Ofunato Bay Marine Environmental Survey
11 July 2022

1. Introduction

The survey of Ofunato Bay started in April 2021 as a concurrent comparative survey with Hirota Bay; five surveys were conducted in April, July, September, December and March 2022. The results of last financial year's five surveys were described in the Ecosystem Research Institute's "Waterfront Restoration Project; Shimanto River Survey and Ofunato Bay and Hirota Bay Surveys" for FY2021 (published in August 2022).

The weather on July 11, 2022 was cloudy and calm. The survey team departed from Shimofunato Port at 9:01 a.m., took measurements at an oyster farm in Shimofunato, obtained long-term water temperature data from thermometers, and reconfigured the thermometers, then headed to the bay area, passing the mouth of the Sakari River and off the Pacific Cement Plant, and then north along the Akazaki coast to make observations inside and outside the seawall at the bay mouth. At 11:30 a.m., the vessel returned to Shimofunato Port.

Characteristics of this survey and changes from the previous survey:
(1) First, survey was conducted near the mouth of the Susaki River.
(2) The first site was Takonoura, an important area for oyster farming, as requested by Mr. Kimiaki Toda, Mayor of Ofunato City.
(3) The two sites in the Hosoura area are not particularly unique, so measurements were suspended from this time onward.
(4) The area outside the seawall at the mouth of the bay has no special characteristics, so the two previous observation points were reduced to one.
(5) The total number of observation points was reduced from 16 to 12, and the total survey time was reduced to about 3 hours (previously it took 4 hours).

2. Surveyors and equipment used

The survey team consisted of Masayuki Komatsu as leader, Koichi Watanabe as surveyor, and Mitsuo Ito as local field surveyor. The survey vessel was Mr. Keiji Niinuma's oyster boat; built in 2013, 14.1 meters long, 450 horsepower.

Equipment used

(1) AAQ-RINKO AAQ170 was used. Water temperature, salinity, chlorophyll content, turbidity, and dissolved oxygen were measured and instantly displayed on a handy terminal for the D-10 total water quality meter. The data were later imported into a personal computer.

(2) A compact memory flow velocity system INFINITY-EM AEM-USB was used.

(3) A DEFI-1F continuous water thermometer was installed on an oyster culture raft in the Shimofunato area for long-term measurements.

3. Survey Results

(1) Current direction and velocity

① On the morning of July 11, the low tide was at 7:22 a.m. and the tide level was 20 cm, and the high tide was at 15:16 p.m. and the tide level was 125 cm.

Therefore, this survey was conducted during the rising tide. However, due to the low tide level in the bay, a current from the mouth of the Sakari River to the seawall at the mouth of the bay was observed both at the surface and at a depth of 10 m. This was also the case at the opening. This was also the case at the opening, where the main flow was from the inside to the outside of the bay, despite the fact that the survey was conducted at the time of high tide.

However, in the outer part of the bay, the direction of the current flowing into the bay on the rising tide was observed.

② The velocity of surface water was observed to be 30 to 50% faster than the velocity at a depth of 10 meters. This was also observed and measured in Ofunato Bay, Hirota Bay, Ishinomaki Bay, and Momoura Bay during the FY2021 survey period, suggesting that the flow velocity slows down due to water pressure at 10 meters depth. The velocity of the current is further slowed down at a depth of 30 meters.
(However, no significant difference was observed between the 10-meter and 30-meter depths at Ozaki and at the opening in this survey.

