

A methodology for acoustic and geospatial analysis of diverse artificial-reef datasets

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A methodology is introduced for understanding fish-school characteristics around artificial reefs and for obtaining the quantitative relationship between geospatial datasets related to artificial-reef environments using a new geographic information system application. To describe the characteristics of fish schools (energetic, positional, morphological characteristics and dB difference range), acoustic data from two artificial reefs located off the coast of Shimonoseki, Yamaguchi prefecture, Japan, were used. To demonstrate the methodology of the geospatial analysis, diverse datasets on artificial reefs, such as fish-school characteristics, marine-environmental information from a conductivity, temperature, and depth sensor, information on artificial reefs, seabed geographic information, and sediment information around the reefs, were utilized. The habitat preference of fish schools was demonstrated quantitatively. The acoustic density of fish schools is described with respect to the closest distance from reefs and the preferred reef depths, the relationship between fish schools and environmental information was visualized in three dimensions, and the current condition of the reefs and their connection to seabed type is represented. This geospatial method of analysis can provide a better way of comprehensively understanding the circumstances around artificial-reef environments.

Keywords: acoustic, artificial reef, fish schools, geospatial, GIS, three-dimensional visualization.

Introduction

A lot of effort has been devoted to ensuring that fishing grounds established on artificial reefs around Japan are managed sustainably and deliver high yields. Artificial reefs can enhance the productivity but also protect and recover fish habitat, as well as preserve and nurture fisheries resources (Jensen, 2002; Relini *et al.*, 2002; Seaman, 2002). Monitoring the marine ecology of artificial reefs is essential, specifically examining changes in the complex marine environment, in local fishing productivity, and in the diversity of marine organisms and species (Fabi and Sala, 2002; Nakamura and Hamano, 2009; Boswell *et al.*, 2010). To understand the marine ecology, biological information along with appropriate marine-environmental information needs to be considered (Iida *et al.*, 1995). Further, to evaluate the effectiveness of artificial reefs quantitatively, a methodology for understanding fish-school distribution in and around artificial reefs and for recognizing the relationship between a variety of datasets relating to marine organisms and the reef environment is crucial.

A diverse dataset in relation to reef environment is not easy to analyse, particularly with respect to the relationships between various datasets based on the spatial location. The reasons for this difficulty are (i) the spatial distribution of fish around artificial reefs, especially their distance from reefs, is difficult to estimate because they live in a complex marine environment, and travel freely, and (ii) data formats and scales of time and space in terms of biological information and marine-environmental

information differ considerably. As a consequence, the data processing and analysis needed to understand the relationships between various datasets and the complexities of artificial reefs are intricate (Hamano *et al.*, 2000). Nevertheless, to estimate quantitatively the environmental influence of artificial reefs, and their effect on the distribution and characteristics of fish schools, is of great importance.

Knowledge of fisheries and oceanography and the availability of data have both increased dramatically along with information technology (IT) and exploration technology. The burgeoning knowledge of marine ecology and biodiversity has come about using many measuring instruments, e.g. conductivity, temperature, and depth sensors (CTDs), video and stereo cameras, and various acoustic and net-sampling systems (Shyue and Yang, 2002; Ryan *et al.*, 2009). Vast, high-resolution datasets on marine organisms and their environments are now easily acquired by advanced survey instruments. As a result, both the sampling rate and volume of datasets have expanded. Hence, time and effort is required for processing and analysing the various and vast datasets. A solution can be the use of a geographic information system (GIS), which uses state-of-the-art IT, can manage a wide variety of information from diverse data sources, can visualize the relationship between datasets, and can support quantitative comparable analysis between the datasets. Therefore, GIS has been used widely in fisheries and oceanographic fields (Tseng *et al.*, 2001; Tanoue *et al.*, 2008).

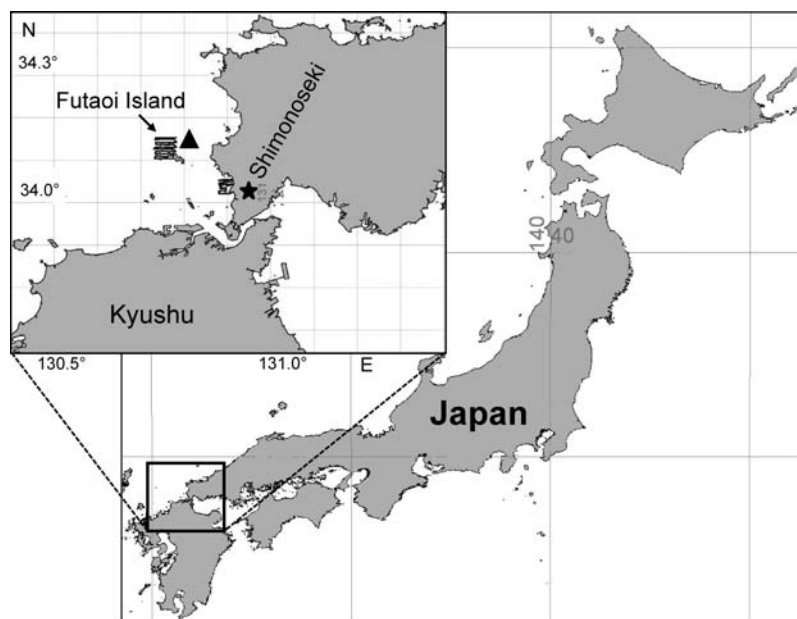


Figure 1. Map of Japan showing the study areas. The transect lines next to the triangle indicate the site of the 2001 acoustic survey, and those near the star the site of the 2008 acoustic survey.

The aim of this study was to attempt to introduce a methodology for understanding fish-school distribution around artificial reefs and for deducing the relationships between geospatial datasets related to artificial-reef environments using a GIS application.

Methods

Data collection

Artificial reefs have been established from 1955 to 1997 along the Kitaura Coast, Shimonoseki City, Japan. Information is derived from two sites around Futaoi Island and along the Shimonoseki Coast. The study area includes two sites of artificial reefs and two of acoustic-transect surveys (Figure 1). Information on artificial reefs, such as reef location, material, area, and seabed type, was obtained from a reef register managed by the Shimonoseki City Council.

For the artificial reefs at Futaoi Island, a sidescan sonar (Edgetech, 272TD, 100 and 500 kHz) was used to determine the precise locations on 10 June 2001. They were measured with DGPS (GR-80, Furuno) and GPS (GP-50 Mark3, Furuno); the total number of artificial reefs was 1442 (Hamano *et al.*, 2002). Futaoi Island reefs were established on the seabed between 34°08'N and 34°10'N and between 130°43'E and 130°49'E. Minimum and maximum depths were 26 and 70 m, respectively. Futaoi Island reefs were constructed of a variety of material, e.g. concrete, used motorcar tyres, and fibreglass-reinforced plastic.

Shimonoseki Coast reefs were installed on the seabed between 33°57'N and 34°23'N and between 130°38'E and 130°58'E, with minimum and maximum depths of 1 and 79 m, respectively (average water depth and standard deviation, s.d., was 29.85 ± 23.13 m). The materials used for the constructions along the Shimonoseki Coast were stone, concrete, steel, rubber, old boats, etc.

