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GEOSPATIAL AND ACOUSTIC APPLICATION IN AN ARTIFICIAL REEF SITE OF SOUTH KOREA

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RESEARCH ARTICLE

Geospatial and Acoustic Application in an Artificial Reef Site of South Korea

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Abstract

Artificial reefs are important since they provide additional habitat leading to increasing abundance and biomass of marine biota. In a Bukchon artificial reef, Jeju Island, South Korea, environment data, artificial reef properties, and acoustic data in four seasons were integrated to visualize and examine their connections using a geographic information system (GIS). As a result, regarding the spatial and temporal distributions of fishes, January had the lowest Nautical Area Scattering Coefficient (NASC, m^2/nm^2) and June had the highest NASC, and relatively high NASC was observed from 5 to 30 m deep throughout seasons. The influential circle (effective distance from reef) had a trend to decrease in January, April, and October except for June. Based on interconnection between June fish schools, interpolated water temperature, and reef property, the fish schools preferred approximately 18.4 °C and concrete of reef material, and their average closest distance to reefs was 405.2 m. A dominant species in four seasons from biological samplings was benthopelagic. This study pointed that the GIS application with primarily acoustic data could be one of great tools for fish resources and reef management in complex reef environments.

Keywords: Artificial reef, Echosounder, Geospatial, Fish school, Visualization

1. Introduction

In many countries worldwide, artificial reefs have been deployed on the sea floor to enhance the fishery resources since they provide additional habitat, shelter, and nursery ground, which increase the environmental accommodation ability and lead to increase the abundance and biomass of marine biota, especially finfish [7,12,24,42]. Also, the artificial reefs can preclude the trawling net tows, and provide food supplies and spawning ground to improve the survival and growth rates of larvae and juveniles [25,41]. The presence of artificial reefs as new hard-substrate allows algae and larvae of hard-substrate benthic invertebrates to be settled. These survived organisms may lead to an increase of local trophic efficiency in areas [47]. Artificial reefs might hold

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higher fish abundance [8] and diversity [37] than natural reefs. It is important to remark that artificial reefs should not be considered replacements of natural reefs. Additionally various types of artificial reefs have been built for multifunctional purposes such as habitat restoration and rehabilitation, enhancement recreational fishing, fisheries production and coastal protection [9,36,29,6].

The detection and evaluation of fishery resources inhabiting the artificial reefs has been done by several different methods, such as visual census by scuba divers [38,11,18,3,49], fishing survey [30,16,52,40,49], video recording by remotely operated vehicle (ROV) [1], and scientific echosounder [46,15,53,39,50,24,55]. Fishing surveys have the advantage of identifying the species composition and the body length; however it takes considerable time when the number of net sampling station is large. Diving and underwater camera surveys are difficult to obtain quantitative data because they highly provoke fish avoidance instincts when approaching fishes. Also, there are limitations of environmental factors, such as depth limits and turbidity, and of survey coverage [23,19]. Each method has strengths and weaknesses, and provides unique information relating to artificial reefs. Among them, there are a number of studies using echosounders on the quantitative and qualitative evaluations of artificial reefs in various seas around the world. The acoustic method offers several benefits, including the ability to acquire data continuously across a wide area over a relatively long time period at low cost, and is one of promising methods in relation to the artificial reefs study. The formation of fish aggregation is affected by various biological and environmental factors, such as water depth, diurnal rhythm, habitat complexity, water temperature, the relationship between prey and predation, and foraging competition, thus it varies largely. Meanwhile, a great number of scientific instruments have been employed for investigating the fish aggregations residing in the artificial reefs and their environmental characteristics. Accordingly, a great dataset yet diverse data format from the scientific instruments are collectable. Thus, a useful tool which deals with enormous and various data sets are required. One of powerful tools can be geographic information system (GIS) which allows one to visualize a variety of information from different data sources and to extract the relationships between data sets qualitatively and quantitatively [50,24].

In South Korea, artificial reefs have been set in five sea areas in Tongyeong, Yeosu, Uljin, Taean, and Jeju since 2001 [43,26]. In order to create coastal fishery ground on the coastal waters, relatively small-sized artificial reefs were established, aiming for 50 sites in high potential areas across the coast of the South Korea from 2006 to 2020. It is a future-oriented and comprehensive system which contributes to improve fisherman's income since it can be combined with the leisure tourism industry to revitalize fishing villages and increase the number of employee, especially young people. The artificial reefs have various types for multiple purposes. To have a better planning and managing the reefs sites, the distributional characteristics of fish aggregations in relation to the reefs and their relationship with marine environmental information are crucial. This study integrated seasonal marine environment data, artificial reef information, and acoustic data collected in the artificial reef site at Bukchon Sea of Jeju Island in South Korea, to visualize the properties of the data sets and their quantitative and qualitative connections in three dimensions. The aim of this study was to understand the comprehensive circumstances in relation with artificial reef by connecting relevant data sets and extracting meaningful relationship among them. It is hoped that it can provide a new aspect on fish resources and reef managements in artificial reef environments.

2. Methods

2.1. Data collection

The field survey area was 6.51 km^2 including the 18.4 km of transect line off Bukchon of Jeju Island in South Korea (Fig. 1). The water depth in the study area ranged from 7 m to 117 m, its average depth was 33.3 m. A calibrated 38 kHz split-beam echosounder (EK60, Simrad) was used to investigate the distribution of fishes off Bukchon coastal reef in Jeju Island. The setting parameters for the echosounder are presented in Table 1. The 38 kHz transducer was attached at the side of a chartered fishing vessel and was positioned 1.5 m below the water surface. The position information (latitude and longitude) from a GPS was feed to the echosounder. The vessel speed was maintained between 5 and 6 knots. Four field surveys representing four seasons were conducted. The survey dates were April 12 2018, June 9 2018, October 24 2018, and January 29 2019. The acoustic surveys were conducted during day time.

