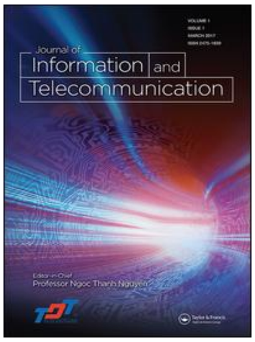


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# Development of seawater temperature announcement system for improving efficiency of fishery industry

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**ABSTRACT**
Obtaining accurate information about the seawater temperature and visualizing it in real time is of great importance for aquaculture fishers, as water temperature fluctuations due to tide inflows greatly affect the development of fish and shellfish. Fishery researchers install a lot of multiple depth water temperature continuous observation equipment in the sea, and then, they collect and accumulate the data on the seawater temperature to realize its visualization. In this research, we develop a novel system to visualize the current conditions of seawater and its variations over time based on the collected water temperature data. Our system allows representing the most recent seawater temperature information and its variation over time in the forms of a table, graph and a three-dimensional temperature distribution chart through a web browser. In addition, in this system, it is possible to download the seawater temperature information measured during a period in the past. Our system can be used to improve the efficiency of feeding, thereby reducing the costs associated with aquaculture maintenance; moreover, it can serve to avoid damages caused by red tide and to prevent fish diseases.

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**KEYWORDS**
Information system; IoT; big data; visualization; design thinking

## 1. Introduction

The critical problems related with the lack of food emerge due to an increase in the world population, which has exceeded 7.5 billion people in 2017 and is expected to reach 9.8 billion in 2050 and 11.2 billion in 2100 (United Nations, 2017). Under these circumstances, aquaculture fishery is considered as an important food supply source, as it can serve to establish stable production.

Ehime Prefecture achieves high production levels with the annual output of 85.1 billion yen in 2017 and takes the third place in Japan (Ehime Prefectural Government Office, 2018a) in the fishery industry. Aquaculture fishery in the Uwa Sea area is specifically important to support the production of fish (the annual output of 61.3 billion yen in 2017, taking the first place in Japan, Ehime Prefectural Government Office, n.d.).

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In aquaculture, the water temperature is one of the most important information indicators, as it allows mitigating the damage caused by fish diseases and red tide, which are the major obstacles. Previously, the data on the water temperature in Ehime Prefecture was collected through conducting fixed point surveys and implementing observation devices. However, the data collected by the existing audit systems were insufficient as temporally and spatially continuous data. Moreover, there was no way for fishery workers to exploit and browse these data.

Therefore, we built Multi-depth Sensor Network System in Uwa Sea and developed Seawater Temperature Announcement System provides information collected on this network system to fisheries workers and fisheries researchers.

In this paper, we describe our system and describe its functions. Moreover, we discuss the effectiveness of this system based on the evaluation of user satisfaction with respect to requirements and the investigation of quantitative data, such as the number of effective accesses.

## 2. Background

### *2.1. Utilization of information and communication technology in the fishery industry*

The Uwa Sea in Ehime Prefecture is considered as a suitable sea area to implement aquaculture. Rias coasts with calm waves serve as an appropriate environment for this purpose; however, such a characteristic as the presence of red tide may have a negative effect as it causes serious damage. It is likely to occur as seawater in this region is stagnant and is prone to the eutrophication progress. Nevertheless, in the Uwa Sea, there is the other feature such as the occurrence of high-temperature tide called 'rapid tide' near the sea surface, which allows quickly replacing seawater in the bay, thereby mitigating the effect of eutrophication. In addition, low-temperature tide called 'bottom tide' flows near the ocean bottom, supplying well-balanced nutrients into the Uwa Sea and the Seto Inland Sea. Therefore, rapid and bottom tides flowing into the Uwa Sea have a major impact on biological production (Takeoka, 2017).

The Ehime University developed a system that announced the sea discoloration and plankton concentration information to fishery workers (Ando et al., 2016, March). Moreover, a system that announced an occurrence of red tides was introduced (Suehiro et al., 2018, March) to support aquaculture production in the Uwa Sea.

In the present research, we focus on the development of a system to announce the seawater temperature information.

### *2.2. Importance of water temperature*

The water temperature is an important indicator of the current environment conditions in aquaculture due to the following reasons. First, water temperature zones that cause fish diseases (e.g. Red sea bream iridovirus infection (Nakajima & Kurita, 2005)) exist. It is necessary to reduce the amount of feeding for fish weakened by fish disease and feeding more than necessary will lead to deterioration of fish health and disease death. However, if fishery workers can obtain the up-to-date information about the water temperature in their aquaculture ground, it can serve to evaluate the health of fish and accordingly, to reduce the damage caused by fish diseases. Second, fishery workers can obtain the information about the current tide flow based on the data on the water temperature at various depth levels. The extent of the influence of tidal currents on aquaculture depends on the time, the thickness of an inflow and the range of the tidal current. Therefore, the amount of feed has to be adjusted according to the tidal currents. This issue can be effectively managed by fishery workers based on the accurate and up-to-date information about the current conditions in sea regions in question. Moreover, the water temperature can serve as an important indicator for fishery researchers, as it can be used to facilitate the prediction of the occurrence of red tides from an ocean physics perspective by observing temporal changes in the historical data on the water temperatures.

### *2.3. Issues*

In this section, we describe the situation before implementing the proposed system from a viewpoint of fishery workers and researchers.

Previously, fishery workers estimated the water temperature based on the general atmosphere temperature at that location as there was no way to measure the water temperature at their aquaculture grounds. However, the actual water temperature differed considerably from the estimates, as the water temperature changed drastically due to the inflow of rapid and bottom tides in the Uwa Sea.

Fishery researchers survey the water temperature every month in the Uwa Sea, at 24 fixed points, against this problem. In addition, five water temperature observation devices set on the sea bottom (Figure 1 shows the location) to measure the value every hour.

However, Rapid tides occur at intervals of 2 weeks so it cannot be captured by a fixed-point survey every month. In addition, the five devices alone do not surround the entire Uwa Sea. Moreover, fishery workers cannot browse the information measured.

### *2.4. Proposed system*

We proposed a system, as shown in Figure 2, to address the problem of water temperature information announcement.

First, we constructed a sensor network system enabling measurements on multiple depths (min: 1 m, max: 60 m), covering 16 (as of March 2019) water temperature observation devices (Figure 1 shows the location of devices). It is possible to surround the entire Uwa Sea and to monitor the situation of the upper and lower layers of the tidal current by constructing such network system. When constructing this network system, we made the observation device that was inexpensive, and sufficiently accurate as information obtained by fisheries workers and fisheries researchers, because setting of devices required a great deal of cost (Araki et al., 2018, March).

Next, we developed a system called 'Seawater Temperature Announcement System' that provided the information collected on using this network system to fishery workers and researchers. This visualization system allows fishery workers to check the latest water temperature information and past information at any time through a web browser.

