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Vulnerability and Adaptation Strategies to Sea-level Rise in Japanese Coastal Region

Haruyuki Kojima[1]

1. Introduction

The Japanese land stretches from latitude 20°24' to 45°30' and mainly faces the Pacific and Sea of Japan in the east and the west, respectively. Japan has over 34,000km of coastline and approximately 4.5million square km of ocean within its territorial sea. The majority of the population and economic activities in Japan are concentrated in coastal zones. As shown in Figure 1, the area of Coastal municipalities occupies only about 32% of the total area of 370,000km². They hold about 46% of the total population of approximately 120millions. They produce about 47% of the industrial output, and amazingly 77% of the total expenditure for retail business or market goods is spent in the coastal municipalities. Demands on coastal and marine resources have been constantly increasing, and as coastal areas become more developed, the vulnerability of human settlements to typhoon, storm surges, and flooding events also increases. Sea-level rise is anticipated to increase, with dramatic impacts in those regions where the vulnerability to these events already exists.

This paper describes a general overview of national coastal conditions and trends, and reviews studies on vulnerability assessment to impacts of sea-level rise on the Japanese coastal zone. Conceivable response strategies and adaptation technologies are also discussed.

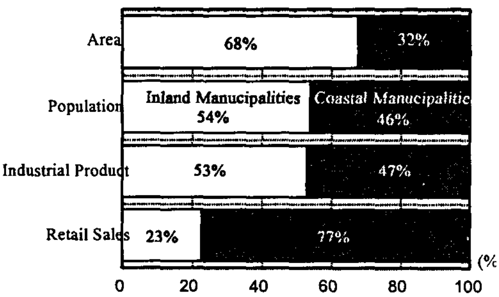

Figure 1. Basic Statistics of Japanese Costal Zone

2. Present Situation and Problems in the Coastal Zone of Japan

2.1 Changes in sea-level

The changes in mean sea-level associated with global warming is not uniform in space and affected by the dynamics and thermodynamics of the ocean, such as the difference of seawater density, large-scale wind field, ocean currents, etc. Several researches have been carried out to understand how much mean sea-level changes in the ocean waters surrounding Japan. The rate of the changes varies from −1.0mm/year to +5.0mm/year, the rising rate being high along the Pacific coast in the northeastern part of Japan (Yanagi and Akaki, 1993). The lower rate of 0.6mm/year was found on Sea of Japan and East China Sea coast (Uda et al, 1992).

2.2 Natural coast

The total coastline amounts to about 34,000km, where due to weather and oceanic conditions, various coastal features exist such as sandy beach, gravel beach, rocky coast, cliff, mud flat, tide land, coral reef, and mangrove swamp, as shown in Table 1.

The sandy beaches, that occupy 24% of the total coastline, have been eroded significantly, and the beach erosion has already been recognized as a seri-

[1] Dept. of Civil Eng., Kyushu Kyoritsu University, Kitakyushu, Fukuoka 807-8585, Japan
Email:kojima@kyukyo-u.ac.jp

Table 1. Coastal Landforms

Item	Present State
(1) Coastal Features (Length)	
1) Total length	34,390km
2) Natural Beach	
Sandy beach	6,700km
Mud flat tidal flat	400km
Rocky shore	6,200km
3) Artificial Beach	
Embankment revetment	8,800km
Groin	400km
Detached breakwater	630km
Wave dissipating works	1,100km
(2) Coastal Features (Area)	
Tidal flat	540km^2
Submerged vegetation	1,370km^2
Coral reef	870km^2

