CHAPTER 2

TOKYO BAY: ITS ENVIRONMENTAL STATUS – PAST, PRESENT, AND FUTURE

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1. INTRODUCTION

1.1. Natural conditions

Tokyo Bay is centrally located in Japan, between latitude 35 00'N and 35 40'N, and longitude 139^{o}40' E and 140^{o}05'E (Figure 1). This region has a temperate, humid climate. The lowest temperature is approximately 5 ^{o}C during January and February, and the highest temperature is approximately 30 ^{o}C during July and August. The months with the least precipitation are January and February. There is heavy precipitation during the rainy season in June, and during September and October, when typhoons often hit Japan. The monthly precipitation is approximately 50 mm and 150 mm in, respectively, January and September.

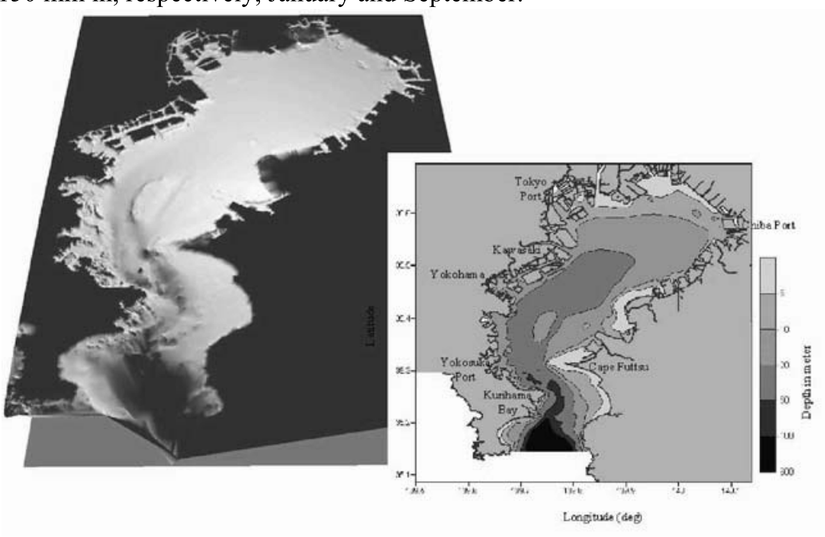

Figure 1. *Location map and bathymetry of Tokyo Bay.*

E. Wolanski (ed.), The Environment in Asia Pacific Harbours, 15–34.

The bay is the area north of the broken line connecting the eastern and western points of Suzaki and Kenzaki (see Figure 2a). The bay has an open interchange with the Pacific Ocean. The Kuroshio Current in the Pacific Ocean flows near the mouth of the bay.

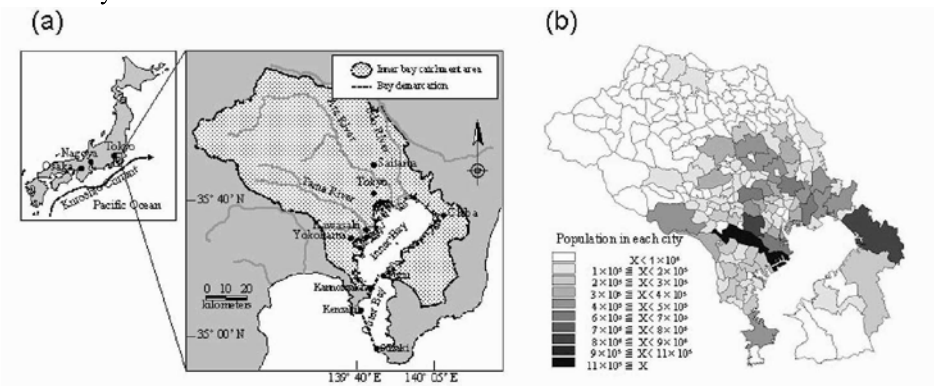

Figure 2. *Tokyo Bay catchment area. (a) location, (b) population in 2000.*

The bay has the shape of the letter "S." The narrowest width of the bay is 6 km on a line connecting the points of Futtu and Kannonzaki. Generally, the side to the North of that line is called the "inner bay", and the side to the South the "outer bay". In addition, the inner bay is often called simply "Tokyo Bay." In this chapter, "Tokyo Bay" refers to the inner bay. The inner bay has a length of 50 km and a width of 20 km. The average depth of the inner bay is 15 m, and its surface area is 960 km^2. The volume of the inner bay is 15 km^3. The catchment area of the inner bay is 7548 km^2. Its depth increases gradually from the head of the bay toward the mouth of the bay. The maximum depth of the inner bay is 50 m at its mouth. The seafloor is covered by silt or sand. The outer bay is deeper than the inner bay (Figure 1), with a maximum depth of approximately 600 m. The seafloor has a steep profile and is covered by rock or sand. The surface area of the combined inner bay and outer bay is 1380 km^2.

Rainwater falling in the catchment area of Tokyo Bay flows into the bay mainly through the Edo and Ara Rivers. Both rivers discharge into the head of the bay. The combined water discharge of both rivers accounts for approximately 50 % of all fresh water entering the bay. This water discharge forms a clear estuary circulation from the head of the bay toward its mouth.

The currents in the bay are caused mainly by tides, density gradients, wind stress, and the input of oceanic water.

The tides are typically semidiurnal, with tidal ranges of about 1.5 m during the spring tide and about 0.5 m during the neap tide. The maximum tidal current is about 1.2 m s^{-1} around Kannonzaki and about 0.2 m s^{-1} in the center of the bay. Generally, the residual current forms a clockwise circulation in the inner bay during summer.