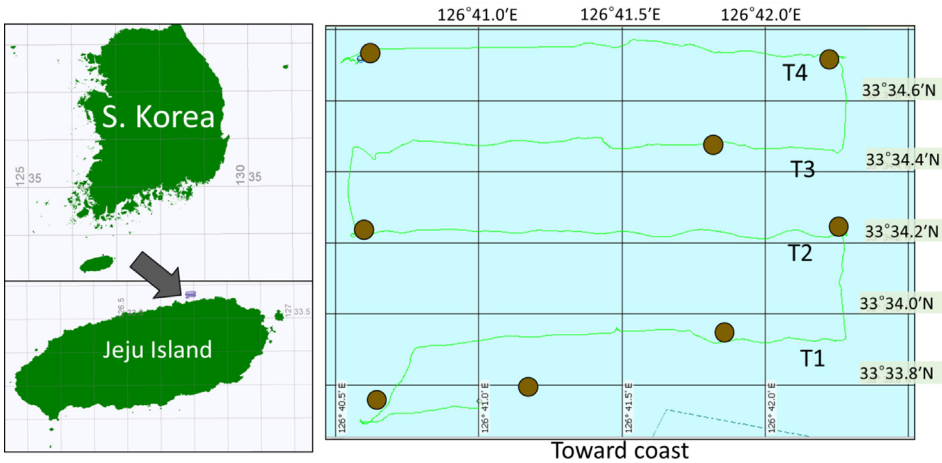

Fig. 1. Study area. The green line indicates the cruise track line and the closed circle in dark brown means the location of CTD on the right panel. The gray arrow points the study area.

Table 1. The setting parameters of an EK60 echosounder, bottom line pick algorithm, and fish school detection algorithm.

EK60 echosounder	
Operating frequency (kHz)	38
Transmitted power (W)	1000
Absorption coefficient (dB/m)	0.0097
Sound speed (m/s)	1493.9
Pulse length (ms)	0.512
Major axis 3 dB beam angle (°)	12.5
Minor axis 3 dB beam angle (°)	12.5
Best candidate line pick algorithm	
Discrimination level (dB)	−50
Peak threshold (dB)	−60
Maximum dropout (samples)	2
Window radius (samples)	8
Minimum peak asymmetry	−1
Fish school detection algorithm	
Minimum total school height (m)	3
Minimum total school length (m)	8
Minimum candidate length (m)	5
Minimum candidate height (m)	2
Maximum vertical linking distance (m)	3
Maximum horizontal linking distance (m)	5

The marine environmental information was collected using a conductivity, temperature, and depth (CTD) probe (Ocean seven 304, Idronaut) at eight stations (Fig. 1). Artificial reef data such as artificial reef type, material, number, size, and deployed water depth and location were obtained from the Korea fisheries resources agency which played a role in deploying and maintaining the artificial reefs. The property of the artificial reef is shown in Table 2.

2.2. Biological sampling

A single gill net and a trap were used to collect biological samples. The single gill net had 50 m of length and 2 m of height, and the mesh size was 81 mm. The gill net sampling was conducted at artificial reefs for approximately 24 h. The trap was a spring-net-pot. The total number of trap was 90. The shape of a spring-net-pot was cylinder, its length

Table 2. The property of the artificial reef.

Reef Type	Material	Reef number	Reef size	Reef volume (m^3)
3 layers	Steel	2	12.0 × 12.0 × 10.7 m	1541
Cross	Concrete	58	2.2 × 3.0 × 1.8 m	12
Cross sea forest	Concrete	131	3.0 × 3.0 × 0.5 m	5
Fan shape	Concrete+oyster shell	27	3.0 × 3.0 × 3.5 m	32
Hexagon	Steel	2	11.55 × 11.55 × 7.0 m	934
Horn triangle	Concrete	1402	1.4 × 1.3 × 1.5 m	3
House	Steel+riprap	61	2.4 × 3.5 × 1.38 m	12
Maze	Concrete	33	2.25 × 2.25 × 2.2 m	11
Octagon	Steel	3	14.0 × 14.0 × 6.0 m	1176
Rectangle	Concrete	2500	2.0 × 2.0 × 2.0 m	8
Sea forest	Steel+riprap	2	8.0 × 12.0 × 1.65 m	158
Stone combined	Steel+riprap	1	13.2 × 13.2 × 8.2 m	1429
Tent	Steel+Concrete	49	3.0 × 3.0 × 2.1 m	19
Triangle	Concrete	53	3.1 × 3.1 × 2.9 m	28
Tunnel	Concrete	62	2.5 × 2.1 × 2.1 m	11
Turtle type	N/A	80	N/A	N/A

was 60 cm and its height, that is diameter, was 31 cm, and the mesh size was 20 mm. A small piece of sardine was used as bait. It was installed near artificial reefs nearly 24 h for one sampling.

2.3. Data analysis

2.3.1. Acoustic data

The acoustic data from the 38 kHz echosounder was analyzed using Echoview (ver. 9, Echoview Software Pty. Ltd). Data above the water surface line including ring down noises were excluded using the threshold offset feature. The sea bottom line was created using the best candidate line pick algorithm. The setting parameters of the algorithm are shown in Table 1. Data below the sea bottom line were not included for further analysis. Then, the two lines were manually edited to exclude any sea bottom signal and noises near water surface. Overall, echo signals were precisely scrutinized by eyes in consideration of the voyage course, locations of reefs, and context. Echogram curtain, which is the entire echogram, was exported to visualize it with other datasets in the GIS program. To understand the vertical distribution of the marine organisms in the artificial reefs, Nautical Area Scattering Coefficient (NASC, that is, scattering coefficient per unit area, m^2/nm^2) so called acoustic biomass was extracted by every 5 m of the water depth. To investigate the horizontal distribution of marine organisms in the reef area, NASC in every 100 m in horizontal and the entire water column was exported. The school detection feature in Echoview was used to define fish schools. Note that fish schools were observed in June alone. Accordingly, the school detection feature was applied only in June data. The feature was developed based on the SHAPES algorithm which defined fish schools as polygons in order to calculate their energetic, morphometric, and positional properties [10]. The parameters for the school detection algorithm were set to detect even a small fish school. Several operators such as Region bitmap, Mask, Dilation filter 3 × 3, Line bitmap, and were used to define fish schools precisely and accurately. In detail, after detecting fish schools, the 'region bitmap' operator, which made regions specified (fish schools detected) be true and others be false, was used. The 'mask' operator selected the volume backscattering strength (Sv, dB re m^2/m^3) where the true of region bitmap, and the 'Dilation filter 3 × 3' expanded the area of true region bitmap. Fish school detection was performed once more on the dilation filter 3 × 3 echogram. The 'region bitmap' operator was used again to select fish schools enlarged. Meanwhile, the data between water surface line and sea bottom line was chosen using 'line bitmap'. The 'And' operator combined region bitmap echogram and line bitmap echogram to extract only true parts that is only fish schools without any signal of sea bottom. Finally, the 'mask' operator concealed false parts, which means S_V values of only true parts were remained [14]. Then, the school properties including mean S_V were exported in comma separated values (CSV) format. In particular, the area (A_c) of fish school was calculated with corrected school length (L_c) and thickness (T_c). The correct length means the length corrected for the effect of the beam width by using the term of 2D tan θ/2.

