AGO BAY

Toward a New Sato-Umi

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Shima City

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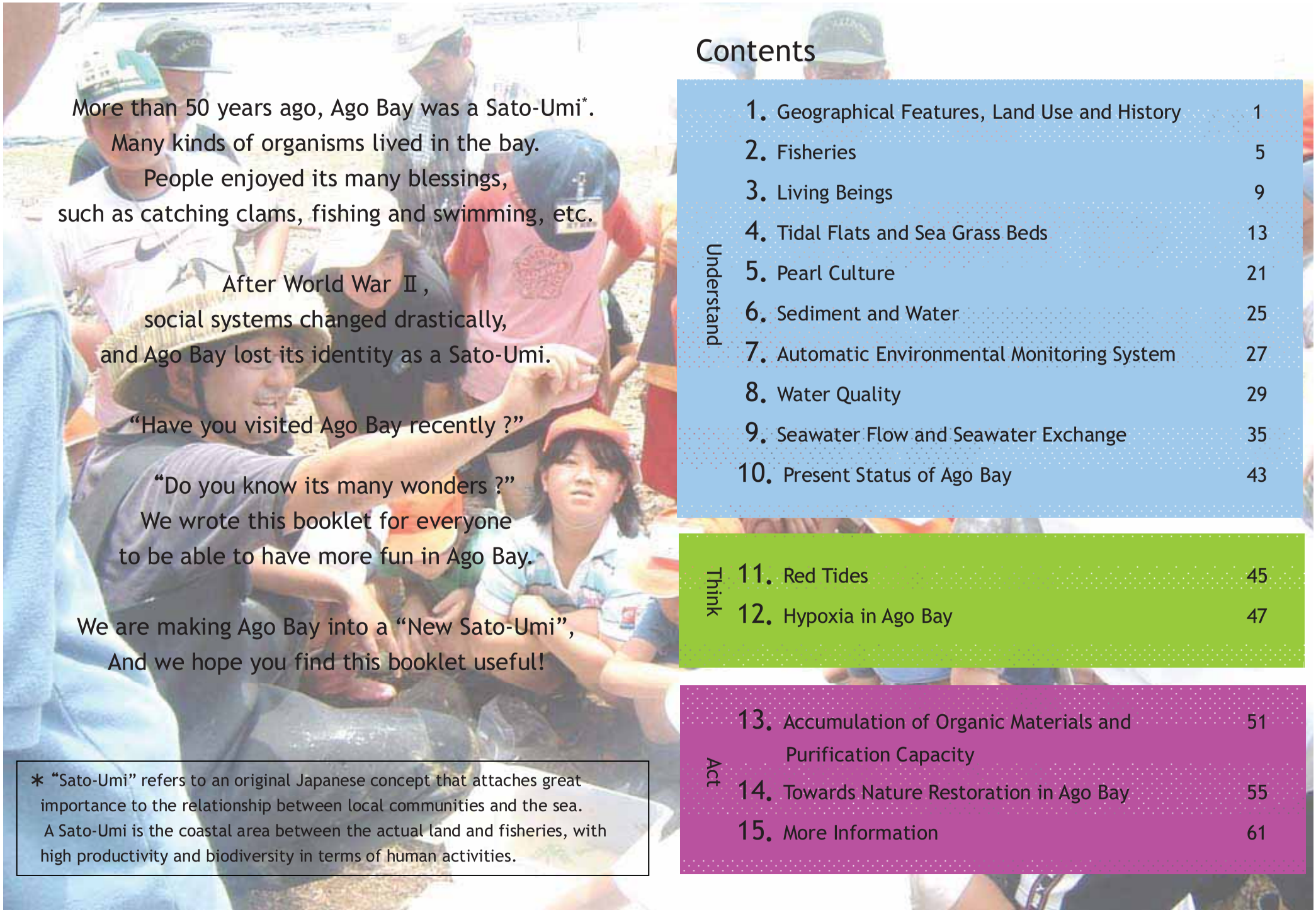


More than 50 years ago, Ago Bay was a Sato-Umi*.
Many kinds of organisms lived in the bay.
People enjoyed its many blessings,
such as catching clams, fishing and swimming, etc.

After World War Ⅱ,
social systems changed drastically,
and Ago Bay lost its identity as a Sato-Umi.

"Have you visited Ago Bay recently ?"

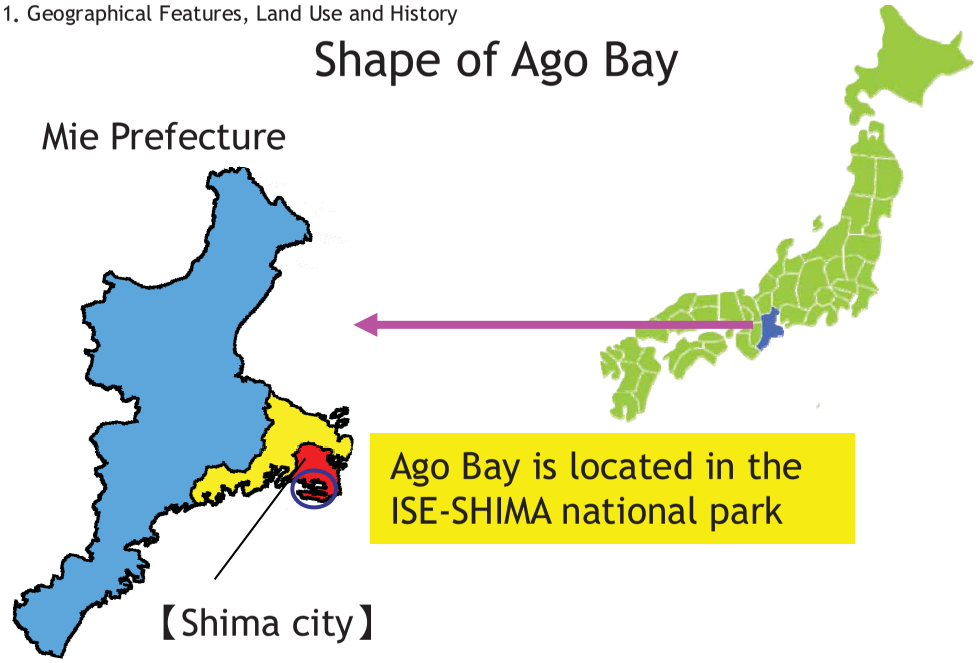
"Do you know its many wonders ?"
We wrote this booklet for everyone
to be able to have more fun in Ago Bay.

We are making Ago Bay into a "New Sato-Umi",
And we hope you find this booklet useful!

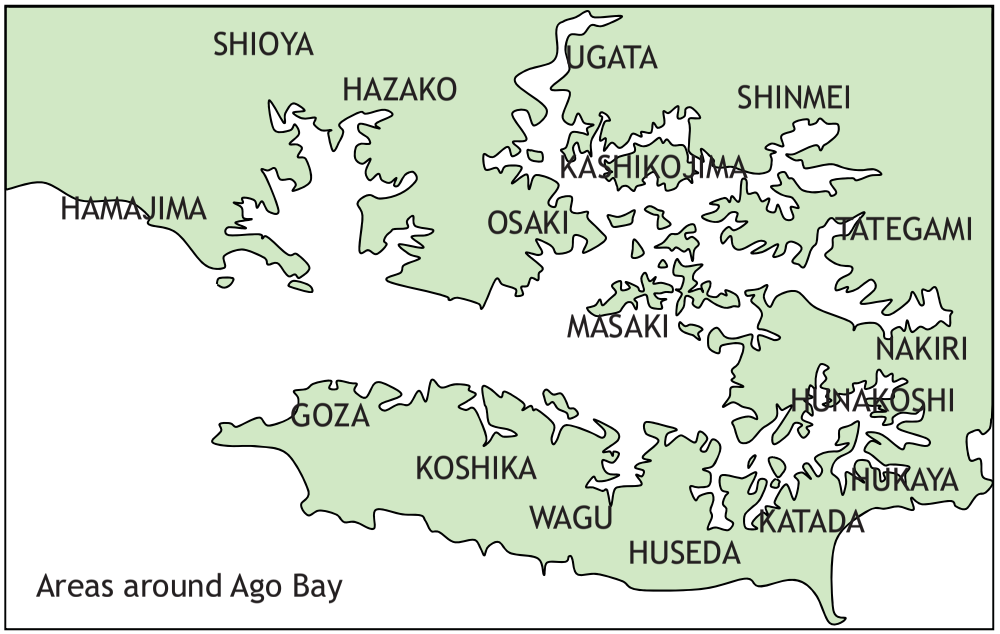
* "Sato-Umi" refers to an original Japanese concept that attaches great importance to the relationship between local communities and the sea. A Sato-Umi is the coastal area between the actual land and fisheries, with high productivity and biodiversity in terms of human activities.

Contents

Shape of Ago Bay



In Oct. 2008, Shima City was formed with the merger of 5 towns (Ago-cho, Isobe-cho, Shima-cho, Daio-cho and Hamajima-cho)



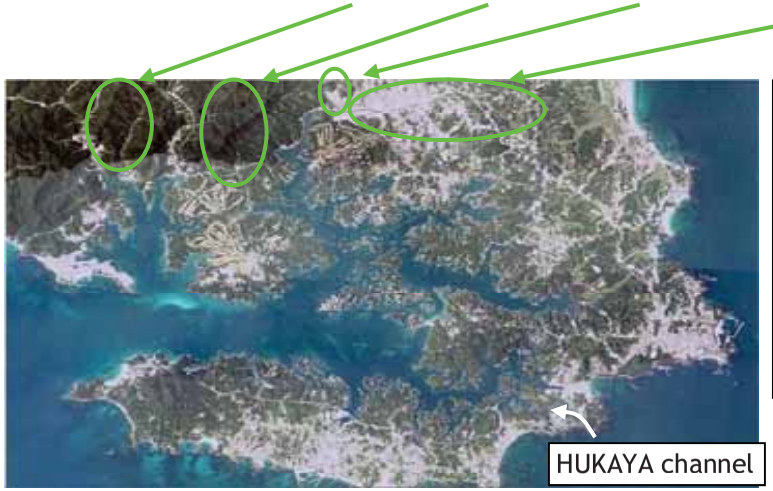
1. Geographical Features, Land Use and History

【Complex Coastlines】

Ago Bay has an intricate coastline, known as a ria-type coast.

【No Long Rivers】

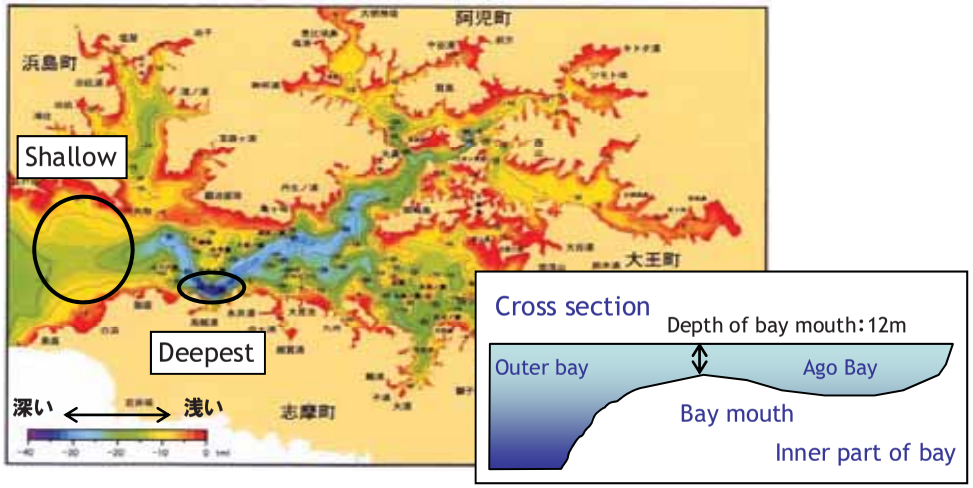
Principal rivers are the HIYAMAJI, HAZAKO, NISHIKAWA and MAEGAWA.



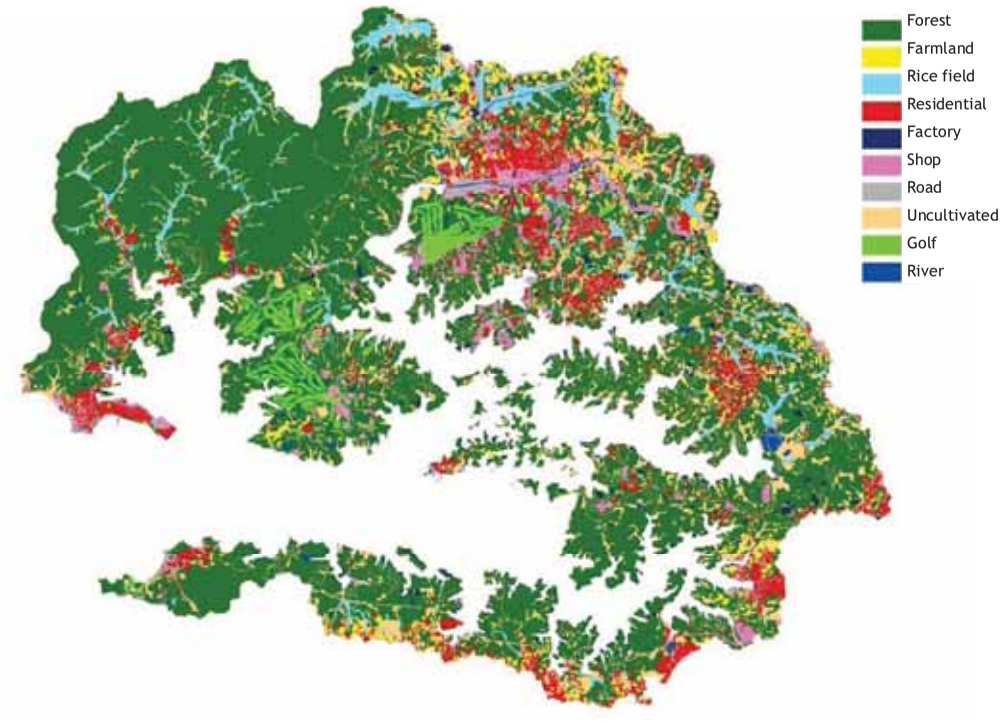
Area:26 km^2
Coast:140 km
Depth
Max:40m
Bay mouth:12m
Width of bay mouth:1.7 km

【Shallow Waters】

The inner part of the bay is about 5m, with a maximum of about 40m and a bay mouth depth of 12m. Because the bay mouth is shaped like a bottle neck, water exchange is not simple.



Land Use Around Ago Bay



【Surrounding Forests】

More than 50% of the land is forest. 19.4% of the land is made up of building lots, factories and roads.

Because there is little flat land available around Ago Bay, rice fields and farms are not very large. The surrounding forests allow rain to flow right into the bay.

History of Ago Bay and Pearl Culture

Ago Bay is very famous for pearl culture. Because of its harmony between nature and pearl culture, Ago Bay was designated as the first National Park after World War Ⅱ.

【History of Ago Bay】

The Edo era [Beginning of land reclamation]

1668～1704 Rice fields were constructed by land reclamation.

The Meiji era [Beginning of pearl culture]

1893 Kokichi Mikimoto produced a semi-circular pearl.

The Taisho era [Spread of pearl culture]

1923 Mie Prefectural Fisheries Research Institute started seed collections of pearl oysters.

The Early Showa era [Reduction of pearl culture]

1932 The Fukaya channel was constructed in Ago Bay.
1942～1945 Reduction of pearl culture due to WWⅡ.

The Middle Showa era [Development of pearl culture and setbacks]

1946 Ago Bay was designated the first Japanese National Park.
1950～ Rapid development of pearl culture.
1959 Heavy damage from typhoon “Isewan”.
1960 Heavy damage from a tsunami from Chile.

The latter Showa era [Decline of pearl culture and development of tourism]

1966～ Drop in pearl culture from low quality and overproduction.
1976 Pearl oyster seed production was developed.
1988～ Development of leisure facilities was promoted.

Aquaculture in Ago Bay

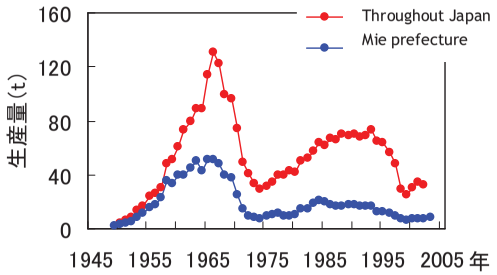
【Pearl Culture】

Ago Bay is very famous for being the cradle of pearl culture.