1.2. Social background

Tokyo, the capital of Japan, is located in the catchment area of Tokyo Bay and has a population of 8 million people. Several other major cities are located in the inner bay catchment area: Yokohama, 3.5 million people; Kawasaki, 1.3 million people; Saitama, 1.0 million people; and Chiba, 0.9 million people (Figure 2 (b)). The inner bay catchment area has a total population of some 27.8 million.

The concentrations of population and industry in the catchment area of Tokyo Bay are very high according to estimates based on the population per surface area (= population in the catchment area/ surface area of the bay) and the total annual amount of freight at all ports in the bay. The population per surface area of Tokyo Bay is 29.0×10^3 people km^{-2}, while the population per surface area of San Francisco Bay and Chesapeake Bay in the United States of America are 8.1×10^3 people km^{-2} and 0.9×10^3 people km^{-2}, respectively (Table 1). In addition, the amount of annual shipping freight containers in Tokyo Bay is 5.8×10^6 TEU per year, while the amounts for San Francisco Bay and Chesapeake Bay are 1.9×10^6 and 1.6×10^6 TEU per year, respectively.

Table 1. *Comparison of the geographic and human use indicator between Tokyo Bay, Chesapeake Bay and San Francisco Bay. * Ogura (1993). * * International EMECS Center (2003). *** Degerlund (2005).*

	Tokyo Bay	San Francisco Bay	Chesapeake Bay
Surface area (km^2)	960*	1222**	18130**
Catchment area (10^3 km^2)	7.6*	156.0**	166.0**
Average depth (m)	15*	5**	6**
Population in the catchment area (in 2000) (10^6 people)	27.8	10.0**	15.7**
Population per catchment area (10^3 persons km^{-2})	3.7	0.06	0.1
Population per surface area (10^3 persons km^{-2})	29	8.1	0.9
Reclamation area (km^2)	249 (24.9 %)	240 (19.4 %)	12 (0.1 %)
Annual shipping freight containers (in 2000)(10^6 TEU)***	5.8	1.9	1.6

Some of the reasons behind the concentration of population and industry in the catchment area of Tokyo Bay include the following: (1) there are many suitable locations for ports in Tokyo Bay, where wave conditions are calm. (2) The catchment area of Tokyo Bay includes a wide plain (the Kanto plain) in Japan. (3)

The hinterlands of the bay are suitable for industry in Japan, which imports resources and exports products by sea. (4) The capital of Japan is located in the catchment area. (5) The climate of the catchment area is conducive to habitation.

The concentration of population and industry in the catchment area of Tokyo Bay has brought remarkable changes to its coastal area. Figure 3 illustrates the changes in the shape of the bay from 1920 to 2002. The reclamation of tidal flat areas and shallow water area increased rapidly from 1958 to 1976. Consequently, the surface area of Tokyo Bay decreased by 26% from 1900 to 2000. The present tidal flat area of Tokyo Bay is only 10 km^2, compared to 136 km^2 in 1900.

2. CHANGES IN THE ENVIRONMENT OF TOKYO BAY

How did the water quality of Tokyo Bay change over the past 100 years? One of the main factors in the deterioration of the water quality of Tokyo Bay is its conditions of eutrophication. The level of eutrophication in a semi-enclosed bay is determined by the balance between the volume of sea water exchange and the nutrient load. Organic matter accumulates in a bay when the nutrient load is greater than the volume of sea water exchange. The accumulated organic matter causes eutrophication in the bay. Therefore, this paper will firstly examine the volume of water exchange and the nutrient load in Tokyo Bay. Next, the changes in the typical phenomena of eutrophication and sediment conditions will be addressed. Moreover, the change in fish haul in Tokyo Bay will be examined as an index of ecological changes in the bay due to changes in water quality.

3. SEA WATER EXCHANGE

The present residence time of sea water in the inner Tokyo Bay has decreased in comparison with that in the past. The residence time of sea water for the inner bay in 2002 was 0.5 month during summer and 1.5 months during winter (Takao et al., 2004). In contrast, the residence time of sea water in the 1960s was 1 month during summer and 3 months during winter (Unoki and Kishino, 1977). Numerical simulations have indicated that the reduction in the residence time of sea water was caused mainly by an increase of fresh water input due to human population importing water from other catchments and the decrease in the surface area of the bay. The mechanisms of the reduction in the residence time of sea water are the following: (1) Estuary circulation due to fresh water input is the main cause of sea water exchange in Tokyo Bay (Unoki, 1998). As a result, the increase in fresh water input promotes estuary circulation and enhances sea water exchange. (2) The decrease in water surface area has caused a reduction in the tidal speeds. The reduction in tidal currents weakens vertical mixing and strengthens stratification in Tokyo Bay. Consequently, estuary circulation is promoted, and sea water exchange is enhanced.

