

Ecology for Environmental Conservation of Coastal Area and Harbors

Yasushi KURIHARA

D.Sc., Professor of Ohu University and Professor Emeritus of Tohoku University

COASTAL ECOSYSTEMS

The coastline is the interface between sea and land, and is an active zone where many ecosystems develop. These include rocky reefs, boulder beaches, gravel beaches, sandy beaches, tidal flat, tidal rivers, tidal marshes, and lagoons, and they are often categorized into three main types: rocky shorelines, sandy beaches, and sheltered bays.

Such ecosystems are generally formed by the combinations of the kind of substrata, such as mud, sand, gravel, or rock, as well as the state of water, such as waves, tides, tidal currents, salinity and so on. Especially, substratum, tide and wave are the most fundamental factors for the characterization of coastal ecosystem. Each such ecosystem is characterized by a unique set of life forms that depend also on climatic zone as well as the quality and quantity of nutrient materials. Outlines of these three main ecosystems, rocky shorelines, sandy beaches and sheltered bays, are given below.

A rocky shoreline is typically characterized by hills or mountains falling down to capes and bays and indentations that form the actual shoreline. The projection areas which are capes, are land that remains after erosion, while inlets which are bays, are shaped by the hydropressure of wave. If such a topography is exposed to a strong wave action, cliffs or rocky reefs develop. On the other hand, relatively mild wave action results in boulder and gravel beach. A rocky reef ecosystem is characterized by the immobility of the substrate. This encourages the growth of sessile organisms that attach themselves to the rock in a belt-like pattern that depends on tidal level. In general, *Littorina* grow in supralittoral zone, *Balanus*, *Mytilus* and oyster grow in the upper part of tidal zone, and large seaweeds on boulders and rocks in the infralittoral zone.

Open beaches develop where the hinterland is flat, and if the wave action is strong a berm may develop that remains mostly exposed to the air. The beach begins with a steep slope of foreshore to seaward, while the bottom of inshore becomes a sandy flat. Large seaweeds

are unable to grow on such sandy bottom because the substratum is mobile. Phytoplankton, on which zooplankton prey, simply sink to the seabed after death since there are few zooplankton which consume them. Further, since mass transport by waves is directed landward, detritus consisting of dead phytoplankton in the process of microbial decomposition accumulates in the intermediate zone between the breaker zone and the shore line. Therefore, a fairly large number of endobenthos and semi-endobenthos are observed in the intermediate zone. Specifically, *Collembola* and *Tylos* are common in the supralittoral zone, interstitial animals such as *Callianassa* in the tidal zone, and many kinds of shellfish, including bivalves, in the detritus-deposit zone.

In general, the sea water in sheltered bay is calm. If the water is shallow, the temperatures of mud and water are susceptible to air temperature changes. Further, the concentrations of inorganic nutrient and organic material tend to be high and suspended matter and detritus tend to concentrate and be deposited. In the waters which are influenced by tidal variation and fresh river water, brackish marsh often develop at high water level (in Japan, reeds, *Phragmites*, dominates in such areas.) and tidal flat develop within the tidal zone. These tidal flats are particularly abundant with life forms; the main inhabitants are shellfish, polychaetes, crabs, crustaceans, fish, and benthic algae, reeds, and other larger plants; and snipe, plover, and other migratory birds.

HARBOR AND ROCKY REEF LIFE

In the previous section, the three major coastal ecosystems were outlined: rocky reefs as a typical rocky shorelines; sandy beaches; and tidal flat as the typical expression of sheltered bays. If these ecosystems could be classified on the basis of four characteristics, or wave action, substrate, tidal range, and bottom slope, they may be viewed as shown in Table 1. On the other hand, harbor areas, in general, are characterized by steep slope because of navigation and anchoring. Breakwaters are usually constructed to calm wave motion. Further, harbors are usually surrounded by perpendicular quay

Table 1 Comparison of environmental characteristics of coastal ecosystems

Environmental characteristics		Rocky reef	Sandy beach	Tidal flat
Wave motion	Strong			
	Weak			
Substrate	Firm			
	Soft			
Tidal range	Large			
	Small			
Seabed slope	Gentle			
	Steep			

walls made of concrete. Thus, the environmental features of harbors are calm waters, quay and breakwater, and extremely steep seabed slope. These characteristics are in considerable contrast to those of a natural coastal ecosystems, as is clear from Table 1.