Acoustic transects were run to investigate fish-school distributions around two artificial-reef sites, with the echosounder calibrated following the standard method of calibration (Foote *et al.*, 1986). The calibration-setting parameters and other parameters

Table 1. Parameter settings of the scientific echosounder.

Parameter	2001	2008	
Frequency (kHz)	70	70	200
Transmit power (W)	800	800	400
Pulse length (ms)	0.512	0.256	0.064
Transducer gain (dB)	20.47	18.76	26.00
Absorption coefficient (dB m ⁻¹)	0.02	0.022	0.052
Minor-axis beam width (°)	11.52	15.83	6.22
Major-axis beam width (°)	11.62	11.19	5.90
Equivalent beam width (dB re 1 Steradian)	−16.80	−16.80	−20.70

are listed in Table 1. Acoustic data at the Futaoi Island reefs were collected from 08:50 to 15:20 local time on 5 July 2001 using an echosounder (Simrad EK60, 70 kHz). Acoustic data from the Shimonoseki Coast reefs were obtained using the same sounder (but two frequencies: 70 and 200 kHz), from 09:42 to 12:50 local time on 25 May 2008. Vessel speed for the 2001 and 2008 surveys was ~4–5 knots. The lengths of the parallel transect lines were ~2 nautical miles (hereafter, miles) and the intervals between them were 0.16 miles. For the 2008 survey from the Shimonoseki Coast reefs, marine-environmental data were obtained with a CTD (JFE Advantech, AAQ1183) at the same time as the acoustic survey. The marine environmental data were acquired from three points on each acoustic transect, e.g. two points at the edge and one position in the centre. Sediment data (grain size) and information on the coastline were obtained from the Japan Hydrographic Association, and bathymetric information from the Environmental Simulation Laboratory Company, Ltd.

Detection of fish schools and their characteristics

To understand the characteristics of fish schools, acoustic data from two acoustic surveys from two different artificial reefs over different periods of time were used. The school-detection feature

Table 2. Setting parameters of school detection for 2001 fish schools and 2008 fish schools using acoustic data.

Parameter	2001 fish schools	2008 fish schools
Minimum data threshold	−65	−70
Minimum total school length	4	5
Minimum total school height	2	1
Minimum candidate length	4	4
Minimum candidate height	1	1
Maximum vertical linking distance	1	1
Maximum horizontal linking distance	5	4

of Echoview (Myriax, version 4.90; Myriax, 2011a) was used to detect the schools from acoustic data. Table 2 shows the parameters used for school detection on the 70-kHz echograms of both 2001 and 2008 surveys. With school detection, the aim is to identify even small schools around the artificial reefs. To decide the appropriate parameters of school detection, a small but representative number of fish schools was selected initially to measure length, height, and the distance between neighbouring schools. The parameters were decided according to the sizes of the fish schools measured. Vessel speed and ping repetition rate were set at a suitable minimum candidate length, and a vertical resolution based on pulse length was applied to select an appropriate minimum candidate height. In 2001, weak signals were observed in the acoustic data over almost the entire water column. Therefore, as a minimum threshold for that year, the data threshold was set at −65 dB. The characteristics of the schools detected in both years were exported in a comma-separated-value (CSV) file format. The schools detected using acoustic data in 2001 and 2008 are referred to hereafter as “2001 fish schools” and “2008 fish schools”, respectively. There were 425 schools in 2001 and 179 schools in 2008.

Fish-school characteristics were categorized into energetic, morphological, and positional types (Reid *et al.*, 2000). One reason why school descriptors are used in this study is that they have been very influential in the classification of fish schools in other studies (Haralabous and Georgakarakos, 1996; Coetzee, 2000). To determine the energetic characteristics of a fish school, the mean volume-backscattering strength of a school (S_V) and its standard deviation were used. The positional characteristics included fish-school depth, bottom depth, and altitude. The morphological characteristics included length, height, perimeter, and a measure of area defined as a cross-sectional area of the plane of the echogram. Altitude is the distance between the lower part of a fish school and the seabed, and it is derived from the equation

$$\begin{aligned} \text{Altitude of a fish school} &= \text{Mean water depth} \\ &- \text{Mean depth of school} \\ &- \frac{\text{mean height of school}}{2}. \end{aligned} \quad (1)$$

The acoustic data in 2008 were collected at two frequencies, 70 and 200 kHz. Therefore, frequency characteristics using a multifrequency technique, the difference between the mean volume-backscattering strength at two frequencies, the so-called dB difference, were used for 2008 fish schools. This technique has been used widely, especially to distinguish fish schools from krill or plankton and to classify age groups among the same

species (Kang *et al.*, 2002, 2006). However, it has not been used to discriminate fish schools in an artificial-reef environment though can be beneficial for supporting fish-species identification in the environment (Nakamura and Hamano, 2009). The dB difference is

$$\Delta S_V = \frac{S_{Vf_2}}{S_{Vf_1}}, \quad (2)$$

where S_{Vf_1} and S_{Vf_2} are the mean S_V (m^{-1}) values in a cell (range in vertical and horizontal) at 70 and 200 kHz, respectively. However, when the decibel domain is used, Equation (2) transforms to the more generally used Equation (3):

$$\Delta \text{MVBS} = \text{MVBS}(f_2) - \text{MVBS}(f_1), \quad (3)$$

where MVBS is the mean volume-backscattering strength, i.e. mean S_V (dB m^{-1}), and f_1 and f_2 are 70 and 200 kHz, respectively. In this study, frequency characteristics apply to all the fish schools detected, meaning that the region of a detected fish school was used as a cell. Therefore, ΔMVBS was calculated based on an individual fish school.

Three-dimensional interpolation of marine-environmental data

Marine-environmental data (salinity, temperature, turbidity, chlorophyll, and dissolved oxygen) were determined from the CTD survey carried out along with the acoustic survey in 2008. It was interpolated using an inverse distance-weighted (IDW) interpolation method in the GIS application Eonfusion (Myriax, version 2.1; Myriax, 2011b); one of the most commonly used techniques for interpolating scatterpoints is that of IDW interpolation (Tomczak, 1998). It works on the premise that observations farther from the core should have a diminished contribution according to how far away from the core they are. It assigns values to unknown points using values from a normally scattered set of known points. Here, the value at the unknown point is a weighted sum of the values of N known points. An interpolated value u at a given point x based on samples $u_i = u(x_i)$ for $i = 0, 1, \dots, N$ using IDW (an interpolating function) is

$$u(X) = \frac{\sum_{i=0}^N \frac{w_i(X)}{\sum_{j=0}^N w_j(X)} u_i}{\sum_{j=0}^N w_j(X)}, \quad (4)$$

where

$$w_i(X) = \frac{1}{d(X, X_i)^p} \quad (5)$$

is a simple IDW weighting function. Here, X denotes an interpolated point, X_i an interpolating point, d is a given distance from the known point X_i to the unknown point X , N the total number of known points used in interpolation, and p the power parameter, here taken as a value of 1. A weight decreases as the distance from the interpolated points increases. The quantity d is calculated using Euclidean distance. When $X = (A_1, B_1, C_1)$ and $X_i = (A_2, B_2, C_2)$, the distance between X and X_i is