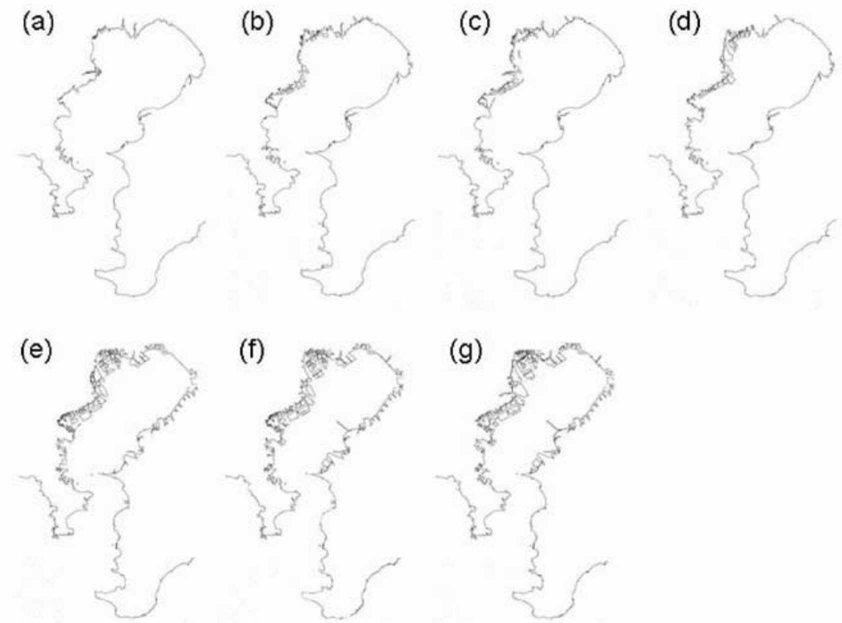

Figure 3. *Changes in Tokyo Bay coastline. (a) 1920, (b) 1940, (c) 1958, (d) 1969, (e) 1976, (f) 1990, and (g) 2002.*

The fresh water input into Tokyo Bay increased by approximately 50 $m^3 s^{-1}$ from 1960 to 1970: it was approximately 350 $m^3 s^{-1}$ before 1960 and 400 $m^3 s^{-1}$ after 1970. The reason for the increase in fresh water input was the increase in the imported water mass from neighboring catchments during the period from 1960 to 1970. The imported water mass was used as city water and industrial water in the catchment area of Tokyo Bay. Reclamation in Tokyo Bay drastically decreased the surface area of the bay from 1960 to 2000, to 80% of the former area (i.e. 1960). The decrease in surface area caused an 11% decrease in the tidal range of M_2 (Unoki and Konishi, 1999). In addition, the tidal current at the mouth of the outer bay decreased by 20% from 1968 to 1983 (Yanagi and Onishi, 1999).

4. NUTRIENT LOAD

The nutrient load (represented by the parameter Chemical Oxygen Demand or COD) in Tokyo Bay reached its peak in the 1980's but decreased markedly thereafter (Figure 4). The nutrient load was 100×10^3 kg d^{-1} until 1940. It increased in proportion to the economic development of Japan after 1940 and reached 580×10^3 kg d^{-1} in the 1980s. After that, it decreased to 320×10^3 kg d^{-1} in the 2000s. The reasons for the decrease in nutrient load from the 1980s to the 2000s are the following: (1) The nutrient load from domestic waste decreased because of increased sewage treatment, (2) The nutrient load from factories decreased because of the obligation to treat liquid waste.

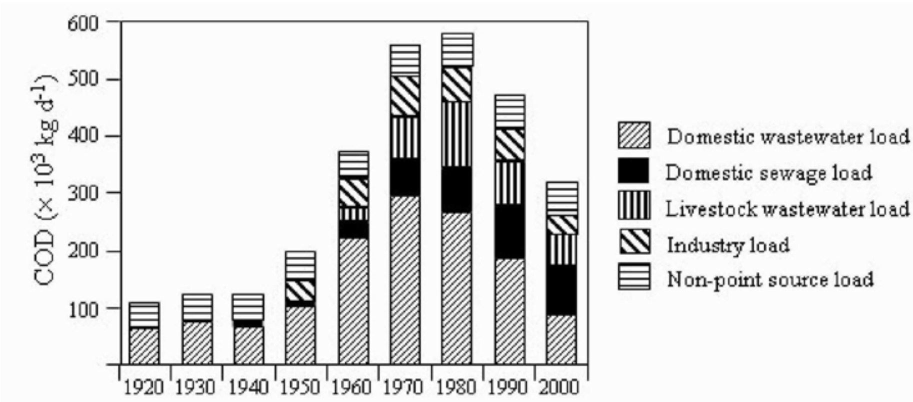

Figure 4. *Changes in nutrient load into Tokyo Bay.*

4.1. Eutrophication

Both the residence time of sea water and the nutrient load into the bay have decreased, yet the condition of eutrophication remains. The COD value currently remains at 3-5 mg l^{-1}, while it was about 6 mg l^{-1} in 1960s. In addition, the typical phenomena of eutrophication such as "red tide," "anoxic water," and "blue tide (aoshio)," still occur in Tokyo Bay. The sediment condition is sludge. These conditions will be described in greater detail.

4.2. Red tide

The red tide condition is a phenomenon of phytoplankton bloom. Its definition depends on the species of phytoplankton. Generally, the criteria for a red tide condition in Tokyo Bay are (1) less than 1.5 m of transparency; (2) at least 10^3 cells ml^{-1} of phytoplankton density for large species, or 10^4 cells ml^{-1} for small species; and (3) at least 50 μg m^{-1} of chlorophyll *a* (Nomura, 1998).

The red tide condition was an uncommon phenomenon between the 1900 and 1910 in Tokyo Bay (Okamura, 1907; Asakura, 1907), but when present, the main species of phytoplankton were flagellates such as the genera *Gynodinim*, *Pouchetia*, and *Peridinium* (Nomura, 1998). There are little data available regarding the red tide condition occurrence and constituent species prior to 1950. Nomura (1998) gave a historical review of red tide phytoplankton species and occurrences in Tokyo Bay. Beginning in the 1950's, the species of phytoplankton present in the red tide condition diversified. Red tide conditions with diatoms such as *S. costatum* began to occur (Nomura, 1998). After the 1970's, red tide conditions with *S. costatum* appeared throughout the year (Furota, 1980). The red tide condition with *S. costatum* became frequent after the 1980's. Very highly concentrated blooms, however, were not composed of diatom species but flagellates, such as *H. akashio* and the genus *Prorocetrum* (Nomura, 1998).