In 1893, Kokichi Mikimoto succeeded in producing a semi-circular pearl for the first time in the world. After this success pearl culture prospered in Ago Bay.

Fishermen work hard to produce high quality pearls.

Pearl production in Mie prefecture always ranks high in Japan.

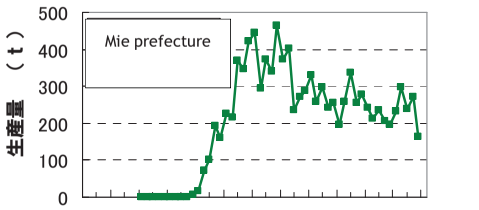


Changes in pearl production.

【Cultivation of Green Laver】

In Ago Bay, green laver culture is booming. From autumn to spring, laver nets are placed along the coast, and are a typical sight all over the Bay. Harvested green laver is sold after drying. Mie prefecture holds about a 60% share of the green laver in Japan, with Ago Bay contributing about 50% of Mie's product.

Green laver absorbs CO_2 and nutrients in sea water, and also produces oxygen by photosynthesis, thus proving to be very useful to the environment.



Changes in green laver production.

Coastal Fisheries in Ago Bay

There are various kinds of coastal fisheries in Ago Bay.

【Sea Cucumber】

Sea cucumbers inhabit the sea bottom. Fishermen catch them with a net and hook from their boats. Fisheries of sea cucumber are very famous around the HAMAJIMA region, and are called “HISHI-TSUKI-RYO”.

Sea cucumber

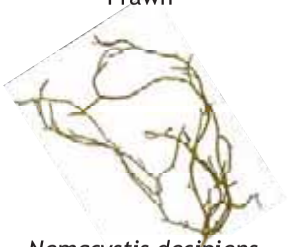
【Prawn】

Prawns crawl about the sandy sea bottom. Fishermen catch them with grill nets. The seeds of prawns are produced at the Fish Farm Center, and then these seeds are released into the sea.

Prawn

【*Nemacystis Decipiens* and *Codium Mucronatum*】

Nemacystis decipiens can be gathered in March and April. *Codium mucronatum* is collected in summer with a net. *Nemacystis decipiens* can be eaten with vinegar, and *Codium mucronatum* is eaten dipped in miso and vinegar sauce after boiling.



Nemacystis decipiens

Codium mucronatum

【Swimming Crab】

Swimming crabs can be gathered by grill nets or cages in early summer. Their claws are so strong they can cut through a twig. Swimming crabs can be eaten after boiling.

Swimming crab

Picture: Faculty of bioresources, Mie University, Department of Fisheries, Mie Prefecture

【Clam】

Clams were gathered everywhere in Ago Bay until 1990. However, now there are very few. It is thought that environmental changes and harmful red tides are the main reasons why clams have disappeared.

Clam

【Other Fisheries】

Japanese black porgies and sting rays can be caught by grill nets. Around the bay mouth, *Sargassum fusiforme* and *Gelidiaceae* can be found.

Gelidiaceae

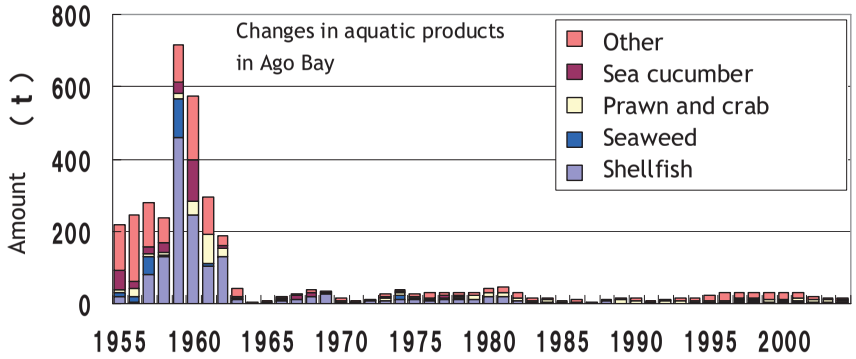
Japanese black porgy

Sting ray

Sargassum fusiforme

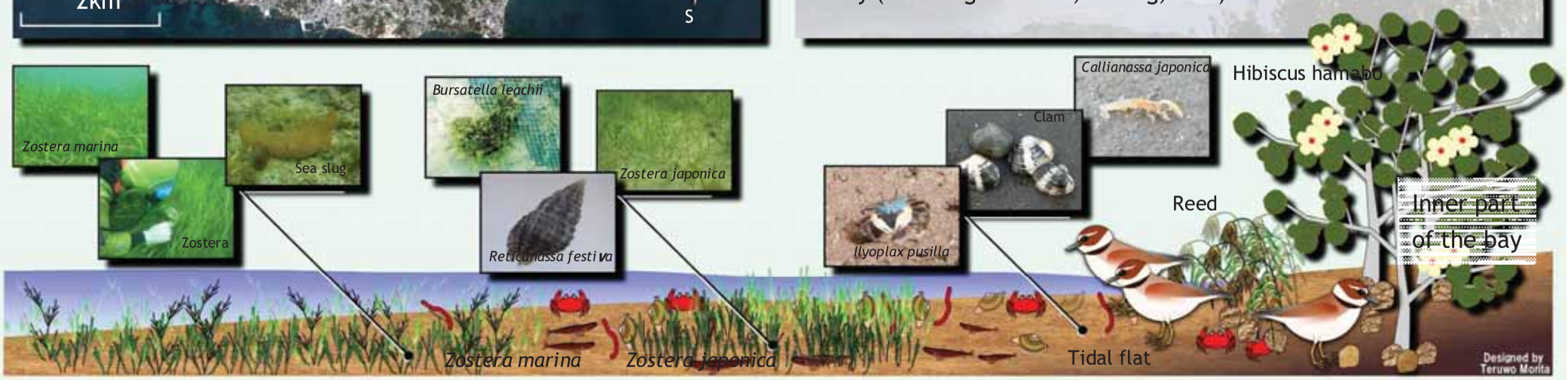
【Changes of Catchment in Ago Bay】

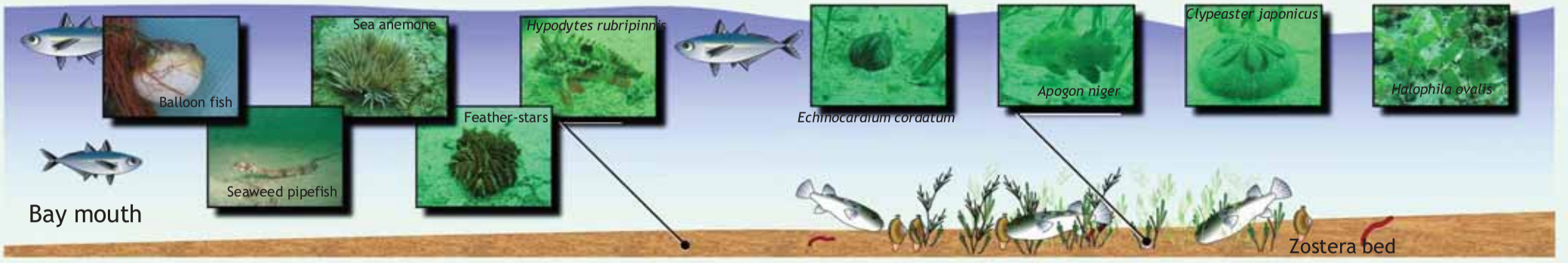
Until 1960, more than 600t of aquatic products (shellfish, sea cucumbers, prawns and seaweed) were caught in Ago Bay. However, since 1965, this amount has decreased dramatically.



Living Beings in Ago Bay

Hibiscus hamabo communities are seen along the coast in Ago Bay. More than 50 years ago, there were a continuous natural coastal ecotones (reeds→tidal flats→seagrass beds). There should be a lot of biodiversity in these areas. However, nature around Ago Bay has being lost because of development, leaving just a few kinds of living things in the coastal area. In order to restore the bay to a “Sato-umi”, we have to understand the environmental situation. If living beings increase, we will be able to enjoy the many blessings of Ago Bay (catching shellfish, fishing, etc.).





Name: *Hypodytes rubripinnis*
Photo location: Hamajima
Depth:12m

About 10cm long. *Hypodytes rubripinnis* has strong poison on the dorsal fin. This fish is nocturnal, and lives in Zostera beds.

Halophila ovalis
Tategami
5m

Halophila ovalis grows in shallow areas. The leaves are oval and 1-3cm long.

Zostera japonica
Tategami
1m

Zostera japonica grows in inter tidal areas from Hokkaido to Okinawa. The leaves are about 3mm wide, and 20cm long.

A diver
Tategami
2m

To investigate a Zostera bed, divers must wear an oxygen tank in Ago Bay.

Clypeaster japonicus
Hamajima
12m

About 10cm long. *Clypeaster japonicus* has a petal-like pattern on its body. Although it doesn't have needles, it belongs to the sea urchin family.

Zostera marina
Tategami
2m

Zostera marina grows in shallow areas. The leaves are 0.5-1.5m long and taste sweet. More than 50 years ago, *Zostera marina* was used as fertilizer for farming.

Reticunassa festiva
Tategami
1m

About 3cm long. *Reticunassa festiva* lives on the surface of tidal flats. It eats dead fish and shellfish.

Callianassa japonica
Tategami
2m

About 5cm long. *Callianassa japonica* digs a nest about 1m deep into the tidal flats.

Seaweed pipefish
Hamajima
12m

About 20cm long. Seaweed pipefish live in calm zostera beds. They coil around *Zostera marina*.

Apogon niger
Hamajima
10m

About 10cm long. *Apogon niger* has big eyes. It comes to the Zostera beds for spawning.

Bursatella leachii
Tategami
1m

About 5-10cm long. *Bursatella leachii* has a green-brown body with many spines.

Shortneck clam
Tategami
0m

About 3-5cm long. Shortneck clams live in tidal flats. They can be eaten in miso soup and spaghetti. Nowadays they cannot be gathered in Ago Bay.

Sebastes inermis
Hamajima
12m

About 20cm long. *Sebastes inermis* has big eyes. They live in Zostera beds. Sometimes they swim hovering around the Zostera beds.

Echinocardium cordatum
Hamajima
10m

About 10-15cm long. *Echinocardium cordatum* belongs to the sea urchin family. It moves quickly by using its spines. It lives on the sandy bottom.

Atylus swammerdami
Tategami
1m

About 2-5mm long. *Atylus swammerdami* lives in the Zostera beds. It eats detritus, and plays an important role as food for many animals.

Ilyoplax pusilla
Tategami
0m

About 1cm long. *Ilyoplax pusilla* lives in tidal flats. It dances while moving its claws.

Bay mouth — Inner part of the bay

Tidal Flats

Estuary tidal flat at ANO river, MIE pref.

Tidal flats are coastal wetlands where mud is deposited by tides or rivers. They are submerged and exposed approximately twice daily. Tidal flats are typically important regions for wildlife, supporting a large population, although the level of biodiversity is not particularly high. They are often of particular importance to migratory birds. Thus they are called “nursery grounds”. Tidal flats are good fishing grounds for shellfish.

Because tidal flats are on the boundary between land and sea, they are very important areas for recreation and shellfish gathering.

4. Tidal Flats and Sea Grass Beds

Function of Tidal Flats

【Function of Habitats】

There are many living beings in tidal flats such as crabs, shellfish and polychaeta. Many juvenile fish live there, too, and migratory birds use tidal flats as feeding and resting grounds.

【Function of Natural Purification】

In tidal flats, bacteria decompose organisms from the land and clams eat plankton by filtering sea water. Birds and fish feed the macrobenthos and control the populations. That’s how sea water becomes clean. Thus all living beings contribute towards natural purification.

Tidal Flats in Ago Bay

Tidal flats in Ago Bay are classified as follows.

【Existant tidal flat】

Estuary tidal flats（sand-mud）

Formed at the mouth of a river.

They have high biodiversity because of a sufficient supply of nutrients from land.

ex. Ugatahama, Hazako, Hiyamaji

Foreshore tidal flats（sand）

Formed in a small bay without rivers.

They have low biodiversity because of insufficient nutrient supply.

ex. Inner part of the bay

【Reclaimed area】

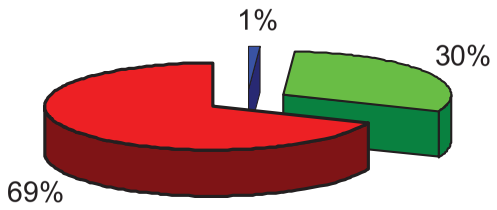
Reclaimed areas（mud）

More than 50 years ago, these areas were natural tidal flats. Now they have become unused wetlands.

They have low biodiversity because of environmental deterioration.

ex. Inner part of the bay (behind dykes)

Historical Changes in Tidal Flats



【Existant Tidal Flat】

Estuary tidal flats 3ha

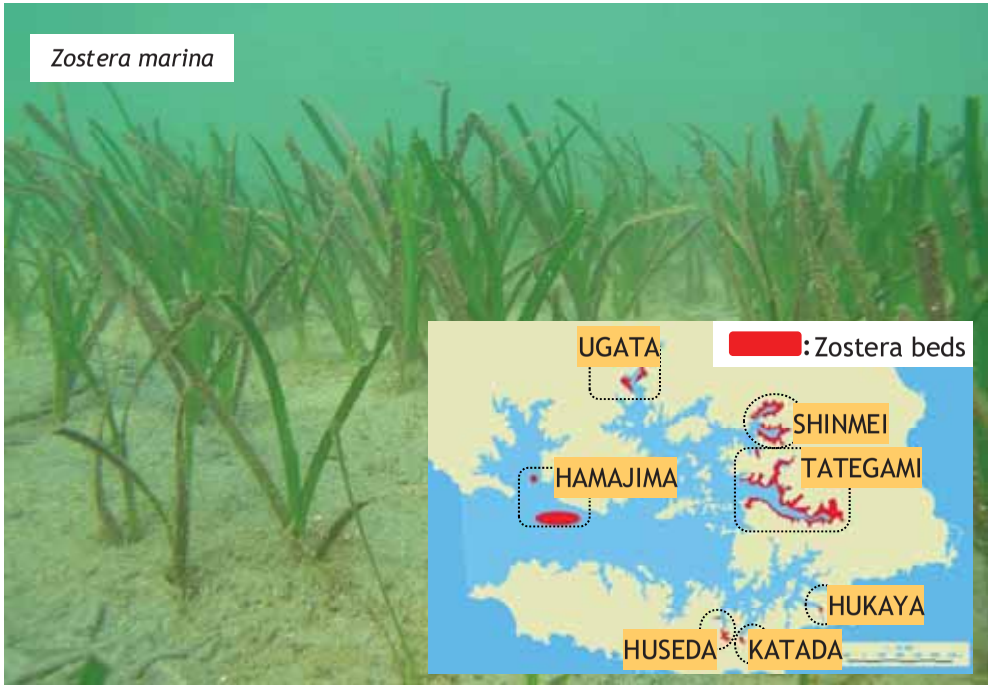
Foreshore tidal flats 81ha

【Reclaimed Area】

Reclaimed areas 185ha

More than 50 years ago, there were about 269ha of tidal flats in Ago Bay. That's about 10% of the sea surface area. However the tidal flats were reduced to construct rice fields. And even worse, the natural purification ability and biodiversity also decreased. Now, more than 80% of reclaimed areas have become unused wetlands. If these areas are restored to tidal flats again, the natural purification ability and biodiversity may increase in Ago Bay.

Zostera Beds

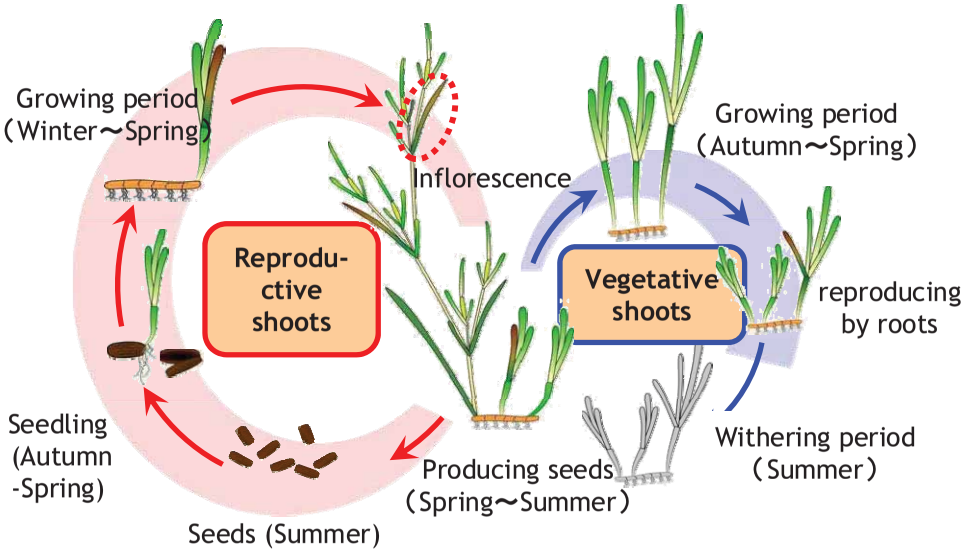


Zostera marina are more widely known as “seagrass”. They produce seeds by flowering, which is different from seaweed. They live on sand and mud coasts everywhere in Japan. They grow about 1.5m high from autumn to spring. In summer, their roots wither and they float to the surface.