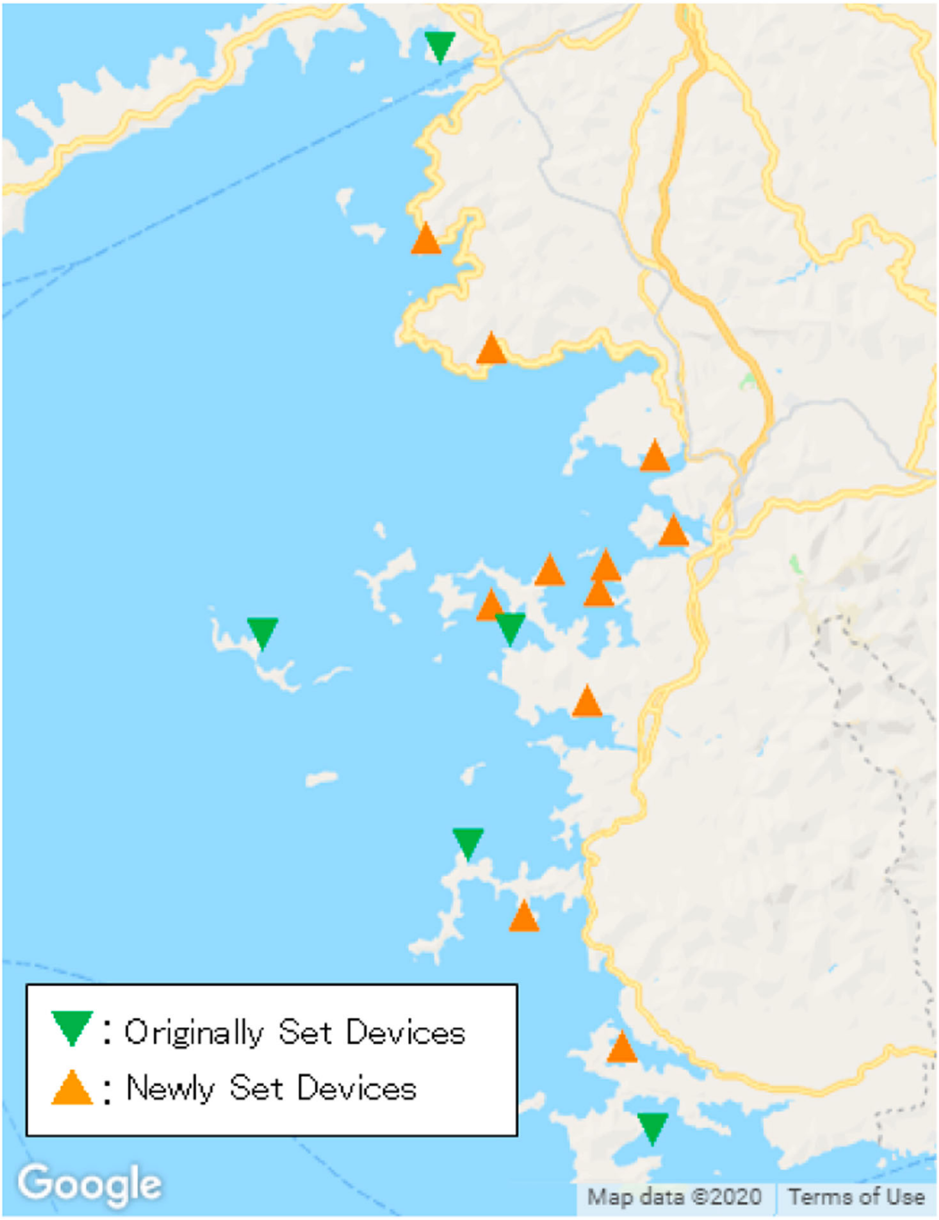



**Figure 1.** Location of water temperature observation devices.

### *2.5. System specificity*

The web system called 'Akashio Net' (URL: http://akashiwo.jp/) is the system similar to the proposed system. This system provides the current status and forecasts the data (until 1 or 2 weeks after) in the East China Sea (Ariake Sea and Yatsushiro Sea, etc.) and the Seto Inland Sea. Table 1 represents difference between our system and 'Akashio Net'.

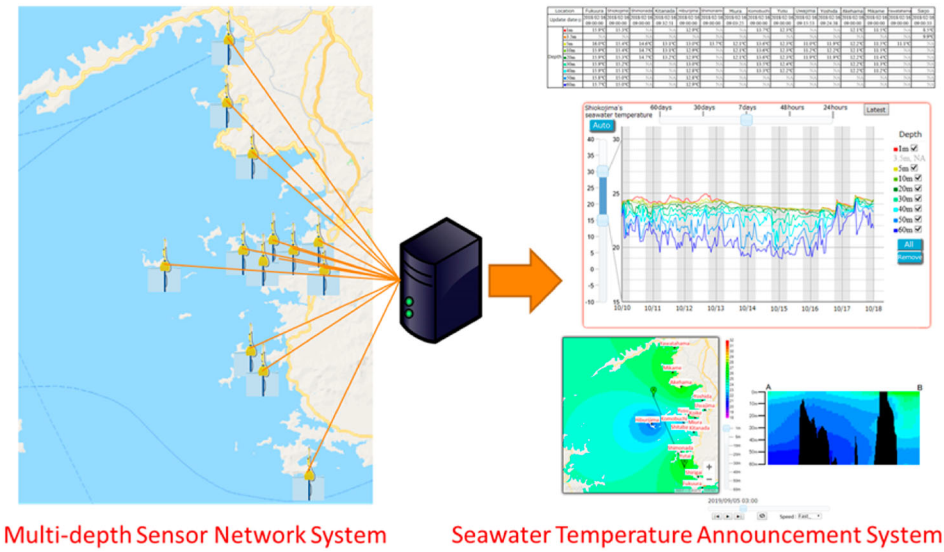



**Figure 2.** Proposed system.

**Table 1.** Our system vs Akashio Net.

| | Our system | Akashio Net |
|---|---|---|
| Measurement depth | Up to 8 layers | Only 1 layer |
| Estimate around measurement point | Yes | No |
| Provide forecast | No | Yes |

Akashio Net provides information for only one layer of water depth at each measurement point, while our system provides information for up to eight layers. In addition, our system does not generate forecasts as of March 2019 but provides the estimated values around a measurement point.

### *2.6. Purpose*

The proposed system is aimed to promptly announce the current information and changes of the seawater temperature in the Uwa Sea to fishery workers and researchers. This system can be used to improve the efficiency of feeding, to avoid the damage caused by red tide and to prevent fish diseases in aquaculture. In addition, it is expected to efficiently catch and manage the resources of fish migrating to the Uwa Sea through the Kuroshio Current, including such fish as horse mackerel that is expensive.

The main purpose of this study is to contribute to the improvement of fishery industry productivity in the Uwa Sea by developing the proposed system.

In this paper, we introduce a system called Seawater Temperature Announcement System. It has been designed based on the interviews with fishery workers and researchers. Moreover, we examined whether our system was effective by analysing the quantitative data, such as the number of accesses to the system.

## 3. Seawater temperature announcement system

### 3.1. Overview

Seawater Temperature Announcement System is an information system aimed at promptly announcing the seawater temperature data measured by observation devices to fishery workers and researchers.

This system consists of two subsystems: Storage System and Visualization System. The storage system immediately decrypts the data and store it on the server after measuring the water temperature. The visualization system is designed as a web application that reads the data stored on the server by the storage system and displays it on a web page in the forms of such as tables or graphs.

### 3.2. Storage system

The observation devices used in our sensor network can be roughly classified into two types. The first type includes devices that perform measures every 30 minutes or 1 hour and send e-mails containing data to the predetermined e-mail address from various e-mail address dedicated to each measurement point. The second type comprises the devices that measure the data every 30 minutes, connect to the server via a communication module and store the measured data on the server (Araki et al., 2018, March).

The storage system can be used to decode the e-mails sent from the devices and to extract the data upon receiving them. When the extracted data are the data measured for the first time by a device, this system generates a text file named the same as the sender's e-mail address and writes the data in this file on the server. Otherwise, this system adds the data to a text file named the same as the sender's e-mail address on the server. Using the above method, the data can be stored on the server.

### 3.3. Visualization system

Fishery workers and researchers can browse the data accumulated on the server using the storage system by using the visualization system. To satisfy all aforementioned requirements, we realize the announcement system as a Web application, as it can represent the seawater temperature information regardless of platforms. When this system is launched (accessed), the data stored on the server can be read. Thereafter, this system allows creating such as dynamic tables and graphs based on the registered data and displaying them on the Web page.