The frequency of the red tide condition in Tokyo Bay was less than 5 days per year before the 1940's. It gradually increased from the 1950's to the 1980's, reaching 20 days per year during the 1980's. The frequency has remained at 15-20 days per year since then.

4.3. Anoxic water

The frequency of the anoxic water condition in the bottom layer of Tokyo Bay has almost remained constant at 3-4 months per year since the 1980's. The area where anoxic water exists usually extends over 50% of the inner bay in summer.

4.4. Blue tide (aoshio)

The anoxic water condition in the bottom layer enhances the release of sulfide. When the anoxic water with sulfide upwells to the surface layer, the oxygen in the surface layer oxidizes the sulfide to sulfur. Then, the color of the surface layer changes to blue-white. This is called a "blue tide (aoshio)". In addition, the sulfide is harmful to marine organisms. In Tokyo Bay, the blue tide condition occurs in the inner bay when strong north winds continue for several days during summer and autumn. The blue tide condition inflicts significant damage on benthos such as shellfish that cannot escape from the blue tide water.

The blue tide condition in Tokyo bay was first observed in the 1950s. The frequency of the blue tide condition reached its peak in the 1980's, at about 6 times per year. It has since decreased to a current level of about 4 times per year, each event persisting on average for 2-3 days duration.

5. BOTTOM SEDIMENT

The seafloor of the shoreward area in Tokyo Bay was covered by sand in the 1950's. The present seafloor of this region however, is covered by sludge with a moisture content (= weight of water / weight of sediment × 100) of over 200 (Figure 5). The reasons for the change in sediment conditions are the reclamation of sand areas and the accumulation of organic matter. Figure 5b shows the distribution of water content in Tokyo bay. Our field observations of 75 points in the bay indicated that a moisture content of over 200 corresponds to at least 8% ignition loss, 20 g cm^{-3} COD, 0.5 mg S g^{-1} of sulfate, 0.6 mg g^{-1} of total phosphorus, 15 mg g^{-1} of total organic carbon, and 1.5 mg g^{-1} of total nitrate, 0.5-1.3 g m^{-2} d^{-1} of sediment oxygen uptake rates, along with less than 0.001 mm of sediment grain diameter.

6. FISH CATCH

The total annual catch of fish was more than 1×10^5 tons in the 1950's. About 90% of the catch was shellfish. The catch started to decrease gradually after 1960, reaching less than 5×10^4 tons per year in the 1970's. The main factor in the overall decrease was the decrease in the shellfish catch. Since then, the catch has continued to decrease. In the 1990's, the total annual catch of fish was 4×10^4 tons per year, with a shellfish catch of 3×10^4 tons per year.

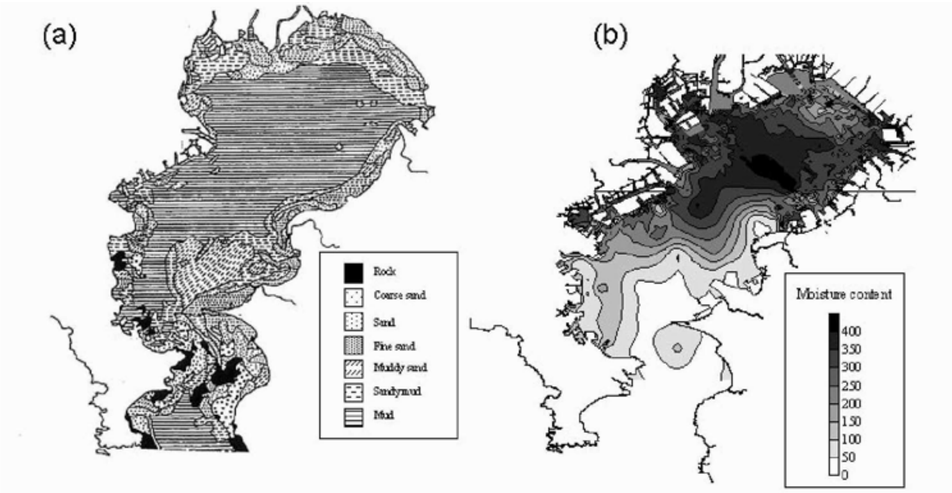

Figure 5. *Distribution of sediment in Tokyo Bay. (a) 1960's (Kaizuka, 1963), (b) 2000's.*

The factors causing the decrease in the shellfish catch are the following: (1) the decrease of habitat in the areas of tidal flats and shallow water regions because of reclamation; (2) the degradation of shellfish habitat environment due to anoxic water, red tide, and blue tide; (3) the competition with newly introduced species; (4) the disease; and (5) the destruction of the tidal flats network for benthic larvae transport.

The area of tidal flats decreased about 90% over the last 100 years (Ogura, 1993). A internal zone biomass of 12.6×10^4 tons was lost as 126 km^2 of tidal flats were reclaimed (Furota, 1994). Furthermore, Kakino (1986) suggested that 3×10^4 tons of bivalve biomass were killed by the blue tide condition in September 1985.

The decrease in benthos biomass has caused a decrease in the purification capability of Tokyo Bay (Furota, 1994). This is considered to be the main reason why the frequencies of red tide and anoxic water conditions in Tokyo Bay have not decreased, even though the nutrient load has decreased.