The areas where the zostera grow are called “zostera beds”.

In Hamajima and Hukaya, they grow in sand, but in Ugata, Shinmei, Tategami and Huseda, they grow in mud.

Life Cycles of *Zostera marina*

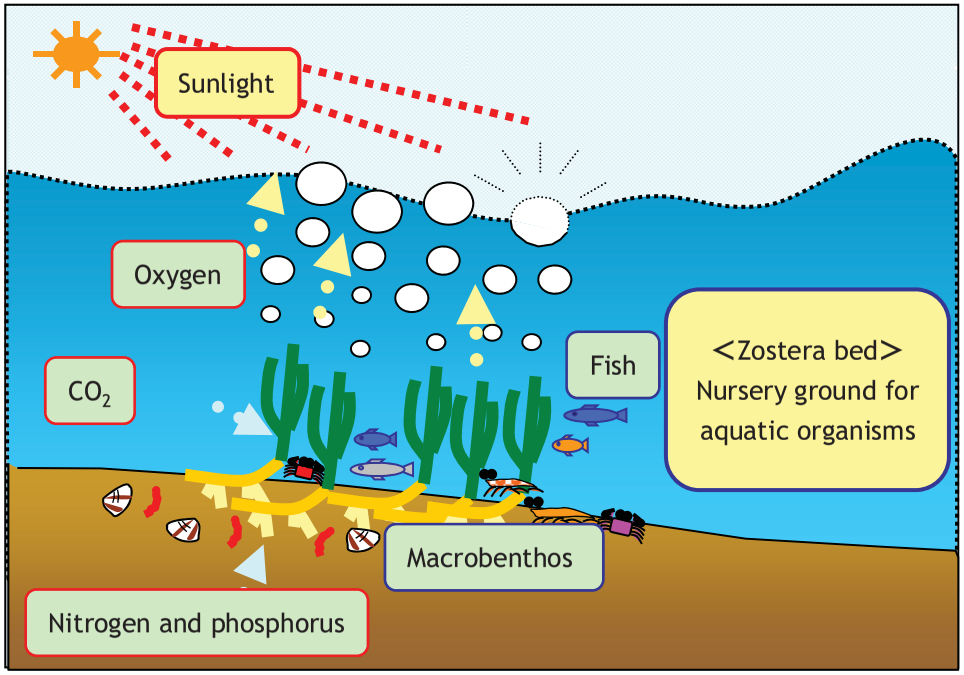


Zostera marina have two reproduction types, sexual and vegetative. Almost all *Zostera marina* are vegetative.

The vegetative type grows by spreading its roots from autumn to spring and enlarging its leaves. In summer, its leaves wither and shorten. After that it grows again by producing leaves from the remaining roots.

Some vegetative types change to sexual types. In spring, they produce seeds by inflorescence. In summer, their leaves and roots wither. The seeds drop to the sea bottom and sprout due to the low water temperature in autumn.

Function of Tidal Flats

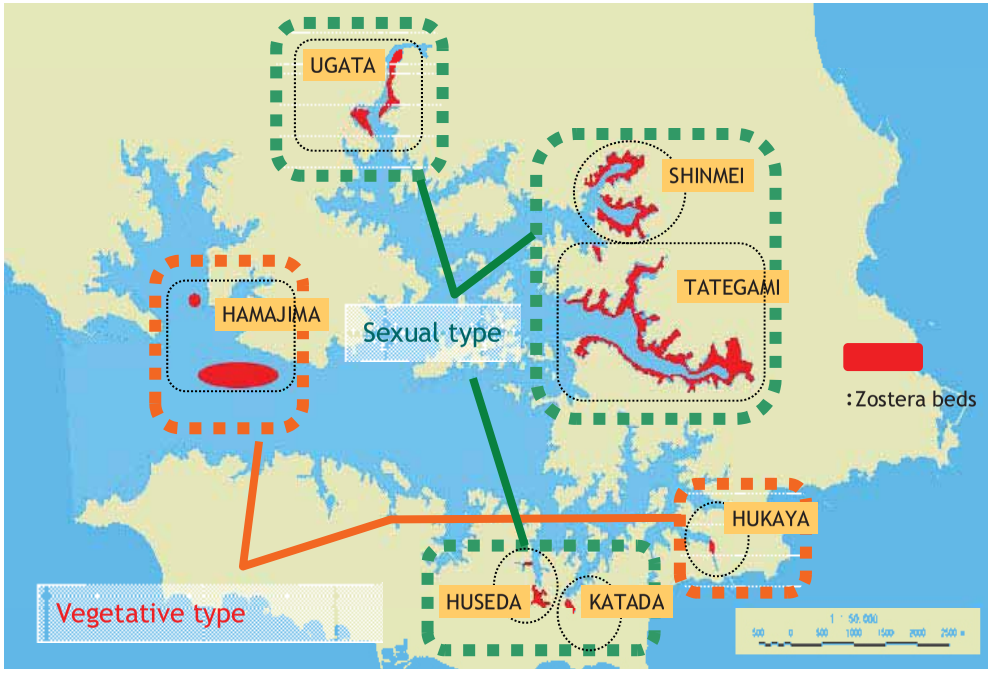


In Zostera beds, the waves and water currents are reduced by zostera marina. Because there are many hiding places, Zostera beds are perfect as nursery grounds for aquatic organisms (fish, shellfish, shrimp and crabs). Therefore, they are called the “cradle of the sea”.

Zostera marina absorb CO_2 and nutrients in seawater and produce oxygen by using sunlight. Therefore Zostera beds are ideal for aquatic organisms. The amount and diversity of aquatic organisms in Zostera beds are more than 10 times larger than those areas without. Zostera beds are very important places to protect biodiversity.

4. Tidal Flats and Sea Grass Beds

Zostera Beds in Ago Bay



The Zostera marina in Hamajima and Hukaya are vegetative types. Other areas have the sexual type. These are rare and only grow in certain areas of Japan.

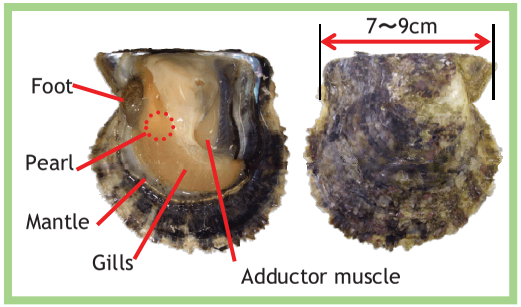
【*Zostera japonica*】

Zostera japonica belong to the *Zostera marina* family but grow in shallower water. They are smaller and more difficult to displace because of their strong roots. They grow in Ago Bay.

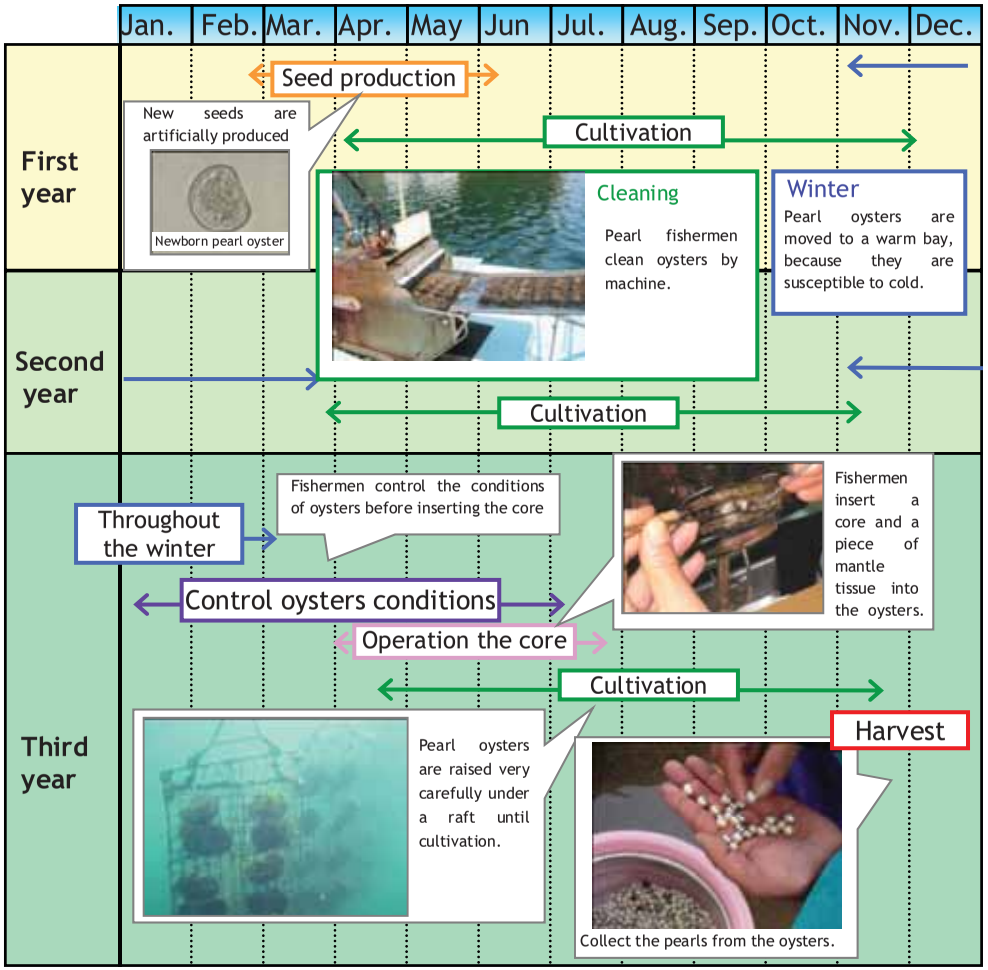

Zostera japonica

Pearl Culture in Ago Bay

Pearl oysters are used for pearl culture. They grow about 3-5cm long for the first year, and 7-9cm after 3 years. That's when they are used to make pearls.



【Production Process of Pearl Culture】

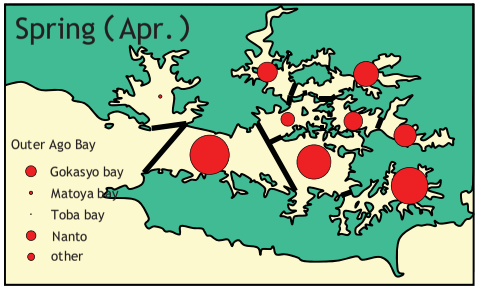


Cultivation Cycle in Ago Bay

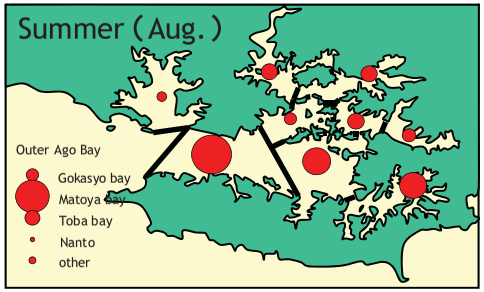
Fishermen move the pearl oysters to areas which are suitable for each season.

● indicates the number of pearl oysters

In spring, fishermen move the oysters from a southern, warm bay to Ago Bay to insert the cores.
(Apr. ～ Jun.: 80 ～100 million)

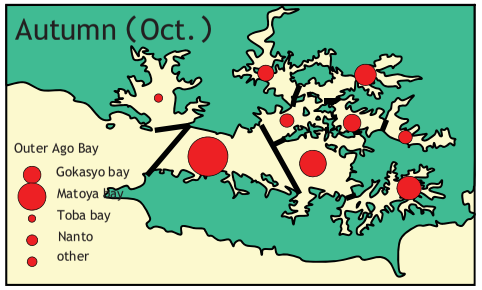


In summer, fishermen move the oysters to the center of the bay or other bays to avoid high water temperatures.
(Jul.～Sep.: 80 ～90 million)

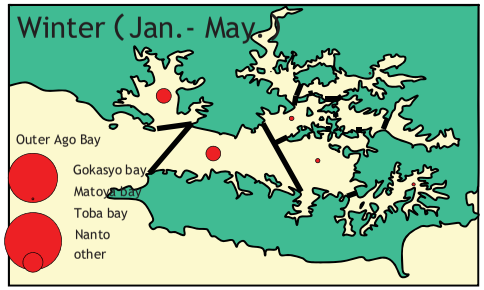


In autumn, the oysters stay where they are for treatment.

(Oct. ～ Nov.: 65 ～80 million)



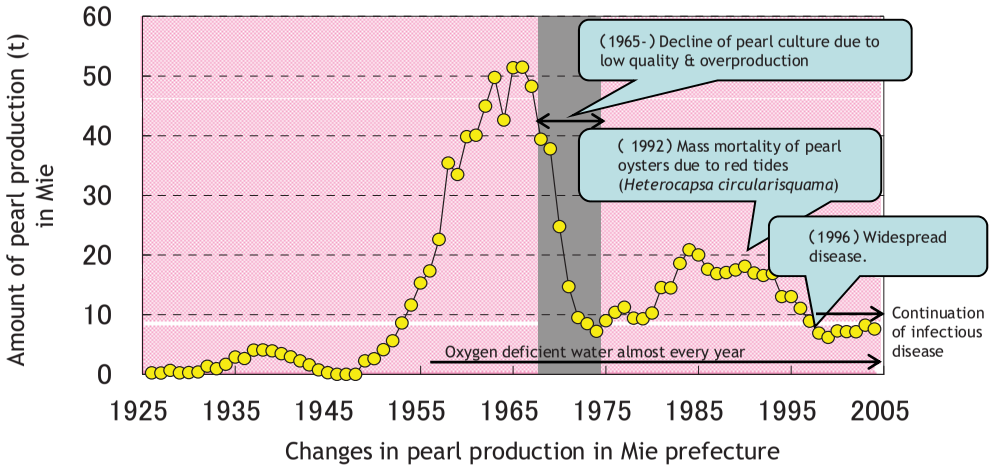
In winter, fishermen collect mature pearls and move the 2-year-old pearl oysters to a southern, warm bay.
(Dec.: 36 million, Jan.～May:6 million)



※Number of oysters in 2003.
()indicates number of oysters in Ago Bay.

Changes in Pearl Production in Ago Bay

The pearl culture is the main industry in Shima city.



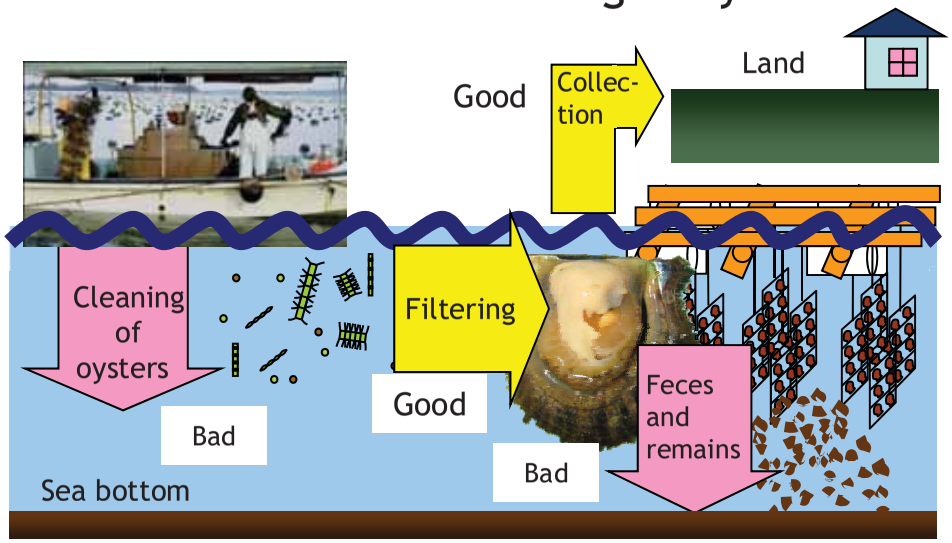
Changes in pearl production in Mie prefecture

After WWⅡ, pearl production increased sharply because of exports to America. However, the environment of Ago Bay deteriorated because of overcultivation. In the inner bay, many pearl oysters died due to an outbreak of hydrogen sulfide.