$$A_c = A\ (L_c T_c)/(LT) \quad (1)$$

Here, θ indicates the attack angle defined as the angle between an on-axis line and another line toward the school edge. A, L, and T are uncorrected area, length, and thickness, respectively. Corrected thickness compensates the effect of the pulse width (cτ/2). Here τ denotes the pulse duration [13].

2.3.2. Geospatial analysis

To visualize and derive the results on the basis of geographic information from multiple dataset, Eonfusion (ver. 2.3.1, Echoview Software Pty. Ltd.) and ArcGIS (ver. 10.3, ESRI) were used (Fig. 2). Each reef module was placed based on their locational information in Eonfusion. The closest distance between a fish school and a reef module was computed using the positional information from the fish schools properties (vector format) and reef properties (vector format). The locations (latitude, longitude and depth) of the fish schools and the reefs were transformed into X, Y and Z in the Cartesian coordinates system, respectively. Two data

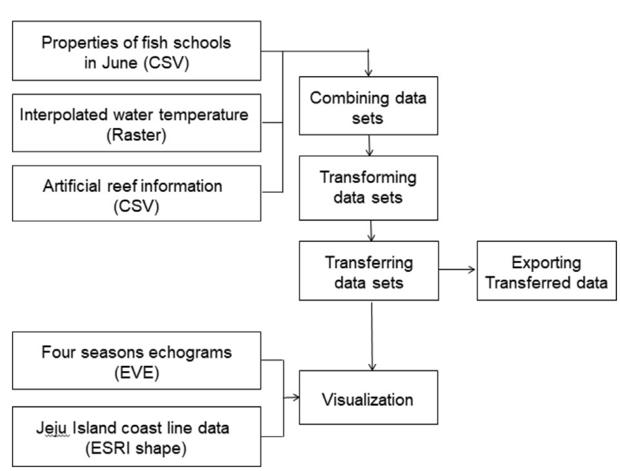

Fig. 2. Dataflow of geospatial data analysis.

sets such as the fish schools and the reefs were integrated in accordance with their coordinates. Then, the closest distance of a reef from each fish school was calculated. All relevant reef properties such as reef depth, material, and the closest reef distance to a fish school were transferred into the corresponded fish school. Meanwhile, the interpolated water temperature (raster format) was intersected to each fish school (vector format), for example the water temperature was migrated to the exact location of every fish school. Accordingly, the water temperature, reef, and fish school were integrated to extract relevant information on the basis of positional information. The shape file of Korean map and the echogram curtain (EVE format) exported from Echoview were used in Eonfusion. The influential circle 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. To evaluate the influential circle, the buffer analysis, that is buffer polygons around input features (artificial reef) to a specified distance, was used in ArcGIS. A circle buffer analysis (radius = 50, 100, 150, and 200 m) was used to extract the NASCs in the circle buffers.

2.3.3. *Water temperature interpolation*

The CTD data consisted of a series of marine environmental information such as water temperature in a vector format. The water temperature among environmental information was interpolated using an inverse distance weighting (IDW) interpolation method which is one of the simplest and most readily available methods. It is deterministic assuming closer values are more related than further values with its function. Weighting is assigned to sample points through the use of a weighting value that controls how the weighting influence will drop off as the distance from new point increases. Thus, the closer the distance is, the higher the weight value is applied during the interpolation process [33]. The IDW interpolation method was used in Eonfusion.

3. Results

3.1. *Visualization of multiple dataset on artificial reefs*

Based on the geographical information of dataset associated the artificial reefs, the echogram curtains along with the various attributes (volume, number, material) of the reefs and detected fish schools were visualized (Fig. 3). It was found that artificial reefs were largely composed of concrete (sphere in blue violet), and the most number of reefs was made of concrete. The concrete reef accounted for 94.9% of the total number of reefs. The volume of reefs made by steel only and steel with riprap were considerably larger than that of reef with other materials (Fig. 3a). Relatively large fish schools were observed on the coast, especially on the second transect line from the coast and around 126.7° E (Fig. 3b). It was difficult to see diverse aspects of artificial reefs and fish schools on the two dimensional figure. However, the GIS tool (Eonfusion) was able to change views and to magnify the scene in three dimensions,

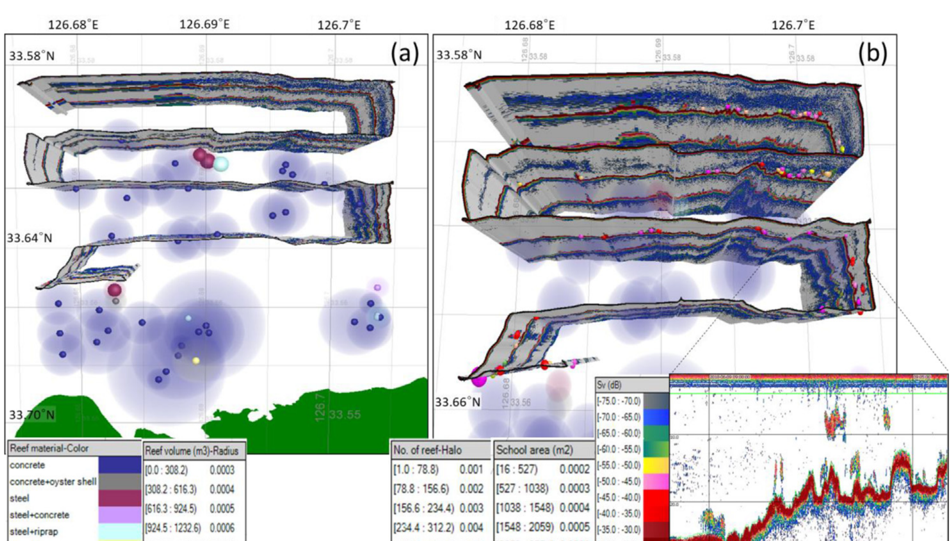

Fig. 3. The visualization of artificial reefs, detected fish schools and echogram curtain on the basis of geospatial information. The artificial reef is represented by the sphere, the color of the sphere indicates the material of the reef, the size of the sphere means the volume of the reef (m^3), and the translucent circle denotes the number of the reef (a). The sphere means the detected fish school, the sphere color indicates the volume backscattering strength (Sv, dB re m^2/m^3), and the sphere size corresponds to the school area (m^2). An example echogram including fish schools is shown (b).

