Southeastern Coast of Bali

Initial Risk Assessment

Bali National ICM Demonstration Site Project
BAPEDALDA Bali Provincial Government
Bali, Indonesia

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

Southeastern Coast of Bali
Initial Risk Assessment

Bali National ICM Demonstration Site Project
BAPEDALDA Bali Provincial Government
Bali, Indonesia

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

SOUTHEASTERN COAST OF BALI INITIAL RISK ASSESSMENT

September 2004

Published by GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) and the Bali National ICM Demonstration Project, Environmental Impact Management Agency of Bali Province.

Printed in Quezon City, Philippines

PEMSEA and Bali PMO. 2004. Southeastern Coast of Bali Initial Risk Assessment. PEMSEA Technical Report No. 11. 100 p. Bali Project Management Office, Denpasar, Bali, Indonesia and 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), Quezon City, Philippines.

ISBN 971-92799-8-2

A GEF Project Implemented by UNDP and Executed by IMO

MISSION STATEMENT

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) aims to promote a shared vision for the Seas of East Asia:

> "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;
- advance scientific and technical inputs to support decision-making;
- develop integrated information management systems linking selected sites into a regional network for data sharing and technical support;
- establish the enabling environment to reinforce delivery capabilities and advance the concerns of non-government and community-based organizations, environmental journalists, religious groups and other stakeholders;
- strengthen national capacities for developing integrated coastal and marine policies as part of state policies for sustainable socio-economic development; and
- promote regional commitment for implementing international conventions, and strengthening regional and sub-regional cooperation and collaboration using a sustainable regional mechanism.

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

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

ADB	–	Asian Dvelopment Bank
ASEAN	–	Association of Southeast Asian Nations
BOD	–	Biochemical oxygen demand
CN	–	Cyanide
CNSN	–	Center of National Science and Nature
COD	–	Chemical oxygen demand
CPUE	–	Catch per unit of effort
DAO	–	DENR Administrative Order
DO	–	Dissolved oxygen
EIA	–	Environmental Impact Assessment
ERA	–	Environmental Risk Assessment
GEF	–	Global Environmental Facility
Gm	–	Geometric mean/Geomean
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
MEC	–	Measured environmental concentration
MEL	–	Measured environmental levels
MEY	–	Maximum efficiency yield
MPN	–	Most probable number
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
PEC	–	Predicted environmental concentration
PEL	–	Predicted environmental levels
PEMSEA	–	Partnerships in Environmental Management for the Seas of East Asia
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 phospohate (orthophosphate)
ppm	–	parts per million or mg/l
ppt	–	parts per thousand or μg/l
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
SEAFDEC	–	Southeast Asian Fisheries Development Center
TDI	–	Tolerable daily intake
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
U.S. EPA	–	United States Environmental Protection Agency
VNS	–	Vietnam National Standards
WWF	–	World Wide Fund for Nature

Acknowledgments

This report was initially prepared during the Training Course on Environmental Risk Assessment held from 14-19 January 2002 in Bali, Indonesia. The training course was organized by the GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA). Risk assessment represents one component of the Bali National Integrated Coastal Management (ICM) Demonstration Project, which is being implemented in collaboration with several government departments and agencies of the Indonesian government. These efforts are jointly coordinated by the Bali National ICM Demonstration Project – Project Management Office (PMO) and PEMSEA Regional Programme Office (RPO).

The contributions of the following are greatly acknowledged:

The participants to the Training Course on Environmental Risk Assessment: Dr. Dewa Ngurah Suprapta, MS; Dr. Nyoman Arya; Dr. Made Antara, MS; Drs. K.G. Dharma Putra, MSc (from Udayana University); Ir. Ketut Sudiarta, M.Si from Warmadewa University, Ir. A.A.G.A Sastrawan, S.IP; Luh Dewi Komarini, S.Pi; I Putu Agus Sumartananda, ST; Gst. Ayu Kade Armaheni, ST; I Wayan Suambara, ST; I Gst. Ngurah Wiryawan, SH; and Ni Putu Wiwin Setyari, SE (from the Environmental Impact Management Agency – Bali Province);

Ms. Cristine Ingrid S. Narcise and Mr. Alexander T. Guintu of PEMSEA RPO for technical refinements of the draft document;

Mr. S. Adrian Ross, Senior Programme Officer and Technical Coordinator of PEMSEA, for providing guidance in the technical refinement of the draft reports; and

Dr. Jihyun Lee of PEMSEA, the Principal Coordinator for the Bali National ICM Demonstration Project.

Executive Summary

Environmental risk assessment estimates the likelihood of harm being done to identified targets as a result of factors emanating from human activity, 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.

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. There can be two approaches to protect the environment and human health. One approach is to eliminate the contaminant or stop the activity that produces it. Another approach is to prevent the contaminant level from exceeding an allowable level that presents acceptable risk. Elimination of contaminations to zero concentration 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. These studies also present possible consequences for contaminant levels that exceed the threshold values. 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.

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. Risk assessment evaluates the consequences of these activities and weighs the adverse effects to the environment against the contributions to economic development and the benefits to society.

The risk assessment attempted to answer two questions: "What evidence is there for harm being done to targets in the area?" (Referred to as 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 prospective risk assessment).

To answer these questions, it is necessary to identify appropriate targets, assessment endpoints, and corresponding measurement endpoints. Assessment endpoints are features related to the continued existence and functioning of the identified targets such as community structure or diversity, production, density changes and mortality. These, however, may not be easy or would take much time to measure, so other features related to the assessment endpoints and which are easier to measure (called measurement endpoints) are used instead. For the earlier mentioned assessment endpoints, the corresponding measurement endpoints are presence of indicator species (for community structure/diversity), biomass (for production), abundance (for density changes), LC_{50} or biomarkers (for mortality) (MPP-EAS, 1999a).

The initial risk assessment (IRA) of the Southeastern Coast of Bali was conducted as a preliminary step to the refined risk assessment. It provides a glimpse of environmental conditions in the area using available secondary data. It serves as a screening mechanism to identify priority environmental concerns in the area, identify data gaps and uncertainties and recommend areas for immediate management intervention or further assessment. It identifies contaminants that present acceptable risks and, hence, may not need further assessment, and highlights contaminants that present risks to the environment and/or to human health. It also identifies resources and habitats that are at risk and recognizes significant causes of risks. The results of the IRA will be used to formulate an action plan for a more comprehensive risk assessment that is focused on the identified priority areas of concern. Evaluating the results of the IRA will also facilitate improvement and refinement of the methods used.

The IRA also draws attention to the importance of collaboration among different government agencies, universities and scientific and technical research institutions, and the roles that these groups may undertake in the risk assessment. The wide range of expertise and knowledge of these different groups would contribute to the efficient conduct and success of the risk assessment. A mechanism to facilitate sharing of information and access to existing data should also be put in place.

In the refined risk assessment, should one be necessary, the methodologies, conclusions and recommendations in the IRA will be verified and, if possible, updated. The assessment will be focused on the identified human health and ecological issues. More in-depth characterization of contamination with respect to spatial distribution will be conducted, geared at identifying hotspots and determining the relative contribution of various sources of contamination. Predicting the levels and distribution of contaminants will be made possible by employing models that incorporate information on contaminant releases, inputs from tributaries and major point sources, fate of pollutants and the hydrodynamics of the area. More sophisticated techniques will also be used to improve uncertainty analyses. For parameters for which data are unavailable, the refined risk assessment will include a systematic collection of primary data.

The results of the risk assessment – "What is at risk and how can it be protected against the risk?" – are essential to ensure its sustainability. It gives management decisions a certain degree of confidence and it is hoped that refinement will provide resource managers the opportunity to predict specific ecological changes brought by specific stressors for use in alternative management decisions. As a management tool, risk assessment is expected to play a significant role in strengthening marine pollution risk management.

In risk management, options for addressing priority environmental concerns are identified. The benefits and costs to society of employing the identified management options are considered, as well as stakeholder consensus on appropriate management interventions.

The IRA of the Southeastern Coast of Bali began with the delineation of the boundaries of the coast as study area for the risk assessment. The Bali National ICM Demonstration Site is located at the Southeastern Coast of Bali Island, covering a 219-km coastline. The region includes Bali mainland and four inhabited small islands namely Serangan, Nusa Penida, Lembongan, and Ceningan Islands. Administratively, the Southeastern Coast of Bali Island includes one municipality and four regencies, i.e., Denpasar Municipality, Badung, Gianyar, Klungkung, and Karangasem Regencies. Altogether, the municipality and regencies consist of 12 sub-districts and 74 coastal villages.

The overall population for the municipality and regencies in the ICM area is 1,769,261 (56.6 percent of Bali Province population) based from the 2000 population census. Population densities vary and range from 428 to 4,214 persons/km^2.

The Southeastern Coast of Bali has a high shallow water habitat diversity including mangroves, coral reefs, seagrass beds, and sandy beaches. Mangrove forest provides a valuable physical habitat for a variety of important coastal species such as crabs, shrimps, fishes and the important juvenile stages of commercial fishes. Shoreline mangrove at Denpasar Municipality is recognized as a buffer against storm-tide surges and is very important as natural land protection. Coral reefs can be found along the shallow waters of Badung Regency, Denpasar Municipality, Karangasem Regency and sister islands. Coral reefs have important ecological values in terms of supporting high species diversity, which support artisanal fisheries that are dependent on these resources. Coral reefs also serve as natural beach protection, deterring beach erosion and retarding storm waves. Coral reefs also play an important economic role in Bali tourism. Seagrass beds are essential elements of coastal ecosystems; they play an important ecological role by providing substantial amounts of nourishment and nutrients, and functioning as habitats. Seagrass attract diverse biota and serve as essential nursery areas to some important marine species.

The main economic activities in these areas are fisheries, aquaculture, port and shipping, industries and tourism. Bali Island is known as a famous tourist destination in Indonesia and the southeastern region is the center of tourism development in Bali, especially for coastal and marine tourism. Fishery activities are dominated by artisanal fisheries, which cover capture areas less than 12 miles from the shore. Seaweed culture is undertaken at shallow coastal water around adjacent islands, and shrimp culture is undertaken at the coast of the mainland. In the Southeastern Coast of Bali Island, there are two harbors, i.e., Benoa Harbour at Denpasar Municipality and Padangbai Harbour at Karangasem Regency. In Bali, small-scale and household industries are being prioritized for development.

The coastal water receives drainage from approximately 1,790.8 km^2 of watershed consisting of seven catchment areas and three river basins. The river basins in this area are Ayung, Oos and Unda river basins.

The coastal water bordering the southeastern region of Bali Island is Badung Strait that separates the mainland and three neighboring islands and directly connects to Indian Ocean. Almost all areas along the coastline have high elevation. Current patterns are mostly influenced by the movement of water mass from the Indian Ocean. During the wet season, water mass moves from Indian Ocean to Badung Strait, entering through the southwest, while during the dry season, water enters through the southeast.

The tide is predominantly diurnal with an average tidal range of 1.3 m during the spring tide and 0.6 m during neap tide. Water temperature fluctuates with small ranges from the maximum at 26.6°C and the minimum at 25.6°C. Temperature decreases less than 4°C with every 5-m increase in depth. The salinity of the water column is relative homogeneous throughout the year. The average salinity of surface water is 34.4 ppt (parts per thousand or μg/l), with the maximum at 34.5 ppt and minimum at 34.3 ppt.

The results of the retrospective and prospective risk assessment are summarized in the following sections.

Retrospective Risk Assessment

In the retrospective risk assessment, qualitative and quantitative observations on the resources and habitats were assessed in reference to earlier observations to determine if there were significant changes, particularly the declines. Potential agents were identified and the likelihood that these agents caused the impacts on the resources and habitats were determined.

Data for the retrospective assessment were mostly taken from the Environmental Profile of Southeastern Coast of Bali (Bali ICM, 2001) that was completed under the ICM project. Other sources of information include the Annual Reports of the Fisheries Agency of Bali Province (1991-2000), Bali Beach Conservation Project (1998), Yayasan Bahtera Nusantara Denpasar (2001), WWF Wallacea (2001), BAPEDALDA-Bali (1998- 2001) and BAPPEDA-Bali (1998/1999).

The resources considered include fisheries, cultured shrimps and cultured seaweeds. For habitats, mangroves, coral reefs, seagrass beds and beaches were assessed.

Results

A clear evidence of decline based on research information (Annual Reports of the Fisheries Agency of Bali Province, 1991-2000) was established for fisheries. In 1991, annual fish production declined from 19,581.8 tonnes to 11,985.4 tonnes in 1995 and 11,494.9 tonnes in 2000. The trend in catch per unit of effort (CPUE) clearly indicates that there is a decline in fisheries in the Southeastern Coast of Bali. There was reduction from the 18.75 kg/trip to 8.81 kg/trip from 1991 to 1995 and further declining to 4.35 kg/trip in 2000. Overfishing was identified as a main agent for fish catch decline. The level of exploitation mostly exceeded the level of maximum sustainable yield (MSY) in 1998, which was 7,773 tonnes/year. Destructive fishing was also considered an agent in the decline. The contribution of the degradation and loss of important habitats such as mangroves, coral reefs and seagrass beds to the decline in fisheries is potentially considerable although assessment of the extent of adverse effects requires more supporting information.

Commercial shrimp culture in the Southeastern Coast of Bali Island is undertaken mainly in Denpasar Municipality, Badung and Gianyar Regencies. Shrimp production in 1991 was 1,339.9 tonnes but this declined to 65.6 tonnes in 1995 and 16.7 tonnes in 2000. Shrimp pond productivity declined from 6.2 tonnes/ha to 4.8 tonnes/ha from 1991 to 2000. Outbreak of diseases in shrimp ponds is induced by the deterioration of water quality, which may provide a favorable condition for agents of diseases, especially as a result of organic wastes. The high loads of the organic wastes also increase the biochemical oxygen demand (BOD) concentration, which in turn reduce the dissolved oxygen (DO) concentration.

Seaweed culture in Bali is centralized in the southeastern region, undertaken by 2,149 households distributed at Nusa Penida sub-district, Serangan Island and Nusa Dua (Badung Regency). Two species of seaweed, i.e., *Eucheuma spinosum* and *Eucheuma cottoni* have been cultured in Bali since 1983. Before 1995, seaweed production from the area increased continuously but from 1995 until 2000, production declined from 94,097.3 tonnes/year to 87,443.7 tonnes/year. Ice-ice disease was identified as the most likely cause for the decline in seaweed production in the region. Disease outbreak is induced by environmental conditions such as poor water quality, potentially resulting from intensive culture practices, that are stressful to the plants and that can be aggravated by the presence of opportunistic bacteria.

The primary factors identified in the decline of mangrove cover were land clearing for various purposes such as reclamation for development projects (e.g., shrimp ponds, rice field, garbage disposal, settlement, power generator station, estuary dam, electricity transmission facilities, housing, sewage treatment plant and airport expansion conversion). From 1977 to 2000, a decrease of about 314.46 ha representing 23 percent of the total mangrove area in Benoa Bay was reported. About one hectare of mangrove vegetation died due to solid waste and sedimentation, and about one hectare of mangroves in Benoa Bay was cut for airport navigation safety purposes. The lack of waste management systems in the uplands also tends to bring about waste accumulation at the mangrove area. In addition, sedimentation resulting from land reclamation in

Serangan Island, which is located at the mouth of Benoa Bay, was also identified as an agent for mangrove decline. Liquid wastes produced from domestic activities and pollutants from dyeing industries could have contributed to the decline in mangroves.

Coral reefs significantly contribute to fish production, marine tourism and coastline protection in Bali. Coral reefs in the Southeastern Coast of Bali are widely distributed along the coastal waters of Denpasar Municipality, Badung, Klungkung and Karangasem Regencies. According to the Bali Beach Conservation Project (1998), the percentage of live corals in the Sanur coastal waters (Denpasar City) and Nusa Dua (Badung Regency) declined by about 50 percent at 3-m depths from 1992 to 1997 and by about 60 percent at 10-m depths. The decline in coral reefs was attributed to destruction through large-scale collection activities like coral mining for construction, destructive fishing practices, as well as smothering of corals due to increased sedimentation from reclamation and other land-use conversion activities. The collection of ornamental fishes through the use of toxic substances such as cyanide, anchoring, and marine tourism activities such as diving, snorkeling and recreational fishing were also identified as likely agents in the decline of the coral reefs. The levels of some chemical contaminants in the water column and sediments may also have contributed to the decline.

Seagrass beds in the Southeastern Coast of Bali Island are found mainly in Nusa Dua, Serangan, Sanur and Lembongan Islands. This habitat is an important component of the food chain in coastal areas. Seagrass beds in Bali are known feeding habitats of sea turtles and sea cows and it supports the livelihood of small-scale fishers as well. The seagrass beds in Serangan Island have disappeared or were converted by reclamation for land extension. In Lembongan Island, about 50 percent of the seagrass beds were converted for seaweed culture expansion.

For Balinese people, beaches are very important to the tourism industry as well as for social and religious purposes. In the last two decades, erosion was identified as the primary agent in the decline of beach quality. Of the 219-km coastline in the Southeastern Coast of Bali, 32.5 km was affected by erosion in 1987, while a longer stretch of 37.1 km was reportedly affected in 1997. For the entire province of Bali, the length of eroded beach was reported as 51.5 km of the total 430-km coastline in 1987, and this further increased to 64.85 km in 1997. Beach erosion can be brought about by natural as well as human factors. In Bali, human activities such as coastal mining, land reclamation, building of coastal engineering structures and urban encroachment into beach areas have been recognized as important contributors to coastal erosion.

PROSPECTIVE RISK ASSESSMENT

In the prospective risk assessment, potential stressors in the area of interest were identified and the measured environmental concentrations (MECs) of the stressors were compared with threshold values or predicted no-effect concentrations (PNECs) to obtain risk quotients (RQs). An RQ less than 1 indicates acceptable risk and suggests limited concern while an RQ greater than 1 signifies cause for concern. The level of concern increases when the RQ increases.

The maximum RQ (RQ_{Max}) provides a hotspot perspective while the average RQ (RQ_{Ave}) provides an area-wide perspective. On the other hand, a minimum RQ (RQ_{Min}) that exceeds 1 indicates cause for concern for all the areas covered by the risk assessment.

The six major areas in Bali that were covered by the prospective risk assessment are Nusa Dua, Sanur, Benoa Bay, Gianyar, Candidasa, and Nusa Penida. Separate risk assessments for various chemical and physical parameters in the water column, such as nutrients, coliform, DO and oxygen demand, oil and grease, suspended solids, detergents/surfactants, and heavy metals, were conducted in these areas.

The major source of the threshold values for water quality is the Bali Province Criteria for Seawater Quality, which was adopted largely from the National Criteria for Seawater Quality for Indonesia. In cases where the Bali criteria could not be used to generate RQs (e.g., zero limits), values from the national criteria were applied as PNECs. Since Bali Island is a famous tourist destination in Indonesia and the southeastern region is a center of tourism development, especially coastal and marine tourism, the more stringent criteria for tourism and recreation were mostly applied. In the absence of suitable local threshold values, other criteria or standards from the region were applied. Details are provided in the main report with regard to the choice of threshold values. The risk assessment also enabled the evaluation of the usefulness of some specified local threshold values in estimating risks to both human and ecological targets. Recommendations for enhancing the water quality standards are also included in this report.

Results

The following are the results of the comparative risk assessment for both human health and ecological risks. Risk agents are classified either as priority or localized risks. Priority risk agents were determined based on RQ_{Min} and 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 ($RQ_{Max} < 1$) and for which assessments were not carried out due to lack of data are also presented.

<u>Human Health Risk</u>

Human health risk associated with bathing in coastal waters at the Southeastern Coast of Bali are presented primarily by *E. coli*, which is part of coliform coming from human waste. *E. coli* gave high average RQs at Sanur (RQ_{Ave} = 374) and Gianyar (RQ_{Ave} = 1,100), and average RQs slightly higher than 1 in Nusa Dua (RQ_{Ave} = 3) and Candidasa (RQ_{Ave} = 2). Sanur and Gianyar are both located near rivers that transport domestic wastes and other contaminants from the upstream areas to the coastal waters. This indicates the inadequacy or ineffectiveness of sewage collection and treatment systems in the areas traversed by these river systems. Elevated levels of *E. coli* in coastal waters pose risk to human health and will undoubtedly have adverse effects on the tourism industry in Bali. The slightly elevated levels of *E. coli* in Nusa Dua and Candidasa may be due to direct discharges of untreated or partially treated wastes from communities and establishments along the coast. There was no data on *E. coli* for Benoa Bay.

<u>Ecological Risk</u>

The separate assessments of risk in various coastal areas have shown that ecologically, the priority areas of concern are the nutrients phosphate (PO_4) and nitrate (NO_3) and the heavy metals cadmium (Cd) and lead (Pb), which gave minimum and average RQs that exceeded 1 in majority of the areas assessed. Copper (Cu), zinc (Zn), chemical oxygen demand (COD), BOD, total suspended solids (TSS), DO and ammonia (NH_3) also came out as priority concerns in specific areas.

For the nutrients PO_4 and NO_3, which are agents of eutrophication in coastal waters, minimum RQs exceeded 1 in Benoa Bay, indicating general concern for the area, while average RQs exceeded 1 in Sanur and Nusa Dua. The RQ_{Ave} for NH_3 also exceeded 1 in Candidasa. Development and human activities in the Southeastern Coast of Bali are focused in these locations, and nutrients may come from cleaning agents and organic wastes from households, hotels, restaurants, and commercial establishments. Rivers that pass through densely populated, industrial, and agricultural areas before draining to Benoa Bay also contribute to the nutrient load in the bay. The high concentration of nutrients in these areas arising from inadequate waste treatment in the upstream and coastal areas may present serious threat for critical habitats, especially the coral reefs.

Summary of Agents Presenting Ecological Risks.

RQ	Nusa Dua	Sanur	Benoa Bay	Gianyar	Candidasa	Nusa Penida
$RQ_{Min} > 1$	Cd > Pb		$NO_3 > PO_4$, TSS, Pb	Pb	Cd	Cd > Pb
$RQ_{Ave} > 1$	PO_4, NO_3 > COD	$PO_4 > NO_3$	Cd	Cu, Zn	NH_3 > BOD, COD, TSS > DO	Cu
$RQ_{Max} > 1$	DO, TSS	DO > BOD	COD	DO, TSS	Detergent	Cr, NO_3
$RQ_{Max} < 1$	NH_3, BOD, oil & grease, detergent, Cu	TSS	BOD, DO, oil & grease, detergent	NH_3, BOD, oil & grease	NO_3, oil & grease, Cu	TSS
No MECs	Zn, Cr	COD, oil & grease, detergent, Pb, Cu, Cd, Zn, Cr	NH_3, Cu, Zn, Cr	PO_4, NO_3, COD, detergent, Cd, Cr	PO_4, Pb, Zn, Cr	NH_3, PO_4, BOD, COD, DO, oil & grease, detergent

For heavy metals, the Bali Criteria for Tourism and Recreation, which were adopted from the minimum limits prescribed in the national criteria, were very low compared to those from other locations and thus generated very high RQs (in the order of thousands), which may not be accurate.

In an effort to perform a more accurate assessment of risks from heavy metals, various sets of threshold values were applied, which include:

a.) The maximum limits for heavy metals for tourism and recreation in the national criteria which are more comparable to the thresholds from other areas in the region;

b.) The Bali Criteria for Marine Biota and Fisheries, which are lower that the maximum limits in the national criteria; and

c.) International standards/criteria.

Using the Bali Criteria for Marine Biota and Fisheries, the minimum and average RQs for Pb and Cd exceeded 1 in almost all areas assessed. Average RQs for Cu and Zn also exceeded 1 in Gianyar. These results indicate ecological concern for all the heavy metals assessed particularly Pb and Cd. Heavy metals may come from the various industrial establishments in Bali, particularly from the numerous small-scale industries, which are not equipped with appropriate wastewater treatment facilities. These include textile industries that use dyeing substances that contain harmful substances including heavy metals and small-scale jewelry shops. Port activities such as ship and boat maintenance may also be potential sources of heavy metals. The highest RQ for Cd (RQ_{Max} = 77) was, however, found in Nusa Penida Island, which is one of the major tourist destinations in the Southeastern Coast of Bali due to its numerous diving and snorkeling sites. The average and best-case RQs for Cd (RQ_{Ave} = 3 and RQ_{Min} = 1.4) also exceed 1 in this island, which should prompt the identification of significant sources of Cd entering coastal waters. The relatively high frequency of vessel landing in this island, including visits by cruise ships and catamarans, may be one of the potential sources of heavy metals in the water column.

BOD, which is a parameter that indicates the degree of organic pollution in waters, gave an RQ_{Ave} exceeding 1 only at Candidasa. Average RQs for COD and DO were also highest and exceeded the critical threshold of 1 at this area. The potentially anoxic water condition in Candidasa is further confirmed by the RQ for NH_3 that also exceeds 1.

TSS, which is one of the physical parameters of water quality, gave RQ_{Min} exceeding 1 in Benoa Bay, RQ_{Ave} exceeding 1 in Candidasa, and RQ_{Max} exceeding 1 in Gianyar. Suspended solids in Benoa Bay come from river flows and run-off from the surrounding areas, while in Candidasa and other locations, most TSS enter the water through land run-off and domestic waste discharges.

Detergents or surfactants present localized risk in Candidasa, which is known for its diving sites. Detergents can affect seawater quality and aesthetics through reaction with calcium (Ca), magnesium (Mg) and iron (Fe) to form precipitates or bubbles at the water surface. The hotels in the area were identified as chief sources of detergent discharges, particularly from dishwashing and laundry activities.

All RQs for oil and grease are less than 1, indicating acceptable risk or low concern at Benoa Bay, Nusa Dua, Gianyar and Candidasa.

Link between Identified Risks and Human Activities in Bali

The retrospective risk assessment has directly and indirectly implicated human activities in the Southeastern Coast of Bali to the decline in its coastal resources and habitats. This has been clearly shown in the disappearance of seagrass beds due to reclamation in Serangan Island and loss of mangrove areas due to various development purposes. Coral reef degradation has also been attributed to various activities including tourism-related activities, although the contribution of each activity to the decline needs further evaluation. Ecologically, these habitats are recognized as vital in view of the life-support functions that they provide, manifested among others through fisheries productivity and stability of the coastline. Economically, these coastal and marine ecosystems are integral parts of the tourism industry in Bali and the coastal area of southeastern Bali is regarded as the center of marine tourism in the island.

The decline in fisheries has been attributed primarily to increased fishing pressure. In spite of the generally recognized adverse effects of habitat loss and degradation to fisheries productivity, further work is required to establish these linkages in Bali, as well as the linkages between environmental quality and occurrence of diseases in aquaculture and seaweed farms.

Some specific activities related to the development of Bali have been identified in the risk assessment to have caused the observed adverse effects on some resources and habitats.

The reclamation of Serangan Island, located at the mouth of Benoa Bay, to four times its original size has been attributed in this risk assessment as the cause of the seagrass disappearance around the island's coast; changes in the current pattern leading to increased sedimentation in some portions of the mangrove area in Benoa Bay, causing some mangrove species, such as *Sonneratia*, to die; wide coral damage arising from siltation and sedimentation; and the reduction of coral cover and hard substrate for new reef growth due to coral material extraction for construction work in Serangan, Nusa Penida and Candidasa.

Tourism development has been attributed to have caused damage to coral reefs due to marine tourism activities such as diving, snorkeling and recreational fishing, and from souvenir collection and breakage from boat anchors. Tourism was also linked to the degradation of marine habitats due to elevated levels of nutrients and organic wastes especially in highly developed tourism areas such as Sanur, Nusa Dua and Candidasa.

The lack of effective solid waste management in the upland areas has also been attributed to have caused accumulation of solid wastes in mangrove areas, which cover the aerial root and eventually kill the plants, and siltation and sedimentation in reef areas.

In the prospective risk assessment, the pressure from domestic, commercial, industrial, agricultural and tourism activities that directly or indirectly discharge untreated or inadequately treated wastes into receiving waters was demonstrated. In the prospective risk assessment, human health risks are presented by the levels of pathogens in the water column and ecological risks are posed by nutrients (PO_4 and NO_3), heavy metals, organic load and suspended solids. The data for the assessment were obtained from tourism areas, such as Nusa Dua, Sanur, Benoa Bay, Gianyar, Candidasa and Nusa Penida. *E. coli* in Sanur and Gianyar may be attributed to the major rivers that empty into these coastal areas, stressing the need for adequate waste treatment facilities not only in coastal areas but also further into the watershed areas. These areas are used for bathing and the problem on E. coli contamination may have strong implications on tourism not only in these areas but on Bali as a whole.