7. FUTURE PLAN FOR ENVIRONMENTAL RESTORATION OF TOKYO BAY

As shown in above section, the environmental health of Tokyo Bay is susceptible to degradation because a large volume of water is entrapped in the enclosed area, the poor water exchange rate resulted in a long residence timescale, a large amount of nutrients is discharged, and bio-chemical activities makes further exacerbate the stresses. In this section, some restoration efforts are listed by describing the legislative condition, the history of environmental rehabilitation projects, and the Tokyo Bay Restoration Plan. It will highlight the possible future activities in Tokyo Bay for environmental restoration for the "Wise Use (RAMSAR, 2004)".

7.1. Legislation on environment restoration in Japanese coastal line

There is now a strong public desire to conserve and restore the natural environment of the coastline and a trend towards public participation for managing those activities by coastline communities. National policy initiatives in this regard include the enactment of the Environment Basic Law (1993). The Basic Environment Law states our responsibility for future generations, stipulating the framework for environmental policies which ensure the benefit of a sound and rich natural environment for both a social structural development that would reduce as much as possible the load of socio-economic activities on the environment. Also of paramount importance is the need for international collaboration to achieve these goals. The focus is also directed towards the need for economic measures, the promotion of recycling programs, the designation of a public national holiday (Environment Day), the support for environmental education, and the importance of cooperation with private organizations. Based on this Law, the Basic Environment Plan was introduced in 1994 followed by revised in 2000 (Table 2).

Japanese coastlines are managed by several different organizations. After the enactment of the Environment Basic Law, the revision of the River Law (1997), the Coast Law (1999), the Port and Harbour Law (2000), and the Fisheries Basic Law (2001) were enacted. All these revised laws are clearly expressing a concern for environmental protection and restoration. For example, the Port and Harbour Law clarified the governmental commitment to environmental conservation in the port and harbour administration, stipulating that environmental considerations must be incorporated in port and harbour developments. The basic policies were modified to add descriptions about the conservation, the restoration, and the creation of favourable port environments as well as the interaction between human activities and natural ecosystem, which are referred to as "basic matters to consider regarding environmental conservation in the development, utilization and improvement of ports and harbours, along with the development of channel development". An another example, the Coast Law is adding coastal management measures from a comprehensive perspective. These include coastline protection, which is the fundamental objective of the old law; the improvement and conservation of coastal environments; and an appropriate use of coasts by the public. The Law was therefore designed to further promote comprehensive coastal conservation approaches with well-balanced views on disaster prevention, environment conservation and public use.

The goal to create a symbiosis between human activities and the natural ecosystem becomes a government goal. This has in turn led to a change in governmental approach towards nature conservation, in which ecological restoration and rehabilitation shall be actively promoted rather than just having its current status conservation. It may also include human assistance for the process of natural restoration. In order to make such a commitment to natural restoration to be handed down to future generations, there also is the need to establish procedures and a framework that can support the growing desire for commitment by the local residents who are increasingly aware of the environment.

Table 2. *Recent issues related to environmental restoration in Tokyo Bay port and harbour area.*

Year	Environmental measures in ports and harbors	Other domestic measures in Japan	International issues
1900s	Formulation of the policy "the creation a healthy and productive environment on water fronts"		
1970	Water Pollution Control Law was introduced		
1971			International cooperation for the conservation and wise use of wetlands was adopted in Ramsar
1972	Water Pollution Control Law was enacted		
1973		Law Concerning Special Measures for Conservation of the Environment of the Seto Inland Sea was enacted	
1975			International cooperation for the conservation and wise use of wetlands was come into force
1980			1st Meeting of the Conference of contracting parties (COP), Cagliari,
1987			3rd Meeting of the COP, Regina (Wise Use)
1988			"No net loss" declaration by President Bush, USA
1991			Earth Summit in Rio
1992			Adoption of Convention on Bio-diversity Habitat Directives is enacted, EU
1993		Conclusion of Convention on Biological Diversity Introduction of Basic Environment Law	

1994	Formulation of a new environmental port and harbor policy, "Eco-port" Eco-port model project started	Basic Environment Plan was authorized in the Cabinet	Effectuation of Convention on Bio-diversity
1995	Experiments on tidal frats started in Port and Harbor Research Institute	National Strategy on Bio-diversity of Japan	Establishment of International Coral Reef Initiative
1996	Formulation of the policy "Ports and harbors supporting mass transport and interaction"		Asia-Pacific Migratory Water bird Conservation Strategy
1997		Environmental Impact Assessment Law was enacted Revision of River Law	Adoption of Kyoto Protocol to the United Nations Framework Convention on Climate Change
1998		"Grand Design for the 21st Century" was formulated	
1999		Revision of Coast Law	7th Meeting of the COP, San Jose
2000	Revision of Port and Harbor Law Modification to the basic policies regarding port and harbor development A new port and harbor policy for the 21st century "Minato Vision connecting our lives to the sea and the world"	Six laws concerning water management and recycling was formulated	Adoption of Cartagena Protocol on Biosafety to the Convention of Bio-diversity Conference of contracting parties to the Convent on Bio-diversity Natura 2000 is enacted, EU
2001	Ministerial reformation Creation of the center of greenery along coastal areas	Prime Minister Koizumi's policy speech "Creation of a society with harmonious coexistence of nature and humans" Basic Environment Law was enacted	2nd Asia-Pacific migratory Water bird Conservation Strategy Millennium Ecosystem Assessment
2002	"Restoration of the sea" was included in urban restoration projects	National Bio-diversity Strategy of Japan was formulated Law Concerning Special measures for restoring Ariake and Yatsushiro Seas Law for the Promotion of Nature Restoration was introduced	Earth Summit in Johannesburg 8th Meeting of the COP, Valencia (ICZM)

The cabinet has advocated strategies in its documents "Creation of Cities and Land in a Coexisting Relationship with Nature (2001)", the "New Biodiversity

Strategy (2002)" and the "Law for the Promotion of nature Restoration (2003). Furthermore, the Urban Restoration Office of the cabinet enacted the tertiary decisions including the Restoration of the Sea under the Urban Restoration Project. This was followed up by the creation of Tokyo Bay Restoration Committee that includes central government agencies and local governments. The action plan to restore Tokyo Bay was enacted (2003). It gives specific goal of restoring Tokyo Bay to the municipal and public organizations by working together.