$$d(X, X_i) = \sqrt{(A_1 - A_2)^2 + (B_1 - B_2)^2 + (C_1 - C_2)^2}. \quad (6)$$

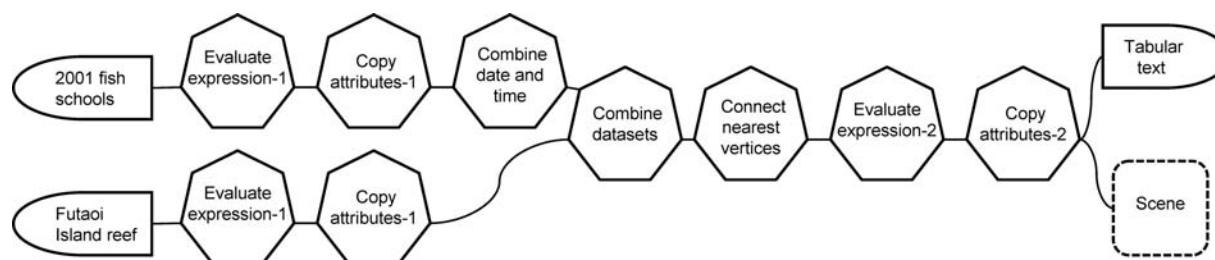


Figure 2. An example of dataflow in Eonfusion, where dataflow is the logical flow and transformation of information from data sources (bullet shapes aimed to the left) via a series of operator objects (heptagons) to the scene (rounded square with a dotted outline) and to tabular text (bullet shape aimed to the right) for exporting the processed data. A set of objects can be connected though pipes. Each object has its own property that controls its functionality. The function of each object is described in Table 3.

Table 3. Functionality of each data object in dataflow.

Name	Data object	Functionality
2001 fish schools	Data source	To input characteristics of the 2001 fish schools in CSV format
Futaoi Island reef	Data source	To input Futaoi Island artificial reefs in CSV format
Evaluate expression-1	Operator	To convert from the minus sign to the plus sign of depth. In the original data, distances below surface are positive, but Eonfusion deems distance above the water surface as positive. This operator allows customized operations to be performed on data attributes, in this case, the conversion of the sign for depth
Copy attributes-1	Operator	To transform the locations (latitude, longitude, and depth) of the fish schools and the reefs to X, Y, and Z, respectively
Combine date and time	Operator	To combine date with time. Originally, date and time information were created separately
Combine datasets	Operator	To integrate two datasets (2001 fish schools and Futaoi Island reefs)
Connect nearest vertices	Add-in	To connect to the nearest reef from each fish school according to the coordinates (X, Y, and Z) of the 2001 fish schools and the Futaoi Island reefs
Evaluate expression-2	Operator	To calculate the closest distance of a reef from each fish school
Copy attributes-2	Operator	To transfer all relevant reef information (reef depth, reef material, reef seabed type, and the closest reef distance to a fish school) into the corresponding fish school
Tabular text	Data writer	To export the processed data in CSV format
Scene	View	To visualize the result analysed

Using the interpolation in Eonfusion, a range (latitude 0.007, longitude 0.007, depth 0.7 m) was used, meaning that the number of data in range is N in Equation (4).

Geospatial analysis

Geospatial analysis of the various datasets related to artificial reefs was performed in Eonfusion. This application can integrate diverse datasets of different formats, such as vector, raster, audio, and video files, and can convert or fuse multiple datasets to a single dataset to analyse the relationship between datasets based on geospatial information. When multiple datasets are coincident in space and time, data attributes can be migrated from one dataset to another. It allows the connection between datasets to be visualized strongly and analysed quantitatively. It can deal with each step of the data process as an object from data input to output or display and performs relatively well without too much time or effort. Figure 2 is an example of the data flow, just part of the entire flow, used to extract the relationship between 2001 fish-school data and the Futaoi Island reef data. However, it provides an idea of how Eonfusion works in term of geospatial analysis. It demonstrates how to integrate the 2001 fish-school data and the Futaoi reef data and how to analyse their relationship quantitatively. The number of the detected 2001 fish schools was 425 and that of Futaoi reefs was 1442, although the dates of data collection and surveying were slightly different. However, in Eonfusion, any scale of data can be input, processed, and visualized. A detailed description of each object is shown in Table 3.

The format for ESRI shape file data was used for sediment data, bathymetric data, and Japan coastline data. The interpolated CTD data were in raster format and an echogram at 70 kHz was in EVE format, an exported data file from Echoview for Eonfusion. When vector data, like that of the CSV format, are intersected with raster data, raster attributes can be transformed and transferred to the coordinates of the vector data. Hence, the connection between multiple datasets can be examined readily. For example, when the seabed map (raster format) is intersected to each reef unit (vector format), all information on the seabed map is migrated to the exact location of each reef unit, providing the seabed type of each unit. Therefore, the geospatial analysis was conducted by integrating and processing multiple datasets on the characteristics of fish schools, the echogram at 70 kHz, the interpolated water temperature data, sediment data, bathymetric information, the coastline data for Japan, and the artificial-reef information. The datasets analysed were then exported in CSV format. This meant that all the Futaoi reef information was transformed to the corresponding 2001 fish schools and from the Shimonoseki Coast reefs to the corresponding 2008 fish schools, based on the closest distances between schools and reefs.

Quantitative approach

To describe the relationships between fish schools and reefs, schools and the environment, and reefs and the seabed, the exported CSV format data were used. Habitat preferences for the 2001 and 2008 fish schools were investigated to understand

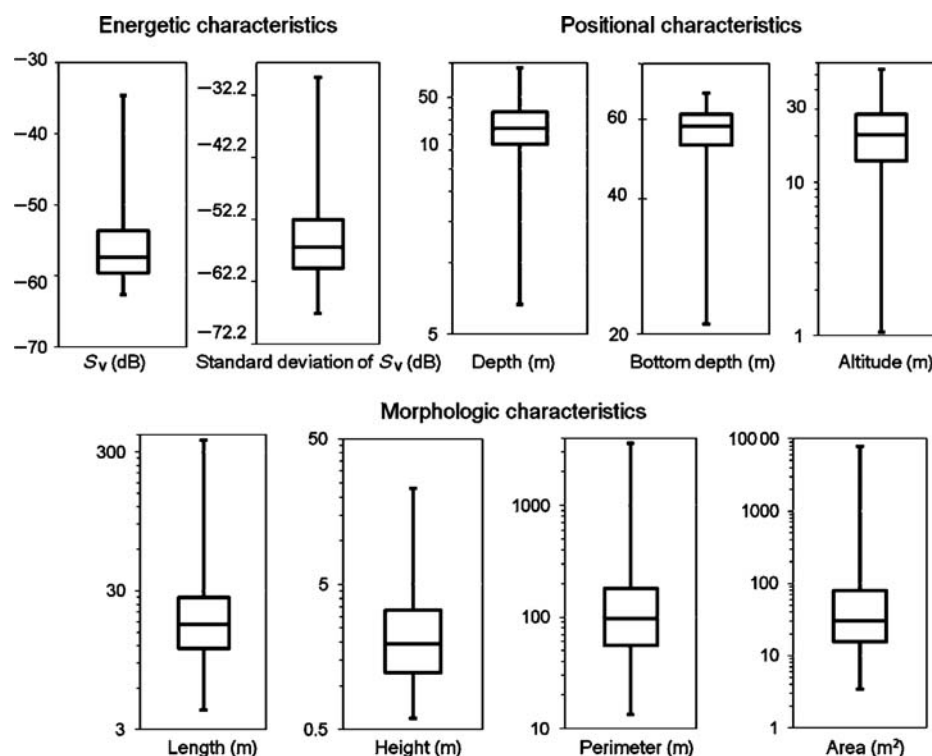


Figure 3. Boxplot of various characteristics of the 2001 fish schools. Half the samples (box) and the first and third quartiles (bars) are shown, and a logarithmic scale is used except for S_V and the s.d. of S_V .