This Web page structure contains a public page and special page for fishery researchers, as fishery workers require the simplified information, while fishery researchers need the detailed information. On each page, users can switch between the displayed information, including the current status and the past status, by pushing button.

### 3.4. Requirements

Here, we list the requirements determined based on interviewing fishery workers and fishery researchers as follows:

1 Requirement 1 The display system should visualize the seawater temperature considering the spatial spread of marine area.
2 Requirement 2 The display system should store the historical water temperature information.

In addition to the above requirements, the data need to be narrowed down by a simple operation so that the visualized data become easier to analyse, and the displaying operation can be completed in a short time to enable users to predict the occurrence of red tide quickly and accurately.

### 3.5. Functions

Concerning Requirement 1, we implemented five functions defined as follows:

Function (a) Displaying the location of the observation point on the map
Function (b) Displaying the measurement data in a tabular form
Function (c) Displaying the current state of the seawater temperature as a graph
Function (d) Displaying the seawater temperature variation over time as a graph
Function (e) Displaying the seawater temperature variation over time in three dimensions using a distribution chart

To realize Requirement 2, we implemented a function as follows:

Function (f) Saving the measured data in a file in .csv format on the user's terminal

#### 3.5.1. Display of observation points

This system can display the position of each measurement point as a point on a map using Function (a).

#### 3.5.2. Tabular display of data

Using Function (b), the system can display the measurement data of each measurement point in a table format, as shown in Figure 3(a) in the 'Current status', or as shown in Figure 3(b) in the 'Past status'.

In each table, the horizontal items denote the location (the measurement point) and the vertical items represent the water depth to analyse variations in the seawater temperature due to the differences in the latitude of the measurement point. In the 'Past status' mode, it is possible to obtain the measurement data as of an arbitrarily specified date and time by a simple operation, such as moving a slider or pressing a button.

#### 3.5.3. Graph display of current state

Using Function (c), as shown in Figure 4, the latest measurement data can also be displayed as a line graph in which lines are colour-coded according to the water depth, with the seawater temperature on the vertical axis and the measurement point on the horizontal axis.Users can change the upper and lower limits of the seawater temperature to be

| Location | | Fukuura | Shirigai | Yutai | Shimonada | Kitanada | Hiburijima | Shitaba | Komobuchi | Miura | Koike | Yusu | Uwajima | Yoshida | Akehama | Mikame | Yawatahama |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Update Date | | 2019/01/24 23:00:00 | 2019/01/24 23:30:04 | 2019/01/24 23:00:00 | 2019/01/24 23:00:00 | 2019/01/24 23:32:27 | 2019/01/24 23:00:00 | 2019/01/24 23:00:00 | 2019/01/24 23:00:00 | 2019/01/24 23:30:33 | 2019/01/24 23:30:03 | 2019/01/24 23:00:00 | 2019/01/24 23:32:32 | 2019/01/24 23:18:25 | 2019/01/24 23:00:00 | 2019/01/24 23:00:00 | 2019/01/24 23:00:00 |
| Depth | 1m | 17.1℃ | 15.9℃ | 16.1℃ | NA | NA | 15.1℃ | NA | 15.0℃ | NA | 14.4℃ | 14.4℃ | NA | NA | 14.4℃ | 14.3℃ | NA |
| | 5m | 17.0℃ | 15.9℃ | 16.1℃ | 15.5℃ | 14.7℃ | 15.1℃ | 15.1℃ | 15.0℃ | 14.4℃ | 14.4℃ | 14.5℃ | 14.3℃ | 14.3℃ | 14.5℃ | 14.4℃ | 14.1℃ |
| | 10m | 17.1℃ | 16.0℃ | 16.1℃ | 15.5℃ | 14.7℃ | 15.1℃ | NA | 15.1℃ | 14.4℃ | 14.4℃ | 14.5℃ | 14.3℃ | 14.3℃ | 14.4℃ | 14.3℃ | NA |
| | 20m | 17.1℃ | 15.9℃ | 16.0℃ | 15.5℃ | 14.7℃ | 15.1℃ | NA | 15.0℃ | NA | 14.4℃ | 14.5℃ | 14.4℃ | 14.4℃ | 14.4℃ | 14.3℃ | NA |
| | 30m | 17.2℃ | NA | 16.2℃ | NA | NA | 15.2℃ | NA | 15.1℃ | NA | 14.4℃ | 14.6℃ | NA | NA | 14.5℃ | 14.3℃ | NA |
| | 40m | 17.1℃ | NA | 16.1℃ | NA | NA | 15.1℃ | NA | 15.0℃ | NA | 14.4℃ | 14.5℃ | NA | NA | 14.4℃ | 14.3℃ | NA |
| | 50m | 16.9℃ | NA | 16.0℃ | NA | NA | 15.1℃ | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | 60m | 16.0℃ | NA | NA | NA | NA | 15.1℃ | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

(a)

Measurement Date : 2019/01/19 13:00:00

30 days ago |◀ 1 day ago ◀◀ 1 hour ago ◀ ▶ 1 hour later ▶▶ 1 day later ▶| Current

| Location | | Fukuura | Shirigai | Yutai | Shimonada | Kitanada | Hiburijima | Shitaba | Komobuchi | Miura | Koike | Yusu | Uwajima | Yoshida | Akehama | Mikame | Yawatahama |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | 1m | 17.5℃ | 16.2℃ | 16.6℃ | NA | NA | 15.5℃ | NA | 15.5℃ | NA | 15.0℃ | 14.9℃ | NA | NA | 15.0℃ | 14.7℃ | NA |
| | 5m | 17.4℃ | 16.4℃ | 16.5℃ | 16.1℃ | 15.1℃ | 15.4℃ | 15.4℃ | 15.5℃ | 14.8℃ | 14.9℃ | 15.0℃ | 14.4℃ | 14.6℃ | 15.1℃ | 14.6℃ | 14.3℃ |
| | 10m | 17.4℃ | 16.4℃ | 16.6℃ | 16.1℃ | 15.2℃ | 15.4℃ | NA | 15.5℃ | 14.8℃ | 14.8℃ | 14.9℃ | 14.4℃ | 14.6℃ | 14.9℃ | 14.5℃ | NA |
| | 20m | 17.4℃ | 16.2℃ | 16.4℃ | 16.1℃ | 15.1℃ | 15.3℃ | NA | 15.4℃ | NA | 14.8℃ | 14.8℃ | 14.4℃ | 14.6℃ | 14.8℃ | 14.4℃ | NA |
| | 30m | 17.4℃ | NA | 16.5℃ | NA | NA | 15.4℃ | NA | 15.4℃ | NA | 14.7℃ | 14.9℃ | NA | NA | 14.9℃ | 14.4℃ | NA |
| | 40m | 17.4℃ | NA | 16.4℃ | NA | NA | 15.3℃ | NA | 15.3℃ | NA | 14.7℃ | 14.8℃ | NA | NA | 14.7℃ | 14.4℃ | NA |
| | 50m | 17.2℃ | NA | 16.4℃ | NA | NA | 15.3℃ | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | 60m | 17.3℃ | NA | NA | NA | NA | 15.3℃ | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

(b)

**Figure 3.** The measurement data in a tabular: (a) current status and (b) past status.

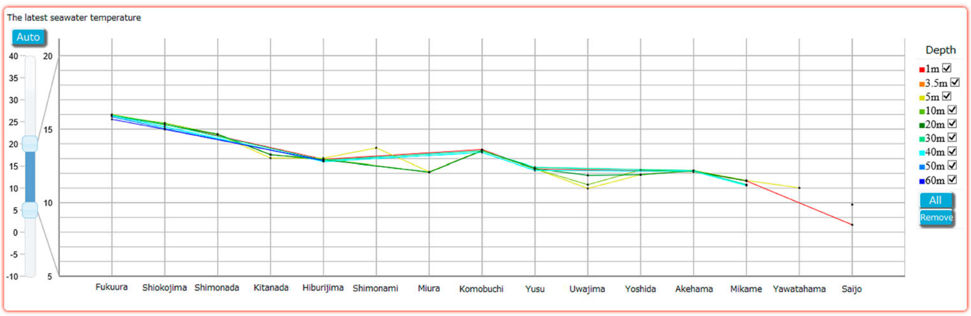



**Figure 4.** Displaying the latest measurement data as a graph.

displayed by moving a slider, and the water depth to be displayed can be selected by unchecking a check box.