thus it was easy to grasp the relationship between artificial reefs and fish schools.

The interpolated water temperatures in four seasons were displayed in Fig. 4. In January and April the water temperature was very similar with the range of 15–16 °C. In October, the water temperature had the range of 20–21 °C. In January, April and October, the water temperature was not changed much on the basis of water depth. Namely, no thermocline was found in January, April and October. In June, the range of water temperature was 15–20 °C, and the water temperature around 40 m was 15 °C. Only June, a number of fish schools appeared and was visualized by overlapping with the water temperature.

The interpolated water temperature overlapped with the echogram curtain (Fig. 5). The top of water temperature was at 22.5 m. Fish schools, which were displayed as spheres, were color-coded with the water temperature. The size of the sphere was corresponded with the area of the fish schools. The unit of the size of sphere such as 0.0002 to 0.0006 was degree, indicating approximately 22–56 m. The fish schools with similar sizes and water temperatures (18–19 °C) were observed close to the sea bottom.

3.2. Vertical and horizontal distributions

In regard to the vertical distribution of marine organisms, the NASC in January was considerably low and the peak was observed in 30 m water depth (Fig. 6). The line in the figure was moving average line using two periods, indicating underlying a trend by smoothing out fluctuations. In April, relatively high NASC (28.2–88.0 m^2/nm^2) was found in the range of 15 m and 30 m. No signal was found in deeper than 40 m. In June the high NASC (203.0–594.7 m^2/nm^2) was observed from 10 m to 30 m. Echo signals were very weak below 40 m. Noticeably in June, considerably high NASC was observed compared to other months. In October, the highest NASC (122.7 m^2/nm^2) was found in 15 m and then that was gradually decreased along water depth. Overall, relatively high NASC was observed from 5 to 30 m throughout months.

With respect to the horizontal distribution of marine organisms, low NASC was observed in January (Fig. 7). The level of NASC was constantly low throughout the cruise track line. In April, moderately high NASC was intermittently observed. The second and third transect lines from the coast had relatively high NASC. In June, area before the first transect line (T1 of Fig. 1) had highest NASC (24,230 m^2/nm^2) and showed continuously high NASC. Other than this area, high NASC was observed in the right side of transect lines (around 126°42′ E). In October, the highest NASC was observed at the first transect line (T1). The third and fourth lines (T3 and T4) had very low NASC. On the whole, January had the lowest NASC and June had the highest NASC.

3.3. Influential circle of an artificial reef

On the basis of buffering analysis, the NASC in the influential circle such as 50, 100, 150, and 200 m was

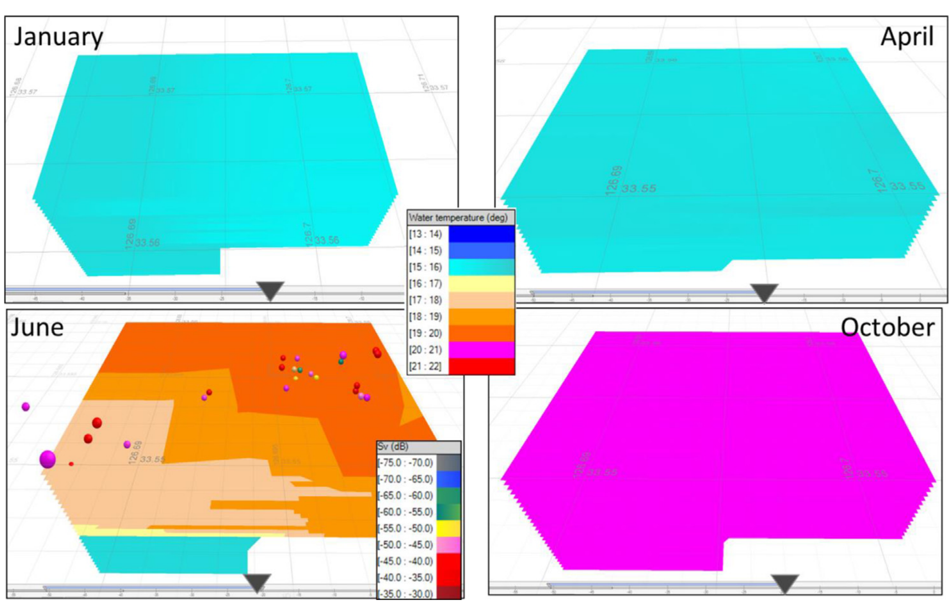

Fig. 4. The 3D like interpolated water temperature in four seasons. The top of the interpolated water temperatures are at 20 m depth (inverted triangle in gray) in January, April, June, and October. In June, fish schools as spheres are color-coded with Sv.

