U.S. EPA, 2000)	
			Marine acute criteria	Marine chronic criteria
Nitrate		0.06		
DIN	0.30			
DIP	0.030	0.015 – 0.045 (coastal-estuaries)		
DO	> 5	4		
COD	3			
Fecal coliform (ind/L)	2,000			
TSS	Man-caused increment = 10	50 (Malaysia)		
Copper (Cu)	0.01	0.008	0.0029	0.0029
Mercury (Hg)	0.0002	0.00016	0.0021	0.000025
Lead (Pb)	0.005	0.0085	0.14	0.0056
Cadmium (Cd)	0.005	0.01	0.043	0.0093
DDT	0.0001		0.13	0.000001
666	0.002			
Oil/grease	0.05	0.14 (Water soluble fraction)	0.09	0.004
PAHs			300	

The application of the threshold values or PNECs is based on the following scheme — the local criteria values, i.e., Sea Water Quality Standard of China (GB-3097-1997), are initially applied. In the absence of local criteria values, the ASEAN Marine Water Quality Criteria (ASEAN, 2003) is then applied. Finally, the criteria value from other jurisdictions, e.g., United States, is applied. The standards/criteria are listed in Table 37.

There are four classes in the seawater standard of China. Class 1 waters are those zoned for fisheries and protected areas for some endangered species. Class 2 is for recreational purposes with direct skin contact, for aquaculture and bathing beaches and for water areas of industrial purposes. Class 3 is for industrial waters and class 4 for ports. In this report, Class 2 is considered to be appropriate and applied. The parameter DIN refers to Dissolved Inorganic Nitrogen, that is, the sum of nitrate, nitrite and ammonia.

The Chinese seawater quality standard for marine sediments was also adopted (Table 38). The sediment quality is divided into three classes. Class 1 waters are those zoned for fisheries, protected areas for some endangered species, for recreational purposes with direct skin contact, for aquaculture, bathing beaches, and water areas for industrial purposes. Class 2 is for common industrial waters while Class 3 is for ports. Class 2 was adopted for the prospective risk assessment. Table 39 shows the PNECs applied for each of the parameters under consideration.

Table 38. Marine Sediment Qualities of P.R. China (Class 1, GB 18668-2002)

Agent	Sediment Quality Standard (mg/kg dry weight)
Hg	0.20
Cu	35.00
Pb	60.00
Cd	0.50
Arsenic	20.00
DDT	0.02
Oil/grease	500.00
666	0.50

Table 39. PNECs Used in Calculating RQs for the Ecological Risk Assessment.

Parameter	Matrix	PNEC Applied
Nutrients	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
DO	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
COD	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
Coliform	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
TSS	Water column	Interim Marine Water Quality Standard for Malaysia
Heavy Metals	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
	Sediment	Marine Sediment Quality for Class 1 (GB 18668-2002)
Pesticides	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
	Sediment	Marine Sediment Quality for Class 1 (GB 18668-2002)
Oil	Water column	Seawater Quality Standard for Class 2 (GB 3097-1997)
	Sediment	Marine Sediment Quality for Class 1 (GB 18668-2002)
PAHs	Sediment	Hong Kong Interim Sediment Quality Criteria

For the human health risk assessment, TDIs used in calculating RQs are shown in Table 40. One of the major difficulties associated with the human health risk assessment is the lack of Chinese TDIs. Most of the TDIs are derived from the U.S. FDA, and there are recommended daily allowances (RDAs) for the essential metals such as copper (Cu) instead of a TDI. RDA is widely available for nutritional supplements, however, it should be noted that an essential metal exceeding an RQ of 1 is less likely to cause a risk to human health than a non-essential metal exceeding an RQ of 1. In considering the risks associated with essential metals such as mercury (Hg), it should be noted that for chromium (Cr) the U.S. FDA has set the TDI for adults at 200 g/day, whereas the RDA for it is 50 g/day for adults. Thus, for adults the difference between RDA and TDI is a factor of 4. In the absence of further information, this shall be used as a general rule of thumb for the remaining essential metals, such as Cu.

The CR used here is an average level in the whole domestic scope while the local value maybe higher. Considering the differences in the physiologic and metabolic characteristics of the average American and the average Chinese, the local seafood quality standard is also listed. The standard, shown in Table 40, is made up initially by the seafood sanitation standard and, due to the lack of criteria for some contaminants, the halobios quality standard was adopted.

The reliability of the assessment largely depends on the quality of data used as MECs and on the quality and relevance of the threshold values used as PNECs or LOCs. The lack of Chinese values for LOCs represents a major source of uncertainty in the risk assessment.

Uncertainty can also arise from the variability in the RQs obtained. An initial measure of uncertainty was obtained by taking the average and worst-case RQs. A more quantitative measure of uncertainty can be carried out using the Monte Carlo estimation, a re-sampling technique which randomly re-samples pairs of MECs and PNECs to come up with the percentage of the measured values exceeding the threshold.

NUTRIENTS

Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP) are regular monitoring parameters in marine environmental management. The high concentration of DIN and DIP in Bohai Sea has caused many environmental problems such as HABs. To some degree, the growth of some kinds of shrimps has a negative correlation with the concentrations of DIN and DIP.

Table 40. Human Health Guidelines

Agents	TDI for adults (µg/person/day*)	Average CR Level (kg/person/day)	Level of Concern mg/kg in seafood	Seafood Standard of PR China (mg/kg wet weight)
Cu***	2,000	0.027**	74.07	50.0
Hg	16		0.59	0.3
Pb	75		2.78	0.5 (fish &shrimp)
Cd	55		2.04	0.1 (fish)
As	130		4.81	< 0.5 (fish)
				< 1.0 (shellfish)
				< 2.0 (algae)
				< 1.0 (crustacean)
DDT	80		2.96	1.0

*Source: *TDI from U.S. FDA, **China Statistic Yearbook (1999); *** MPP-EAS, 1999b.*

Water Column

Worst-Case RQs

DIN and phosphate (P) are two main pollutants in the water columns in the Bohai Sea. The DIN indicates the sum of nitrate (NO_3), nitrite (NO_2), and ammonia (NH_3). The PNEC of DIN has the same value in the Chinese Seawater Standard. The worst-case RQ of DIN is 25.67 and the worst-case RQ of DIP is 11.83 (Table 41). Moreover, the worst-case RQs for DIN and DIP were both from Liaodong Bay. The waters of Liaodong Bay have been seriously polluted by nutrients, which have caused frequent HABs in the area.

Average

The RQ_{Ave} for DIN and DIP are shown in Table 41. The average concentrations are below the critical level and hence the RQs are lower than 1. However the RQ_{Ave} for DIN is very close to 1.

Uncertainty Analysis

In Bohai Sea, DIN has increased since 1985. DIN reached 0.25 mg/l in 1998, ten times that in 1985. This increasing trend should be a cause for concern in the whole Bohai Sea.

The distribution of DIN varies with the locations in Bohai Sea. The highest RQ of DIN is in Liaodong Bay, where RQ_{Max} reaches 25.67 and RQ_{Ave} is 5.37. In 66 percent of the water area, DIN exceeds the critical level, which indicates that an immediate action be taken to reduce the discharge of DIN in Liaodong Bay.

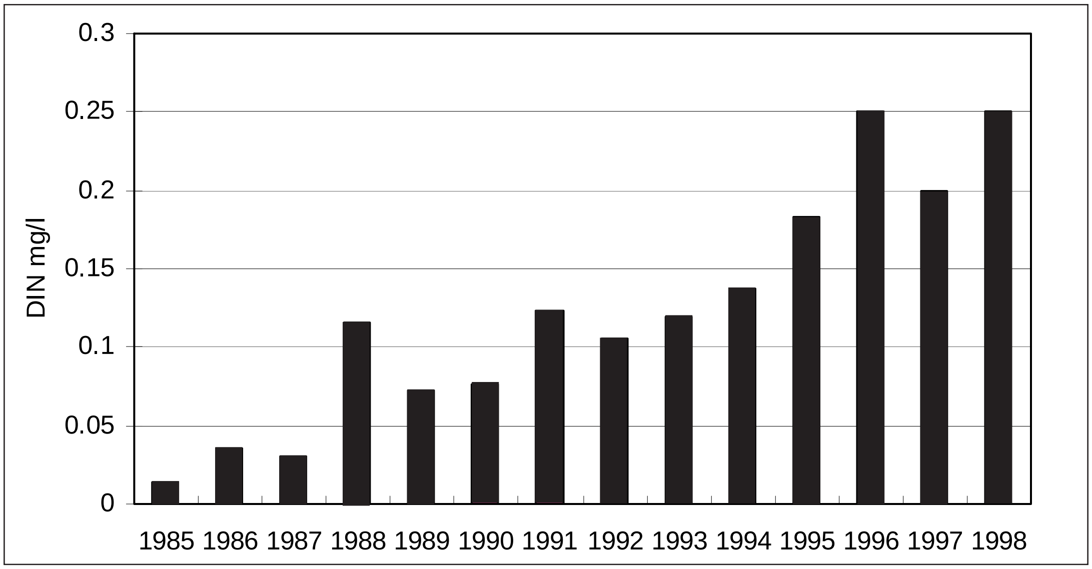
The RQ_{Max} of Bohai Bay is 3.43 and RQ_{Ave} is close to 1. In 68 percent of the water area, DIN

Table 41. RQs for Nutrients.

Agent	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC (mg/l)	RQ_{Ave}	RQ_{Max}
DIN	0.25	7.70	0.3	0.83	25.67
DIP	0.019	0.355	0.03	0.63	11.83

Source: Ocean Environment Bulletin, 1998.

Figure 30. Annual Changes in DIN in the Bohai Sea.



Source: Agriculture Department and ADB, 2000.

exceeds the critical level. But in other areas, especially in the central Bohai Sea, both the RQ_{Max} and RQ_{Ave} are still very low.

The distribution of DIP in Bohai Sea (Figure 31) is presents a similar trend to the annual changes of DIN (Figure 30). The concentration of DIP has increased in Bohai Sea since 1985. The trend should also be a cause for concern especially in Liaodong Bay and Bohai Bay. Liaodong Bay had the highest RQ (11.83), as shown in Table 43. The RQ_{Max} of Bohai Bay is also higher than 1. But the two average RQs are both lower than the critical level.

The polluted area has rapidly expanded in recent years, which got worse in 1998 (Figure 32). The area where the seawater quality is over the Class 2 water quality standard accounts for 76 percent of the whole Bohai Sea. Poor water quality has resulted in large-scale HABs in the Bohai Sea.

Table 42. RQs for DIN from Different Locations.

	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC (mg/l)	RQ_{Ave}	RQ_{Max}
Liaodong Bay	1.61	7.7	0.3	5.37	25.67
Bohai Bay	0.23	1.03	0.3	0.77	3.43
Laizhou Bay	0.091	0.202	0.3	0.30	0.67
Central Waters	0.028	0.038	0.3	0.09	0.13

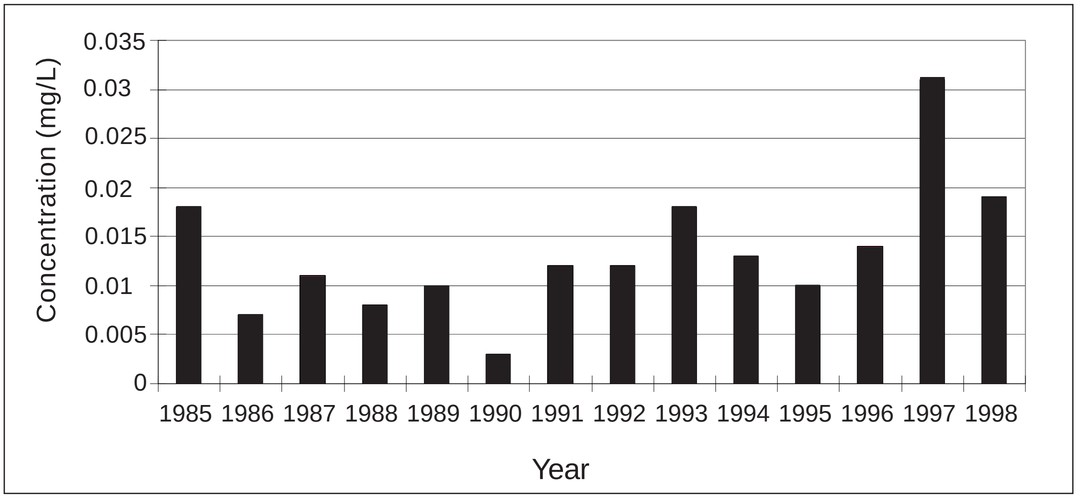
Source: Agriculture Department and ADB, 2000.

Table 43. RQs for DIP from Different Locations.

	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC (mg/l)	RQ_{Ave}	RQ_{Max}
Liaodong Bay	0.026	0.355	0.3	0.87	11.83
Bohai Bay	0.022	0.197	0.3	0.73	6.57
Laizhou Bay	0.004	0.005	0.3	0.13	0.17
Central Waters	0.008	0.012	0.3	0.27	0.40

Source: Agriculture Department and ADB, 2000.

Figure 31. Annual Changes in DIP Concentration in the Bohai Sea.



Source: Agriculture Department and ADB, 2000.

Possible Sources of Nutrients in Bohai Sea

Chemical/Industrial Wastes

There are main chemical industrial bases located around Liaodong Bay, which discharge nutrients into rivers and/or the bay. There are 73 sewage outfalls in Liaoning Province, which account for 33.6 percent of the whole nation's sewage. As shown in Figure 33, a great deal of wastewater is drained into Liaodong Bay with Daliaohe River. It was estimated in 1995 that Daliaohe River receives 1.9 billion tons of wastewater annually. It is an urgent task to cut down the wastewater output from Daliaohe River.

According to the Liaoning Marine Environment Bulletin, during the end of the 20th century, DIN pollution of waters in the Liaohe River estuary is the fourth most serious among the main estuaries and sea areas in China, and the first in Bohai Sea. Moreover DIP pollution in the Liaohe River estuary tops all water areas investigated in China.

Agriculture/Aquaculture

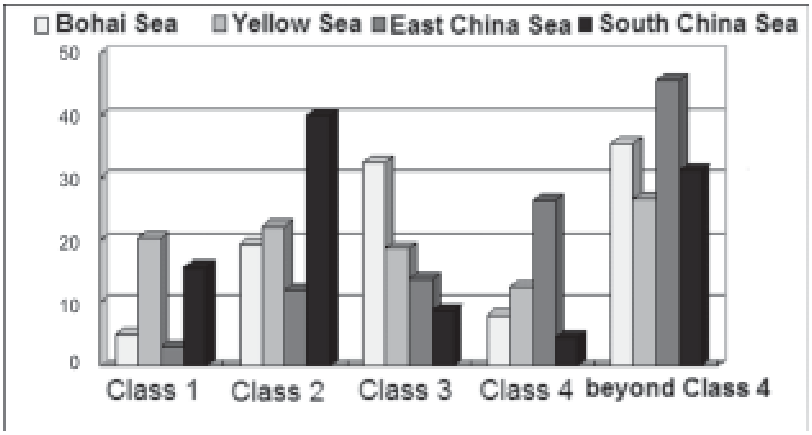
Based on the statistical results of agricultural fertilizer dosage, it is calculated that the annual non-point load of DIN and DIP is 48,000 tons and 9,000 tons respectively. The load of DIN from Yantai and Huludao towns, which are also the highest, amounts to 8,000 tons per year (Figure 34). The DIP load of Huludao Town (3,000 tons/yr) was also the highest.

Unit usage of total fertilizer (2,000 kg/ha) and nitrogenous fertilizer (150 kg/ha) also has increasing trends yearly. As proved in the eluviation experiment, the eluviation rate of NO_3-N is about 10 percent when the fertilizer use per hectare is not more than 150 kg, but which reaches 20 percent when use is more than 150 kg/ha, thus the fertilizer loss is doubled. Thus the non-point load of nutrients into the Bohai Sea likely increases. In Liaoning Province, there are as many as 36,000 tons of nitrogenous fertilizers flowing into the sea because of the low eluviation rate.