7.2. Restoration projects

Specific restoration project by the port and harbour bureau will be introduced as an example of history of environmental restoration. In this section "Restoration" has been taken as the collective expression for creating, altering, or improving wetland environments. This term therefore encompasses a number of terms used in previous works (PIANC, 2003):

- **Creation:** The conversion of a persistent non-wetland area into wetland through some activity of man.
- **Enhancement:** The alteration of existing wetlands to provide conditions that did not previously exist and that increase one or more user-defined values.
- **Reclamation:** The conversion of a water area or wetland area into a more terrestrial-based system or into a wetland above mean water level through some activity of man.
- **Regeneration:** Natural regrowth after disturbance.
- **Rehabilitation:** Human activity aiming at repairing damaged or blocked ecosystem functions.
- **Remediation:** The cleaning up of a polluted wetland site.

Efforts to conserve marine environment were represented by the Marine Environmental Improvement Project to clean-up floating garbage and oil (1974-), the "Sea-Blue" Project to improve seawater quality (1988-), and the "Eco-Port" project proposal (1994-).

7.3. 1970s: the marine environmental improvement project

Since 1960, Japan experienced rapid economic growth of economics. Unfortunately this growth was accompanied by the quasi-unregulated discharge of hazardous material (heavy metal and oil etc.) discharge in to bay. In 1974, the Water Pollution Control Law was enacted. The ministry of Environment has started to monitor water quality in public water (lakes, rivers and the sea).

The Marine Environmental Improvement Project was started under this initiative. The port and harbour bureau equipped Marine Environmental Improvement Vessels to collect floating garbage on a daily operational basis (Figure 6, Animation 1). At the same time, the vessel can be used for oil recovery when an oilspill occurs. It is a symptomatic measure for mitigating the degradation of the environment. Results are instantaneous and visible, nevertheless continual operation is required.

To support these activities, studies were undertaken of the water exchange mechanisms using hydraulic models. Large scale model tests using tanks, were conducted (Kaneko et.al., 1973) to estimate the transport and diffusion of materials in the bay. These demonstrated a close relation between bathymetric changes due to port construction and the flow and diffusion patterns.

In addition to hydraulic model studies, a numerical model was also developed. In the first stage of the development, the modelers attempted to calculate the steady-

Figure 6. *The marine environmental improvement vessel to collect floating garbage in daily operational basis in Tokyo Bay.*

Animation 1. *Equipped marine environmental improvement vessel to collect floating garbage.*

state, tidal residual currents in the bay (Kaneko et al., 1975). It took 5 hours to run a 4 tidal cycle model using a 2 km mesh model for Tokyo Bay. Thus, to speed up the calculations, ADI (Alternative Direction Implicit) scheme were well studied.

Nevertheless, the relationship between the flow field and the changes in bathymetry could not be checked by numerical models. To resolve this problem, there was the need for a combined approach using numerical and hydraulic modeling to study the steady state situation of current and material transport.

7.4. The "Sea-Blue" project

In 1980s, the hazardous material contamination problem seems to be under controlled. Nevertheless, the problems due to eutrophication, red tide (algal broom), odor problem, and oxygen depleted water caused by organic pollutants still remained. The "Sea-Blue" project was designed to tackle with this problem Study (Committee of Sea-Blue Technology, 1989). The "Sea-Blue" is a Japanese word expressing blue sea environment. The concepts of the "Sea-Blue" project were;

- Active good environment creation
- Close relation between land and sea
- Environment improvement in concern with use
- Enhance potential of self purification ability of sea
- Combination of techniques.

It aimed to enable water purification by putting together "Sea-Blue techniques" which were process oriented technologies to improve water quality and reduce environmental degradation. It is aiming to reduce source of environmental degradation. Nevertheless, the indices of environmental health were not directory related to ecosystem, but related to physical and chemical status such as flow and water quality. Furthermore, the plan did not take into account ecosystem sustainability. Thus, each measure must quantify its ability to enhance the water purification potential and its duration. The model used for such tests including considered nutrient cycling processes.

One example of such modeling is for "sand capping" techniques (Figure 7). A clean sand layer placed on top of the contaminated materials (capping) decreases completely or partially the re-entrainment of nutrients in the water column. Furthermore, the introduced sand layer gives a new habitat for organisms. Nevertheless, the new sand layer can become contaminated by detritus in the water column. Material transport in sand layer also diminishes the effect of capping.

A phosphorous cycling model was established to test the sand capping techniques (Horie and Hosokawa, 1985). The detail nutrient exchange process between the sand layer and the water column were modeled. A long term prediction using the model showed that the re-entrainment was suppressed by half for 20 years. Such studies gave a technical justification for implementing the plans in the field.
At this stage, a variety of models were developed for tackling specified problems those focused on specific areas and specific micro-processes.