Risks are also presented by organic load and nutrients on the marine living resources which are among the main tourist attractions in Bali. Decomposition of excessive amounts of organic matter in the water column may pose risks to marine organisms through the reduction of DO, which is required for their survival. On the other hand, elevated levels of nutrients in the water column may enhance the proliferation of algae and reduce DO levels during decomposition.

The identified environmental risks may also be linked to current activities in particular sites. In areas such as Sanur, Nusa Dua and Candidasa where coastal tourism establishments such as hotels, restaurants and commercial enterprises abound, nutrients and organic load were found to exceed environmental thresholds. PO_4 is a component of detergent and inadequate waste treatment may bring this and other contaminants into the coastal waters. Highest demand for DO for organic decomposition (high RQs for BOD and COD) were shown in Candidasa, which was confirmed by the high RQs for NH_3 which is the dominant nitrogen species in oxygen-deficient environments. The highest RQ for TSS were also found in Candidasa, and may be related to the organic fine solid particles in the water column from waste discharges.

It is also important to note that among all locations assessed, best-case or lowest RQs for PO_4, NO_3 and TSS were found in Benoa Bay, indicating that all measurements exceeded the criteria, and, in all the areas assessed, these agents present ecological risks.

Potential risks to the functional integrity of the Benoa Bay resource system are also presented by the proposed expansion of the Benoa Harbour and Ngurah Rai Airport, which will involve coastal land reclamation of approximately 373 ha for the port and 139 ha for the airport (64.7 ha of mangrove forest) and dredging of shipping routes and port basin. The loss of fish spawning grounds and natural filtering capacity and the accelerated erosion arising from the loss of mangrove forests, damages to corals, seagrass beds and seaweed areas, and change in sedimentation patterns are among the potential adverse effects associated with the planned airport and port development. These proposed developments may also act concurrently with the environmental changes brought about by the reclamation in Serangan Island.

Hence, decisions concerning the uses of coastal lands and waters should adequately consider environmental impacts founded on reliable scientific assessments.

The motivation for the activities that were identified as causes for decline in resources and habitats and potential sources of contaminants that present human health and ecological risks are to support the growing population and advance the tourism industry and economy in Bali. The documented environmental concessions of these activities and the potential adverse effects of further development, however, should lead decision-makers and the general population to ponder how much longer should short-term gains be allowed to prevail over long-term benefits, and what needs to be done to achieve a balance between economic development and protection of Bali's natural resources and environment.

Data Gaps

A retrospective risk assessment was not carried out for some resources and habitats, such as those for shellfishes, phytoplankton, soft-bottom communities and mudflats, due to lack of comparative information.

The IRA also identified other data that would be necessary as starting points for fisheries management in the coastal area. For economically important resources such as fish and shellfish, there is a need to acquire survey data, preferably from more recent surveys. Production data, preferably on a per-species classification, including corresponding economic information (i.e., market and non-market values) would be necessary for the development of a model describing fish and shellfish population dynamics and hence indicate sustainable and efficiency yields. Data on shellfish abundance and distribution will also be useful. For shellfish, data on tissue quality and information on possible health implications of bacterial/coliform contamination, as well as harmful algal blooms, should also be gathered.

For mudflats, sandflats and rocky shores, there were no available time series and spatial distribution data. There were also no information on access and use of mudflats, sandflats and rocky shores.

A prospective risk assessment was not carried out for some environmental compartments, such as sediments and seafood tissue, due to lack of measured concentrations. A prospective risk assessment was not carried out for some parameters such as pesticides, some heavy metals, and toxic algae due to lack of measured water column concentrations.

Based on experience, the risks posed by toxic algal blooms are considerable and obviously important for human health. There were no recent reports of toxic blooms in the area, but this cannot preclude future occurrences. Plankton data in the water column, cyst counts in sediments and toxin levels in shellfish are important indicators of this phenomenon. The ciguatera case, a form of human food poisoning caused by the consumption of subtropical and tropical marine finfish that have accumulated naturally occurring toxins originating from dinoflagellates (algae) through their diet, and the massive death of reef fishes occurred in Nusa Penida in 1995.

Uncertainties

1. MECs and PNECs

The risk quotients obtained and the conclusions drawn depend largely on the accuracy of the measured concentrations (MECs) as well as the suitability of the threshold values used in calculating the RQs.

Considerable effort has been placed to evaluating the reliability of the data used in the risk assessment, although for some parameters for which there were very few data, the risk assessment was done using the available data.

For the threshold values, uncertainty may be associated with the use of criteria or standards that were specified for temperate regions or other locations. The suitability of these values for the tropics particularly for the Southeastern Coast of Bali still has to be verified.

More importantly, uncertainty may also arise from the choice of some threshold values from the Bali Province Seawater Quality Criteria (Decree of Bali Governor No. 515/2000), which specifies concentration limits for waters used for tourism and recreation, as well as for marine biota and fisheries. The threshold values prescribed for each water use were based mostly on the National Water Quality Criteria, which specify a range of criteria values (minimum and maximum limits). For marine biota and fisheries, the maximum limits in the national criteria were adopted for Bali. For tourism and recreation, the minimum values in the national criteria were adopted, including the very low threshold levels for heavy metals and the zero thresholds for NH_3, nitrite (NO_2), detergent, and other parameters. For oil and grease and *E. coli*, the minimum limits in the National Criteria for Tourism and Recreation were not adopted and zero thresholds were prescribed. In the real environment, these parameters will hardly be equal to zero and may be present at very low levels even in pristine environments. For heavy metals, the minimum limits for tourism and recreation in the national criteria, which were adopted for Bali, are very low (close to analytical detection limits) and are one to three orders of magnitude higher than criteria and standards from within and outside the region (Philippines, Thailand, Vietnam, ASEAN and U.S. EPA). Application of the very low thresholds will result in very high RQs (in the order of thousands) and may cause unwarranted concern. The maximum limits in the national criteria, on the other hand, were close to criteria and standard values from other locations, so these were chosen as PNECs for the prospective risk assessment. The choice of threshold values and associated uncertainties are described in detail in the main report.

Therefore, an urgent need is seen for a review and reconsideration of the Bali Province Seawater Quality Criteria, as well as the National Seawater Quality Criteria for Indonesia since it provides basis for the choice of criteria values at the provincial levels. This evaluation may be carried out based on a comprehensive assessment of toxicological data for specific local marine species, background levels, concentration levels prevailing in tropical environments, or the criteria limits of other jurisdictions.

2. Limited Data

The limited number of monitoring stations for all the parameters does not allow area-wide generalizations to be made. If would be safe to apply the statements only to the areas where measurements were taken and not to all locations. For example, data for nutrients and heavy metals were available only for some locations.

3. Spatial and Temporal Variation

Worst-case conditions indicate potential hotspots but these were not identified. This would require analysis of spatial variability. Contaminant levels may also be seasonally affected so temporal variability should also be assessed. To some extent, analysis of spatial variability was done by getting separate RQs for different municipalities and regencies.

The IRA was based on average and worst-case conditions. More detailed uncertainty analysis is needed to clarify some of the assessments. Consideration of spatial and temporal variability in the data would also enable more detailed and specific assessments to be made, such as the determination of relationships between predominant human activities and contaminant levels. These would be useful particularly in the identification of contaminant sources and setting up of interventions.

At this point, it would be wise to reiterate that the results of the risk assessment are not always representative of the entire areas. For some of the parameters, the data represented only certain areas in the Southeastern Coast of Bali. Even for the parameters that were taken from stations spread throughout the surrounding areas, the large distances between stations do not allow absolute generalizations to be made. In using the results of the IRA, it would be more accurate to clearly state whether the statements apply to certain locations only or are being applied, with caution, to the whole area. A more in-depth analysis of data in a refined risk assessment may be able to address this.

SUMMARY OF RECOMMENDATIONS

On Human Health Risks

1. *Risks to Human Health from* E. Coli *Contamination*

Coliform bacteria are indicator-organisms of water safety. These bacteria are naturally found in the intestines of warm-blooded animals, including humans. High amounts of these bacterial groups in a study area suggest that the water could be contaminated with intestinal pathogenic bacteria that reach the coast via wastewater from household and agricultural areas. Human health risk could arise from total coliform and fecal coliform bacteria themselves and from suspected pathogenic bacteria in the water column and in seafood tissues.

The risk assessment shows that human health risk is presented by *E. coli* contamination of coastal waters particularly at Gianyar and Sanur. The high bacterial load is mainly attributed to sewage generated from household and commercial, agricultural, institutional and industrial establishments that directly discharge to the area or to the drainage and river systems, which eventually enter the area. Gianyar and Sanur are both located near major rivers that transport domestic wastes and other contaminants from the upstream areas to the coastal waters. Risk from *E. coli* in the water column was also found in Nusa Dua and Candidasa although in a lesser degree. These areas are major tourist destinations and the slightly elevated *E. coli* levels may be due to direct discharges of untreated or partially treated wastes from hotels, establishments, and communities along the coast. To address this problem, several short-term and intermediate/long-term risk management recommendations are provided.

The following short-term recommendations are designed to confirm baseline information on the impact of sewage discharge into the Southeastern Coast of Bali as well as to avoid human health problems:

a.) Conduct routine monitoring of water, fish and shellfish in market places, and water in beaches or contact recreation areas;

b.) Control food supply from contaminated areas and regulate the use of contaminated beaches and bathing stations;

c.) Conduct an information campaign on the results of monitoring and establish other measures to prevent possible human contact with contaminated waters and food;

d.) Gather secondary data on *E. coli* contamination or *E. coli* loadings for all major tributaries;

e.) Develop models that can be used to identify and evaluate impacts as well as management options; and

f.) Perform benefit-cost analysis to identify appropriate interventions.

The following management recommendations are designed to address the root cause of sewage contamination in the Southeastern Coast of Bali:

a.) Accelerate sewage collection and treatment programs in urban or highly populated areas;

b.) Eliminate direct discharges of domestic, industrial and agricultural wastes, including septic or sludge disposal to the Southeastern Coast of Bali and its tributaries;

c.) Implement control programs for indirect discharges, such as urban and agricultural run-off, to the area and its tributaries; and

d.) Provide safe potable water supply to households.

These recommendations will require massive investment and may take considerable time, but the IRA has determined these as priority areas for consideration as part of the risk management program.

Although the data used in the IRA only come from a limited number of stations and involved limited data, the likelihood of similar situations (inadequate or lack of sewage treatment programs) exists so these recommendations should be considered for the entire Southeastern Coast of Bali.

On Ecological Risks

2. Ecological Risk from Nutrients

PO_4 and NO_3 were determined to be priority risk agents throughout the area, while NH_3 was shown to be a localized concern in Candidasa.

Nutrients are required for primary productivity but elevated concentrations may cause eutrophication and may lead to phytoplankton blooms and, potentially, may trigger harmful algal blooms. These have implications on DO levels in the Southeastern Coast of Bali and, eventually, on the benthos and other sessile organisms.

To be able to determine the areas in the Southeastern Coast of Bali where high nutrient concentrations were obtained and where marked impacts may be more likely to occur, a detailed analysis of spatial variability is necessary. Analysis of temporal variability would also be needed to determine seasonal effects on the nutrient concentrations. Nitrogen:Phosphate ratios in the coastal area may indicate trends in nutrient loading and should also be determined. A more detailed assessment of the linkage between elevated nutrient concentrations and phytoplankton blooms would be a useful first step toward understanding the environmental and economic implications of nutrient discharges.

Spatial and time series data of nutrients and DO at sediment-water interface and in sediments will also be useful in assessing changes in the benthic community. Collaboration with research groups conducting such studies should be considered.

The possible sources of nutrients in the Southeastern Coast of Bali are domestic, commercial and institutional wastes and sewage, untreated or partially treated industrial effluents, particularly from the detergent and fertilizer industries and agricultural discharges or run-off. All of these contribute significant amounts of nutrients to the area, but there is a need to determine the most significant sources to be able to prioritize interventions. This can be done by estimating or gathering information on loadings from the identified sources and, if feasible, by modeling.

Based on sound scientific information, measures to control nutrient discharges into the marine environment should be formulated and implemented. Local criteria for nutrients should also be developed to improve the assessment of ecological risks in Bali.

3. *Ecological Risks from Heavy Metals*

For heavy metals in the water column, the IRA showed ecological risks associated with Cd, Pb and Zn in all locations assessed, Cu in Gianyar and Nusa Penida, and chromium (Cr) at Nusa Penida. These results indicate concern for all the heavy metals assessed. The risk assessment was, however, performed using very limited data. A refined risk assessment for heavy metals in the water column is necessary although data on heavy metals in the water column may not be available. It is recommended that levels of heavy metals in the water column be verified through an environmental monitoring program that will provide more sufficient information to characterize risks, changes in risk levels, and risk agent sources. If primary data collection for heavy metals could not be undertaken, in view of associated costs and the need to prioritize other agents, rapid appraisal can serve as alternative to estimate heavy metal loading.

Difficulties were encountered in applying the Bali Criteria for Heavy Metals (for tourism and recreation) in the risk assessment since these were very low and generated very high RQs. Other values were therefore applied such as the Bali Criteria for Marine Biota and Fisheries, maximum limits in the national criteria for tourism and recreation, and thresholds from other locations.

The following are the recommendations for future risk assessment as well as risk management:

a.) Verify the suitability of the local criteria values used, and, if necessary, update the results of the risk assessment using more suitable criteria as well as additional data. Requirements for scientific research in relation to the Water Quality Criteria should also be identified;

b.) Verify the reported high levels of Cu and Cd in seawater since determination of the low levels of these elements in seawater is recognized as difficult and prone to contamination;

c.) Evaluate the waste management practices of potential sources of heavy metals including small industries (e.g., textile, metal, jewelry industries, etc.), estimate their contributions to heavy metal loading in the coastal environment, and recommend actions to control discharge of untreated liquid wastes containing heavy metals into natural waters; and

d.) As part of an overall environmental management of the area, develop an integrated environmental monitoring program to conduct routine monitoring of heavy metals in the water column, sediments and seafood, particularly shellfish tissue, and use the results as basis for developing control measures to address heavy metal contamination of coastal areas.

4. *BOD/COD/DO*

The low levels of DO in the water column at certain locations in the Southeastern Coast of Bali may have significant ecological consequences on the benthos and shellfisheries and, indirectly, on the organisms that feed on the benthos.

The main cause of reduced DO levels is the oxygen demand for the decomposition of organic materials in the water column. Organics come from continuous organic discharges from land-based human activities, tank-cleaning or operational discharges from ships and also from the decay of marine organisms especially during phytoplankton blooms.

BOD and COD are important water quality indices that reflect the amount of organic contaminants in the water. The importance of these parameters in the Southeastern Coast of Bali can be gathered from the average RQs for BOD, COD and DO that exceed 1 in Candidasa and average RQ for COD that exceed 1 in Nusa Dua. Maximum RQs greater than 1 were also obtained for BOD in Sanur, COD in Benoa Bay and Nusa Dua, and DO in Sanur, Nusa Dua, and Gianyar.

To ascertain the effect of organic loading on DO levels and the degree of ecological impact of reduced DO levels in different areas in the bay, and also to identify principal sources of organic load, it is recommended that a detailed analysis of spatial variability be performed.

A detailed analysis of DO measurements through time (temporal analysis) should also be performed to determine the duration of organism exposure to low DO and the likely acute or chronic effects.

Information on DO measurements during phytoplankton blooms should be gathered to determine the degree to which blooms affect DO levels, extent of area affected and duration of exposure of organisms to low DO levels.

It is also recommended that significant sources of the organic load be identified and the relative contribution of these sources be determined.

The data available for the risk assessment only provides limited information and may not allow a more detailed assessment of risks. This demonstrates the need for a monitoring program that will purposefully measure DO levels and oxygen demand in the water column, allow better characterization of risks, and identify principal sources of organic load.

5. TSS

Suspended solids in the water column may reduce light penetration in the water and impair photosynthesis thereby affecting primary production and, consequently, the organisms at higher trophic levels. Suspended solids may cause smothering of corals and, potentially, adversely affect seagrasses. Suspended solids may also serve as adsorption surfaces for toxic contaminants and a transport route to the bottom sediments.

Suspended solids refer to organic and inorganic fine solid particles suspended in seawater. It includes contributions from biological components like plankton and the excretion and remains of marine organisms. Other natural sources include eroded soil and rocks that are carried to the sea by run-offs. Suspended solids may also be derived from various land-use practices in the watersheds and along the coast such as land reclamation projects, aquaculture and agricultural activities, and mining activities; from coastal erosion as a consequence of habitat destruction and sea level rise; from resuspension of bottom sediments as a consequence of dredging, trawling and natural mixing; and from industrial solid wastes, wastewater, domestic discharges and waste dumping.

Ecological risk from TSS was shown for Benoa Bay where even the best-case RQ exceeded 1 and for Candidasa where the average RQ also exceeded 1. Some hotspot areas also need to be identified in Nusa Dua and Gianyar.

There is a need for a detailed analysis of spatial and temporal variability to determine the areas where elevated TSS concentrations were obtained and the variability in the concentrations with time.

For environmental management, the contributions of various potential sources, especially those associated with human activities, should be evaluated. Environmental impact assessments (EIAs) of reclamation and coastal development projects, in particular, should carefully assess the potential contributions of these activities to the suspended solids in the coastal waters of the Southeastern Coast of Bali.

6. Oil

Oil in the marine environment may come from various land-based sources, in particular, municipal wastes, urban run-off and petroleum refineries. It may also come from sea-based sources such as shipping and port activities.

The complex mixture of organic compounds in oil may have different adverse effects on marine life particularly shellfisheries and benthic organisms. It also has implications on the oxygen demand for biological degradation and on aesthetics and recreation.

The IRA indicated acceptable risk and, therefore, low concern for oil in the water column, using the local minimum criteria value of 1 mg/l.

Comparison of critical values for oil and grease from various sources, however, show differences by orders of magnitude, which implies that additional consideration should be given to the choice of critical water concentrations for oil. The data used for the risk assessment should also be evaluated with regard to adequacy of spatial representation of the site.

On Resources and Habitats

7. Resources

The decreasing trends in fish catch indicate that there is a decline in the Southeastern Coast of Bali fisheries. Overfishing and destructive fishing methods have been identified as the main causes for the decline and the fishing pressure exerted on the coast is indicated by the increase in number of fishers/km coastline and increase in number of boats/km coastline. The degradation of habitats like mangroves, seagrasses and coral reefs also contributed to the decline. These have led to reduced fish biodiversity, loss of economically important species, reduced fish yield, and consequent ecological, economic and social losses.

The results of the IRA clearly indicate that fisheries in the Southeastern Coast of Bali are at risk and call attention to the strengthening of fisheries management in the area by:

a.) Strengthening the enforcement of existing laws and regulations on fisheries utilization and evaluating their effectiveness and relevance for present circumstances;

b.) Developing appropriate management frameworks for sustainable development of the fisheries sector and implementing specific interventions that aim to reduce the pressure on nearshore fisheries, such as limiting the number of existing fishing vessels and providing alternative occupational skills for fishers;

c.) Promoting public awareness among the local population on the long-term adverse impacts of destructive fishing practices and overexploitation of fisheries, the need to appropriately manage the declining fisheries and the expected benefits, and the important roles that they need to perform to ensure sustainability of the fisheries resources;

d.) Formulating measures to prevent degradation of mangrove forests, coral reefs, and other coastal habitats, and promote rehabilitation efforts; and e.) Developing management plans for the protection of fisheries resources from discharges of untreated wastewater containing organic and inorganic wastes, release of solid wastes and other polluting substances, and other activities that compromise the integrity of the resources and the environment.

The retrospective risk assessment also showed decline in shrimp culture and seaweed culture production due to diseases, which are induced by poor water quality arising from poor practices in the culture farms. Sustainability of coastal aquaculture/mariculture should be ensured through application of environmentally sound aquaculture practices, designation of coastal aquaculture zones, and development of management guidelines in accordance with environmental quality management plans, land-use plans and environmental capacity.

It is recommended that interventions that will help in the recovery or restoration of the identified resources at risk be identified as part of the Coastal Strategy Implementation Plan for the Southeastern Coast of Bali.

Monitoring and research efforts aimed at addressing the identified data gaps on resources should also be supported.

8. *Habitats*

The results of the IRA have shown that mangroves, coral reefs, and seagrass beds are at risk in the Southeastern Coast of Bali. Mangrove forests have declined significantly due to conversion and reclamation for various economic development activities. In Benoa Bay, a decrease of approximately 314 ha representing 23 percent of the total mangrove area was reported for the period 1977-2000. Sedimentation resulting from reclamation activities and accumulation of solid wastes due to ineffective waste management systems also contributed to the decline in mangroves. Live corals at Sanur (Denpasar Municipality) and Nusa Dua (Badung Regency) also declined by 50 percent in 3-m depths and 60 percent in 10-m depths from 1992 to 1997. This was attributed to various activities ranging from large-scale coral mining to marine tourism activities, as well as destructive fishing and sedimentation. In Serangan Island, all of the seagrass beds have disappeared due to reclamation, while in Lembongan Island, about 50 percent of the seagrass has been altered due to seaweed culture expansion.

The decline in these important habitats might have had adverse affects on the reproduction and survival of various aquatic species that relied on these environments at various stages of development. The thriving tourism industry of Bali also depends on the state of these marine and coastal resources and environment. To prevent further damage to these ecosystems and ensure the sustainability of the ecological goods and services that they provide, the following actions are recommended:

a.) Formulate and implement measures to prevent and control degradation of coastal resources and habitats particularly arising from both public and private development projects;

b.) Improve and revise laws, rules, and regulations relevant to utilization and conservation of coastal resources and ensure strict enforcement;

c.) Require economic benefit-cost analysis of all development projects, particularly those that involve reclamation, as part of the government approval process;

d.) Designate specific zones for controlled utilization and preservation of coastal resources and habitats;

e.) Promote the designation of more conservation areas for coastal resources;

f.) Encourage mangrove reforestation in areas with high potential for rehabilitation;

g.) Encourage stakeholder participation in the rehabilitation of degraded coastal resources and support the projects and activities of volunteer groups; and

h.) Support monitoring and research activities that will fill data gaps and provide reliable information to support effective environmental management in Bali.

In coming up with land- and water-use plans as part of the Coastal Strategy Implementation Plan for the Southeastern Coast of Bali, an appropriate balance between the resources of the coastal area and economic activities should be targeted.

9. Erosion

In the IRA, areas in the Southeastern Coast of Bali where shoreline changes have occurred were assessed and possible causes of erosion were identified. The identified potential agents are human activities that cause disturbance in the dynamic balance of sediment accretion and erosion in the beach areas such as coastal mining, construction of coastal engineering structures, setback invasion (encroachment into beach areas) and reclamation. The contribution of these activities to coastal erosion are considered to be more significant than the effects of natural factors such as waves, tides, current, wind and sea-level rise which is associated with the global climate change and is attributed to cause coastal erosion in some areas.

Erosion threatens structures along the coast, agricultural areas and sites for religious ceremonies, and decreases the natural values of the affected areas.

There is a need, however, for more technical information to support the results of the IRA and to determine the relative importance of the potential agents in causing erosion of the coasts. Specific studies relating occurrences of erosion to the alteration of natural coastal processes as a consequence of the identified activities will be important.

In developing environmental management plans for the Southeastern Coast of Bali, attention should be given to minimizing the contributions of coastal and watershed activities to shoreline changes and establishing mechanisms to guarantee this.

On Data Gaps and Sources of Uncertainty

10. Retrospective Risk Assessment

In the retrospective risk assessment, prioritization of agents that caused the observed decline in resources and habitats should be based on weight of evidence. In the risk assessment for Bali, there was insufficient information for establishing correlation between the observed losses and exposure to various agents; cause-effect relationship based on field or laboratory observations; and specific effects of agents on targets. To enhance management planning, more technical information is required to demonstrate the extent of contribution and relative importance of various agents in bringing about the observed adverse effects ecologically and socioeconomically. A particular example is the observed erosion of coastal areas, which may be attributed to natural factors and man-induced causes such as coastal mining, construction of coastal engineering structures, encroachment into beach areas, reclamation and dam building in the upland areas. Primary agents have to be identified to enable development of appropriate management actions. Adequate comparative information is also necessary to establish changes in the targets through time.

11. Prospective Risk Assessment

There were no data on pesticides and other organic contaminants in all media. The potential for these agents to pose human and ecological risks to the Southeastern Coast of Bali should be assessed either through primary data gathering or through rapid appraisal of inputs from potential sources of these agents.

Data on heavy metals, pesticides and coliform in the sediment and seafood tissue from the surrounding areas of the Southeastern Coast of Bali also need to be collected to verify the assessments that have been made using the limited data available for the water column and to estimate direct risks to human health from consumption of contaminated seafood.

Frequently, phytoplankton blooms indicate ecological problems in the coastal area such as eutrophication. These blooms may also affect DO levels with consequent effects on organisms in the bay and should be evaluated through a refined risk assessment. There is also a need for a detailed understanding of the dynamics of harmful algal blooms and their interaction with environmental conditions. It is recommended that a more detailed risk assessment be done in collaboration with agencies and institutions involved in algal bloom studies.

It is also important to recognize that the IRA has been based largely on worst-case and average scenarios. For a number of the agents, further insight will come from making the spatial and temporal variations clear and explicit. This will also enable the distinction between localized and coast-wide conditions and the corresponding risk assessment results.

12. Water Quality Criteria

Water Quality Criteria refer to the scientific information upon which decisions may be made concerning the suitability of the environment to support a desired use. The criteria are normally expressed in the form of limiting concentrations that, when not exceeded, will protect an organism/community or prescribed water use/quality with an adequate degree of safety.

The prospective risk assessment, therefore, requires careful consideration of the threshold values to be used in computing for the RQs for each parameter.

The primary source of threshold values was the Bali Province Seawater Quality Criteria (Decree of Bali Governor No. 515/2000) which specifies threshold values for the protection of coastal waters used for tourism and recreation and marine biota and fisheries. The Bali criteria was adopted mostly from the National Water Quality Criteria for Indonesia, which specifies minimum and maximum limits for both water uses. For the protection of marine biota and fisheries in Bali, the maximum limits in the national criteria were adopted. For tourism and recreation, the minimum limits in the national criteria were adopted.

In the prospective risk assessment, some problems were encountered with the use of the Bali criteria to generate RQs, which is the ratio of the measured concentrations and the threshold values. For a lot of parameters including NH_3, NO_2, oil and grease, detergents (surfactants), and *E. coli*, zero-threshold values have been prescribed, which do not allow the computation of RQs. Moreover, these criteria values may not be attainable since these parameters will hardly ever be zero in the natural environment.

For heavy metals, initial application of the criteria specified to protect waters used for tourism and recreation in Bali resulted in RQs in the order of thousands, which could result in undue alarm if these results were reported as is. Comparison of the Bali Criteria for Heavy Metals with standards and criteria from the Philippines, Thailand, Vietnam, ASEAN and the U.S. EPA showed that the local thresholds are one to three orders of magnitude lower. The criteria from other locations are more comparable with the maximum limits provided in the National Water Quality Criteria for Indonesia so these were the values applied in the risk assessment.

The foregoing observations highlight the need to review the Bali Seawater Quality Criteria as well as the National Criteria for Water Quality upon which criteria at the local levels are being based. In particular, the low limits specified for heavy metals and the criteria values specified as zero need to be evaluated. Specific scientific researches required in relation to the review of the Water Quality Criteria should be identified.

13. Risk Assessment for Solid Wastes

The RQ approach has not been suitable for dealing with risks posed by solid wastes, yet these are obvious problems in the coastal area (and the surrounding river systems) for shipping, human health, ecological systems, and aesthetics. To refine the assessment of risks posed by solid waste will require increased understanding about sources, distribution and impacts. For example, there may be ecological problems arising from physical disruption of habitats caused by the accumulation of plastics and other solids. This could be particularly important for systems like mangrove forests.

14. More Explicit Linkage with Socioeconomic Activities

The IRA has focused entirely on a consideration of risks to human health and ecological systems from conditions in the coastal area that are influenced by human activities. The consequent impacts therefore derive from socioeconomic activities and have implications on the economy. Refinement of the risk assessment should make these links more explicit in the form of qualitative risk pathways and more quantitative socioeconomic analyses.

Risk Management

Taking into consideration the identified environmental risks and various recommendations on resource conservation and coastal and marine environment protection, the following activities are considered important in managing environmental concerns in the Southeastern Coast of Bali:

15. Integrated Land- and Water-Use Zoning

Some of the concerns on utilization of coastal resources and habitats and environmental risks are associated with existing land and water uses in the Southeastern Coast of Bali, largely arising from economic developments arising from and in support of its thriving tourism industry. Considering the potential for further development and the need to protect its natural coastal resources upon which this development relies on, it is recommended that an integrated land- and water-use zoning scheme with associated institutional arrangements be developed. This will reduce conflicting uses of land and water resources, promote uses based on the potential of each area, and prevent adverse effects to the ecosystem and human health.