Soil Erosion

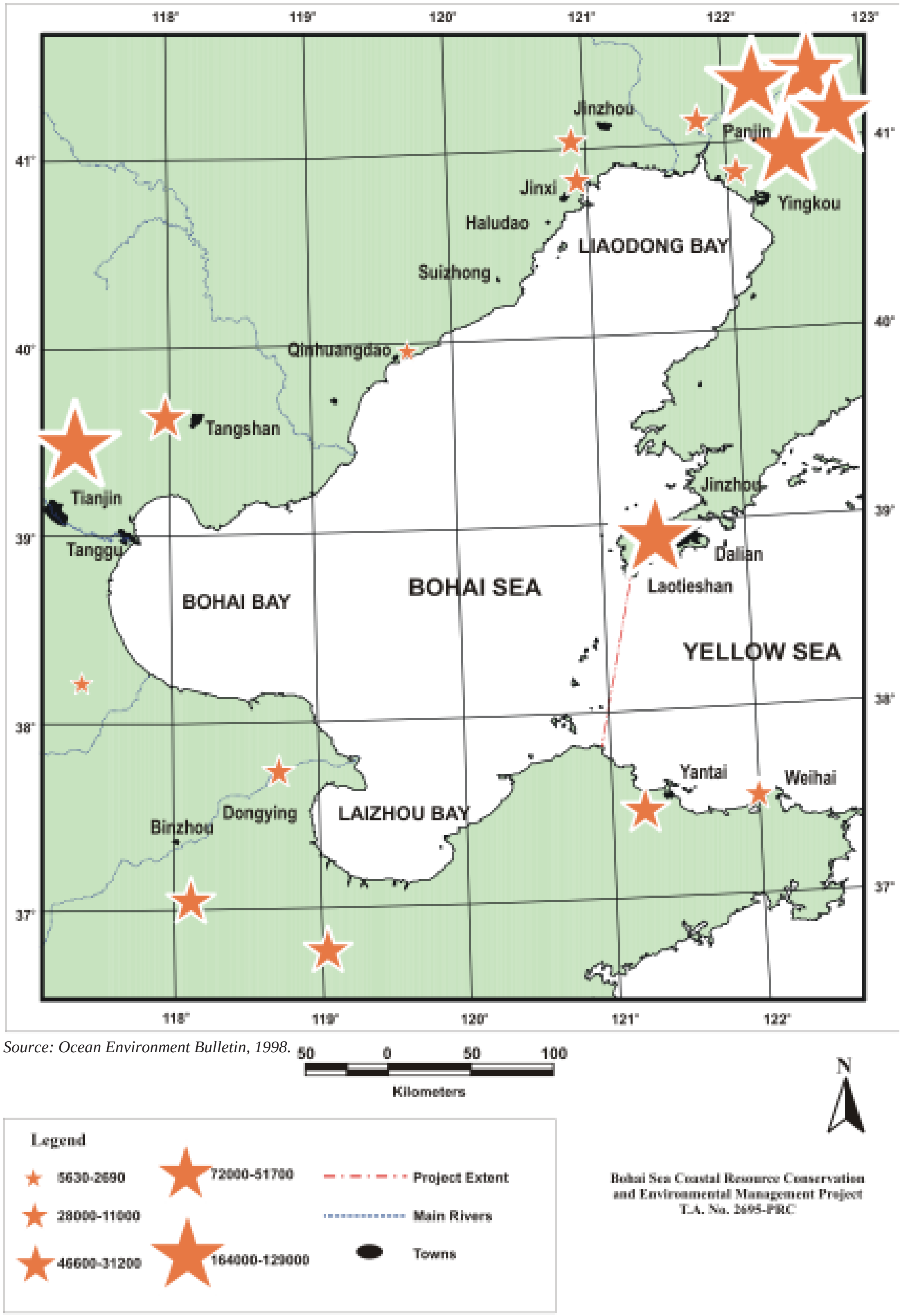
Soil erosion due to intensive farming and strong dust storm has taken much nutrient into nearby rivers. The erosion is very serious as indicated in Figure 36. Soil erosion may lead to fertilizer loss, which depends on the soil texture, dank capability and the covering extent. The scour of upper water caused by precipitation is the main reason of non-point pollution.

Figure 32. Nearshore Seawater Quality of China in 1998.



Source: SOA, 2000.

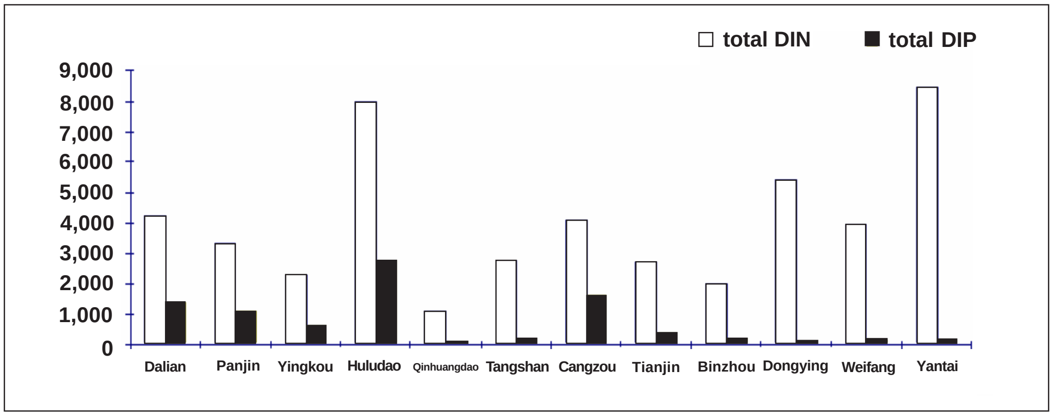
Figure 33. Wastewater Outputs in the Bohai Area (tons/yr).



Source: Ocean Environment Bulletin, 1998.

Source: Agriculture Dept. and ADB, 2000.

Figure 34. Non-point Nutrient Load of Main Cities around Bohai Sea (tons/yr).



Source: SOA, 2000.

Figure 35. Fertilizer Use in Areas adjacent to the Bohai Sea.

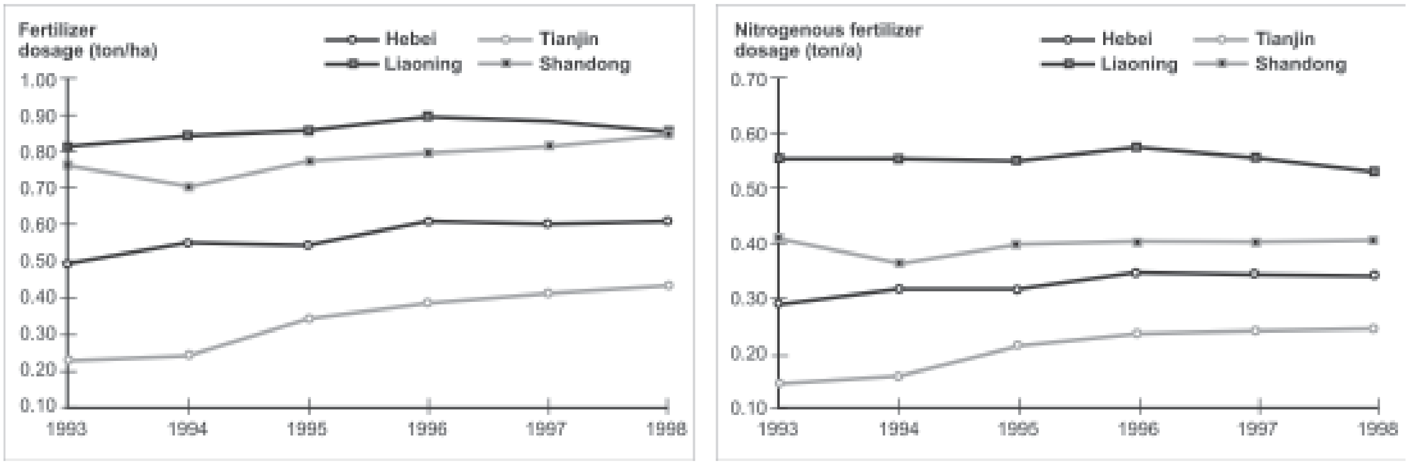
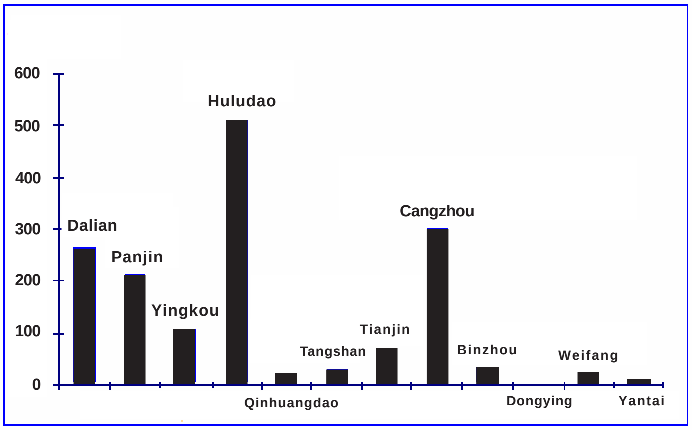


Figure 36. Soil Erosion of Main Cities around Bohai Sea in 1997 (tons/yr).



Source: SOA, 2000.

Among the towns around Bohai Sea, the soil erosion of Huludao Town (506 tons/yr) is the worst, which accounts for 32.1 percent of the whole area total of 1,577 tons/yr.

Domestic/Commercial Waste and Sewage

More than 50 million people live around Liaodong Bay. The domestic/commercial waste and sewage are considered the major sources of nutrients. Some are discharged directly into the bay and some through the river systems.

Table 44. Non-point Contaminant Discharge of 13 Cities around Bohai Sea.

City	Discharge into	Contaminant Discharge			
		DIN		DIP	
		(t/a)	(%)	(t/a)	(%)
Dalian	Liaodong Bay	10,075.3	14.5	583.0	18.6
Panjin		19,700.0	28.3		
Yingkou		118.7	0.2		
Cangzhou	Bohai Bay	33.1	0		
Qinhuangdao		1,487.8	2.1	118.5	3.8
Tangshan		21.2	0	4.4	0.1
Tianjin		24,877.2	35.7	1,254.9	40.0
Binzhou		8,372.2	12.0	783.2	25.0
Dongying	Laizhou Bay	2,519.5	3.6		
Weifang		455.0	0.7		
Yantai		2,009.2	2.9	389.7	12.4
Total		**69,669.3**	**100.0**	**3,133.7**	**100.0**

Source: SOA, 2000.

COD/DO

COD (chemical oxygen demand) is the amount of O_2 equivalent to the oxidants, which can oxidate all the organic compounds of one liter seawater into CO_2 and H_2O. COD is the parameter in token of the organic pollution. It was studied that COD has a negative correlation (γ = -0.8) with shrimp numbers in some seawaters.

For DO (Dissolved Oxygen), unlike other parameters, concentrations lower than the threshold value signal the deteriorating environmental conditions. Therefore RQ for DO is the ratio of PNEC over MEC.

Water Column

Worst-Case Scenario

Under the worst-case scenario, RQ for COD in Bohai Sea is 3.57. It means the organic pollution is serious and should be a cause for concern in some waters. No RQ_{Max} for DO exceeds 1, but it does not imply DO concentration in the whole Bohai Sea is sufficient.

Average Scenario

The RQ_{Ave} for both COD and DO are less than 1. Since the RQ_{Max} for COD is above the critical level, it is necessary to conduct an uncertainty analysis to determine the probability of the RQ value over 1.

Uncertainty Analysis

Since 1985, COD concentration has shown a strong increasing trend in the seawater of the Bohai Sea (Figure 37).

The spatial and temporal distribution of COD is different in Bohai Sea (Table 46). In Liaodong Bay, both RQ_{Ave} and RQ_{Max} are above 1. In Laizhou Bay, the RQ_{Ave} is less than 1 but the RQ_{Max} is above 1. There were 32.5 percent of the areas in Liaodong Bay and 20 percent in Laizhou Bay over the critical level. Immediate action should be taken in Liaodong Bay and prior concern should be paid in Laizhou Bay.

From the 1960s land-based pollution from Xiaoqinghe River has caused a series of problems. In the autumn of 1986 and the spring of 1987 about

100,000 tons of neritic shellfish died of COD pollution. The Shouguang Town, located downriver of Xiaoqinghe River, has suffered an income reduction of RMB 80 million (about US$9.6 million) per year because of severe pollution.

Possible Sources and Relative Importance

The above analysis shows a very depressing result for Bohai Bay due to the riverine pollutants being discharged into the bay. Liaodong Bay received 1.89 billion tons of sewage and 740,000 tons of COD in 1995. Liaohe River, the worst polluted river in China, is the biggest river inflowing into Liaodong Bay. In 2000, 834,000 tons of COD in Liaodong Bay came from Liaohe River.

Sources for COD pollution include:

1. Several chemical industries were setup in Liaoning Province in the 1950s, and little consideration was given to sewage treatment facilities when those factories were built. Now with the low profits of these industries, they cannot afford to run and improve the sewage treatment equipment. There are more than 200 factories and mines around Liaodong Bay which discharge about 7 million tons of contaminants annually.

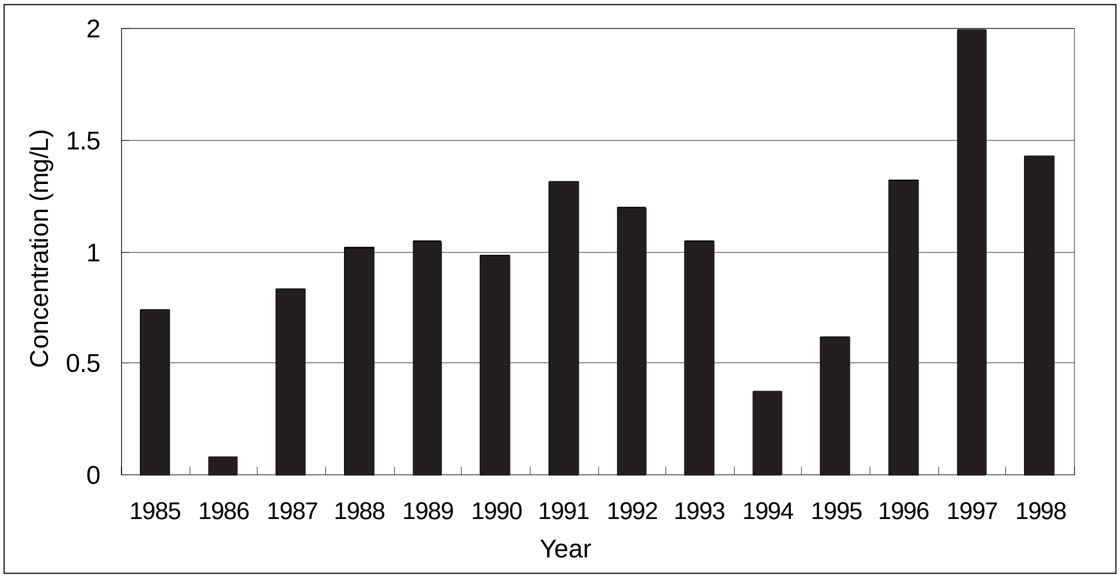
2. Very little domestic sewage is treated before being discharged. With more than 200 million people living around Bohai Sea, the domestic discharge into coastal waters is of huge quantities. It is estimated that the top

Table 45. RQs for COD/DO.

Agent	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC (mg/l)	RQ_{Ave}	RQ_{Max}
COD	1.74	10.7	3	0.58	3.57
DO	10.09	6	5	0.50	0.83

COD source: Agriculture Department and ADB, 2000.
DO source: Monitoring Report for Land-based Pollution and its Effects on the Coastal Waters and Resources in China, P87, Table 2-22.

Figure 37. Annual Changes of COD in Bohai Sea.



Source: Agriculture Department and ADB, 2000.

efficiency of depuration plants is only 20 percent. The water quality research done by SEPA (2001) showed that 71 percent of the Daliaohe River water system should be ranked into Class 4 or 5 while the percentage of Haihe River and Luanhe River was about 44 percent.

3. Due to over-developed farmlands, heavy rain and worsening soil erosion took huge amounts of mud into Bohai Sea. The decomposition of organic compounds in mud can reduce DO in water and release nutrients at the same time. Water quality further worsened.

4. Lots of sewage from mariculture was discharged directly into Bohai Sea. An estimated 720 million tons of sewage from mariculture is directly discharged into the sea from the whole nation daily, 35 percent (252 million tons) of which is discharged into Bohai Sea (State Ocean Environment Monitoring Center, 1997).

5. The vessel sewage, such as domestic fecal sewage and some organic wastes discharged from watercrafts, can also increase COD in water.

Table 46. RQs for COD from Different Locations.

Area	**MEC_{Ave} (mg/l)**	**MEC_{Max}(mg/l)**	**PNEC (mg/l)**	**RQ_{Ave}**	**RQ_{Max}**
Liaodong Bay	3.16	10.7	3	1.05	3.57
Bohai Bay	1.32	2.3	3	0.44	0.77
Laizhou Bay	1.68	3.6	3	0.56	1.20
Central Waters	0.8	0.96	3	0.27	0.32

Source: Agriculture Department and ADB, 2000.

Table 47. Sources of Sewage and COD into the Liaohe River in 1995.

	Sewage (Million Tons)			**COD (Tons)**		
	Industry	Domestic	Total	Industry	Domestic	Total
Liaohe River watershed	1,173.33	717.63	1,890.96	470,423	274,110	744,532

Source: SOA, 2000.

Table 48. COD Discharge of Bays and Districts in 1999 (in tons).

Bay	**COD**
Liaodong Bay	632,514
Baohai Bay	400,401
Laizhou Bay	333,437
Liaoning Province	614,821
Hebei Province	87,431
Tianjin Municipality	208,771
Shandong Province	455,329

Source: SOA, 2000.

COLIFORM

Water Column

Because coliform is not part of the regular monitoring activities, there are no available data for coliform in the whole Bohai Sea. The data used here for fecal coliform is from the Office of Ocean and Fishery (2001).

In Laizhou Bay, the RQ_{Ave} for fecal coliform is less than 1 (0.37), however, the RQ_{Max} (1.20) is over the critical level, which means that most of the waters of Laizhou Bay are not polluted by fecal coliform, but some hotspots were polluted by fecal coliform. Risks from fecal coliform in the Yellow River estuary is depressive, where RQ_{Ave} reached 5.68 and RQ_{Max} reached 12. The situation was even worse in Beidaihe area, where the RQ_{Ave} was 9.24. Urgent attention should be given to reduce the risk from fecal coliform in the estuary of Yellow River and Beidaihe. However, the fecal coliform in Panjin was quite less than the criteria, RQ_{Max} was only 0.31. Through analysis, the risk for fecal coliform can be learned that it varies in the different areas.

Uncertainty Analysis

Since the investigation was put up in the wet season and only at four locations, the calculated figures may be higher than the actual and the general scenario in the Bohai Sea may not be as bad as the RQs obtained here. Concern should be given to verify these figures and reduce the level of risk in hotspot areas.