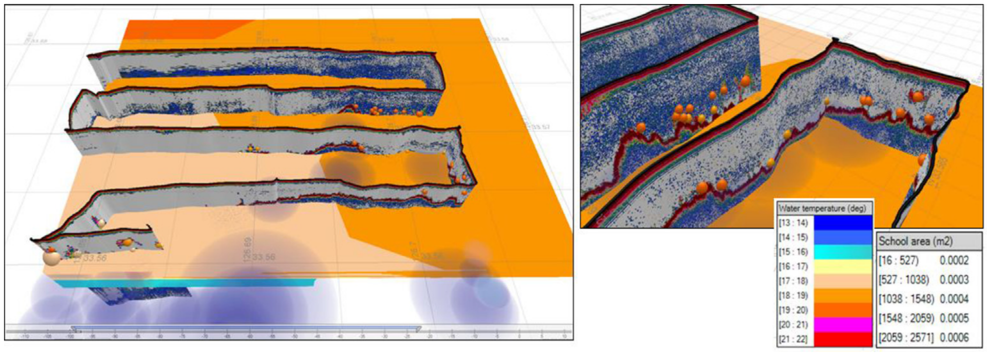

Fig. 5. The visualization of integrated datasets such as the layers of the interpolated water temperature at 22.5 m, fish schools as sphere color coded with the water temperature at their position. The size of the sphere indicates the fish school area.

graphed in Fig. 8. In January, the highest NASC (527.2 m^2/nm^2) was observed at 50 m circle, and then NASC was exceedingly decreased. In April, the peak of NASC (317.6 m^2/nm^2) was at 50 m circle, and it fell down at 100 m and very slightly rose at 150 and 200 m. In June, the lowest NASC (395.4 m^2/nm^2) was found at 50 m circle, it increased to be 844.5 m^2/nm^2 at 100 m, decreased to 430.9 m^2/nm^2 at 150 m and greatly increased to be the highest NASC (1246.1 m^2/nm^2) at 200 m. In October, the highest NASC (701.1 m^2/nm^2) was observed at 100 m circle, it decreased largely at 150 m circle and decreased again gently at 200 m. Overall three months except for June had a trend to decrease along the distance from reef.

3.4. Connections of multiple data set

The reef properties and the interpolated water temperature transferred on the exact location of fish school in June are shown in Fig. 9. It was resulted by connecting among data sets in accordance with their positional information. The average water temperature in fish schools was 18.4 °C with the range of 15.9 and 19.9 °C. It can be said that the preference water temperature of the fish schools was that range. The average closest distance between fish schools and reefs was 405.2 m with the range of 28.4 m and 947.3 m. Approximate 62% of the fish schools fell in 400 m of the closest distance. The preferred reef material was concrete which accounted for approximately 90% and the concrete was the most common reef material. The average distributional water depth of fish schools was 22.5 m, and their distributional depth from 15 to 30 m accounted for 80.7%. The average corrected area of fish schools was 138.1 m^2 and the average Sv was −48.2 dB. Exampled fish schools are shown in Fig. 3.

3.5. Biological sampling results

The catch result from two fishing gears was presented in Table 3. In January, the dominant species

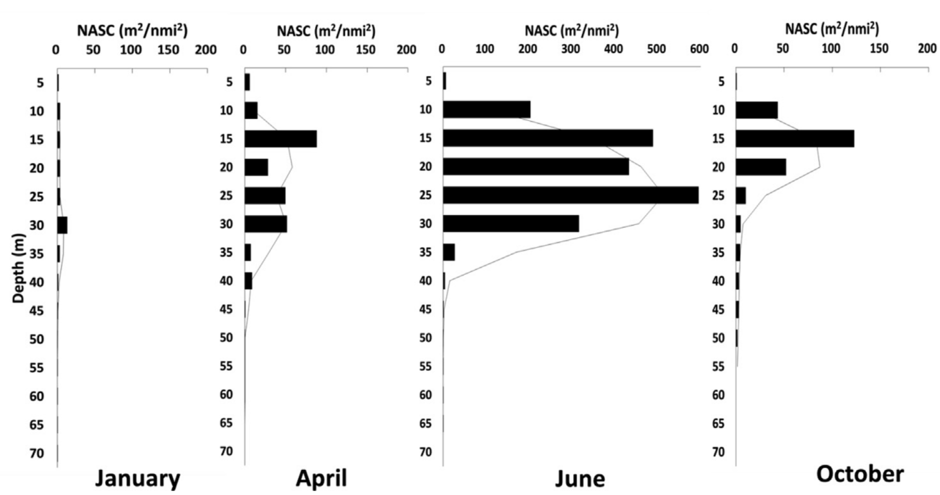

Fig. 6. The vertical distribution of marine organisms in the artificial reef area. The black line is moving average line revealing underlying a trend.

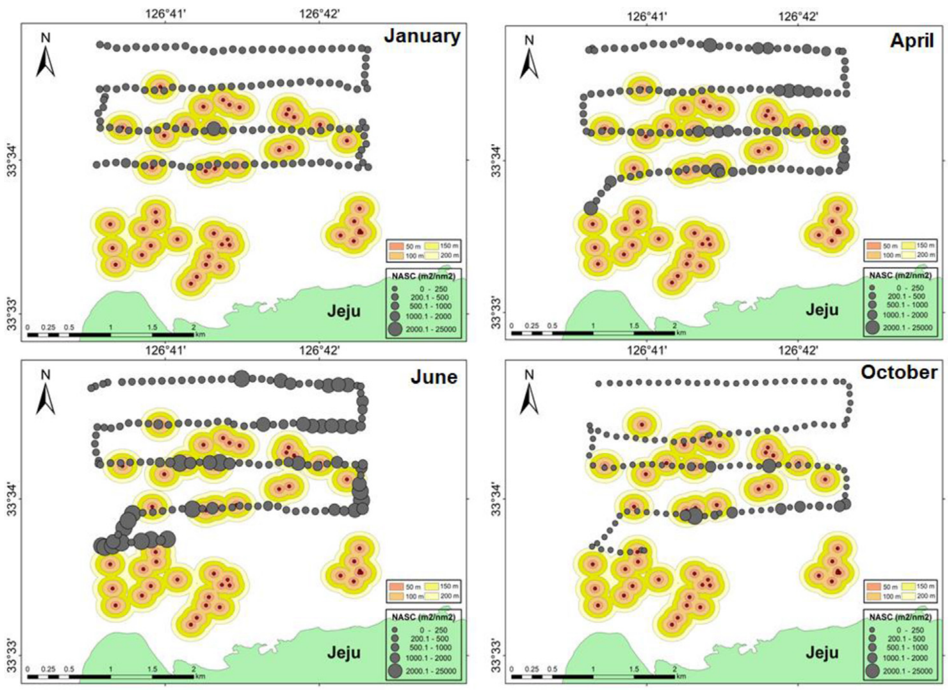

Fig. 7. The horizontal distribution of marine organisms and the influential circle of artificial reef. The buffering circles are made in 50, 100, 150 and 200 m from the artificial reef.