quantitatively the relationship between fish schools and reefs. In detail, a preferable reef material, a preferable reef seabed type, a preferable reef depth, and the closest distance between a school and a reef were examined. Here, the term “preferable” is used when most fish schools are considered against each reef property. Such an examination of habitat preference was based on direct measurement. Meanwhile, the mean S_V value can be used as acoustic density (Simmonds and MacLennan, 2005; Boswell et al., 2010). Therefore, it is expected that the acoustic density will be higher as S_V is higher. The relationships between the S_V of a fish school and its closest distance from the reef and between that and preferable reef depth were investigated for both 2001 and 2008 fish schools. All 2001 and 2008 fish schools were grouped in 100 m intervals of the closest distance from a fish school to a reef. For example, the first interval is from the reef to a distance of 100 m away, and the second the distance between 100 and 200 m from the reef. The last interval was defined as from 600 to 2000 m. The reason for choosing 100 m as interval is to cover all the fish schools detected, and they were broadly scattered. The depth interval for the 2 years of fish schools was quite different: in the 2008 survey, the water depth was much shallower. Therefore, an interval of 5 m starting at 1 m and rising to 25 m was used. For the 2001 fish schools, the depth started at 30 m, with an interval of 10–70 m.

Results

Characteristics of the 2001 and 2008 fish schools

Energetic characteristics (mean S_V and s.d.), positional characteristics (distribution depth, bottom depth, and altitude), and morphological characteristics (length, height, perimeter, and area) of

the 2001 fish schools at Futaoi Island reefs are shown as a boxplot in Figure 3. The mean S_V from all schools was -56 dB. The centre of 50% of the 2001 fish schools had a range of mean S_V values of -59.6 to -53.7 dB. The s.d. of the mean S_V between the first and third quartiles was -61.01 to -54.25 dB. The mean depth, bottom depth, and altitude of all fish schools were 37.1, 56.3, and 17.7 m, respectively. The average length of the fish schools was 25.8 m, their mean height 2.9 m, their mean perimeter 188.6 m, and their mean area 146.5 m^2 . In terms of morphological characteristics, the difference between the third quartile and the maximum values is large, perhaps indicating that the top 25% of schools were very large.

The 2008 fish-school characteristics along the Shimonoseki Coast are shown in Figure 4. The mean S_V from all schools was -55.68 dB, and the centre of 50% of the 2008 fish schools had a range of mean S_V values of -61.3 to -49.2 dB. The s.d. of the mean S_V from the centre of 50% the schools was -60.43 to -46.66 dB. The mean depth, bottom depth, and altitude of the schools were 9.8, 12.2, and 2 m, respectively. The altitude was very low, meaning that most of the 2008 fish schools were very near the seabed. The mean length, height, perimeter, and area of all the schools were 12 m, 0.9 m, 49.7 m, and 13.4 m^2 . The morphological sizes of most fish schools that fell between the minimum value and the third quartile were very small.

The dB difference of the 2008 fish schools

The dB difference range of the 2008 fish schools at 70 and 200 kHz is shown in Figure 5. If the range of dB difference is -5 to $+5$ dB, 64% of the total fish schools are allocated in the range, if the range is -3 to $+3$ dB, then half the schools fall into the range, but if the range is -6 to $+6$ dB, 70% of the schools are in the range.

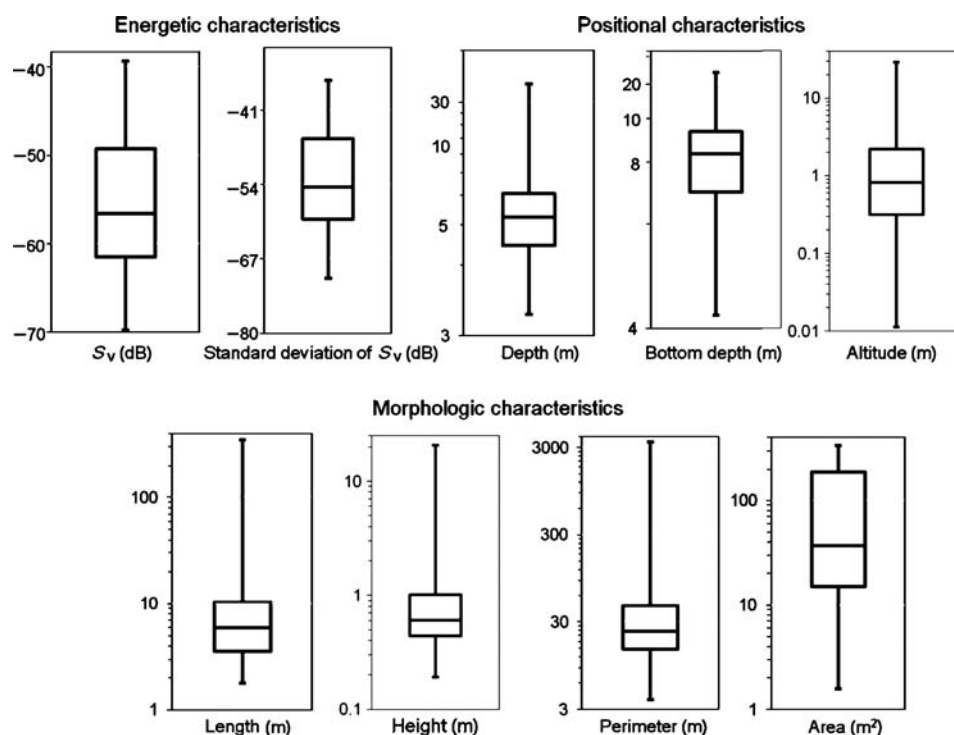


Figure 4. Boxplot of various characteristics of the 2008 fish schools. Half the samples (box) and the first and third quartiles (bars) are shown, and a logarithmic scale is used except for S_V and the s.d. of S_V .

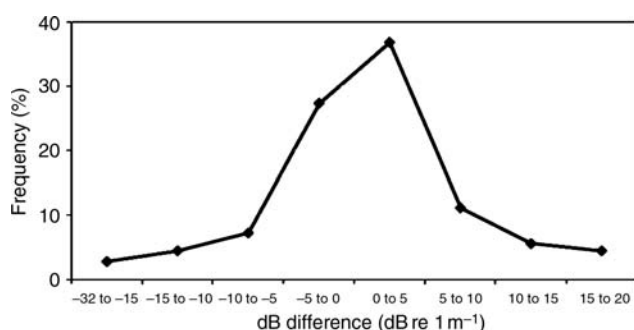


Figure 5. The dB difference (70 and 200 kHz) range of the 2008 fish schools distributed around Shimonoseki Coast reefs on 25 May 2008.