Shellfish Tissue

There were only few data on the fecal coliform of shellfish tissue in Bohai Sea. Since the concentration in average seawater is lower than in estuary water, the calculation result maybe worse than the actual scenario in Bohai Sea. The PNEC for fecal coliform of shellfish tissue, which was 3,000 ind/kg fresh weight, was cited from the Interim Criteria for Shellfish Intendance of China (1997). Calculated RQs were shown in Table 50, the RQ_{Ave} was 1.48 in Beidaihe area, while the RQ_{Max} was 4.33. These results illustrated that some actions should be put into implementation to control the fecal coliform risk in shellfish tissue.

Table 49. RQs for Fecal Coliform in Water Column from Different Locations.

Location	MEC_{Ave} (ind./l)	MEC_{Max}(ind./l)	PNEC (ind./l)	RQ_{Ave}	RQ_{Max}
Laizhou Bay*	733	2,400	2,000	0.37	1.2
Yellow River Estuary*	11,362	24,000	2,000	5.68	12
Beidaihe**	18,487	48,000	2,000	9.24	24
Panjin**	353	620	2,000	0.18	0.31

**Office of Ocean and Fishery, 2001 (Table 77-78).*
***He Jie, et al., 2002.*

Table 50. RQs for Fecal Coliform in Shellfish in Some Estuaries.

Location	MEC_{Ave} (ind./l)	MEC_{Max}(ind./l)	PNEC (ind./l)	RQ_{Ave}	RQ_{Max}
Beidaihe**	4,428	13,000	3,000	1.48	4.33

Source: He Jie, et al., 2002.

Uncertainty Analysis

Since the data for fecal coliform in shellfish tissue was only limited to a few estuaries, the results of the risk assessment represent only some spots of Bohai Sea.

TOTAL SUSPENDED SOLIDS (TSS)

Water Column

Data of total suspended solids (TSS) of the whole Bohai Sea is currently unavailable. An investigation in Laizhou Bay in 1991 showed that the maximum TSS was in bottom waters, the RQ of which was double the critical level while in the upper waters. TSS was far below the criteria. Another average observed value of TSS in March 1995 in Jinzhou Bay, one small bay in Liaodong Bay, was 249.6 mg/l, and the maximum 464 mg/l.

The criterion for TSS in seawater is from the interim standard of the Department of Environment of Malaysia. RQs in the waters of Jinzhou Bay exceeded the critical level of 1 for all the 10 sampling stations. RQ_{Ave} is 4.99 and RQ_{Max} is 9.28, hotspot waters were the borders of Jinzhou Bay.

During the investigation in 1998 and 1999, the scenario was similar to that in 1991. RQ of TSS in bottom water is more than twice that in surface water. The figure shows that some waters in Bohai Sea have TSS above the critical level though the situation is not serious.

During another investigation in Laizhou Bay, the TSS flux through Xiaoqinghe River in 1998 was 13,864.5 mg/l, which shows that land-based import is a major source of TSS in Bohai Sea.

Some researches have shown that for such a shallow sea as Bohai Sea, tidal current can cause the periodic change of TSS while the ocean wave by wind obtrusion is the main reason of the seasonal changes.

HEAVY METALS

Water Column

Worst-Case Scenario

In Bohai Sea, the main heavy metal pollutants are Hg, Pb, Cd and Cu. The RQ_{Max} of Pb and Cd are both above 1, with Pb having the highest RQ (6.52), followed by Cd (3.22). Pb and Cd should be a cause for concern in some areas.

Average Scenario

In the four major metals, only Pb has an RQ_{Ave} above 1, which means Pb is the most serious metal contaminant and should be given high priority of concern.

Uncertainty Analysis

Table 53 shows the results of RQ analysis for Pb in different areas of Bohai Sea. Liaodong Bay is severely polluted by Pb. Its RQ_{Ave} is 1.40 and

Table 51. RQs for TSS.

Location	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC (mg/l)	RQ_{Ave}	RQ_{Max}
Jinzhou Bay*	249.6	464	50	4.99	9.28
Laizhou Bay**	12.3	99.6	50	0.25	1.99
Surface Water***	8.25	43.67	50	0.17	0.87
Bottom Water***	16.31	98.04	50	0.33	1.96

*Source: *State Environment Monitoring Center, 1995, p87, Table 2-22.*
***FIO-SOA, 1991, p55.*
****Su Jian, et al., 2001.*

RQ_{Max} amounts to 6.52. Pb in Liaodong Bay should be given the first priority for management. Table 54 shows that the RQ_{Max} for Cd was also obtained at Liaodong Bay. Cd concentrations in the other areas are still at low levels. Table 55 shows that Hg in the four parts of Bohai Sea are far below the critical level, which poses little risk. As far as the other bays are concerned, all the RQs for heavy metals are below critical level.

Heavy metal pollution in Bohai Sea is not very serious except in some areas in Liaodong Bay and Bohai Bay. Concentrations of Pb and Cd are high in Liaodong Bay, where sewage from heavy industries was discharged into the bay untreated or with incomplete treatment, and Pb in Bohai Bay is also beyond the criterion. Pb in Liaodong Bay should be given the first priority, while Pb in Bohai Bay and Cd in Liaodong Bay, the second.

As is shown in Table 56 and Figure 38, metals concentrations have been increasing in the past four years. The concentration of Pb in 1997 is 3.7 times that of 1993. The figure reaches as high as 5.2 when Cd is concerned. Effective steps must be put into practice to restrain the ascending trend.

Table 52. RQs for Heavy Metals in the Water Column.

Agent	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC(mg/l)	RQ_{Ave}	RQ_{Max}
Hg	0.000027	0.0001	0.0002	0.14	0.50
Cu	0.00389	n/a	0.01	0.39	n/a
Pb	0.00557	0.0326	0.005	1.11	6.52
Cd	0.00083	0.0161	0.005	0.17	3.22

Source: Agriculture Department and ADB, 2000.

Table 53. RQs for Pb in the Water Column from Different Locations.

Area	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC(mg/l)	RQ_{Ave}	RQ_{Max}
Liaodong Bay	0.00698	0.0326	0.005	1.40	6.52
Bohai Bay	0.00245	0.0131	0.005	0.49	2.62
Laizhou Bay	0.00134	0.005	0.005	0.27	1
Central Waters	0.00034	0.00059	0.005	0.07	0.12

Source: Agriculture Department and ADB, 2000.

Table 54. RQs for Cd in the Water Column from Different Locations.

Area	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC(mg/l)	RQ_{Ave}	RQ_{Max}
Liaodong Bay	0.00168	0.0161	0.005	0.34	3.22
Bohai Bay	0.00008	0.00025	0.005	0.02	0.05
Laizhou Bay	0.00006	0.0001	0.005	0.01	0.02
Central Waters	0.00001	0.00015	0.005	0.002	0.03

Source: Agriculture Department and ADB, 2000.

Table 55. RQs for Hg in the Water Column from Different Locations.

Area	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC(mg/l)	RQ_{Ave}	RQ_{Max}
Liaodong Bay	0.00003	0.0001	0.0002	0.15	0.50
Bohai Bay	0.000033	0.000068	0.0002	0.17	0.34
Laizhou Bay	0.000025	0.00008	0.0002	0.13	0.40
Central Waters	0.00016	0.000042	0.0002	0.08	0.21

Source: Agriculture Department and ADB, 2000.

In general, Pb in Liaodong Bay and Bohai Bay should be given first priority. More efforts should be paid to reduce Pb pollution in Liaodong Bay and Bohai Bay and to cut down the upward trend of Pb and Cd.

Sediment

RQ analysis for the heavy metals in the sediment is shown in Table 57. The maximum RQs for Hg, Cu and Cd in sediment exceed the critical level although their average RQs are not beyond 1, which shows some regions are polluted. RQs for Pb are still less than 1 and pose low risk. According to this analysis, Cd in sediment in Bohai Sea should be given the first priority and Hg, the second.

Uncertainty Analysis

Risk for heavy metals is discussed in terms of different regions (Table 58–61).

Cu in Bohai Bay (Table 58) should be one of the concerns for management since both RQ_{Ave} and RQ_{Max} in the bay average exceeded the critical level, where Cu concentration in 75 percent of the sampling stations has exceeded the criterion. RQs in the other three areas are under 1 while in central waters the data is extremely close to 1, and 33 percent of the sampling stations investigated have Cu beyond the critical level.

For Pb, all RQs in the four parts are under 0.5, showing a good scenario.

As shown in Table 60, RQ_{Ave} and RQ_{Max} of Cd in Liaodong Bay are 1.87 and 4.56 respectively, which pose comparatively high risk. Concentrations of Cd in 66.7 percent of the sampling stations were over the critical level. Those in the other three areas are still under the critical level. Attention to Cd in Liaodong Bay should also be given.

Table 61 shows that only RQ_{Max} of Hg in Liaodong Bay exceeds the critical level, which also shows that some waters in Liaodong Bay have been polluted by Hg.

In summary, heavy metals in sediment should be given concern because of the risks they pose. Priority should be given to Cd in Liaodong Bay, followed by Hg in Liaodong Bay and Cu in Bohai Bay.

Table 56. Concentrations of Heavy Metals in Several Years (µg/L).

Year	Cu	Pb	Cd	Hg
1993	2.69	1.41	0.23	0.08
1995	2.54	3.07	0.15	0.03
1997	3.05	5.17	1.20	0.18

Source: Agriculture Department and ADB, 2000.

Table 57. RQs for Heavy Metals in the Sediment.

Agent	MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	PNEC (mg/kg)	RQ_{Ave}	RQ_{Max}
Hg	0.06	0.57	0.2	0.30	2.85
Cu	22.80	45.6	35	0.65	1.30
Pb	18.30	29.1	60	0.31	0.49
Cd	0.27	2.28	0.5	0.54	4.56

Source: Agriculture Department and ADB, 2000.

Figure 38. Changes of Heavy Metals for 1993, 1995 and 1997.

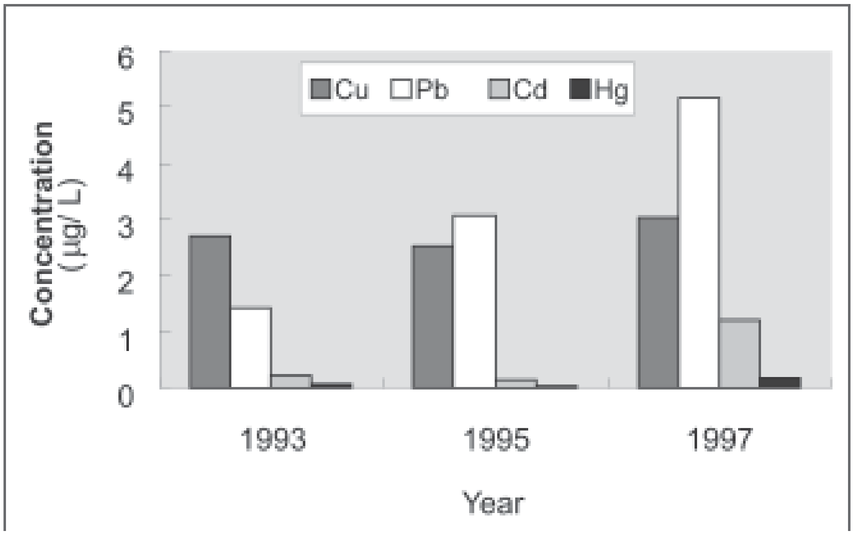


Table 58. RQs for Cu in the Sediment of Different Locations.

Area	MEC$_{Ave}$ (mg/kg)	MEC$_{Max}$(mg/kg)	PNEC (mg/kg)	RQ$_{Ave}$	RQ$_{Max}$
Liaodong Bay	15.3	21.9	35	0.44	0.63
Bohai Bay	36.2	45.6	35	1.03	1.30
Laizhou Bay	19.1	26.8	35	0.55	0.77
Central Waters	22.1	33.7	35	0.63	0.96

Source: Agriculture Department and ADB, 2000.

Table 59. RQs for Pb in the Sediment of Different Locations.

Area	MEC$_{Ave}$ (mg/kg)	MEC$_{Max}$(mg/kg)	PNEC (mg/kg)	RQ$_{Ave}$	RQ$_{Max}$
Liaodong Bay	16.8	29.1	60	0.28	0.49
Bohai Bay	16.8	22.6	60	0.28	0.38
Laizhou Bay	15	23.2	60	0.25	0.39
Central Waters	17.1	23	60	0.29	0.38

Source: Agriculture Department and ADB, 2000.

Table 60. RQs for Cd in the Sediment of Different Locations.

Area	MEC$_{Ave}$ (mg/kg)	MEC$_{Max}$(mg/kg)	PNEC(mg/kg)	RQ$_{Ave}$	RQ$_{Max}$
Liaodong Bay	0.934	2.280	0.5	1.87	4.56
Bohai Bay	0.141	0.238	0.5	0.28	0.48
Laizhou Bay	0.063	0.080	0.5	0.13	0.16
Central Waters	0.081	0.141	0.5	0.16	0.28

Source: Agriculture Department and ADB, 2000.

Table 61. RQs for Hg in the Sediment of Different Locations.

Area	MEC$_{Ave}$ (mg/kg)	MEC$_{Max}$(mg/kg)	PNEC(mg/kg)	RQ$_{Ave}$	RQ$_{Max}$
Liaodong Bay	0.169	0.500	0.2	0.85	2.50
Bohai Bay	0.031	0.050	0.2	0.16	0.25
Laizhou Bay	0.044	0.074	0.2	0.22	0.37
Central Waters	0.024	0.045	0.2	0.12	0.23

Source: Agriculture Department and ADB, 2000.

Tissue

The heavy metals (Hg, Cu, Pb, Cd) in the tissue of shellfish, seaweed and fish are analyzed respectively in Tables 62 to 65.

None of the RQ_{Ave} in Table 62 was over 1, and only RQ_{Max} for Pb was 1.26. These results show that the heavy metals in shellfish do not show cause for concern in the Bohai Sea, except for Pb in some hotspots (RQ_{Max} = 1.26).

Pb in seaweed tissue (Table 63) also poses very high risk. Its RQ_{Ave} has reached 1.38 while RQ_{Max} is 2.58. People should be careful of seaweed consumption in the Bohai Sea area. Management programs should be undertaken immediately to reduce the risk from Pb in seaweed tissue.

In Table 64, heavy metals in fish tissue from Tianjin and Laizhou Bay are all under the criteria. Both their RQ_{Ave} and RQ_{Max} did not exceed 1. There is no cause for concern for heavy metal content during fish consumption.

Arsenic (As) is included since it is another contaminant from natural or anthropogenic sources, is easy to accumulate by organism, and is still used in agriculture. Table 65 shows the RQs for As in shellfish tissue in the three bays. However, their RQs are all under the critical level.

In summary, Pb in seaweed tissues posed high risks, thus, it should be given first priority. The other heavy metals, which have very low RQs, indicate that no urgent concern is needed.

Uncertainty Analysis

Compared with the RQs for Pb in the three bays, the high risk from seafood may have something to do with the accumulation rates in

Table 62. RQs for Heavy Metals in Shellfish Tissue.

Location		MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	LOC (mg/kg)	RQ_{Ave}	RQ_{Max}
Tianjin and Dalian	Hg	0.020		0.59	0.03	
	Cu	13.005	19.500	74.07	0.18	0.26
	Pb	1.785	3.510	2.78	0.64	1.26
	Cd	0.475	0.870	2.04	0.23	0.43

Source: Agriculture Department and ADB, 2000.

Table 63. RQs for Heavy Metals in Seaweed Tissue.

Location		MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	LOC (mg/kg)	RQ_{Ave}	RQ_{Max}
Dalian and Yantai	Hg	0.065	0.09	0.59	0.11	0.15
	Cu	5.16	7.88	74.07	0.07	0.11
	Pb	3.84	7.18	2.78	1.38	2.58
	Cd	1.25	1.63	2.04	0.61	0.80

Source: Agriculture Department and ADB, 2000.

Table 64. RQs for Heavy Metals in Fish Tissue.

Location of Maximum Concentration		MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	LOC (mg/kg)	RQ_{Ave}	RQ_{Max}
Tianjin	Hg	0.08	0.09	0.59	0.14	0.15
Laizhou Bay	Cu	1.58	2.50	74.07	0.02	0.03
Laizhou Bay	Pb	0.93	1.52	2.78	0.33	0.55
Laizhou Bay	Cd	0.44	0.62	2.04	0.22	0.30

Source: Agriculture Department and ADB, 2000.

several tissues. Accumulation rates in shellfish (392 times), fish (9 times) and seaweed (705 times), show that Pb is more easily accumulated in seaweed tissue, followed by shellfish tissue.

Hotspots for Pb in shellfish tissue were observed in some specific locations while the scenario of the whole Bohai Sea cannot be shown without concrete data. Data on heavy metals has been assigned a score of 2 for data quality since QA/QC procedures were not specified in the documentation.

RQ_{Max} for Cu is not available due to lack of corresponding period raw data.

Considering the differences in seafood consumption and in the physiologic and metabolic characteristics of the average American and the average Chinese, the U.S. TDI is unsuitable for the risk assessment.

A single CR was also applied for computing the RQs for metals in shellfish, fish and algae. This CR is the average for the whole nation's population. Evidence shows that people living around the seashore consume more seafood than people living inland. Some further analysis and investigation should be carried out for risk assessment of seafood tissues around the Bohai Sea as calculations gathered could create uncertain results.

Possible Sources of Heavy Metals

Industrial emissions and wastes are the main source of heavy metal pollution. Other sources such as domestic sewage and atmosphere sedimentation also contribute to pollution.

From Table 66, there is a huge amount of heavy metals discharged into Bohai Sea. Of the five heavy metals, Pb, Cd and Hg discharged into Bohai Sea accounted for over 90 percent of the whole nation’s discharges.