ous problem. In order to determine how seriously beaches have been eroded, an extensive study was carried out through comparing old topographic maps with more recent ones (Tanaka *et al.*, 1993). The main results of this study are tabulated in Table 2. With two different periods, one for 70 years from 1900's to 1978 and the other for much shorter period of 15 years form 1978 to 1987, the older period shows annual average loss of 72ha as compared with 160ha for the recent period. This result indicates that in the recent years an erosion rate is accelerating, that is, the erosion rate of the recent years is twice as high as that of the older period.With 43percent of the sandy beach coastlines being eroded, 41percent in stable condition, and only 6 percents accreting, approximately 120km^2 of coastal land area have been lost over the past 70 years. The main causes of this erosion problem are attributed to a decrease in sediment supply due to the construction of dams and embankment along rivers, and a change in the longshore drift related to the construction of ports facilities and coastal protection works. Because of this problem and other sea-related disasters, the coastline of about 16,000km, corresponding to 46% of the total, has been designated as a protected shoreline on which some kind of engineering measures are needed. On the 9,320km shoreline, or 27% of the total, shore protection works such as embankment and wave dissipating structures have already been constructed. It is important to note that what type of erosion protective measures have been implemented and will be implemented in the future would certainly affect vulnerability of the sandy beaches.

Table 2. Historical Shoreline Changes in Area and Width

Period	Shoreline Changes (Area)				Shoreline Changes (Width)			
	Erosion (ha)	Accretion (ha)	Net Loss (ha)	Annual Average Loss (ha/year)	Erosion (m)	Accretion (m)	Net Loss (m)	Annual Average Loss (m/year)
1900's~1978 (70years)	12,539	7,480	5,059	72	13.2	7.9	5.3	0.076
1978~1993 (15years)	4,605	2,210	2,395	160	4.8	2.3	2.5	0.168

2.3 Land use and sea-related natural disasters

Most of the major cities and infrastructures supporting industrial production, power generation, transportation, fisheries, etc are located in the coastal zones. For example, marine transportation and fisheries have highly developed in Japan, with 1,094 commercial and industrial ports and 2,950 fishing ports. These numbers are quite large as compared with those of the U.S. and U.K. Environmental Agency of Japan (1992) conducted a study on the ratio of three types of coastal features, namely natural beaches, artificial beaches and semi-natural beaches. In the entire country, the natural beaches cover about 57% of the total length of the coastline, with 29% for the artificial beaches and 14% for the semi-natural beaches. Land reclamation and artificial islands, amounting to 1,357km^2, attribute to increase in the percentage of the artificial beaches. They have been constructed to obtain lands for industrial factories, power plant facilities, farming ground, and other development. Since land reclamation usually takes place in the shallow seas such as a tidal flat, loss of tidal flat in area is approximately 288km^2 since 1945. Remaining area of tidal flat amounts to a little more than 540km^2. As Japanese coastal zones are intensively used, they are always on the verge of suffering from natural disasters.

The Japanese coastal zone is prone to several types of coastal disasters, namely typhoons in the summer, wind waves in the winter, earthquakes and tsunamis. Figure 2 depicts the location of such disaster-prone areas, major earthquake epicenters and severely eroded beaches, as well as the path of major typhoons that have caused devastating storm surge damage (Takayama, 1997). Yoshikura (2000) compiled the number of damage occurrences and the restoration project expenditures for port-related disasters between 1950 and 1999, as shown in Figure 3. Causes of the Port-related disasters include high waves and storm surges by typhoons, as well as earthquakes and their consequent tsunamis. The average annual number of damage cases accounts for more than 440, and the restoration expenditure exceeds 240million US$.

3. Vulnerability of Coastal Zone to Sea-level Rise

3.1 Changes in coastal topography

Various government sectors and university researchers have studied the comprehensive vulnerability assessment. The assessment studies include erosions of the sandy coastlines, hazard potential risk, impacts of storm surges on highly populated bays and protection costs of coastal infrastructures such as port facilities and coastal protection structures. Among these, one of the most significant impacts is aggravation of beach erosion. Mimura et al. (1994) estimated the area of erosion of Japanese sandy beaches by sea-level rise based on the Brunn Rule model. Bruun rule states that if we have a rise in sea-level, shoreline will recede not only to the position of water level increase but also to the position by wave actions. The lengths of shoreline retreat and the areas of eroded sandy beach in each of the prefectures facing the sea were estimated by using the data from 9,688 locations, which included the length and the width of sandy beaches, average sea bottom slop, and the characteristics of offshore and onshore waves. The scenarios of sea-level rise adopted were 30, 65, and100cm according to IPCC (1990). It has been estimated, as shown in Figure 4, that 56.6, 81.7 and 90.3% in area of the existing Japanese sandy beaches would be eroded due to sea-level rises of 30, 65 and 100cm, respectively.