Therefore, the dB difference of the 2008 fish schools has a relatively small range, i.e. there is not much difference between the 70- and the 200-kHz output.

Relationship between 2008 fish schools and interpolated information on the marine environment

Water temperature interpolated using the IDW method is depicted on Figure 6a and appears as many thin layers throughout the water depth. An example of an echogram from the echosounder is given in Figure 6b. When the locations of the 2008 fish schools (vector format) were intersected with the location of interpolated marine-environmental data (raster format), all the environmental data attributes were transferred to the exact location of the data for every school. The interpolated water temperature (the colour of a sphere) on the spatial location of the 2008 fish schools (sphere) is illustrated in Figure 6c. The water temperature of the schools in relatively shallow water is $\sim 1^\circ\text{C}$ higher than that of schools in

deep water. The interpolated water temperature at the exact location of fish schools was three-dimensionally visualized to facilitate understanding the relationships. The interpolated environmental data at the precise locations of each school were used to calculate average values and their standard deviations individually; for salinity, temperature, turbidity, chlorophyll, and dissolved oxygen, respectively, they were 34 ± 0.14 psu, $18.4 \pm 0.2^\circ\text{C}$, 0.5 ± 0.26 ftu, 0.8 ± 0.16 mg m^{-3} , and 9.7 ± 0.19 mg l^{-1} . The difference in associated environmental data from school to school was not significant because the s.d. of the environmental data was small and the 2008 fish schools around Shimonoseki Coast reefs seemed to be distributed relatively uniformly.

Relationship between artificial reefs and the seabed

Taking the information on artificial reefs (location, material, size) of the Shimonoseki Coast and around the coast of Japan, the sediment (grain size) and bathymetry data were integrated, visualized collectively and three-dimensionally, and the relationship between reefs and seabed type was examined. Figure 7 is an example of a three-dimensional visualization constructed by combining multiple datasets from the Shimonoseki Coast reefs to provide an interpretation of the state of the reefs. The major reef materials are stone, which is colour-coded brown, and concrete, which is colour-coded green. Most stone reefs are ~ 2500 m^3 in volume and are in water shallower than 10 m, whereas concrete reefs vary in size. The biggest reef volume comprises a sunken vessel. The colour-coded seabed map was made by overlapping the classified seabed with bathymetry, then classifying the seabed type by grain size from the sediment data. Table 4 shows the relationship between the Shimonoseki Coast reefs and the Futaoi Island reefs in regard to seabed type. Medium-sized sand, small pebble and rock are classified based on grain size, e.g. 0.25–0.5, 4–64, and

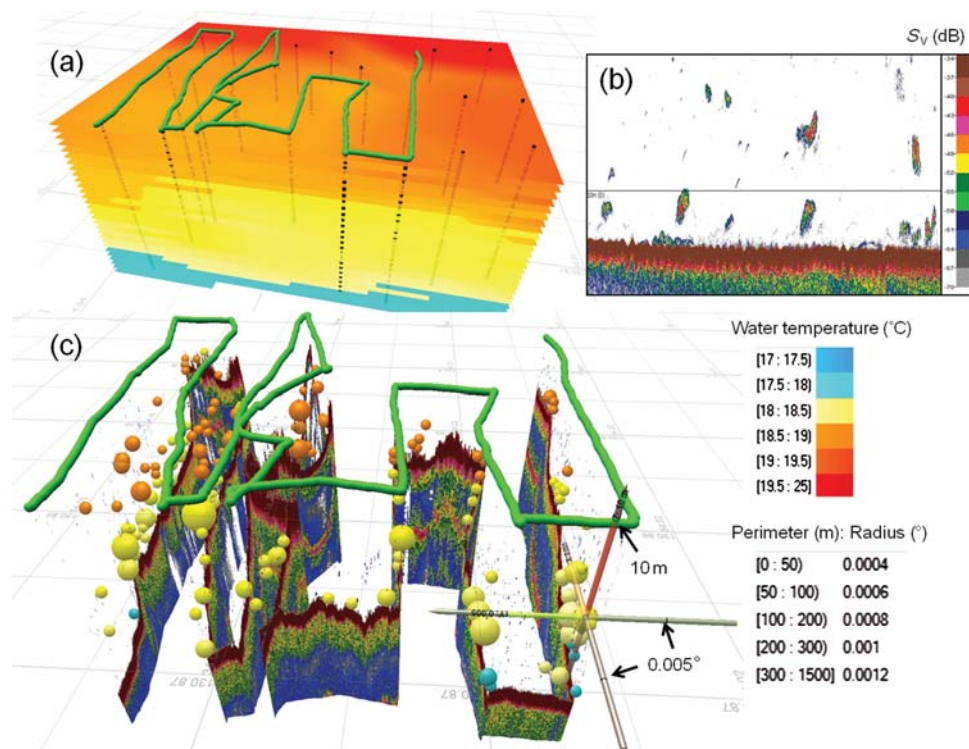


Figure 6. (a) Interpolated water temperature layers using the IDW method. Multiple dots inside temperature layers represent CTD datapoints. The ship's cruise track (green) is shown on the water surface. (b) A typical example of an echogram from the 70 kHz echosounder. (c) Three-dimensional visualization of the interpolated water temperature transferred to the exact fish-school locations. The colour of a fish school (sphere) represents the water temperature at that location, and the size of the sphere indicates the perimeter of a school. The colour legend describes the water temperature for both (a) and (c). The echogram data from Echoview are also displayed. Echo signals that appear as a long maroon band on the echogram are from the seabed. This colour represents S_V and is the same as that on the example of echogram (b). The green cruise track above the echogram data in (c) is the same as that on the water temperature layers in (a). The annotated unit axes show a scale depicting 0.005° of an interval in the x- and y-axes and 10 m of an interval in the z-axis.

64–256 mm, and these three types constituted 24, 29, and 26% of Shimonoseki Coast reefs, respectively. Medium and coarse sand constituted 33 and 49% of Futaoi Island reefs.

Habitat preference of the 2001 and 2008 fish schools

An example of a three-dimensional visualization for the 2001 fish schools detected around Futaoi Island reefs on the seabed map is given in Figure 8. Mean S_V values of the 2001 fish schools at Futaoi Island are shown in Figure 8a against the background of acoustic transect lines, shown in green. Fish schools colour-coded brown, pink, and yellow relatively near the water surface are at higher acoustic density than those shown blue, in deeper water. Figure 8b is an example of a visualization of Futaoi Island reef material on the precise locations of the 2001 fish schools, to some extent illustrating habitat preference. Many reefs of concrete and car tyres are visualized, which means that the 2001 fish schools were distributed near reefs constructed of those materials. Figure 8c shows the Futaoi Island reefs colour-coded based on their main construction material, supporting Figure 8b, in which the fish schools were clearly located around specific reef material.

Figure 9 is a series of bar graphs defining preferable reef material and reef seabed types for the 2001 and 2008 fish schools, along with the closest distance from reefs to the schools and the preferable reef depths of the schools. The bar graphs

should be viewed independently, i.e. no seeming pair in Figure 9 is related to each other. The 2001 fish schools clearly preferred concrete reefs and sandy seabed (Figure 9a). More than half the fish schools were distributed within 300 m of reefs, and many were near the seabed. As reef depth increases, there tend to be more fish schools (Figure 9c). The 2008 fish schools preferred a habitat of stony reefs and small-pebble seabed (Figure 9b). Slightly more than half the fish schools were within 600 m of the reefs and many were in the top part of the water column (Figure 9d).