Among the three cities listed in Table 67, Tianjin has the largest Pb discharge. RQ

Table 65. RQs for Arsenic in Shellfish Tissue.

Location	MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	LOC (mg/kg)	RQ_{Ave}	RQ_{Max}
Liaodong Bay	1.13	3.12	4.81	0.23	0.65
Bohai Bay	1.02	1.89	4.81	0.21	0.39
Laizhou Bay	0.76	1.43	4.81	0.16	0.30

Source: Agriculture Department and ADB, 2000.

Table 66. Heavy Metal Discharged into Whole Nation and Bohai Sea Annually.

	Cu	Pb	Cd	Hg	As
Whole Nation	390.69	634.47	146.36	6.17	66.58
Bohai Sea	67.46	572.61	143.26	5.75	39.58
Percentage (%)	17.3	90.3	97.9	93.2	59.40

Source: State Environment Monitoring Center, et al., 1995.

Table 67. Annual Discharge of Pb from Three Typical Cities.

City	Location	Pb discharge (T/yr)
Huludao	Liaodong Bay	76.79
Tianjin	Bohai Bay	272.77
Dongying	Laizhou Bay	37.97

Source: State Environment Monitoring Center, et al., 1995.

distribution for Pb in Liaodong Bay and Bohai Bay may have something to do with the ocean current since some of the seawater swarming into Liaodong Bay come from Bohai Bay.

PESTICIDES

Pesticides are divided into insecticide, weed killer, bactericide, raticide and so on. Some of them are organophosphorus compounds; some are sulphide, mercurial, arsenide, or organochlorine compounds. The total classes are over 400 varieties. The main insecticide employed in China are organophosphorus compounds, such as trichlorphon, dimethoate and parathion.

Only two major insecticides are considered in the RA. DDT (dichlorodiphenyltrichloroethane) and 666 (benzene hexachloride) are both difficult to degrade and decompose, and were commonly used in the 1960s then abandoned in the early 1980s. Attention is then placed to DDT and 666 in the Bohai Sea. RQs will be analyzed in the sediment and seafood tissue.

For pesticides in sediment, the high RQ_{Ave} for DDT amounted to 5 and for 666 to 111.2, while MEC_{Max} is unavailable, it is sure to be higher. Degradation is slow, which means that such compounds will remain for a long period. Consequently, the high risk posed by these pesticides will also exist for a long time. Actions must be taken immediately to cease further discharge of such compounds into the sea.

Figure 39. Pesticides are insufflating.

Shellfish Tissue

As shown in Table 69, DDT exhibited RQ_{Ave} very close to 1 and RQ_{Max} as high as 4.42. Further analysis needs to be done when the Chinese TDI is available.

Uncertainty Analysis

Data on pesticides has been assigned a score of 2 for data quality since QA/QC procedures were not specified in the documentation.

Table 68. RQs for Pesticide in Sediment.

Agent	MEC_{Ave} (mg/kg)	MEC_{Max} (mg/kg)	PNEC (mg/kg)	RQ_{Ave}	RQ_{Max}
DDT	0.1	n/a	0.02	5	n/a
666	55.6	n/a	0.50	111.2	n/a

Source: Agriculture Department and ADB, 2000.

Table 69. RQs for Pesticide in Shellfish Tissue.

Location	Agent	MEC_{Ave} (mg/kg)	MEC_{Max} (mg/kg)	PNEC (mg/kg)	RQ_{Ave}	RQ_{Max}
Bohai Sea	DDT	2.83	13.27	2.96	0.96	4.48

Source: SOA, 2000.

Only RQ_{Ave} for DDT and 666 in the sediment was calculated since their RQ_{Max} is unavailable. Since the Chinese TDI is unavailable, RQ analysis for DDT in shellfish tissue may have associated uncertainties.

Sources of Pesticides

Agricultural intensification is the main source of pesticides. The application rate of pesticides in Dongying is 76.05 kg/ha while other regions around Bohai Sea may have higher values due to the development of local agriculture.

OIL

With the development of maritime transportation and oil exploitation come the spread of oil pollution. When oil concentration is 0.12 mg/l, the death rate of Zoea shrimp is 50 percent. But in some regions of Bohai Bay and Laizhou Bay, oil concentration in surface waters is 0.1–0.3 mg/l, which is sure to have effects on shrimp survival and metamorphism. At the estuary of Wulihe River in Huludao, floating oil was as thick as 2–4 mm, which has led to nonliving water areas as large as 5 km^2. From 1985–1990, oil pollution was fairly severe, with 20 percent of the sampling stations exceeding the criteria. In 1993, oil in Laizhou Bay came to a concentration as high as 0.091 mg/l. From 1996–1997, the average level amounted to 0.07 mg/l, with 60 percent of the stations over the critical level (0.05 mg/l). In Jinzhou Bay, the figure rose to 94 percent of the sampling stations in 1997. The oil concentration range of the whole Bohai Sea in 1999 was 0.04–0.06 mg/l, with 25–65 percent of the stations exceeding the standard.

Water Column

Oil pollution is very serious in Bohai Sea. For oil, RQ_{Ave} = 2 and RQ_{Max} = 4.4. The high RQ value indicates that actions should be done to reduce oil pollution.

Uncertainty Analysis

Oil pollution has aggravated in the past years especially in Bohai Bay, Figure 40 illustrates the changes of oil pollution in recent years. Oil concentration in Bohai Sea has increased from 1985–1997. The trend has accelerated in 1996 and 1997, with the 1997 concentration 4.35 times that of 1985.

Possible Sources:

- **Sewage Discharge**

Table 71 shows oil discharge in different regions around Bohai Sea. The top discharge is in Liaoning Province, with oil receipt of Liaodong Bay amounting to 4,846 tons the same year, followed by Bohai Bay with 3,271 tons. It is obvious that sewage discharge is the main source of oil in Bohai Sea.

- **Discharge of Ballast from Fishing and Cargo Ships**

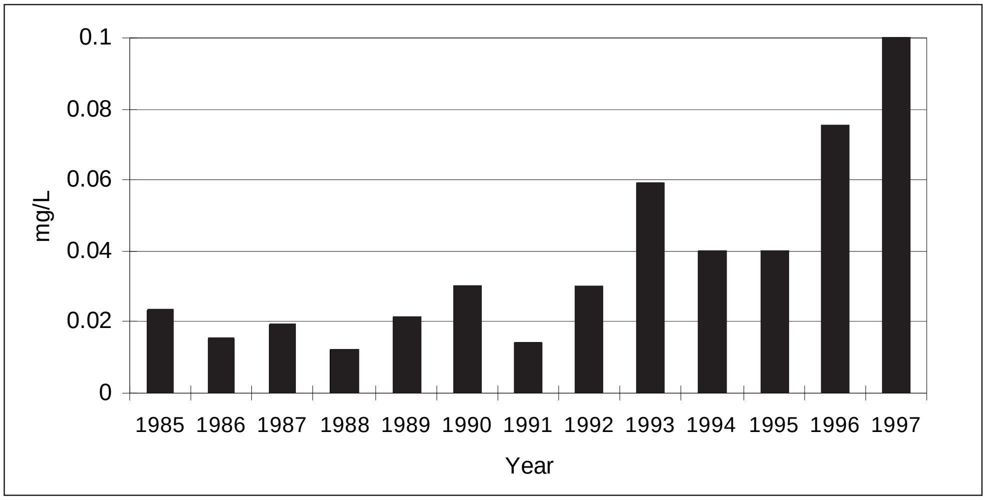
Mobile ballast (all kinds of ships) account for 13.2 percent of total oil pollution. There are 27,723 powerboats registered in Bohai area and 1,515 T of oil is discharged into the sea each year. However, it is difficult to estimate how much oil comes from transportation ships or unregistered boats.

Table 70. RQs for Oil in the Water Column.

Agent	MEC_{Ave} (mg/l)	MEC_{Max}(mg/l)	PNEC (mg/l)	RQ_{Ave}	RQ_{Max}
Oil	0.10	0.22	0.05	2	4.4

Source: Agriculture Department and ADB, 2000.

Figure 40. Annual Changes of Oil Concentration in Seawater.



Source: Agriculture Department and ADB, 2000.

In addition, watercrafts coming in and going out of the wharfs as well as ship breaks may also produce much oil contamination. There were 330,000 incoming and outgoing vessels in the wharfs in Liaoning Province in 1995.

- **Discharges from Oil Platform**

Another main source of oil pollution is the oil platforms. There are five major oil platforms built in Bohai near-shore, two in Panjin and three in Dongying, which discharge 1,484 T of oil and 2,140 T of sewage each year. The reasons for the discharge may be mechanical or production accidents. Discharges from oil platforms account for 3.7 percent of the total oil pollution in Bohai Sea.

Table 71. Oil Discharge in Four Districts in 1999.

	Oil (Tons)
Liaoning	4,822
Hebei	137
Tianjin	3,052
Shandong	1,924

Source: SOA, 2000.

Sediment

Whether from land-based or sea-based sources, most of the oil in Bohai Sea was light oil. When discharged into the sea, most of the oil either vaporizes, degrades, or becomes deposited in the seabed. In the environment quality investigation in 1997, average oil concentration in the sediment of the whole Bohai Sea was 61.4 mg/kg (RQ_{Ave} = 0.12). But some estuaries are severely

Table 72. Oil Discharged by Moving Source.

City	Merchant ship (time/yr)	Fishing ship	Oil sewage (ton/yr)	Oil content (ton/yr)
Dalian	7,000	12,983		1,116
Yingkou		3,500		
Panjin		780	3,600	3
Jinzhou		1,600		25
Huludao		3,469	3,798,600	347
Tangshan	518	3,237	523,100	5
Binzhou		1,242	500,000	4
Weifang		912	13,900	13

Source: Agriculture Department and ADB, 2000.

Figure 41. The Black Xiaoqinghe River reflects the serious pollution of sewage, heavy metals and oil.

Source: Agriculture Department and ADB, 2000.

polluted by oil. It is reported that in some shore areas in Laizhou Bay, oil has a maximum concentration of 350.53 mg/kg (Xie, 1993), with RQ_{Max} = 0.70.

Tissue

In the past, several fish poisoning accounts were reported. In 1985, when oil concentration in fish tissue was high, several people in Huanghua County were hospitalized. But because of the lack of the TDI, RQ-based risk cannot be analyzed.

POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

Sediment

Total polycyclic aromatic hydrocarbons (PAHs) have been measured in the sediments of Bohai Sea but local PNECs for PAHs in sediment were unavailable, so RQs were calculated using the criteria for total PAHs from the Hong Kong Interim Sediment Quality Values (EVS, 1996) though it may not have the appropriate suitability.

In Table 75, RQ_{Ave} for total PAHs is only 0.22 while RQ_{Max} amounts to 1.38, which means some sediment was polluted by PAHs and potentially pose risk to aquatic organisms.

PAHs are organic compounds that are derived from natural as well as anthropogenic sources, such as petroleum products, combustion processes and municipal effluents. PAHs are relatively water insoluble and most PAHs are adsorbed in particulate matter in aquatic ecosystems, accumulating in sediments and biota. PAHs in sediment are persistent and some species are considered to have potentially harmful effects on the environment, but most studies in the aquatic environment look at the total group of PAH compounds and less is known about the specific effects of individual compounds. Some

Table 73. RQs for Oil in Sediment.

Agent	MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	PNEC (mg/kg)	RQ_{Ave}	RQ_{Max}
Oil	61.4	350.53	500	0.12	0.70

Source: MEC_{Ave}: Agriculture Department and ADB, 2000.
MEC_{Max}: Xie Xudong, 1993.

Table 74. RQs for Oil in Shellfish Tissue.

Agent	MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	LOC (mg/kg)	RQ_{Ave}	RQ_{Max}
Oil	14.3	80.5	n/a		

Source: SOA, 2000.

of the observed environmental effects of PAHs include tumors in fish; inhibited reproduction in aquatic invertebrates; toxicity among crustaceans; reduced embryo survival and development in birds; and mutagenic, carcinogenic and teratogenic effects to birds and mammals (Eisler, 1987).

Possible Sources

Based on the PAHs components, possible sources may be the decomposition of oil; release of gasoline, fuel and coal burning; and import of land-based sewage.

Shellfish Tissue

As shown in Table 76, total PAHs have been measured in some shellfish tissues. There were, however, no available TDIs for PAHs hence RQs could not be calculated. Assessment on PAHs should be carried out when TDI can be defined.

Effects on human health of PAH-contamination of the marine environment usually occur through food chain effects and consumption of aquatic food products especially the filter-feeding bivalve mollusks from severely contaminated areas. Consumption of PAH-contaminated seafood could pose cancer risk to humans although only some PAHs have been shown to be potentially carcinogenic and measurements of total PAHs cannot be directly equated with carcinogenic potential (Eisler, 1987).

OIL SPILLS

Ten serious oil spill accidents in Bohai Sea have occurred in the past ten years. Oil spill rate is 0.2 percent of the total loading oil in Bohai Sea, as estimated.

Some serious oil spill accidents around Bohai Sea are listed below:

- In 1979, Shengli Oil Field discharged 45,708 T of oil into the Sea.
- In 1987, Qinhuangdao oil pier spilled 1,470 T of oil.
- In 1990, a Panama cargo ship crashed with a Libyan ship, 120 km^2 area was polluted by oil.
- In 1998, an oil derrick owned by Shengli Oil Field collapsed in Laizhou Bay and the oil spill lasted for six months.

A response system for oil spill and mitigation in Bohai Sea was organized and set up by several departments, such as SOA for the accidents in oil exploitation, traffic department for the tanker oil spill, and MoA for the aquaculture area. However, its response capability is not enough to deal with the incremental dangers of oil spill accidents in Bohai Sea and its response time is too long. In 1993, two oil tanks crashed and 800 T of oil was leaked into Bohai Sea. The spilled oil was diffused to maricultured regions and caused tremendous economic loss and long-term ecological effects on the living resources.

Table 75. RQs for Total PAHs in Sediment.

Agent	MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	PNEC (mg/kg)	RQ_{Ave}	RQ_{Max}
∑ PAHs	0.8772	5.5342	4.0220	0.22	1.38

Source: SOA, 2000.

Table 76. RQs for Total PAHs in Shellfish Tissue.

Agent	MEC_{Ave} (mg/kg)	MEC_{Max}(mg/kg)	LOC (mg/kg)	RQ_{Ave}	RQ_{Max}
∑ PAHs	10.4	20.1	n/a		

Source: SOA, 2000.

A predicting system for oil spill has been set up in Bohai Sea, which makes use of verified models for both hydrodynamics and oil behavior and gives out predicted information, including position, covered area, and distribution of oil spill.

HARMFUL ALGAL BLOOMS (HABS)/ TOXIC ALGAE

HABs

HABs have occurred frequently in recent years, especially in Liaodong Bay and Bohai Bay, where 60 percent of the HABs occurred in Bohai Sea. HABs have occurred 2.3 times per year in Liaodong Bay, and 1.3 times in Bohai Bay in the past decades. The main HABs are listed in Table 77.

Figure 45 shows very few HAB incidents before 1990 and with a number of HABs after 1990. There were 14 HAB incidents in 1999.

When HAB occurs, the energy flow of the ecosystem will be blocked at the phytoplankton level, and will cause the crash of the pelagic ecosystem, which is usually followed by oxygen depletion in the water column. If the toxic species bloom, much toxin will then be produced which will be accumulated in shellfish tissues and do harm to human health (Figure 46).

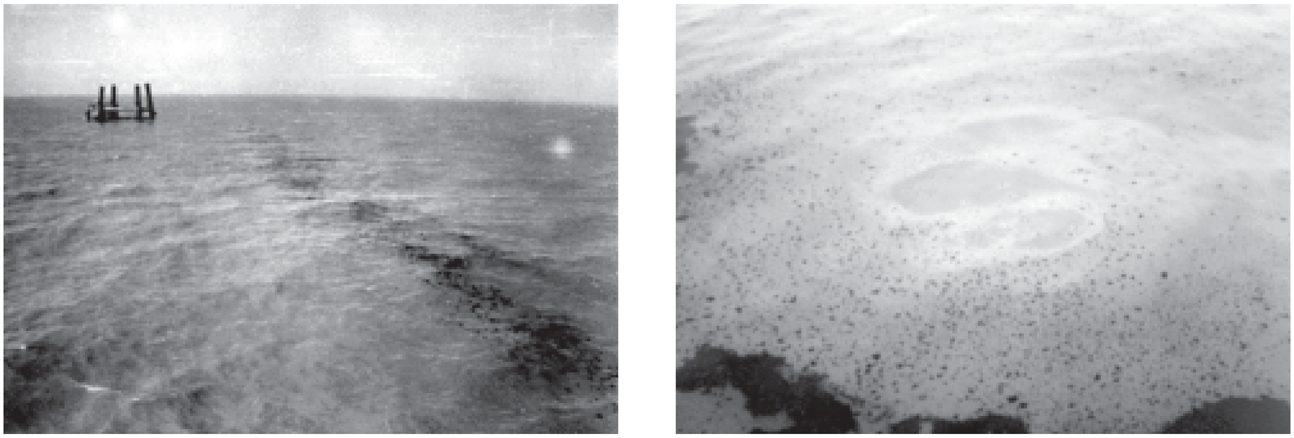
Figure 42. **CB6A Oil Derrick of Shengli Oil Field Collapse.**

Source: SOA, 2000.

Figure 43. **Knocked Oil Tanker with Spilled Oil.**

Source: SOA, 2000.

Figure 44. **Spilled Oil from the CB6A Wells of Shengli Oil Field (10 June 1999).**



Source: SOA, 2000.