### *3.5.4. Graph display of time change*

Function (d) is the function aimed to graphically display the variations in the past seawater temperature for each measurement point, as shown in Figure 5. Each graph is defined as a line graph representing the seawater temperature on the vertical axis and the time on the horizontal axis. It allows analysing the variations in the seawater temperature due to the course of time and the difference in water depths at the same time. In addition, similarly as in Function (c), the colour of lines in a graph are coded, and users can select the depth of water to be displayed and change the display settings of the upper and lower limits of the seawater temperature arbitrarily. Furthermore, users can select the display period from 24 hours, 48 hours, 7 days, 30 days and 60 days, as fishery researchers may require to analyse the seawater temperature variation over time during a short-term or a long-term period. Selecting a period to display can be switched by a simple operation using the slider method.

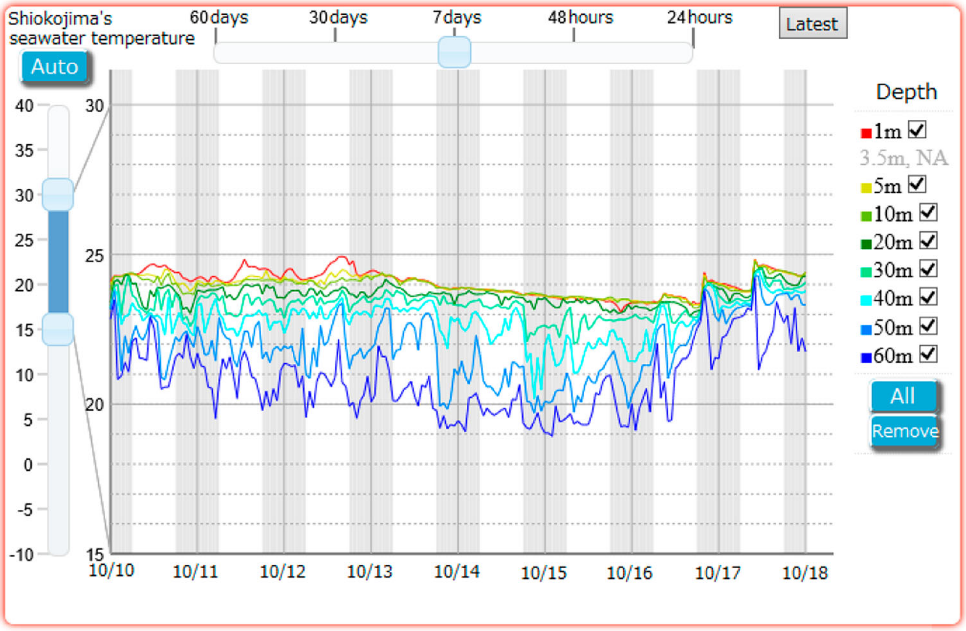



**Figure 5.** Displaying variations in the seawater temperature over time.

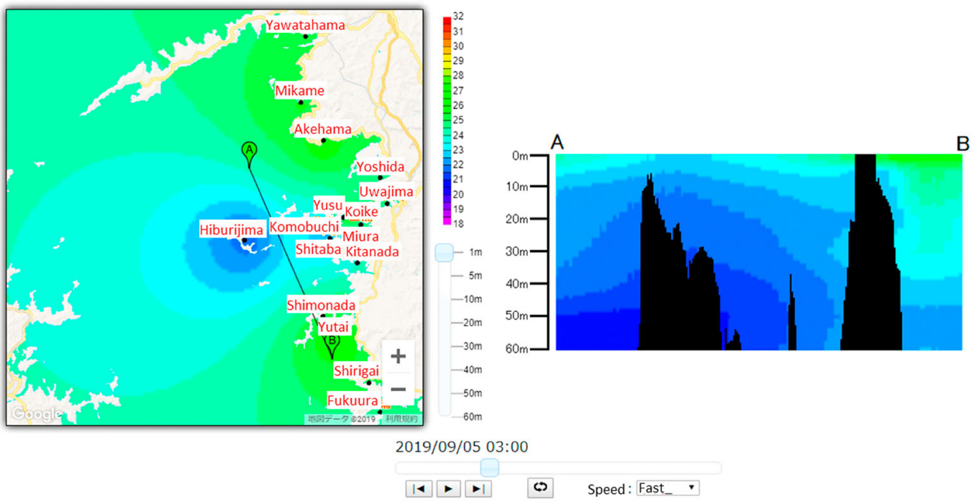



**Figure 6.** Displaying the seawater temperature variation over time in three dimensions.

### *3.5.5. Three-dimensional display*

In Function (e), the seawater temperature variation over time can be visualized in three dimensions by displaying a temperature distribution map on a plane of the specified water depth and the cross-sectional temperature distribution map of the two points specified on the map, as shown in Figure 6. Users can change the display water depth and the display time arbitrarily by a simple operation using the slider system. In addition, we implement a function to switch a displayed temperature distribution chart in constant time intervals (animation function) as a device to enable users to analyse the seawater temperature variation over time. Users can animate a temperature distribution chart similarly as using a video playback software and a video playback interface often embedded in web sites.

We discussed a method of interpolating the water temperature at a certain point in the area surrounded by the measurement points based on the water temperature information obtained from the surrounding measured points to implement this function. We decided to apply linear interpolation (Meijering, 2002) to a depth direction and to utilize the inverse distance waited method (IDW) (Bailey & Gatrell, 1996) to plane interpolation. Figure 7 represents a simple interpolation image.

IDW is a method to estimate the data at a certain point by weighting the reciprocal of the square of the distance to the measurement point to the measurement data. In this function, the estimated value at point $s$ is calculated using the following formula:

$$\mu(s) = \frac{\sum_{i=1}^{n} w_i(s)\mu_i}{\sum_{j=1}^{n} w_j(s)}, \qquad w_i(s) = \frac{1}{d(s, s_i)^2}$$

Symbol $n$ denotes the number of measurement points; symbol $\mu_i$ corresponds to the real value of the $i$th measurement point; function $d(s, s_i)$ describes the distance between points and measurement point $s_i$, and function $w_i(s)$ means the weight of measurement point $s_i$ at point $s$ in the equation.