A somewhat different interpretation may be made, however. A breakwater or steep concrete protection wall may be considered equivalent to a rocky reef. Certainly, it is a fact that sessile organisms attach themselves to the concrete walls in the tidal zone, and are very similar to those on natural rocky reefs (Photos 1 and 2).

A similarity in the species component does not necessarily, however, indicate that the ecosystems are of similar types. This is exemplified by the bottom sediment below breakwaters. As shown in Table 2, the average particle size of the bottom sediment below a breakwater is very small compared with that at a reef because of the high silt and clay contents and Redox potential in mud of breakwater is lower than that of reef. In addition, there is a far greater concentration of organic matter in sediment and organic suspended substances in the water near a breakwater than around a reef. Why is that?

Of the sessile organisms on concrete breakwaters or rocks, the population density of *Mytilus* and oysters are very high. They intake particulate organic matter such as suspended organic matter, plankton and bacteria, assimilate them, and excrete feces. More important, these organisms cement together particulate organic matter with secretions from their gills and these cemented materials fall to the seabed. These droppings, referred to as pseudofeces, together with feces amount to huge quantities. According to some reports, they account for 60% of the total amount of food taken in the case of oysters and 50% in the case of *Mytilus*.



Photo 1 Rocky reef (photo by Satoshi Takeda, Asamushi Marine Biological Station, Tohoku University)



Photo 2 Perpendicular concrete wall (photo by Port and Harbor Research Institute, Ministry of Transport)

Table 2 Sediment environment at rocky reefs and breakwaters (Survey by Makoto Tsuchiya)

	Rocky reef	Breakwater
Average grain size of sediment	0.25 ~ 0.5mm	0.063 ~ 0.125mm
Redox potential	+200 ~ +300mV	-10 ~ +50mV
Organic matter in sediment	7 ~ 9%	15%
Organic suspended matter	< 10mg/l	20 ~ 40 mg/l

At natural rocky reefs, these feces and pseudofeces are dispersed by the turbulence of wave action against the complex reef base. This scatters the material and

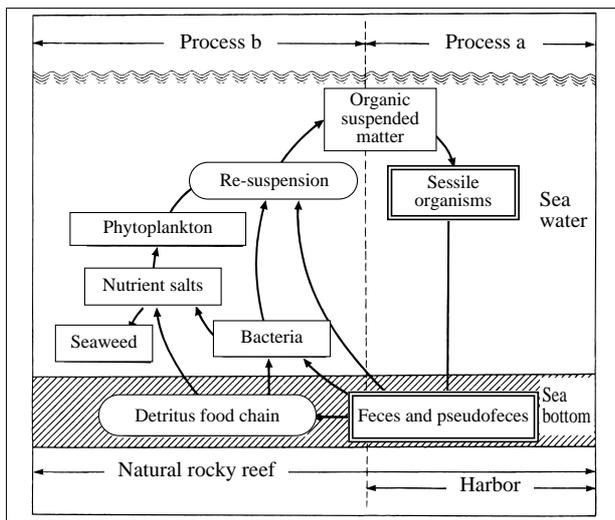


Fig. 1. Relationship between intake and excretion of periphytons at natural reefs and harbors (for harbors, process b is weak or lacking)

splashes it around for later re-intake by *Mytilus* or oysters. Bacteria that grow in the feces and pseudofeces and phytoplankton are also intaken by *Mytilus* and oysters. The irregular topography of the infralittoral zone of a rocky reef is also a favored habitat for many sessile organisms and endobenthos. The feces and pseudofeces are also ingested by these organisms both directly and indirectly; this is indeed a food chain that begins with fecal material (Process b in Fig. 1).