There were massive HABs along the shore area in Hebei Province from August to September 1989. As large as 1.5x10^4 ha of shrimp ponds were affected and about 10,000 tons of shrimps suffered in the tide. The total loss amounted to RMB 300 million (US$36 million). It was the most disastrous and long-lasting HAB incident in China. Another incident was the HABs that occurred in Liaodong Bay in August 1995, which caused the death of breed aquatics in some sea areas.

The disaster happened again in 1998. The HABs occurred first in Liaodong Bay, and spread to Bohai Bay and Laizhou Bay, with the area expanding to 5,000 km^2 in September. The dominant species was *ceratium*, the maximum cell density of which was 1.25×109 cells/m^3. The alga is nontoxic but usually makes waters anoxic.

Figure 47 shows the area where HABs took place in the past 10 years. Almost all the areas had HAB incidents except the central part of Bohai Sea. An area of 25,000 km^2 in the east part of Jinzhou Bay suffered from HAB occurrences and the economic loss reached RMB 60 million (US$7 million).

Toxic Algae

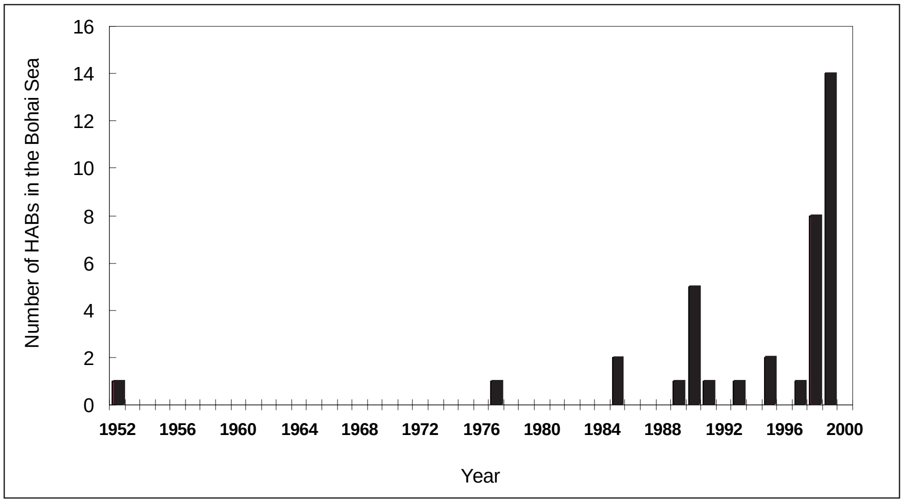
Some known toxic algae species in Bohai Sea are listed in Table 78. None of the toxic algae has ever bloomed in Bohai Sea, although some species have bloomed and produced toxins in other regions. Diarrhetic shellfish poisoning (DSP) is the toxin of most concern, followed by paralytic shellfish poisoning (PSP). When HABs occurred in Liaoning Province, even other harmless seafood was unmarketable, which led to

Table 77. Main HAB Occurrences.

Year	Month	Location	Area (km^2)	Species
1952	June	Laizhou Bay	1,400	*Noctiluca scintillans*
1977	August	Bohai Bay	560	*Prorocentrum minimum*
1985	June/August	Liaodong Bay	Unknown	*Dinophysis*
1989	August/September	Bohai and Laizhou Bays	1,300	*Dinophysis*
1990	June/July	Bohai Bay	10	*Noctiluca*
1990	August	Laizhou Bay	10	Unknown
1990	August	Laizhou Bay	1,200	Unknown
1990	August	Laizhou Bay	1,000	Unknown
1990	September	Laizhou Bay		Unknown
1991	July	Liaodong Bay	100	Unknown
1993	August	Liaodong Bay	40	Unknown
1995	June	Laizhou Bay	90	*Noctiluca scintillans*
1995	August	Laizhou Bay	100	Unknown
1997	April	Laizhou Bay	Unknown	Unknown
1998	August/September	Laizhou Bay	Unknown	*Noctiluca ceratium*
1998	September	Laizhou Bay	Unknown	*Noctiluca ceratium*
1998	September/October	Bohai Sea	Unknown	*Noctiluca ceratium*
1998	September	Liaodong Bay	Unknown	*Noctiluca ceratium*
1998	September	Liaodong Bay	Unknown	*Noctiluca ceratium*
1998	October	Bohai Bay	Unknown	*Noctiluca ceratium*

Source: Agriculture Department and ADB, 2000.

Figure 45. HAB Occurrence in Bohai Sea (1952-1999).



Source: Agriculture Department and ADB, 2000.

unnecessary economic loss. The phenomenon in other regions is called "inordinate response."

Diarrhetic Shellfish Poisoning

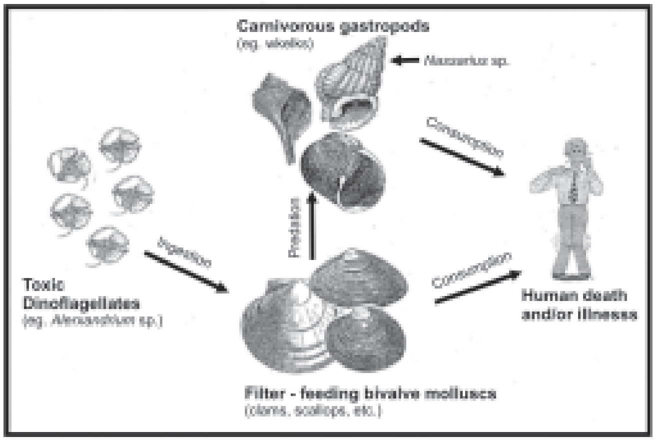
In November 1998, several kinds of bivalve samples in Liaodong Bay were determined positive for DSP. The DSP in digestive gland of *Chlamys farreri* and *Meretrix meretrix* were 16.8 µg OA/g and 8.6 OA/g respectively (Agriculture Department and ADB, 2000). According to the DSP ingestion standard in Japan, DSP in the digestive gland of shellfish should not exceed 2.5 µg OA/g, thus the RQs for DSP in digestive gland of *Chlamys farreri* and *Meretrix meretrix* are 6.72 and 3.44 respectively. Actions should be taken immediately to control the risks of DSP.

Paralytic Shellfish Poisoning

In September 1997, PSP in clams was 133 µg STXeq/kg tissue in Yantai City (Agriculture Department and ADB, 2000.) With the maximum PSP concentration level of 80 µg STXeq/100g tissue to the human body (Sanitation Department, 1988), the RQ is 1.66. In addition, *Alexandrium monilata* and many species of the same genus were reported poisonous.

PSP in shellfish could affect its domestic sale and export. The European Community (EC) has forbidden live shellfish importation since 1997 because the International Food Safety and Quality Regulation has not yet been implemented in China. Shellfish export to EC account for 11 percent of the total shellfish export in 1995, dropping to 3.3 percent in 1998.

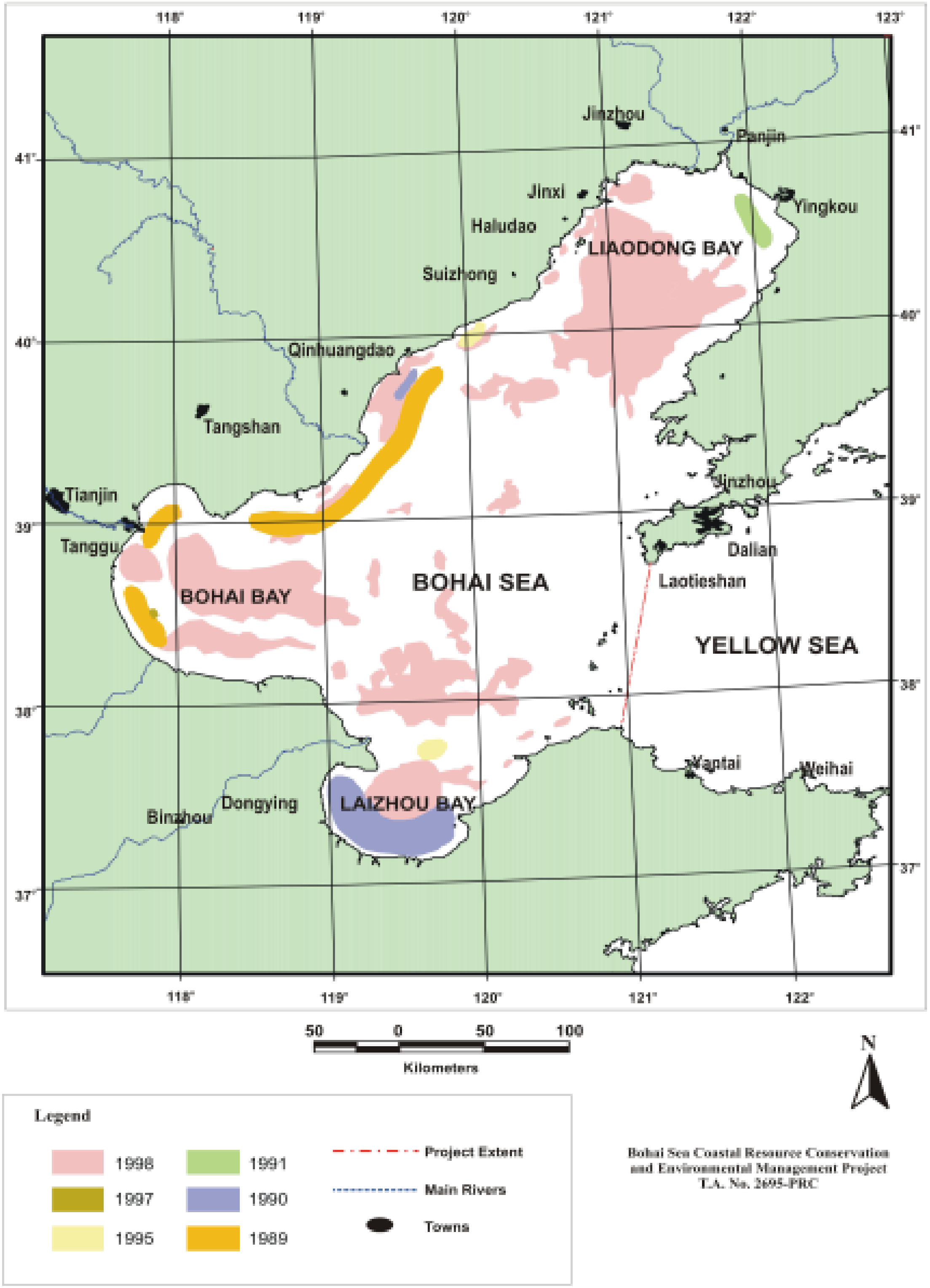
Figure 46. Poisoning Path of PSP to the Human Body.



* *In China,* Nassarius *is the main source of PSP toxin to the human body.*

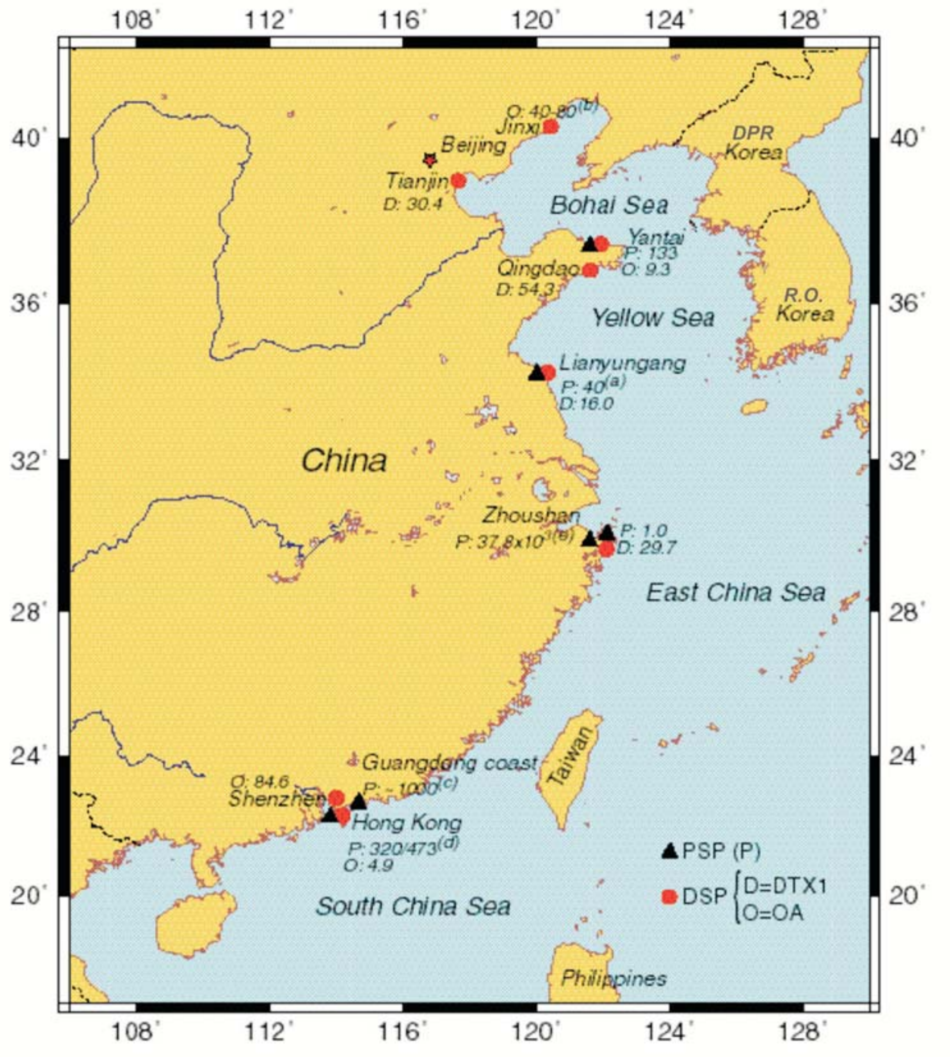
Source: Agriculture Department and ADB, 2000.

Figure 47. HABs in the Bohai Sea from 1989 to 1998.



Source: Agriculture Department and ADB, 2000.

Figure 48. Highest DSP/PSP Content Locations in China.



Source: Agriculture Department and ADB, 2000.

Table 78. Some Known Toxic Algae Species and Its Effects.

	DSP	NSP	PSP	ASP	other	Fish killed	Shellfish killed	Mammal Or Bird Killed	Anoxia	References
Alexandrium monilata			X			?	X	(M) (B)		Shumway, et al.，1987
C. fusus , C. tripos *Ceratium furca*					?	X	X			Rensel and Prentice, 1980; Cardwell, et al.，1977
Chaetoceros spp.						X				Bruno, et al., 1989；Rensel, 1992, 1993
Gonyaulax sp.					?	X	X			Kim, 1998; Yuki and Yoshimatsu, 1989
Dinophysis ovum Schutt	X									Kat 1985; Shumway, 1990
Gonyaulax polygramma						X			X	Lam and Yip, 1990; Grindley and Taylor, 1962
Gymnodinium breve						X	X	X		Steidinger, et al., 1998
Gymnodinium mikimotoi					X	X	X		?	Matsuyama, et al., 1998
Heterosigma akashiwo					?	X				Gowen, et al., 1982;Taylor and Haigh, 1993
Leptocylindrus minimus					?	X				Clement and Lembeye, 1994
Noctiluca scintillans					X	X				Okaichi and Nishio, 1976
Prorocentrum minimum					?		X		X	Wikfors and Smolowitz, 1993, 1995；Lukenbach, et al., 1993; Cassie, 1981; Tangen, 1983
P. micans									X	Hallegraeff, 1991
Nitzschia spp.				X			X	X		Bates, etc., 1989; Jones, et al., 1995a，b; Martin, et al., 1990；Haya, et al., 1991
Skeletonema costatum						X			X	Kent, et al., 1995
Thalassiosira spp.						X				Kent, et al., 1995
Trichodesmium erythraeum					?				X	Hawser, et al.,1991; Suvapepun, 1989

Source: Agriculture Department and ADB, 2000.

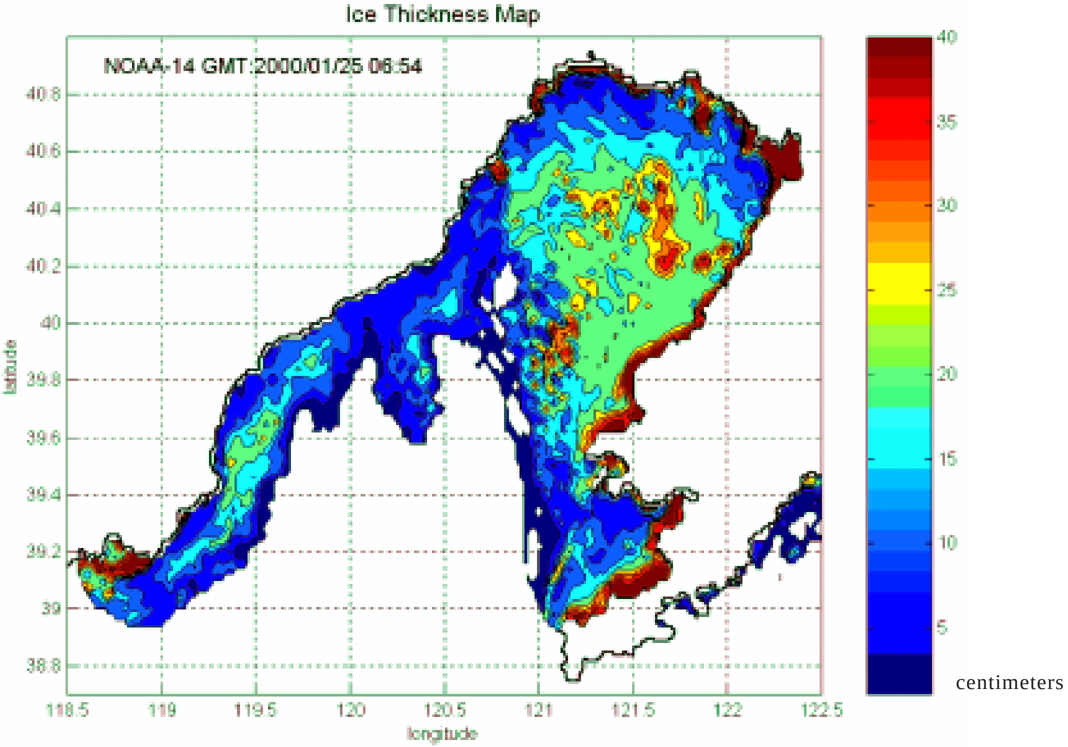
SEA ICE

Frost usually appears in Bohai Sea every year from November to March and mainly in terms of drift ice.

