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Hydroacoustic method and GIS-Dashboard visualization for fish size in Banggai Sea Waters

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Abstract. Estimating fish stocks, including their distribution and density, plays a vital role in the management of capture fisheries. Hydroacoustic technology is widely utilized for fish stock estimation study. In September 2022, BRIN and IPB University conducted hydroacoustic data measurement in the Banggai Sea as part of the "Banggai Upwelling Dynamics Exploration and Experiment" to estimate fish stocks. Very large fish (>58 cm) has a density of 12,452 fish km^{-2}. The spatial distribution of fish occurs in the eastern waters of Banggai Island and the northern waters of Taliabu Island. The most significant potential is the epipelagic layer (0 to -200 meters), with very small-sized fish having the highest density, followed by large-sized and small-sized fish. To summarize the analysis results of fish density distribution , a GIS-Dashboard is utilized. This online platform integrates various maps and charts, offering an engaging and easily understandable visualization of the information.

1 Introduction

The Banggai Sea area is located inside the “Wilayah Pengelolaan Perikanan Republik Indonesia” 715 (WPP NRI 715) which includes the waters of Tomini Bay, Maluku Sea, Halmahera Sea, Seram Sea, and Berau Bay. This area is in the Maluku Sea, to the east of Central Sulawesi Province and sharing borders with the Banggai Regency, Banggai Laut, and Banggai Islands. In the Decree of the Minister of Maritime Affairs and Fisheries Number 82 of 2016, the dominant fish species found in WPP NRI 715 are “Cakalang” (*Katsuwonus Pelamis*), “Layang” (*Decapterus spp.*), “Madidihang” (*Thunnus Albacares*), “Teri” (*Stolephorus spp.*) and “Selar” (*Selaroides spp.*). The potential for capture fisheries in WPP NRI 715 is estimated are 1.2 million tons. Capture fisheries production in Central Sulawesi Province reached 165,403.77 tons in 2021 [1].

The National Research and Innovation Agency (BRIN) and IPB University conducted a marine survey at the Banggai Sea; Banggai Upwelling Dynamics Exploration and Experiment 2022 (BUDEE). This survey was conducted to track traces of the upwelling phenomenon in the Banggai Sea and record fisheries' hydroacoustic data to estimate fish

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stocks. The upwelling phenomenon is a natural phenomenon that affects fishing results at sea. The upwelling phenomenon is characterized by low temperature, high salinity, and high chlorophyll density [2] . In simple terms, this phenomenon brings cooler and more nutrient-rich water, which is fish food, to the sea surface, so that fish resources will be concentrated there and if fish stock estimates are conducted the results will be better. BRIN and IPB University collected data to estimate fish stocks, namely distribution, and density, using the hydroacoustic method to obtain good data accuracy [3].

Estimation of fish stocks or fish abundance is conducted using the hydroacoustic method [3–8]. The hydroacoustic data used is usually the result of measurements by the Split Beam Echosounder [9]. However, currently there has been no fish stock estimation study conducted in the Banggai Sea area specifically using the hydroacoustic method. Analysis of fish stock estimates based on the hydroacoustic method is conducted by analysing the Area Backscattering Coefficient (Sa) value which produces the density of organisms per area [5, 7]. In addition, hydroacoustic data can visualize the spatial distribution and density of fish based on its size, time, and depth. [3, 7, 8, 10].

From previous research, the processed data (tables, graphs, and maps) are very numerous and complex [3, 5, 7, 8, 11], so that a better and more dynamic visualization is needed to facilitate the delivery of analysis results. Among the outputs produced in previous research, there are a tables and graphs of the calculation results of fish density distribution estimates per depth, and fish density maps based on depth and time. The complexity of visualization of analysis result that is tied to spatial information can be circumvented by Geographic Information System, namely in the form of a GIS-Dashboard [12]. A Geographic Information System (GIS) is a computer-based system or technology built to collect, store, process, analyse, and present information from an object or phenomenon related to its location or existence on the Earth's surface[13]. Management and visualization of spatial and non-spatial data can be done easily using GIS. There are many methods developed to manage and visualize spatial data with GIS.

Dashboards are a popular data visualization method and have advantages in terms of managing the visualized data [12]. With dashboards, the visual presentation of data is carried out via internet services, so that users or viewers can interact directly with the visualized data [14]. GIS-Dashboard can display spatial data together with non-spatial data, so that all analysis information can be loaded and accessed by users on one page [15]. Apart from maps, other non-spatial data can be displayed with diagrams, plots, histograms, and other graphs [14], so that it is easier to understand. The focus of the dashboard is the delivery of information or reports in a simple manner. In the context of fish density distribution analysis, GIS-Dashboard can be used to display the results of calculations of fish density estimates per depth, and fish density distribution maps based on depth also time. All analysis results can be displayed on one page in an uncomplicated way but are easy to read and understand, even easy to access because they are published online.