16. Environmental Investments

The results of the risk assessment show the need to develop long-term strategies and action programs to address environmental issues such as sewage, solid wastes and industrial wastes. With the current economic activities in the Southeastern Coast of Bali and the potential for further growth, environmental services and facilities and clean technologies will be necessary to achieve a balance between economic growth and environmental protection and management. Sustainability of the coastal tourism industry will also depend primarily on the maintenance of an environment that is regarded as safe by its patrons. Facilities to manage solid wastes, sewage and industrial wastes should therefore be put in place to protect human health, marine resources and environment, and the tourism industry as well. Such facilities will also provide investment opportunities that will create income, employment and livelihood. Large financial investments and technological resources, however, will be required such that innovative approaches to facilitate the participation of various sectors in coastal and marine pollution prevention and resource conservation will have to be employed.

17. Integrated Environmental Monitoring Program

The risk assessment identifies priority areas of concern and data gaps with regard to resources, habitats, and environmental stressors, and the need for an efficient environmental monitoring program to assess the impacts of human activities on the environment and the effectiveness of management measures to address these adverse impacts. It is recommended that a systematic, cost-effective and coordinated environmental monitoring program be developed, which will integrate the monitoring of priority pollutants, the monitoring of human health impacts of priority pollutants, and the monitoring of resource and habitat conditions. Specifically, the integrated environmental monitoring program will aim to:

- Address the priority concerns and data gaps identified in the risk assessment;
- Pool the efforts and resources of relevant agencies through an operational monitoring network;
- Enhance exchange and integration of information through an information-sharing network;
- Enhance local technical capability with regard to field and analytical tools and human resources; and
- Strengthen the linkage between environmental monitoring and environmental management through application of the risk assessment/ risk management framework.

18. Collaboration and Institutional Arrangements

Partnerships between different government agencies, universities and scientific and technical research institutions, local government units, communities, non-governmental organizations, and the private sector would be vital to the development and sustainability of environmental management programs for the Southeastern Coast of Bali and, therefore, should be promoted. This should be aimed at promoting mutual interests and strengthening the capacity of each sector in the conservation of the natural resources and environment.

To facilitate and ensure sustainable multi-agency and cross-sectoral collaboration, appropriate institutional arrangements will have to be put in place. This will be particularly important in evaluating and strengthening policies, rules and regulations, implementation frameworks and enforcement capabilities on resource utilization and environmental protection.

Background

The GEF/UNDP/IMO Regional Programme on Building Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) has identified the southeastern coastal areas of Bali as one of a number of demonstration sites in the East Asian region to implement ICM in partnership with the national government and local stakeholders in the public and private sectors.

Risk assessment is one of the component activities of the Bali ICM Project. Risk assessment is used in a wide range of professions and disciplines and is now increasingly being used in examining environmental problems. Environmental risk assessment (ERA) uses scientific and technical assessment of available information to determine the significance of risk posed by various factors emanating from human activities on human health and the ecosystem.

The gradual shift in environmental policy and regulation from hazard-based to risk-based approaches was partly due to the recognition that zero discharge objectives are unobtainable and that there are levels of contaminants in the environment that present "acceptable" risks (Fairman et al., 2001). Aiming for zero discharge levels or using the best available technology may not be cost-effective and could result in excessive economic burdens to society and adversely affect the provision of goods and services that contribute to human welfare. Risk assessment is a systematic and transparent process that provides comprehensive and logical information to environmental managers and decision-makers for identifying rational management options. Identifying areas of concern through the risk assessment also prevents the pitfalls of wasting effort and resources on minor concerns.

Various methodologies and techniques for ERA have been developed and different organizations are presently involved in further improving this management tool (ADB, 1990; UNEP-IE, 1995; UNEP-IETC, 1996; Fairman et al., 2001). The approach adopted by PEMSEA is based on the RQ approach. It starts by simply 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 IRA of the Bali ICM Project area is a preliminary step to identifying priority environmental concerns that will be the focus of a more comprehensive refined risk assessment.

The IRA of the Bali ICM Project area was initially conducted during the Training Course on Environmental Risk Assessment held from 14-19 January 2002 at Werdhapura Hotel, Sanur, Denpasar, Bali, Indonesia.

Objectives

The objective of the study is to conduct an initial environmental risk assessment of the Bali ICM Project area using available information to determine the effects of factors derived from human activities on human and ecological targets.

Specifically, it aims to:

1. Evaluate the impacts of various pollutants on human and ecological targets and identify the priority environmental concerns;

2. Identify activities that contribute to pollution;

3. Identify gaps and uncertainties that will need more effort in future environmental monitoring and risk assessment activities;

4. Make recommendations for an integrated risk assessment and environmental monitoring program that is focused on the identified areas of concern;

5. Identify agencies and institutions that can play significant roles in the integrated risk assessment and environmental monitoring program and in the long-term management of the site; and

6. Identify priority concerns to be addressed under risk management.

SOURCES OF INFORMATION

Data for the retrospective assessment were mostly taken from the Bali government institutional reports. Data on habitats, marine resources and species were obtained from the Bali Beach Conservation Project, BAPPEDA-Bali, the Department of Forestry, Fisheries Agency of Bali Province, the World Wide Fund for Nature Foundation (WWF), Bahtera Nusantara Foundation and different universities.

The primary source of information for the prospective risk assessment was the Environmental Profile of the Southeastern Coast of Bali (2001)

Most of the data used were presumed to be accurate and reliable, although preliminary screening was done for some data for which ranges of concentrations in different environmental conditions are known. Ideally, the reliability of data should be more systematically assessed based on the sampling design and laboratory techniques used to produce the data as well as the period when these were obtained. A more thorough assessment of data should be made in a refined risk assessment.

The choice of criteria was based on what were available with the assumption that these values were suitable for the site of concern. Most criteria and standards used were from the Bali Province Seawater Quality Criteria. Other threshold values from the region were also used. Caution was exercised in applying threshold values generated in temperate regions since their relevance in tropical areas still need to be reviewed.

DEFINITION OF KEY TERMS

The following are key terms used in risk assessment. A more comprehensive list of terms, as modified from U.S. EPA (1997), U.S. EPA (1998) and IUPAC (1993), is found in the Glossary.

Effects assessment – The component of a risk analysis concerned with quantifying the manner in which the frequency and intensity of effects increase with increasing exposure to 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 may be 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-effect concentration (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.

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 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 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.

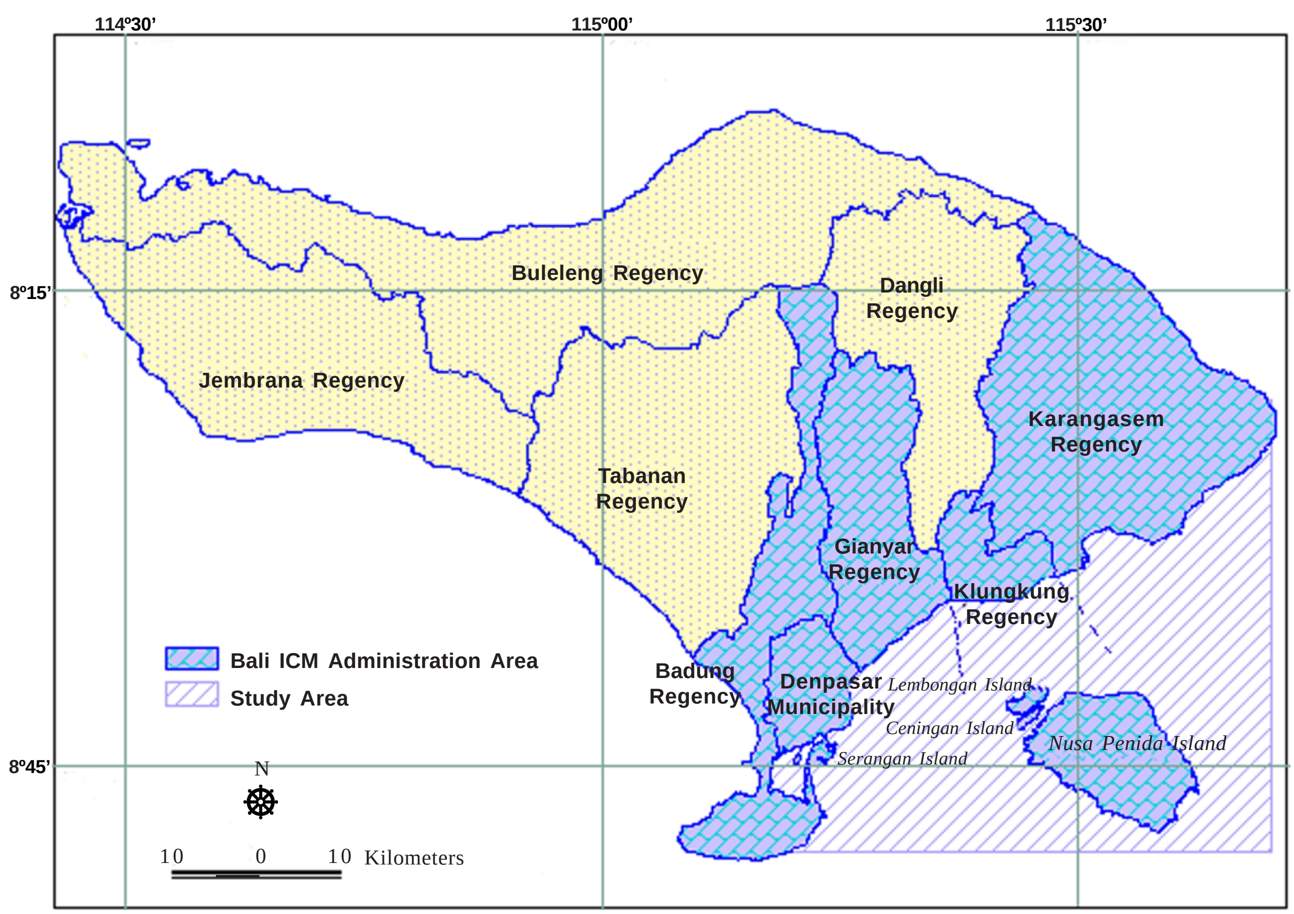
Description of the Southeastern Coast of Bali

The Bali ICM National Demonstration Site is located at the Southeastern Coast of Bali Island, covering a 219-km coastline. The area includes Bali Island (mainland) and four inhabited small islands: Serangan Island, Nusa Penida Island, Lembongan Island and Ceningan Island. Administratively, the Southeastern Coast of Bali is composed of one municipality and four regencies — these are the Denpasar Municipality and the Badung, Gianyar, Klungkung, and Karangasem Regencies, respectively — and which consist of 12 sub-districts and 74 coastal villages.

Based on the 2000 census, the population in the overall study area is 1,769,261 (about 56.6 percent of the total population of Bali Province). Population densities for each regency/municipality vary from 428 to 4,214 persons/km^2. In 1998, there were 481,651 inhabitants at the coastal villages.

The Southeastern Coast of Bali Island has a high shallow water habitat diversity including mangroves, coral reefs, seagrass, seaweeds, and sandy and rocky coasts. Mangrove forests provide a valuable physical habitat for a variety of important coastal species such as crabs, shrimps, fishes, and commercial fishes in their important juvenile stages. Mangroves along the shoreline at Denpasar Municipality are recognized as buffers against storm-tide surges. Coral reefs are found

Figure 1. The Administrative Boundaries and Study Area of the Southeastern Coast of Bali.



along the shallow waters of the Badung Regency, Denpasar Municipality, Karangasem Regency and the other islands. Coral reefs have important ecological values in terms of supporting a diverse and wide array of species, particularly on which artisanal fisheries are dependent. Coral reefs also serve as natural beach protection, deterring beach erosion and retarding storm waves. Coral reefs also play an important economic role for Bali tourism. Seagrass beds are essential elements of coastal ecosystems; they play an important ecological role, providing a substantial amount of nourishment and nutrients, and functioning as habitats. Seagrass beds attract a diverse profile of biota and serve as essential nursery areas for some important marine species.

The main economic activities in these areas are fisheries, aquaculture, port and shipping, industries and tourism. Bali Island is a famous tourist destination in Indonesia and the southeastern region is a center of tourism development in Bali, especially coastal and marine tourism. Artisanal fisheries dominate fishery activities, and involves capture areas less than 12 miles from the shoreline. Seaweed culture is undertaken at shallow coastal waters around the other islands, while shrimp culture is undertaken at the coast of the mainland. In the Southeastern Coast of the Bali Islands, there are two harbors, namely Benoa Harbour at Denpasar Municipality and Padangbai Harbour at Karangasem Regency. Industries developed in Bali mainly involve small-scale and households industries.

The coastal water receives drainage from approximately 1,790.8 km^2 of watershed consisting of seven catchment areas and three river basins. The river basins in this area are Ayung, Oos and Unda river basins.

The coastal water bordering the southeastern side of Bali Island is Badung Strait which separates the mainland and three other smaller islands and which is connected to the Indian Ocean. The movement of water mass from the Indian Ocean influences current patterns. During the wet season, water mass moves from the Indian Ocean to the Badung Strait entering through the southwest, while during the dry season, water enters through the southeast.

The tide is predominantly diurnal with an average tidal range of 1.3 m during spring tide and 0.6 m during neap tide. The water temperature fluctuates within a relatively small range. The maximum temperature of surface water is 26.6°C and the minimum is 25.6°C. Temperature decreases less than 4°C for every 5-m increase in depth. The salinity of the water column is relatively homogeneous throughout the year. The maximum salinity of surface water is 34.5 ppt, the minimum is 34.3 ppt, and the average is 34.4 ppt.

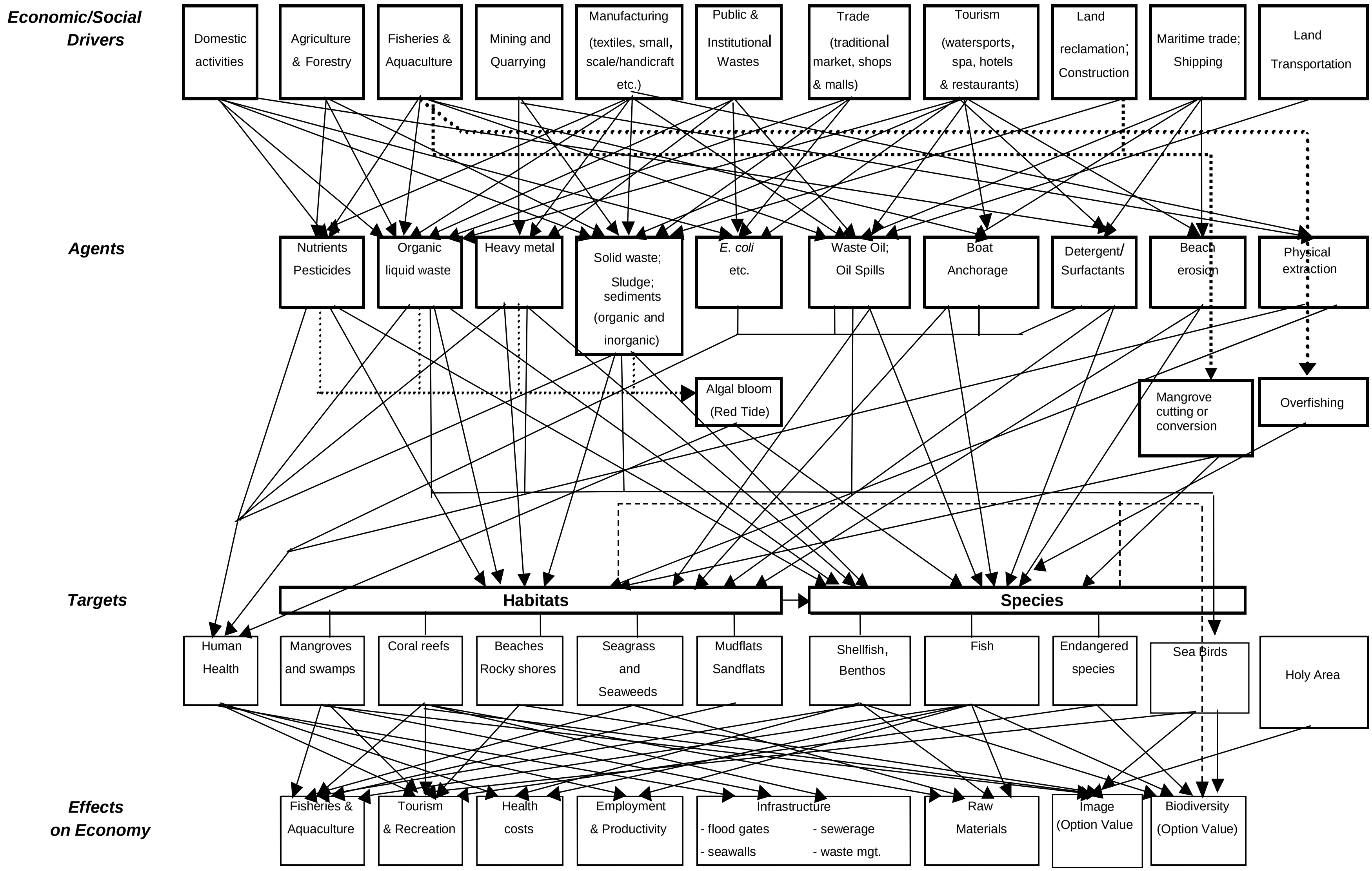
The Risk Assessment Approach

Risk is the probability of an adverse effect on humans or the environment resulting from a given exposure to a substance. It can be carried out as a retrospective risk assessment or a prospective risk assessment. For the retrospective risk assessment, the fundamental question concerns the extent to which conditions are likely to have caused adverse effects observed in specific targets. A prospective risk assessment considers the extent to which current conditions, and/or those likely to pertain to the future due to new developments, would likely cause harm. Both can be used as a basis for environmental management and imply the desire to control activities and conditions to levels that do not cause harm and which are likely to be non-zero. At the Bali ICM Project National Demonstration Site for Indonesia, a combination of retrospective and prospective approaches is used. A retrospective approach is applied to explain observed deterioration in ecological targets and/or the occurrence of human health problems in terms 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. The approaches converge to indicate the relative importance of different adverse effects and their causes. This should lead to appropriate, cost-effective management programs.

The fundamental features of both retrospective and prospective risk assessment are that they identify problems and their causes based on systematic and transparent principles that can be justified in public and can be revisited as more information and understanding become available. The key concept for risk assessment is 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 a prospective risk assessment, this is made explicit as an RQ, derived from the ratio of an environmental concentration that is either predicted (PEC) or measured (MEC) with PNEC for the target of concern ($RQ = P(M)EC/PNEC$). An $RQ < 1$ indicates a low, and thus acceptable risk, and an $RQ \geq 1$ indicates a level of concern and possibly the implementation of appropriate management programs.

The basic principles and techniques for both retrospective and prospective risk assessments are described in the *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (MPP-EAS, 1999a).

The simplified risk pathways in the Bali ICM Project National Demonstration Site (Figure 2) brings together the possible sources of hazards to human health and the environment and shows the possible effects on the economy. It also indicates the relationships between the sources of hazards and various economic and social drivers. This qualitative illustration draws attention to specific activities that may cause problems to human health and the environment and aids in the prioritization of concerns for risk assessment and, ultimately, risk management, especially when human health and environmental protection will need to be weighed against economic realities.


Economic/Social Drivers
Domestic activities
Agriculture & Forestry
Fisheries & Aquaculture
Mining and Quarrying
Manufacturing (textiles, small, scale/handicraft etc.)
Public & Institutional Wastes
Trade (traditional market, shops & malls)
Tourism (watersports, spa, hotels & restaurants)
Land reclamation; Construction
Maritime trade; Shipping
Land Transportation
Agents
Nutrients Pesticides
Organic liquid waste
Heavy metal
Solid waste; Sludge; sediments (organic and inorganic)
E. coli etc.
Waste Oil; Oil Spills
Boat Anchorage
Detergent/ Surfactants
Beach erosion
Physical extraction
Algal bloom (Red Tide)
Mangrove cutting or conversion
Overfishing
Targets
Habitats
Species
Human Health
Mangroves and swamps
Coral reefs
Beaches Rocky shores
Seagrass and Seaweeds
Mudflats Sandflats
Shellfish, Benthos
Fish
Endangered species
Sea Birds
Holy Area
Effects on Economy
Fisheries & Aquaculture
Tourism & Recreation
Health costs
Employment & Productivity
Infrastructure
- flood gates
- seawalls
- sewerage
- waste mgt.
Raw Materials
Image (Option Value
Biodiversity (Option Value)

Retrospective Risk Assessment

Introduction

The retrospective risk assessment is an evaluation of the causal linkages between observed ecological effects and stressor(s) in the 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 coastal zone?" (MPP–EAS, 1999b). 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 the site 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.

Methodology

A considerable volume of materials on risk assessment for the Bali ICM Project, from various studies, reports, and projects, were reviewed and relevant data on identified targets (habitats and resources) at the site were put together for the retrospective risk assessment. Steps prescribed in the *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (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 to reduce harm.

It is also 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. So 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 interrelatedness of agents and targets, a simplified risk pathway (Figure 2) was used.

The suspected agents for the different resources and habitats include: a.) nutrients;

b.) organic and inorganic liquid wastes; c.) *E. coli;* d.) sedimentation; e.) solid wastes; f.) detergents/surfactants; g.) boat anchorage; h.) physical extraction; i.) destructive fishing; j.) overfishing; k.) reclamation and coastal construction; and l.) oil and grease.

The identified targets for resources and habitats include: a.) fisheries; b.) aquaculture; c.) seaweed; d.) mangrove; e.) beaches; f.) seagrass; and g.) coral reefs.

For each target, evidence of decline was established using information on their past and present states and other related information that can support these observations. Potentially significant agents that may have contributed to the observed decline of the target were identified based on knowledge about the presence of these agents in the study area or the presence of activities that give rise to these agents. A detailed retrospective risk assessment for each suspected agent was carried out to determine the likelihood of its contribution to the decline of the targets.

Retrospective Risk Assessment

Under the retrospective risk assessment phase, a set of questions, answerable by yes (Y), no (N), maybe (M), no data (ND), and unknown (?) was formulated to establish evidences of decline, and the causes and consequences of the decline. The following questions were adapted from the *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems* (MPP-EAS, 1999a).

a.) Is the target exposed to any of the agents?
b.) Was there any loss/es that occurred following exposure? Was there any loss/es correlated through space?
c.) Does the exposure concentration exceed the threshold where adverse effects start to happen?
d.) Do the results from controlled exposure in field or laboratory experiments lead to the same effect? Will removal of the agent lead to amelioration?
e.) Is there an effect in the target that is known to be specifically caused by the agent (e.g., a contaminant-specific biomarker response)?
f.) Does it make sense (logically and scientifically)?

To facilitate the assessment, all the abovementioned 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. Agents that were likely to have caused adverse effects were systematically identified by assigning the likelihood of these agents to have caused the decline in resources and habitats.

The different categories of likelihood of harm are defined, based on the answers obtained for the mentioned questions, as follows:

a.) Very Likely;
b.) Likely;
c.) Maybe;
d.) Possibly;
e.) Unlikely; and
f.) Unknown.

After establishing evidences of decline in the resources and habitats and identifying significant agents for the decline, the ecological, economic and social consequences of decline were evaluated.

RESOURCES

Fisheries

Evidence of Decline

Data from the Annual Report of the Fisheries Agency of Bali Province show that fish production from 1991 to 2000 has declined in the Southeastern Coast of Bali. Annual fish production decreased from 19,581.8 tonnes in 1991 to 11,985.4 tonnes in 1995, and has further decreased to 11,494.9 tonnes in 2000.

Catch per unit of effort (CPUE) is the weight of fish caught by a unit of fishing effort, e.g., weight in kilograms (kg)/number of trips. The trend in CPUE clearly indicates that there is a decline in fisheries in the Southeastern Coast of Bali. The CPUE decreased from 18.75 kg/trip in 1991 to 8.81 kg/trip in 1995 and 4.35 kg/trip in 2000.

Based on the study using the Surplus Production Model (Schaeffer and Fox) by the BAPPEDA-Bali and Bogor Agricultural University (2000), the value of the maximum sustainable yield (MSY) in 1998 in this area was 7,773 tonnes per year. The data from 1991 to 2000 shows that annual fish production in this area has always exceeded the MSY, which indicates overfishing. Table 1 provides a summary of the retrospective analysis for fisheries in the Southeastern Coast of Bali. Table 2 provides the detailed retrospective risk assessment table used to determine the likelihood of agents to have caused the decline in fisheries.

Attributed Causes

Overfishing was identified as the most likely cause for the decline in fish production and CPUE. This can be correlated with the corresponding increase in the number of fishers per kilometer of the coastline (coastline length of the Southeastern

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

Table 1. Summary of Information for the Retrospective Risk Assessment for Fisheries.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Fisheries	Large (3,350 km^2 area of coastal water)	**Quantity:** Decline in fish production (tonnes): 19,581.8 to 11,985.4 (1991-1995) 11,985.4 to 11,494.9 (1995-2000) Decline in CPUE (kg/trip): 18.75 to 8.81 (1991-1995) 8.81 to 4.35 (1995-2000) **Related Information:** Increase in number of trips: 1,044,617 to 1,360,800 (1991-1995) 1,360,800 to 2,644,213 (1995-2000) Increase in number of boats: 5,725 to 7,536 (1991-2000) Increase in boats/km coastline: 25 to 33 (1991-2000) Increase in number of fishers: 6,404 to 7,982 (1991-2000) Increase in fishers/km coastline: 28 to 35 (1991-2000)	**Likely:** Overfishing Destructive fishing Habitat degradation **Possibly:** Domestic waste Industrial waste	Reduced/ unsustainable fish yield (production)

Source: Annual Reports of the Fisheries Agency of Bali Province (1991, 1995, 2000).

Table 2. Detailed Retrospective Risk Assessment for Fisheries.

Fisheries	Domestic waste	Industrial waste	Overfishing	Destructive Fishing	Habitat Degradation
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	M	M	Y	Y	M
2b. Was there any loss/es correlated through space?	?	?	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?	ND	ND	ND	ND	NR
4b. Will removal of the agent lead to amelioration?	?	?	Y	Y	M
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	?	?	?	?	ND
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y
Likelihood	P	P	L	L	P

Legend: Y – Yes, M – Maybe, ND – No Data, ? – Unknown, NR – Not Relevant, L – Likely, P – Possibly

Coast of Bali is 219 km), from 28 in 1991 to 33 in 2000. The number of boats increased from 25 units/km in 1991 to 33 units/km in 2000, indicating the intensity of fishing efforts in the area.

In addition, destructive fishing was considered to have adversely affected the fishery production in the area. The destructive fishing assessment by Bahtera Nusantara Foundation (2001) found that cyanide fishing was conducted in almost all coastal waters of Bali. This illegal fishing practice not only kills the target species but also destroys the habitats and kills young fish and juveniles.

Degradation and loss of important habitats like mangroves, coral reefs and seagrass beds were identified as potential causes of decline in fisheries. Mangrove areas are very productive components of the ecosystem, supporting production and conserving biodiversity, among other functions; and loss of about 23 percent of mangroves in Benoa Bay between 1977 and 2000 (see section on mangroves, page 38) may have brought significant losses to fisheries. The decrease in live coral cover by 50-60 percent at Sanur and Nusa Dua from 1992 to 1997 (see section on coral reefs, page 41), disappearance of all seagrass beds in Serangan Island from 1994 to 1998 due to land reclamation, and decrease of seagrass beds in Lembongan Island by 50 percent from 1983 to 1999 due to extension of seaweed culture (see section on seagrass beds, page 43) may have also affected recruitment and productivity.

Domestic wastes and industrial wastes from the food processing, dyeing, and tourism industries along the coastal area that are not supported by adequate waste treatment facilities, may have also contributed to the observed decline. The prospective risk assessment has shown concern for the levels of nutrients, organic load, DO, TSS, heavy metals, detergents (surfactants) and coliform in the water column in various locations in the Bali ICM area. The relative contributions of these factors to the decline in fisheries, however, still need further assessment.

Aquaculture

Shrimp Culture

Evidence of Decline

Commercial shrimp culture in the Southeastern Coast of Bali Island are mainly undertaken in Denpasar Municipality, Badung and Gianyar Regencies. The total area of shrimp and fish culture was approximately 50.3 ha in 2000, but decrease in area has been observed every year, caused by unplanned developments across the new road built by the government close to the location of aquaculture farms.