There were five serious sea ice disasters in the 20th century, with the most serious occurring from January to March 1969. The whole Bohai Sea, except the Strait, was covered by drift ice. Oil platforms were pushed over, 58 of the 123 passenger liners/cargo ships were blocked, and a screw propeller of a 50 thousand-tonnage ship was destroyed by draft ice. The direct loss amounted to several hundred millions of RMB. The extent of sea ice in 2000 is shown in Figure 49. Sea ice in Liaodong Bay is the most serious among the three bays with the thickness of 20–40 cm and maximum monolayer ice as thick as 80 cm.

Sea ice in China originates from Liaodong Bay. Sea ice characteristics in the three bays are shown in Table 79. Sea ice is very common and occurs every year in Bohai Sea. Risk of ice is very high and loss to the economy is huge.

Figure 49. Ice Thickness Map of Bohai Sea on 25 January 2000.



Source: SOA, 2000.

Table 79. Sea Ice Characteristics in the Three Bays.

	Frost time	Ice period (day)	Distance of draft ice to shore	Fixed Ice
Liaodong Bay	Mid November/early December	105–130	West 18 km, East 24 km, North 74 km	
Bohai Bay	Early/mid December	65	10–20 km	North 3–4 km, South 2 km
Laizhou Bay	Early/mid December	75	Along 5 m-deep line	Estuary and West 0.5–2 km

Source: SOA, 2000.

Figure 50. Maritime Engineering Structure Damaged by Sea Ice.

Source: SOA, 2000.

A kind of dynamic-thermodynamic ice model for simulation of the ice growth, decay and drift in Bohai Sea is presented for review of the climate and ice conditions. This model was linked to a numerical weather prediction with an atmospheric boundary layer model and tidal current model for forecasting ice conditions in Bohai Sea.

WINDSTORM

Most windstorms in Bohai Sea arise from Temperate Zone cyclones, others are by typhoons. Laizhou Bay and Bohai Sea coast are the main regions that experience windstorms.

Windstorms due to Temperate Zone Cyclone

According to statistics for the past 40 years, the variable zone storms are as many as 50 times, which is 78 percent of the total windstorms.

A Temperate Zone windstorm is aroused by westerly weather. Yellow Sea and the Bohai Sea coastlands are the main suffering regions, with Laizhou Bay coastland as the most seriously affected area. Temperate Zone windstorms in Laizhou Bay happen mostly in spring, autumn and winter.

Based on high tide records from 1952 to 1999 of the Yangjiaogou Hydrological Station, downriver of the Xiaoqinghe River, the maximum tide exceeded 5.1 m for 56 times, and 50 (89 percent) of which occurred in spring, autumn and winter as shown in Table 80. The top seasonal storms occurred 23 times in autumn (41 percent). Tides higher than 6 m occurred four times during the past 48 years, which resulted in huge disasters — once in September while the other three were all in April, showing that serious windstorms are most likely to happen in April in Laizhou Bay.

Table 80. Monthly Temperate Zone Windstorm in Laizhou Bay.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Times	2	5	5	9	3	0	2	4	5	9	9	3
Percentage	3.6	8.9	8.9	16.1	5.4	0	3.6	7.1	8.9	16.1	16.1	5.3

Source: FIO, 2003.

Table 81. Serious Windstorms in Laizhou Bay and Bohai Bay.

Date	Region	Max Wind Speed (m/s)	Max Tide Height (m)	Max Water Level (m)
1964 (April 5)	Laizhou Bay	26.4 (Yantai)	3.21	6.16
1965 (November 7)	Bohai Bay	22.8 (Yangjiaogou)	1.94	4.72
1966 (February 10)	Bohai Bay	25.4 (Yantai)	2.38	-
1969 (April 23)	Laizhou Bay	34.9 (Yangjiaogou)	3.55	6.74
1980 (April 5)	Laizhou Bay	31.3 (Yangjiaogou)	-	-
1987 (November 26)	Laizhou Bay	-	2.46 (Xiaying)	2.90

Source: SOA, 2000.

Typhoon Windstorm

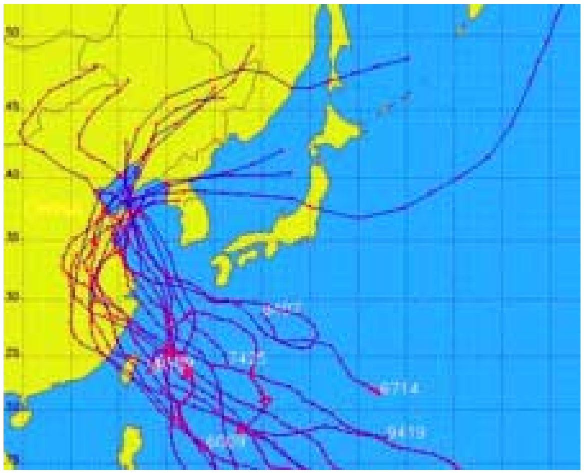
There have been 20 relatively serious typhoon windstorms in Laizhou Bay since 1949. From 1949 to 1980, there were 11 windstorms, 9 of which were very serious. From 1981 to 2000, there were nine windstorms, six of which were very serious.

Table 81 shows that Laizhou Bay and Bohai Bay are the areas where windstorms are the most serious. Though the data was recorded in the 1960s, the phenomenon caused by the weather may not be greatly dissimilar.

Figure 51 shows the typhoon windstorms in the past 50 years in Laizhou Bay.

Figure 52 shows the most severe typhoon windstorm caused by typhoon No. 9216 on 23 April 1969. The highest sea level reached 6.74 m in Laizhou Bay and the maximum increased water was 3.55 m and 1.74 m above the critical water line. The enhancive water over 1 m lasted 38 hours and those over 3 m lasted 8 hours. Water level rose over 3 m in the south seacoast of Laizhou Bay, which broke the more than 50-km sea dam and pouring seawater back 30–35 km. The loss reached RMB 5 billion (US$600 million).

Figure 51. Typhoons Touching Laizhou Bay (1945–1997)



Source: FIO, 2003.

Figure 52. Windstorm by Typhoon No. 9216.

Source: FIO, 2003.

Comparative Risk Assessment

Comparative risk assessments for the range of agents of potential concern for Bohai Sea have been carried out separately for water, sediment and seafood tissue. The results of these analyses are summarized in Tables 82–87. The comparative risk assessments also highlighted data gaps in terms of lack of MECs and criteria.

Risk agents are classified either as priority risks or localized risks. Priority risk agents were determined on the basis of RQ_{Ave} exceeding 1. Localized risks were indicated by RQ_{Max} that exceeded 1. The ranking of priority or localized risks was done based on the order of magnitude of RQs as presented in the comparative RA tables. Agents for which risks are acceptable ($RQ_{Max} < 1$) are also presented.

SEAWATER

The assessment was made on 7 groups and 13 kinds of agents in seawater in Bohai Sea and their risk quotients were calculated (Table 82). Average RQs for fecal coliform, TSS, Pb and oil of these 13 agents exceeded the critical value, which showed that these are the most serious pollutants in the whole Bohai Sea. However, in addition to these three

Table 82. Refined Risk Assessment Summary for Water Column.

No.	Agents	MEC_{Ave}	MEC_{Max}	PNEC	RQ_{Ave}	RQ_{Max}
	Nutrients (mg/l)					
1	DIN	0.250	7.700	0.3	0.83	25.67
2	DIP	0.019	0.355	0.03	0.63	11.83
	COD/DO (mg/l)					
3	COD	1.740	10.7	3	0.58	3.57
4	DO	10.090	6	5	0.50	0.83
5	**Fecal Coliform (ind/l)**					
	Laizhou Bay	733	2,400	2,000	0.37	1.2
	Yellow River estuary	11,362	24,000	2,000	5.68	12
	Beidaihe	18,487	48,000	2,000	9.24	24
	Panjin	353	620	2,000	0.18	0.31
6	**TSS (mg/l)**					
	Jinzhou Bay	249.6	464	50	4.99	9.28
	Metals (mg/l)					
7	Hg	0.000027	0.0001	0.0002	0.14	0.50
8	Cu	0.00389	n/a	0.01	0.39	
9	Pb	0.00557	0.0326	0.005	1.11	6.52
10	Cd	0.00083	0.0161	0.005	0.17	3.22
	Pesticides (mg/l)					
11	DDT	n/a	n/a	0.0001		
12	666	n/a	n/a	0.002		
13	**Oil (mg/l)**	0.1	0.22	0.05	2.00	4.40

contaminants, DIN, DIP, COD and Cd have RQ_{Max} that exceeded 1. There were no MECs available for water column concentrations of DDT and 666, and no MEC_{Max} of Cu. The criterion for TSS was the interim standard adopted by the Department of Environment in Malaysia in MPP-EAS, 1999a.

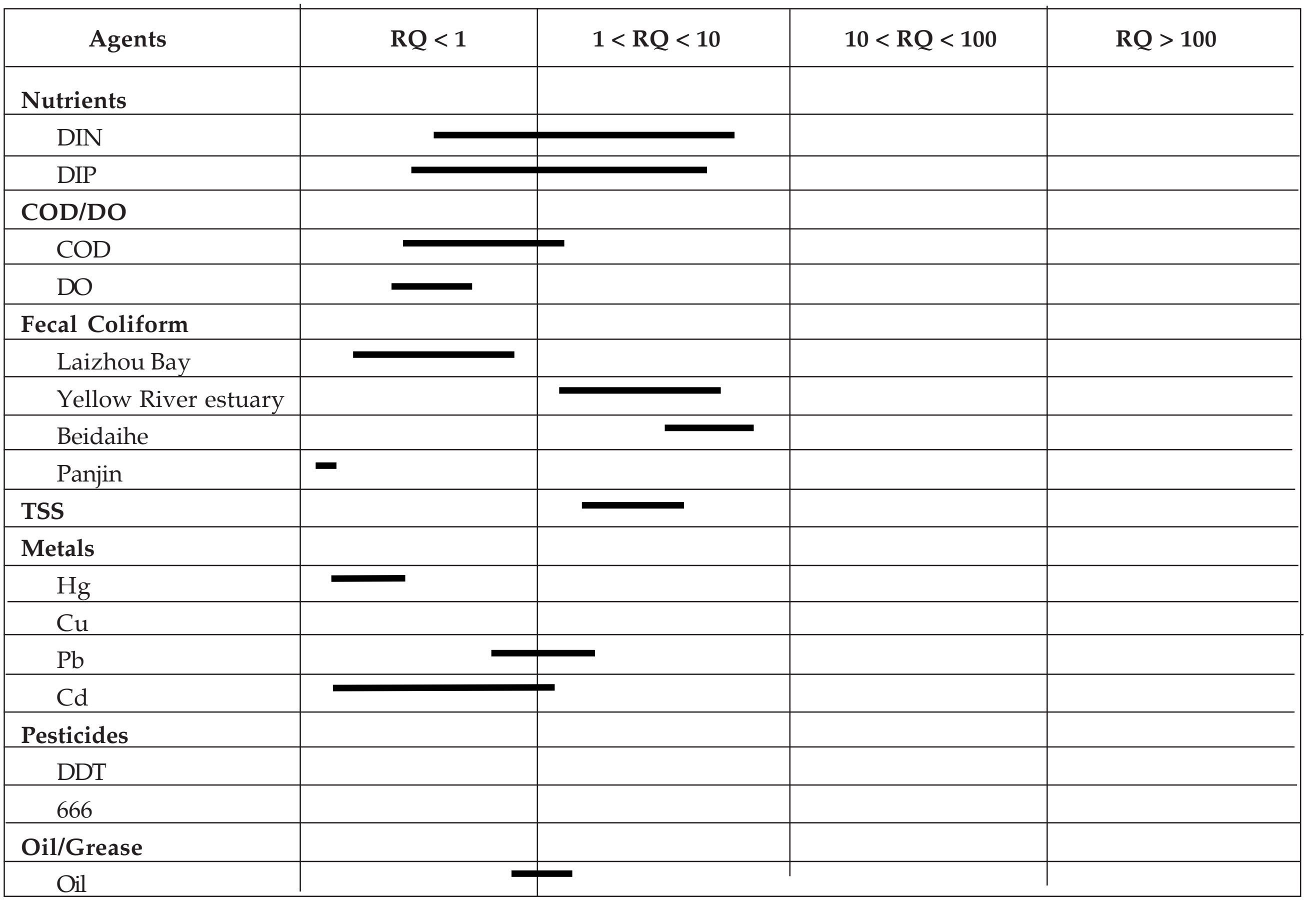
In Table 83, the range of RQs (from average to maximum) across pollutants was compared in the order of magnitude of RQ. It is clear that for water columns, risks to the ecology of Bohai Sea associated with fecal coliform and TSS, Pb and oil are priority concerns. For nutrients, COD and Cd in the water column, the maximum RQs exceeding 1 indicate localized risks from potential hotspots.

SEDIMENT

From Table 84, it is clear that no contaminants for which sediment data were available had average RQs exceeding the critical threshold of 1 except for pesticides. RQ_{Ave} for DDT and 666 are both over the critical level, which means high risk from those pesticides. Cd, Hg and Cu have maximum RQs that exceed 1.

Table 85 compares the range of RQs (from average to maximum) across sediment-associated contaminants in the order of magnitude of RQs. It is clear that the sediment risks to the ecology of Bohai Sea are associated with pesticides, heavy metals and PAHs in this order.

Table 83. Comparative Risk Assessment for Water Column Based on RQ_{Ave} to RQ_{Max}.



Human Health

Table 86 shows the summary of risk assessment for human health. For shellfish, fecal coliform shows high health risk in Beidaihe (RQ_{Ave} = 1.48), DSP and PSP also show quite high health risks. People also need to take care of the DDT and Pb in shellfish, because their maximum RQs exceed 1. For seaweeds, Pb needs urgent concern since its RQ_{Ave} is 1.38. However, there is no cause for concern in fish tissue, because their RQs did not reach critical levels. The assessment, however, needs to be refined using local TDIs instead of the U.S. TDI with the application of more specific consumption rates for various seafood items. There was no LOC available for oil and PAHs.

Table 87 compares the range of RQs (from average to maximum) for contaminants in seafood tissues in the order of magnitude of RQs. It is clear that seafood risks to human health are very low except for fecal coliform, Pb, DSP and PSP. However, cumulative action should not be neglected for these risks.

Table 84. Refined Risk Assessment Summary for Sediment.

Agents	MEC_{Ave} (mg/kg)	MEC_{Max} (mg/kg)	PNEC (mg/kg)	RQ_{Ave}	RQ_{Max}
Metals					
Hg	0.06	0.57	0.2	0.30	2.85
Cu	22.80	45.6	35.0	0.65	1.30
Pb	18.30	29.1	60.0	0.31	0.49
Cd	0.27	2.28	0.5	0.54	4.56
Pesticides					
DDT	0.1	n/a	0.02	5.0	n/a
666	55.6	n/a	0.50	111.2	n/a
Oil	61.40	350.53	500	0.12	0.70
PAHs	0.8772	5.5342	4.0220	0.22	1.38
TSS	8.25	43.67	50	0.17	0.87

Table 85. Comparative Risk Assessment for Sediment Based on RQ_{Ave} to RQ_{Max}.

Agents	RQ < 1	1 < RQ < 10	10 < RQ < 100	RQ > 100
Metals				
Hg				
Cu				
Pb				
Cd				
Pesticides				
DDT		●		
666				●
Oil				
PAHs				
TSS				

EXPOSURE ASSESSMENT

Exposure assessment is the aspect of risk assessment that determines the actual level of exposure and absorption of toxicants among the population of exposed individuals.

The use of RQs in human health risk assessments has its limitations, as threshold values below which no adverse effects appear for all the contaminants in the RRA. All the TDI values used here were based on U.S. FDA standards. In adopting these TDIs, it is assumed that relative toxicity, persistence and bioaccumulation are factored into the TDI. Further, most of the available TDI values are for adults while children are generally considered the more sensitive group since their body weights are less those of adults. Hence, the relative risks to children are considerably higher. This is an important consideration in assessing and prioritizing human health risks to certain contaminants such as heavy metals and pesticides.

Table 86. Risk Assessment Summary for Human Health.