2 Methods

2.1 Research location

The location of this research is the Banggai Sea waters.. The survey tracks analysed in this study are divided into tracks (a), (b), (c), (d), and (e) (Figure 1).

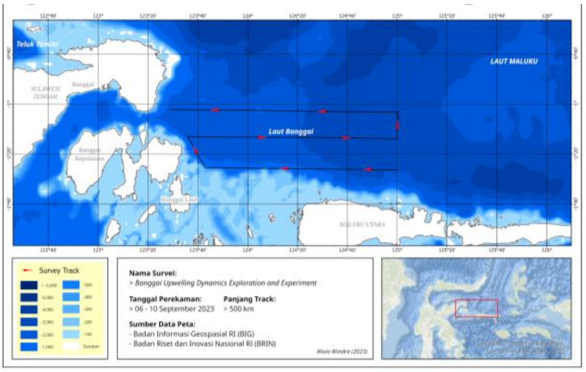

Fig. 1. Map of Research Location.

2.2 Research data

The main data used for analysis in this research, namely hydroacoustic data, comes from the results of measurements during the 2022 Banggai Upwelling Dynamics Exploration and Experiment (BUDEE) Survey activities on 4-18 September 2022 in the Banggai Sea. This hydroacoustic data was recorded using a SIMRAD-EK60 Scientific Echosounder instrument with Split-beam Windows (TM) type which is specifically for fish stock assessment activities (Kongsberg, 2021). The measurement results along the survey track are in the form of acoustic data in [.RAW] format with a frequency of 120kHz.

2.3 Analysing hydroacoustic data

To calculate fish density acoustically, an echo integration process is needed which is conducted from the Volume Scattering Strength (SV) value to obtain a fish density value. The Sa value is a derivative of the SV value resulting from echo integration. SV is obtained by processing the Target Strength (TS) values measured by the Split Beam Echosounder tool. TS is the value of the back reflection of a single object (single target) of fish and SV is the value of the back reflection of a group of fish. Both SV and TS are logarithmic values with units of [dB], so to conduct calculations it is necessary to convert them to linear form first. The resulting fish density value can be m^{-2} fish or km^{-2} fish. The results of fish density distribution calculations are usually visualized in the form of tables, graphs, and maps.

Acoustic data is processed using an open-source application, the Echo Sounder Package or ESP3 (*https://sourceforge.net/projects/esp3/*). ESP3 is an acoustic data processing application developed by the National Institute of Water and Atmospheric Research (NIWA), New Zealand [16]. This application can be used freely for various acoustic data processing such as studies of gas leaks from underwater faults [17, 18], abundance of marine organisms [19–21], and other studies within the scope of hydroacoustic [22–24]. Fish density calculations were conducted using the Microsoft Excel application based on the results of processing in ESP3.

Information on fish density distribution is obtained from the results of acoustic data processing in the form of echo integration processing. First, pre-processing is applied to acoustic data in the form of noise filtering, bad data detection, and bottom detection. Detection is conducted at a depth of 0 to -500 m (2 m below the transducer reference). This process is conducted in the ESP3 application. Fish density (km^{-2}) (ρA) is obtained from equation (1) below, [25]:

$$\rho A = \left(\frac{Sa}{\overline{\sigma_{bs}}}\right) \times 10^6 \quad (1)$$

The Sa or the Area Backscattering Coefficient (m^2 m^{-2}) value is obtained from equation (2):

$$Sa = 10^{\left(\frac{\overline{SV}}{10}\right)} \times \overline{TS} \quad (2)$$

The values of $\overline{SV}$ and $\overline{\sigma_{bs}}$ are the average of Sv or Volume Backscattering Coefficient (m^{-1}) and σ_{bs} or Volume Backscattering Strength, they obtained from equations (3) and (4):

$$Sv = 10^{\left(\frac{(SV)}{10}\right)} \quad (3)$$

$$\sigma_{bs} = 10^{\left(\frac{(TS)}{10}\right)} \quad (4)$$

The SV or Volume Backscattering Strength (dB re 1 m^{-2}) and TS or Average Target Strength (dB re 1 m^2) values are logarithmic values (dB) obtained from measurement data. Every acoustic data calculation must be converted and use its linear form. Echo integration processing in the ESP3 application produces parameters (TS), ($\overline{Sv}$), & (Sa) along with other parameters in [.csv] output file, so that the calculation of the (ρA) value can be done in the Microsoft Excel application based on the previous equation. The threshold setting for the SV value during the echo integration process is set at -60 dB re 1 m^2. The Elementary Distance Sampling Unit (EDSU) or acoustic survey horizontal bin size is set every 500 m in length and every -10 m in depth. Echo integration is conducted at depths from 0 to -500 m (with a transducer tolerance of -2 m). TS value for fish ranges from -70 dB re 1 m^2 to -20 dB re 1 m^2 while for plankton it is lower [11], then refer to [26] a value of -50 dB re 1 m^2 will detect fish up to about 6 cm long.