Linear interpolation is a method of estimating the estimated value at one point between two measured points as approximately linear expression. In this function, the estimated value at water depth $d$ ($d_1 < d < d_2$) between the measured values $\lambda(d_1)$

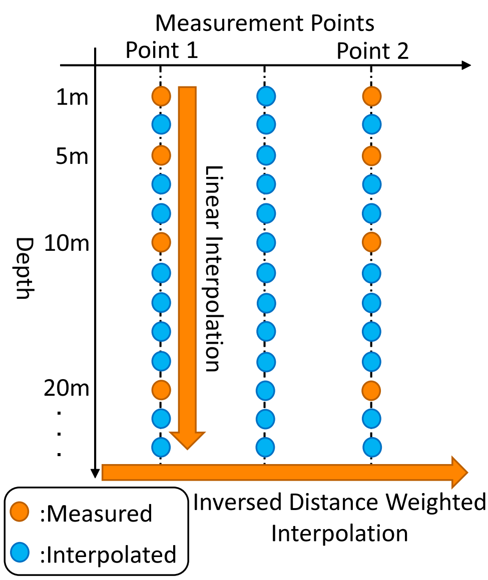



**Figure 7.** Interpolation method.

and $\lambda(d_2)$ is calculated by the following formula:

$$\lambda(d) = \lambda(d_1) + \frac{\lambda(d_2) - \lambda(d_1)}{d_2 - d_1}(d - d_1)$$

Another issue with implementing this function is associated with the time required to display a distribution map after it is requested. This is because when interpolation calculation is executed every time it is required, it takes more 1 minute to display. To solve this issue, we develop a program that generates interpolation data and saves them to the server. This program runs every hour. The interpolation data created by this program can be read as much as necessary for displaying, when it is requested. It is possible to display the data in approximately 20 seconds by incorporating such ingenuity.

#### 3.5.6. Storing historical data

Users can download the measurement data (.csv format file) corresponding to a selected measurement place and a measurement period by specifying them and pressing the button named as 'Download' in Function (f). Specifically, we enabled to designate the location by the radio button method, to select the period using a text box and to display the calendar when entering the required period so that a user could download the required data through a simple operation.

### 3.6. Effects of function implementation

In this section, we describe how implementing of each function has changed the environment where fishermen and fisheries researchers are placed.

First, we describe the effect induced by function (a). Fishery workers did not have any way to locate observation devices before this function was implemented. However, they can now check the location of the devices near their fishing grounds and the overall setting status at any time by running this function.

Next, we describe the effect induced by function (b), function (c) and function (d). Only persons involved in the installation of an observation device could obtain the water temperature data measured by this device, before this function was implemented. However, fishery workers can now easily understand how the water temperature changes over time at the measurement points near their fishing grounds by implementing this function. In addition, fishery researchers no longer need to create a graph for each measurement data point.

Next, we describe the effect induced by function (e). Functions (a)–(d) were implemented before the time of reporting at ACIIDS 2018 (Agusa et al., 2018). Function (e) was newly implemented after presenting that report.

Fishery workers and researchers were able to get access only to the most recent information and changes over time on each measurement point before this function was implemented. However, by implementing this function, they can now easily analyse the water temperature in the entire Uwa Sea.

Finally, we describe the effect caused by function (f). Fishery researchers performed the work of collecting the measurement data and putting them together into a single file (such as a csv file) before this function was implemented. However, this effort is no longer necessary, as it leads to the reduction in time costs required to analyse the water temperature information by implementing this function.

## 4. Evaluations

An information system is an individual and one-time action that can be used by an intended person (owner) to change the activities of individuals or organizations with a certain intention, according to Information Processing Society of Japan, Special Interest Group on Information Systems (IPSJ-SIG-IS, 2012, 2013). Therefore, we consider that a system that only combines multiple programs and does not have any positive impact on society does not have any value as an information system.

We evaluated user satisfaction and the impact of the proposed system based on the quantitative data to perform the effectiveness assessment.

### 4.1. Evaluation of user satisfaction

#### 4.1.1. Purpose

The seawater temperature announcement system is a tool in which functional requirements have been identified based on interviewing fishery workers and fishery researchers, and specific functions have been implemented to satisfy these requirements. Such requirements need to be met to realize a relevant and useful information system.

Therefore, we examined whether the proposed system satisfied the requirements by conducting the operational testing of each function.

#### 4.1.2. Methods

To perform the operational testing of the table and graph display functions on the proposed system, we created tables and graphs using dummy data by running relevant functions. We aimed to verify whether it was possible to obtain the accurate output for positive values, negative values and abnormal values in dummy data. Then, we verified whether each execution result corresponded to the test item.

In addition, we tested whether the data download was realized appropriately under the following conditions:

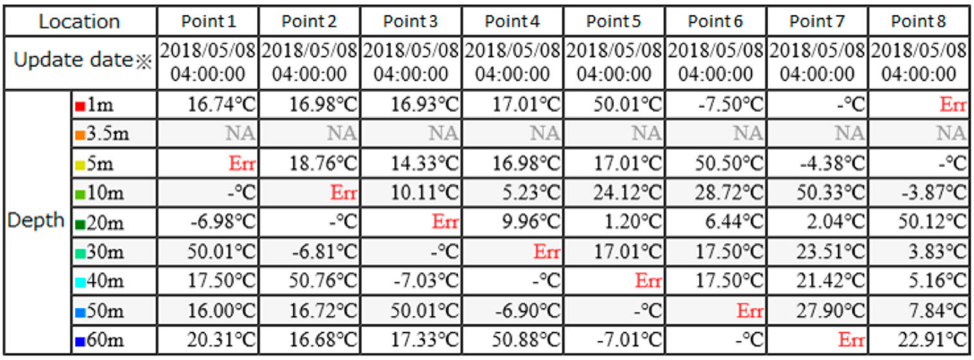
- The case in which the specified period is within the measurement period of the selected measurement point
- The case in which the start point of the specified period is before the measurement start date of the selected measurement point
- The case in which the end point of the specified period is after the current date.

**Table 2.** Experimental environment.

| CPU | Intel(R) Core(TM) i7-6700 CPU 3.40 GHz |
|---|---|
| OS | Windows 10 education |
| RAM | 16.0 GB |
| Browser | Internet explorer 11.371.16299.0 |

**Table 3.** Dummy data used for evaluation (Displaying table).

| Depth | Point1 | Point2 | Point3 | Point4 | Point5 | Point6 | Point7 | Point8 |
|---|---|---|---|---|---|---|---|---|
| 1 m | 16.74 | 16.98 | 16.93 | 17.01 | 50.01 | −7.50 | (Blank) | (Error) |
| 5 m | (Error) | 18.76 | 14.33 | 16.98 | 17.01 | 50.50 | −4.38 | (Blank) |
| 10 m | (Blank) | (Error) | 10.11 | 5.23 | 24.12 | 28.72 | 50.33 | −3.87 |
| 20 m | −6.98 | (Blank) | (Error) | 9.96 | 1.2 | 6.44 | 2.04 | 50.12 |
| 30 m | 50.01 | −6.81 | (Blank) | (Error) | 17.01 | 17.50 | 23.51 | 3.83 |
| 40 m | 17.50 | 50.76 | −7.03 | (Blank) | (Error) | 17.50 | 21.42 | 5.16 |
| 50 m | 16.00 | 16.72 | 50.01 | −6.90 | (Blank) | (Error) | 27.90 | 7.84 |
| 60 m | 20.31 | 16.68 | 17.33 | 50.88 | −7.01 | (Blank) | (Error) | 22.91 |



| Location | | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 | Point 6 | Point 7 | Point 8 |
|---|---|---|---|---|---|---|---|---|---|
| Update date※ | | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 | 2018/05/08 04:00:00 |
| Depth | 1m | 16.74°C | 16.98°C | 16.93°C | 17.01°C | 50.01°C | -7.50°C | -°C | Err |
| | 3.5m | NA | NA | NA | NA | NA | NA | NA | NA |
| | 5m | Err | 18.76°C | 14.33°C | 16.98°C | 17.01°C | 50.50°C | -4.38°C | -°C |
| | 10m | -°C | Err | 10.11°C | 5.23°C | 24.12°C | 28.72°C | 50.33°C | -3.87°C |
| | 20m | -6.98°C | -°C | Err | 9.96°C | 1.20°C | 6.44°C | 2.04°C | 50.12°C |
| | 30m | 50.01°C | -6.81°C | -°C | Err | 17.01°C | 17.50°C | 23.51°C | 3.83°C |
| | 40m | 17.50°C | 50.76°C | -7.03°C | -°C | Err | 17.50°C | 21.42°C | 5.16°C |
| | 50m | 16.00°C | 16.72°C | 50.01°C | -6.90°C | -°C | Err | 27.90°C | 7.84°C |
| | 60m | 20.31°C | 16.68°C | 17.33°C | 50.88°C | -7.01°C | -°C | Err | 22.91°C |

**Figure 8.** Evaluation results (displaying table).

### *4.1.3. Experimental environment*

Table 2 represents a computer environment and a browser used to perform the evaluation of the proposed system.