7.5. 1990s: the "Eco Port" project

In the 1990s, the port and harbour bureau released the "Eco Port" plan. It extended the "Sea-Blue" project not only for water quality improvements, but also for the creation of ecosystem such as tidal flats and sea grass meadows. The goals of the projects are:

- Maintain or improve the water circulation and material cycling

- Take into account dominant processes of contamination
- Take into account the macro balance of material cycling
- DO (Dissolved oxygen) is important indicator of water quality
- Monitor the sediment quality and its change
- Monitor indicator species

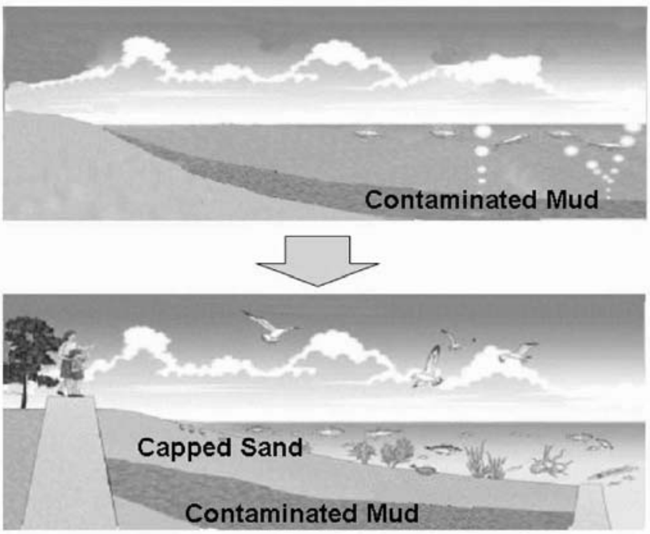

Figure 7. *Sand capping techniques in the "Sea-Blue" technologies.*

- Care for the monotonous ecosystem
- Take into account the shallow water, tidal flat and sea grass meadow ecosystems.

The difference between "Sea-Blue" and "Eco-Port" project is as follows. The "Sea-Blue" project provides a list of techniques, and it lets a planner choose. However, in the "Eco-Port" project, only the environmental concept is provided; a list of techniques is not provided. It not gives a list of techniques solely. This forces the planner to find the best way to do that, and to provide an analysis for this. On this point, the bureau has thus started to address the issues of ecosystem rehabilitation and restoration.

To support the project, the experimental facility shown in Figure 8 has been used since 1995. It consists of three water pools, each with an area of 20 m^2. Bottom mud was taken from the Banzu Tidal Flat in Tokyo Bay, thoroughly dried and vigorously mixed, then spread to a depth of 50 cm in the pools. Benthos was not observed in the accumulated dried mud. Fresh sea water was taken from Kurihama Bay and placed in the pools without any treatment. The water level was controlled to create tidal cycles in each pool. Biological succession and communities development were carefully monitored. It shows that the larger the body size (> 10^1-10^3 mm), the lower the population density (< 10^{-1}-10^9ind cm^{-2}). These ecotone experiments reproduced well the field observations on the Banzu tidal flat (Kuwae and Hosokawa, 2000; Kuwae et.al., 2004).

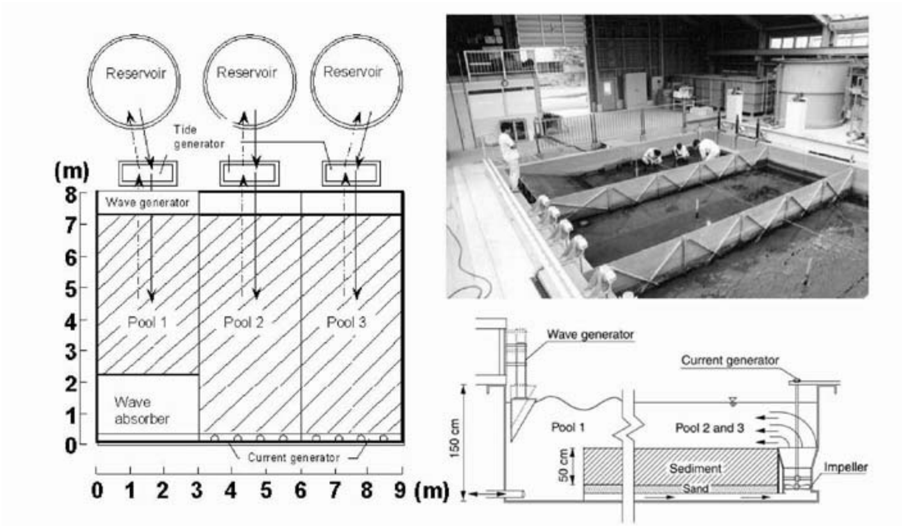

Figure 8. *The Intertidal Flat Experiment Facility (IFEF) at the Port and Airport Research Institute.*

Physical-biological interactions have been also studied in field. For example, the cluster analysis of macrofauna and sediment quality of a natural sandy tidal flat shows a strong relation between sediment quality and benthic community development (Furukawa et.al., 1999). Not only sediment quality, but also physical forces such as current and wave height distribution contribute to biological zonation in this area. These research findings support the idea of controlling ecosystems by controlling physical external forces and sediment quality by civil engineering measures.

8. TOKYO BAY RESTORATION PLAN

On 26 March 2003, the "Tokyo Bay Restoration Plan" was endorsed by the Council for Promotion of Tokyo Bay Restoration, which is formed of 11 central government bodies and 7 regional government bodies (4 prefectures and 3 cities). The plan consists of five parts: (1) overview of Tokyo Bay restoration planning, (2) present status of Tokyo Bay environment, (3) specific goal of Tokyo Bay restoration, (4) promotion of measures to achieve the goal, and (5) related activities.

8.1. Overview of Tokyo Bay restoration planning

The Tokyo Bay Restoration Planning initiative was initiated by a decision of the Japanese Cabinet in December 2001. Seven prefectures and cities surrounding the bay and related central government ministries formed a council to promote the restoration of Tokyo Bay.