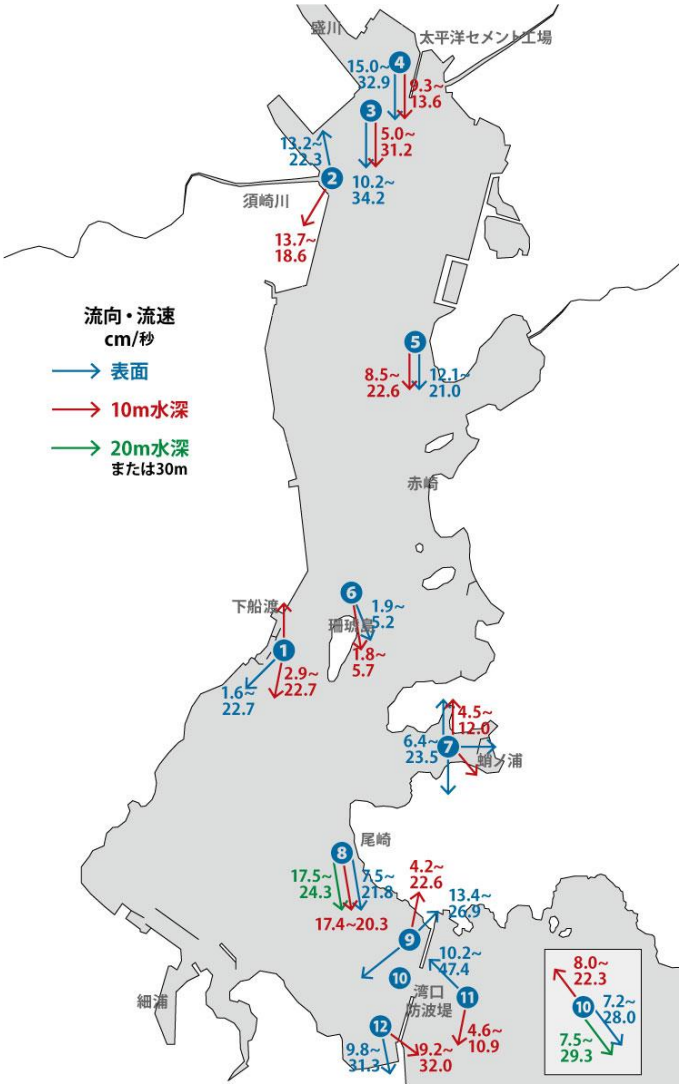

Chart 1: Currency direction and velocity in Ofunato Bay at the time of rising tide on 11 July 2022

③ The effect of the seawall at the mouth of the bay was as pronounced as ever. It was clear that the current velocity inside the bay slowed down by about 30% compared to that outside the bay mouth. This is true for the entire area of Ofunato Bay. Therefore, the seawalls at the mouth of the bay slowed down the flow velocity in the bay by about

30%, and this caused aggravation of turbidity (FTU) and deterioration of dissolved oxygen (DO) which tend to remain.

④ In general, the current velocity in Ofunato Bay is judged to be slower than that in Hirota Bay. In particular, the 10 meter depth is even slower.

⑤ The current velocity in the waters off Sango (Coral) Island and Akasaki is 1.9 to 5.2 centimeters/second at the surface, which is a small current velocity like stagnant waters inside an inlet. The current direction and velocity in the vicinity of Sango Island were reconfirmed in the results of the 2021 survey (when the report was prepared on August 17, 2022). On the other hand, we did not find any observation that the current speed tends to be faster because of the narrowing of the sea area. We will investigate the cause of this phenomenon in the future. Dissolved oxygen (DO) near the seafloor (30 meters deep) in this area was extremely low at 49%. Turbidity tended to be high, but not extremely high.

(2) Chlorophyll amount (μg/ℓ)

The chlorophyll amount generally exceeded 1 μg/ℓ in all areas, indicating good phytoplankton blooms. The values were higher at the back of the bay near the Sakari River and tended to decrease as closer to the seawall at the mouth of the bay. In the open ocean outside the seawall at the mouth of the bay, phytoplankton levels were 0.7 μg/ℓ at the surface, and 1.3 μg/ℓ and 1.1 μg/ℓ at depths of 10 and 30 meters, respectively, which were similar to those found inside the area around the seawall at the mouth of the bay.

High levels of chlorophyll (>2 μg /ℓ) were observed at the mouth of the Susaki River,

at the mouth of the Sakari River, and at the surface off the Pacific Cement Plant and off Akasaki. Even at a depth of 10 meters, chlorophyll levels of 1.6 to 2.6 μg/ℓ were observed.

Comparing these values to the results of last year's survey on July 6, they are very close. However, the general trend of higher chlorophyll levels at the back of the bay and lower chlorophyll levels near the seawall at the mouth of the bay was the same, but last year's chlorophyll levels tended to be higher.

(3) Turbidity (FTU)

Both last year and this July, the offshore water outside the seawall at the mouth of the bay showed extremely clean values in terms of turbidity. In particular, turbidity was relatively high at the surface of the mouth of the Sakari River (0.67 FTU), the surface off the Pacific Cement Plant (0.6 FTU), Sango Island at a depth of 30 meters (0.84 FTU), and Takonoura 16 meters deep (0.92 FTU), the worst value measured this time. At a depth of 30 meters off Ozaki, turbidity was 0.66 FTU)and at a depth of 34 meters in the opening at 0.67 FTU, and at a depth of 32 meters inside the south side of the South Seawall at 0.62 FTU.

The worst of these was 0.92 FTU at Takonoura. Compared to last year, when the number of sites with turbidity (FTU) exceeding 1 FTU was large both at the surface and at depths of 10 meters, the level of pollution in terms of turbidity (FTU) was considered to be somewhat lower this year. However, poor sites (30 meters deep at Sango Island, 30 meters deep at Ozaki, and 30 meters deep inside the south seawall) are usually observed frequently.

(4) Dissolved Oxygen (DO)

Dissolved oxygen at the surface and at a depth of 10 meters was above 100%, indicating no particular problems. This trend is similar to the results of the July 2021 survey. There were no problems at that time either.