The main shrimp species cultured in this area are banana shrimp (*Penaeus monodon*). The Annual Reports of the Fisheries Agency of Bali Province show the decline of production trends of shrimp from 1991 to 2000. Shrimp production in 1991 was 1,339.9 tonnes, but this declined to 65.6 tonnes in 1995 and to 16.7 tonnes in 2000. Shrimp pond productivity declined from 6.2 tonnes/ha to 4.8 tonnes/ha from 1991 to 2000. Table 3 provides a summary of the retrospective analysis for shrimp culture in the Southeastern Coast of Bali. Tables 4 shows the details of the retrospective risk assessment.

Attributed Causes

The main causes of the decline in shrimp culture production are viral and bacterial diseases. The disease outbreak in shrimp ponds is induced by the deterioration of water quality especially as a result of organic wastes. The high loads of the organic wastes also increase BOD, which in turn reduce the DO concentration. The rapid development of dyeing industries with inadequate waste management in this area also contributes to the water quality deterioration.

The outbreak of bacterial and viral diseases in Bali began in early 1990. According to the Marine and Coastal Culture Research Center of Gondol, Bali (1992), the outbreak of bacterial and viral diseases in Bali and other locations is induced by uncontrolled shrimp pond intensification. Increase of organic substances in ponds and adjacent waters may provide a favorable habitat for the disease agents.

Consequences

The decline in shrimp culture production has led to loss of income and employment. Since the outbreak of the diseases, most of the shrimp ponds in the Southeastern Coast of Bali have been closed.

Table 3. Summary of Information for the Retrospective Risk Assessment for Shrimp Culture.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Shrimp Culture	Small (50.3 ha)	**Quantity:** Decline in shrimp culture production (tonnes): 1,339.9 to 65.6 (1991-1995) 65.6 to 16.7 (1995-2000) Decline in shrimp pond productivity (tonnes/ha) 6.2 to 4.8 (1991-2000)	**Very Likely:** Bacteria and virus **Possibly:** BOD, DO, Nutrients, TSS, Heavy Metals **Unlikely:** Oil and Grease **Unknown:** Solid Waste, Pesticides	Loss of employment, Loss of income

Source: Annual Reports of the Fisheries Agency of Bali Province (1991, 1995, 2000).

Table 4. Detailed Retrospective Risk Assessment for Shrimp Culture.

Shrimp Culture	Solid Waste	TSS	Oil and Grease	Heavy Metals	Pesticides	BOD	DO	Nutrients	Bacteria and Viruses
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?	ND	ND	ND	ND	ND	ND	ND	ND	Y
2b. Was there any loss/es correlated through space?	ND	ND	ND	ND	ND	ND	ND	ND	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	ND	Y	N	Y	ND	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	ND	ND	ND	ND	ND	Y	Y	ND	Y
4b. Will removal of the agent lead to amelioration?	ND	ND	ND	ND	ND	ND	Y	ND	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	ND	ND	ND	ND	ND	ND	ND	ND	Y
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y	Y	Y	Y	Y	Y
Likelihood	?	P	U	P	?	P	P	P	VL

Legend: Y – Yes, ND – No Data, ? – Unknown, VL – Very Likely, P – Possibly, U – Unlikely

There were 215.1 ha of shrimp ponds in 1991 but the area declined to 13.4 ha in 2000.

Seaweed Culture

Evidence of Decline

In Bali, the seaweed culture is centralized in the southeastern region, undertaken by 2,149 households, distributed at Nusa Penida sub-district, Serangan Island and Nusa Dua (Badung Regency). Two species of seaweed, *Eucheuma spinosum* and *Eucheuma cottoni*, have been cultured in Bali since 1983. Figure 3 shows the seaweed production in 1992, 1995, 1997 and 2000. Seaweed production in 1992 was 90,261.4 tonnes and increased to 94,097.3 tonnes in 1995. However, from 1995 to 2000, the production declined from 94,097.3 tonnes to 87,443.7 tonnes. Table 5 provides a summary of the retrospective analysis for seaweed culture in the Southeastern Coast of Bali. The details of the retrospective risk assessment are presented in Table 6.

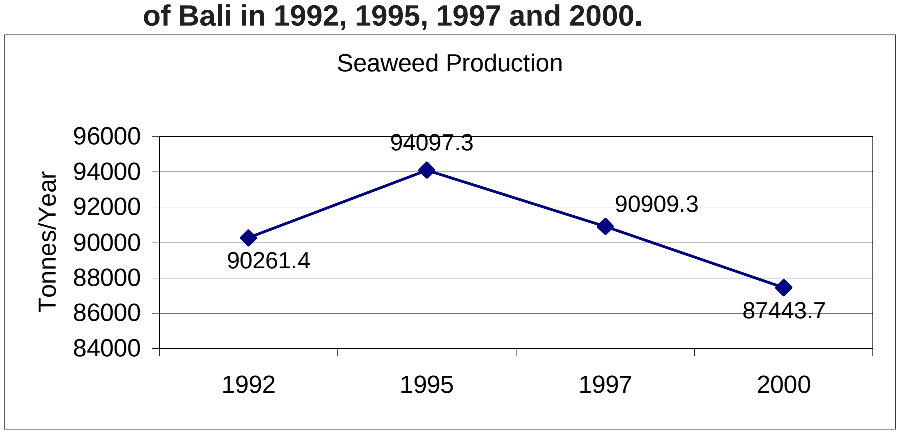
Attributed Causes

Intensive seaweed culture in large areas may cause the outbreak of bacterial diseases like the ice-ice disease, which is characterized by whitish spots or white segments on the surface of the branches. Ice-ice disease is a phenomenon caused by low salinity, temperature, and light intensity. When the plant is under stress, it exudes an organic substance that is mucilaginous in nature, and the presence of opportunistic bacteria in the water column aggravates the whitening of the branches (SEAFDEC, 2003). Ice-ice disease was identified as the most likely cause for the decline in seaweed production in the region. Other factors that may cause seaweed growth retardation include decrease in water salinity and increase in sedimentation during the rainy season, oil discharges from marine transportation and marine tourism activities (water sport, catamaran activities), and discharge of domestic wastes. In addition to light, temperature and water motion, salinity and clean water quality are among the important environmental factors in seaweed productivity (SEAFDEC, 2003). However, in the retrospective risk assessment for seaweed, lack of data prevented the attribution of seaweed production decline to other specific chemical and physical factors aside from the ice-ice disease.

Consequences

Seaweed culture activities provide employment and have become the major livelihood for coastal people in Nusa Penida, thus, the destruction of seaweed habitats will bring about a serious impact on export and the socioeconomic status of local people.

Figure 3. Seaweed Culture Production in the Southeastern Coast of Bali in 1992, 1995, 1997 and 2000.



HABITATS

Mangroves

Evidence of Decline

The data used for the assessment of mangroves were mostly obtained from the *Environmental Profile of Southeastern Coast of Bali* (Bali ICM, 2001). About 1,575.5 ha of mangrove forest are concentrated in Benoa Bay and Lembongan Island. It was estimated that during the period covering 1977 up to 2000, about 314.46 ha of the total 1,373.5 ha mangrove area in Benoa Bay was lost, including a hectare cut for airport expansion. About one hectare of mangrove vegetation has also died due to solid waste and sedimentation. The mangrove area in Lembongan Island (202 ha), has shown no change until 1998.

The summary of the retrospective analysis of mangroves in Benoa Bay and Lembongan Island

Table 5. Summary of Information for the Retrospective Risk Assessment for Seaweed Culture.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Seaweed Culture	Large (all areas of seaweed culture in the region)	**Quantity:** Production (tonnes) increase: 90,261.4 to 94,097.3 (1992-1995) Production (tonnes) decline: 94,097.3 to 87,443.7 (1995-2000)	**Very Likely:** Ice-ice Disease **Unknown:** Domestic waste, Oil and grease, Sedimentation, Salinity **Unlikely:** Nutrients	Loss of employment Loss of income Loss of devisal

Source: Annual Reports of the Fisheries Agency of Bali Province (1992, 1995, 1997, 2000).

Table 6. Detailed Retrospective Risk Assessment for Seaweed Culture.

Seaweed Culture	Domestic Waste	Oil and Grease	Sedimentation	Pesticides	Salinity	Nutrients	Ice-ice Disease
1. Is the target exposed to the agent?	Y	Y	ND	ND	ND	?	ND
2a. Was there any loss/es that occurred following exposure?	ND	ND	ND	ND	ND	ND	Y
2b. Was there any loss/es correlated through space?	?	ND	?		?	ND	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	ND	ND	ND	ND	ND	N	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	ND	ND	ND	ND	ND	ND	Y
4b. Will removal of the agent lead to amelioration?		?	?	ND	?	ND	Y
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	ND	ND	ND	ND	ND	ND	Y
6. Does it make sense (logically and scientifically)?	ND	ND	ND	ND	Y	N	Y
Likelihood	?	?	ND	?	?	U	VL

Legend: Y – Yes, N – No, ND – No Data, ? – Unknown, VL – Very Likely, U – Unlikely is shown in Table 7. The details of the retrospective risk assessment are presented in Table 8.

Attributed Causes

The retrospective risk assessment for mangroves in the Bali ICM area (Table 8) shows that reclamation, clearance, land conversion, solid wastes and sedimentation are among the most likely causes of mangrove cover decline.

The loss of approximately 314 ha of mangrove area in Benoa Bay has been attributed mostly to conversion to shrimp ponds, rice paddies, a dumpsite, and settlement areas; as well as to accommodate a power station, estuary dam, electric transmission facilities, sewage treatment plant, and airport expansion. About a hectare of mangroves were cut in Benoa Bay for airport navigation safety purposes. Table 9 from the *Environmental Profile of Southeastern Coast of Bali* (Bali ICM, 2001) presents the extent of mangrove conversion in Benoa Bay for some of the identified activities.

About a hectare of mangrove trees in Benoa Bay have also died due to pollution and sedimentation. Mangrove trees in Benoa Bay are found in the lowland and the densely populated area of Denpasar. The lack of waste management in the areas upstream allows waste to accumulate in the mangrove area. Solid wastes, such as plastics, cover the aerial root and eventually kill the plant.

Reclamation of Serangan Island, which is located at the mouth of the bay, has led to changes in the current pattern leading to increased sedimentation in some portions of the mangrove area. Sedimentation has already caused some species to die, with *Sonneratia* as one of the most vulnerable among the species. The reclamation of Serangan Island also involved the transfer of approximately 103 ha of mangroves to other areas.

Table 7. Summary of Information for the Retrospective Risk Assessment for Mangroves.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Mangrove	Large Benoa Bay (1,373,5 ha in 2000) Lembongan (202 ha in 1998)	Decline of areal coverage of about 314.46 ha in Benoa Bay from 1977 to 2000	**Very Likely:** Reclamation Solid waste disposal Land conversion Clearance Sedimentation **Unknown:** Heavy metals Oil and related substances Pesticides BOD/COD/DO	• Reduction of natural land protection • Reduction of good quality fish habitat • Reduction of nutrient sources for surrounding water • Reduction of number of fisheries • Reduction of waste filter system • Increasing susceptibility to diseases • Increasing salt water intrusion • Reduction of oxygen supply • Loss of potential tourism • Loss of bird habitat • Loss of sea fauna

Source: Management Plan of Tahura Ngurah Rai (2000); Bali Turtle Island Development, (1995); Bappeda (1998)

Table 8. Detailed Retrospective Risk Assessment for Mangroves.

Mangroves	Oil and related substances	BOD/COD	DO	Heavy Metals	Pesticides	Solid Waste	Sedimentation	Reclamation	Clearance	Land Conversions
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	ND	ND	ND	ND	ND	Y	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	ND	ND	ND	ND	ND	Y	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	ND	ND	ND	ND	ND	Y	Y	Y	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	ND	ND	ND	ND	ND	Y	Y	NR	NR	NR
4b. Will removal of the agent lead to amelioration?	ND	ND	ND	ND	ND	Y	Y	N	?	?
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	ND	ND	ND	ND	ND	Y	ND	Y	Y	Y
6. Does it make sense (logically and scientifically)?	ND	ND	ND	ND	ND	Y	Y	Y	Y	Y
Likelihood	?	?	?	?	?	VL	VL	VL	VL	VL

Legend: Y – Yes, ND – No Data, ? – Unknown, NR – Not Relevant, VL – Very Likely

The conversion of mangrove areas has been driven primarily by requirements for land due to population growth and development of tourism facilities and infrastructure to support the rapid development of tourism in Bali. The pressure on mangrove areas in Benoa Bay is related to its strategic location between the Ngurah Rai Airport and Benoa Harbour and between popular tourist destinations. A planned airport construction is also bound to affect approximately 64.7 ha of mangroves.

Approximately 185 ha of mangroves were rehabilitated over a period of 7 years (1992-1999) in conjunction with the Japan International Cooperation Agency (JICA), but a large area still requires rehabilitation.

Liquid wastes from domestic activities and industries are also suspected to have contributed to the decline in mangroves although the extent

Table 9. Mangroves Forest Conversion in Benoa Bay.

Conversion to:	Area (ha)	
	Actual	Licensed
Shrimp ponds	162.42	162.42
Rice fields	13.00	-
Garbage dumpsite	14.42	10.00
Residential	7.50	7.50
Sewage treatment plant (BTDC Nusa Dua)	30.00	30.00
High Intensity Approach Light System	0.50	0.50
Jalan By Pass Nusa Dua	7.60	7.90
Ceramic Research Center and Development	4.00	4.00
Fuel Pipeline (Avtur)	0.40	0.4
SUTT 70 KV	14.34	14.34
SUTT 150 KV Pesanggaran-Kuta dan Kuta-Nusa Dua	30.00	30.00
Total	284.46	267.06

Sources: Bali ICM (2001)

to which chemical contaminants have affected the mangrove cover cannot be firmly established yet due to limited information.

Consequences

The destruction of mangrove forests in Benoa Bay has led to the loss of its ecological function as nursery ground, natural protection from waves and coastal erosion, and habitat of bird and sea fauna. It also has secondary adverse impacts to adjacent coral reefs, seagrass beds, and other habitats. The consequent decrease in fish productivity ultimately affects the economic conditions of people who engage in fishing, especially the small-scale fishers. The loss of natural coastal protection may also increase the threat of flooding in coastal communities.

Coral Reefs

Evidence of Decline

Coral reefs significantly contribute to fish production, marine tourism, and coastline protection in Bali. Coral reefs in the Southeastern Coast of Bali Island are widely distributed along the coastal waters of Denpasar Municipality, Badung, Klungkung and Karangasem Regencies. The conditions of coral reefs in this region vary from poor to good condition. The percentage of live corals are as follows: Nusa Dua: 26.4 – 44.8 percent at a depth of 3 m and 18.5 – 45.2 percent at 10 m; Sanur: 26.3 – 37 percent at 3 m and 19.4 – 23.8 percent at 10 m; Klungkung: 17.7 – 53.8 percent at 3 m and 20.0 – 61.4 percent at 10 m; and Karangasem: 22.6 percent at 3 m and 32.3 percent at 10 m. There has been a decline in coral reefs in the Southeastern Coast of Bali Island. According to the Bali Beach Conservation Project (1998), the percentage of live corals at 3-m depths in the Sanur coastal waters (Denpasar City) and Nusa Dua (Badung Regency) declined by about 50 percent from 1992 to 1997 and at 10-m depths the decline was about 60 percent. Table 10 presents the summary of the retrospective risk assessment of coral reefs. The details of the retrospective risk assessment are shown in Table 11.

Attributed Causes

The coral reefs in the Southeastern Coast of Bali Island are exposed to various stressors arising from land-based activities as well as marine-based activities. The retrospective risk assessment was conducted to determine the relative importance of these stressors in causing the observed decline in coral reefs. Suspected agents include activities such as coral mining, illegal fishing, boat anchorage, souvenir collection, and marine tourism activities such as diving, snorkeling and recreational fishing; sedimentation arising from coastal reclamation and upland activities; and agents such as nutrients, organic load (indicated by BOD, COD and DO), heavy metals, oil and related substances and TSS.

The results of the retrospective risk assessment (Table 10) show that coral mining, illegal fishing, boat anchorage, souvenir collection, marine tourism activities, sedimentation, TSS and nutrients are likely causes of the decline in coral reefs, while most of the chemical agents are possible causes of decline.

The extraction of coral materials from the reef area for construction at the Serangan, Nusa Penida and Candidasa areas directly reduces coral cover and indirectly reduces hard substrate for new reef growth. The collection of ornamental fishes using toxic substances, such as cyanide, is prevalent in Bali. Destructive fishing using dynamite is still being employed in certain sites especially in Karangasem and Klungkung Regencies. The uncontrolled collection of exotic species for sale at the marine aquarium market, which is very

Table 10. Summary of Information for the Retrospective Risk Assessment for Coral Reefs.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	**Identified Agents**	
Coral reef	Large	**Coral reef coverage at 3-m depths:** Decrease in percentage of live coral from 1992 to 1997 at Sanur and Nusa Dua: 50 percent. **Coral reef coverage at 10-m depths**: Decrease in percentage of live coral from 1992 to 1997 at Sanur and Nusa Dua: 60 percent	**Likely:** Coral mining Destructive fishing Anchoring Collection Marine tourism activities Sedimentation Nutrients TSS **Possibly:** BOD/COD/DO Heavy Metals **Unlikely:** Oil and related substances	• Degradation of habitat • Reduced tourism potential • Reduced natural beach protection • Reduced population and diversity of ornamental fishes • Reduced fish production/ yield

Sources: Yayasan Bahtera Nusantara Denpasar (2001); WWF Wallacea (2001), BAPPEDA 1998/1999; Bali Beach Conservation Project (1998).

Table 11. Detailed Retrospective Risk Assessment for Coral Reefs.

Coral Reefs	Oil and related substances	Nutrients	BOD/COD	DO	TSS	Heavy Metals	Sedimentation	Coral Mining	Destructive Fishing	Marine Tourism Activities	Anchoring	Collection
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	ND	Y	ND	ND	Y	ND	Y	Y	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	ND	ND	ND	ND	ND	ND	ND	Y	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	N	Y	Y	Y	Y	Y	Y	Y	M	M	M	M
4a. Do the results from controlled exposure in field experiments lead to the same effect?	ND	ND	ND	ND	ND	ND	Y	ND	ND	ND	ND	ND
4b. Will removal of the agent lead to amelioration?	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	ND	Y	ND	ND	ND	ND	ND	Y	Y	ND	Y	Y
6. Does it make sense (logically and scientifically)?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Likelihood	U	L	P	P	L	P	L	L	L	L	L	L

Legend: Y – Yes, M – Maybe, ND – No Data, L – Likely, P – Possibly, U – Unlikely popular in Bali, also contributes to coral damage. The boom of marine tourism activities, such as diving, snorkeling and recreational fishing, in coral reef areas has also resulted in the destruction of corals. Tourist visits to reef systems can result to breakage due to boat anchoring and souvenir collecting.

Siltation and sedimentation created by dredging and filling for land extension activities/ reclamation at Serangan Island have caused wide coral damage in the area. Poor upland management has also caused siltation and sedimentation in reef areas. Silt and suspended solids that cover the surface of the reef may kill coral polyps, because the ability of corals for self-purification is very limited.

According to the Bali Beach Conservation Project (1998), great damage to coral communities can be done by elevated levels of nutrients (eutrophication). The release of phosphorous and nitrogen from land run-off and point sources of wastewater (such as from hotels) may have induced the algal blooms at the Sanur coral reef area. Algal blooms can cover the entire surface of the reef and kill coral organisms.

The results of the prospective risk assessment also show that, with the exception of oil and grease, all the physical-chemical agents evaluated are parameters of concern in the Bali ICM area, although more information will be required to specifically relate the losses in coral cover to these agents.

The identified agents for coral reef decline are brought about primarily by illegal fishing practices and tourism and development activities. The natural coastal resources of Bali stimulate tourism development, with its coral reefs considered as major attractions. Coral reefs, however, are fragile ecosystems and are susceptible to factors arising from human activities that adversely affect its environment. Inadequate consideration of environmental protection and conservation in the planning and implementation of some development projects and in the management of tourism-related activities have brought considerable and potentially irreversible damage to the reef systems in the Southeastern Coast of Bali.

Consequences

The degradation of coral reefs along the coastal waters of Sanur, Nusa Dua, Nusa Penida and Karangasem have resulted in the reduction of natural beach protection, and has contributed to the increase in the beach erosion rate in this region. Coral reef decline also threatens the sustainability of marine tourism. With regard to its function as a habitat, coral reef destruction will lead to reduction in biodiversity and fisheries production.

Seagrass Beds

Evidence of Decline

Seagrass beds in the Southeastern Coast of Bali are found mainly in Nusa Dua, Serangan, Sanur and Lembongan Islands. This habitat is an important component of the food chain in coastal areas. Seagrass beds in Bali are known feeding habitats of sea turtles and sea cows. It also supports the livelihood of small-scale fishers. There has been marked seagrass disappearance, especially around the coast of Serangan. Almost 50 percent of seagrass beds at Lembongan Island have also disappeared. Table 12 presents the summary of the retrospective risk assessment of coral reefs. The details of the retrospective risk assessment are shown in Table 13.

<u>**Attributed Causes**</u>

The disappearance of all seagrass beds in Serangan Island was mainly caused by land reclamation to increase the land area by four times its original size. In Lembongan Island, the decrease in seagrass cover was caused by the extension of seaweed culture.

The retrospective risk assessment also looked at other possible agents that may have contributed to the seagrass cover decline in the Bali ICM area

Table 12. Summary of Information for the Retrospective Risk Assessment for Seagrass Beds.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	Identified Agents	
Seagrass beds	Large	Decrease in percentage of areal cover of seagrass at Serangan Island from 1994 to 1998: 100 percent Decrease in areal cover of seagrass beds at Lembongan Island from 1983 to 1999: 50 percent	**Likely:** Land reclamation Seaweed culture extension **Possible agents:** Sedimentation **Unknown:** Pesticides, Collection, Nutrients, BOD, DO, TSS, Heavy metals, oil and related substances	• Loss of habitat for certain species (such as sea turtles, sea cows); • Degradation of sediment filtering system; • Reduced fisheries production; • Reduced nursery and feeding habitat

Sources: Bali ICM (2001); Koba (1993); Bali Beach Conservation Project (1998); BAPPEDA (1998).

Table 13. Detailed Retrospective Risk Assessment for Seagrass Beds.

Seagrass Beds	Oil and related substances	Nutrients	BOD	DO	Heavy Metals	Pesticides	TSS	Sedimentation	Collection	Land Reclamation	Seaweed Culture
1. Is the target exposed to the agent?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	ND	ND	ND	ND	ND	ND	ND	Y	ND	Y	Y
2b. Was there any loss/es correlated through space?	ND	ND	ND	ND	ND	ND	ND	Y	ND	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	ND	ND	ND	ND	ND	ND	ND	ND	ND	Y	Y
4a. Do the results from controlled exposure in field experiments lead to the same effect?	ND	ND	ND	ND	ND	ND	ND	ND	ND	NR	NR
4b. Will removal of the agent lead to amelioration?	ND	ND	ND	ND	ND	ND	ND	ND	ND	Y	ND
5. Is there an effect in the target that is known to be specifically caused by exposure to the agent (e.g., biomarkers)?	ND	ND	ND	ND	ND	ND	ND	ND	ND	Y	ND
6. Does it make sense (logically and scientifically)?	ND	ND	ND	ND	ND	ND	ND	Y	ND	Y	Y
Likelihood	?	?	?	?	?	?	?	P	?	L	L

Legend: Y – Yes, ND – No Data, NR – Not Relevant, L – Likely, P – Possibly such as collection, sedimentation, TSS, oil and related substances, heavy metals, nutrients, and organic load (indicated by BOD and DO). Sedimentation was identified as a possible agent but due to lack of information, the likelihood that the other agents contributed to the decline could not be determined.

Depending on the sediment load, sedimentation was established as an agent that can lead to seagrass bed decline, including its total destruction. Pollution from domestic and industrial areas is also recognized to cause seagrass degradation (Sudara, 1994). Even nutrients, which are also essential to seagrass growth, can, at elevated levels, cause decline in production by stimulating growth of phytoplankton and algae resulting in turbidity and reduced light availability for seagrasses (Vermaat et al, 1996). The potential for these agents to affect the remaining seagrass areas in Nusa Dua and Sanur should be considered, taking into account that these are popular tourist areas and that eutrophication and sedimentation have been observed in these areas.

Consequences

The disappearance of seagrass beds in Serangan Island and the decline of seagrass cover at Lembongan Island have brought about serious impacts on fish and shellfish capture due to the loss of their ecological functions as habitat, particularly as nursery, feeding and spawning grounds for sea turtles, sea cows, and fish. In Lembongan Island, a sharp decline in fish production was observed over a 15-year period since the start of seaweed cultivation in 1964. Decline in fish, crab, and lobster catch was also observed in Serangan Island since the reclamation in 1994. This adversely affected the socioeconomic conditions of the communities dependent on these resources.

Beaches

Evidence of Decline

For Balinese people, beaches are very important with respect to supporting the tourism industry as well as for social and religious purposes. In the last two decades, erosion was identified as the primary agent in the decline of beach quality. The length of eroded coasts in Bali accounted for 51.5 km of the total 430 km coastline in 1987, and in 1997, the length of eroded beach increased to 64.85 km (Bali Beach Conservation Project, 1998). Table 14 presents the summary of the retrospective risk assessment for beaches. The details of the retrospective risk assessment that was done to determine the likelihood of the suspected agents to have caused the beach erosion are presented in Table 15.

Attributed Causes

The dynamic interaction of water, wind and sediments in the coastal area results in the movement of sediment materials resulting in erosion in some areas and accretion in others. Waves can be a major factor in this process. Another factor affecting beach erosion is sea level rise, which is a known global issue resulting from global climate change.

In Bali, however, beach erosion is also attributed to human activities. The construction of buildings close to the beach, particularly in popular coastal tourism areas such as Sanur, Nusa Dua and Candidasa, has caused a disturbance to the dynamic balance of sediment accretion and erosion in the beach. Some of the engineering structures that protrude into the sea, such as jetties, groins, and other beach protection that were built to prevent erosion, can create more severe erosion problems due to the impedance in the sediment

Table 14. Summary of Information for the Retrospective Risk Assessment for Beaches.

Resource Type	Areal Extent	Results		Impact
		Changes Observed/Time	**Identified Agents**	
Beach	Large	**Length of Eroded Beach:**	**Possibly:** Coastal mining; Coastal engineering structure; Setback invasion; Reclamation	Destruction of the temple, recreation area, hotel, beach habitat, restaurant and agriculture area, road, sites for religious ceremonies, and other public facilities
	Southeastern Coast of Bali: Length of Coastline – 219 km	Increased from 32.5 km to 37.1 km (1987-1997)		
	Badung Regency: Length of Coastline – 64.0 km	11.5 km (maintained from 1987 to 1997)		
	Denpasar Municipality: Length of Coastline – 8.0 km	Increased from 7 km to 7.6 km (1987-1997)		
	Gianyar Regency: Length of Coastline – 15 km	5 km (maintained from 1987 to 1997)		
	Klungkung Regency: Length of Coastline – 62.0 km	Increased from 3 to 7 km (1987-1997)		
	Karangasem Regency: Length of Coastline – 70.0 km	6 km (maintained from 1987 to 1997)		
	Bali: Length of Coastline – 430 km	Increased from 51.5 km to 64.85 km (1987-1997)		

Source: Bali Beach Conservation Project (1998)

Table 15. Detailed Retrospective Risk Assessment for Beaches.

Fisheries	Coastal Mining	Land Reclamation	Coastal Engineering Structure	Set back Invasion
1. Is the target exposed to the agent?	Y	Y	Y	Y
2a. Was there any loss/es that occurred following exposure?	Y	Y	Y	Y
2b. Was there any loss/es correlated through space?	Y	Y	Y	Y
3. Does the exposure concentration exceed the threshold where adverse effects start to happen?	ND	ND	ND	ND
4a. Do the results from controlled exposure in field experiments lead to the same effect?	NR	NR	NR	NR
4b. Will removal of the agent lead to amelioration?	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	N	N
6. Does it make sense (logically and scientifically)?	Y	Y	Y	Y
Likelihood	P	P	P	P

Legend: Y – Yes, N – No, ND – No Data, NR – Not Relevant, P – Possibly transport to the same area. Such structures can be found in Nusa Dua and Sanur. The sea walls built in Candidasa, Sanur and Nusa Dua can also affect the stability of the area around these structures. Sea sand mining also causes reduction in beach materials. In Klungkung Regency, which is the largest sand and gravel-producing area in Bali, the length of eroded area increased from 3 to 7 km from 1987 to 1997.