From 1975～1985, the pearl production increased because of high economic growth and increasing demand from foreign countries. But after the bubble economy collapsed (1994), the demand for pearls stagnated, and pearls suffered mass death from harmful red tides (*Heterocapsa circularisquama*) and infectious disease.

Pearl production is still in a slump, due to the deterioration of the environment and the diversified tastes of customers.

Pearl Culture and Ago Bay



The pearl culture has both good and bad points for the environment.

【Good points】

Pearl oysters eat phytoplankton by filtering seawater, thereby cleaning the seawater in Ago Bay. Not only pearls but the oyster meat can be collected, too.

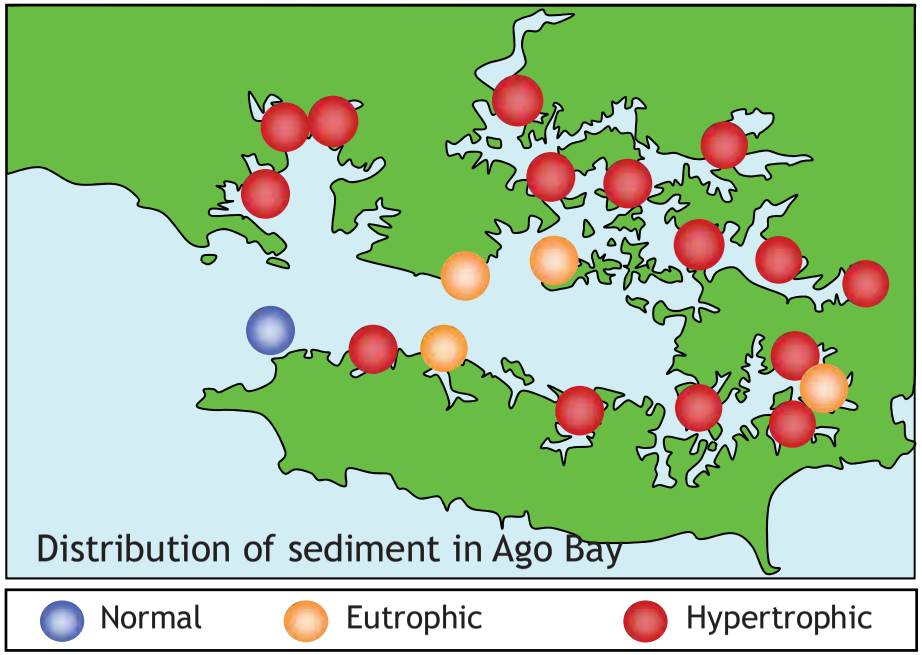
【Bad points】

After filtering the oyster's feces are dropped to the sea bottom. If fishermen cultivate many oysters, large amounts of feces accumulate.

It is necessary to remove the attached organism when producing pearls. If fishermen throw these attached organisms and oyster meat into Ago Bay, the sea bottom becomes dirty. Also when oysters die, their remains accumulate on the bottom.

Fishermen should pick up the waste from cleaning, use oyster meat and prevent oysters from dying.

Sediment and Water Quality in Ago Bay

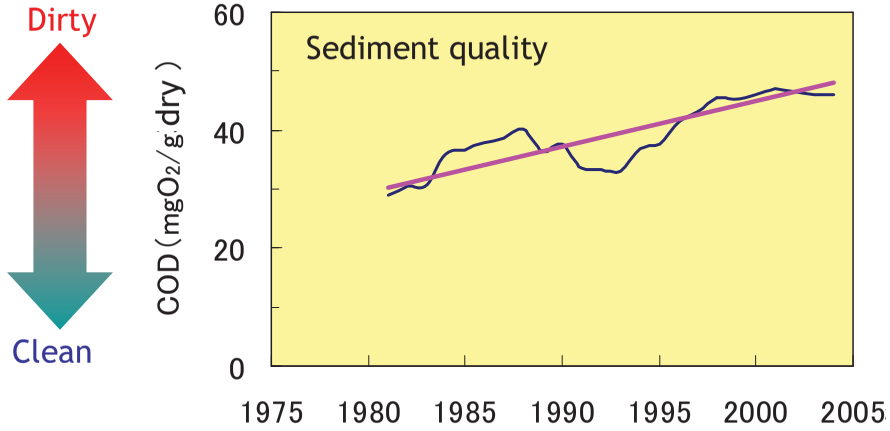


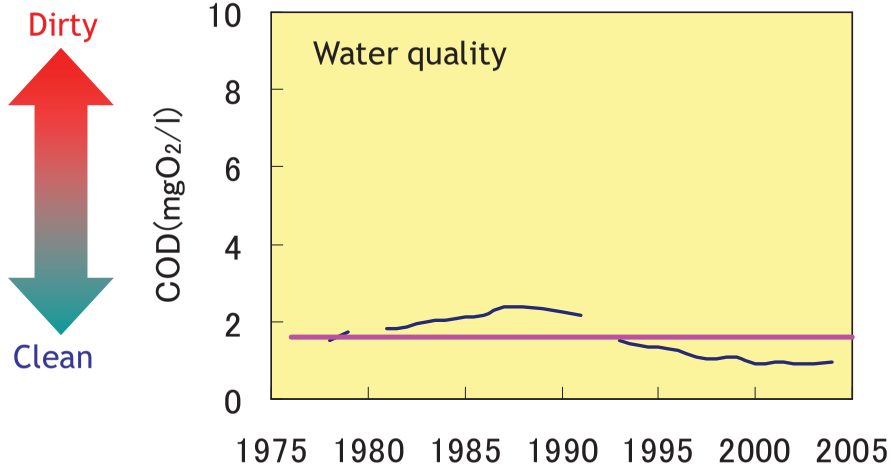
Although Ago Bay looks fine environmentally, large amounts of eutrophic sediment have accumulated on the sea bottom. The sediments can be classified in 3 types (normal, eutrophic, hypertrophic). Most sediments belong to “eutrophic” and “hypertrophic”, with “normal” in the bay mouth only. The sediment at the bay mouth is brown sand. The sediment at the inner part of the bay is black mud.

6. Sediment and Water

The sediment is getting more eutrophic every year due to accumulating organisms. However, the seawater has not changed.

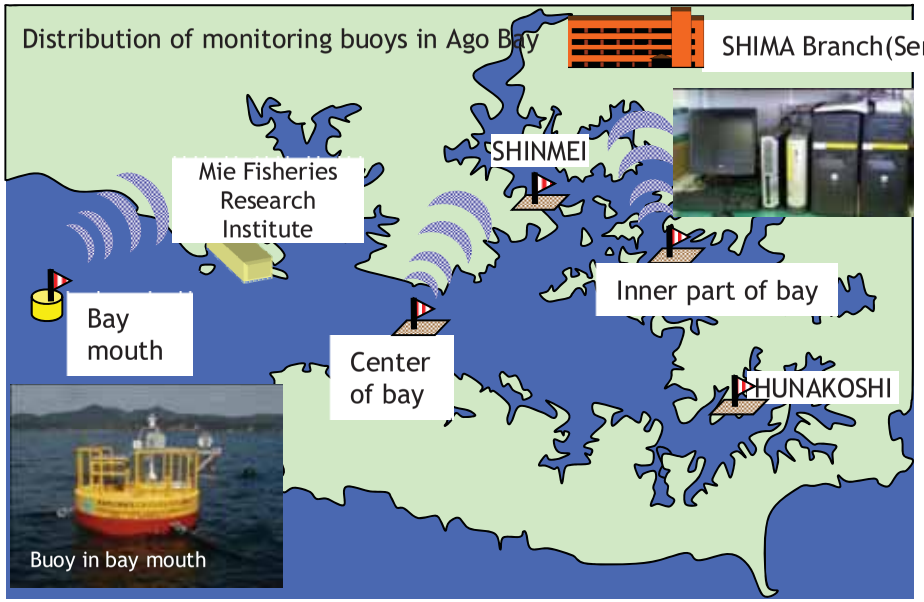
※COD indicates the amount of organisms.





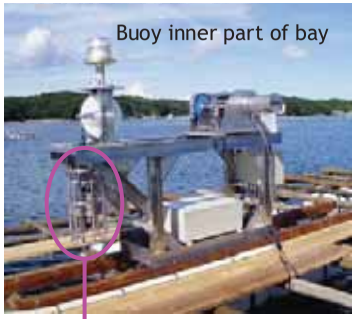
More than 50 years ago, Ago Bay was not eutrophic.
Why did Ago Bay become eutrophic? How Ago Bay become clean? Many researchers are trying to restore the environment in Ago Bay.

Ago Bay Automatic Environmental Monitoring System



It is necessary to know the present status of Ago Bay for environmental restoration. Therefore, the Ago Bay automatic environmental monitoring system was adopted.

This system monitors the water quality automatically every hour. The 5 monitoring buoys can monitor water temperature, salinity, dissolved oxygen, chlorophyll-a, and turbidity. This monitoring system is used not only by researchers but also by pearl fishermen.



Sensor

The results of monitoring can be seen on a PC or cell phone anytime and anywhere.

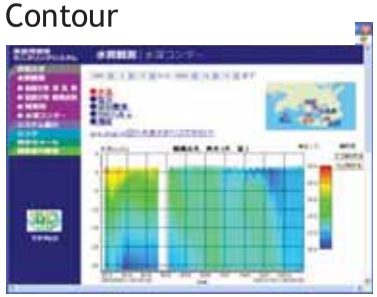
7. Automatic Environmental Monitoring System

【PC】

5 monitoring results

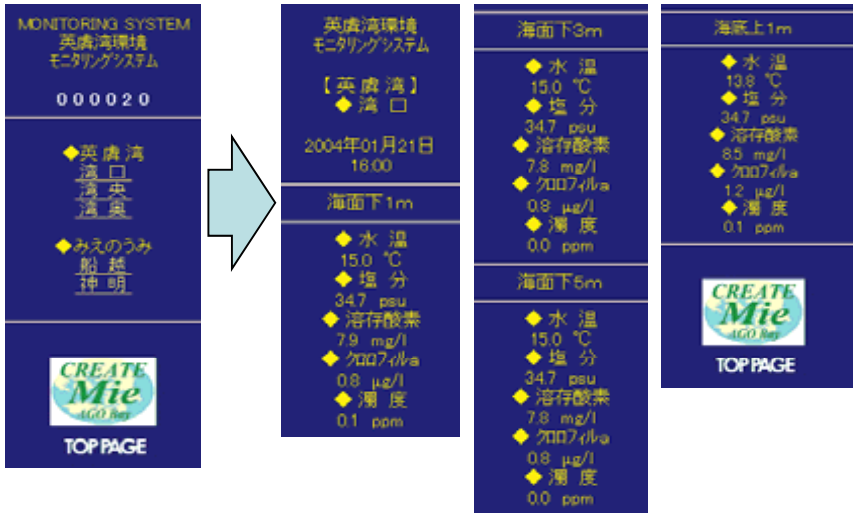
Time series behavior

Contour



The results of monitoring can be seen on the following URL by PC.
(http://www.agobay.jp/agoweb/index.jsp)

【Cell phone】



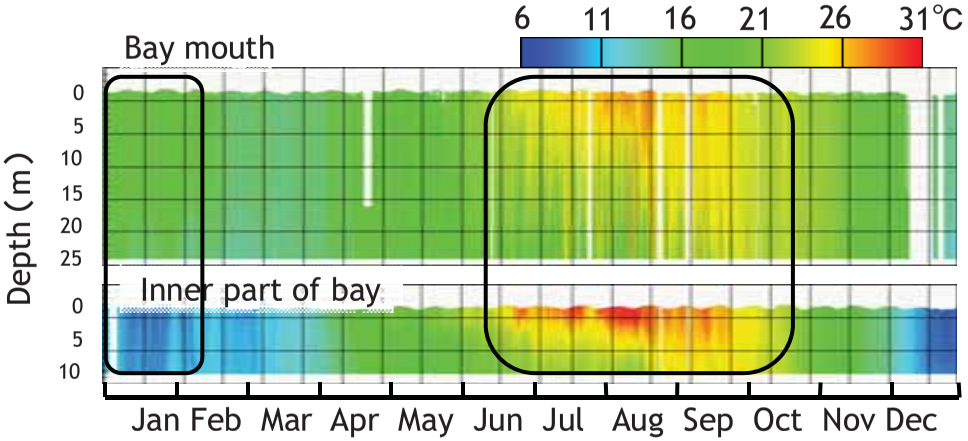
The results of monitoring can be seen on the following URL by cell phone.
(http://www.agobay.jp/agoweb_i/index.jsp)

2-dimensional barcode

Understanding Water Quality in Ago Bay

We can see the present status of water quality by using the monitoring system.

【Water Temperature】 We can monitor the water temperature.
For example, the best temperature for pearl oysters is 13～27℃.
If the water temperature is too high (above 27℃) or too low (below 13℃), the pearl oysters are apt to die.



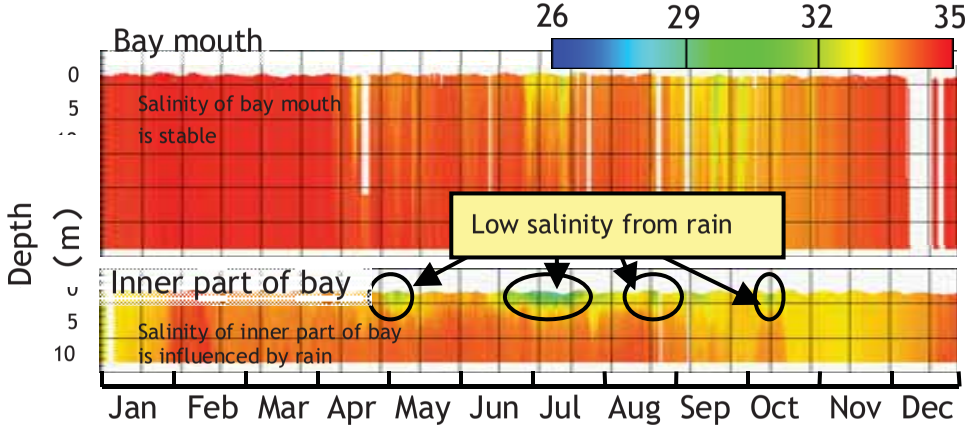
The water temperature in the bay mouth is relatively stable because of the influence of the outer sea. However, water temperature in the inner part of the bay changes significantly because of the influence of air temperature.

【Chlorophyll-a】 We can see the amount of phytoplankton, bait, and observe the occurrence of red tides.

○High Chlorophyll-a → large amount of phytoplankton
○Low Chlorophyll-a → small amount of phytoplankton

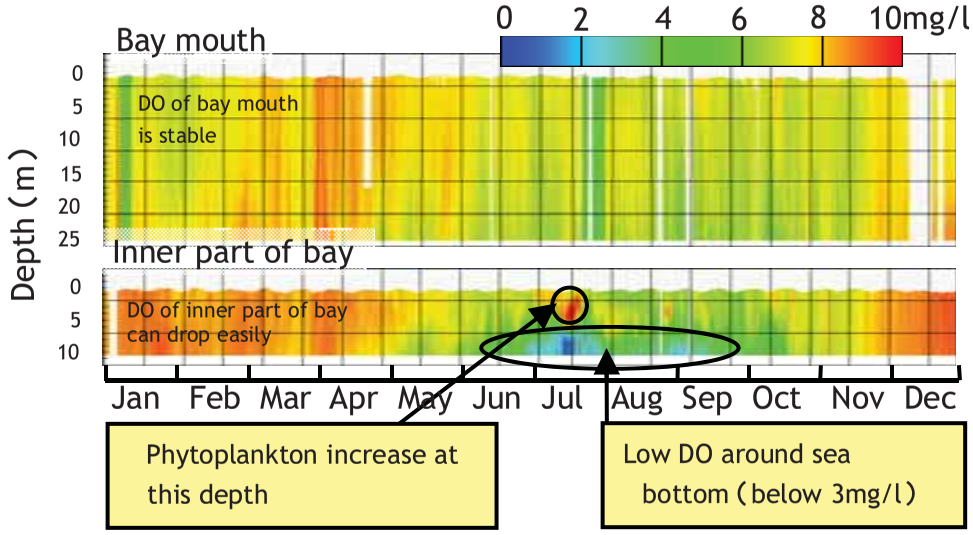
【Salinity】 We can see the effects of rain in Ago Bay.