### *4.1.4. Results and considerations*

Table 3 provides the dummy data used to perform the operational testing of the table display function. We set the data measurement time to 4 a.m. on 8 May 2018. Figure 8 represents a table displaying the program execution. The test items and the results of the operational test are shown in Table 4. 'Yes' in the 'Result' column in Table 4 confirmed the satisfaction of test items. Table 4 shows that all test items have been satisfied. Table 5 shows the dummy data used in the operational testing of the graph display function. Figure 9 represents the graph displayed when the program is executed. The test items and the results of the operational test are shown in Table 6. 'Yes' in 'Result' column in Table 6 confirms the user satisfaction of test items. Table 6 indicates that all test items are satisfied. Table 7 shows the results of operational testing on the data storing function. 'Yes' in the 'Result' column in Table 7 confirms the possibility to

**Table 4.** Results of the operational test (the table display function).

| No. | Test item | Result |
|---|---|---|
| 1 | Is it possible to output the value of data correctly in the case of the normal seawater temperature data? | Yes |
| 2 | If the seawater temperature data of a specific depth is blank, Is it possible to output '–'? | Yes |
| 3 | If the seawater temperature data of a specific depth is damaged, is it possible to output 'Err'? | Yes |
| 4 | Is it possible to output 'NA' in the column representing the depth that was not covered? | Yes |

**Table 5.** Dummy data used for evaluation (Displaying graph).

| Date | 1 m | 5 m | 10 m | 20 m | 30 m | 40 m | 50 m | 60 m |
|---|---|---|---|---|---|---|---|---|
| 2018/05/07 5 p.m. | 16.91 | 16.98 | 16.93 | 17.01 | 17.01 | 16.98 | 16.97 | 50.71 |
| 2018/05/07 6 p.m. | (Blank) | (Error) | 10.11 | 5.23 | 24.12 | 28.72 | 19.34 | 20.28 |
| 2018/05/07 7 p.m. | −2.38 | (Blank) | (Error) | 9.96 | 1.2 | 6.44 | 12.25 | 20.12 |
| 2018/05/07 8 p.m. | | | | (No Data) | | | | |
| 2018/05/07 9 p.m | 50.34 | −6.81 | (Blank) | (Error) | 17.01 | 17.50 | 16.01 | 17.31 |
| 2018/05/07 10 p.m. | 16.12 | 50.76 | −7.03 | (Blank) | (Error) | 17.50 | 16.33 | 17.31 |
| 2018/05/08 11 p.m. | 16.14 | 16.72 | 50.01 | −6.90 | (Blank) | (Error) | 16.12 | 17.79 |
| 2018/05/08 0 a.m. | 16.16 | 16.68 | 17.33 | 50.88 | −7.01 | (Blank) | (Error) | 17.53 |
| 2018/05/08 1 a.m. | 16.15 | 16.60 | 17.97 | 16.98 | 50.01 | −7.50 | (Blank) | (Error) |
| 2018/05/08 2 a.m. | 16.12 | 16.33 | 17.65 | 16.98 | 18.05 | 50.50 | −6.00 | (Blank) |
| 2018/05/07 3 a.m. | 16.56 | 16.02 | 17.22 | 16.98 | 19.22 | 5.88 | 50.00 | −0.31 |
| 2018/05/08 4 a.m. | (Error) | 18.76 | 14.33 | 16.98 | 17.01 | 17.50 | 16.00 | 20.31 |

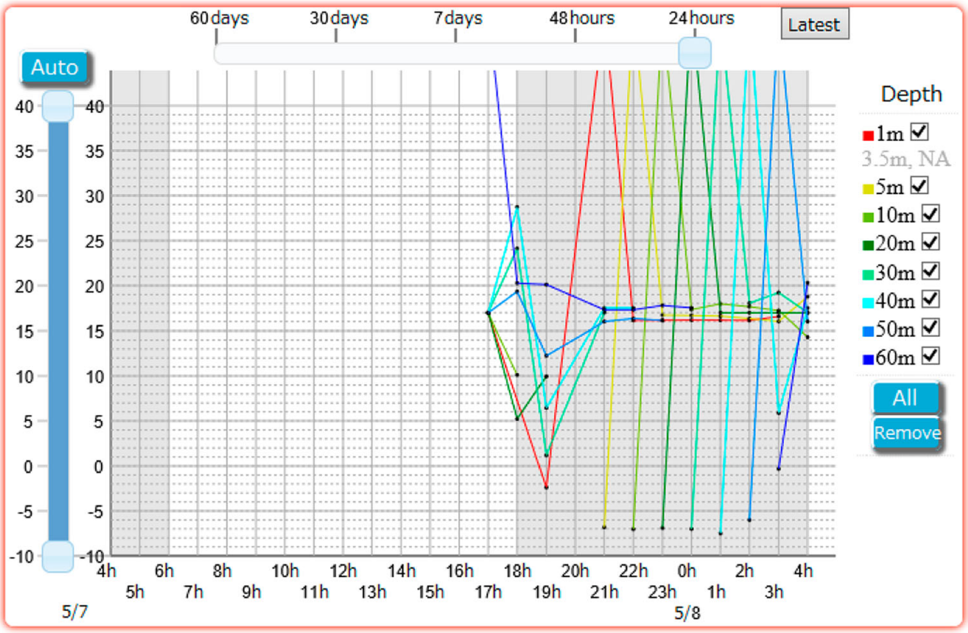



**Figure 9.** Execution result (displaying graph).

**Table 6.** Evaluation results (displaying graph).

| No. | Test item | Result |
|---|---|---|
| 1 | Is it possible to output the points correctly for all regular seawater temperature data? | Yes |
| 2 | Are the points and those connected by lines without coming out? | Yes |
| 3 | Is the empty point is outputted when the seawater temperature data about a specific location or the seawater temperature data measured at a specific depth does not exist or damaged? | Yes |
| 4 | Is it possible to display a graph accurately even while changing the display setting? | Yes |

**Table 7.** Evaluation results (storing data).

| Case | Result |
|---|---|
| The specified period is within the measurement period of the selected measurement point | Yes |
| The start point of the specified period is before the measurement start date of the selected measurement point | Yes |
| The end point of the specified period is after the current date | Yes |

operate normally under particular conditions. Table 7 shows that the download of the measurement data was completed successfully under all conditions.

## 4.2. Evaluation of interpolation accuracy

### 4.2.1. Purpose

We decided to employ IDW to perform the plane and linear interpolation for depth direction while implementing the function that visualized the seawater temperature variation over time in three dimensions.

We evaluated the interpolation accuracy to examine whether the adopted interpolation method was suitable for this function.

### 4.2.2. Methods

We evaluated the applicability of IDW as an interpolation method using the following two approaches.