2.4 Designing a GIS-Dashboard

After the distribution and density of fish are obtained, the result is visualized using tables, graphs, and maps either in total or based on some parameters (fish size, time, and depth). The results are visualized with a dashboard using the ArcGIS Online service for online web map host and ArcGIS Dashboard for the dashboard host, as well as the Google Sheets service for graph host.

3 Results and discussion

3.1 Results

Fish density maps result from echo integration are displayed per depth of -100 m (Figure 2). There are five density classes, namely [0-10 km^{-2}], [10-100 km^{-2}], [100-1,000 km^{-2}], [1,000-10,000 km^{-2}], and [10,000-100,000 km^{-2}] which is in transparent colour. On the map, the highest density is shown in the -100 m strata. The spatial distribution tends to be north of Taliabu Island, North Maluku, and east of Banggai Island, Central Sulawesi. The fish density class that appears dominantly in the first stratum is [1,000-10,000 km^{-2}]. Eight of the ten highest density classes, the [10,000-100,000 km^{-2}], appear in this stratum. The other two appear in the second stratum. The density of fish in the second stratum decreased compared to the first stratum, but the dominant density class was still the same, the [1000-10,000 km^{-2}] class. In the third, fourth, and fifth strata, the density of fish is extremely low compared to the previous strata. They dominated by smaller density classes. However, when combined as a whole, each measurement track has a high fish density, except at the beginning of the track where there are no fish density estimation results at all.

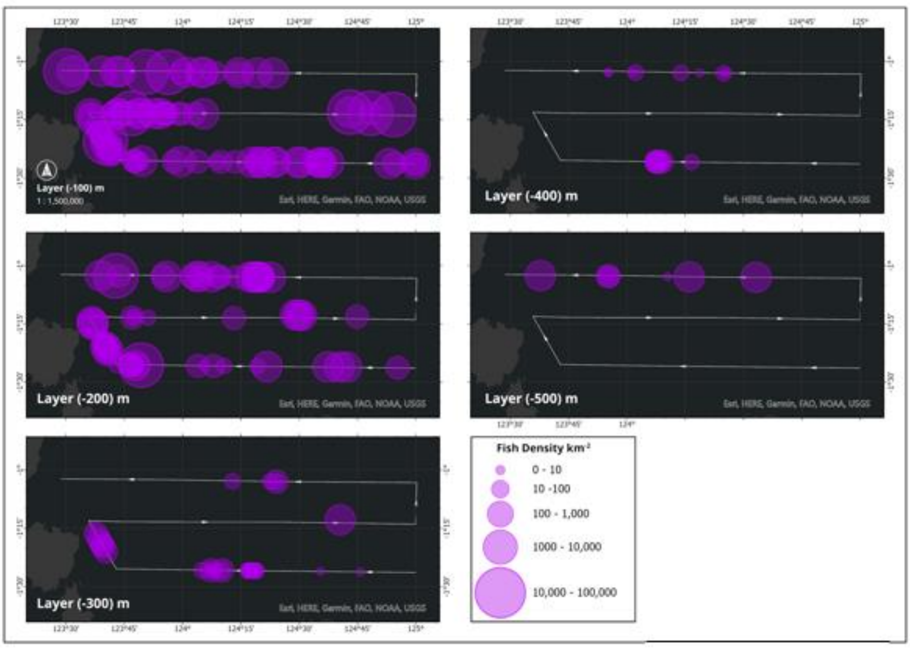

Fig. 2. Fish Density Map.

This fish size categories follows the classification of Foote, (1987) that derived from TS Mean value [8]. In the scatter plot between depth and TS Mean values for echo integration (Figure 3), the TS Mean range of -55 dB re 1 m^2 to -40 dB re 1 m^2 tends to be at a depth of 0 m to -200 m. Meanwhile, TS Mean values that are > -40 dB re 1 m^2 are more likely to be detected at depths of -100 m to -500 m.

Table 1. Total Fish Density Based on Size.