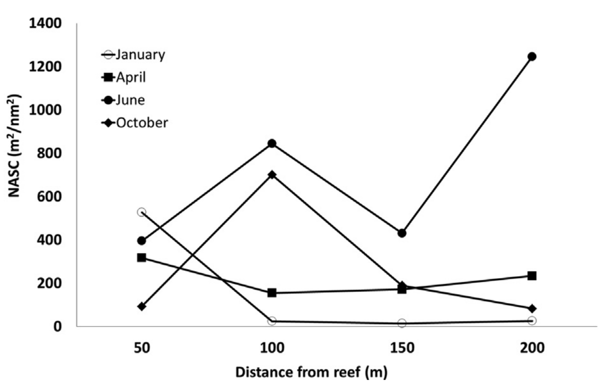

Fig. 8. The influential circle of artificial reefs. The circle buffers are in 50, 100, 150 and 200 m from the artificial reef.

were John dory, marbled rockfish, bambooleaf wrasse, and the catch of three dominant species accounted for approximately 75% of the total weight. They were all benthopelagic species and preferred to live in rock zone. The average body length and body weight of John dory were 28 cm and 393.7 g, respectively. Other species of 17 species such as blue-spotted boxfish, conger eel, stripped boarhead accounted for 7.8% of total catch. In April, the most dominant species was marbled rockfish which occupied 18.9% of total catch and the second most dominant one was stripped boarhead (12%). They are fond of living in rock area. Scarbreast tuskfish, John dory, and blackbarred morwong accounted for approximately 9–10% of total catch. In June, the most dominant species was black scraper accounted for about 40% of the total catch. The second dominant species was marbled rockfish (20%). In October, two most dominant species were John dory and black scraper, respectively. Their percentages of total catch were 44.2 and 16.3%. Many species accounted for approximately 4–8% of total catch weight. Other species accounted for approximately 6% with 9 species. In addition, from the trap, marbled rockfish and redfin velvetfish were caught throughout the months. Bambooleaf wrasse was found in January, April, and June. It seemed that those three species were frequently resided near seafloor in this study area.

4. Discussion

4.1. Fish aggregation by time and space

Spatial and temporal variation of fish species composition and their distribution was observed associated with the artificial reef structures. The fish species composition was varied seasonally, indicating that its variation was driven by the emigration, immigration, and possibly recruitment of fish species in their habitat [45]. In daily time base, the fish

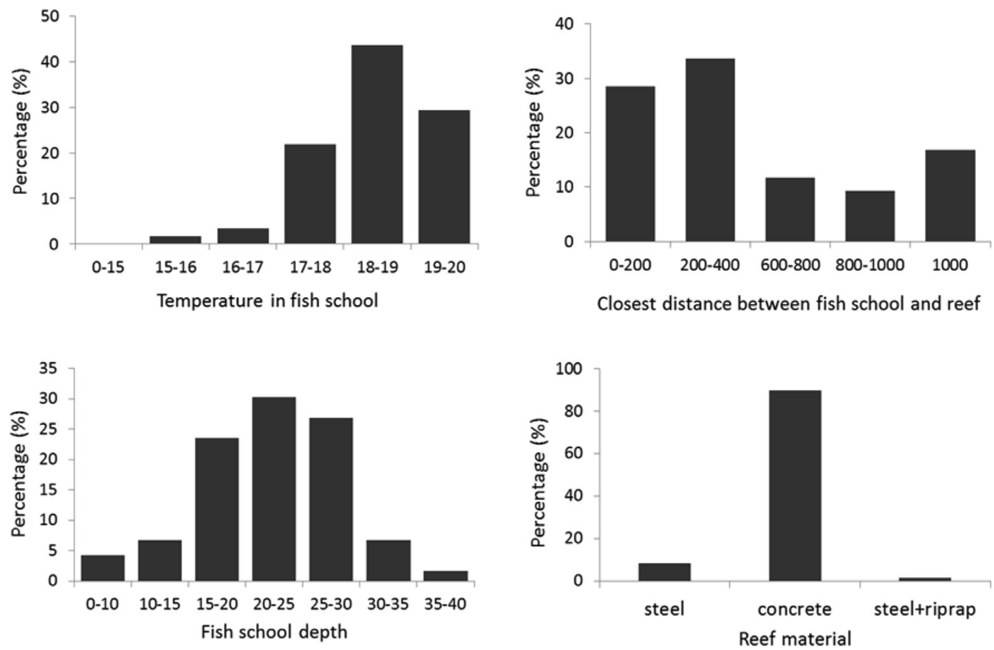

Fig. 9. The relationship between fish schools, reef property, and water temperature. Percentage means the relative frequency.

aggregations were emerged toward the water surface before sunset in the vicinity of the artificial reefs [19]. In the artificial reef site, the highest density of fish aggregations appeared in the early morning and night, and in the area where distant from the artificial reefs, the highest density occurred in early morning and afternoon [15,39]. The density of fishes in different time zones seemed to be various, which is one of their natural properties. Accordingly, the distributional properties of fishes in reefs in worldwide vary over time. In practice, to know the optimal time for acoustic survey for a quantitative purpose in reef sites, 24 h monitoring and seasonal surveys, which can bring on the movement pattern of fish by time, should be performed. Using a stationary sounder would be an effective method to know fish behaviors based on time.

4.2. Influential circle

Quantifying the interconnected distance between fishes and artificial reefs is important. The Influential circle was used to describe the effective area of a reef. Based on a number of studies on it, the size of Influential circle for representing the effectiveness of a reef was very different e.g., 50–600 m since it was depending on the reef size, the number of reef, survey method (transect line survey or stationary survey in acoustics), the length of transect line or the distance between a stationary sounder and a reef site [46,15,53,39,24]. In this study, the direct measurement between fish schools and their nearest reef unit was a different way to evaluate an influential circle. [45] used an oil platform as an artificial reef and deployed a fixed transducer horizontally to investigate an influential circle, and found that the density of fish schools was remarkably decreased when they were further than 16 m from the reef unit. Soldal et al., 2002 [57] conducted a circular acoustic transect survey (5 nm of radius centered on the reef) along with trawls around an oil platform. They observed that fish aggregations were regularly distributed approximately 50–100 m from reefs, and were scattered up to 300 m. [15] Employed a fixed echosounder on the center of the reef and another sounder was positioned at 80 m apart from the reef. The distribution of the fish aggregations was considerably dropped at 80 m. On the basis of the above mentioned studies, the maximum influential circle of 200 m in this study was determined. The maximum influential circle was decided to estimate the effective and important distances from a reef unit for a future stationary experiment which will be mentioned at the last part of discussion. The precise information on influential circle from this study and future study can support to design an optimal way of reef deployment.