Generally, the salinity of the bay is 33-35. After heavy rains salinity drops below 30. Although pearl oysters don't die due to low salinity, it is necessary to monitor it, because low salinity (below 25) has a damaging effect on the quality of pearls.



【Dissolved Oxygen】 We can monitor the amount of oxygen.

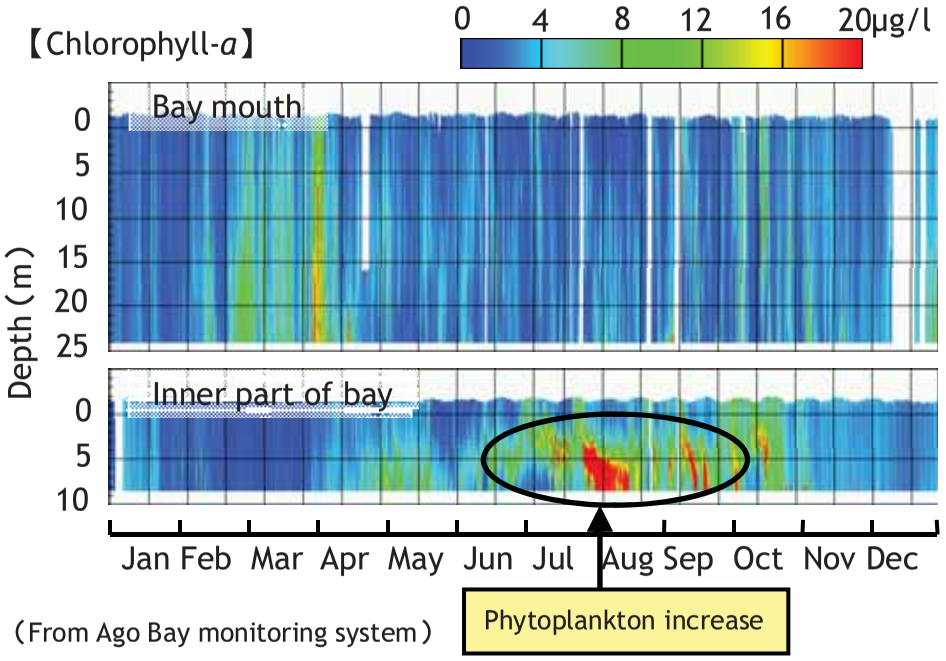
Living things cannot survive below 3mg/L of DO. If phytoplankton increase excessively, the DO rate becomes too high at this depth.



Phytoplankton in Ago Bay

The amount of phytoplankton is small from winter to spring. In May, they begin to increase, and the numbers go up and down depending on climate and nutrients. Generally, phytoplankton increase in spring and autumn, but in Ago Bay they increase in autumn only.

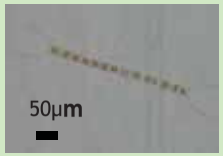
The amount of phytoplankton is checked by using a microscope or analyzing the chlorophyll-*a*.



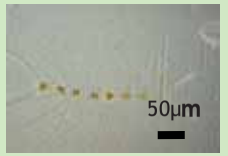
(From Ago Bay monitoring system)

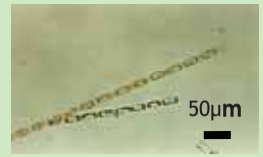
Generally, diatom and dinophyta are on the increase. Diatom are ingested by bivalves such as pearl oysters. There are harmful and toxic plankton in the dinophyta family. Therefore, it is necessary to react quickly to outbreaks of dinophyta.

Diatom

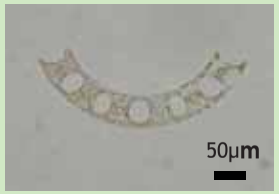


Chaetoceros sp.

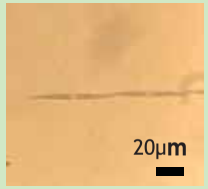




Skeletonema cestatum



Eucampia zodiacus



Nitzschia sp.

Asterionella graciallis

Dinophyta

Prorocentrum dentatum

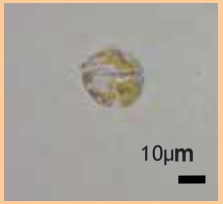
Ceratium furca

Noctiluca scintillans
(illuminated at night)

Harmful and toxic kinds

Heterocapsa Circularisquama

(Highly toxic for bivalves)



Karenia mikimotoi

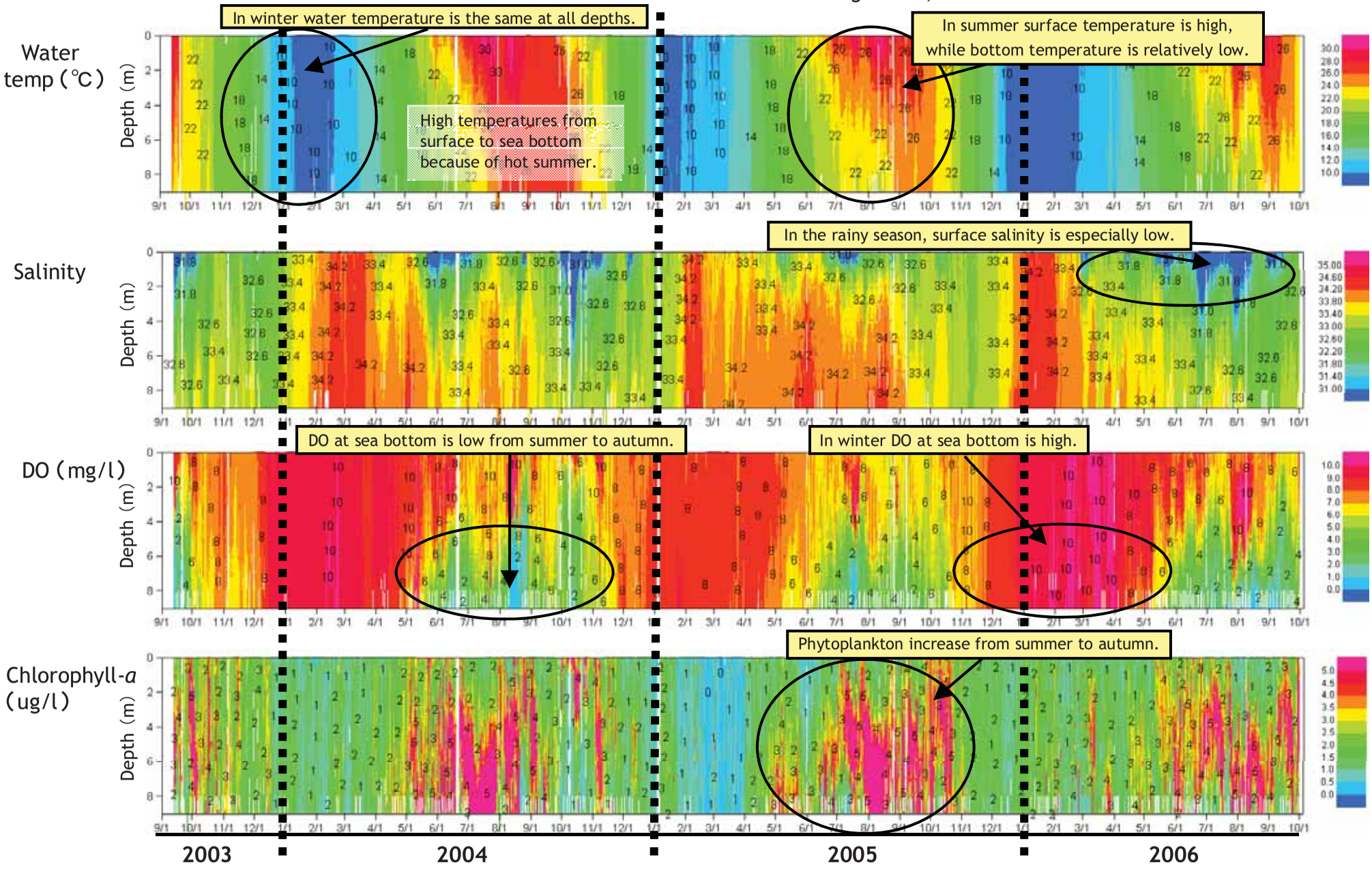
(Highly toxic for bivalves and fish)

Alexandrium catenella

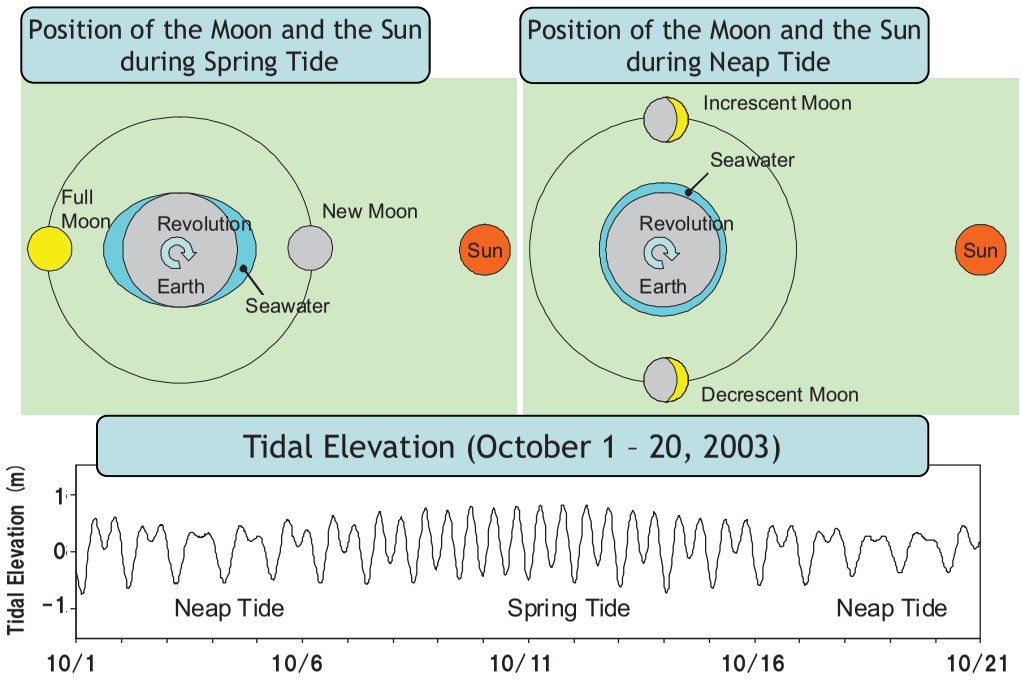
(Cause of shellfish poisoning)

Seasonal Changes in Water Quality

Water quality in the inner part of the bay changes seasonally because of the strong effect of climate. In the following charts, red indicates a high value, blue indicates a low value.



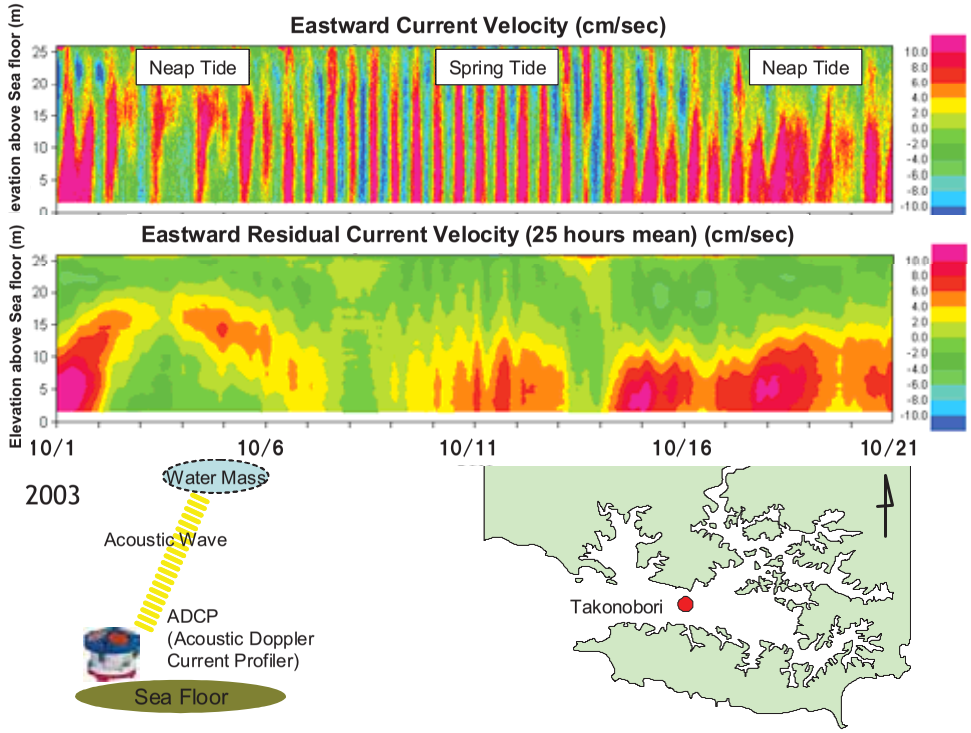
Causes of Seawater Currents



Flows or currents of water in the coastal sea are generated by various sources of energy like tides, wind, solar radiation, rain precipitation and changes in water density in the outer sea. Tides create a difference of thickness in seawater on the earth's surface as shown in the above figures. The gravitational forces of the sun and the moon make the seawater thickness uneven. High and low tide take place on the thick and thin areas, respectively. When the moon is in line with the sun (upper left figure), the gravitational force acting on seawater is intensified and the difference of water surface elevation between high and low tide is maximized. This corresponds to spring tide. When the moon stands perpendicular to the sun (upper right figure), the gravitational force is weakened and the difference of water surface elevation between high and low tide is minimized. This corresponds to neap tide.

This can be seen in the observation data of sea surface levels recorded at Ago Bay during October 2003, where the spring and neap tide occur periodically almost every 15 days. This period corresponds to the moon's revolution around the earth. The half-diurnal change of sea level is due to the revolution of the earth.

Tidal Currents and Residual Currents

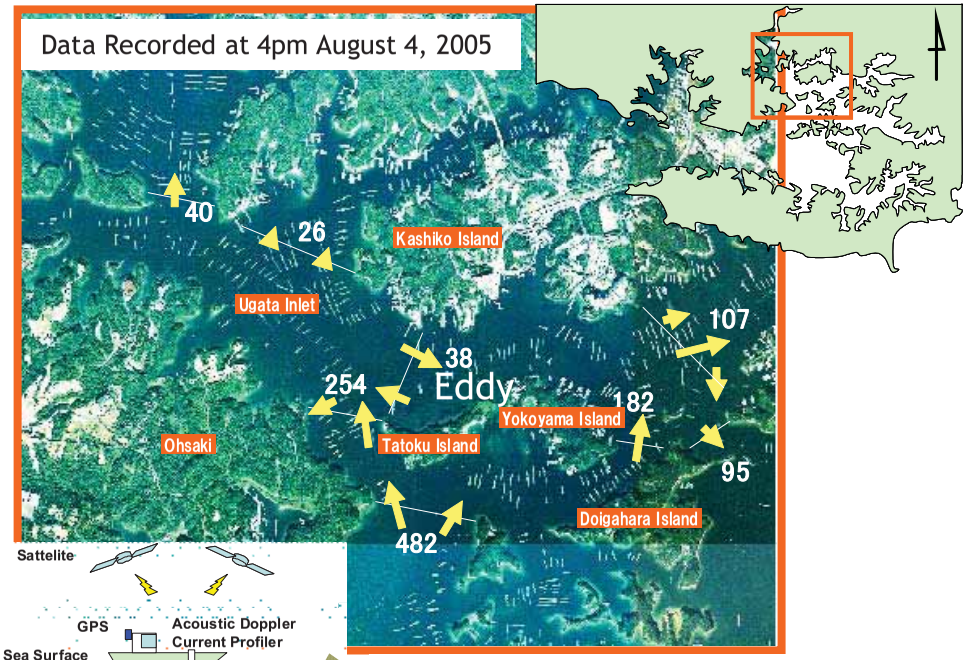


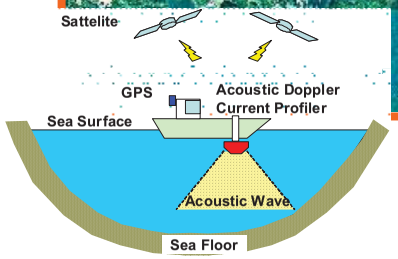
Seawater drawn into the bay during high tide returns to the outer sea. This period of time when the outward current velocity is maximized is called an ebb tide. Conversely, the period of time when the seawater flows into the bay is called a flood tide. The flow caused during the flood and ebb tides is known as a tidal current.