The perpendicular walls of quays and breakwaters also serve as a habitat for sessile organisms. However, the feces and pseudofeces precipitate to the seabed because of their simplified configuration as well as calmed wave and water depth. Further, harbors exhibit a high concentration of suspended organic material, as shown in Table 2, which eventually increases the amounts of feces and pseudofeces. As a matter of course, this leads to sludgy polluted sediment and reduction of water depth (Process a in Fig. 1).

HARBORS AND SEAWEEDS BEDS

S seaweeds beds comprising seaweed and sea grass play an important role in improving the water environment in various ways: by generating oxygen, absorbing nutrients such as nitrogen and phosphorus, and by trapping floating suspended matter. Detritus formed by the microbial decomposition of dead seaweeds is eaten by benthos. Typical benthic animals living in eelgrass beds are polychaetes, bivalves and *Temnopleurus* while gulfweed beds support shellfish

such as abalone and *Turbo*, Echinoidea such as *Pseudocentrotus* and *Anthocidaris*, and Eucarida and crabs. Hydrozoa, Porifera, Bryozoa, and starfish are frequently observed in seaweeds beds. These periphyton and benthos are also prey for fish, so various types of fish are attracted to weeds beds. The types of fish that gather at seaweeds beds are very important for fishery.

As is clear from the above, seaweeds beds are an important ecosystem, both from the viewpoint of marine life form and also with regard to human activity. Harbors, however, are a particularly unfavorable environment for the development of seaweeds beds. The main reasons for this are outlined below.

Firstly, harbor waters contain high concentrations of suspended matter. Since seaweed is a photosynthesizing life form, the reduced transparency of the water has a negative effect to its physiology, ecology, and reproduction. In particular, when turbidity results mainly from organic suspended matter, the COD rises, hydrogen sulfide is generated, and the growth of seaweed is inhibited.

Secondly, wave action is reduced by breakwaters. That is, water in harbor is stagnant. A flow of water is important to seaweed for a number of reasons: it washes out metabolic waste, promotes the adhesion of suspended matter to plant bodies, prevents precipitation of particulate organic matter onto seabed, and disperses spores.

Thirdly, the quality of bottom is important. There is a significant relationship between bottom and type of seaweeds. *Ulva*, which is a green alga, and eelgrass, which is a sea grass, can form vegetation on sandy mud, whereas kelp and gulfweed, which are brown algae, grow only on boulders or rocky seabeds. Muddy sediment, as often found on harbor floor, is unsuitable for the growth of algae other than *ulva* and eelgrass.

Lastly, the quality of water is an important factor. As mentioned above, feces and pseudofeces from sessile organisms that inhabit rocky reefs have a major effect on the water. Another factor is effluent from sewage treatment plants, including domestic wastewater. Domestic wastewater contains the nutrients needed by algae, such as nitrogen and phosphorus, but also contains other growth inhibitors such as amines, residual chlorine, detergent, and COD factors. If such chemicals flow in harbor water, they tend to remain there because of the closed aquatic environment.

HARBOR ENVIRONMENT

The Ministry of Transport has been making great efforts to create the environment in harbors so that many kinds of marine organisms may co-exist. To be more specific, the efforts have included the creation of artificial seaweeds beds on breakwaters and seawalls, construction of artificial beaches and tidal flat to provide the places favorable for wildlife, removal of bottom sludge and purification of water and bottom substrate using covering sand, water conveyance, gravel friction, living filters and so on. The key issue is the deterioration of the sediment, as mentioned in the earlier discussions. Since polluted sediment degrades the water quality, and the water is purified through the process of the sedimentation of suspended materials. The relationship between sludge and the upper water layers is very complicated.