Coral mining, which supplies the needs of building and construction industries, have also led to the reduction of natural beach protection and sources of sand materials, as observed in Sanur and Nusa Dua. In addition to man-induced factors that cause erosion in the coastal areas, dam construction for irrigation purposes in the upland areas can also contribute to coastal erosion by preventing the transport of sediments to the sea. This factor is considered important in Gianyar and Klungkung Regencies (Bali ICM, 2001).

Consequences

In the last two decades, beach erosion in Badung Regency and Denpasar Municipality has threatened various structures such as recreation facilities, hotels, temples, houses, and even roads. In Gianyar, Klungkung and Karangasem Regencies, beach erosion was also attributed to be the cause for the loss of agricultural areas and sites used for religious activities/ceremonies.

The most serious impacts of beach erosion in the Bali coastal area are the decrease in optional and intrinsic values of the resources, which in turn may bring about the loss of economic development opportunities, especially for coastal tourism.

SUMMARY OF RISK ASSESSMENT

Resources

For resources, clear evidences of decline were established for fisheries (Annual Reports of the Fisheries Agency of Bali Province, 1991-2000), commercial shrimp culture (Annual Reports of the Fisheries Agency of Bali Province, 1991, 1995 and 2000) and seaweed culture (Annual Reports of the Fisheries Agency of Bali Province, 1992, 1995, 1997 and 2000). The adverse ecological, economic and social consequences of the decline in these resources are considered significant. Small-scale fishers who are dependent on these resources for livelihood are particularly affected.

A comprehensive retrospective risk assessment was not carried out for shellfisheries due to lack of information.

Table 16 shows the assessment of the evidences of decline, scope of impact and consequences of the decline of different resources on the ecological system, economy and society in the Southeastern Coast of Bali.

Habitats

For habitats, decline was clearly established for mangroves (Management Plan of Tahura Ngurah Rai, 2000; Bali Turtle Island Development, 1995; and BAPPEDA-Bali, 1998), coral reefs (Yayasan Bahtera Nusantara Denpasar, 2001; WWF-Wallacea, 2001, BAPPEDA-Bali, 1998-1999; and Bali Beach Conservation Project, 1998), seagrass beds (Bali ICM, 2001; Koba, 1993; Bali Beach Conservation Project, 1998; and BAPPEDA-Bali, 1998) and beaches (Public Work Agency of Bali Province, 1998).

The destruction of habitats will have large ecological consequences due to the loss of their ecological functions as breeding, spawning and nursery grounds for various marine life. Economic consequences will arise from loss of goods and services that are directly or indirectly derived from these habitats. For other habitats such as soft-bottoms and mudflats, retrospective risk assessment was not carried out due to lack of comparative information.

Table 17 shows the evaluation of the evidences of decline, scope of impact and consequences of decline of each habitat on ecology, economy and society.

Table 16. Summary of Evidences, Areal Extent and Consequences of Resource Decline.

Resources	Evidence	Areal Extent	Consequences		
			Ecological	Economic	Social
Marine fisheries	Enough	**	Unknown	**	**
Shrimp Culture	Few	*	*	*	*
Seaweeds	Few	*	*	*	*

Note: (*) - Small; (**) - Medium

Table 17. Summary of Evidences, Areal Extent and Consequences of Habitat Decline.

Resources	Evidence	Areal Extent	Consequences		
			Ecological	Economic	Social
Mangroves	Few	*	**	Unknown	Unknown
Coral Reefs	Few	*	**	Unknown	Unknown
Seagrass Beds	Few	*	***	**	**
Beaches	Not enough	*	**	**	**

Note: (*) - Small; (**) - Medium; (***) – Large

Prospective Risk Assessment

In the prospective risk assessment, potential stressors in the area of interest were identified and the MECs of these stressors were compared with threshold values or PNECs to obtain RQs. An RQ less than 1 indicates acceptable risk and suggests little concern while an RQ greater than 1 signifies cause for concern. The level of concern increases with RQ increase.

Introduction

A prospective risk assessment aims to determine if measured or predicted levels of environmental parameters are likely to cause harm to targets of interest, and is accomplished by identifying the likely targets then comparing the MECs or PECs with appropriate threshold values (PNECs) to get RQs. For human health, risk through seafood ingestion is estimated by comparing measured or predicted environmental levels (MELs or PELs) with levels of concern (LOCs) as PNECs.

From an ecological point of view, different thresholds should be specified for each specific target. These are rarely available, and so, in general, we use environmental quality standards that are derived by extrapolation from ecotoxicological endpoints (MPP-EAS, 1999a).

For the study site, a simplified ecological risk assessment was carried out using values from the local/national criteria, regional criteria and literature as thresholds to estimate the risk to the entire ecosystem. The principles and techniques applied are described in MPP-EAS (1999a).

For the ecological risk assessment, RQs are the ratios of MECs (or PECs) and PNECs. For human health, RQs are the ratios of MELs (or PELs) and LOCs. LOCs are obtained by dividing the tolerable daily intakes (TDIs) by seafood consumption rates. When an RQ is less than 1, it is presumed that the likelihood of adverse effects is low. When an RQ is greater than 1, there is a likelihood of adverse effects, the magnitude of which increases with increase in RQ.

For ecological risk assessment:

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

For human health:

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

Where	RQ	< 1	Low risk
		≥ 1	High risk

In this risk assessment, however, no data on seafood tissue was available so risks to human health arising from consumption of contaminated seafood were not estimated. This kind of information is very important particularly for coastal communities like Bali so efforts should be made to generate this in future risk assessments.

The reliability of the assessment depends largely on the quality and relevance of the data used as exposure concentrations (MECs) and effects thresholds (i.e., PNECs). Although there may be uncertainties associated with MECs used in the risk assessment, the RQs nevertheless provide useful signals of potential areas of concern. The uncertainties can be minimized through the careful selection of good quality data and relevant thresholds or these can be described so that future use of the risk assessment results would take the possible effects of the uncertainties into consideration.

An initial measure of uncertainty was obtained by taking the average, best-case (minimum) and worst-case (maximum) 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.

The primary source of threshold values was the Bali Criteria for Seawater Quality (Appendix 2), which specifies threshold values for both tourism and recreation and marine biota and fisheries.

The worst-case RQ (RQ_{Max}) was obtained by taking the ratio of the maximum MEC (MEC_{Max}) and the specified criteria (PNEC) to generate the highest possible RQ. Conversely, the best-case RQ (RQ_{Min}) was obtained by taking the ratio of the minimum MEC (MEC_{Min}) and the criteria value (PNEC) to generate the lowest possible RQ. An RQ_{Max} that is greater than 1 indicates a hotspot perspective of the study area. On the other hand, an RQ_{Max} that is less than 1 indicates acceptable concern for the parameter in all the areas studied. Conversely, an RQ_{Min} that is greater than 1 indicates a cause for concern for the parameter in all the areas studied.

The average RQ (RQ_{Ave}) is the indicator of more characteristic conditions in the site and was obtained by dividing the average MEC (MEC_{Ave}) by the PNEC. The MEC_{Ave} is actually the geometric mean of the MECs, not the arithmetic mean, since environmental measurements usually form a lognormal distribution and the geometric mean provides a less biased estimate than the arithmetic mean.

In cases where the Bali criteria could not be used to compute for RQs (i.e., zero limits), such as for oil and grease and detergents, limits from the National Seawater Quality Criteria for Indonesia (Appendix 3) were applied. The national criteria specify a range of limits (minimum and maximum) for tourism and recreation and for marine biota and fisheries. Except for oil and grease and *E. coli* for which zero thresholds were specified for Bali, the Bali Seawater Quality Criteria for Tourism and Recreation adopted the minimum limits specified in the national criteria. For marine biota and fisheries, the maximum limits in the national criteria were adopted for Bali except for NH_3 and detergent for which other values were provided for local application.

For heavy metals, the minimum limits for tourism and recreation from the national criteria that were adopted for Bali were very low and were orders of magnitude lower than criteria from other areas in the region. In this case, the maximum limits in the national criteria were applied to generate RQs for heavy metals and criteria from other locations were applied for comparison.

Data for the IRA of the site came primarily from the Annual Water Quality Monitoring by BAPEDALDA-Bali (1999-2001), Bali Beach Conservation Project (1998), BAPPEDA-Bali (1998), and Benoa Port Authority (1999). The summary of references for the assessment is shown in Table 18. A description of sampling locations can be found in Appendix 1.

The threshold values used as PNECs came primarily from the Bali Province Seawater Quality Criteria. For almost all parameters, the criteria for tourism and recreation were used. In the absence of suitable local criteria, values from the National Criteria for Indonesia were applied followed by thresholds from other locations (Appendix 4). For

Table 18. Summary of Information for the Prospective Risk Assessment.

Parameter	Description of data	Location	References	Sources of PNECs
Water Column 1. Nutrients a. PO_4	Raw data 1997-1999, yearly, 12 stations, 3 replications	Sanur, Nusa Dua and Benoa Bay	Bali Beach Conservation Project (1998); Benoa Port Authority (1999)	ASEAN Marine Water Quality Criteria
b. NO_3	Raw data 1997-1999, yearly, 16 stations, 3 replications	Sanur, Nusa Dua, Benoa Bay, Candidasa and Nusa Penida	Bali Beach Conservation Project (1998); Benoa Port Authority (1999); BAPPEDA-Bali (1998)	ASEAN Marine Water Quality Criteria
c. NH_3	Raw data 1997-1999, yearly, 8 stations, 3 replications	Nusa Dua, Gianyar and Candidasa	Bali Beach Conservation Project (1998); BAPEDALDA-Bali (1999-2001)	Bali Criteria for Seawater Quality (for marine biota and fisheries)
2. *E. coli*	Raw data 1998-2001, yearly, 11 stations, 4 replications	Sanur, Nusa Dua, Gianyar, Candidasa and Nusa Penida	Bali Beach Conservation Project (1998); BAPEDALDA-Bali (1999-2001); Indonesian Environmental Management Agency (2001)	Bali Criteria for Seawater Quality (for tourism and recreation)
3. COD/ BOD/ DO	Raw data 1997-2001, yearly, 10 stations, 5 replications	Sanur, Benoa Bay, Nusa Dua, Gianyar and Sanur	Bali Beach Conservation Project (1998); BAPPEDA-Bali (1998); BAPEDALDA-Bali (1999-2001); Benoa Port Authority (1999); Indonesian Environmental Management Agency (2001)	Bali Criteria for Seawater Quality (for tourism and recreation; and for marine biota and fisheries for DO)
4. Oils	Raw data 1997-2001, yearly, 8 stations, 5 replications	Benoa Bay, Nusa Dua, Gianyar and Candidasa	Benoa Port Authority (1999); BAPEDALDA-Bali (1999-2001); Indonesian Environmental Management Agency (2001)	Indonesian Criteria for Seawater Quality (minimum limit for tourism and recreation)
5. TSS	Raw data 1997-2001, yearly, 16 stations, 5 replications	Sanur, Benoa Bay, Nusa Dua, Gianyar, Candidasa and Nusa Penida	Benoa Port Authority (1999); BAPEDALDA-Bali (1999-2001); BAPPEDA-Bali (1998); Bali Beach Conservation Project (1998)	Bali Criteria for Seawater Quality (for tourism and recreation)
6. Heavy Metals (Pb, Cu, Cd, Zn, Cr)	Raw data 1999-2001, yearly, 12 stations, 3 replications	Benoa Bay, Nusa Dua, Gianyar, Nusa Penida, and Candidasa	Benoa Port Authority (1999); BAPEDALDA-Bali (1999-2001); BAPPEDA-Bali (1998)	Indonesian Criteria for Seawater Quality (maximum limits for tourism and recreation); Criteria for bathing from other areas in the region; Bali Criteria for Seawater Quality (for marine biota and fisheries)
7. Detergents (Surfactants)	Raw data 1999-2001, yearly, 6 stations, 3 replications	Benoa Bay, Nusa Dua and Candidasa	Benoa Port Authority (1999); BAPEDALDA-Bali (1999-2001)	Indonesian Criteria for Seawater Quality (maximum limit for tourism and recreation)

NO_3 and PO_4, the ASEAN criteria (ASEAN, 2003), which were specified to protect marine waters from eutrophication, were used. The actual PNECs applied for each parameter are described in Table 18 and will be discussed in greater detail in the section for each parameter. Appendix 2-4 presents the compilation of criteria and standards.

NUTRIENTS

The data for nutrients, i.e., phosporus (P) as orthophosphate or phosphate (PO_4-P) and nitrogen as nitrate (NO_4-N) and ammonia (NH_3-N), in the water column at sampling points found in the Nusa Dua and Sanur coastal waters were from the Bali Beach Conservation Project Final Report (1998). Data for nutrients in the water column at Candidasa, Nusa Penida, and Benoa Bay coastal waters were from the BAPEDALDA-Bali (1999-2001), BAPPEDA-Bali (1998), and Benoa Port Authority (1999).

The data on PO_4, NO_4 and NH_3 at Nusa Dua coastal waters were obtained from 4 stations consisting of 30 sampling points; data from Benoa Bay were obtained from 7 stations; data from Nusa Penida were obtained from 11 stations; and data for Sanur were obtained from 6 stations with consisting of 36 sampling points.

There were no criteria values for PO_4 and NO_3 in the Bali Province Seawater Quality Criteria, so values from the ASEAN Marine Water Quality Criteria (ASEAN, 2003) were used. These ASEAN nutrient criteria were specified to protect marine waters from eutrophication. The ASEAN criteria value for NO_3 is 0.055 mg/l (parts per million or ppm); for PO_4, the criteria values are 0.015 and 0.045 ppm for coastal and estuarine waters, respectively. The PO_4 criteria for coastal waters was used for the risk assessment. For NH_3, the Bali criteria for waters suitable for marine biota and fisheries is 1 ppm.

Average and maximum RQs for NH_3 greater than 1 were found in Candidasa (RQ_{Ave} = 2.61; RQ_{Max} = 16.28), while in other locations (Nusa Dua and Gianyar) the RQs were less than 1. The magnitudes of the RQs for NH_3 in Candidasa present serious cause for concern.

All calculated average and maximum RQs for PO_4-P in all locations were greater than 1. Minimum PO_4-P RQ in Benoa Bay was also greater than 1 (RQ_{Min} = 5.53), while in Nusa Dua and Sanur coastal waters, minimum RQs were less than 1. All minimum NO_3-N RQs were less than 1 in all locations except for Benoa Bay (RQ_{Min} = 3.47), while all maximum NO_3-N RQs were greater than 1 except for Candidasa (RQ_{Max} = 0.09). Average NO_3-N RQs in Nusa Dua, Sanur and Benoa Bay were all greater than 1, while for Candidasa and Nusa Penida, the average RQs were less than 1 (Table 19). The minimum RQs for PO_4 and NO_3 that both exceeded 1 in Benoa Bay indicate general cause for concern for the levels of these nutrients in the bay.

Nusa Dua and Sanur coastal waters are affected mostly by economic activities that take place in the coastal areas. The high concentration of PO_4-P in the water may be attributed to the hotels, restaurants, commercial establishments and households that use phosphorus-containing detergents for cleaning purposes. The NO_3-N in the water may also be attributed to inadequate management of organic wastes from hotels and restaurants. In addition, rivers that pass through densely populated and industrial areas before draining to Benoa Bay also contribute to the nutrient load in the bay. Poor management of wastes in the upstream areas is also contributory to increased NO_3 and PO_4 concentrations in coastal waters.

The possible sources of nutrients in Badung and Denpasar coastal areas are domestic/

commercial/institutional wastes and sewage, untreated or partially treated industrial effluents, and agricultural discharge or run-off.

All of these contribute significant amounts of nutrients in the coastal area, but domestic/ commercial/institutional waste and sewage can be considered as the major sources of contaminants and these can be discharged or transported to the coastal areas through the river system.

Nutrients are required for primary productivity but elevated concentrations may cause eutrophication and may trigger phytoplankton and green seaweed blooms. This has implications on DO levels in the coastal area and, eventually, on the benthos and other sessile organisms. For locations where there are coral reefs, phytoplankton blooms can block sunlight and therefore reduce photosynthetic rate of *Zooxanthellae* in coral tissues. The high density of green seaweed in the coral reef area may cover coral polyps until these suffocate and eventually die.

Uncertainty Analysis

Based on uncertainty analysis using the Monte Carlo Simulation through the Crystal Ball software, the probability that RQ for PO_4 will exceed the value of 1 is 91 percent, indicating a need for risk management. Loading from major rivers can also be evaluated to determine their relative contribution to nutrient levels in the marine water. An alternative method that can identify whether nutrients in marine water are coming from sources inside or outside the coast is the calculation of nutrient budgets in the coastal area.

The results of the risk assessment highly depend on the MECs and PNECs employed in the calculations. For PO_4 and NO_3 for which local standards were not available, thresholds from other sources were used to compute for RQs. The use of local threshold values will provide a more suitable assessment of risks. With regard to the MECs, PO_4 and NH_3 data were available for three locations only, so RQs were not generated for the other areas. The maximum and average RQs generated for the regencies/municipalities provide

Table 19. RQs for Nutrients.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
NH_3	Nusa Dua	0.001	0.004	0.00075	1	0.001	0.004	0.001
	Gianyar	0	0.001	0	1	0	0.001	0
	Candidasa	0.001	16.280	2.61000	1	0.001	16.280	2.610
PO_4	Sanur	0	0.930	0.13000	0.015	0	62.000	8.670
	Benoa Bay	0.083	0.133	0.11000	0.015	5.530	8.870	7.330
	Nusa Dua	0	0.987	0.13000	0.015	0	65.80	8.670
NO_3	Sanur	0	0.500	0.17700	0.055	0	9.090	3.220
	Benoa Bay	0.191	1.500	0.53000	0.055	3.470	27.270	9.640
	Nusa Dua	0	0.835	0.08000	0.055	0	15.180	1.450
	Candidasa	0	0.005	0.00200	0.055	0	0.090	0.040
	Nusa Penida	0.012	0.087	0.05000	0.055	0.220	1.580	0.910

Sources of MECs: Bali Beach Conservation Project Final Report (1998), BAPEDALDA-Bali (1999, 2000, 2001), BAPPEDA-Bali (1998), and Benoa Port Authority (1999).

Sources of PNECs: For PO_4 and NO_3: ASEAN Criteria for Marine Water Quality (ASEAN, 2003); For NH_3: Bali Province Seawater Quality Criteria for Marine Biota and Fisheries.

indications of the extent of contamination in these areas, although more detailed analyses of the spatial and temporal distribution of risks, using more data, will be useful in developing appropriate risk management actions.

E. coli

The data of *E. coli* for this assessment were obtained from various sources. Data were obtained from three stations in Nusa Dua and four stations in Sanur (BAPEDALDA-Bali, 2000); two stations each in Gianyar and Candidasa with six and seven sampling points, respectively (BAPEDALDA-Bali, 2000, Indonesian Environmental Management Agency, 2001); and seven stations with nineteen sampling points in Nusa Penida (BAPPEDA-Bali, 1999 and BAPEDALDA-Bali, 1999-2001).

The criteria value for *E. coli* in the Bali Seawater Quality Criteria for Tourism and Recreation is zero, which could not be used to compute for RQs and which is practically unachievable. The minimum limit specified in the national seawater quality criteria, 10 cells/100 ml, was applied as PNEC.

The calculation of risk quotient for *E. coli* in the coastal waters showed that worst case and average RQs exceeded 1 in all locations, except in Nusa Penida where average RQ was less than 1, while best case RQs were less than 1 for all locations. Average and maximum RQs in Sanur and Gianyar, particularly, are very high (Table 20). The RQs indicate that all of the locations present certain levels of human health risk from exposure to *E. coli* in the water column. Sources of *E. coli* contamination in coastal waters include household, tourism, and institutional wastes. The high concentrations of *E. coli* in Sanur and Gianyar coastal waters are also due to domestic wastes, which reach the coastal waters through the river systems. Since most coastal waters in these areas are used for bathing, recreation, and swimming, the high concentrations of *E. coli* can potentially bring about serious harm to human health.

Uncertainty Analysis

A potential source of uncertainty in this assessment is the limited number of observations used to generate the RQs for each site. Considering the natural variability in coliform concentrations in natural waters due to various factors such as exposure to the sun, temperature, salinity, and water movement, among others, more data will be required to come up with a more representative assessment, preferably one that provides a more detailed spatial and temporal assessment of risks.

BOD/COD/DO

The data for BOD/COD/DO were obtained from various sources namely, Indonesia Port Authority (1999), Indonesia Environmental

Table 20. RQs for *E. coli*.

Agents	Location	MEC_{Min} (cell/100ml)	MEC_{Max} (cell/100ml)	MEC_{Ave} (cell/100ml)	PNEC (cell/100ml)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
E. coli	Sanur	0	11,000	3,736.67	10	0	1,100.0	373.7
	Nusa Dua	3	64	32.75	10	0.300	6.4	3.3
	Gianyar	0	24,000	8,059.00	10	0	2,400.0	805.9
	Candidasa	0	45	17.57	10	0	4.5	1.8
	Nusa Penida	0	20	7.00	10	0	2.0	0.7

Sources of MECs: BAPEDALDA-Bali (1999-2001), BAPPEDA-Bali (1999), and Indonesian Environmental Management Agency (2001).
Sources of PNECs: Indonesian Criteria for Seawater Quality for Tourism and Recreation (minimum).

Management Agency (2001), BAPEDALDA-Bali (2000) and Bali Beach Conservation Project (1998).

Data for COD were available for Benoa Bay, Candidasa and Nusa Dua, and were generated from 10 stations. The data for BOD and DO for Benoa Bay, Candidasa, Nusa Dua, Sanur, and Gianyar were also obtained from 10 stations.

The threshold values are from the Bali Seawater Quality Criteria for Tourism and Recreation. The criteria values are 20 ppm for COD, 10 ppm for BOD, and 5 ppm for DO. For DO, concentrations higher than the threshold indicate better water quality for marine biota, which are especially dependent on it. In view of the importance of DO for marine biota, the DO criteria for the protection of marine biota and fisheries (4 ppm) was also applied.

RQs are usually obtained by dividing the MECs by the PNECs. For DO, however, since higher levels indicate better water quality, RQs for DO were obtained by taking the reciprocal of the previously mentioned ratio. Furthermore, the lowest DO measurement is considered the worst-case MEC and is used in getting the maximum RQ, while the highest DO measurement is considered the best-case MEC. With regard to criteria values, the higher numerical value is the minimum limit while the lower value is the higher limit.

The results of the assessment show that all maximum RQs for COD were greater than 1, while average RQs also exceeded 1 in Nusa Dua and Candidasa (Table 21). Among the three locations, the highest maximum RQ for COD was computed for Candidasa coastal waters (RQ_{Max} = 51.6) and the lowest for Nusa Dua (RQ_{Max} = 1.13). The highest average RQ for COD was also computed for Candidasa (RQ_{Ave} = 8.28) while average RQ in Nusa Dua was 1.02 and the value for Benoa Bay was less than 1. It should be noted that in Nusa Dua, the RQ generated from the lowest measurement is already approaching 1 (RQ_{Min} = 0.91).

Just like the results for COD, the highest RQ_{Max} for BOD was also computed for Candidasa coastal waters (RQ_{Max} = 37.51). Except for Sanur (RQ_{Max}= 1.27), other locations showed RQ_{Max} less than 1 (Table 21). RQ_{Ave} for BOD which exceeded 1 was computed only for Candidasa coastal waters (RQ_{Ave} = 9.52), while average RQs for all the other locations were less than 1.

Using the criteria for tourism and recreation, all maximum RQs for DO were greater than 1 except for Benoa Bay, although the value for Benoa Bay was very close to 1 (RQ_{Max} = 0.95). The highest RQ_{Max} was obtained in Sanur (RQ_{Max} = 25), although the only RQ_{Ave} that exceeded 1 was found in Candidasa coastal waters (RQ_{Ave} = 1.02).

Application of the DO criteria for marine biota and fisheries gave average RQs that are less than 1 for all areas assessed and maximum RQs exceeding 1 in Sanur (RQ_{Max} = 20), Nusa Dua (RQ_{Max} = 1.08) and Gianyar (RQ_{Max} = 1.14).

BOD and COD levels indicate the amounts of organic matter in the water column that are susceptible to biochemical oxidation through microbial activities and by a strong chemical oxidant, respectively. Decomposition of higher amounts of organic matter will require higher levels of oxygen, thereby potentially depriving aquatic fauna of their oxygen requirements. This may result to migration for mobile organisms such as fishes and serious harm or even death to sessile organisms such as the benthic species.

The main sources of organic wastes in the Bali ICM area are domestic and tourism activities. In Candidasa and Sanur where there are several hotels and restaurants, the values of BOD/COD were notably higher compared to the other locations. These hotels and restaurants often lack the appropriate waste management facilities, which might account for the higher RQs in these areas.

Uncertainty Analysis

For BOD in Benoa Bay, Nusa Dua and Gianyar, maximum RQs were all less than 1, indicating that all other values would yield RQs that are less than 1. For Candidasa, maximum and average RQs were both significantly greater than 1, indicating greater probability that RQs will exceed 1 as compared to Sanur where RQ_{Max} was greater than 1 but RQ_{Min} was significantly less than 1.

For DO, using the criteria for tourism and recreation, the average RQs at Sanur, Benoa Bay, Nusa Dua, Gianyar and Candidasa were close to 1 and based on the uncertainty analyses, the probability that RQ will exceed 1 is 87.7 percent for Sanur, 62 percent for Candidasa, and 20.8 percent for Nusa Dua.

OIL AND GREASE

Oil consists of a wide variety of hydrocarbon chain compounds with different properties and hence will have different possible effects on marine life as well as on human health. Once the oil is released into the environment, it will continue to change due to biological degradation, photo-oxidation, wave action, and other processes.

Oil and grease concentrations in seawater were recorded in Benoa Bay, Nusa Dua, Gianyar

Table 21. RQs for BOD, COD and DO.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
Tourism and Recreation								
BOD	Sanur	0.60	12.68	3.17	10	0.06	1.27	0.32
	Benoa Bay	1.27	2.56	1.94	10	0.13	0.26	0.19
	Nusa Dua	0.80	3.70	1.93	10	0.08	0.37	0.19
	Gianyar	1.16	7.10	4.06	10	0.12	0.71	0.41
	Candidasa	1.57	375.06	95.24	10	0.16	37.51	9.52
COD	Benoa Bay	11.85	26.19	16.73	20	0.59	1.31	0.84
	Nusa Dua	18.19	22.50	20.44	20	0.91	1.13	1.02
	Candidasa	14.81	1,031.92	165.69	20	0.74	51.60	8.28
DO	Sanur	0.20	10.80	7.40	5	0.46	25.00	0.68
	Benoa Bay	5.26	7.28	6.29	5	0.69	0.95	0.79
	Nusa Dua	3.70	11.60	7.32	5	0.43	1.35	0.68
	Gianyar	3.50	7.46	5.63	5	0.67	1.43	0.89
	Candidasa	4.60	5.20	4.90	5	0.96	1.09	1.02
Marine Biota and Fisheries								
DO	Sanur	10.80	0.20	7.40	4	0.37	20.00	0.54
	Benoa Bay	7.28	5.26	6.29	4	0.55	0.76	0.64
	Nusa Dua	11.60	3.70	7.32	4	0.34	1.08	0.55
	Gianyar	7.46	3.50	5.63	4	0.54	1.14	0.71
	Candidasa	5.20	4.60	4.90	4	0.77	0.87	0.82

Sources of MECs: Indonesia Port Authority (1999), Indonesia Environmental Management Agency (2001); BAPEDALDA-Bali (2000) and Bali Beach Conservation Project (1998) .
Sources of PNECs: Bali Province Seawater Quality Criteria for Tourism and Recreation, and Marine Biota and Fisheries.

and Candidasa. In Gianyar, measurement of oil and grease was done at three different beaches, namely Lebih, Purnama and Saba. The Bali Criteria for Seawater Quality specifies a criteria value for oil and grease that is equal to zero, which cannot be used to compute for RQs and which is realistically not attainable. The specified zero limit is also not within the range of threshold values specified for oil and grease in seawater in the National Criteria for Seawater Quality for Tourism and Recreation (minimum = 1 mg/l and maximum = 5 mg/l). For this risk assessment, the minimum limit specified in the National Criteria for Tourism and Recreation (1 mg/l) was applied as PNEC.