The top figure shows the velocity data of the eastward tidal current measured by the ADCP on the sea floor at 'Takonobori' during October 2003. The site location is indicated on the map. The vertical axis of the figure shows the elevation above the sea floor. The colors represent intensity and direction of currents. The red and blue colors correspond to the east and westward currents, respectively. Strong currents were recorded during spring tide, while relatively weaker currents occurred during neap tide.

The middle figure shows the data obtained by a time-average of 25 hours on the same data shown in the top figure. The current determined by this mathematical operation is called a tidal residual current, or simply, residual current. It is the residual current that mainly affects the movement of substances in the ocean. Thus, the residual current strongly affects water quality of the bay.

The Complex Flow near Kashiko Island



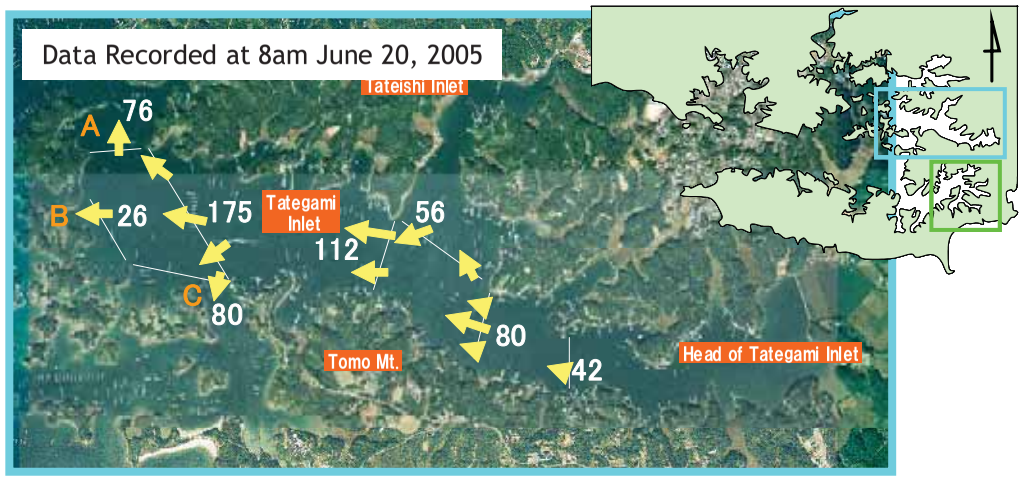


The yellow arrows show the magnitude and direction of currents. The numbers show the flow rate (ton/s) through the cross section marked by the white line. Same in the following two pictures.

This picture shows the complex flow pattern near Kashiko Island during flood tide. The flow from the bay mouth divides into northward and eastward flows at the southern edge of Tatoku Island. The northward flow heads for Ugata Inlet, while the eastward component goes to the narrower channel between Yokoyama and Doigahara Islands. A portion of the northward flow turns east at the north-western area of Tatoku Island and heads for Shinmei Inlet. The eastward flow in the southern and northern channels of Tatoku Island joins together at the north-eastern area of Tatoku Island and goes on toward Shinmei and Tategami Inlet.

The reverse (westward) flow along the northern coast of Tatoku Island indicates the occurrence of an eddy and implies the complexity of flow patterns there. The data shown herein including those on the following page were measured by an ADCP attached to a small vessel.

The Tidal Currents in Tategami and Funakoshi Inlets

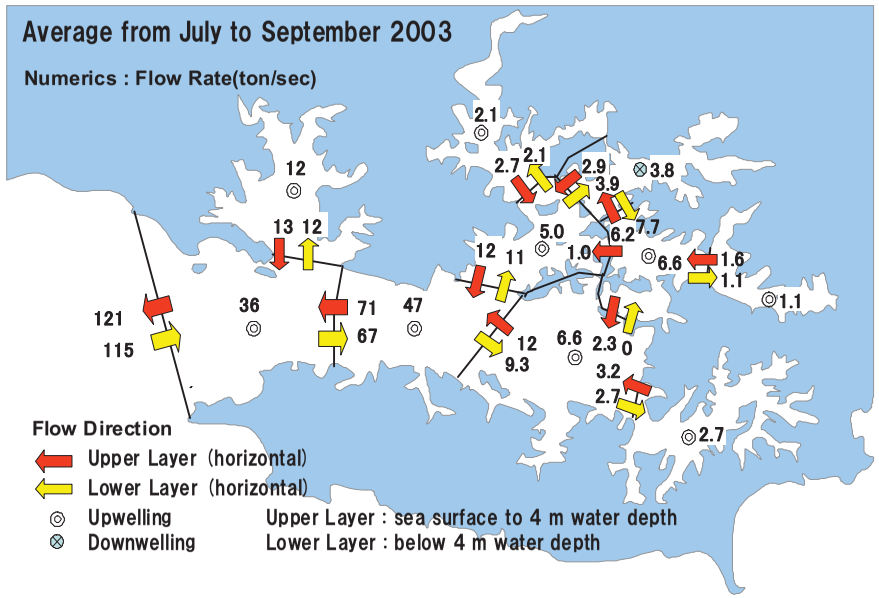


The next picture shows flow patterns in Tategami Inlet during ebb tide. The most important point is that the discharge takes place simultaneously through the three channels (A, B and C) that connect the inlet to the outer region. Similar trends were also observed during flood tide. These features are evidence that the inlet is positioned at the innermost part of Ago Bay in a hydro-dynamic sense. This could explain the lower quality of seawater and sediment in the inlet.

Data Recorded at 2pm September, 2005

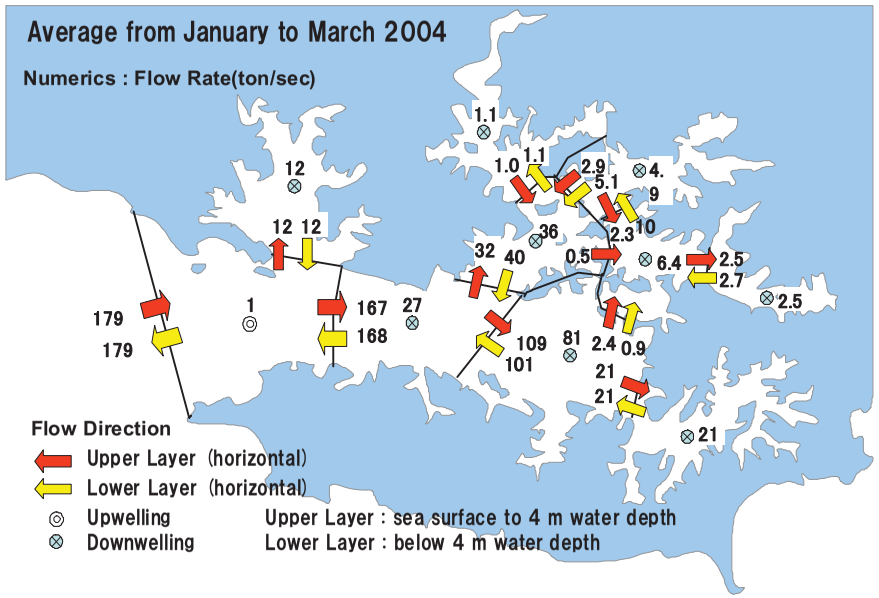
The left picture shows the flow pattern in Funakoshi Inlet during flood tide. The most instructive point is the contribution to water exchange by the Fukaya canal, which directly connects the inner part of the inlet to the Pacific Ocean. As shown, the flow rate to Katada port from the Funakoshi Inlet is more than that from the Fukaya canal. This shows the canal's limitations concerning water quality enhancement to Fukaya Inlet.

The Residual Flow of Ago Bay in Summer



It is essential to investigate the path of the flow around Ago Bay as well as the flow rate, when talking about water quality. The data depicted above was obtained by a three-dimensional hydrodynamic computer simulation. It shows the directions and the flow rates of the residual current in the upper and lower layers at the transverse sections placed in the channels of the bay. As described in the previous pages, the residual current plays the primary role of substance (e.g., oxygen) transportation and has a strong connection to water quality. All flow directions in the upper layer go to the bay mouth, while those in the lower layer go to the bay head. This type of flow pattern, called an estuarine circulation, is caused by the water density difference between the bay and the outer sea. The high water temperature from solar heating and the salinity decline from river discharge promote a decrease in water density in the bay. The flow pattern shown above occurs because the gravitational force acts to push lighter water toward the outer sea where the water density is relatively high.

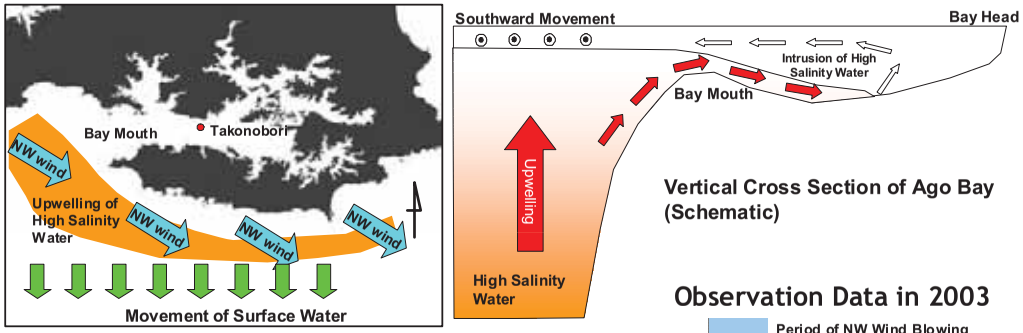
The Residual Flow of Ago Bay in Winter



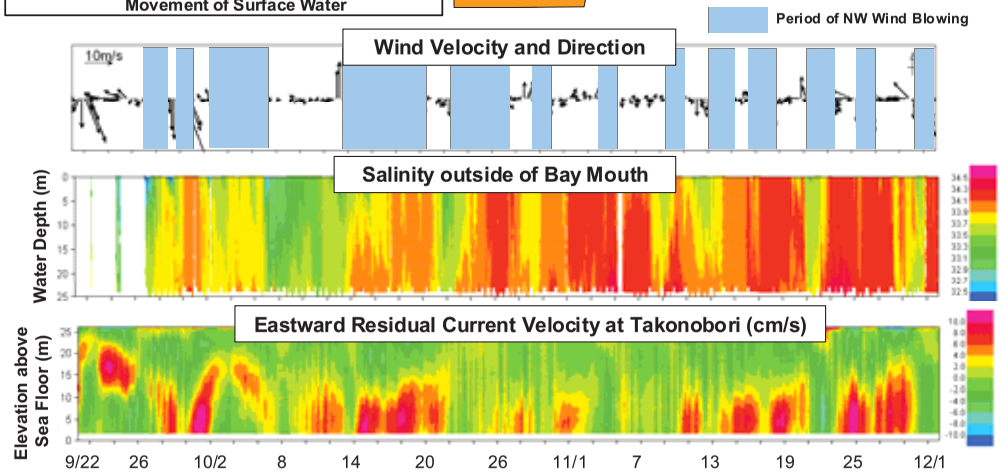
The flow direction in winter is almost opposite to that in summer. Thus, the flow in the upper and the lower layer head for the bay head and the bay mouth, respectively. The north-west wind (monsoon) which dominates in winter is the cause of this flow pattern. The density stratification diminishes and the density difference between the bay and the outer sea also weakens as winter progresses, and the influence of wind becomes significant.

As seen in the data of residual flow in summer, there also exists a big difference in the flow rate between the bay mouth and the bay head area in winter. The magnitude of residual flow velocities in the upper layer are about 2cm/s (summer) and 3cm/s (winter) in the bay mouth area, while those in Tategami Inlet are about 0.8mm/s (summer) and 1.3mm/s (winter). The difference is more than 1/20. The stagnation period of substances calculated from the flow rate is a few days in the bay mouth area and a few dozen days in Tategami Inlet. These physical aspects are the fundamental cause of the big difference in the quality of seawater and sediment between the bay mouth and the bay head area.

Intrusion of Oceanic Seawater, Triggered by North-Western Wind (Spring, Summer, Autumn)

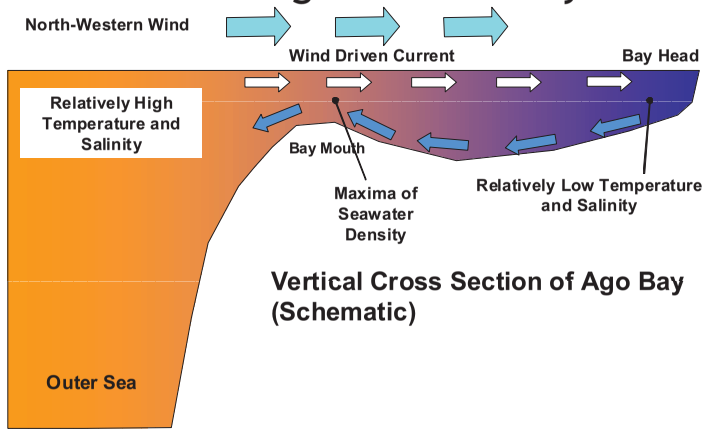


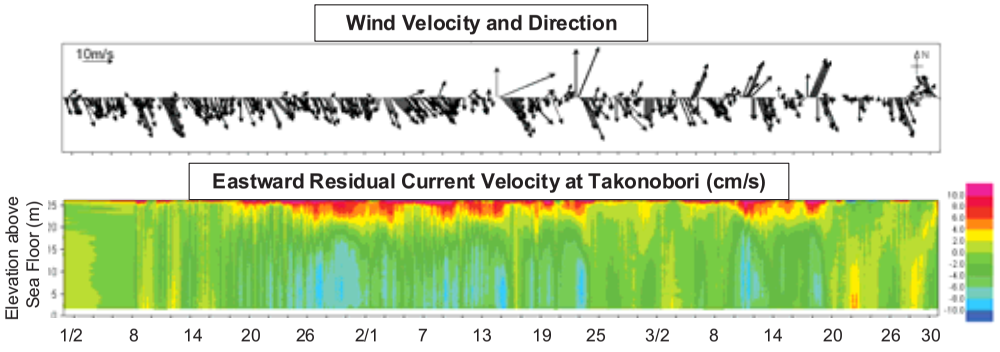
Observation Data in 2003



The seawater exchange between the bay and the outer sea has a strong effect on the water quality of the bay. In Ago Bay, during Spring to Autumn, the high salinity water of the outer sea intermittently intrudes into the lower layer of the bay, which triggers seawater exchange. It is known that this intrusion is connected to the occurrence of the north-western wind. When the NW wind blows, the wind force conveys water near the sea surface to the south. Concurrently, the more saline water in the deeper sea moves toward the shallower sea. This phenomenon is called upwelling. If the high salinity water rises beyond the sea floor height of the bay mouth, the water rushes into the lower layer of the bay. The observation data shown above depicts the relation between the wind, the salinity outside of the bay and the eastward residual current velocity at Takonobori. Upwelling of seawater is caused by the rise in salinity.

Seawater Exchange in Winter by Monsoon



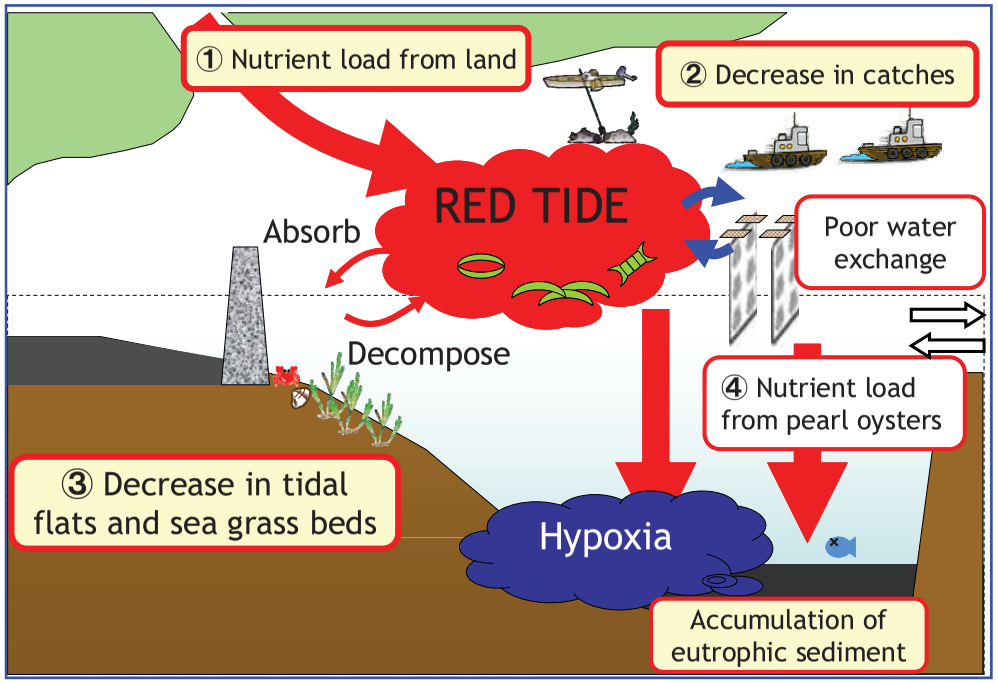


As described earlier, the wind-driven current caused by the monsoon strengthens from January to March, and this causes another type of seawater exchange. The observation data above shows that the eastward residual current velocity near the sea surface is strengthened when the monsoon wind (north-western wind) blows hard and continuously. The current strength is intense within the thin layer just below the sea surface. The reverse flow toward the bay mouth (westward) in the middle and lower layers complements the wind-driven current.