Agent	MEC$_{Ave}$	MEC$_{Max}$	PNEC/ LOC	RQ$_{Ave}$	RQ$_{Max}$	Location
Fecal Coliform in Shellfish (ind./kg)						
	4,428	13,000	3,000	1.48	4.33	Beidaihe
Metals in Shellfish (mg/kg)						
Hg	0.020	n/a	0.59	0.03	n/a	Tianjin and Dalian
Cu	13.005	19.500	74.07	0.18	0.26	Tianjin and Dalian
Pb	1.785	3.510	2.78	0.64	1.26	Tianjin and Dalian
Cd	0.475	0.870	2.04	0.23	0.43	Tianjin and Dalian
Metals in Fish (mg/kg)						
Hg	0.08	0.09	0.59	0.14	0.15	Tianjin
Cu	1.58	2.5	74.07	0.02	0.03	Laizhou Bay
Pb	0.93	1.52	2.78	0.33	0.55	Laizhou Bay
Cd	0.44	0.62	2.04	0.22	0.30	Laizhou Bay
Metals in Seaweed (mg/kg)						
Hg	0.065	0.09	0.59	0.11	0.15	Dalian and Yantai
Cu	5.16	7.88	74.07	0.07	0.11	Dalian and Yantai
Pb	3.84	7.18	2.78	1.38	2.58	Dalian and Yantai
Cd	1.25	1.63	2.04	0.61	0.80	Dalian and Yantai
Pesticides in Shellfish (mg/kg)						
As	1.13	3.12	4.81	0.23	0.65	Liaodong Bay
As	1.02	1.89	4.81	0.21	0.39	Bohai Bay
As	0.76	1.43	4.81	0.16	0.30	Laizhou Bay
DDT	2.83	13.27	2.96	0.96	4.48	Bohai Sea
Oil in Shellfish (mg/kg)						
Oil	14.3	80.5	No LOCs			
PAHs in Shellfish (mg/kg)						
PAHs	10.4	20.1	No LOCs			
DSP in Shellfish						
Chlamys farreri	16.8µg OA/g		2.5µg OA/g	6.72		
Meretrix meretrix	8.6µg OA/g		2.5µg OA/g	3.44		
PSP in Clams	1.33 µg STXeq/g		0.8 µg STXeq/g	1.66		Yantai

Aside from the uncertainties introduced by the absence of age-specific local TDIs that can be used in calculating RQs, actual exposure to these contaminants are inferred through the use of the average consumption rate without regard to sub-populations such as the coastal population that may consume more seafood.

The levels of exposure are measured based on the frequency and duration of exposure as well as the levels of contaminants in the exposure media such as soil, water, air and food. Actual absorption is determined by toxicological studies.

For the RRA, four groups (general population, children, pregnant women and lactating mothers) were identified as the population most at risk from the effects of the contaminants present in the sea.

$$\text{Exposure} = \frac{Concentration * daily\ intake}{body\ weight}$$

This expresses milligram toxicant per kilogram body weight per day (mg/kg/day).

Based on the formula, the exposure of children is higher under the same conditions than adults

Table 87. Comparative Risk Assessment for Human Health.

Agents	RQ < 1	1 < RQ < 10	10 < RQ < 100	RQ > 100	Location
Heavy Metals in Shellfish					
Hg	●				Tianjin and Dalian
Cu	—				Tianjin and Dalian
Pb	—				Tianjin and Dalian
Cd	—				Tianjin and Dalian
Heavy Metals in Fish					
Hg	—				Tianjin
Cu	—				Laizhou Bay
Pb	—				Laizhou Bay
Cd	—				Laizhou Bay
Metals in Seaweed					
Hg	—				Dalian and Yantai
Cu	—				Dalian and Yantai
Pb		—			Dalian and Yantai
Cd	—				Dalian and Yantai
Pesticides in Shellfish					
As	—				Liaodong Bay
As	—				Bohai Bay
As	—				Laizhou Bay
DDT	—	—			Bohai Sea
Oil in Shellfish					
PAHs in Shellfish					
DSP in Shellfish		—			*Chlamys farreri* and *Meretrix meretrix*
PSP in Clams		●			Yantai
Fecal Coliform in Shellfish		—			Beidaihe

due to differences in body weight. For lack of data on the consumption rates of children, pregnant women and lactating mothers, the exposure dose for several contaminants cannot be calculated yet.

Liaodong Bay

From Table 88, it is clear that data of all contaminants of water column and sediment are available, and only DIN, COD and Pb in water and Cd in sediment have average RQs exceeding the critical threshold. However, in addition to these four contaminants, DIP and Cd in water as well as Hg in sediment have maximum RQs that exceed 1.

Table 89 compares the range of RQs (from average to maximum) across contaminants in order of magnitude of RQ. It is clear that for Liaodong Bay, the nutrients, especially DIN, pose relatively high risks to ecology followed by Pb and COD in the water and Cd in sediments. Localized risks were shown for DIP and Cd in water and Hg in sediments, but the relatively high RQ_{Max} for DIP indicates cause for concern. Reducing risk from nutrients should be given priority concern.

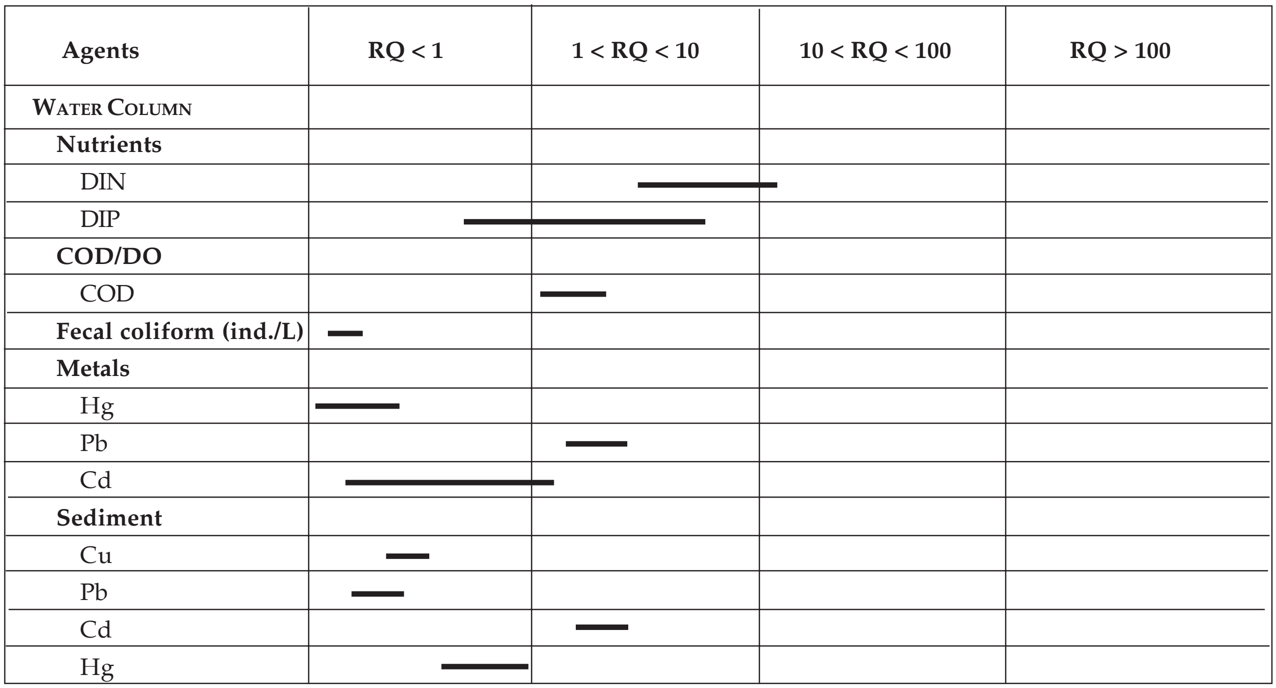
Bohai Bay

From Table 90, based on available data on contaminants for water column and sediments, fecal coliform in the water column and Cu in sediment gave RQ_{Ave} exceeding the critical threshold of 1. High average and maximum RQs were obtained for fecal coliform. The nutrients (DIN, DIP) and Pb in water have maximum RQs that exceed 1.

Table 88. Refined Risk Assessment Summary for Liaodong Bay.

Agents	**MEC_{Ave}**	**MEC_{Max}**	**PNEC**	**RQ_{Ave}**	**RQ_{Max}**
Water Column					
Nutrients (mg/L)					
DIN	1.61	7.70	0.3	5.37	25.67
DIP	0.026	0.355	0.03	0.87	11.83
COD/DO (mg/L)					
COD	3.16	10.7	3	1.05	3.57
Fecal coliform (ind./L)					
353	620	2,000	0.18	0.31	
Metals (mg/L)					
Hg	0.00003	0.0001	0.0002	0.15	0.50
Pb	0.00698	0.0326	0.005	1.40	6.52
Cd	0.00168	0.0161	0.005	0.34	3.22
Sediment (mg/kg)					
Cu	15.3	21.9	35 0.44	0.63	
Pb	16.8	29.1	60 0.28	0.49	
Cd	0.934	2.28	0.5	1.87	4.56
Hg	0.169	0.50	0.2	0.85	2.50

Table 89. Comparative Risk Assessment for Liaodong Bay.



Agents	RQ < 1	1 < RQ < 10	10 < RQ < 100	RQ > 100
WATER COLUMN				
Nutrients				
DIN		▬	▬	
DIP	▬	▬		
COD/DO				
COD		▬		
Fecal coliform (ind./L)	▬			
Metals				
Hg	▬			
Pb		▬		
Cd	▬	▬		
Sediment				
Cu	▬			
Pb	▬			
Cd		▬		
Hg	▬			

Table 90. Refined Risk Assessment Summary for Bohai Bay.

Agents	MEC_{Ave}	MEC_{Max}	PNEC	RQ_{Ave}	RQ_{Max}
WATER COLUMN					
Nutrients (mg/L)					
DIN	0.23	1.03	0.3	0.77	3.43
DIP	0.022	0.197	0.03	0.73	6.57
COD/DO (mg/L)					
COD	1.32	2.3	3	0.44	0.77
Fecal Coliform (ind./L)	18,487	48,000	2,000	9.24	24.0
Metals (mg/L)					
Hg	0.000033	0.000068	0.0002	0.17	0.34
Pb	0.00245	0.0131	0.005	0.49	2.62
Cd	0.00008	0.00025	0.005	0.02	0.05
Sediment (mg/kg)					
Cu	36.2	45.6	35	1.03	1.30
Pb	16.8	22.6	60	0.28	0.38
Cd	0.141	0.238	0.5	0.28	0.48
Hg	0.031	0.050	0.2	0.16	0.25

Table 91 compares the range of RQs (from average to maximum) across contaminants in the order of magnitude of RQ. Bohai Bay risks to the ecology of Bohai Sea are mainly associated with fecal coliform, nutrients (DIN, DIP) and Pb in water column and Cu in sediment.

LAIZHOU BAY

From Table 92, it is clear that except for fecal coliform in the water column, no other contaminant in the water column and sediment has an RQ_{Ave} exceeding the critical level of 1. COD and Pb in water have maximum RQs that exceed 1.

Table 93 compares the range of RQs (from average to maximum) across contaminants in the order of magnitude of RQ. It shows that the risk brought by Laizhou Bay to the ecology of Bohai Sea is very low. Human health risk is however presented by the high RQs for fecal coliform in the water column.

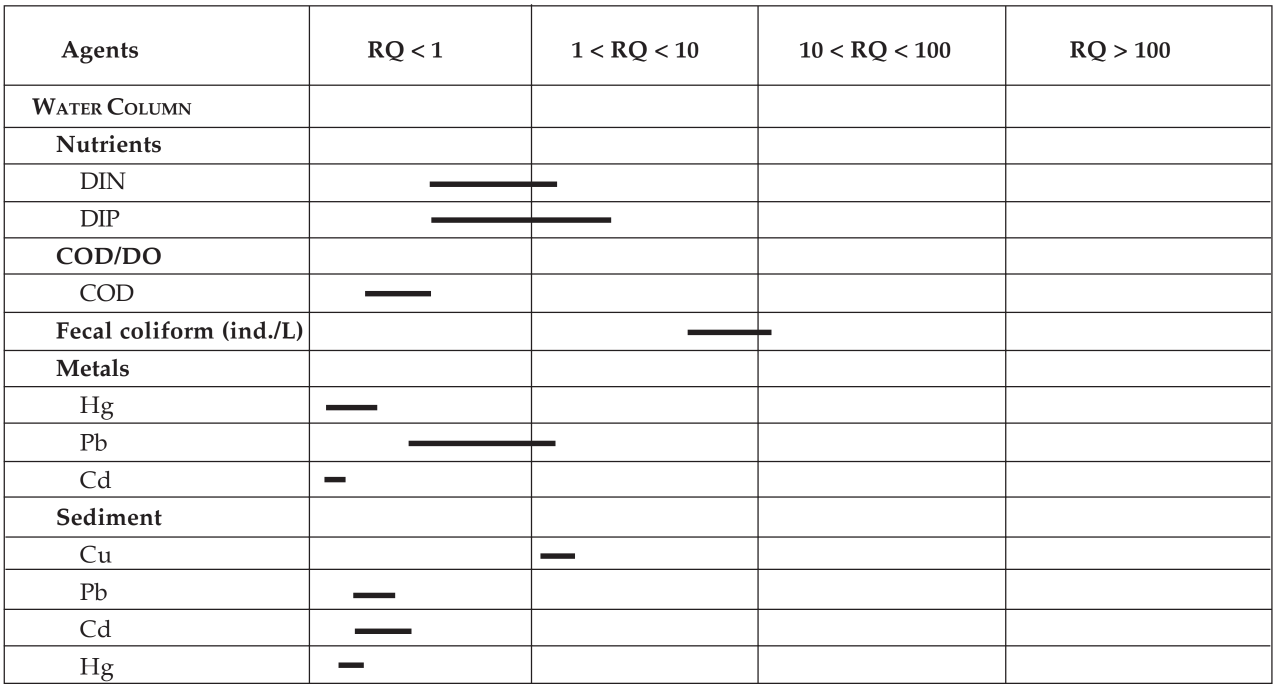
CENTRAL PART OF BOHAI SEA

From Table 94, it is clear that no contaminant in the water column and sediment of the center part of Bohai Sea has average or maximum RQs exceeding the critical threshold. However, Cu in sediment has RQ_{Max} approaching 1.

Table 95 compares the range of RQs (from average to maximum) across contaminants in the order of magnitude of RQ. It is clear that the risks from the central part of Bohai Sea to the Bohai Sea ecology is very low.

Based on the above analysis, it may be concluded that the seawater and sediment of Liaodong Bay and Bohai Bay were more

Table 91. Comparative Risk Assessment for Bohai Bay.



Agents	RQ < 1	1 < RQ < 10	10 < RQ < 100	RQ > 100
WATER COLUMN				
Nutrients				
DIN	▬	▬		
DIP	▬	▬		
COD/DO				
COD	▬			
Fecal coliform (ind./L)		▬	▬	
Metals				
Hg	▬			
Pb	▬	▬		
Cd	▬			
Sediment				
Cu		▬		
Pb	▬			
Cd	▬			
Hg	▬			

Table 92. Refined Risk Assessment Summary for Laizhou Bay.

Agents	MEC_{Ave}	MEC_{Max}	PNEC	RQ_{Ave}	RQ_{Max}
WATER COLUMN					
Nutrients (mg/L)					
DIN	0.091	0.202	0.3	0.30	0.67
DIP	0.004	0.005	0.03	0.13	0.17
COD/DO (mg/L)					
COD	1.68	3.6	3	0.56	1.20
Metals (mg/L)					
Hg	0.000025	0.00008	0.0002	0.13	0.40
Pb	0.00134	0.005	0.005	0.27	1.00
Cd	0.00006	0.0001	0.005	0.01	0.02
Fecal Coliform (ind./L)					
Laizhou Bay	733	2,400	2,000	0.37	1.2
Yellow River estuary	11,362	24,000	2,000	5.68	12.0
Sediment (mg/kg)					
Cu	19.1	26.8	35	0.55	0.77
Pb	15.0	23.2	60	0.25	0.39
Cd	0.063	0.080	0.5	0.13	0.16
Hg	0.044	0.074	0.2	0.22	0.37

Table 93. Comparative Risk Assessment for Laizhou Bay.

Agents	RQ < 1	1 < RQ < 10	10 < RQ < 100	RQ > 100
WATER COLUMN				
Nutrients (mg/L)				
DIN	▬			
DIP	▬			
COD/DO (mg/L)				
COD	▬			
Metals (mg/L)				
Hg	▬			
Pb	▬			
Cd	▪			
Fecal Coliform (ind./L)				
Laizhou Bay	▬			
Yellow River estuary		▬		
Sediment (mg/kg)				
Cu	▬			
Pb	▬			
Cd	▪			
Hg	▬			

Table 94. Refined Risk Assessment Summary for the Central Part of Bohai Sea.

Agents	MEC_{Ave}	MEC_{Max}	PNEC	RQ_{Ave}	RQ_{Max}
Water Column					
Nutrients (mg/l)					
DIN	0.028	0.038	0.3	0.09	0.13
DIP	0.008	0.012	0.03	0.27	0.40
COD/DO (mg/l)					
COD	0.8	0.96	3	0.27	0.32
Metals (mg/l)					
Hg	0.000016	0.000042	0.0002	0.08	0.21
Pb	0.00034	0.00059	0.005	0.07	0.12
Cd	0.00001	0.00015	0.005	0.002	0.03
Sediment (mg/kg)					
Cu	22.1	33.7	35	0.63	0.96
Pb	17.1	23.0	60	0.28	0.49
Cd	0.081	0.141	0.5	0.16	0.28
Hg	0.024	0.045	0.2	0.12	0.23

Table 95. Comparative Risk Assessment for the Central Part of Bohai Sea.

Agents	RQ < 1	1 < RQ < 10	10 < RQ < 100	RQ > 100
Water Column				
Nutrients				
DIN	▬			
DIP	▬			
COD/DO				
COD*	▬			
Metals				
Hg	▬			
Pb	▬			
Cd	▪			
Sediment				
Cu	▬			
Pb	▬			
Cd	▬			
Hg	▬			

severely polluted than the other parts of Bohai Sea.