Maximum RQs were less than 1 for all locations, although the highest RQ was close to 1 (RQ_{Max} = 0.90), and was obtained for Benoa Bay, a busy area where there are a variety of activities that include tourism, harbor, and fishing. The oil and grease present in the bay waters may be attributed to harbor activities that use oil, particularly for boat and ship operations at Benoa Harbour. It was observed that oil at the point of measurement was brought in mostly by the waves. In contrast, oil concentration levels at Nusa Dua region and Candidasa were very low and provided worst-case RQs that were much lower than 1. In Gianyar, oil and grease concentrations in the three locations were not significantly different, and yielded RQs that were all less than 1. The highest oil and grease concentration in Gianyar (0.3 mg/l), which gave RQ_{Max} equal to 0.3, was obtained at Lebih beach, and may be attributed to the cafés and related activities along the coast.

The results of the risk assessment show that RQs for oil and grease at all locations are lower than 1 (Table 22). Oil concentration at these locations present acceptable risk for the environment, although oil and grease concentrations in Benoa Bay need to be monitored regularly to determine changes in the level of risk.

Marine transportation by motorized boats and small ships are the main sources of oil contaminants in seawater in these areas. Except for Benoa Bay, however, these activities are relatively not intense in the Bali ICM area. Non-motorized vessels are still being used. Being an open coastal area where water exchange is faster, oil in the water column is more easily dispersed and degraded.

Uncertainty Analysis

Since all the RQs for oil and grease for all locations were well below 1, quantitative uncertainty analysis using the Crystal Ball software was no longer performed. However, the suitability of the criteria used as PNEC (1 mg/l) for a tourist area like Bali should be verified, while reconsideration should also be made regarding the specified criteria for oil and grease in Bali (zero) which might not be realistic and attainable.

Table 22. RQs for Oil and Grease.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	$PNEC_{Min}$ (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
Oil and Grease	Benoa Bay	0.0020	0.8960	0.1640	1	0.00200	0.900	0.1600
	Nusa Dua	0.0002	0.0046	0.0033	1	0.00020	0.005	0.0030
	Gianyar	0.1000	0.3000	0.1830	1	0.10000	0.300	0.1800
	Candidasa	0.0010	0.0019	0.0009	1	0.00100	0.002	0.0009

Sources of MECs: Benoa Port Authority (1999), BAPEDALDA-Bali (1999-2001), and Indonesian Environmental Management Agency (2001).
Sources of PNECs: Indonesian Criteria for Seawater Quality for Tourism and Recreation (minimum).

Total Suspended Solids (TSS)

The data on TSS were available for all locations. The data on TSS in Benoa Bay were obtained from the Indonesian Port Authority (1999) and derived from seven stations. The data for Sanur and Nusa Dua were obtained from the Bali Beach Conservation Project (1998), while data for Gianyar, Candidasa, and Nusa Penida were generated from BAPEDALDA-Bali (2000). The criteria value for TSS in the Bali Province Seawater Quality Criteria for Tourism and Recreation is 20 ppm.

Table 23 shows that maximum RQs of TSS exceeded 1 for Benoa Bay (RQ_{Max} = 8.34), Nusa Dua (RQ_{Max} = 1.3), Candidasa (RQ_{Max} = 25.1), and Gianyar (RQ_{Max} = 1.1). The highest RQ_{Max} was computed for Candidasa and the RQ_{Ave} also exceeded 1 in this area (RQ_{Ave} = 4.45) although it was only in Benoa Bay where average as well as minimum RQs exceeded 1 (RQ_{Min} = 4.53 and RQ_{Ave} = 5.66), indicating more general concern for TSS levels in this area. In contrast, maximum RQs for Sanur and Nusa Penida are lower than 1, indicating low concern for TSS levels in these areas. These RQ values indicate that TSS poses the highest risk at Benoa Bay and Candidasa coastal waters.

High concentrations of suspended solids (organic and inorganic matter) in coastal waters may increase turbidity, reduce light penetration into the water and potentially adversely affect photosynthetic activities. Settling of the suspended particles may also cover important habitats such as coral reefs and lead to suffocation of organisms.

Suspended solids in Benoa Bay come from river flows and run-off from the surrounding areas, while in the case of Candidasa and other locations, most TSS enter the water through land run-off and discharge of domestic wastes.

Uncertainty Analysis

The data clearly shows that all RQs were less than 1 in Sanur and Nusa Penida; all RQs were greater than 1 in Benoa Bay; and most RQs exceeded 1 in Candidasa. Hence, uncertainty analysis through the Monte Carlo simulation using the Crystal Ball software was performed only on data from Nusa Dua since maximum RQ was greater than 1 but average RQ was less than 1 in this area. The uncertainty analysis shows that the probability that RQs will exceed 1 in Nusa Dua is greater than 2.5 percent, indicating limited concern for TSS levels in this area. A lower probability that RQs will exceed 1 is therefore expected for Gianyar, which gave lower RQs than Nusa Dua.

Table 23. RQs for TSS.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	$PNEC_{Min}$ (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
TSS	Sanur	3.0	17.0	9.832	20	0.15	0.850	0.49
	Benoa Bay	90.5	166.7	113.157	20	4.53	8.335	5.66
	Nusa Dua	7.0	26.0	11.562	20	0.35	1.300	0.58
	Gianyar	3.0	22.0	8.500	20	0.15	1.100	0.43
	Candidasa	7.0	502.0	89.000	20	0.35	25.100	4.45
	Nusa Penida	3.0	14.0	6.750	20	0.15	0.700	0.34

Sources of MECs: Bali Beach Conservation Project (1998); Indonesian Port Authority (1999); BAPEDALDA-Bali (2000)
Sources of PNECs: Bali Province Seawater Quality Criteria for Tourism and Recreation.

HEAVY METALS

The data on several heavy metals in the water column for various locations were obtained from various sources that include Benoa Port Authority (1999), BAPEDALDA-Bali (1999-2001) and BAPPEDA-Bali (1998). Data on Pb were available in Benoa Bay, Nusa Dua, Gianyar and Nusa Penida; data on Cu were available for Nusa Dua, Gianyar, Candidasa and Nusa Penida; and data for Cd were available in Benoa Bay, Nusa Dua, Candidasa, and Nusa Penida. The data on Zn were available only for Gianyar and Nusa Penida, while data for Cr were available only for Nusa Penida.

In the Bali Seawater Quality Criteria, the threshold values for heavy metals for waters used for tourism and recreation are very low (close to analytical detection limits) and are orders of magnitude higher than criteria from other locations. These values are the minimum limits recommended in the National Seawater Quality Criteria adopted for Bali (Table 24). Application of these very low thresholds will generate RQs in the order of thousands and over-estimate the risk, and may create unwarranted concern. Table 24 shows that, except for Cu, the maximum limits in the Indonesian Criteria for Seawater Quality for tourism and recreation are comparable with the standards from Vietnam and Thailand and criteria from the Philippines, ASEAN and U.S. EPA. In this risk assessment, therefore, the maximum limits for tourism and recreation in the National Seawater Quality for Indonesia were applied as PNECs. For Cu, the maximum limit for tourism and recreation in the national criteria is much higher than for the other sets of criteria so the minimum value will be applied although this value is still considerably lower than the other criteria. For comparison, RQs for Cu were also computed using criteria for bathing from the Philippines and Vietnam and the proposed ASEAN Water Quality Criteria for recreational activities. The Bali Criteria for Waters used for marine biota and fisheries, adopted from the maximum limits in the national criteria, were also applied. Computed RQs for heavy metals are listed in Tables 25 and 26.

Using the criteria for tourism and recreation, maximum RQs for Zn did not exceed 1 in all locations, but maximum, average and minimum

Table 24. Criteria for Heavy Metals in Seawater from Different Locations.

Heavy Metals	Indonesian Seawater Quality Criteria				Vietnam[2]		Thailand[3]	Phil.[4]	ASEAN[5, 6]		U.S. EPA[7]
	Tourism and Recreation		Marine Biota and Fisheries								
	Min[1]	Max	Min	Max[1]	A	B	Class 2-4	Class SB	A[5]	B[6]	Chronic
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Pb	0.00002	0.05	0.00020	0.01	0.100	0.050	0.050	0.05	0.0085		0.0056
Cu	0.00100	1	0.00100	0.06	0.020	0.010	0.050	0.02	0.0080	0.500	0.0029
Cd	0.00002	0.01	0.00002	0.01	0.005	0.005	0.005	0.01	0.0100	0.0357	0.0093
Zn	0.00200	1.50	0.00200	0.10	0.100	0.010	0.100		0.0500	1.250	0.0550
Cr	0.00004	0.01	0.00004	0.01	0.05 Cr^{6+}	0.05 Cr^{6+}	0.05 Cr^{6+}	0.1 Cr^{6+}	0.050 Cr^{6+}		0.0500

[1] *Adopted as criteria values in the Bali Criteria for Seawater Quality*
[2] *Vietnamese Standards for Seawater Quality (VNS 5943 –1995): A: Bathing, B: Aquaculture*
[3] *Coastal Water Quality Standard of Thailand (PCD, 1994), Class 2: Conservation of Coral Community; Class 3: Conservation of Natural Area; Class 4: Propagation of Marine Life*
[4] *Philippine Marine Water Quality Criteria (DAO 34, 1990), Class SB (bathing and fisheries)*
[5] *ASEAN Marine Water Quality Criteria (ASEAN, 2003), Criteria for Protection of Aquatic Life*
[6] *Proposed Marine Water Quality Criteria (Jusoh, et al., 1999), Proposed Criteria for Protection of Human Health (recreational activities)*
[7] *U.S. EPA Marine Chronic Criteria for Regulatory Purposes*

RQs for Cu and Cd were equal to or greater than 1 for all locations. For Cu, the highest maximum, average and minimum RQs were obtained in Nusa Penida (RQ_{Max} = 390, RQ_{Max} = 160 and RQ_{Min} = 40) while for Cd, the highest maximum and minimum RQs were obtained also in Nusa Penida (RQ_{Max} = 77 and RQ_{Min} = 1.4 for Cd) while the highest average RQ was obtained for Nusa Dua (RQ_{Ave} = 6.0). For Cu, use of the higher criteria, 0.02 mg/l, from the Philippines and Vietnam still yielded RQs greater than 1 for all areas assessed. For Cr, only the RQ_{Max} in Nusa Penida exceeded 1 (RQ_{Max} = 3.3), while for Pb, RQ_{Max} in Nusa Penida (RQ_{Max} = 1.5) and maximum and average RQs in Nusa Dua (RQ_{Max} = 1.6 and RQ_{Min} = 1.2) exceeded 1. These RQs show that there is general concern for Cu and

Table 25. RQs for Heavy Metals.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
Tourism and Recreation								
Pb	Benoa Bay	0.0120	0.034	0.026714	0.050	0.240	0.680	0.534
	Nusa Dua	0.0380	0.080	0.060500	0.050	0.760	1.600	1.210
	Gianyar	0.0100	0.036	0.016500	0.050	0.200	0.720	0.330
	Nusa Penida	0.0100	0.075	0.034947	0.050	0.200	1.500	0.699
Cu	Nusa Dua	0.0240	0.030	0.027000	0.001	24.000	30.000	27.000
	Gianyar	0.0220	0.090	0.070000	0.001	22.000	90.000	70.000
	Candidasa	0.0120	0.050	0.030000	0.001	12.000	50.000	30.000
	Nusa Penida	0.0400	0.390	0.160000	0.001	40.000	390.000	160.000
Cd	Benoa Bay	0.0015	0.050	0.010000	0.010	0.150	5.000	1.000
	Nusa Dua	0.0110	0.180	0.060000	0.010	1.100	18.000	6.000
	Candidasa	0.0110	0.200	0.050000	0.010	1.100	20.000	5.000
	Nusa Penida	0.0140	0.770	0.030000	0.010	1.400	77.000	3.000
Zn	Gianyar	0	0.500	0.380000	1.500	0.000	0.333	0.253
	Nusa Penida	0.0120	0.500	0.220000	1.500	0.008	0.333	0.147
Cr	Nusa Penida	0.0020	0.033	0.006000	0.010	0.200	3.300	0.600
Marine Biota and Fisheries								
Pb	Benoa Bay	0.0120	0.034	0.026714	0.010	1.200	3.400	2.67
	Nusa Dua	0.0380	0.080	0.060500	0.010	3.800	8.000	6.05
	Gianyar	0.0100	0.036	0.016500	0.010	1.000	3.600	1.65
	Nusa Penida	0.0100	0.075	0.034947	0.010	1.000	7.500	3.49
Cu	Nusa Dua	0.0240	0.030	0.027000	0.060	0.400	0.500	0.45
	Gianyar	0.0220	0.090	0.070000	0.060	0.367	1.500	1.17
	Candidasa	0.0120	0.050	0.030000	0.060	0.200	0.830	0.50
	Nusa Penida	0.0400	0.390	0.160000	0.060	0.667	6.500	2.67
Cd	Benoa Bay	0.0015	0.050	0.010000	0.010	0.150	5.000	1.00
	Nusa Dua	0.0110	0.180	0.060000	0.010	1.100	18.000	6.00
	Candidasa	0.0110	0.200	0.050000	0.010	1.100	20.000	5.00
	Nusa Penida	0.0140	0.770	0.030000	0.010	1.400	77.000	3.00
Zn	Gianyar	0	0.500	0.380000	0.100	0.000	5.000	3.80
	Nusa Penida	0.0120	0.500	0.220000	0.100	0.120	5.000	2.20
Cr	Nusa Penida	0.0020	0.033	0.006000	0.010	0.200	3.300	0.60

Sources of MECs: Benoa Port Authority (1999), BAPEDALDA-Bali (1999-2001) and BAPPEDA-Bali (1998).
Sources of PNECs: Indonesian Criteria for Seawater Quality for Tourism and Recreation, and Marine Biota and Fisheries.

Cd levels in the coastal waters of the Bali ICM area, Pb and Cr in selected locations in Nusa Penida, and Pb in some areas in Nusa Dua.

Applying the Cu criteria from the Philippines and Vietnam, all RQs still exceeded 1 and the same trends were observed, although the RQs were 20 times lower than those obtained using the minimum limit for Cu in the Indonesian criteria. Using the proposed criteria for ASEAN, all RQs were less than 1. The wide range of RQs obtained for Cu highlight the importance of the choice of criteria in estimating risks posed by heavy metals as well as other contaminants and the need for a careful consideration of the suitability of designated criteria values.

In view of the lower values specified in the Bali Criteria for the Protection of Marine Fisheries (relative to the applied values for tourism and recreation from the national criteria) and the likelihood of fish exposure to heavy metals in the study areas, risks to fisheries were also estimated using the Bali Province Seawater Quality Criteria for Marine Biota and Fisheries. The criteria values for Cd and Cr are the same as the thresholds for tourism and recreation while those for Pb, Cu and Zn are lower. Risk quotients for Cd and Cr, therefore, showed the same levels of risk while all RQs for Pb (minimum, maximum and average) exceeded 1 for all locations assessed, all maximum and average RQs for Zn also exceeded 1, and maximum and average RQs for Cu exceeded 1 in Gianyar and Nusa Penida. These results indicate concern for all the heavy metals in the assessment, particularly Pb and Cd for all sites.

In Bali Province, the development of industries is focused on home industries or small-scale industries, while big-scale and heavy industries are prohibited. Most of these home industries have poor waste management practices, and lack adequate waste treatment facilities. For textile industries, many dyeing substances employed are harmful and often contain heavy metals. These substances are discharged into coastal waters, and accumulate in the water column, sediment and/or marine biota. Small-scale jewelry shops in the Gianyar Regency have also been identified as potential sources of heavy metals. Port activities such as ship and boat maintenance use toxic and harmful substances that potentially contain heavy metals such as Pb.

Heavy metals are very persistent and tend to accumulate in the environment. These elements can be taken in by marine biota and passed on, through the food chain, to subsequent trophic levels where it can potentially exert adverse effects. Consumption of large amounts of seafood

Table 26. RQs for Copper Using Criteria from Other Areas in the Region.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
Using criteria from the Philippines and Vietnam								
Cu	Nusa Dua	0.024	0.03	0.027	0.02	1.200	1.500	1.350
	Gianyar	0.022	0.09	0.07	0.02	1.100	4.500	3.500
	Candidasa	0.012	0.05	0.03	0.02	0.600	2.500	1.500
	Nusa Penida	0.04	0.39	0.16	0.02	2.000	19.500	8.000
Using the ASEAN Marine Water Quality Criteria								
Cu	Nusa Dua	0.024	0.03	0.027	0.5	0.048	0.060	0.054
	Gianyar	0.022	0.09	0.07	0.5	0.044	0.180	0.140
	Candidasa	0.012	0.05	0.03	0.5	0.024	0.100	0.060
	Nusa Penida	0.04	0.39	0.16	0.5	0.080	0.780	0.320

contaminated with heavy metals can potentially bring risks to human health, both chronic and acute, depending on the heavy metal and the concentration in the seafood tissue.

Uncertainty Analysis

Management of the risk arising from the elevated concentrations of heavy metals, particularly Pb and Cd, in the water column will require substantial effort. Before getting on with potentially costly risk management actions, therefore, it would be worthwhile to verify the levels of these heavy metals in the water column particularly since accurate measurement of the low concentrations of heavy metals in the water column have always faced the challenge of preventing contamination both in the field and laboratory.

The risk assessment also shows the potential need to review the Bali Province Seawater Quality Criteria for Heavy Metals. The minimum limits for the protection of tourism and recreation and marine biota and fisheries are very low, compared with other thresholds in the region, and are actually close to analytical detection limits. Application of these values in the risk assessment would generate very high RQs and may cause unwarranted concern.

DETERGENTS (SURFACTANTS)

The term detergent applies to any substance that acts as cleaning agent. At Benoa Bay, detergent discharges come mostly from the harbor activities connected with the cleaning of ships, boats, or other activities related with fisheries and water sports. High concentrations of detergents can adversely affect seawater quality through the reaction of Ca, Mg, and Fe with detergent molecules to form precipitates or bubbles at the water surface, thereby affecting seawater quality and aesthetics.

Data on detergents were available for Benoa Bay, Nusa Dua and Candidasa. The Bali Province Seawater Quality Criteria for Tourism and Recreation specifies a threshold value for detergents equal to zero, which cannot be used to compute for RQs. This criteria value was adopted from the minimum limit specified for tourism and recreation in the National Criteria for Seawater Quality, which also specifies a maximum limit equal to 0.5 ppm. The maximum value in the national criteria was used as PNEC for all the computations. However, almost all the MECs for detergents are non-zero values and, therefore, exceed the zero limit specified in the Bali criteria.

The MEC_{Min} measured at Benoa Bay was 0.048 ppm and MEC_{Max} was 0.2 ppm (Table 27). The computed RQ_{Max} is less than 1 (RQ_{Max} = 0.4), indicating acceptable risk or low concern for detergent concentrations in Benoa Bay.

At Nusa Dua, the MEC_{Max} was 0.051 ppm, which generated an RQ_{Max} of 0.1. Care should be taken to keep detergents at low levels in this area because Nusa Dua is known as an international tourist destination with high standards.

Table 27. RQs for Detergents.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
Detergent	Benoa Bay	0.048	0.200	0.089	0.5	0.096	0.400	0.178
	Nusa Dua	0	0.051	0.025	0.5	0	0.102	0.050
	Candidasa	0.032	0.960	0.354	0.5	0.064	1.920	0.708

Sources of MECs: Benoa Port Authority (1999) and BAPEDALDA-Bali (1999-2001).
Sources of PNECs: Indonesian Criteria for Seawater Quality for Tourism and Recreation.

At Candidasa, the concentrations of detergents were higher than the measurements in Benoa Bay and Nusa Dua (MEC_{Min} was 0.032 and MEC_{Max} was 0.96), and the RQ_{Max} exceeded 1 (RQ_{Max} = 1.92) although average and minimum RQs were still less than 1.

Hotels are identified as the chief sources of detergent discharges, particularly from the dishwashing and laundry activities. Concerns over elevated detergent concentrations are significant since Candidasa is a popular destination for tourists who want to enjoy a special Balinese place that is highly traditional in culture and art. Candidasa is also known for its diving sites blessed with a variety of beautiful fishes and corals.

Uncertainty Analysis

For detergents, the data are available only for three locations namely Benoa Bay, Nusa Dua and Candidasa. The highest MECs for detergents in Benoa Bay and Nusa Dua were greater than the minimum criteria value, which was actually zero, but still lower than the maximum criteria value. A threshold value equal to zero does not allow the computation of RQs. Assumption of a low value as minimum threshold, e.g., 0.01 ppm, in order to compute for RQs will result in high RQs (greater than 1) for all locations. On the other hand, applying only the maximum threshold might underestimate the risk from surfactants.

The risk assessment approach for detergents/surfactants should consider the suitable values to be used as PNECs. A review of the Bali Province Seawater Quality Criteria for Detergents should consider taking into account that concentrations of contaminants in the water column will hardly ever be zero.

Comparative Risk and Uncertainty Assessment

Comparative risk assessments for the range of agents considered a potential concern for the Southeastern Coast of Bali have been carried out for the water column. The results of these analyses are summarized in Tables 28-29.

For all targets, minimum, average and maximum MECs for the range of agents are shown. Average MECs were calculated as geometric means since data of this kind often follow a lognormal distribution and, in such cases, the geometric mean will provide a less biased measure of the average than the arithmetic mean. For each contaminant, the criteria used for calculating the risk quotients are shown in columns 5 and 6 of Table 28. These criteria were chosen primarily from the Bali Seawater Quality Criteria and from those provided in Appendix 2. The last three columns of this table provide minimum, maximum and average RQs. Maximum RQs provide a hotspot perspective of risk while average RQs provide a wider perspective of risk in the area. Minimum RQs that are greater than 1 indicate general cause for concern for all areas assessed.

For the comparative risk assessment (Table 29), lines were drawn using the average and maximum RQs to present the area-wide and hotspot perspectives of risks, respectively. Minimum RQs that exceeded 1 were highlighted using filled dots.

Table 28 shows contaminants for which water column data were available at specific locations. Average RQs for NH_3 exceeding the critical threshold of 1 were found at Candidasa coastal waters. Average RQs for PO_4 greater than 1 were found at all locations for which data were available. Average RQs for NO_3 exceeding the critical threshold of 1 was found at Sanur, Benoa Bay and Nusa Dua, which are the locations consisting of dense human activities. These RQs indicate ecological risks associated with eutrophication and potential occurrence of harmful algal blooms.

Average RQs for *E. coli* exceeding the critical threshold of 1 were found at Sanur, Gianyar, Nusa Dua and Candidasa coastal waters. The average RQs at Sanur and Gianyar, which are both near rivers that carry out contaminants from the upland areas, are much higher than the RQs at Nusa Dua and Candidasa, indicating higher human health risks associated with bathing in Sanur and Gianyar.

Average RQs for BOD/COD/DO greater than 1 were found only at Candidasa coastal waters. This is a very busy area with dense hotels and restaurants without waste treatment facilities.

TSS with average RQs exceeding the critical threshold of 1 were found in Benoa Bay and Candidasa.

For heavy metals, using the criteria for marine biota and fisheries, average RQs exceeding 1 were obtained for Pb and Zn in all sites assessed, Cd at Benoa Bay, Candidasa, Nusa Dua and Nusa Penida, Cu in Gianyar and Nusa Penida, and Cr at Nusa Penida. These results indicate concern for all the heavy metals in the assessment.

Table 28. Initial Risk Assessment Summary for Water.

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
NH_3	Nusa Dua	0.001	0.004	0.00075	1	0.001	0.004	0.001
	Gianyar	0	0.001	0	1	0	0.001	0
	Candidasa	0.001	16.28	2.61	1	0.001	16.28	2.61
PO_4	Sanur	0	0.93	0.13	0.015	0	62.00	8.67
	Benoa Bay	0.083	0.133	0.11	0.015	5.53	8.87	7.33
	Nusa Dua	0	0.987	0.13	0.015	0	65.80	8.67
NO_3	Sanur	0	0.5	0.177	0.055	0	9.09	3.22
	Benoa Bay	0.191	1.5	0.53	0.055	3.47	27.27	9.64
	Nusa Dua	0	0.835	0.08	0.055	0	15.18	1.45
	Candidasa	0	0.005	0.002	0.055	0	0.09	0.04
	Nusa Penida	0.012	0.087	0.05	0.055	0.22	1.58	0.91
E. coli	Sanur	0	11000	3736.67	10	0	1100	373.7
	Nusa Dua	3	64	32.75	10	0.300	6.4	3.3
	Gianyar	0	24000	8059	10	0	2400	805.9
	Candidasa	0	45	17.57	10	0	4.5	1.8
	Nusa Penida	0	20	7	10	0	2	0.7
BOD	Sanur	0.6	12.68	3.17	10	0.06	1.27	0.32
	Benoa Bay	1.27	2.56	1.94	10	0.13	0.26	0.19
	Nusa Dua	0.8	3.7	1.93	10	0.08	0.37	0.19
	Gianyar	1.16	7.1	4.06	10	0.12	0.71	0.41
	Candidasa	1.57	375.06	95.24	10	0.16	37.51	9.52
COD	Benoa Bay	11.85	26.19	16.73	20	0.59	1.31	0.84
	Nusa Dua	18.19	22.5	20.44	20	0.91	1.13	1.02
	Candidasa	14.81	1031.92	165.69	20	0.74	51.60	8.28
DO	Sanur	0.2	10.8	7.4	5	0.46	25.00	0.68
	Benoa Bay	5.26	7.28	6.29	5	0.69	0.95	0.79
	Nusa Dua	3.7	11.6	7.32	5	0.43	1.35	0.68
	Gianyar	3.5	7.46	5.63	5	0.67	1.43	0.89
	Candidasa	4.6	5.2	4.9	5	0.96	1.09	1.02
Oil and Grease	Benoa Bay	0.002	0.896	0.164	1	0.002	0.90	0.16
	Nusa Dua	0.0002	0.0046	0.0033	1	0.00020	0.005	0.003
	Gianyar	0.1	0.3	0.183	1	0.10	0.3	0.18
	Candidasa	0.001	0.0019	0.0009	1	0.0010	0.002	0.0009
TSS	Sanur	3	17	9.832	20	0.15	0.85	0.49
	Benoa Bay	90.5	166.7	113.157	20	4.53	8.335	5.66
	Nusa Dua	7	26	11.562	20	0.35	1.3	0.58
	Gianyar	3	22	8.5	20	0.15	1.1	0.43
	Candidasa	7	502	89	20	0.35	25.1	4.45
	Nusa Penida	3	14	6.75	20	0.15	0.7	0.34
Detergent	Benoa Bay	0.048	0.2	0.089	0.5	0.096	0.4	0.178
	Nusa Dua	0	0.051	0.025	0.5	0	0.102	0.05
	Candidasa	0.032	0.96	0.354	0.5	0.064	1.92	0.708

Table 28. Initial Risk Assessment Summary for Water (continuation).

Agents	Location	MEC_{Min} (ppm)	MEC_{Max} (ppm)	MEC_{Ave} (ppm)	PNEC (ppm)	RQ_{Min}	RQ_{Max}	RQ_{Ave}
Pb	Benoa Bay	0.012	0.034	0.026714	0.01	1.200	3.40	2.67
	Nusa Dua	0.038	0.08	0.0605	0.01	3.800	8.00	6.05
	Gianyar	0.01	0.036	0.0165	0.01	1.000	3.60	1.65
	Nusa Penida	0.01	0.075	0.034947	0.01	1.000	7.50	3.49
Cu	Nusa Dua	0.024	0.03	0.027	0.06	0.400	0.50	0.45
	Gianyar	0.022	0.09	0.07	0.06	0.367	1.50	1.17
	Candidasa	0.012	0.05	0.03	0.06	0.200	0.83	0.50
	Nusa Penida	0.04	0.39	0.16	0.06	0.667	6.50	2.67
Cd	Benoa Bay	0.0015	0.05	0.01	0.01	0.15	5.00	1.000
	Nusa Dua	0.011	0.18	0.06	0.01	1.10	18.00	6.000
	Candidasa	0.011	0.2	0.05	0.01	1.10	20.00	5.000
	Nusa Penida	0.014	0.77	0.03	0.01	1.40	77.00	3.000
Zn	Gianyar	0	0.5	0.38	0.1	0.000	5.00	3.80
	Nusa Penida	0.012	0.5	0.22	0.1	0.120	5.00	2.20
Cr	Nusa Penida	0.002	0.033	0.006	0.01	0.200	3.30	0.60

Source of PNECs:

For PO_4 and NO_3 – Proposed ASEAN Marine Water Quality Criteria; for NH_3 and Heavy Metals – Bali Province Seawater Quality Criteria for Marine Biota and Fisheries;

For BOD/COD/DO and TSS - Bali Province Seawater Quality Criteria for Tourism and Recreation;

For E. coli *and Oil and Grease – National Seawater Quality Criteria for Tourism and Recreation (minimum value) – Indonesia;*

For Detergent – National Seawater Quality Criteria for Tourism and Recreation (maximum value) – Indonesia

Most of the maximum RQs of contaminants evaluated exceeded 1, indicating cause for concern in specific hotspot areas. Minimum or best-case RQs for some contaminants, however, also exceeded 1, indicating general concern for the contaminant levels in the areas where all the measurements were taken. Minimum RQs exceeded 1 for PO_4, NO_3 and TSS in Benoa Bay, Cu and Cd in Nusa Dua, Candidasa and Nusa Penida, and Cu in Gianyar.