The strength of seawater exchange is expressed by the number of days in which the entire water in the bay is exchanged with the outer sea. The number of days of seawater exchange for Ago Bay is calculated in our research at about 24 days in summer and 16 days in winter.

Environmental Problems in Ago Bay

In Ago Bay, large amounts of eutrophic sediment have accumulated on the sea bottom. As a result, red tides and hypoxia occur frequently.
This is a big environmental problem for Ago Bay!



10. Present Status of Ago Bay

○ Causes of sediment eutrophication

【① Nutrient Load from Land】

Because forests exist very close to the sea, nutrient loads flow swiftly into Ago Bay. As a result, phytoplankton increase and it's easy for red tides to occur.

【② Decrease in Catches】

Until 1960, more than 600t of fish were caught in Ago Bay. However since 1965, little has been collected except for pearls and laver. Therefore picking up nutrients from Ago Bay has decreased.

【③ Decrease in Tidal Flats and Sea Grass Beds】

Tidal flats and seagrass beds have the function of preventing sediment eutrophication. In Ago Bay, more than 70% of tidal flats deteriorated due ro land reclamation. As a result, the natural purification capacity has become very small.

【④ Nutrient Load from Pearl Oysters 】

Pearl culture is the basic industry of Ago Bay. However, if fishermen don't pick up the waste from cleaning and pearl oyster meat, sediment eutrophication will increase.

Red Tides

Red tide is a common name for a phenomenon where phytoplankton increase explosively in seawater. As a result, seawater becomes discolored (red, green or brown).

【Red Tide Kills Bivalves】

In 1992, a red tide formed by new phytoplankton (*Heterocapsa Circularisquama*) occurred in Ago Bay. After 1992 this red tide has often occurred and damaged pearl culture.

A red tide of *Heterocapsa Circularisquama*
(At TATOKU island, 13 Aug., 2004)

Pearl oysters killed by
Heterocapsa Circularisquama

【Large Amounts of Phytoplankton are Bad for the Environment】

Large amounts of diatom, which is food for pearl oysters, is not good for the environment, because these diatoms will die and accumulate on the sea bottom. As a result, oxygen deficient water occurs.

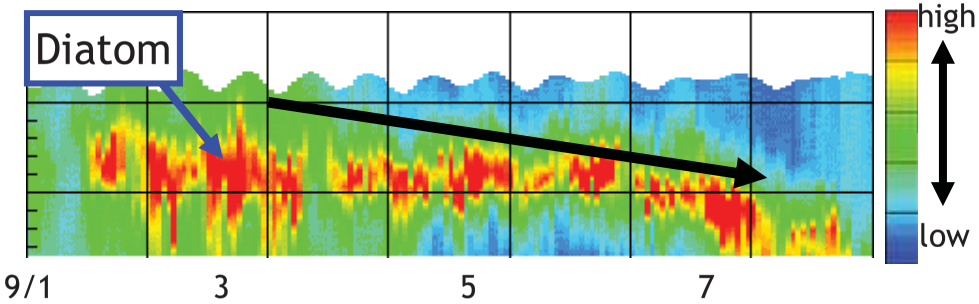
Phytoplankton need nutrients. If large amounts of nutrients flow into Ago Bay, a red tide will occur. Our lifestyles are related to red tides, because large amounts of nutrients are discharged by our way of living.

Checking for Red Tides

By using the Ago Bay monitoring system, we can see the present status of red tides and hypoxia on a PC or cell phone anytime and anywhere.

【Checking for Chlorophyll-a by PC】

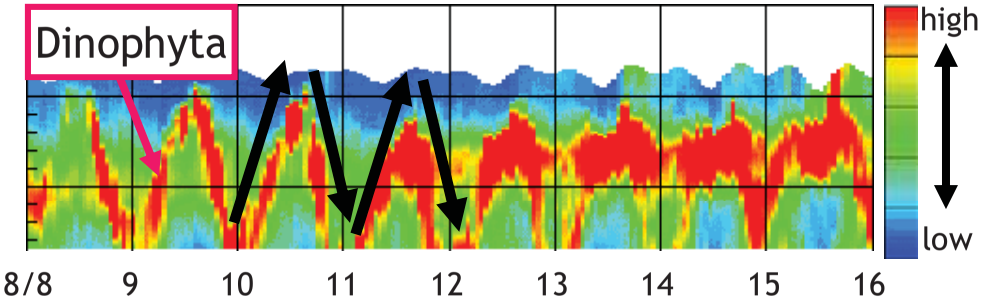
2004 Inner part of bay (TATEGAMI)



Diatom gradually sink to the sea bottom.

Diatom are good food for pearl oysters.

2004 Inner part of bay (TATEGAMI) ※these dinophyta are *Heterocapsa circularisquama*



Dinophyta move up and down because they can swim. During the daytime dinophyta move to the surface, while at night they move to the bottom.

※When a high chlorophyll-a pattern moves up and down on the monitoring system, this indicates a red tide of dinophyta.

Hypoxia in Ago Bay

Hypoxia is a phenomenon that occurs as dissolved oxygen becomes reduced in concentration (below 3mg/l) to a point detrimental to aquatic organisms living in the system. In Ago Bay hypoxia occurs every summer.

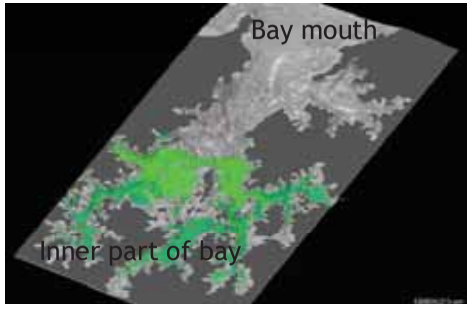
【The Menace of Hypoxia】

In Ago Bay, hypoxia occurs every year. Especially from Jun. to Oct. dissolved oxygen from the center to the inner part of the bay decreases. Fish can escape hypoxia, but aquatic organisms living on the sea bottom such as shellfish and polycaeta die. In 2002, large scale hypoxia occurred in Ago Bay, and pearl culture and aquatic organisms were significantly damaged.

【Hypoxia is Not Good for the Environment】

In summer, aquatic organisms disappear in the inner part of the bay because of hypoxia. Hypoxia damages not only fisheries but also natural purification capacity.

Mass mortality of bivalves by hypoxia
(at UGATAHAMA Oct., 2002)

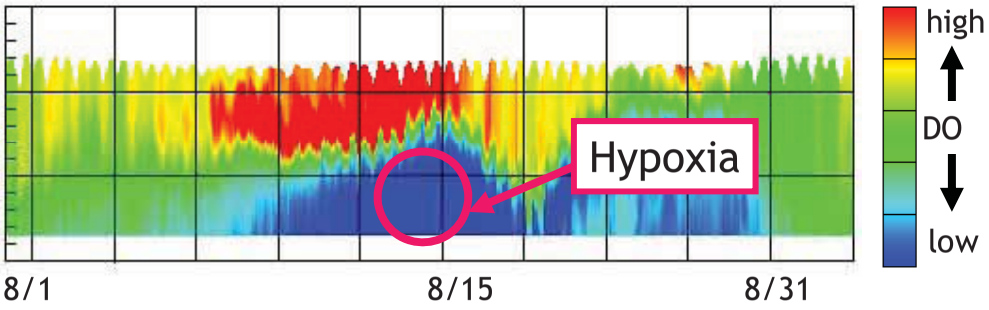


Hypoxia areas in Ago Bay

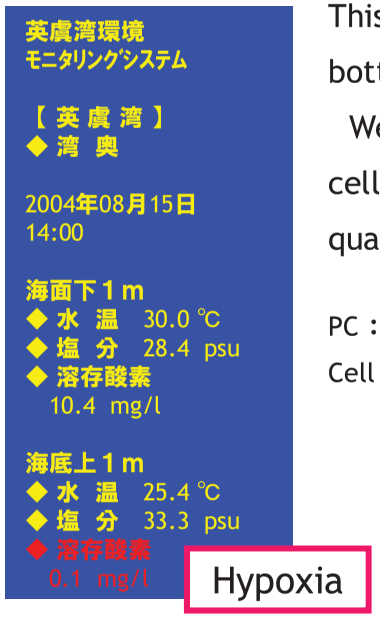
Checking for Hypoxia

【Checking the DO on a PC】

2004 Inner part of bay (TATEGAMI)



【Checking the DO on a Cell Phone】



This figure indicates that the DO on the sea bottom is greatly decreased by hypoxia.

We can see the monitoring data on a PC or cell phone. Let's check the changes in water quality in Ago Bay.

PC：http://www.agobay.jp/agoweb/index.jsp

Cell phone:

http://www.agobay.jp/agoweb_i/index.jsp

Mie Fisheries Research Institute gives information on phytoplankton every week. We can see the water quality in Ago BAY at the following URL.

(http://www.mpstpc.pref.mie.jp/SUI/kankyo/)

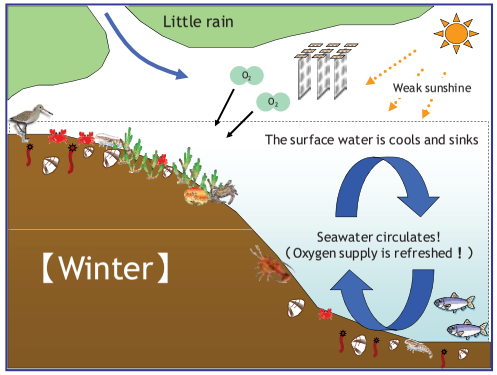
The Causes of Hypoxia

The causes of hypoxia are ① deterioration of the oxygen supply to the sea bottom and ② accumulation of organic materials on the sea bottom.

① Deterioration of the oxygen supply

In Ago Bay, the mixing processes of seawater are different every season.

In summer, the weight of surface water becomes light because of warming and low salinity due to rain. On the sea bottom, there is high salinity and relatively cold, heavy water. That's why in summer seawater doesn't circulate well and oxygen cannot be supplied to the sea bottom.



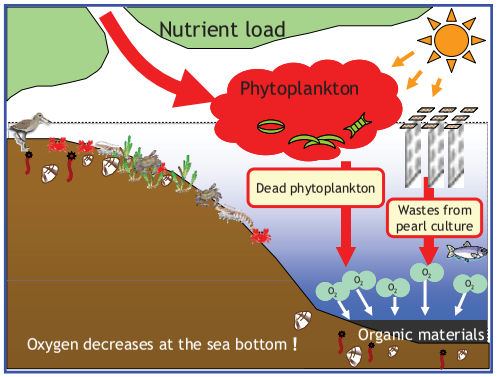
In winter, the weight of surface water becomes heavy because of cooling and little rain. The heavy surface water sinks to the bottom. Therefore, in winter, seawater is naturally mixed and oxygen can be supplied to the sea bottom.

In summer, because seawater cannot circulate and sufficient quantities of oxygen cannot reach the sea bottom, hypoxia is apt to occur.

12. Hypoxia in Ago Bay

② Accumulation of organic materials

Hypoxia may also occur when the wastes from pearl culture and dead phytoplankton accumulate on the sea bottom.



Phytoplankton increase due to nutrient supply from the land. Organic materials accumulate on the sea bottom because dead phytoplankton and the wastes from pearl culture sink. To decompose these organic materials, bacteria use large amounts of oxygen in the seawater. As a result, oxygen at the sea bottom decreases immensely.

①＋②：Hypoxia occurs in summer in Ago Bay

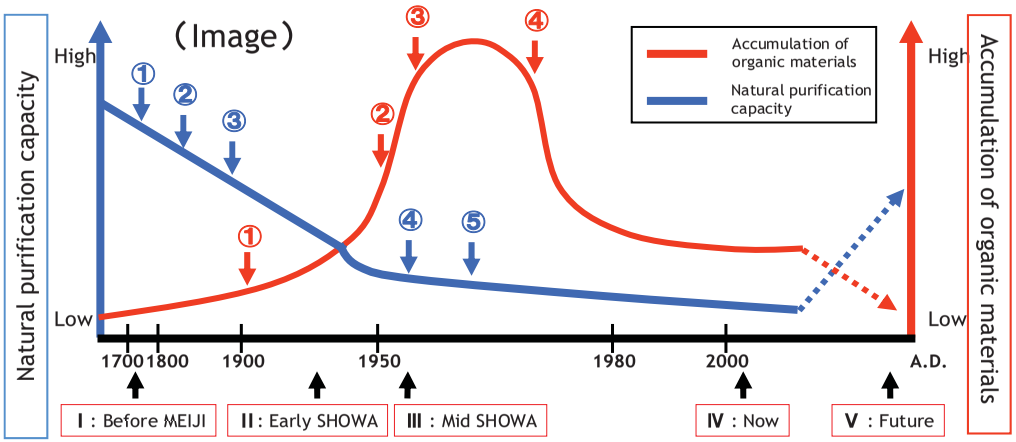
As mentioned, hypoxia occurs in summer because seawater cannot circulate and the decomposition of organic materials increases. As a result, oxygen is depleted on the sea bottom and aquatic organisms die.

When the organic materials on the sea bottom decompose, oxygen is consumed. Hypoxia occurs when the amount of oxygen consumption becomes larger than the oxygen supply. To prevent hypoxia, it is necessary to reduce the accumulation of organic materials.

Historical changes in Natural Purification Capacity and Accumulation of Organic Materials in Ago Bay

In Ago Bay, hypoxia is a very serious problem.

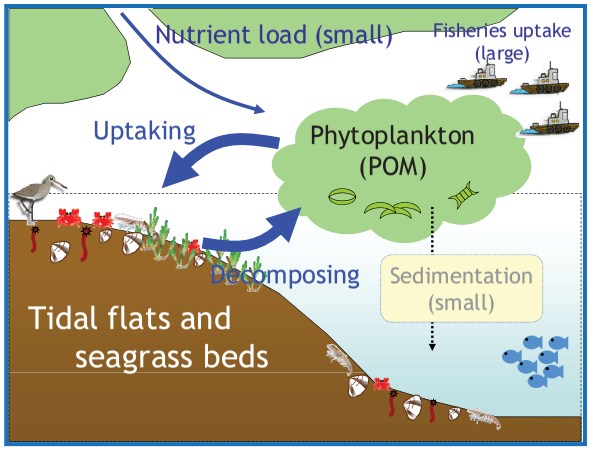
To remove hypoxia, it is important to keep the balance between natural purification and the accumulation of organic materials. Before the Meiji era, natural purification capacity was higher. However, it decreased because more than 70% of tidal flats were reclaimed, and organic materials increased due to population growth and pearl culture. Unfortunately, the accumulation of organic materials is higher now than the natural purification capacity of Ago Bay.



① 1668 ～ : Beginning of reclamation.
② ～ 1945 : Large amounts of fish were caught.
③ 1892 : Large scale red tide occurred.
④ 1950s : Decrease in aquatic organisms due to hypoxia.
⑤ 1960～ : Decrease in fish gathering.

① 1868～1945 : Increase of nutrient load due to population growth.
② 1956 : Large scale hypoxia occurred.
③ 1950s : Increase in the accumulation of organic materials by rapid growth of pearl culture.
④ 1960s : Decrease in the accumulation of organic materials by depression of pearl culture.