For the water column, risks to human health associated with fecal coliform and risks to the ecology of Bohai Sea associated with nutrients, Pb and oil are priority concerns. The risks to the ecology of Bohai Sea from sediment-borne contaminants are associated with pesticides and heavy metals. It is clear that seafood risks to human health are associated with fecal coliform, DSP, Pb and PSP.

For Liaodong Bay, nutrients (DIN, DIP), COD and Pb in the water column and Cd in sediment pose relatively high risks to the ecology of Bohai Sea. Bohai Bay risks are mainly associated with nutrients (DIN, DIP) and Pb in the water column and Cu in sediment. Risk to the ecology of Bohai Sea from Laizhou Bay and the central part of Bohai Sea is relatively low, although the human health risk from fecal coliform in the water column in some parts of Laizhou Bay require urgent attention.

Conclusions and Recommendations

RETROSPECTIVE RISK ASSESSMENT

Marine Living Resources

For fisheries, a clear evidence of significant decline in quantity and quality was confirmed. A manifestation of decline in fish quantity is the decline in trawl CPUE from 138.8 kg/net.hr in 1959 to 11.2 kg/net.hr in 1998. Evidence of the deterioration in quality include: 1) the change in trawl catch composition from economically valuable to less valuable species; 2) disappearance/near-absence of some dominant species; and 3) fish sizes have become smaller. The identified primary agent for the significant decline in fishery is overfishing. Other factors such as waste discharges from land- and sea-based activities cannot be excluded.

Most of the maricultured species developed rapidly in the past few years with only shrimp and crab production declining. The fast development of marine cultivation could bring about some adverse effects. The wastewater discharge from farming could pollute the environment, especially BOD and COD pollution. The fast development of farming would occupy more land and/or inter-tidal areas, which could lead to habitat destruction. The reason for the decline in shrimp and crab production was mainly the spread of disease and environmental pollution.

As far as benthos is concerned, evidence of significant decline in quantity and quality was found. The decline in quantity can be confirmed by the large decrease in mean number per haul and mean catch per haul. The deterioration in benthos quality is shown by the change in species composition and change of dominant species from 1982 to 1992. The most important reasons were overfishing and the use of destructive fishing methods. In some coastal waters, discharge of pollutants, e.g., heavy metals and pesticides may have contributed to the decline. Overfishing and habitat pollution caused the degradation of benthic ecosystem and lower biodiversity.

There is evidence for definite decline in the abundance and density of phytoplankton from 1982 to 1992. The retrospective risk assessment indicates that the reasons for decline are the fast development of shellfish culture and environmental pollution.

The biomass of zooplankton in Bohai Sea decreased sharply from 1982 to 1992. One reason for the decline is the decrease in phytoplankton. Another is the fast development of shellfish aquaculture. Increase in zooplankton biomass was observed from 1992 to 1998.

Habitats

For wetlands, the evidence of decline in the total area was found only in Liaohe River Delta Wetland. Although the total area of Yellow River Delta Wetland did not decline, the area of natural wetlands has declined and is seriously damaged. Oil exploitation is the primary reason for the decrease of natural wetlands. The secondary reason may be attributed to land reclamation for conversion into farming lands, reservoirs, ponds, salt-fields and paddy fields.

These two damaged wetlands have caused the following consequences: 1) the service function of the damaged wetland ecosystem will decrease and support less food for other living organisms; and 2) the fragmented wetland provide easily vulnerable and unsafe habitats and/or refuge for waterfowls and other species (local and alien) and birds, such as red-crowned cranes and white cranes, often wintering in the wetland around Bohai Sea may be exposed to their predators; 3) the degradation of wetland decreased its biodiversity and aesthetic function for human entertainment; and 4) the damaged wetland ecosystem decreased its ability to treat waste discharges.

Some beaches around Bohai Sea, which are mainly located in the Liaohe River Delta and Yellow River Delta, have also been lost because of the building of tourism facilities, ports, dams and others structures. But the available data was very limited for a detailed analysis.

Based on historical data, the Bohai Sea coast had been severely eroded, especially in Jinzhou, Tianjin and Laizhou Bays. Human activities are the major reasons for coastal erosion, especially the building of reservoirs in the upriver areas and illegal- and over-excavation of sand in the coastal areas. The natural reasons include seawater intrusion, strong windstorms and sea level rise.

PROSPECTIVE RISK ASSESSMENT

The risk agents were classified into three classes (priority risks, localized risks, and acceptable risks) according to the prospective risk assessment. The standards for this classification are:

If $RQ_{Ave} > 1$, then it is priority risk;
If $RQ_{Max} > 1$, then it is localized risk; and
If $RQ_{Max} < 1$, then it is acceptable risk.

All the agents for ecosystem risks are summarized in Table 96, and all the agents for human health risks are summarized in Table 97. The results showed that TSS, Pb, and Oil belong to the priority of concerned agents in the Bohai Sea. DDT and 666 in the sediment are also in the first priority class. While DIN, DIP, COD, and Cd in the water column are the localized risk agents and should be of concern in some hotspots, as well as Hg, Cu, Cd, and PAHs in sediment. However, DO, Hg, Cu in water and oil, and TSS in the sediment are acceptable, thus concern is minimal.

HAB occurrence has been a persistent problem, with the causes for its occurrence still very unclear. However, the huge nutrient load in recent years maybe one of the main reasons. How to predict and prevent HABs is now becoming a grim problem

Table 96. Risk Classification for the Bohai Sea Ecosystem.

	Priority Risks	Localized Risks	Acceptable Risks
Water Column	• TSS • Pb • Oil	• DIN, DIP • COD • Cd	• DO • Hg • Cu
Sediment	• DDT • 666	• Hg • Cu • Cd • PAHs	• Oil • TSS

for scientists. Every effort must be taken to reduce the occurrence of HABs.

For human health risks in the Bohai Sea, the primary concern group includes fecal coliform in the water column of Beidaihe and estuary of Yellow River; DSP, PSP, and fecal coliform (Beidaihe) in the shellfish; and Pb in the seaweed. The localized group includes fecal coliform in the water column of Laizhou Bay, and Pb and DDT in the shellfish. The acceptable risk agent group includes fecal coliform in Panjin waters; Hg, Cu,

Table 97. Risk Classification for Human Health.

	Priority Risks	Localized Risks	Acceptable Risks
Water Column	• Fecal coliform in the estuary of Yellow Yiver • Fecal coliform in Beidaihe	• Fecal coliform in Laizhou Bay	• Fecal coliform in Panjin
Shellfish Tissue	• DSP • PSP • Fecal coliform	• Pb • DDT	• Hg • Cu • Cd • As
Fish Tissue			• Hg • Cu • Pb • Cd
Seaweed Tissue	• Pb		• Hg • Cu • Cd

Table 98. Risk Classification for Liaodong, Bohai and Laizhou Bays.

Area	Media	Priority Risks	Localized Risks	Acceptable Risks
Liaodong Bay	Water	• DIN • COD • Pb	• DIP • Cd	• Fecal coliform • Hg
	Sediment	• Cd	• Hg	• Cu • Pb
Bohai Bay	Water	• Fecal coliform	• DIN, DIP	• COD • Hg • Cd
	Sediment	• Cu		• Pb • Cd • Hg
Laizhou Bay	Water		• COD • Fecal coliform • Pb	• DIN, DIP • Hg • Cd
	Sediment			• Cu • Pb • Cd • Hg

Cd and As in shellfish; and Hg, Cu and Cd in seaweed. There are no cause for concern in fish tissue since the risks are minimal.

The risks in Liaodong Bay, Bohai Bay and Laizhou Bay are listed in Table 98, according to the data analyzed.

Priority must be placed on minimizing the very high risks presented by DIN, COD and Pb in the water column and Cd in the sediment to the ecosystem in Liaodong Bay. MECs of DIN are over the critical level in 80 percent of the area of Liaodong Bay. Meanwhile, DIP and Cd in the water column and Hg in the sediment should also be of priority in some areas, because they present risks to the ecosystem in the hotspots. However, fecal coliform, Hg in the water column and Cu and Pb in the sediment are now in acceptable levels and will not present high risks to the ecosystem in Liaodong Bay. The possible sources of nutrients include domestic, commercial, chemical, industrial, agricultural and maricultural waste. It means further actions should be taken to treat sewage before discharge and control the nutrient load from agriculture or aquaculture.

In Bohai Bay, some urgent actions should be given to the fecal coliform in the water column and Cu in sediment. Concern should be given to DIN, DIP and Pb in the water column in some areas, since they present risks to the ecosystem. The other agents are still in acceptable levels and present no harm to the ecosystem.

In Laizhou Bay, concern should be given to COD, fecal coliform and Pb in seawater in some important areas. Other agents were not within harmful levels to create high risks to the ecosystem.

RECOMMENDATIONS FOR IMMEDIATE MANAGEMENT CONSIDERATION

Based on the ecological risk assessment in the Bohai Sea, it is clear that there is an overexploitation of fishery and benthic resources. Evidence shows of the decline in quantity and quality in fishery production, a situation serious enough to need immediate action, such as prolonging the fishing ban period, reducing the fishing boat catch amount, and increasing fish fries by artificial technology.

To protect the natural wetlands in Yellow River and Liaohe River Deltas from degradation, laws should be enforced to control the overexploitation of area conversion into ponds, paddies and salt fields.

For pollution risks in the Bohai Sea, consideration must be made towards building more water treatment facilities and reducing the amount of discharge.

But all these management actions should benefit society; should be good for the sustainable economic development in the WBSA; and should be taken with minimal investment cost. A further analysis of the ecological risk management in Bohai Sea is being conducted right now, which will enable suggestions and recommendations to be made from the analyzed report.

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Glossary

Accuracy. The degree to which a measurement reflects the true value of a variable.

Adverse ecological effects. Changes that are considered undesirable because they alter valued structural or functional characteristics of ecosystems or their components. An evaluation of adversity may consider the type, intensity, and scale of the effect as well as the potential for recovery.

Agent. Any physical, chemical, or biological entity that can induce an adverse response (synonymous with stressor).

Assessment endpoint. An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes.

Attribute. A quality or characteristic of an ecological entity. An attribute is one component of an assessment endpoint.

Benthic community. The community of organisms dwelling at the bottom of a pond, river, lake, or ocean.

Bioaccumulation. General term describing a process by which chemicals are taken up by an organism either directly from exposure to a contaminated medium or by consumption of food containing the chemical.

Bioconcentration. A process by which there is a net accumulation of a chemical directly from an exposure medium into an organism.

Biomagnification. Result of the process of bioaccumulation and biotransfer by which tissue concentrations of chemicals in organisms at one trophic level exceed tissue concentrations in organisms at the next lower trophic level in a food chain.

Community. An assemblage of populations of different species within a specified location and time.

Comparative risk assessment. A process that generally uses a professional judgment approach to evaluate the relative magnitude of effects and set priorities among a wide range of environmental problems.

Concentration. The relative amount of a substance in an environmental medium, expressed by relative mass (e.g., mg/kg), volume (ml/L), or number of units (e.g., parts per million).

Contaminant of concern. A substance detected at a hazardous waste site that has the potential to affect ecological receptors adversely due to its concentration, distribution, and mode of toxicity.

Correlation. An estimate of the degree to which two sets of variables vary together, with no distinction between dependent and independent variables.

Disturbance. Any event or series of events that disrupts the ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

Ecological component. Any part of an ecosystem, including individuals, populations, communities, and the ecosystem itself.

Ecological entity. A general term that may refer to a species, a group of species, an ecosystem function or characteristic, or a specific habitat. An ecological entity is one component of an assessment endpoint.

Ecosystem. The biotic community and biotic environment within a specified location and time, including the chemical, physical, and biological relationships among the biotic and abiotic components.

Ecotoxicology. The study of toxic effects on nonhuman organisms, populations, or communities.

Effects assessment. The component of a risk analysis concerned with quantifying the manner in which the frequency and intensity of effects increase with an increasing exposure to the substance.

Environmental risk assessment. The likelihood that an environmental condition caused by human activity will cause harm to a target. It involves estimating the likelihood of harm being done to human health and/or ecosystems through factors emanating from human activities that reach their natural targets via the natural environment.

Exposure. Co-occurrence of or contact between a stressor and an ecological component. The contact reaction between a chemical and a biological system or organism.

Exposure assessment. The component of a risk analysis that estimates the emissions, pathways and rates of movement of a chemical in the environment, and its transformation or degradation, in order to estimate the concentrations/doses to which the system of interest may be exposed.

Fate. Disposition of a material in various environmental compartments (e.g., soil or sediment, water, air, biota) as a result of transport, transformation, and degradation.

Food-chain transfer. A process by which substances in the tissues of lower-trophic-level organisms are transferred to the higher-trophic-level organisms that feed on them.

Habitat. Place where a plant or animal lives, often characterized by a dominant plant form and physical characteristics.

Hazard. The likelihood that a substance will cause an injury or adverse effect under specified conditions.

Hazard assessment. Comparison of the intrinsic ability of a substance to cause harm (i.e., to have adverse effects for humans or the environment) with its expected environmental concentration, often a comparison of PEC and PNEC. Sometimes referred to as risk assessment.

Hazard identification. Identification of the adverse effects that a substance has an inherent capacity to cause, or in certain cases, the assessment of a particular effect. It includes the identification of the target populations and conditions of exposure.

Ingestion rate. The rate at which an organism consumes food, water, or other materials (e.g., soil, sediment). Ingestion rate usually is expressed in terms of unit of mass or volume per unit of time (e.g., kg/day, l/day).

LC_{50}. A statistically or graphically estimated concentration that is expected to be lethal to 50 percent of a group of organisms under specified conditions.

Lowest-observable-adverse-effect level (LOAEL). The lowest level of a stressor evaluated in a toxicity test or biological field survey that has a statistically significant adverse effect on the exposed organisms compared with unexposed organisms in a control or reference site.

Measurement endpoint. A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. Measurement endpoints often are expressed as the statistical or arithmetic summaries of the observations that make up the measurement. Measurement endpoints can include measures of effect and measures of exposure.

Population. An aggregate of individuals of a species within a specified location in space and time.

Precision. A measure of the closeness of agreement among individual measurements.

Predicted or estimated environmental concentration (EC). The concentration of a material predicted/estimated as being likely to occur in environmental media to which organisms are exposed.

Primary effect. An effect where the stressor acts on the ecological component of interest itself, not through effects on other components of the ecosystem (synonymous with direct effect; compare with definition for secondary effect).

Prospective risk assessment. An evaluation of the future risks of a stressor(s) not yet released into the environment or of future conditions resulting from an existing stressor(s).

Reference site. A relatively uncontaminated site used for comparison to contaminated sites in environmental monitoring studies, often incorrectly referred to as a control.

Representative samples. Serving as a typical or characteristic sample; should provide analytical results that correspond with actual environmental quality or the condition experienced by the contaminant receptor.

Retrospective risk assessment. An evaluation of the causal linkages between observed ecological effects and stressor(s) in the environment.

Risk. The probability of an adverse effect on humans or the environment resulting from a given exposure to a substance. It is usually expressed as the probability of an adverse effect occurring, e.g., the expected ratio between the number of individuals that would experience an adverse effect in a given time and the total number of individuals exposed to the risk factor.

Risk assessment. A process, which entails some or all of the following elements: hazard identification, effects assessment, exposure assessment and risk characterization. It is the identification and quantification of the risk resulting from a specific use of occurrence of a chemical including the determination of exposure/dose-response relationships and the identification of target populations. It may range from largely qualitative (for situations in which data are limited) to fully quantitative (when enough information is available so the probabilities can be calculated).

Risk characterization. The step in the risk assessment process where the results of the exposure assessment (e.g., PEC, daily intake) and the effects assessment (e.g., PNEC, NOAEL) are compared. If possible, an uncertainty analysis is carried out, which, if it results in a quantifiable overall uncertainty, produces an estimation of the risk.

Risk classification. The weighting of risks in order to decide whether risk reduction is required. It includes the study of risk perception and the balancing of perceived risks and perceived benefits.

Risk Pathways (Exposure Pathways). A diagrammatic representation of the course that all agents take from a source to exposed organisms (target) (Modified from U.S. EPA). In the diagram, each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, transport/exposure media (i.e., air, water) are also included. For the particular use of the report, the major categories found in the diagram include economic/social drivers (sources), hazards, resources and habitats (targets), and the effects on the economy. It may also sometimes be referred to as the *conceptual model* that describes an ecosystem or ecosystem components potentially at risk, and the relationships between measurement and assessment endpoints and exposure scenarios.

Sample. Fraction of a material tested or analyzed; a selection or collection from a larger collection.

Secondary effect. An effect where the stressor acts on supporting components of the ecosystem, which in turn have an effect on the ecological component of interest (synonymous with indirect effects; compare with definition for primary effect).

Sediment. Particulate material lying below water.

Source. An entity or action that releases to the environment or imposes on the environment a chemical, physical, or biological stressor or stressors.

Species. A group of organisms that actually or potentially interbreed and are reproductively isolated from all other such groups; a taxonomic grouping of morphologically similar individuals; the category below genus.

Stressor. Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).

Threshold concentration. A concentration above which some effect (or response) will be produced and below which it will not.

Tolerable daily intake (TDI). Regulatory value equivalent to the acceptable daily intake established relevant regulatory bodies and agencies, e.g., US Food and Drug Administration, World Health Organization, and the European Commission Scientific Committee on Food. It is expressed in mg/person, assuming a body weight of 60 kg. And is normally used for food contaminants.

Trophic level. A functional classification of taxa within a community that is based on feeding relationships (e.g., aquatic and terrestrial plants make up the first trophic level, and herbivores make up the second).

Uncertainty. Imperfect knowledge concerning the present or future state of the system under consideration; a component of risk resulting from imperfect knowledge of the degree of hazard or of its spatial and temporal distribution.

Uptake. A process by which materials are transferred into or onto an organism.