Acoustic density in relation to the closest distance to reefs and preferred depth

The acoustic densities (S_V) of the 2001 and the 2008 fish schools in terms of their closest distances from the Futaoi Island and Shimonoseki Coast reefs, along with their preferred reef depths, are illustrated in Figure 10. The connection between acoustic density and the closest distances of the 2001 fish schools from the reefs was not strong. However, relatively strong S_V values, e.g. -55.5 to -55.7 dB, were recorded 101–300 m from the reefs, and between 501 and 690 m, a value of -55.7 dB was recorded (Figure 10a). Acoustic density declined as the depth of preference increased (Figure 10c), in contrast to the finding that the percentage of fish schools in deep water was greater than

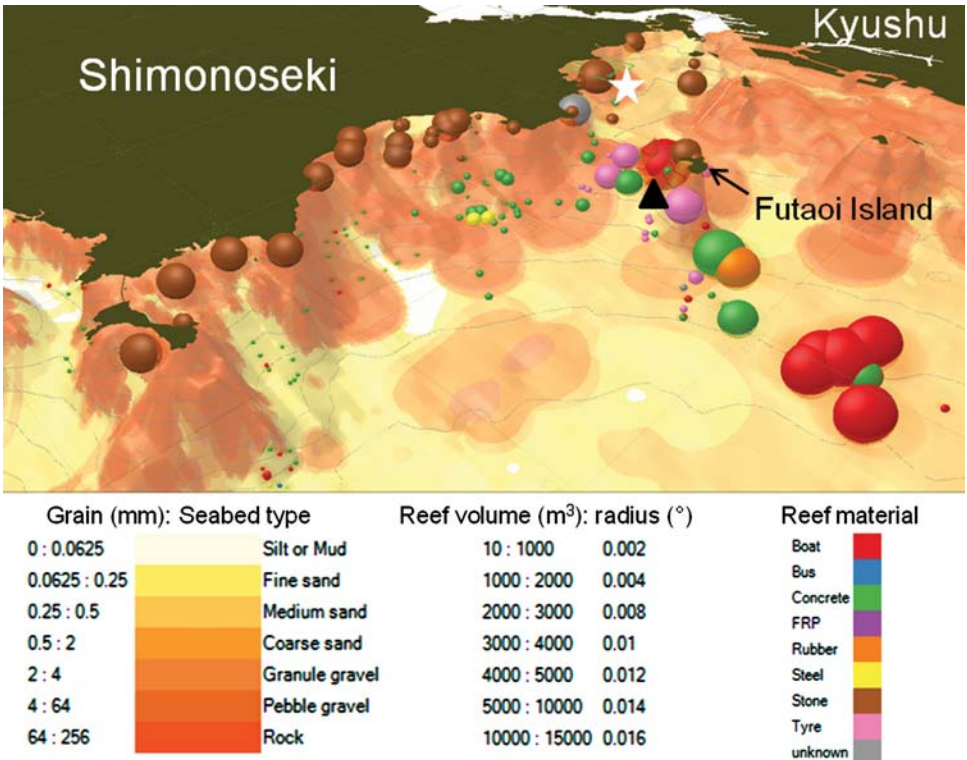


Figure 7. Shimonoseki Coast artificial reefs showing their material by colour and volume (m³) by size of sphere on the seabed map. The grey contour lines on the seabed represent each 10 m of water depth. Type of seabed is mapped onto bathymetry, using grain size (mm) to determine the type of seabed, which is also shown in the descriptor legend. The white star indicates the site of the 2008 acoustic survey, and the black triangle the site of the 2001 survey. FRP, fibreglass-reinforced plastic.

Table 4. Percentages of seabed type in artificial reefs at Futaoui Island and along the Shimonoseki Coast derived by transferring from seabed map information (seabed type) to an individual reef unit when the reef units overlap.

Seabed type	Grain size (mm)	Futaoui Island		Shimonoseki Coast	
		Number of units	Percentage (%)	Number of units	Percentage (%)
Silt or mud	0.0000–0.0625	0	0	0	0
Fine sand	0.0625–0.2500	30	0	30	11
Medium sand	0.2500–0.5000	68	33	68	24
Coarse sand	0.5000–2.0000	24	49	24	8
Granule gravel	2.0000–4.0000	6	2	6	2
Pebble gravel	4.0000–64.0000	81	7	81	29
Rock	64.0000–256.0000	75	9	75	26
Total		1 422	100	284	100

that in shallow water (Figure 9c). In other words, fewer fish schools in shallower water had considerably greater backscattering strength. For the 2008 fish schools, there was a weak connection between acoustic density and closest distance, density decreasing as the distance from reefs increased, although the trend was not linear (Figure 10b). There was also a dramatic decline in acoustic density, especially between 200 and 500 m of the reefs. At 201–300 m from the reefs, the S_V (–50.6 dB) of the 2008 fish schools was strongest. It seems therefore that acoustic density weakens with water depth. The S_V (–53.7 dB) of the 2008 fish schools was strongest at depths of 6–10 m (Figure 10d), a depth range where there were many fish schools (Figure 9d).

Discussion

The “influential ray” of an artificial reef

The “influential ray” can be defined as the distance from the reefs at which fish density decreases notably, so can be used as a scale of reef influence. Several studies have investigated the influential ray of artificial reefs. Stanley and Wilson (1997) found that the density of fish schools declined dramatically more than 16 m from a reef. They treated an oil platform as a reef and installed a fixed transducer horizontally to examine the influential ray. Soldal *et al.* (2002) also used an oil platform as an artificial reef and carried out acoustic surveying and trawl sampling. The circular acoustic survey area was 5 miles in radius, centred on the reef, and the transect-line length and interval were ~3.2 km and 80 m, respectively.