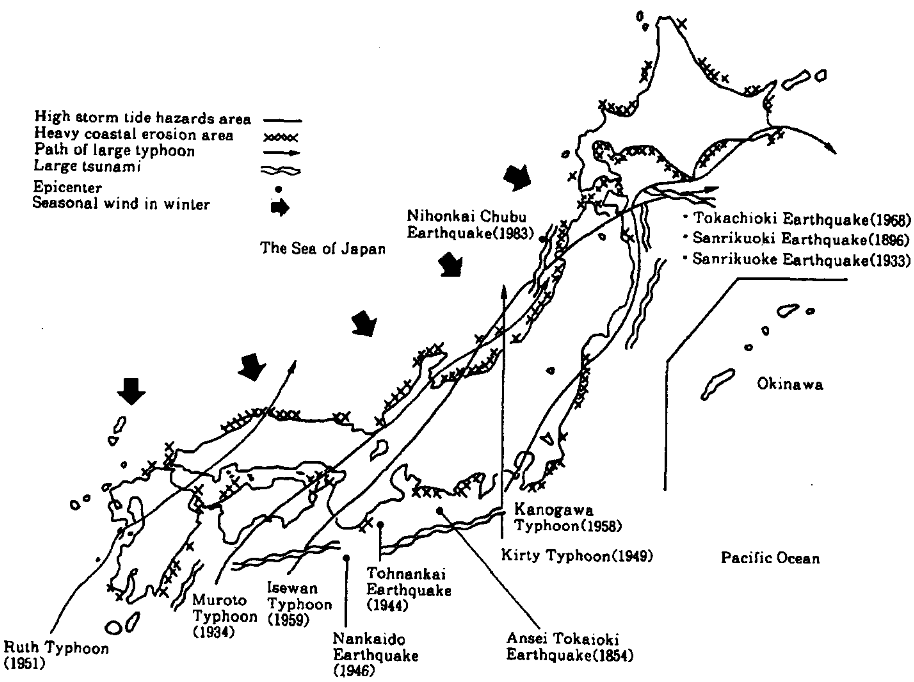

Figure 2. Characteristics of coastal disasters in Japan

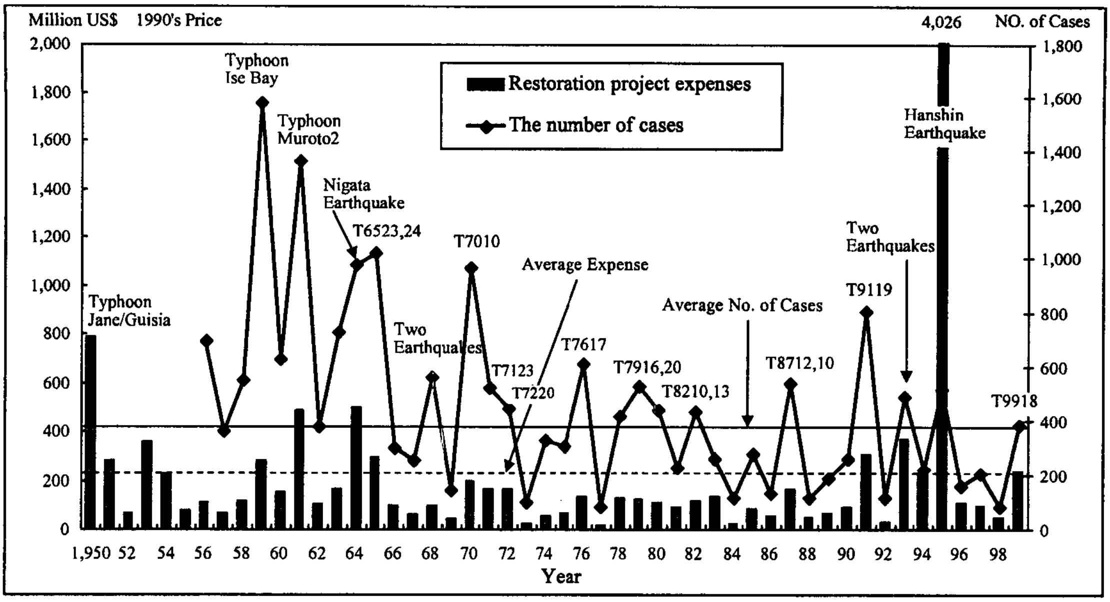

Figure 3. The number of occurrences and the cost of damage for port-related disasters between 1950 and 1999

3.2 Comprehensive vulnerability assessment

As a macroscopic analysis of the coastal vulnerability, area, population and amount of assets at risk by sea-level rise and storm surges were calculated (Matsui, *et. al.*, 1992). Three water levels (mean water; high water; high tide, caused by storm surge or tsunami) were used to be evaluated the possibility of submerging or flooding. Table 3 shows the comparisons of the inundated or flooded areas, populations, and assets for the present and the sea-level rise conditions. Even under the present situation, 861km^2 of land is already located below high water level, where about 2million people live and 540 