The goal is the "Tokyo Bay restoration through water quality improvement". This goal is to be achieved by collaboration among the related bodies within ten years.

8.2. Specific goal of Tokyo Bay restoration

"Creation of a bay for the Tokyo metropolitan area that has amusement-based places, rich habitats with high biodiversity, and beautiful seashore areas" is the stated goal of Tokyo Bay restoration.

This goal does not have quantifiable target, such as "COD less than 5 mg L^{-1}". The goal is not prescriptive: it defines the condition required of a feature and not the actions or processes necessary to obtain or maintain that condition. The basic idea of the goal is that "it should be an expression of purpose".

The indicator for measuring achievements is the bottom layer concentration of dissolved oxygen (DO). The target level is in a "livable environment for benthos throughout the year". A low DO value is not a source material for an adverse condition, like nitrogen, phosphorus, and organic matter; rather, it is the result of an adverse condition. Thus, maintaining DO at a target level requires an integrated approach; simply controlling a specific effluent, for example, is not enough. The creation, restoration, and conservation of integrity of bay system within natural fluctuations are required.

The process for assessing the achievement of the goal is set as follows. Several priority implementation areas with specific targets have been set as points for monitoring (named as "appeal points"). Each point has a specific target image of restoration, as shown in Figure 9. It is thus possible to assess the project in terms of specific goals.

8.3. Promotion of measures to achieve the goal

The measures to achieve the goal are categorized into three areas: those that reduce the load imposed from land, those that promote environmental restoration offshore, and those that implement an environmental monitoring scheme.

The major actions for reducing the load from land are planning total load control, improving combined sewer systems, and suppressing runoff. These plans include wetland restoration to trap nutrients in run-off water, to control non-point source load, and to do a total cost control of the watershed. Not only does the plan list the tasks to be undertaken, but it also discusses the systems to be built.

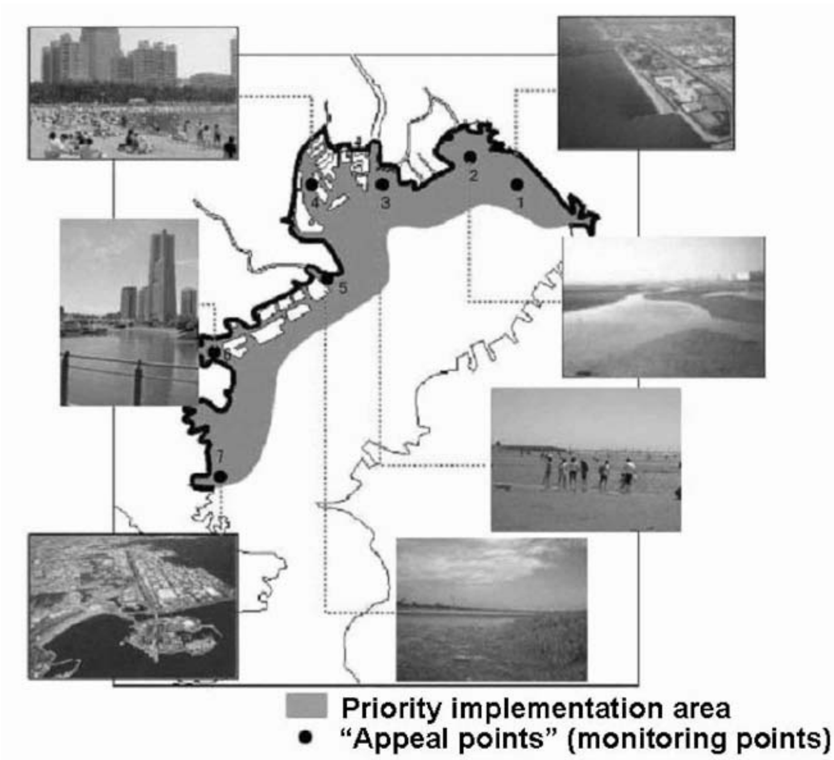

Figure 9. *Tokyo Bay Restoration Plan.*

The major action plans for promoting environmental restoration offshore are reducing the source of the internal load on the seawater and increasing the water purification capacity. These plans include dredging bottom sediment and replacing it with clean sand (sand capping), collecting floating garbage using specially designed vessels, and promoting clean-up campaigns with NGOs and the fishery industry. A network of ecosystems among habitats is an important concept in the restoration of wetlands in coastal areas.

A major action plan for implementing an environmental monitoring scheme in Tokyo Bay is the monitoring of bottom water DO levels. This includes the monitoring of the currents and water quality using moored facilities and vessels. Items to be considered include remote sensing, sharing of monitored data with stakeholders, provision of the results of the monitoring to the public, and public participation in the monitoring.

8.4. Related activities

Experimental actions are also designed to achieve the goal. Because of uncertainties about the natural environment condition, a step-by-step method (an adaptive approach) is needed to examine the techniques or systems to restore the environment. The environmental monitoring using high-frequency radar and knowledge exchange with other countries are examples of these activities.

9. PLANNING THE FUTURE REGIME

People living along a coastline are expected to use it wisely, and the wishes of the local people should be respected. Their support is indispensable for the many measures that require regular observation and long-term maintenance. Ways to determine the wishes of the local people, and ways to carry this out thorough management, must be established. Multi-disciplinary, scientific symposia for gathering experts in modeling, ecosystem assessment, observational techniques and data processing, and other specialized topics are needed to facilitate the sharing of knowledge. Systems for public participation in strategic planning are also needed. The plans should encourage continual improvements in observation methods, accumulation of observation results, development of reliable, user-friendly ecosystem models, analysis of environmental -restoration technologies, and maintaining the cooperation between scientists, local governments, and coastal residents.

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