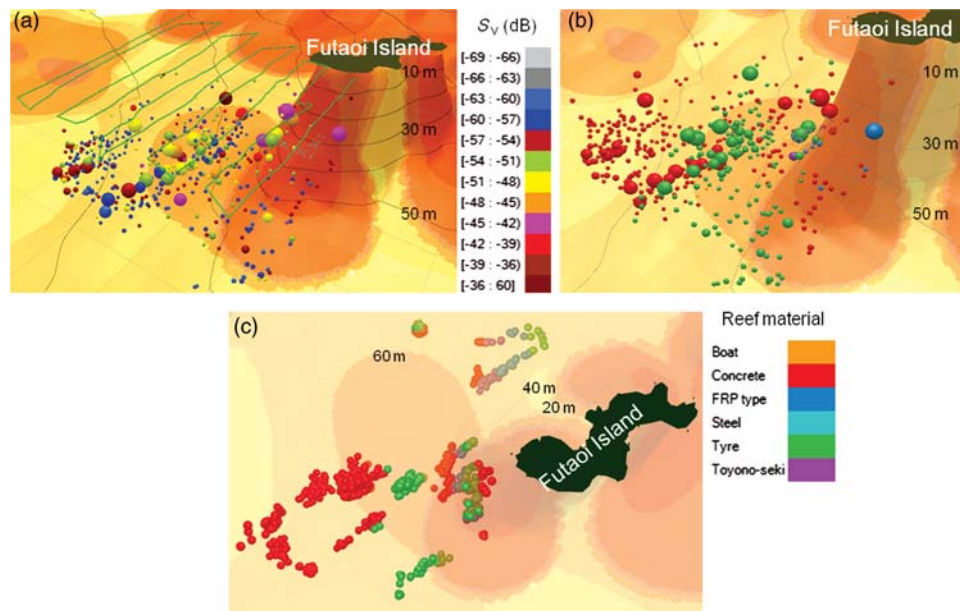


Figure 8. Various views of the 2001 fish schools around Futaai Island artificial reefs. (a) The mean S_v of each school is colour-coded. The green line depicts the cruise track of the 2001 acoustic survey, the sizes of the spheres relate to the area (m^2) of the fish schools, and the locations of the spheres, in (a) and (b), are their exact geographic locations. (b) The colours of the spheres are related to construction-material type at the Futaai Island reefs, with the reef-material legend applying to (b) and (c). The three-dimensional visualization aids understanding at a glance of the relationship between fish schools and artificial reefs based on the spatial location. (c) Colour-coded construction material at each Futaai Island reef, with the spheres being reefs (sizes uniform), and their locations the true geographic site.

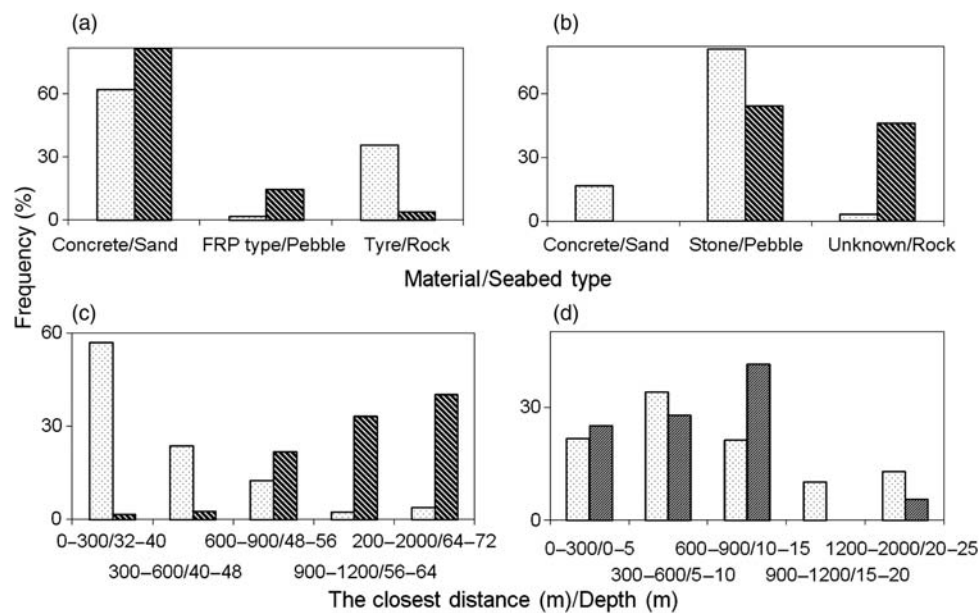


Figure 9. Preferred reef material and reef seabed type of (a) the 2001 fish schools at Futaai Island and (b) the 2008 fish schools at Shimonoseki Coast, and the closest distance from the reefs to the (c) 2001 fish schools at Futaai Island and the preferred reef depths of those schools and to the (d) 2008 fish schools at Shimonoseki Coast and the preferred depth of those schools.

Fish schools were distributed evenly at some 50–100 m from the reefs and were widely dispersed out to 300 m from the reefs (Soldal *et al.*, 2002). Fabi and Sala (2002) used an artificial reef made of concrete, fixing an echosounder at the centre of the reef and another sounder 80 m away from it. The distribution of

schools clearly decreased at 80 m. Ito and Nakano (2007) acoustically surveyed eight 500-m transects around 21 m of artificial reef constructed of steel. They found that Japanese jack mackerel (*Trachurus japonicus*), the target species, was densely distributed up to 65 m from the reef. Boswell *et al.* (2010) conducted an

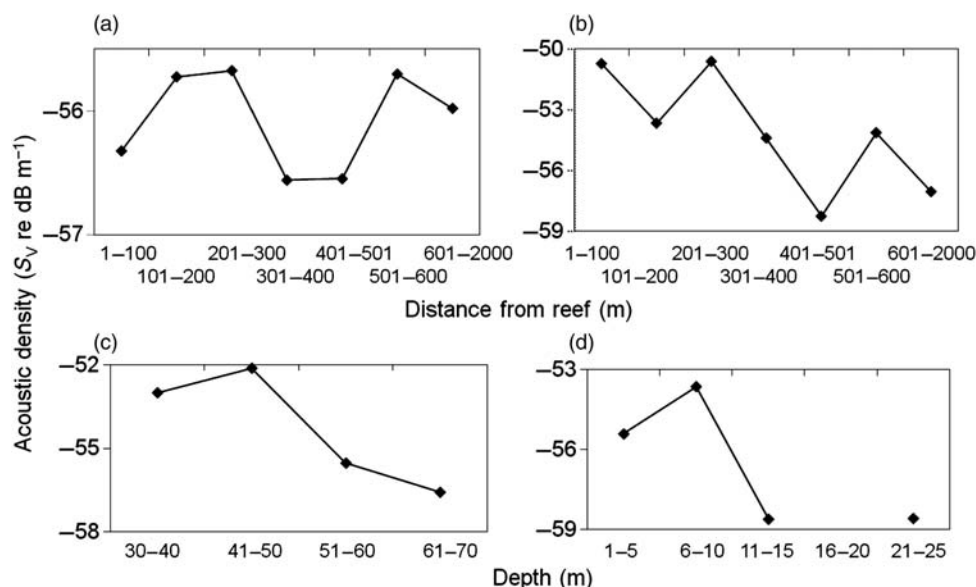


Figure 10. (a) Acoustic density (S_v) of the 2001 fish schools depending on distance from the reefs, and (b) the preferred depth of the reef that year. (c) Acoustic density of the 2008 fish schools depending on the distance from the reefs, and (d) the preferred depth of the reef. Note that no fish school was detected between 16 and 20 m (d) and that the depth scale in (d) is different from that in (c).

acoustic survey along 16 transects either east–west or north–south, each 2 km long and 80 m apart around a decommissioned oil platform. The density in fish schools decreased by five times at 10 m from the reef and by 16 times at 30 m from the reef.

The influential ray from artificial reefs in this study was 300 m for the 2001 fish schools and 600 m for the 2008 fish schools. In all, 57% of the 2001 fish schools were within 300 m of a reef, and another 24% between 300 and 600 m of the reef. For the 2008 fish schools, 22 and 24% of schools were distributed at these same distance ranges, respectively. To estimate an influential ray, a different approach was used here, however. First, acoustic surveys were carried out over a wide range of reef areas. Second, the influential ray was determined from the results of the quantitative analysis, which measured the distances between fish schools and their closest reefs directly. In the method using a fixed transducer, a relatively small survey area is available to compare with the transect-line survey approach, but the use of many fixed transducers located at different distances from the reef can make up for the relatively small area of coverage of a single, fixed transducer. The method we used was similar to the method of Soldal *et al.* (2002) and Boswell *et al.* (2010). However, in both those cases, the survey areas were smaller, so the transect-line method may have use in studying a variety of reef types constructed over an extensive area. Nevertheless, if the target is a massive reef or a number of smaller ones, the fixed transducer method or the transect-line method for a relative small survey area would be effective. Direct measurement can be a powerful tool in estimating the influential ray of artificial reefs under many circumstances.