In the first approach, we evaluated IDW according to the following procedure:

(1) Select one from all measurement points
(2) Remove the selected measurement point from the set of measurement points used for interpolation (assuming that the measured value is unknown)
(3) Calculate the estimated value at the coordinates of the selected measurement point and compare it with the measurement value (calculate the error)
(4) Execute procedures 1–3 for all measurement points.

Then, we compared the results with the data obtained by the measurement outcomes obtained using the research vessels of the Institute of Water Research.

### 4.2.3. Results and considerations

Table 8 represents the difference between the measured values and the interpolated ones for each station/each depth. Among the areas surrounding each measurement point, Fukuura, which was the outer part, exhibited an error of more than 1°C, and in Komobuchi, the central part, the accuracy was less than 0.2°C at maximum. In Akehama, which was in the middle part between them, the accuracy was less than 0.3°C at maximum.

**Table 8.** Difference between the measured and interpolated values.

| Depth | 1 m | 5 m | 10 m | 20 m | 30 m | 40 m | 50 m | 60 m |
|---|---|---|---|---|---|---|---|---|
| Fukuura | 1.143 | 1.390 | 1.305 | 1.388 | 1.091 | 1.067 | 1.357 | 0.858 |
| Shiokojima | 0.310 | 0.805 | 0.797 | 0.764 | 0.321 | 0.342 | 0.841 | 0.722 |
| Shimonada | | 0.619 | 0.629 | 0.591 | | | | |
| Kitanada | | 0.039 | 0.004 | 0.063 | | | | |
| Hiburijima | 0.473 | 0.284 | 0.334 | 0.293 | 0.347 | 0.350 | 0.625 | 0.068 |
| Shitaba | | 0.014 | | | | | | |
| Miura | | 0.097 | 0.116 | 0.076 | | | | |
| Komobuchi | 0.064 | 0.029 | 0.033 | 0.041 | 0.124 | 0.166 | | |
| Yusu | 0.010 | 0.032 | 0.040 | 0.070 | 0.065 | 0.115 | | |
| Uwajima | | 0.042 | 0.016 | 0.141 | | | | |
| Yoshida | | 0.042 | 0.010 | 0.084 | | | | |
| Akehama | 0.074 | 0.070 | 0.128 | 0.103 | 0.224 | 0.268 | | |
| Yawatahama | | 0.700 | | | | | | |

**Table 9.** Maximum error at each depth.

| Depth | 1 m | 5 m | 10 m | 20 m | 30 m | 40 m |
|---|---|---|---|---|---|---|
| Maximum error | 2.399 | 3.257 | 4.910 | 4.776 | 0.721 | 1.040 |

Table 9 shows the maximum error at each depth obtained by the second method. The largest error was the value at the depth of 10 m, being equal to 4.91°C. Such a result could be explained by the fact that the nearby measurement device registered an abnormal value that differed from the actual temperature and used that value in the interpolation calculation. Table 10 provides the experimental data (measured at 11 a.m. on 1 August 2018), and Figure 10 represents the location in which the measurement was conducted by a survey ship and the nearby measurement devices. Table 11 provides the values measured from 10 a.m. to 12 a.m. on 1 August 2018 by the measurement device (Yoshida) that was the nearest to the location in which the measurement was conducted by the survey ship. The measured value provided by Yoshida at 11 a.m. on 1 August 2018 was 3°C higher than the value measured between 10 a.m. and 12 a.m. according to Table 11. It was unlikely that there was a change in the water temperature that suddenly rose and then returned to its original value during a short period of 2 hours, and we concluded that it was highly possible that the measurement device registered an abnormal value.

Processing the occurrence of abnormal values is one of future research tasks.

### 4.3. Quantitative evaluation of effects

#### 4.3.1. Purpose

What is important in the development of information system is to observe what changes have been made to whom by system implementation (IPSJ-SIG-IS, 2012). Therefore, we evaluated the impact of the proposed system on the activity of fishery workers and researchers by investigating the changes in the number of accesses to the proposed system over time and in the access status of each user.

#### 4.3.2. Methods

In the proposed system, we recorded an access log while assigning unique IDs to users utilizing cookies and web beacons. Figure 11 illustrates the access log recording mechanism. When users access the proposed system, user information (the access date, browser, OS, etc.) is processed and stored by the access terminal information recording program using web beacons. This program loads the obtained information to a log file that is stored on the server. In addition, it generates a new unique ID for the first access and stores it in a user's terminal utilizing cookie files. Thereafter, upon the occurrence of an access, it is possible to identify from which terminal the access is performed by referring to the unique ID stored in the user's terminal.

**Table 10.** Experimental data with the maximum error at the depth of 10 m.

| Depth | 1 m | 5 m | 10 m | 20 m | 30 m |
|---|---|---|---|---|---|
| Measurement data | 22.771 | 21.613 | 20.980 | 20.715 | 20.562 |
| Interpolation data | 24.130 | 24.870 | 25.890 | 25.060 | 20.870 |
| Error (Measurement value − Interpolation value) | −1.359 | −3.257 | −4.910 | −4.345 | −0.308 |

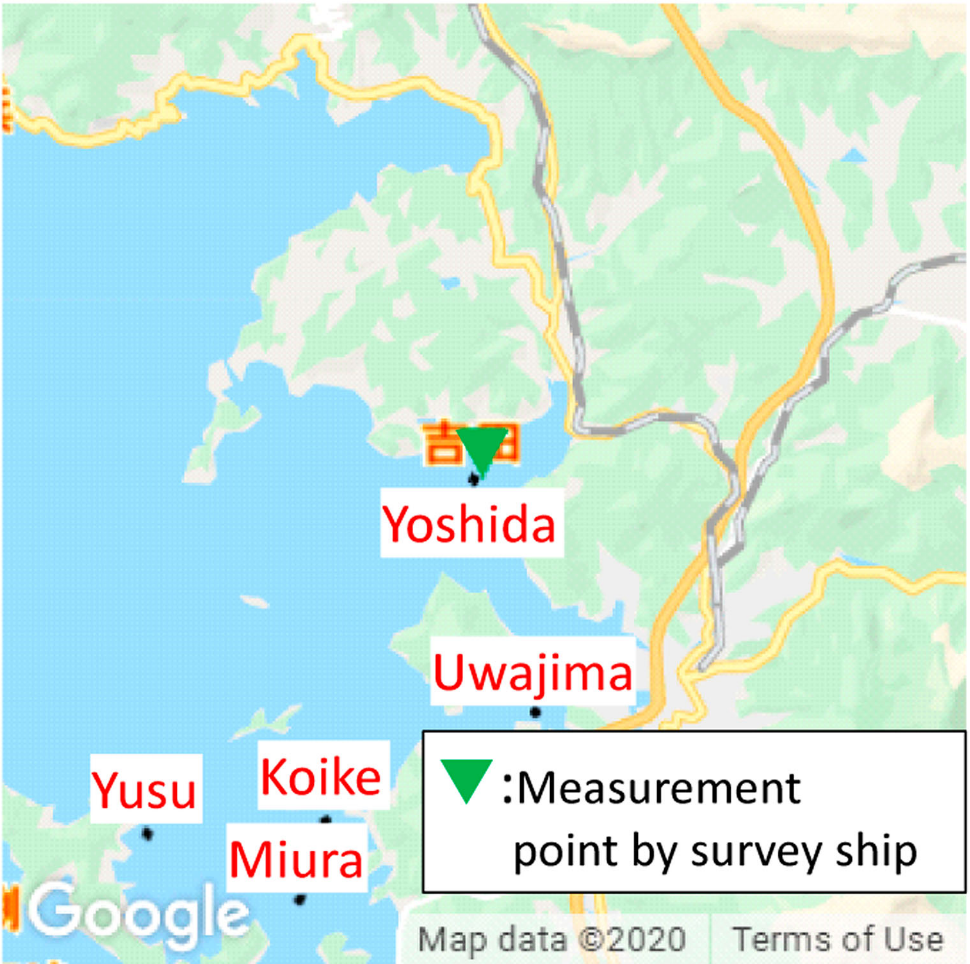



**Figure 10.** Location where the measurement by survey ship.

**Table 11.** Measurement data of the nearest neighbour measurement device (Yoshida).

| | | 2018/08/01 | 2018/08/01 | 2018/08/01 |
|---|---|---|---|---|
| | Measurement date | 10 a.m. | 11 a.m. | 12 a.m. |
| | 5 m | 21.45 | 24.87 | 21.64 |
| Depth | 10 m | 20.99 | 25.89 | 21.07 |
| | 20 m | 20.64 | 25.06 | 20.72 |