In July 2021, the values in question were 89% at a depth of 10 meters off Pacific Cement Plant and 84% at a depth of 20 meters at Sango Island (we did not measure a

depth of 30 meters, but it appears that the water is even more poorly oxygenated at 30 meters).

At this time in July 2022, the 30-meter depth at Sango Island was 49% (the lowest value), 83% at a depth of 16 meters at Takonoura, 50% at a depth of 30 meters off Ozaki and 58% at a depth of 34 meters at the opening, and 73% at a depth of 32 meters inside the south seawall. Although DO at Takonoura had not previously been measured, the latest measurements showed poor values for both turbidity and dissolved oxygen.

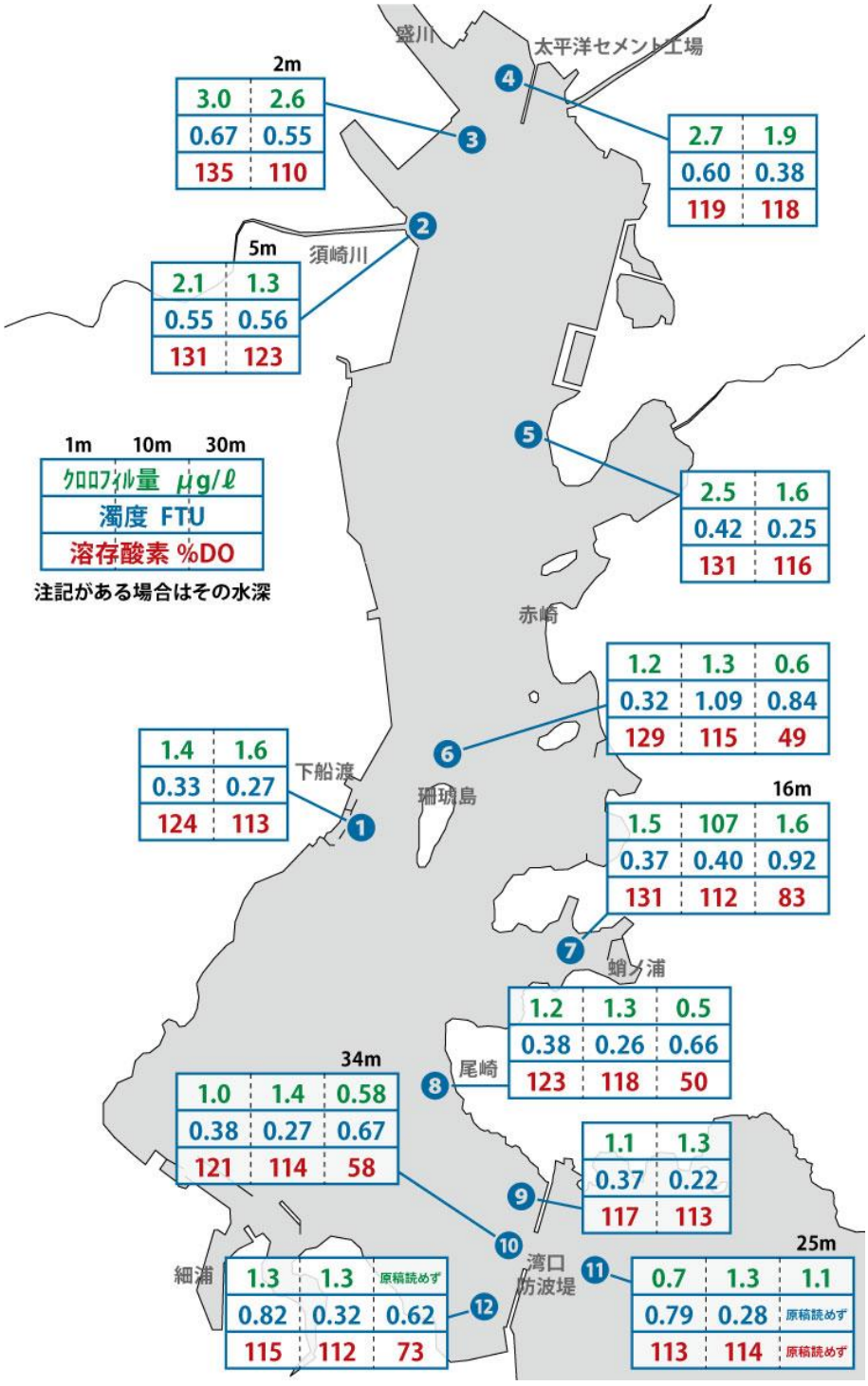

Chart 2: Chlorophyll amount, turbidity and dissolved oxygen at Ofunato Bay at the time of rising tide on 11 July 2022

(5) Evaluation of Survey Results

Dissolved oxygen (DO), which is a characteristic of summer, was observed in extremely poorly oxygenated water at specific locations in waters less than 30 meters deep during this survey as well. This trend is likely to continue annually in the future. Turbidity is also relatively high in these areas, as well as at the mouth of the Sakari River and offshore from the Pacific Cement Plant. It is important to investigate the causes of the decline in water quality in these areas.