Fish-school distribution over time

It is well known that the nature and the composition of fish communities vary in time daily and seasonally around artificial reefs. Stanley and Wilson (1997) found fish-school density to change considerably according to the time of day and season. Their data were collected every 2 h at pre-dawn, full daylight, twilight, and

darkness once per month for a full year. Relini *et al.* (2002) used diver observations around artificial reefs from 105 visual surveys covering 10 years. Their reefs were 30 units of a pyramid type (four perforated cubes at the base and one at the top) and 200 units of concrete. They showed that the number of species and the number of fish schools increased over the 10 years. Fabi and Sala (2002) confirmed that densities were generally lowest in the early afternoon and that abundance was greatest late at night and in the early morning at their study reefs. Of the reefs, 29 were of a pyramid-type, each constructed of five 2-m cubic concrete blocks, and 12 were concrete cages for shellfish culture in a rectangular arrangement. Sala *et al.* (2007) employed the same data as Fabi and Sala (2002) to demonstrate the vertical distribution of fish schools over time. For example, fish biomass at reefs was high at night and in the early afternoon close to the seabed, and in the very early morning in midwater and close to the surface. Nakamura and Hamano (2009) found that the morphology and bathymetry of Japanese jack mackerel around artificial reefs (<100 m depth) varied with the season. In June, schools were small and diffuse at a distance of 51.6 ± 9.3 m over the reefs where the water temperature ranged between 19 and 21°C. Fish schools within 90 m of the artificial reefs and in water <19°C were densest in August. Clearly, fish-school distribution based on time-series of spatial information is essential to improving understanding of the complex ecosystem around artificial reefs. A future plan is to collect data at regular intervals for relatively long periods at various artificial-reef sites, to ascertain the daily and seasonal behaviour of fish schools. Perhaps then, the relationship between fish schools and reefs can be examined in four dimensions (time and space).

Fish identification

Net sampling is commonly used to ground-truth acoustic surveys. However, a survey for species identification was not carried out along with the acoustic survey in this study, because Japanese

fishing regulations did not permit the area of the Shimonoseki Coast reef site to be trawled. In a 2001 survey around Futaoi Island, an underwater camera installed on a remotely operated vehicle (ROV) was used to confirm the identity of the fish species present; they were mainly Japanese jack mackerel and threadsail filefish. No image was presented or analysed in this study because water visibility was poor, but if fish-school characteristics including energetic, positional, morphological, and dB difference range are investigated in terms of the fish species around artificial reefs, it may be possible to find a connection between the two. The dB difference range has potential for fish identification, as explained in detail below using the example of Japanese jack mackerel.

Values of target strength (TS) from previous work were required. Mukai *et al.* (1993) obtained the following equation for TS against body length (L) using 25 and 100 kHz:

$$TS = -64.1 + 20 \log L \text{ at 25 kHz;} \quad (7)$$

$$TS = -68.2 + 20 \log L \text{ at 100 kHz.} \quad (8)$$

Yamanaka *et al.* (1999) used 70 kHz, and their relationship for the same species was

$$TS = -67 + 20 \log L \text{ at 70 kHz.} \quad (9)$$

Simura and Uji (2003) investigated the diel variation in jack mackerel around Sanryu Coast, Yamaguchi Ken, Japan, using an echosounder, carrying out midwater trawls during an acoustic survey, to obtain a value of 9 cm as the modal body length for jack mackerel in the region. When this body length is used for Equations (7)–(9), the TS at 25 kHz is -45.02 dB, that at 70 kHz is -47.92 dB, and that at 100 kHz is -49.12 dB, so the TS decreases as the frequency rises. Here, the TS difference between 25 and 100 kHz is -4.1 dB and that between 70 and 100 kHz is -1.2 dB, meaning that if a fish species has these ranges of dB difference, Japanese jack mackerel is likely to be one of the fish species present. This example is based on experimental TS values. However, the dB difference range is generally obtained from S_V values directly from an acoustic survey, a practical and common method of determining it.

Additionally, Japanese jack mackerel spawn between February and April in the centre of the east China Sea and over the southern continental shelf of the Sea of Japan. Japanese jack mackerel are also carried to the southwestern Sea of Japan between May and July by the Tsushima Current (Sassa *et al.*, 2006), so it can be assumed that schools of jack mackerel are around the Shimonoseki Coast and Futaoi Island at that time of year. In this study, half the 2008 fish schools had a dB difference range of -3 to $+3$ dB, a difference close to the range of TS differences from the examples cited above. The frequencies used in this study were different (Mukai *et al.*, 1993; Yamanaka *et al.*, 1999), however, so direct comparison is not possible.

The various characteristics of fish schools can offer a strong clue to species identity. However, a basic ground-truth survey needs to be carried out to confirm fish-species identity in line with the acoustic characteristics of fish schools. Hence, another plan for the future is to carry out acoustic surveys and ground-truthing trawls. However, in future it might be possible to identify fish species directly using only the acoustic method without relying

on net-sampling, if a database of fish-school characteristics according to species is developed.

Fish density

Our aim in terms of investigating acoustic density was to demonstrate a simple and quick way to understand that density in terms of the presence of artificial reefs. A long-established and standard method of biomass estimation for fish is that of echo-integration (Simmonds and MacLennan, 2005). Fish density can be obtained as the mean value of s_v divided by the mean σ_{bs} of a known water volume based on echo-integration. In linear notation, the relationship for fish density is

$$s_v = n\sigma_{bs}, \quad (10)$$

where s_v (m^{-1}) is the volume-backscattering strength coefficient, i.e. the linear value of S_V , n (fish m^{-3}) is the distribution density, and σ_{bs} (m^2) is the backscattering cross section, i.e. the linear value of TS . Densities (n) of the 2001 and 2008 fish schools were estimated using Equation (10). Here, the TS of -47.92 dB used was derived from Equation (9), and the S_V values of -56 and -55.68 dB were the average S_V values of the 2001 and 2008 fish schools, respectively, so fish density in 2001 and 2008 was 0.16 and 0.17 fish m^{-3} , respectively. Fish density in an artificial-reef environment can be estimated readily if an accurate value of TS is available. A single target-detection method (Soule *et al.*, 1997) and a fish-tracking technique (Blackman, 1986) can assist in obtaining an accurate *in situ* value of TS . Another plan for future research is to carry out *in situ* TS measurements along with ground-truthing to derive an accurate value of TS and estimating the fish density based on fish species. For species composition, an ROV and scuba divers were used to ground-truth by Stanley and Wilson (1997) and Relini *et al.* (2002). In the reef environment researched here, fish density by species can be derived using ground-truthing, possibly using an ROV, along with a modification of Equation (10) (Simmonds and MacLennan, 2005).

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