On the other hand, maximum RQs that are less than 1, and therefore present low concern, were obtained for NH_3 at Gianyar and Nusa Dua; NO_3 at Candidasa; BOD at Nusa Dua, Gianyar and Benoa Bay; DO at Benoa Bay; TSS at Sanur and Nusa Penida; oil and grease in all areas assessed; and detergent at Benoa Bay and Nusa Dua. For heavy metals, almost all maximum RQs exceeded 1 when using the Bali Criteria for Marine Biota and Fisheries except for Cu at Nusa Dua and Candidasa.

Table 29 compares the range of RQs (from average to maximum) across contaminants in order of magnitude bands of RQ. Areas for which minimum or best-case RQs exceed 1 are also identified through filled dots. From this table it is clear that, for the water column, the priority concerns are the risks to human health associated with *E. coli* especially in Sanur and Gianyar and risks to the ecosystem associated with PO_4, NO_3, and the heavy metals especially Cd and Pb. For NH_3, DO, BOD, COD, and TSS, maximum RQs exceeding 1 indicate localized risks from potential hotspots. The table further shows that risks are acceptable for oil and grease and that parameters of concern vary among sites. The table also identifies data gaps in terms of lack of MECs.

Table 29. Comparative Risk Assessment for Water.

Agent/Location	RQs				
	<1	1-10	10-100	100-1000	>1000
Nusa Dua					
NH_3					
PO_4					
NO_3					
E. coli (cell/100 ml)					
BOD					
COD					
DO					
Oil and Grease					
TSS					
Detergent					
Pb					
Cu					
Cd					
Zn	No MECs				
Cr	No MECs				
Sanur					
NH_3	No MECs				
PO_4					
NO_3					
E. coli (cell/100 ml)					
BOD					
COD	No MECs				
DO					
Oil and Grease	No MECs				
TSS					
Detergent	No MECs				
Pb	No MECs				
Cu	No MECs				
Cd	No MECs				
Zn	No MECs				
Cr	No MECs				
Benoa Bay					
NH_3	No MECs				
PO_4					
NO_3					
E. coli (cell/100 ml)	No MECs				
BOD					
COD					
DO					
Oil and Grease					
TSS					
Detergent					
Pb					
Cu	No MECs				
Cd					
Zn	No MECs				
Cr	No MECs				

Table 29. Comparative Risk Assessment for Water (continuation).

Agent/Location	RQs				
	<1	1-10	10-100	100-1000	>1000
Gianyar					
NH_3					
PO_4	No MECs				
NO_3	No MECs				
E. coli (cell/100 ml)					2400
BOD					
COD	No MECs				
DO					
Oil and Grease					
TSS					
Detergent	No MECs				
Pb					
Cu					
Cd	No MECs				
Zn					
Cr	No MECs				
Candidasa					
NH_3					
PO_4	No MECs				
NO_3					
E. coli (cell/100 ml)					
BOD					
COD					
DO					
Oil and Grease					
TSS (ppm)					
Detergent					
Pb	No MECs				
Cu					
Cd					
Zn	No MECs				
Cr	No MECs				
Nusa Penida					
NH_3	No MECs				
PO_4	No MECs				
NO_3					
E. coli (cell/100 ml)					
BOD	No MECs				
COD	No MECs				
DO	No MECs				
Oil and Grease	No MECs				
TSS					
Detergent	No MECs				
Pb					
Cu					
Cd					
Zn					
Cr					

Conclusions, Data Gaps and Uncertainties

Retrospective Risk Assessment

For fisheries, the retrospective risk assessment particularly draws attention to overfishing and destructive fishing as being the important agents in the decline of these resources. Habitat degradation and pollution were also identified as possible agents for the decline. The assessment also showed that the annual fish catch in the Southeastern Coast of Bali has been exceeding the maximum sustainable yield (MSY).

The mangrove areas within the Southeastern Coast of Bali have obviously declined over the past decades. The retrospective risk assessment implicates a combination of factors with the physical removal for reclamation and land conversion as primary agents. Chemical contamination and physical disruption of the habitat by sedimentation and solid wastes might also be contributing factors.

Destructive fishing, collection and anchoring and related uncontrolled human use of coral reefs can be highly destructive to the physical structure and ecological communities of coral reefs. Sedimentation and organic and nutrient loading in coastal waters are also considered agents that threaten coral reefs in the area.

Seagrass beds in the Southeastern Coast of Bali have disappeared, mostly due to land reclamation practices, especially in Serangan Island. In Lembongan Island, seagrass cover decline was caused by seaweed culture expansion.

Shrimp production from aquaculture in the Southeastern Coast of Bali declined drastically in the last decade. The outbreak of bacterial and viral diseases caused by intensive culture and organic pollution were identified as the major agents for decline of shrimp pond production.

Ice-ice disease outbreak related to intensive seaweed culture is the main factor for the decline in seaweed production. The rapid development of marine tourism and increase in activities such as jet skiing, banana boating and parasailing in the area may increase oil concentration in coastal waters. The decline of seaweed culture in the Southeastern Coast of Bali, although not enormous in recent years, must stir up concern for potential intensification.

The length of eroded beach areas has increased significantly in the past two decades. Activities such as coastal mining, land reclamation, building of coastal engineering structures and setback invasion (encroachment into coastal areas) were identified as important contributors to coastal erosion.

Prospective Risk Assessment

Prospective analysis for water shows that the highest average RQs were specific to particular locations. The highest average RQs obtained were for PO_4 at Nusa Dua, E. *coli* at Gianyar, NO_3 at Sanur and Benoa Bay, NH_3 at Candidasa, and Cu and Cd at Nusa Penida.

For systematic prioritization of identified areas of concern, risk agents were classified either as priority risks or localized risks based on the RQs. Priority risk agents were determined based on RQ_{Min} and 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) and for which assessments were not carried out due to lack of data were also presented.

Human health risks associated with bathing in coastal waters at the Southeastern Coast of Bali are presented primarily by *E. coli,* which is part of coliform from human waste. *E. coli* had high average RQs at Sanur (RQ_{Ave} = 374) and Gianyar (RQ_{Ave} = 806), and average RQs slightly higher than 1 in the other locations. Sanur and Gianyar are both located near rivers that transport domestic wastes and other contaminants from the upstream areas to the coastal waters. Elevated levels of *E. coli* in coastal waters pose risk to human health and will undoubtedly have adverse effects on the tourism industry in Bali. The slightly elevated levels of *E. coli* in Nusa Dua and Candidasa may be due to direct discharges of untreated or partially treated wastes from communities and establishments along the coast. There was no data on *E. coli* from Benoa Bay.

Ecologically, the priority areas of concern are the nutrients PO_4 and NO_3 and heavy metals, such as Cd and Pb, which gave average RQs exceeding 1 in all or majority of areas assessed. The ranking of agents that present ecological risks is summarized in the table below.

Nutrients such as PO_4 and NO_3, which are agents of eutrophication in coastal waters, have average RQs exceeding the critical threshold of 1 at Sanur, Nusa Dua and Benoa Bay. Development and human activities in the Southeastern Coast of Bali are focused in the three locations, and nutrients may come from cleaning agents and organic wastes from households, hotels, restaurants, and commercial establishments. Rivers that pass through densely populated, industrial, and agricultural areas before draining to Benoa Bay also contribute to the nutrient load in the bay. The high concentration of nutrients in these areas may present serious threat for critical habitats, especially for coral reefs.

BOD and COD are parameters that indicate the level of organic pollution in natural waters. High average RQs for BOD and COD were found at Candidasa. Average RQs for DO that exceed the critical threshold of 1 were also found in this area and Gianyar.

TSS is one of the physical parameters for water quality, and the average RQs exceeding 1 were

Summary of Agents Presenting Ecological Risks.

RQ	Nusa Dua	Sanur	Benoa Bay	Gianyar	Candidasa	Nusa Penida
RQ_{Min} > 1	Cd > Pb		NO_3 > PO_4, TSS, Pb	Pb	Cd	Cd > Pb
RQ_{Ave} > 1	PO_4, NO_3 > COD	PO_4 > NO_3	Cd	Cu, Zn	NH_3 > BOD, COD, TSS > DO	Cu
RQ_{Max} > 1	DO, TSS	DO > BOD	COD	DO, TSS	Detergent	Cr, NO_3
RQ_{Max} < 1	NH_3, BOD, oil & grease, detergent, Cu	TSS	BOD, DO, oil & grease, detergent	NH_3, BOD, oil & grease	NO_3, oil & grease, Cu	TSS
No MECs	Zn, Cr	COD, oil & grease, detergent, Pb, Cu, Cd, Zn, Cr	NH_3, Cu, Zn, Cr	PO_4, NO_3, COD, detergent, Cd, Cr	PO_4, Pb, Zn, Cr	NH_3, PO_4, BOD, COD, DO, oil & grease, detergent

found at Benoa Bay and Candidasa. Suspended solids in Benoa Bay come from river flows and run-off from the surrounding areas, while in Candidasa and other locations, most TSS enter the water through land run-off and discharge of domestic wastes.

For heavy metals, application of the criteria for marine biota and fisheries gave average RQs that exceed 1 for Pb, Cd and Zn in all areas assessed, Cu in Gianyar and Nusa Penida, and Cr at Nusa Penida. These results indicate ecological concern for all the heavy metals assessed. Heavy metals may come from the various industrial establishments in Bali, particularly from the numerous small-scale industries, which are not equipped with appropriate wastewater treatment facilities. These include textile industries, which use dyeing substances that contain harmful substances including heavy metals, and small-scale jewelry shops. Port activities such as ship and boat maintenance may also be potential sources of heavy metals. The highest RQ for Cd (RQ_{Max} = 77) was, however, found in Nusa Penida Island, which is one of the major tourist destinations in the Southeastern Coast of Bali due to its numerous diving and snorkeling sites. The average and best-case RQs for Cd (RQ_{Ave} = 3 and RQ_{Min} = 1.4) also exceed 1 in this island, which should prompt the identification of significant sources of Cd entering coastal waters. The relatively high frequency of vessel landing in this island, including visits by cruise ships and catamarans, may be one of the potential sources of heavy metals in the water column.

Data for detergents were available only at Benoa Bay, Nusa Dua and Candidasa. Among the three locations, RQ_{Max} exceeding the critical threshold of 1 was found only at Candidasa, which is known for its diving sites. Detergents can affect seawater quality and aesthetics through reaction with Ca, Mg and Fe to form precipitates or bubbles at the water surface. The hotels in the area were identified as chief sources of detergent discharges, particularly from dishwashing and laundry activities.

Minimum or best-case RQs that exceed 1 indicate general concern for all the areas assessed and were obtained for PO_4, NO_3 and TSS at Benoa Bay, Cu at Nusa Penida, Nusa Dua, Candidasa and Gianyar, and Cd at Nusa Dua, Candidasa and Nusa Penida.

All RQs for oil and grease were less than 1, indicating acceptable risks and therefore low concern at Benoa Bay, Nusa Dua, Gianyar and Candidasa.

DATA GAPS

A retrospective risk assessment was not carried out for some resources and habitats, such as for shellfishes, phytoplankton, soft-bottom communities and mudflats due to lack of comparative information. The IRA also identified other data that would be necessary as starting points for fisheries management in the coastal area.

1. For economically important resources such as fish and shellfish, there is a need to acquire survey data, preferably from more recent surveys. Production data, preferably on a per species classification, including corresponding economic information, i.e. market and non-market values, would be necessary for the development of a model describing fish and shellfish population dynamics and hence indicate sustainable and efficiency yields. Data on shellfish abundance and distribution will also be useful. For shellfish, data on tissue quality and information on the possible health implications of bacterial/coliform

contamination, as well as, red tide occurrences, should be gathered.

2. For mudflats, sandflats and rocky shores, there were no available time series and spatial distribution data. There were also no information on access and use of mudflats, sandflats and rocky shores.

A prospective risk assessment was not carried out for some environmental compartments such as sediments and seafood tissue due to lack of MECs. A prospective risk assessment was also not carried out for some parameters such as pesticides, some heavy metals and toxic algae due to lack of measured water column concentrations.

Based on experience, the risks posed by toxic algal blooms are considerable and obviously important for human health. There have been no recent reports of toxic blooms in this area, but this cannot preclude future occurrences. Plankton data in the water column, cyst counts in sediments and toxin levels in shellfish are important indicators of this phenomenon. The ciguatera case, a form of human food poisoning caused by the consumption of subtropical and tropical marine finfish that have accumulated naturally occurring toxins originating from dinoflagellates (algae) through their diet, and the massive death of reef fishes occurred at Nusa Penida in 1995.

UNCERTAINTIES

1. MECs and PNECs

The risk quotients obtained and the conclusions drawn depend largely on the accuracy of the MECs as well as the suitability of the threshold values used in calculating the RQs.

Considerable effort has been put to evaluating the reliability of the data used in the risk assessment although for some parameters for which there were very few data, the risk assessment was done using the available data.

For the threshold values, uncertainty may be associated with the use of criteria or standards that were specified for temperate regions or other locations. The suitability of these values in the tropics, particularly in the Southeastern Coast of Bali, still has to be verified.

More importantly, uncertainty may also arise from the choice of some threshold values from the Bali Province Seawater Quality Criteria (Decree of Bali Governor No. 515/2000), which specifies concentration limits for waters used for tourism and recreation as well as for marine biota and fisheries. The threshold values prescribed for each water use were based mostly on the National Water Quality Criteria, which specify a range of criteria values (minimum and maximum limits). For marine biota and fisheries, the maximum limits in the national criteria were adopted for Bali. For tourism and recreation, the minimum values in the national criteria were adopted, including the very low threshold levels for heavy metals and the zero thresholds for NH_3, No_2, detergent, and other parameters. For oil and grease and *E. coli*, the minimum limits in the National Criteria for Tourism and Recreation were not adopted and zero thresholds were prescribed. In the real environment, these parameters will hardly be equal to zero and may be present at very low levels even in pristine environments. For heavy metals, the minimum limits for tourism and recreation in the national criteria, which were adopted for Bali, are very low (close to analytical detection limits) and are one to three orders of magnitude higher than criteria and standards from within and outside the region (Philippines, Thailand, Vietnam, ASEAN and U.S. EPA). Application of the very low thresholds will result in very high RQs (in the order of thousands) and may cause unwarranted concern. The maximum limits in the national criteria, on the other hand, were close to criteria and standard values from other locations, so these were chosen as PNECs for the prospective risk assessment. The choice of threshold values and associated uncertainties are described in detail in the main report.

Therefore, an urgent need is seen for a review and reconsideration of the Bali Province Seawater Quality Criteria, as well as the National Seawater Quality Criteria for Indonesia, since it provides basis for the choice of criteria values at the provincial levels. This evaluation may be carried out based on a comprehensive assessment of toxicological data for specific local marine species, background levels, concentration levels prevailing in tropical environments, or criteria limits of other jurisdictions.

2. Limited Data

The limited number of monitoring stations for all the parameters does not allow area-wide generalizations to be made. If would be safe to apply the statements only to the areas where measurements were taken and not to all locations. For example, data for nutrients and heavy metals were available only for some locations.

3. Spatial and Temporal Variation

Worst-case conditions indicate potential hotspots but these were not identified. This would require analysis of spatial variability. Contaminant levels may also be affected seasonally so temporal variability should also be assessed. To some extent, analysis of spatial variability was done by getting separate RQs for different municipalities and regencies.

The IRA was based on average and worst-case conditions. More detailed uncertainty analysis is needed to clarify some of the assessments. Consideration of spatial and temporal variability in the data would also enable more detailed and specific assessments to be made such as determination of relationships between predominant human activities and contaminant levels. These would particularly be useful in the identification of contaminant sources and setting up of interventions.

At this point, it would be wise to reiterate that the results of the risk assessment are not always representative of the entire area. For some of the parameters, the data represented only certain areas in the Southeastern Coast of Bali. Even for the parameters that were taken from stations spread throughout the surrounding areas, the large distances between stations do not allow absolute generalizations to be made. In using the results of the IRA, it would be more accurate to state clearly whether the statements apply to certain locations only or are being applied, with caution, to the whole area. A more in-depth analysis of data in a refined risk assessment may be able to address this.

Recommendations and Proposed Actions for Refining the Risk Assessment and for Risk Management

On Resources and Habitats

Resources

To understand and hence appropriately manage fishing activities, it will be necessary to develop models that describe the dynamics of the fish and shellfish populations and hence indicate sustainable and efficiency yields. A comparison with these yields will give a more objective indication of the level of overfishing and the extent to which other factors might be contributing to declines in stocks. For risk management, partial bans on fishing activities have been implemented in some areas to empirically assess how reductions in harvesting may lead to recovery of stocks. Fisheries management in the area should be strengthened by:

1. Strengthening the enforcement of existing laws and regulations on fisheries utilization and evaluating their effectiveness and relevance for present circumstances;

2. Developing appropriate management frameworks for sustainable development of the fisheries sector and implementing specific interventions that aim to reduce the pressure on nearshore fisheries, such as limiting the number of existing fishing vessels and providing alternative occupational skills for fishers;

3. Promoting public awareness among the local population on the long-term adverse impacts of destructive fishing practices and overexploitation of fisheries, the need to appropriately manage the declining fisheries and the expected benefits, and the important roles they need to perform to ensure the sustainability of fisheries resources;

4. Formulating measures to prevent degradation of mangrove forests, coral reefs, and other coastal habitats, and promote rehabilitation efforts; and

5. Developing management plans for protection of fisheries resources from discharges of untreated wastewater containing organic and inorganic wastes, release of solid wastes and other polluting substances, and other activities that compromise the integrity of the resources and environment.

The retrospective risk assessment also showed decline in shrimp culture and seaweed culture production due to diseases, which are induced by poor water quality arising from poor practices in the culture farms. Sustainability of coastal aquaculture/mariculture should be ensured through application of environmentally sound aquaculture practices, designation of coastal aquaculture zones, and development of management guidelines in accordance with environmental quality management plans, land-use plans and environmental capacity.

It is also recommended that interventions that will help in the recovery or restoration of the identified resources at risk be identified as part of the Coastal Strategy Implementation Plan for the Southeastern Coast of Bali.

Monitoring and research efforts aimed at addressing the identified data gaps on resources should also be supported.

Habitats

The decline in important habitats such as mangroves, coral reefs, and seagrass beds might have had adverse affects on the reproduction and survival of various aquatic species that relied on these environments at various stages of development. Erosion also threatens structures along the coast, agricultural areas and sites for religious ceremonies, and decreases the natural values of the affected areas. The thriving tourism industry of Bali depends on the state of these marine and coastal resources and environment, thus, further damage to these ecosystems should be prevented to ensure the sustainability of the ecological goods and services that they provide by:

1. Formulating and implementing measures to prevent and control degradation of coastal resources and habitats particularly arising from both public and private development projects;

2. Improving/revising laws, rules and regulations relevant to utilization and conservation of coastal resources and ensuring strict enforcement;

3. Requiring economic benefit-cost analysis of all development projects, particularly those that involve reclamation, as part of the government approval process;

4. Designating specific zones for controlled utilization and preservation of coastal resources and habitats;

5. Promoting the designation of more conservation areas for coastal resources;

6. Encouraging mangrove reforestation in areas with high potential for rehabilitation;

7. Encouraging stakeholder participation in the rehabilitation of degraded coastal resources and support the projects and activities of volunteer groups; and

8. Supporting monitoring and research activities that will fill data gaps and provide reliable information to support effective environmental management in Bali.

In coming up with land- and water-use plans as part of the Coastal Strategy Implementation Plan for the Southeastern Coast of Bali, an appropriate balance between the resources of the coastal area and economic activities should be targeted.

ON HUMAN HEALTH RISKS

E. coli

There is a need for routine monitoring of coliform levels in bathing areas and for responsible agencies or local government units to sanction the owners of resorts that are proven to present a clear risk to the public. An intensive information and education campaign should also be conducted to inform the public of the adverse effects of bathing in and, more importantly, ingesting seafood from contaminated waters. There is also a need to perform morbidity and mortality statistics analyses in areas surrounding the coastal area to determine the extent to which coliform contamination has affected human health.

More importantly, there is a need to address the source of coliform contamination. The high bacterial load may be attributed mainly to sewage generated from households and commercial, agricultural, institutional and industrial establishments that discharge directly to the coastal area or to the drainage and river systems, which eventually enter the coastal area. There is a need to fast track sewage collection and treatment programs in watershed areas. Direct discharges of domestic, industrial and agricultural waste, including septic or sludge disposal to the Southeastern Coast of Bali and its tributaries should be stopped. A control program for indirect discharges, such as urban and agricultural run-off to the Southeastern Coast of Bali and its tributaries should also be implemented.

ON ECOLOGICAL RISKS

Nutrients

From an ecological point of view, more information will be needed for nutrients in terms of spatial and temporal distributions but, in particular, identification of likely sources from domestic activities is required. Nitrogen: Phosphate ratios in the coastal area may indicate trends in nutrient loading and should also be determined. Predictive models might be developed to identify relative importance of sources and, hence, draw attention to appropriate management. A more detailed assessment of the linkage between elevated nutrient concentrations and phytoplankton blooms would also be useful in understanding the environmental and economic implications of nutrient discharges. Spatial and time series data of nutrients and DO at sediment-water interface and in sediments will be useful in assessing changes in the benthic community. Collaboration with research groups conducting such studies should be considered. Local criteria for nutrients should also be developed to improve the assessment of ecological risks in Bali.

Heavy Metals

Based on the risk assessment using the Bali Province Seawater Quality Criteria for Tourism and Recreation, particular attention needs to be given to spatial distributions of Cd and Pb in the water column, again with consideration being given to possible sources. Based on the risk assessment using criteria for tourism and fisheries, the distribution of heavy metals such as Pb, Zn, Cd, Cu and Cr require additional consideration. Industrial activities are likely to be implicated here, and, as part of an overall environmental management of the coastal area, it will be necessary to develop an integrated environmental monitoring program that will provide more sufficient information to support the development of management programs.

Attention should also be given to verifying the suitability of the criteria applied in the risk assessment, determining requirements for updating the criteria, if necessary, and updating the results of the risk assessment using more suitable criteria and more adequate exposure concentrations.

DO/COD/BOD

Varying degrees of ecological risks from organic load and low DO levels were shown for various areas in the Southeastern Coast of Bali, particularly in Candidasa. To ascertain the effect of organic loading on DO levels and the degree of ecological impact of reduced DO levels in different areas in the bay, and to identify principal sources of organic load, it is recommended that a detailed analysis of spatial variability be carried out. A detailed analysis of DO measurements through time (temporal analysis) should also be performed to determine the duration of exposure of organisms to low DO and the likely acute or chronic effects. Information on DO measurements during phytoplankton blooms should also be gathered to determine the degree to which blooms affect DO levels, extent of area affected and duration of exposure of organisms to low DO levels. It is also recommended that significant sources of the organic load be identified and the relative contribution of these sources be determined.

TSS

Ecological risk from TSS was shown for Benoa Bay where the best-case RQ exceed 1 and for Candidasa where the RQ_{Ave} also exceeded 1. Some hotspots also need to be identified in Nusa Dua and Gianyar. A detailed analysis of spatial and temporal variability is necessary to determine the areas where elevated TSS concentrations were obtained and the variability in the concentrations with time. For environmental management, the contributions of various potential sources, especially those associated with human activities, should be evaluated. EIAs of reclamation and coastal development projects, in particular, should carefully assess the potential contributions of these activities to suspended solids in the coastal waters of the Southeastern Coast of Bali.

DATA GAPS AND SOURCES OF UNCERTAINTY

There were no data on pesticides and organic contaminants in all media. The potential for these agents to pose human and ecological risks to the Southeastern Coast of Bali should be assessed either through primary data gathering or rapid appraisal of inputs from potential sources of these agents.

Data on heavy metals, pesticides and coliform in the sediment and seafood tissue from the surrounding areas of the Southeastern Coast of Bali would be necessary to verify the assessments that have been made using the limited data available for the water column.

Predicting the likelihood of harmful algal blooms is something of a special case. In order to predict likely population explosions of algal cells, it is necessary to have a detailed understanding of their population dynamics and the way environmental factors interact with them. This will entail substantial efforts in monitoring and research, and will require close collaboration among research groups.

The importance of human activities such as coastal mining, construction of coastal engineering structures, encroachment into beach areas and reclamation over natural factors in causing coastal erosion has been recognized. There is no technical information, however, to demonstrate the extent of contribution and relative importance of these activities in bringing about coastal erosion. More information will also be needed to assess the degree of impacts to the ecosystem, community and economy.

The RQ approach has not been suitable for dealing with risks posed by solid wastes, yet these are an obvious problem in the coastal area (and the surrounding river systems) for shipping, human health, ecological systems, and aesthetics. To refine the assessment of the risks posed by solid wastes will require increased understanding about sources, distribution and impacts. For example, there may be ecological problems arising from physical disruption of habitats caused by the accumulation of plastics and other solids. This could be particularly important for systems like mangrove forests.

It is also important to recognize that the IRA has been based largely on worst-case and average scenarios. For a number of the agents, further insight will come from making the spatial and temporal variations clear and explicit. This will also enable the distinction between localized and coast-wide conditions and the corresponding risk assessment results.

Other possible sources of uncertainties in the results of the IRA are mostly associated with the quality, comparability and adequacy of the measured concentrations as well as suitability of the threshold values. Application of quantitative uncertainty analyses may aid in clarifying the results of the risk assessment although enhancing the quality, comparability and adequacy of data will provide more confidence in the results of the risk assessment. Verification of the suitability of local and national threshold values to actual conditions should also be given consideration particularly the very low thresholds for heavy metals and the zero thresholds for other parameters. Specific scientific researches required in relation to the review of water quality criteria should be identified.

To refine all the risk assessments, there must be a general requirement to develop an integrated environmental monitoring program that will provide more sufficient and comparable information to enable more detailed assessment of identified concerns, fill in data gaps, and verify uncertainties. This will also enable the more precise identification of contaminant sources and assessment of relative contributions of contaminant sources to conditions within the coast, especially with regard to partitioning between river and watersheds and coastal activities. The monitoring program will also monitor changes in the risk levels and determine the effectiveness of management interventions. As further support to decision-making, the development of predictive models for specific contaminants, which may provide insights into variations in exposure concentrations given various management options or control scenarios, may also be considered.

The IRA has focused entirely on a consideration of risks to human health and ecological systems from conditions in the coastal area that are influenced by human activities. The consequent impacts therefore derive from socioeconomic activities and have implications on the economy. Refinement of the risk assessment should make these links more explicit in the form of qualitative risk pathways and more quantitative socioeconomic analyses.