It is clear that there is a trade-off between maintaining the functionality of a harbor and improving the quality of water and sediment. The greatest problem faced in maintaining functionality is the dredging of sediment sludge and its disposal. Since it is illegal to dump dredged sludge in the open ocean, the only possible disposal method for such polluted waste is as landfill for reclamation. Landfill, however, lead to destruction of ecosystem; if a beach is reclaimed, the work is generally followed by construction of a concrete quay, which then serves as a habitat for sessile organisms. These organisms are a major cause of sediment pollution, so a vicious circle is set up. To make matters worse, dredged sediment poses a number of serious challenges, such as how to dehydrate and dispose of it in large quantities, how to dredge the sludge without increasing its water content, how to minimize the use of chemicals in the treatment process, and how to reduce the cost of handling.

REMEDIATION OF POLLUTED SEDIMENT — CREATION OF ARTIFICIAL TIDAL FLAT

If polluted colloidal sediment is disposed of in its "raw" state without any pretreatment, one of the few options available is to use it as the bed for artificial tidal flat. Generally speaking, tidal flat receives an abundance of oxygen, nutrients, and sunlight because it is alternately submerged and exposed as the tide rises and falls. The detritus food chain in which benthons play a major role offers excellent remediating performance. However, if polluted colloidal sediment is used



Photo 3 Experiment with zeolite (container filled with soft, black muddy soil simulating tidal flat)

to make artificial tidal flats, there is a risk that they will wash away at high tides because sediment is enriched with silt and clay. Benthos cannot make borrows in this type of bottom owing to deficiency in plasticity. Further, if the reduction of the bottom sediment exceeds the oxidation in ebbtide, the benthons are unable to survive due to lack of oxygen. Another fear is elution of highly concentrated inorganic nutrients and organic substances from polluted sediment at high tides, leading eventually to eutrophication or organic pollution of the upper water layers. For these reasons, finding a method of improving the "raw" sediment is a very important research subject.

The authors once studied the possibility of whether benthons can survive in sediment that had been covered with zeolite, a finely granulated tuff consisting mainly of mordenite. To test the idea, a square pot with no bottom was buried in natural tidal flat. The soil was removed from the pot and replaced by softened and blackened polluted sediment sludge to a depth of 30 cm. The sediment was covered with zeolite to a thickness of 10 cm (Photo 3). A referential pot without the zeolite, was also set up. A comparison of the benthic communities showed that the benthons in the covered sample was similar to that in natural tidal flat, while none were present in the referential pot.

If sea sand were to be used in place of the zeolite, the sand particles sink into the soft mud because of their greater specific gravity. Zeolite, on the other hand, features a smaller specific gravity and good porosity. It provides cover over the mud for a long time. Further, since zeolite absorbs cations such as ammonia, it effectively prevents eutrophication of the upper water. These findings, however, were obtained only from a small-scale field experiment. A full evaluation will certainly require a larger-scale experiment.

CREATION OF "ECOPORT"

If the approach proposed above is shown to be suitable for turning polluted sediment sludge as dredged from harbors into artificial tidal flat, it might offer an effective contribution to the Ecoport Model Project initiated by the Ministry of Transport of Japan. However, a realization of this approach would require preparation of sufficient open space beforehand in or adjacent to the harbor for use as artificial tidal flat. It is an important measure to secure such an area for an artificial tidal flat in the harbor area if environmentally friendly ports and harbors are to be developed.

The concept of "self-treatment" — that is, handling the deleterious products of a harbor within its boundaries without the danger of them spreading — while maintaining full harbor functionality opens up the real possibility of an "Ecoport" in which the manmade and natural ecosystem can co-exist. This harmony will be illustrated by migratory birds, which will be attracted from afar to the artificial tidal flats and the benthons they support. The realization of this concept will truly be a manifestation of the mutual interests between harbors and marine life forms.