billion US$ or 54 trillion JP yen worth assets exist. If 1m sea-level rise occurs, the area at risk will expand to 2,339km^2, 2.7times of the present amount, and population at risk will also increase to 4.1millions.

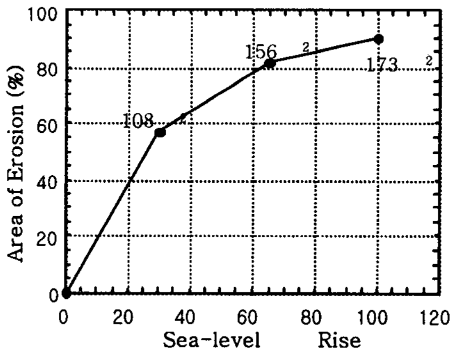

Figure 4. Relation ship between sea-level rise and the area ratio of eroded sandy beach

Table 3. Impacts of sea-level rise on the inundated areas, population, and assets of Japan
unit : area(km^2), population (million persons), assets (billion US$)

	present			0.3m sea-level rise			0.5m sea-level rise			1.0m sea-level rise		
	Area	popu-lation	assets	Area	popu-lation	assets	Area	popu-lation	assets	Area	popu-lation	assets
Mean water level	364	1.02	340	411	1.14	370	521	1.40	440	679	1.78	530
High water level	861	2.00	540	1192	2.52	680	1412	2.86	770	2339	4.10	1090
High tide level	6268	11.74	2880	6662	12.30	3020	7583	13.58	3330	8898	15.42	3780