RISK MANAGEMENT

Taking into consideration the identified environmental risks and various recommendations on resource conservation and coastal and marine environment protection, the following activities are considered important in managing environmental concerns in the Southeastern Coast of Bali:

a.) Integrated Land- and Water-Use Zoning

Some of the concerns on the utilization of coastal resources and habitats and environmental risks are associated with existing land and water uses in the Southeastern Coast of Bali, largely arising from economic developments arising from and in support of its thriving tourism industry. Considering the potential for further development and the need to protect its natural coastal resources upon which this development relies on, it is recommended that an integrated land- and water-use zoning scheme with associated institutional arrangements be developed. This will reduce conflicting uses of land and water resources, promote uses based on the potential of each area, and prevent adverse effects to the ecosystem and human health.

b.) Environmental Investments

The results of the risk assessment show the need to develop long-term strategies and action programs to address environmental issues such as sewage, solid wastes and industrial wastes. With the current economic activities in the Southeastern Coast of Bali and the potential for further growth, environmental services and facilities and clean technologies will be necessary to achieve a balance between economic growth and environmental protection and management. Sustainability of the coastal tourism industry will also depend primarily on the maintenance of an environment that is regarded as safe by its patrons. Facilities to manage solid wastes, sewage, and industrial wastes should therefore be put in place in order to protect human health, marine resources and environment, and the tourism industry as well. Such facilities will also provide investment opportunities that will create income, employment and livelihood. Large financial investments and technological resources, however, will be required such that innovative approaches to facilitate the participation of various sectors in coastal and marine pollution prevention and resource conservation will have to be employed.

c.) Integrated Environmental Monitoring Program

The risk assessment identifies priority areas of concern and data gaps with regard to resources, habitats, and environmental stressors, and the need for an efficient environmental monitoring program to assess the impacts of human activities on the environment and the effectiveness of management measures to address these adverse impacts. It is recommended that a systematic, cost-effective and coordinated environmental monitoring program be developed, which will integrate the monitoring of priority pollutants, monitoring of human health impacts of priority pollutants, and monitoring of resource and habitat conditions. Specifically, the integrated environmental monitoring program will aim to:

- Address the priority concerns and data gaps identified in the risk assessment;
- Pool the efforts and resources of relevant agencies through an operational monitoring network;
- Enhance exchange and integration of information through an information-sharing network;
- Enhance local technical capability with regard to field and analytical tools and human resources; and
- Strengthen the linkage between environmental monitoring and environmental management through application of the risk assessment/risk management framework.

d.) Collaboration and Institutional Arrangements

Partnerships between different government agencies, universities and scientific and technical research institutions, local government units, communities, non-governmental organizations, and the private sector would be vital to the development and sustainability of environmental management programs for the Southeastern Coast of Bali and should be promoted. This should be aimed at promoting mutual interests and strengthening the capacity of each sector in the conservation of the natural resources and environment.

To facilitate and ensure sustainable multi-agency and cross-sectoral collaboration, appropriate institutional arrangements will have to be put in place. This will be particularly important in evaluating and strengthening policies, rules and regulations, implementation frameworks and enforcement capabilities on resource utilization and environmental protection.

References

ADB (Asian Development Bank). 1990. *Environmental Risk Assessment: Dealing with Uncertainty in Environmental Impact Assessment* (Environment Paper No. 7), Asian Development Bank, Manila, Philippines. 182 p.

ASEAN (Association of Southeast Asian Nations). 2003. *The Marine Water Quality Criteria for the ASEAN Region*. www.aseansec.org/14541.htm. July 2003.

Bali Beach Conservation Project. 1998. Field Survey Report Vol. IV Marine Ecological Survey (1) Corals, Seaweed/Seagrass and Bio-Geography of Reef Flat. Directorate General of Water Resources Development, Ministry of Public Works. Denpasar, Bali, Indonesia.

Bali Beach Conservation Project. 1998. Final Report. Directorate General of Water Resources Development, Ministry of Public Works. Denpasar, Bali, Indonesia.

Bali ICM. 2001. Environmental Profile of Southeastern Coast of Bali. Project Management Office, Bali National Integrated Coastal Management (ICM) Demonstration Site.

Bali Province Seawater Quality Criteria. 2000. Decree of Bali Governor No. 515/2000, Concerning Environmental Standard Quality.

Bali Turtle Island Development. 1995. Environmental Impact Analysis of Serangan Island Development, Serangan District, South Denpasar, Denpasar Municipality.

BAPEDALDA-Bali. Data from the Environmental Impact Management Agency of Bali Province. Annual Water Quality Monitoring in Bali (1998-2001).

BAPPEDA-Bali. Data from the Regional Development Planning Board of Bali Province (1998-1999).

BAPPEDA-Bali and Bogor Agricultural University. 2000. Atlas of Natural Resources on Coastal and Marine Area in Bali Province.

Benoa Port Authority. 1999. Environmental Impact Analysis of Master Plan of Benoa Bay Harbor. PT (Persero) Pelabuhan Indonesia III.

DAO 34 (DENR Administrative Order No. 34). 1990. Revised Water Usage and Classification (Water Quality Criteria Amending Section Nos. 68 and 69, Chapter III of the 1978 NPCC Rules and Regulations). Environmental Management Bureau, Department of Environment and Natural Resources, Quezon City, Philippines.

Department of Forestry. 1999. Sustainable Management Models for Mangrove Forest. The Ministry of Forestry and Estate Corps in Indonesia and Japan International Cooperation Agency.

Fairman, R., Mead, C.D. and Williams, W.P. 2001. *Environmental Risk Assessment – Approaches, Experiences and Information Sources.* http://service.eea.eu.int/envirowindows/chapter1h.shtml. March 2001.

Fisheries Agency of Bali Province. Annual Reports of the Fisheries Agency of Bali Province for 1991, 1992, 1995, 1997, 1999, 2000.

Indonesia Port Authority (PT. Pelabuhan Indonesia III). 1999. *Environmental Impact Assessment of Benoa Port Reclamation.*

Indonesian Environmental Management Agency. 2001. Environmental Standards Methodology, Vol. 1: Process and SOPs and Vol. 2: Reference Manual.

IUPAC (International Union of Pure and Applied Chemistry). 1993. Glossary for chemists of terms used in toxicology (IUPAC Recommendations 1993). Chemical Chemistry Division Commission on Toxicology, International Union of Pure and Applied Chemistry. www.sis.nlm.nih.gov/t.htm 05 April 2001.

Jusoh, M.M., K.S. Ong, G.A. Vigers, I.M. Watson and C.A. McPherson. 1999. *A Contextual Framework for the Development and Use of Marine Water Quality Criteria in ASEAN*. In McPherson, C.A., P.M. Chapman, G.A. Vigers and K.S.Ong (eds.). *ASEAN Marine Water Quality Criteria: Contextual Framework, Principles, Methodology and Criteria for 18 Parameters*. ASEAN Marine Environmental Quality Criteria – Working Group (AMEQC-WG), ASEAN-Canada Cooperative Programme on Marine Science – Phase II (CPMS-II). EVS Environment Consultants, North Vancouver and Department of Fisheries, Malaysia. pp. I-1 to I-10.

Kitamura, Shozo. 1997. *Final Report on The Ecosystem Component of the Development of Sustainable Mangrove Management Project, Bali and Lombok, Republic of Indonesia*. Jakarta.

Koba, M. 1993. The Present Conditions of Coral on the Reef Flats in Sanur, Nusa Dua and Kuta of Bali Island, Indonesia. In: M. Inoue (ed.), Ecotechnology Reports, Industrial Institute of Kansai University.

Management Plan of Tahura Ngurah Rai. 2000. The Final Report of Project Administration the Development of Sustainable Mangrove Management Project Bali and Lombok, Republic of Indonesia.

Marine and Coastal Culture Research Center of Gondol, Bali. 1992.

MPP-EAS (Marine Pollution Prevention in the East Asian Seas). 1999a. *Environmental Risk Assessment Manual: A Practical Guide for Tropical Ecosystems*. MPP-EAS Technical Report No. 21. Global Environment Facility/United Nations Development Programme/International Maritime Organization Regional Programme for the Prevention and Management of Pollution in the East Asian Seas, Quezon City, Philippines. 88 p.

MPP-EAS (Marine Pollution Prevention in the East Asian Seas). 1999b. *Malacca Straits: Refined Risk Assessment*. MPP-EAS Technical Report No. 23/PEMSEA Technical Report No. 1. Global Environment Facility/United Nations Development Programme/International Maritime Organization Regional Programme for the Prevention and Management of Pollution in the East Asian Seas (MPP-EAS)/Partnerships in Environmental Management for the Seas of East Asia (PEMSEA), Quezon City, Philippines. 89 p.

National Standards of P.R. China. 1995. Water Quality Standards of Seawater.

Public Work Agency of Bali Province. 1998. Bali Beach Conservation Project, Environmental Studies.

SEAFDEC (Southeast Asian Fisheries Development Center). 2003. "The Farming of Kappaphycus." www.seafdec.org.ph/downloads/kappa.pdf. Downloaded March 2003.

Sudara, S., M. Fortes, Y. Nateekanjanalarp, and S. Poovachiranon. 1994. "Human Uses and Destruction of ASEAN Seagrass Beds, in Living Coastal Resources of Southeast Asia: Status and Management," Report of the Consultative Forum, Third ASEAN-Australia Symposium on Living Coastal Resources, Bangkok, Thailand, May 1994 (Clive R. Wilkinson, ed.). Published by Australian Institute of Marine Science on behalf of ASEAN-Australia Marine Science Project: Living Coastal Resources.

Suter, G.W. 1998. *Retrospective Assessment, Ecoepidemiology: An Ecological Monitoring*, Chapter 7, *In*: Calow, P. (ed.) Handbook of Environmental Risk Assessment and Management. Blackwell Science, Oxford, Utah, U.S.A.

Tong, S.L., Goh, S.H, Abdulah, A.R., Tahir, N.M. and Wang, C.W. 1997. Development of ASEAN Marine Water Quality Criteria for Oil and Grease. In the ASEAN Marine Environmental Management Quality Criteria and Monitoring for Aquatic Life and Human Health Protection. Proceedings of the ASEAN-Canada Technical Conference on Marine Science (24-28 June 1996), Penang, Malaysia (Vigers, G., K.S. Ong, C. McPherson, N. Millson, I. Watson and A. Tang, eds.). EVS Environment Consultants, North Vancouver and Department of Fisheries, Malaysia, pp. VII-1 to VII-15.

UNEP-IE (United Nations Environment Programme – Industry and Environment). 1995. E*nvironmental Management Tools: Facts and Figures.* Industry and Environment. 19:3-10.

UNEP-IETC (United Nations Environment Program – International Environmental Technology Center). 1996. *Environmental Risk Assessment for Sustainable Cities.* Technical Publication Series No. 3. United Nations Environment Programme – International Environmental Technology Center, Osaka/Shiga, Japan. 57 p.

U.S. EPA (United States Environmental Protection Agency). 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments Interim Final*. EPA540-R-91-006 OSWER 9285.7-25 PB97-963211 Solid Waste and Emergency Response US-EPA, Washington, DC., U.S.A.

U.S. EPA (United States Environmental Protection Agency). 1998. *Guidelines for Ecological Risk Assessment: Final*. EPA/630/R-95/002F Risk Assessment Forum US-EPA, Washington, DC., U.S.A.

U.S. EPA (United States Environmental Protection Agency). 2000. *Summary of U.S. EPA Marine Water Quality Criteria*. United States Environmental Protection Agency. www.epa.gov/OWOW/NPS/sec301tech/table3.gif. July 2000.

Vermaat, J.E., et al. 1996. "The Capacity of Seagrasses to Survive Increased Turbidity and Siltation: The Significance of Growth Form and Light Use." *Ambio*, volume 26, No. 8, pp. 499-504.

WWF Wallacea. 2001. *Reef Check 2001*. World Wide Fund for Nature.

Yayasan Bahtera Nusantara Denpasar and Environmental Agency of Denpasar City. 2001. The Report of Coral Reefs Ecosystem Monitoring in Serangan District.

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.

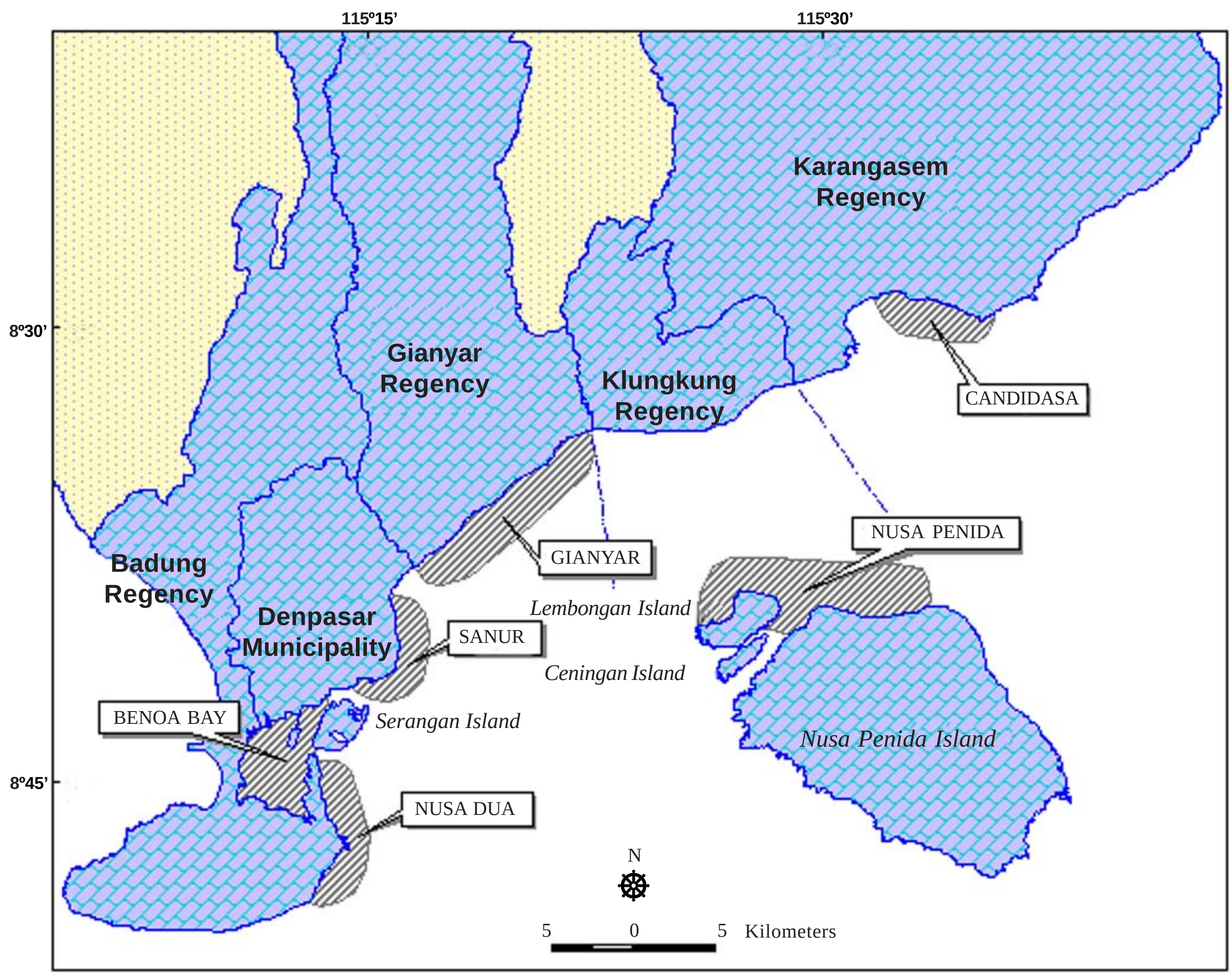
Trophic level. A functional classification of taxa within a community that is based on feeding relationships (e.g., aquatic and terrestrial plants make up the first trophic level, and herbivores make up the second).

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.

APPENDICES

Appendix 1. Locations of Sampling for Water Quality Measurement in the Southeastern Coast of Bali.



Appendix 2. Seawater Quality Standards for Bali Province.

No	Parameter	Unit	Criteria for Tourism and Recreation (Bath, Swim and Dive)	Criteria for Marine Biota and Fisheries
	Physic			
1	Color	CU	30	50
2	Odor		Natural	Natural
3	Transparency	m	30	3
4	Turbidity	TU	10	30
5	Suspended Solids	mg/l	20	80
6	Floating materials		nihil	nihil
7	Oil surface		nihil	nihil
8	Temperature	^{o}C	26-30	Natural
	Chemistry			
1	pH		6.5-8.5	6-9
2	Salinity	$^{o}/_{oo}$	Natural	±10% Natural
3	DO	mg/l	5	4
4	BOD5	mg/l	10	45
5	COD	mg/l	20	80
6	Ammonia (NH_4-N)	mg/l	nihil	1
7	Nitrite (NO_2-N)	mg/l	nihil	nihil
8	Cyanide (CN)	mg/l	0.05	0.200
9	Sulfide (H_2S)	mg/l	nihil	0.030
10	Oil and Grease	mg/l	nihil	5.000
11	Phenol	mg/l	nihil	0.002
12	Pesticide	mg/l	nihil	0.020
13	PCB	mg/l	nihil	0.001
14	Detergent (Surfactant)	mg/l	nihil	0.001
	Metal/Semi-metals			
1	Hg	mg/l	0.00010	0.003
2	Cr	mg/l	0.00004	0.010
3	As	mg/l	0.00260	0.010
4	Se	mg/l	0.00045	0.005
5	Cd	mg/l	0.00002	0.010
6	Cu	mg/l	0.00000	0.060
7	Pb	mg/l	0.00002	0.010
8	Zn	mg/l	0.00200	0.100
9	Ni	mg/l	0.00700	0.002
10	Ag	mg/l	0.00040	0.050
	Biology			
1	E. coli	cell/100 ml	nihil	1,000.000
2	Patogent	cell/100 ml	nihil	nihil
3	Plankton	Individual	Not bloom	Not bloom

Appendix 3. Seawater Quality Standards for Indonesia.

No	Parameter	Unit	Criteria for Tourism and Recreation (Bath, Swim and Dive)		Criteria for Marine Biota and Fisheries	
			Max	Min	Max	Min
	Physic					
1	Color	CU	50	30	50	30
2	Odor		Natural	Natural	Natural	Natural
3	Transparency	m	10	30	3	5
4	Turbidity	TU	30	10	30	5
5	Suspended Solids	mg/l	23	20	80	25
6	Floating materials		nihil	nihil	nihil	nihil
7	Oil surface		nihil	nihil	nihil	nihil
8	Temperature	°C	Natural	26-30	Natural	Natural
	Chemistry					
1	pH		6-9	6.5-8.5	6-9	6.5-8.5
2	Salinity	°/oo	±10% Natural	Natural	±10% Natural	Natural
3	DO	mg/l	5	5	4	6
4	BOD5	mg/l	40	10	45	15
5	COD	mg/l	40	20	80	40
6	Ammonia (NH_4-N)	mg/l	4	nihil	0.300	0.1
7	Nitrite (NO_2-N)	mg/l	nihil	nihil	nihil	nihil
8	Cyanide (CN)	mg/l	0.20	0.05	0.200	0.500
9	Sulfide (H_2S)	mg/l	-	-	0.030	0.010
10	Oil and Grease	mg/l	5	1	5	1
11	Phenol	mg/l	0.002	nihil	0.002	nihil
12	Pesticide	mg/l	0.042	nihil	0.020	nihil
13	PCB	mg/l	0.001	nihil	0.001	nihil
14	Detergent (Surfactant)	mg/l	0.500	nihil	1.000	nihil
	Metal/Semi-metals					
1	Hg	mg/l	0.005	0.00010	0.003	0.00010
2	Cr	mg/l	0.010	0.00004	0.010	0.00004
3	As	mg/l	0.050	0.00260	0.010	0.00260
4	Se	mg/l	0.060	0.00045	0.005	0.00045
5	Cd	mg/l	0.010	0.00002	0.010	0.00002
6	Cu	mg/l	1	0.00100	0.060	0.00100
7	Pb	mg/l	0.05	0.00002	0.010	0.00020
8	Zn	mg/l	1.5	0.00200	0.100	0.00200
9	Ni	mg/l	0.1	0.00700	0.002	0.00700
10	Ag	mg/l	0.05	0.00040	0.050	0.00030
	Biology					
1	E. coli	cell/100 ml	1000	10	1000	10
2	Patogent	cell/100 ml	nihil	nihil	nihil	nihil
3	Plankton	Individual	Not bloom	Not bloom	Not bloom	Not bloom

Appendix 4. International Criteria and Standards.

Water Quality Criteria

	U.S. EPA Quality Criteria for water for regulatory purposes (USEPA, 2000)		Water Quality Criteria for coastal and marine waters in the Philippines (DAO 34, 1990)				ASEAN Marine water quality criteria (ASEAN, 2003)	Chinese Standards for different classifications (National Standards of PR China, 1995)			
	Marine acute criteria	Marine chronic criteria	Classes					Classes			
			SA	SB	SC	SD		I	II	III	IV
Physico-chemical parameters											
DO (mg/l)			5	5	5	2	4.000	6	5	4	3
COD (mg/l)								2	3	4	5
BOD5 (mg/l)			3	5	7	-		1	2	3	4
Nitrate (mg/l)							0.060				
Nitrite (mg/l)							0.055				
Phosphate (mg/l)							0.015-0.045 (coastal - estuaries)				
TSS (mg/l)							50.000 (Malaysia)				
Cyanide (ug/l)	1	1	50	50	50	-	7.000	5	5	100	200
Ammonia (ug/l)							70.000 (unionized)				
Heavy Metals (mg/l)											
Cadmium	43.0	9.300	10	10	10	-	10.00	1	5	10	10
Copper	2.9	2.900	-	20	50	-	8.00	5	10	50	50
Lead	140.0	5.600	50	50	50	-	8.50	1	5	10	50
Mercury	2.1	0.025	2	2	2	-	0.16	0.05	0.2	0.2	0.5
Nickel	75.0	8.300						5	10	20	50
Chromium	1,100.0	50.000	50	100	100	- (VI)	50.00 (VI)	50	100	200	500
Silver	2.3	-									
Zinc	95.0	55.000					50.00	20	50	100	500
Arsenic	69.0 (Tri)	36.000 (Tri)	50	50	50	-	120.00	20	30	50	50
Selenium	410.0	54						10	20	20	50

Water Quality Criteria

	U.S. EPA Quality Criteria for water for regulatory purposes (USEPA, 2000)		Water Quality Criteria for coastal and marine waters in the Philippines (DAO 34, 1990)				ASEAN Marine water quality criteria (ASEAN, 2003)	Chinese Standards for different classifications (National Standards of PR China, 1995)			
	Marine acute criteria	Marine chronic criteria	Classes					Classes			
			SA	SB	SC	SD		I	II	III	IV
Trace Organics (µg/l)											
Chlordane	0.090	0.0040	3	-	-	-					
DDT	0.130	0.0010	50	-	-	-		0.05	0.1	0.1	0.1
Malathion	-	0.1000						0.5	1	1	1
Endosulfan	0.034	0.0067									
Pentachlorophenol	13.000	7.9000									
Heptachlor	0.053	0.0035			-						
Endrin	0.037	0.0023			-						
Aldrin	1.300	-	1	-	-	-					
Dieldrin	0.710	0.0019	1	-	-	-					
Lindane			4	-	-	-					
Toxaphane			5	-	-	-					
Methoxychlor	-	0.0300	100	-	-	-					
Benzene	5,100.000	700.0000									
Phenol							120				
PCBs	10.000	0.0300	1	-	-	-					
PAHs	300.000	-									
Benzo[a]pyrene								2.5	2.5	2.5	2.5
HCHs								1	2	3	5
Organometallics											
TBT (µg/l)							0.01				
Oil & grease(mg/l)	0.09	0.004	1	2	3	5	0.14	0.05	0.05	0.3	0.5
			(Petroleum ether extract)				(Water soluble fraction)				

Sediment Quality Criteria

Heavy Metals	HK-ISQVs (µg/kg) (EVS, 1996)		CANADA (µg/kg) Environment Canada, 1995)		NOAA (µg/kg) Long, et al., 1995)		NETHERLANDS (µg/kg) (MTPW, 1991)	
	Contamination Classification		Threshold/Probable Effects Level		Effects Range		Provisional Test/ Warning Value	
	Lower limit	x	Threshold	Probable	Low	Median	Test	Warning
Cadmium	1.50	9.60	[0.68]	4.21	1.20	9.60	7.5	30
Copper	65.00	270.00	[18.70]	108.00	34.00	270.00	90.0	400
Lead	75.00	218.00	30.20	112.00	46.70	218.00	530.0	1,000
Mercury	0.28	1.00	0.13	0.70	0.15	0.71	1.6	15
Nickel	40.00	N/A	[15.90]	42.80	20.90	51.60	45.0	200
Chromium	80.00	370.00	52.30	160.00	81.00	370.00	480.0	1,000
Silver	1.00	3.70	[0.73]	[1.77]	1.00	3.70	-	-
Zinc	200.00	410.00	124.00	271.00	150.00	410.00	1,000.0	2,500
Arsenic	8.20	70.00	7.24	[41.60]	8.20	70.00	85.0	150

Sediment Quality Criteria

	HK-ISQVs (µg/kg) (EVS, 1996)		CANADA (µg/kg) Environment Canada, 1995)		NOAA (µg/kg) Long, et al., 1995)		NETHERLANDS (µg/kg) (MTPW, 1991)	
	Contamination Classification		Threshold/Probable Effects Level		Effects Range		Provisional Test/ Warning Value	
	Lower limit	x	Threshold	Probable	Low	Median	Test	Warning
Organics								
Acenaphthene	16.00	500	[6.71]	[88.90]	16.00	500.0	-	-
Acenaphthylene	44.00	640	[5.87]	[245.00]	44.00	1,100.0	-	300
Anthracene	85.30	1,100	[46.90]	[128.00]	85.30	640.0	80	-
Fluorene	19.00	540	21.20	[144.00]	[19.00]	540.0	-	-
Naphthalene	160.00	2,100	34.60	[391.00]	160.00	2,100.0	-	-
Phenanthrene	240.00	1,500	86.70	544.00	240.00	1,500.0	[80]	[300]
Low mol. wt. PAHs	552.00	3,160	-	-	552.00	3,160.0	-	-
Benzo[a] anthracene	261.00	1,600	[74.80]	693.00	261.00	1,600.0	80	[300]
Benzo[a]pyrene	430.00	1,600	88.80	763.00	430.00	1,600.0	80	[300]
Chrysene	384.00	2,800	108.00	846.00	384.00	2,800.0	[80]	[300]
Dibenzo[a,h] anthracene	63.40	260	[6.22]	[135.00]	63.40	260.0	80	300
Fluoranthene	600.00	5,100	[113.00]	1,494.00	600.00	5,100.0	200	[700]
Pyrene	665.00	2,600	153.00	1,398.00	665.00	2,600.0	[80]	[300]
High mol. wt. PAHs	1,700.00	9,600	-	-	1,700.00	9,600.0	-	-
Total PAHs	4,022.00	44,792	-	-	4,022.00	44,792.0	[460]	[1,700]
Total PCBs	22.70	ns	21.50	189.00	22.70	180.0	[20]	[40]
p,p′-DDE (4,4′-DDE)	2.20	ns	[2.07]	374.00	2.20	[27.0]	-	-
Total DDT	1.58	ns	3.89	51.70	[1.58]	[46.1]	2	50
Bis(2-ethylhexyl) phthalate			182.00	2,647.00				
Chlordane			2.26	4.79				
Lindane			[0.32]	0.99				
Organometallics								
TBT in interstitial water (µg/l)	0.15	not stated						

Human Health Guidelines

	TDI in µg/person/day (mostly from FDA, USA) (MPP-EAS, 1999b)
Heavy Metals	
Arsenic	130
Cadmium	55
Chromium	200
Copper	400 (1-10yr) 2,000 (adults)
Iron	8,000 (1-10 yr) 14,000 (adults)
Mercury	16
Manganese	1,000 (1-10 yr)
	2,500 (adults)
Nickel	1,200
Lead	6 (0-6 yr) 15 (7-adults) 25 (pregnant women) 75 (adults)
Zinc	5,000 (1-10 yr) 15,000 (adults)

Human Health Guidelines

	TDI in µg/person/day (mostly from FDA, USA) (MPP-EAS, 1999b)
Pesticides	
Chlordane	
DDT/DDE	80
Endosulfan	4.8
Heptachlor	4.8
Endrin	4.8
Aldrin	4.8
Dieldrin	4.8
Lindane	1.6-8

Appendix 5. Summary of the Likelihood of Agents Causing Decline in Resources and Habitats.

Summary of the Likelihood of Agents Causing Decline in Resources.

Resource	Very Likely	Likely	Possibly	Unlikely	Don't Know
Fisheries		Overfishing Destructive fishing Habitat degradation	Domestic waste Industrial waste		
Aquaculture	Bacteria and virus		BOD DO Nutrients TSS Heavy metals	Oil and grease	Solid waste Pesticides
Seaweed	Ice-Ice Disease			Nutrients	Domestic waste Oil and grease Sedimentation, Salinity

Summary of the Likelihood of Agents Causing Decline in Habitats.

Habitat	Very Likely	Likely	Possibly	Unlikely	Don't Know
Mangrove	Reclamation Solid waste disposal Land conversion Clearance Sedimentation				Heavy metals Oil and related substances Pesticides BOD/COD/DO
Coral reefs		Coral mining Destructive fishing Anchoring Collection Marine tourism activities Sedimentation Nutrients TSS	BOD/COD/DO	Oil and related substances	
Seagrass beds		Land reclamation Seaweed culture extension	Sedimentation		Pesticides, collection, Nutrients, BOD, DO, TSS, Heavy metals
Beaches			Coastal mining; Coastal engineering structure; Setback invasion; Reclamation		