4.3. Fishes in the artificial reef site and reef material

The species composition caught by the net consisted primarily of the benthopelagic species which

Table 3. The catch results during survey. The percentage is calculated by weight.

Common name	Scientific name	Fish No.	Total weight (g)	Average body length (cm)	Average body weight (g)	Percentage (%)
January						
John dory	*Zeus faber*	66	25981.8	28.0	393.7	55.2
Marbled rockfish	*Sebastiscus marmoratus*	65	10810.0	21.1	166.3	23.0
Bambooleaf wrasse	*Pseudolabrus sieboldi*	25	1837.0	16.7	73.5	3.9
Bastard halibut	*Paralichthys olivaceus*	1	1249.7	49.2	1249.7	2.7
Thread-sail filefish	*Stephanolepis cirrhifer*	6	984.4	20.3	164.1	2.1
Chub mackerel	*Scomber japonicus*	12	983.8	22.9	82.0	2.1
Black scraper	*Thamnaconus modestus*	3	907.9	26.5	302.6	1.9
Barred knifejaw	*Oplegnathus fasciatus*	2	685.5	24.6	342.8	1.5
Others		35	3657.0	25.9	134.2	7.8
April						
Marbled rockfish	*Sebastiscus marmoratus*	20	3624.1	21.9	181.2	18.9
Striped boarfish	*Evistias acutirostris*	6	2295.1	26.3	382.5	12.0
Scarbreast tuskfish	*Choerodon azurio*	2	1895.5	35.8	947.8	9.9
John dory	*Zeus faber*	6	1787.8	27.1	298.0	9.3
Blackbarred morwong	*Cheilodactylus quadricornis*	6	1747.1	29.1	291.2	9.1
Bambooleaf wrasse	*Pseudolabrus sieboldi*	16	1199.9	16.7	75.0	6.3
Black scraper	*Thamnaconus modestus*	2	955.5	31.6	477.8	5.0
Inshore hagfish	*Eptatretus burgeri*	5	954.7	47.9	190.9	5.0
Others		27	4680.4	23.7	233.3	24.5
June						
Black scraper	*Thamnaconus modestus*	26	8334.8	27.5	320.6	38.5
Marbled rockfish	*Sebastiscus marmoratus*	30	4410.5	20.6	147.0	20.4
John dory	*Zeus faber*	4	1084.9	25.3	271.2	5.0
Blackbarred morwong	*Cheilodactylus quadricornis*	3	1070.0	29.4	356.7	4.9
Conger eel	*Conger myriaster*	4	980.6	20.1	245.2	4.5
Bambooleaf wrasse	*Pseudolabrus sieboldi*	13	922.7	16.2	71.0	4.3
Bluespotted boxfish	*Ostracion immaculatus*	3	838.0	19.6	279.3	3.9
Thread-sail filefish	*Stephanolepis cirrhifer*	4	667.0	21.0	166.8	3.1
Others		19	3362.3	20.7	201.6	15.5
October						
John dory	*Zeus faber*	21	12366.4	31.6	588.9	44.2
Black scraper	*Thamnaconus modestus*	10	4569.2	31.4	456.9	16.3
Marbled rockfish	*Sebastiscus marmoratus*	12	2194.0	21.2	182.8	7.8
Boeseman's skate	*Okamejei boesemani*	3	2027.0	24.5	675.7	7.2
Striped boarfish	*Evistias acutirostris*	5	1931.0	25.7	386.2	6.9
Blackbarred morwong	*Cheilodactylus quadricornis*	4	1126.5	28.7	281.6	4.0
Thread-sail filefish	*Stephanolepis cirrhifer*	7	1022.4	19.2	146.1	3.7
Rock bream	*Oplegnathus fasciatus*	3	1005.2	23.7	335.1	3.6
Others		14	1721.9	19.3	148.9	6.2

prefer rocky reefs area and have territorial home ranges [56]. In this study marble rockfish (*Sebastiscus marmoratus*) was the common fish school found in the spring, black scraper (*Thamnaconus modestus*) was dominated during summer, and John dory (*Zeus faber*) was the dominant species found during fall and winter. The geographic distribution expands from south of Philippines and Southern China to north of Korea and Japan for marble rockfish [48]; the western Pacific in southern Japan, Korea, Australia, and New Zealand, the East and South China seas for John dory [54,51]; the coastal waters of Korea, Southern China, Japan, and Southern Africa for black scraper [26]. The dominant species in this study seems to be distributed in wide range of area in worldwide. Previous tagging study suggested that rockfish species (*Sebastes* spp.) including marble rockfish maintained small areas in coastal or near shore reefs in the spring and summer and dispersed on the outer continental shelf at depth up to 150 m [21] and moved to other reefs during the fall and winter [17]. Black scraper is widely inhabited in the low and warm latitudes including coastal water of Southern sea of Korea. This species was found in the water ranging from 10 to 28 °C [5]. In this study, the range of preferred water temperature for the June fish schools was between 15.9 and 19.9 °C, which were consistent with the results in above studies. This species spawns in the shallow areas during May and June, which might be attributable the high distribution in June in this study. Korean black scraper populations undergo seasonal migrations between spawning and feeding grounds, which allows for potential mixing with other genetically distinct populations [2].

In general, the most common material of artificial reef seemed to be concrete although gigantic reef units were composed by steel [46,15,31,39,32]. In this study, a number of fish schools in June were distributed near artificial reef composed of concrete (Fig. 9). However, it might be difficult to generalize that fish schools favor the concrete material. The concrete reef is very durable, has the strong compatibility with the environment, and is easy to be formed with other materials such as steel, oyster shell, pulverized fuel ash, and so forth. It can be said that a variety of types and sizes of concrete reef have been worldwide used [20,32].