Ⅰ Before Meiji era (～1868) : Natural purification capacity ≫ Accumulation of organic materials

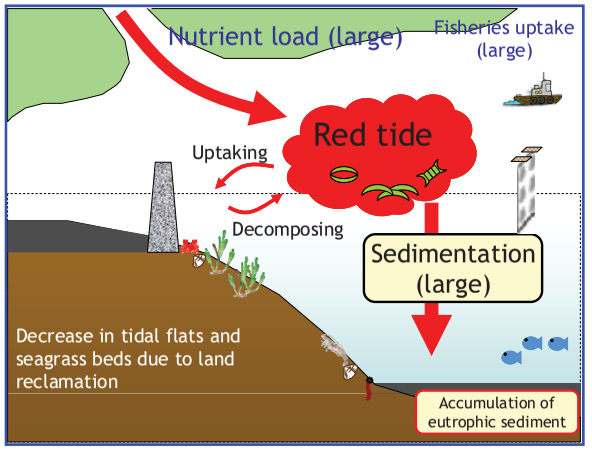


【Natural Purification Capacity】
Many tidal flats and seagrass beds existed and large amounts of fish were gathered by fisheries.

【Accumulation of Organic Materials】
Nutrient loads were small and organic materials hardly accumulated.

Organic materials didn't accumulate in tidal flats and seagrass beds. Aquatic organisms could live throughout the year. Red tides and hypoxia didn't occur.

Ⅱ The early Showa era (1926～50s) : ↓ Natural purification capacity ≦ Accumulation of organic materials ↑

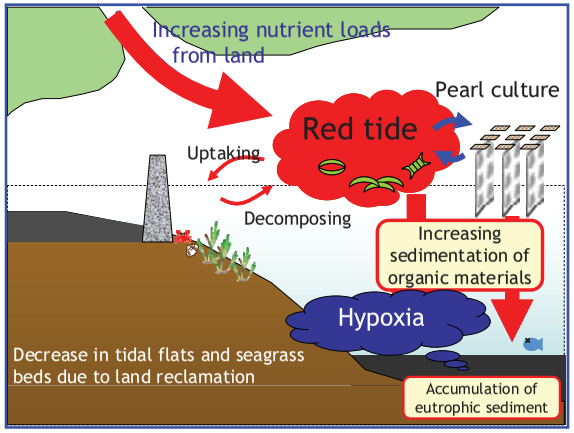


【Natural Purification Capacity】
Tidal flats and seagrass beds were reclaimed. Natural purification capacity decreased.

【Accumulation of Organic Materials】
Nutrient loads increased and organic materials were apt to accumulate.

Red tides occurred due to land reclamation. The accumulation of organic materials increased because of sedimentation of phytoplankton.

Ⅲ The Showa 30s (1950s～60s):Natural purification capacity ≪ Accumulation of organic materials

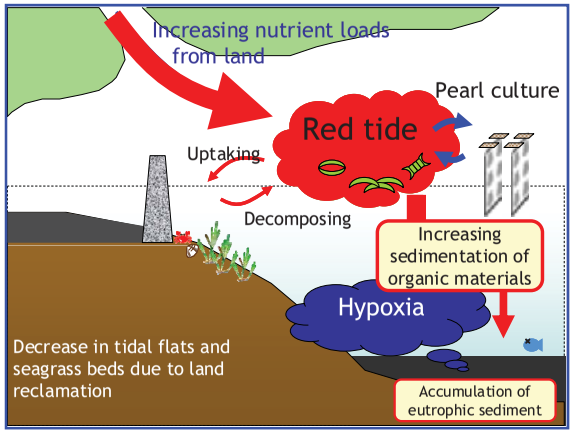


【Natural Purification Capacity 】
Aquatic organisms died from a decrease in fisheries uptake and hypoxia.

【Accumulation of Organic Materials】
Organic materials were apt to accumulate due to increasing nutrient loads and pearl culture.

Organic materials were apt to accumulate due to the rapid increase of pearl culture. Hypoxia and red tides occurred every year.

Ⅳ Heisei era (Present): Natural purification capacity < Accumulation of organic materials



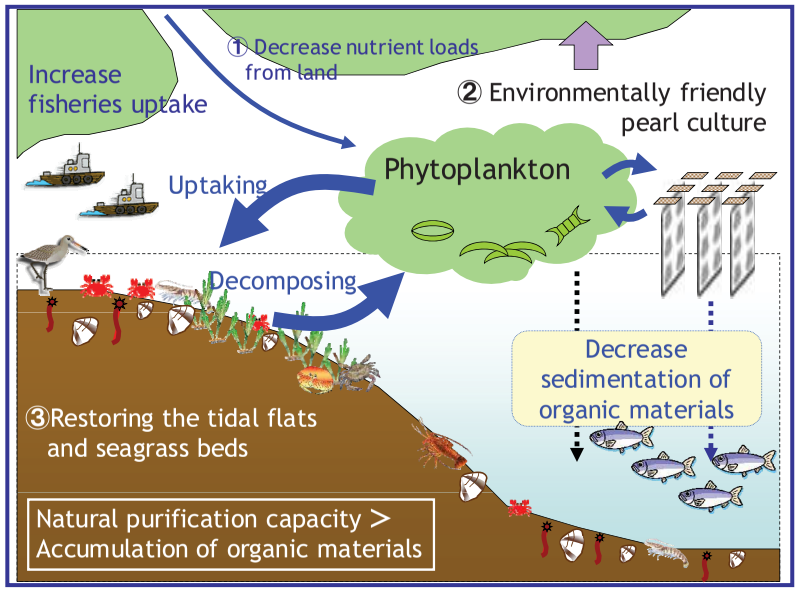
【Natural Purification Capacity 】
Aquatic organisms died from a decrease in fisheries uptake and hypoxia.

【Accumulation of Organic Materials】
In spite of decreasing pearl production, organic materials still were apt to accumulate due to increasing nutrient loads.

Though the accumulation of organic materials decreased a bit because of the decline in pearl production, natural purification capacity was still small. As a result, hypoxia and red tides occurred every year.

Ⅴ Future: Natural purification capacity > Accumulation of organic materials

◎ It is necessary to enhance natural purification capacity by decreasing nutrient loads from the land and pearl culture.



① Decrease nutrient loads from land

If people try to reduce excess nutrient loads from daily activities, such as cooking and washing, sedimentation of organic materials can be decreased.

② Trying environmentally friendly pearl culture

If fishermen stop discarding oyster meat and cleaning wastes in an environmentally friendly manner, sedimentation can be decreased.

③ Restoring tidal flats and seagrass beds

If unused reclaimed areas are restored to tidal flats and seagrass beds, the biodiversity and natural purification capacity can be enhanced in Ago Bay.

If we try ①, ② and ③ individually, hypoxia will not disappear. If we act on ①, ② and ③ at the same time, hypoxia may disappear.

“What we can all do.”
For Nature Restoration in Ago Bay

Restoring nature in Ago Bay means that “Ago Bay will become a Sato-Umi again with high productivity and biodiversity and pearl culture in harmony with nature.”

“Surely you don’t think I’m responsible for nature restoration! ” Because we changed the environment of Ago Bay with our human activities, we should restore it.

For restoration, we propose the following five suggestions.

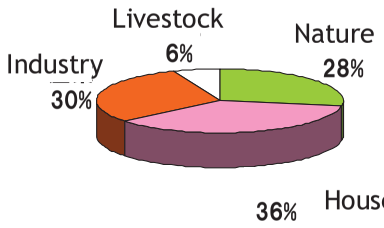
1. Decrease the nutrient load from land
   Be careful not to drain excess nutrient loads
2. Decrease the accumulation of organic materials on the sea bottom.
   Properly dispose of cleaning wastes and oyster meat
3. Enhance biodiversity and natural purification capacity
   Restore tidal flats and seagrass beds
4. Transport organic materials from Ago Bay
   Promote fisheries to be able to fish again
5. Take good care of Ago Bay
   Enjoy a peaceful, ecological life in our Sato-Umi

If we seriously act upon these five suggestions, a new Sato-Umi will be created.

14. Towards Nature Restoration in Ago Bay

1. Decrease the nutrient load from land

One of the major nutrient loads from land is household effluents from our activities.



【Percentage of nutrients that flow into Ago Bay】

People in this region have to be careful to reduce excess nutrients.

We can achieve this by :

- Using only necessary amounts of soap and detergent.
- Disposing of cooking oil by absorbing it with paper or cloth.
- Not allowing garbage to go down the drain.

etc.

Septic tanks and sewage systems clean household effluents. The local government promotes the following ways to clean effluents.

① Connecting every home with the sewage system inside the area.
② Setting up septic tanks in areas outside the sewage system.

Not only the people in this region but also visitors to Ago Bay must be careful not to drain excess nutrient loads.

2. Decrease the accumulation of organic materials on the sea bottom

Cleaning pearl oysters is important to produce good pearls. However, the nutrients from these operations cause large problems for Ago Bay. Therefore, it is important to decrease the accumulation of organic materials on the sea bottom by removing the cleaned wastes. And oyster meat is the same. Fisherman should dispose of it properly after taking out the pearl. If all fishermen do this, hypoxia will disappear.

Using a wastewater treatment machine

Collecting oyster meat by disposable net

3. Enhance biodiversity and natural purification capacity

Many kinds of aquatic organisms live in tidal flats and seagrass beds. They contribute to reducing the accumulation of organic materials on the sea bottom. Currently tidal flats and seagrass beds are slowly being restored by local communities. If these restorations continue, biodiversity and natural purification capacity will be enhanced. As a result, red tides and hypoxia will disappear from Ago Bay.

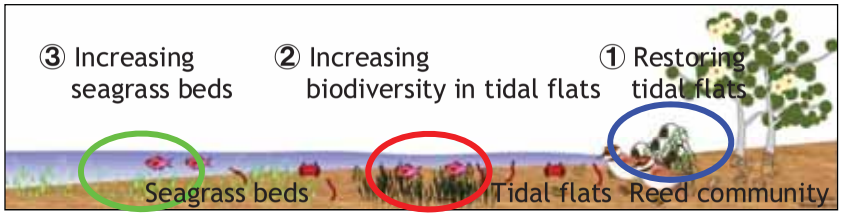
Environmental education on tidal flats

Constructing tidal flats with fishermen

Restoring seagrass beds with fishermen

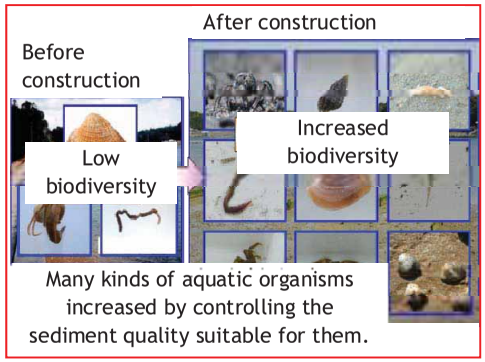
○ Activities for restoring tidal flats and seagrass beds

It is important to restore continuous natural coastal ecotones (reeds→tidal flats→seagrass beds) where many kinds of aquatic organisms can live.



① Restoring tidal flats

② Increasing biodiversity in tidal flats



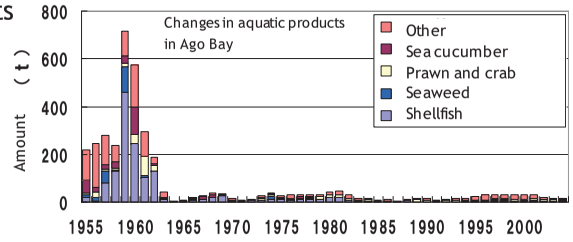
③ Increasing seagrass beds

4. Transport organic materials from Ago Bay



Fisheries have as their function the transport of organic materials from the sea to land areas. However, in Ago Bay there are few fisheries for catching fish and shellfish. Large amounts of organic materials flow into Ago Bay. If there are no fish to catch in Ago Bay, all organic materials from the land accumulate on the sea bottom. We shall try to reduce nutrients from the land and catch fish using fisheries at the same time. Let's promote locally produced and consumed fish in Ago Bay.

※ Of course overcatching affects the environment, too.

Changes of catchment in Ago Bay

5. Take good care of Ago Bay

- People enjoy playing in Ago Bay.
- People take good care of Ago Bay

Our love for the bay is vital for its restoration.

"Have you been to Ago Bay recently?"


Sea kayak


Observing macrobenthos

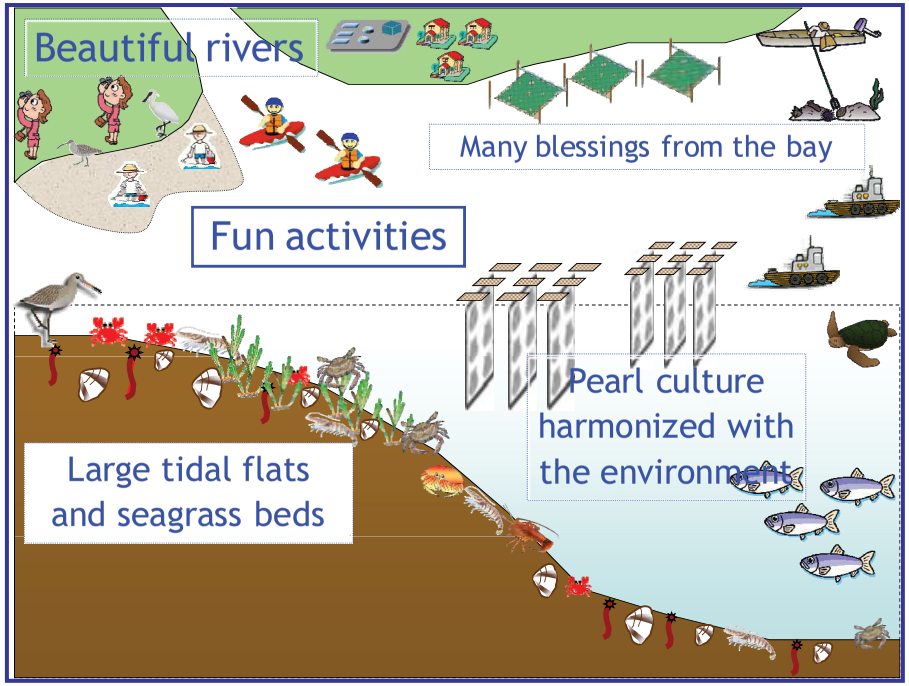

Sunset in Ago Bay

If we act on ①, ②, ③, ④ and ⑤ individually, the environment of Ago Bay cannot be restored. If we do all these things equally at the same time, then restoration is possible.

First, let's all do what we can. If everyone tries to do these five things, we can definitely restore Ago Bay.

The Future of Ago Bay

Ago Bay will become a New Sato-Umi.



Swimming
Gathering of clams
Pearl culture
Eating many fish
Being proud of Ago Bay
Wonderful sight-seeing
Going fishing
Catching fish
Bird watching
Sea kayaking
Observing macrobenthos in tidal flats
Many visitors
Etc.

Let's build a good partnership with Ago Bay and create a New Sato-Umi !

For people who want to know more about Ago Bay

There are many places to learn more about the bay.
Please go there to find out more.

- Mie Fisheries Research Institute
  (http://www.mpstpc.pref.mie.jp/SUI/index.htm)
- Shima City Hall (http://www.city.shima.mie.jp/)
- Ise Shima National Park Yokoyama Visitor Center
  (http://www2.mie-net.ne.jp/iseshima/)
- Society of Wild Animals in Shima
  (http://www.e-net.or.jp/user/ikuowaka/)
- Shima Nature School (http://www.shima-sg.com/f_index1.html)
- Ago Library
- Shima Library
- Mie Prefectural Department of Fisheries「Mie-no-Umi」
  (http://www.sea.pref.mie.jp/)

A Sato-Umi is the coastal area between the actual land and fisheries with biodiversity and high productivity in terms of human activity.

More than 20 years ago, Ago Bay was a Sato-Umi. However, social systems drastically changed, and Ago Bay lost it's identity as a Sato-Umi.

From now on, all the people of this region (inhabitants, visitors and fishermen) must try not only to restore Ago Bay but also to build a new relationship with the bay, harmonized with present society. In other words, it is important that "everyone in this region has a future vision and acts toward a New Sato-Umi harmonized with the environment in which fishermen continue pearl culture and people enjoy eco-tourism."

We wrote this booklet because we want you to know about Ago Bay. We will be delighted if this helps you act toward its restoration.

The contents of this booklet are a result of the JST-CREATE Program, "Project of Environmental Restoration of Enclosed Coastal Seas."
Thanks to this project, a lot was learned about methods to restore Ago Bay. However, we still haven't learned everything there is to know, and we must keep working to completely restore the environment.

Apr. 1st, 2011
Editor: Mie Fisheries Research Institute (COE)