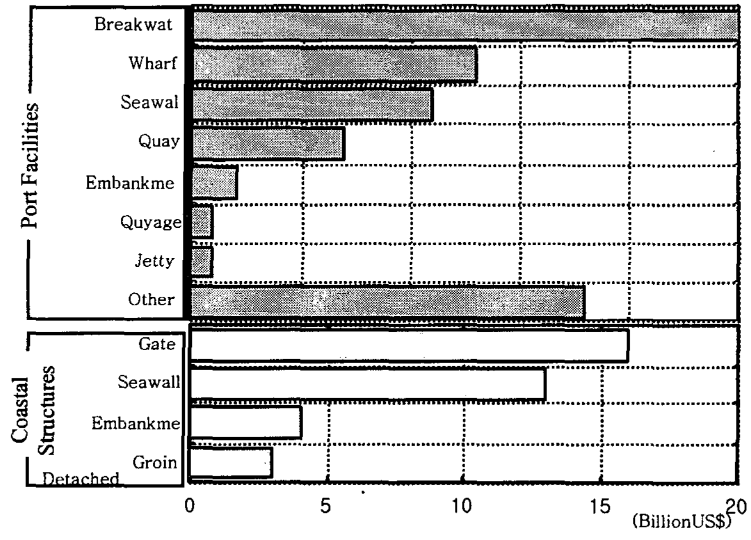

Figure 5. Protection costs of port facilities and coastal structures

3.3 Protection costs of coastal Infrastructures

Kitajima *et al.* (1993) estimated the costs of protecting port facilities and coastal structures in the Japanese coastal zones against 1 m rise in sea level. This estimate assumed no change for the natural environment other than the sea-level rise, no future development for ports and neighboring urban areas, no consideration of time-dependent processes, and the cost estimation based on the monetary values in 1992. The port facilities and coastal structures were classified into three groups in order to simplify the estimation of the protection costs, namely line structures including embankment, seawall detached breakwater and quay; plane facilities comprising of quay shed, warehouse and quayage; and independent facilities such as water gate and pumping station. With these assumptions mentioned above, Figure 5 shows the estimated costs of protecting port facilities and coastal structures in the Japanese coastal zones against 1 m rise in sea level. Total costs for protection were estimated at 115 billion US$ or 11.5 trillion Japanese yen. About 78 billion US$ are necessary for raising the port facilities, another 36 billion US$ are for the coastal protection facilities. These figures are only for port facilities, and there are about 2,900 fishery harbors and about 9,000km of the coastal protection structures. Inclusion of protection costs for these facilities will increase in the total cost of protection options.

4. Responses to Sea-level Rise and Adaptation Options

Adaptive strategies can be classified as "managed retreat", "accommodation" and "protection", which are comprised of a variety of options, as shown in Table 4 (UNEP, 1996). The protection option consists of hard and soft technologies: dikes, seawalls, revetment as a hard one and beach nourishment, wetland restoration as a soft one. Among them protection is most widely applied in Japan because socio-economic activities are highly concentrated in the coastal zones.

As mentioned previously, present hazard potential for many coastal zones in Japan will increase due to sea-level rise. Reducing coastal vulnerability to expected impacts of sea-level rise requires following the same three strategies of protection, retreat and accommodation as for current coastal hazards, including application of technologies used today. The characteristics of current adaptation technologies used to reduce vulnerability of the coastal zones from natural hazards are summarized as follows.

4.1 Protection

(1) Line Structures

Line structures such as embankments, seawalls, revetments and bulkheads have been extensively applied along the Japanese coastlines to protect upland properties. As of 1996, about 8,800km of the shoreline has been covered by such structures. The functions of these structures are to reduce the risk of the flooding by decreasing its probability of occurrence and to reduce the risk of flooding by limiting its potential effects. The cost of building such facilities is quite expensive and they require high maintenance cost and periodic replacement because they are dete-

Table 4. Response strategies to sea-level rise

Response options	Type of adaptation		Timing of adaptation	
	Autonomous adjustments	Strategic action	Reactive	Proactive
(Managed) Retreat				
• no development in susceptible area	√	√		√
• condition phased-out development		√	√	√
• withdrawal of government subsidies		√	√	√
• presumed mobility		√		√
Accommodation				
• advanced planning to avoid worst impacts	√	√		√
• modification of land use	√	√	√	√
• modification of building codes	√	√		√
• protect threatened ecosystem		√		√
• regulation in hazard zones		√	√	√
• hazard insurance to reinforce regulation		√	√	√
Protection				
1) hard structural options				
• dikes, levees and floodwalls	√	√	√	√
• seawalls, revetments and bulkheads	√	√	√	√
• groynes	√	√	√	√
• detached breakwaters		√	√	√
• floodgates and tidal barriers		√	√	√
• seawater intrusion barriers		√	√	√
2) soft structural option				
• periodic beach nourishment		√	√	√
(beach fill)		√	√	√
• dune restoration and creation	√	√	√	√
• wetland restoration and creation		√		√
• afforestation				

riorated by high waves generated by typhoons and winter storms. In addition, the high elevation of the structure crowns blocks people's view and accessing the beaches, thus resulting in isolating people from the water.