4.4. Fish density of June fish schools

The density of majorly dominant two species such as black scraper and marble rockfish was tried to calculate. For black scraper, the relationship between target strength (TS) and body length was expressed as; $TS = 20 \log_{10} (L) - 72.2$ at 75 kHz. [28] The TS of the marble rockfish was not available. Therefore, the TS of rockfish (*Sebastes schlegeli*) replaced. Its *ex-situ* target strength was used; $TS = 20 \log_{10} (L) - 67.7$ dB at 38 kHz [22]. In fact, the TS of black scraper were measured at 75 kHz and the closest TS of marble rockfish was that of the rockfish. Acoustic fish density estimate of June fish schools was calculated by using the mean backscattering cross-section ($\overline{\sigma_{bs}}$) and the mean Sv of the June fish schools −48.2 dB [44]; The number of fish in cubic meter, that is fish density, in linear notation was obtained as:

$$\text{Fish m}^{-3} = s_v \;/\; \sigma_{\text{bs}} \tag{2}$$

$$\text{TS}_\text{s} = 10 \log_{10} (\sigma_{\text{bs, s}}) \tag{3}$$

$$\overline{\sigma_{bs}} = \sum_{s=1}^{N} \left(p_s \times \sigma_{bs,s}\right) \tag{4}$$

The TS_s is the target strength of species *s* (black scraper and marble rockfish). The P_s is the proportion of species *s*. To calculate the mean backscattering cross-section for two species, their body lengths and the percentages of catch were used from Table 3. As a result, the fish density of June fish schools was 0.28 fish m^{-3}. Note that the fish density calculated of June fish school was rough estimation because of no accurate TS for marble rockfish and the usage of different frequency for black scraper. However, the fish density in the artificial reefs can be easily evaluated if accurate TS values are provided for the inhabited species at right frequency.

4.5. Water temperature

In this study, the range of the interpolated water temperature in October was 20–21 °C which was higher than that in June. A study on characteristic of water temperature in coastal waters around Jeju Island revealed that in October and June 1999, the water temperature at Gimnyung, which was very close to the Buckchon, was the same 20 °C while that in January and April was 14.5 and 15 °C, respectively [27]. In 24 October of 2018, the water temperature at Jeju port, which was located approximately 17.5 km away from Bukchon port, had the range of 22.2 and 22.5 °C, while the water temperature in 9 June of 2018 was between 19.6 and 19.9 °C [4]. It is well known that the waters around Jeju Island are directly affected by Tsushima warm current throughout the year; therefore the annual surface water temperature is relatively high. For example, in 2015, the surface water temperature in Jeju Island was 19.4 °C, which was the highest temperature in any sea in South Korea. It was reported that the seasonal fluctuation in surface water temperature in Jeju was very low [34]. In this context, the water temperature in October in this study area was the highest among different seasons and the variation between seasons was relatively small.

4.6. A future plan and others

The GIS has been used in a wide variety of fisheries studies. When the temporal and spatial environmental datasets are need to be combined with high resolution of acoustic data, the GIS method in this study would be a reliable tool to provide a dynamic view and their connections between datasets. In especial, the artificial reef deployment and management require the complex information such as biological and ecological characteristics of targeted fishes (distribution, moving pattern and prey and predator relationship), environmental characteristics (habitat property, water quality, current and tide), the reef engineering factor (reef structure, type, location). The more supportive information can result in the better management of reef for sustainable fisheries. This study pointed that the GIS tool can be one of great tools for fish resources and reef management in the artificial reef environments.

A multibeam echosounder or side scanning sonar has much wider detection range compared to single beam echosounder with high resolution. In artificial reef sites in Adriatic Sea, a multibeam echosounder by combined with trammel net or scuba diver presented the distribution of fish aggregations and their abundance based on season and daily time period [35,42]. However, the three dimensional metric description of fish schools was not presented in the multibeam echosounder applications. It would be beneficial to attempt to use a multibeam echosounder in the artificial reefs to characterize fish schools in more than two dimensions along with other dataset such as environmental data. The GIS tool used data from a multibeam sounder will provide multidimensional views of not only fish schools but also reef units, seafloor, and environmental data for better understanding the complexity of reef site.

Because a number of rocks and reefs were positioned very close to the coast, the acoustic transect line was not designed close to the coast (Figs. 1 and 3). To compensate this matter, a small echosounder inside a buoy will be used in the study area in near future. The echosounder has been already developed with a Korean brand transducer and transceiver (NF560, Samyoung ENC). A small monitor and a GPS were connected to the transceiver with two (50 and 200 kHz) frequencies. It was tested to collect acoustic data for 72 h continuously off Gijang that is the southeast part of South Korea. A future plan is to set up this sounder off Bukchon, Jeju Island in particular the area in which a fishing vessel charted could not access. The sounder can collect acoustic data over 24 h at least, so that the behavioral and distributional characteristics of marine organisms including fish diurnal migration can be observed.

In this study, only 38 kHz was used. If one more frequency such as 120 kHz is added, fish species identification would be attempted. For example the dB differencing method, which is a practical and well established method for species identification, has been applied in many waters in the world. The dB differencing method can support to discriminate fish species in artificial reef areas. Visual surveys, including underwater camera and video, and scuba divers, and net samplings could provide the fish species. However, if acoustic fish species identification is achieved in artificial reef environments, a dominant fish biomass can be rapidly estimated. Moreover, information on fish species can be valuably used for the design of artificial reef module and their deployment layout.

Lastly, reef shape and composition are important attributes for fish community structure, in especial under condition of large volume of reefs. In this study, the major reef material was concrete so that the fish schools in June were found near reef made by concrete. The connection method between datasets in this study allows the quantitative relationship, e.g. between reef and other elements such as fish school, to be elucidated. As mentioned in the Introduction, South Korea has a plan to extend the artificial reef sites. It would be beneficial if the same approaching method as this study is applied in other artificial reef sites, thus the spatiotemporal distributional characteristic of fish aggregation would be revealed around artificial reefs in South Korea.

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