The results of the survey showed that the flow velocity in Ofunato Bay was reduced by 35-45% by the seawall at the mouth of the bay even last year (see table below), and the results of this survey also showed that the flow velocity inside the bay was reduced by about 30% compared to that outside the bay mouth.

Comparison of Current Velocities in and out of Ofunato Bay (Unit: cm/sec)

Surface

	Apr/2021	July	Sept	Dec	Mar/2022	Total
In the bay (A)	10.5	19.0	12.5	9.1	32.4	83.5
Outside the bay(B)	30.0	19.5	33.0	11.2	59.1	152.8
(A)/(B)%	35	97	37.9	81	54.8	54.6

Water depth 10 meters

	Apr/2021	July	Sept	Dec	Mar/2022	Total
In the bay (C)	5.5	17.8	6.5	4.6	19.4	53.8
Outside the bay(D)	11.0	18.0	17.0	9.8	26.4	82.2
(C)/(D)%	50	99	38	47	73	65.5

Source: Ecosystem Research Institute

(Note 1) Based on the Shimanto River Survey, Ofunato Bay and Hirota Bay Survey 2021 Report (issued in August 2022).

(Note 2) The average value was calculated from the respective upper and lower limits of the current velocity outside the bay and the current velocity at points inside the bay (see the figure of current direction and velocity) in April, July, September, and December 2021 and March 2022, and used as the current velocity.
(Note 3) Totals were obtained for each month.

4. Current Status and Problems of Discharging Urban Sewage into Ofunato Bay

(1) Ofunato Sewage Treatment Center

The Ofunato Sewage Treatment Center has been in service since October 1, 1994. The planned water treatment capacity is 11,408 tons/day. The water treatment method used to be long-hour aeration (from October 1994 to March 2020), but this has been changed to the standard activated sludge method (from April 2020).

The discharge is into Ofunato Bay via the Nitta Urban Underground Waterway. The discharge point is the area south of the Sakari River and north of the Susaki River, surrounded by a quadrangle of levees. (Scientific measurements of water quality are scheduled to be conducted on October 28, 2022.) In FY 2018, the waste water treatment was shifted to private sector outsourcing through PPP (Public-Private Partnership). The treatment capacity of the purification center was increased due to the increase in the volume of sewage, and the expansion of treatment lines was replaced by a new high-efficiency treatment system using the latest technology: a high-efficiency solid-liquid separation facility (removes 50% of contamination), a purification drainage canal tank and reaction tank (inflow from the separation facility; oxygen and microbes are used to break down pollutants), etc.

(2) Reaction tank

Treated sewage is separated into sewage and solids in the final sedimentation tank and flows into the cleaned (but not clean) sewage chlorine mixing pond.

(3) Chlorine mixing pond

The treated water from the final sedimentation pond is then brought into contact with fixed chlorine for at least 15 minutes using a 52-meter-long channel to sterilize and disinfect E. coli and microorganisms before being discharged into the Shinden urban

sewerage channel.

(4) Outlet

Treated sewage is discharged into the Nitta Urban Waterway and then discharged into Ofunato Bay.

The amount of water discharged from the sewage treatment center is large during the summer months of June to September, ranging from 4,400 to 4,500 tons per day. On the other hand, it decreases in winter, from 3,900 to 4,000 tons per day. However, the maximum discharge on sunny days reaches 6,110 tons (September) and 8,223 tons (August) on rainy days. In addition, the amount of water discharged from the sewage treatment center reached 4,222 tons per day from 500 tons per day in FY1996 (Source: Ofunato City Sewerage Works, Water Supply and Sewerage Department, Ofunato Municipal Government).

Water quality of effluent

① Chloride ion (residual chlorine) is 0.10 mg/ℓ. However, at the time of inflow into the reaction tank, it was 986 mg/ℓ. It is necessary to ask the purification center how this decrease occurs.

② Dissolved oxygen is 0.3 to 0.4 mg/ℓ in the precipitation discharge water, but it is 2.7 mg/ℓ in the discharge water. This is another point we would like to ask about. The dissolved oxygen (DO) was 9.8 to 10.0 mg/l in the vicinity of the Susaki River and Sakari Rivers in Ofunato Bay on July 11, 2022, which is about 27% of the dissolved oxygen (DO) of the discharged water when expressed as a percentage. This explains that ultra-poor oxygenated water not observed in the waters of Ofunato Bay is being discharged from the sewage treatment center.