(2) Detached breakwater and artificial reef (submerged detached breakwater)

An array of detached breakwaters and/or artificial reefs, protecting about 700km of the shoreline, have been used with varying degrees of success to stabilize beaches and control erosion around Japanese coasts. The main function of these structures is reduction in wave energy at a particular segment of the beach leeward of the structures. This results in redistributing sand along and across the beach profile or preventing further erosion of the coast. Since these structures can not create sand in surf zone, any accumulation of sand produced by the structures is at the expense of an adjacent section of the shore.

(3) Beach nourishment

Beach nourishment, artificially placing sand on the beaches, is a viable engineering alternative for shore protection and the principal technique for beach restoration (National Research Council, 1995). Beach nourishment creates a "soft" (i.e., non-rigid) structure by adding sand to make a larger sand reservoir and a wider beach to effectively dissipate wave energy, thus not only controlling beach erosion but also providing protection from storm and flooding damages. Although beach nourishment is regarded as one of the most acceptable engineering measures for shore protection in the United States, Europe and Australia, Japan has not yet implemented a large-scale beach fill with periodic re-nourishment. This is partly because of speculation against suitability of beach nourish- ment as a shore protection measure and partly because of institutional constraints where beach fill could not be considered as shore protection measure under the former Coastal Protection Act. In 1999 revision of the Coast Protection Act was passed and enacted into law (Kishida, 2000). Under this new Act beach nourishment can be authorized as an engineering alternative for shore protection.

(4) Integrated coastal protection system (Ports and Harbors Bureau, 1998, Kishida, 2000)

Coastal protection works have evolved toward durable and high quality structures to protect human lives and upland properties. An integrated coastal protection system has been introduced in Japan. It consists of offshore artificial reefs, beach fills and gentle slope revetments, as depicted in Figure 6. This system can dissipate even extraordinary strong wave forces with these serial facilities while ordinary line structures are prone to suffer critical functional damage. This protection configuration has another advantage in that artificially added sand beaches provide recreational usage, thereby enhancing amenity of coastal communities. This protection system may become one of the major coastal protection measures in the near future in Japan.

4.2 Managed retreat and accommodation

There are several options for managed retreat and accommodation strategies, as seen in Table 4. For example, land-use planning in coastal zones, such as using building setbacks or allocating low-lying vulnerable lands to lower value uses (i.e., parks rather than housing), will help reduce the overall vulnerability to sea-level rise as well as current coastal hazards. Such a measure however has not been seriously considered in Japan.

One of the most popular legal and institutional measures presently implemented to mitigate coastal hazards would be the U.S. National Flood Insurance Program (NFIP), administrated by the Federal Emergency Management Agency. The NFIP is both a financial protection and a hazard mitigation program (National Research Council, 1990, 1995). Financial protection is provided in the form of flood insurance for homeowners and businesses located in interior and coastal hazard-prone areas. The hazard mitigation program includes improvement of structural integrity and survivability against anticipated flood-related damage through zoning criteria and construction standard. This option seems to be one of the most feasible and promising institutional approaches for carrying out managed retreat and accommodation strategies, in that,

- portion of insurance premium could be paid to relocate and reconstruct housings located in the hazard-prone areas;
- strict construction standard, building regulation and zoning criteria could be applied for eligibility of insurance coverage for any structures build in the vulnerable areas, so as to manage new development as well as encourage relocation of threatened buildings and modification of land use;
- insurance premium rates could be varied so as to control new development in the susceptible zones.