To investigate changes in the number of accesses over time, we aggregated the number of unique accesses (the accesses from the same IP address in the same time zone was counted once) per day. Then, we evaluated the effectiveness of the proposed system based on the information about changes in the number of unique accesses per year. The reason for counting accesses from the same IP address in the same time period once was that the information in the proposed system was updated every hour at most. We considered the use case scenario in which an access to the proposed system could happen again to check the latest information after updating the most recent data. We excluded

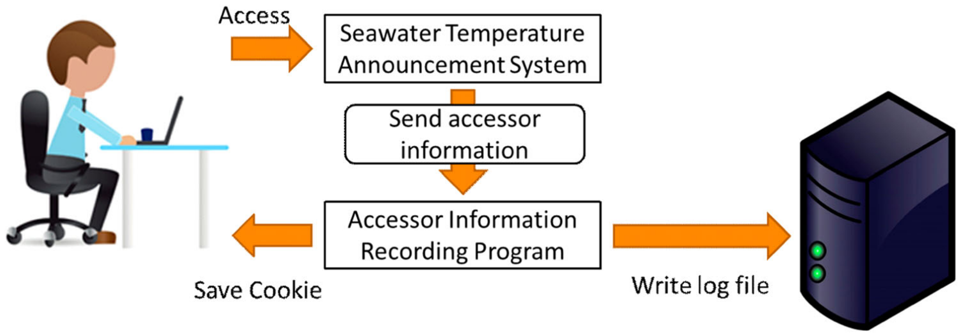



**Figure 11.** Access log recording mechanism.

the accesses from IP addresses corresponding to robots and crawlers to investigate the use of the system by fishery workers and researchers as accurately as possible.

To analyse the access status of each user, we aggregated the number of unique accesses during the last 30 days and the average of daily unique accesses (= Number of accesses in the last 30 days/Number of days in which the system was accessed during the last 30 days), for each user.

#### *4.3.3. Results and considerations*

Figure 12 illustrates the changes in the number of unique accesses to the proposed system over the period from 1 January 2018 to 1 January 2019.

From Figure 12, it can be seen that the number of unique accesses has been increasing until April, gradually decreasing in the period until October, and then, no significant increase or decrease has been observed. According to the information obtained as a result of interviewing fisheries workers and researchers, they had a need for the water temperature information specifically in the period from March to April, as many red tides occur during this period. Therefore, the increase/decrease trend represented by Figure 12 indicates that the demand for the proposed system increases accordingly during this specific period. Since February 2018, when the system was officially launched, 300–700 accesses were registered daily, with respect to seasonal changes. According to Ehime Fisheries Statistics (Ehime Prefectural Government Office, 2018b), the number of farming fishery management bodies in the Uwa Sea in 2017 was 857. Therefore, we conclude that many aquaculture fishers utilize the proposed system, and the impact of its implementation on society is considered to be significant.

Table 12 represents the number of accesses per hour during the last 30 days as of 8 February 2019 and the average number of accesses per day for two users (hereinafter,

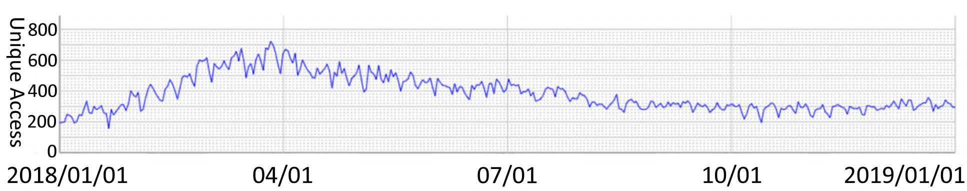



**Figure 12.** Number of unique accesses in 2018.

**Table 12.** Access status for the two considered users (investigated as of 8 February 2019).

| User A | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Access Days: 27 days | | | | | | | | | | | | |
| Average Daily Unique Access: 1.0 times/day | | | | | | | | | | | | |
| a.m. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Counts | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| p.m. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Counts | 0 | 0 | 0 | 0 | 0 | 27 | 0 | 0 | 0 | 0 | 0 | 0 |
| User B | | | | | | | | | | | | |
| Access Days: 28 days | | | | | | | | | | | | |
| Average Daily Unique Access: 2.4 times/day | | | | | | | | | | | | |
| a.m. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Counts | 4 | 3 | 0 | 0 | 1 | 0 | 2 | 7 | 6 | 4 | 2 | 2 |
| p.m. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Counts | 9 | 3 | 1 | 4 | 4 | 7 | 3 | 5 | 5 | 4 | 1 | 2 |

referred to as user A (Table 12(a)) and user B (Table 12(b))) whose activities have been significantly influenced by the implementation of the proposed system.

It was observed that user A accessed the system generally once daily, between 5 p.m. and 6 p.m. These accesses were likely to be artificial, as usually, accesses did not happen at the same time. User B was an example of a user who accessed the system more than once per day. In this way, we confirmed that users were utilizing the proposed system almost on daily basis and multiple times per day. Therefore it can be said that the implementation of our system has induced certain changes in individual activities.

## 5. Conclusion

In the present paper, we proposed a seawater temperature announcement system aimed at improving the productivity of the fishery industry. The proposed system was designed in such a way to provide the accurate water temperature information to fishery workers immediately after performing measurements.

The proposed system could be utilized through a web application that enabled the exploitation on terminals of any type, such as PC, smartphones, tablets and so on. We realized the visualization of the present conditions of the seawater temperature and its variation over time considering a spatial spread of a marine area by incorporating requests from researchers and fishery workers and by implementing the function to display this information in the forms of tables, graphs and distribution maps. The display setting of graphs in the proposed system was designed in such a way that visualizing the seawater temperature information could be launched through a simple operation (e.g. selecting water depth to display was implemented as a check box, setting a range of temperature and a period to display was realized in the form of sliders). Furthermore, we realized the specific layout of the web page in the system interface that allows representing important indicators. For example, the background colour of the 'Update date' column in the table is highlighted in red to indicate the buoy in which a failure had occurred or the measurement process was paused while displaying the latest measured data.

We confirmed 300–700 unique accesses to the proposed system daily since the official operation has been launched. Considering the number of farming aquaculture fishers in the Uwa Sea, we consider the impact of the proposed system on the aquaculture in Ehime Prefecture as significant.

In addition, an increasing number of users utilizing the proposed system on a regular basis is confirmed almost every day. It can be concluded that the introduction of this system has induced a certain change in individual activities.

As the future research work, we plan to improve the interpolation accuracy in the 3D visualization function and to re-examine the interpolation method.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## Note

1. This paper is an extended version of the paper titled 'Development of Seawater Temperature Announcement System for Quick and Accurate Red Tide Estimation' presented at the 10th Asian Conference on Intelligent Information and Database Systems (ACIIDS 2018). We added the description about the functions released and problems discovered since January 2018. We also added the description about the evaluation method of this system and its result.

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