4.3 Integrated coastal management (ICM)

The coastal adaptation can be considered a multi-stage and iterative process, following the real change of the climatic and sea-level conditions. As shown in Figure 7, Klein *et al.* (1999) proposed a conceptual framework of adaptation strategies taking into consideration processes including four basic steps: (i) information collection and awareness; (ii) planning and design; (iii) implementation; and (iv) monitoring and evaluation. Climate change and sea-level rise will impact an evolving coastal environment, which is experiencing other non-climatic stresses brought about existing management practices. To be most effective, therefore, responses to sea-level change need to be integrated with all the other planning taking place in the coastal zone. Integrated coastal management (ICM) has been recognized as the most appropriate process to deal with current and long-term coastal problems induced by sea-level change and other stresses. This recognition has taken place at number of international conferences such as the United Nations Conference on Environment and Development (referred to as the Earth Summit) in 1992 and the World Coastal Conference in 1994. Since the Earth Summit, a number of international entities have made a number of efforts to further define the ICM concept and to develop international guidelines. Five major efforts may be identified (Cicin-Sain *et al.*, 1995):

- OECD (Organization for Economic Cooperation and Development) guidelines (1993)
- World Bank guidelines (1993)
- IUCN (International Union for the Conservation of Nature and Natural Resources) guidelines (Pernetta and Elder, 1993)
- World Coastal Conference Report by Intergovernmental Panel on Climate Change (IPCC, 1994)
- UNEP (United Nation Environment and Programme) guidelines (1995)

It is often important to establish international guidelines like above because they can be viewed as setting standards of an international model for countries to follow. In a view of incorporating climate change issues into broader ICM frameworks, an international workshop entitled "Planning for Climate Change Through Integrated Coastal Management" was convened in 1997 to further elaborate the concept of ICM and improve the guidelines developed in the previous international conferences (Ehler *et al.* 1997). In the workshop a set of the most updated, practical ICM guidelines was adopted. A summary of the guidelines is shown in Table 5 (Kojima *et al.*, 1999).

Japan has not developed the ICM legislations nor formed any administrative structures for the development of institutional arrangements. However, there have been increased debates on ICM issues among academic societies. The consequence of these debates emphasizes the urgency and necessity for making great efforts to formulate, implement and continuously improve ICM programs. A next big step is needed to further inform all relevant people, sectors, and agencies the importance of the ICM programs to deal with sea-level rise issues.

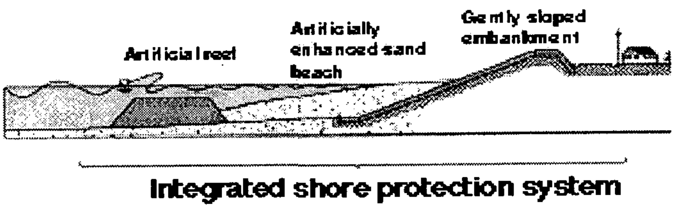

Figure 6. Configuration of an integrated shore protection system

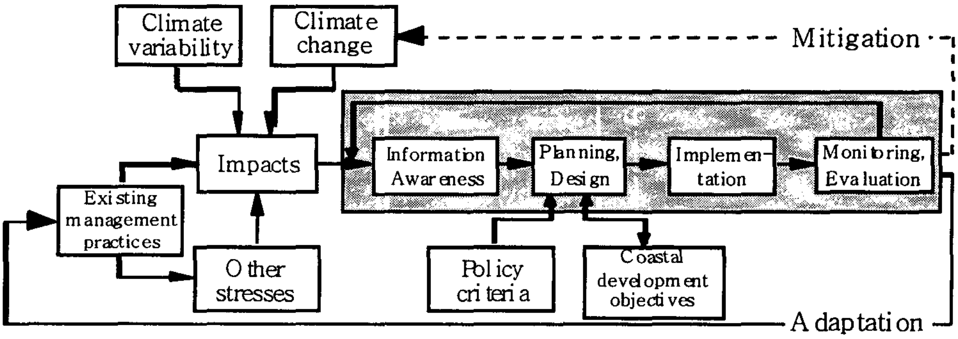

Figure 7. Conceptual framework of coastal adaptation to climate variability and change

Table 5. Principles related to integrated coastal management (ICM)

Principles Related to Environment and Economic Development		• Principle of inter- and intra-generational equity • Principle of the right to develop • Precautionary principle • Polluter pays principle • Principle of openness and transparency
Principles Related to the Special Character of Oceans and Coasts	Principles related to the biophysical na-ture of the coastal zone	• Traditional land-based management approaches unsuitable for managing coastal areas, due to high mobility and interdependence of ocean resources and processes • Land forms fronting on the water's edge (sand dunes, beaches, mangroves, fringing reefs, and headlands) play a key role as buffers to erosion and se-level rise and contribute to long-term sustainability. Their resilience should be maintained to enable their adaptation to fluctuations in climate and other changes. • Efforts to stabilize the coast and to provide infrastructure and facilities should emphasize "designing with nature." • Interruption in the natural longshore drift system should be minimized. • The biodiversity of rare and fragile ecosystems and endangered and threatened species should be protected. • Where retreat is being considered as an adaptation strategy, efforts should be made to create migration paths for habitats and coastal species that otherwise might be lost.
	Principles related to the public nature of the ocean and to the use of coastal/ocean resources and space	• Many countries have traditionally considered ocean resources to be part of public domain. These nations base their management of ocean and coastal resources on a stewardship ethic and their resolution of multiple-use conflicts on fairness & equity. • Wherever possible, historically based claims of indigenous people to coastal/ocean space and ocean resources should be recognized, and their practices of living in harmony with ocean resources should be followed. • Protecting living resources and their habitats should be given priority over exploiting nonliving resources, nonexclusive uses should be preferred over exclusive uses, and reversible exclusive uses should be preferred over nonreversible uses. • Potential conflicts should be identified early and in an orderly fashion, and equitable solutions should be developed by processes that protect and enhance public order. Full involvement of coastal communities is important in the entire ICM process. • New development in coastal areas that are marine- or saltwater-dependent should have priority over those that are not. • The transboundary nature of some coastal and marine problems (such as longshore drift and pollution) may require cooperation within or among countries. • Impacts of climate change in the coastal zone (such as increased erosion, flooding, saltwater intrusion) are best managed within the framework of an ICM program. Effective strategies for adapting to climate change integrate ICM with the other major building blocks of national climate change action plans.
	Overarching themes of these two categories	• Coastal areas are distinctive resource systems that require special management and planning approaches. • Water is the major integrating force of coastal resource systems. • The significant interactions that take place across the land-water boundary require recognizing and managing the whole system (upland, shore land, inter-tidal areas, and near-shore waters) as an integrated unit. • Activities well inland of the coast can significantly affect coastal resources. Where transboundary problems occur, cooperative efforts within and among nations will often be necessary to address them effectively, efficiently, and equitably.

5. Summaries and Conclusions

Summaries and conclusions drown from the present study are as follows:

(1) The Japanese coastal zones are intensively developed and used for socio-economic activities.

(2) The Japanese coastal zones are prone to several types of coastal disasters, namely typhoons, wind waves, storm surge and tsunamis. In addition, beach erosion has already been serious problems.

(3) Based on Brunn Rule model, 108km^2, 156km^2,

173km² (56.6, 81.7, 90.3%) in area of the existing sandy beaches would be lost due to sea-level rises of 30 65 100cm, respectively.

(4) Under 1m sea-level rise, the area at risk by flood would expand to 2,400km², 2.7 times of the present amount, 4million people are at risk, and 1,090 billion US$ worth assets exist.

(5) 115billion US$ would be needed to protect port-related facilities alone against 1m sea-level rise.

(6) Existing adaptive practices in Japan tend toward hard protection options such as embankment, seawall, revetment and detached breakwater. A new integrated coastal protection system consisting of serial hard structures with beach fill is introduced. Managed retreat and accommodation strategies have not been considered seriously in Japan.

(7) Development and implementation of a hazard insurance program seems to be effective in implementing several options of the proposed retreat and accommodation strategies.

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