TS Mean (dB re 1 m^2)	**Fish Length (cm) [3]**	**Fish Size Category [3]**	**Fish Density (km^{-2})**	
<50	< 6	Very Small	313,645	313,645
50 - 47	6 - 10.47	Small	54,634	199,857
47 - 44	10.47 - 14.79		27,391	
44 - 41	14.79 - 20.89		117,832	
41 - 38	20.89 - 29.52	Medium	1,889	5,942
38 - 35	29.52 - 41.68		1,044	

35 - 32	41.68 - 58.88		3,009	
32 - 29	58.88 - 93.17	Large	2,402	4,902
29 - 26	93.17 - 117.48		2,500	
26 - 23	117.48 - 165.96	Very Large	812	3,568
23 - 20	165.96 - 234.40		2,756	
Total			**527,914**	

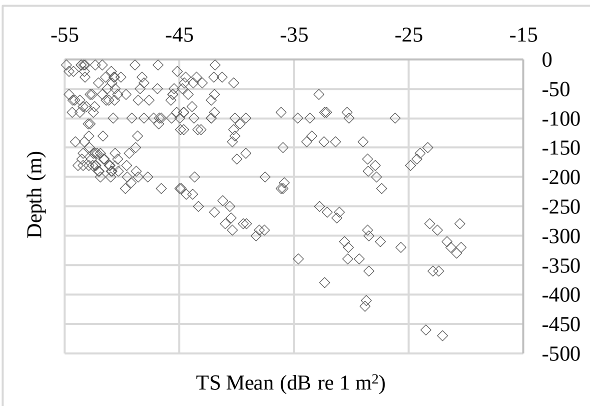

Fig. 3. Scatter Plot Between TS Mean and Depth.

The spatial distribution of fish density based on size are displayed with a density map with the similar classes as before (Figure 4). The small fish (*Ikan Kecil*) category is the density of fish with a TS Mean value < -44 dB re 1 m^2. Meanwhile, the big fish (*Ikan Besar*) category is the density of fish with a TS Mean value ≥ -44 dB re 1 m^2. The estimated value of fish density for the small category is 390,942.69 fish km^{-2}. In the small category, the density class that appears is [10 – 100 fish km^{-2}] to [10,000 – 100,000 fish km^{-2}] and the dominant class that appears is the class [1,000 – 10,000 fish km^{-2}]. This small fish is often found in the waters east of Banggai Island and a few in the waters north of Taliabu Island. The estimated density of fish in the large category is 136,970.86 fish km^{-2}. The density classes that appear in the large category are [0 - 10 fish km^{-2}] to [10,000 – 100,000 fish km^{-2}] with the dominant class [10 – 100 fish km^{-2}]. Large fish are more likely to be found in the waters east of Banggai Island.

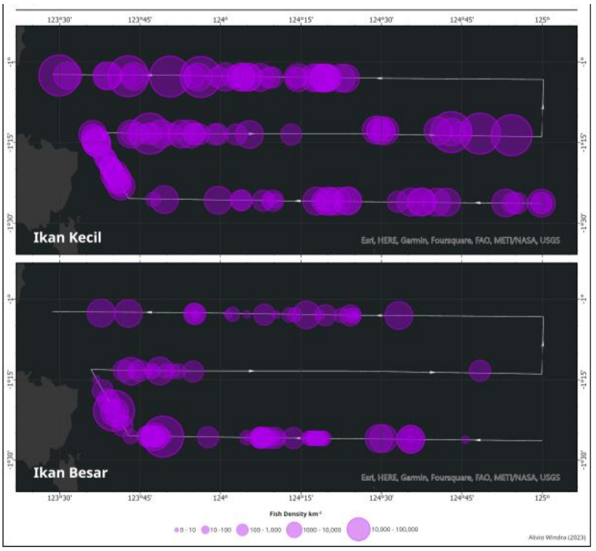

Fig. 4. Fish Density Based on Size Categories.

Referring to the fish size classification which is linked to the TS value by Ma'mun et al. (2018), the density of fish can be calculated based on size [2]. A very small percentage of fish density was found down to a depth of -200 m with an estimated total density of 292,471 km^{-2}. The small category has an estimated total density of 98,472 km^{-2} and is found to a depth of -250 m. Then the large category has an estimated total density of 124,519 km^{-2} and is found to a depth of -300 m. The very large category has an estimated total density of 12,452 km^{-2} and is found at depths of -50 m to -500 m (see Table 1 and Figure 5). The density of fish in the small and very small categories dominates up to a depth of -250 m, while at deeper depths it is dominated by fish in the large and very large categories.

On the GIS-Dashboard main page that have been created, six content panels are displayed; a) summary, b) map, c) legend, d) density graph per -10 m depth, e) density graph per -50 m depth and density based on fish size, and f) table of range of mean TS values per 10 m depth and scatter plot of the relationship between mean TS and depth (Figure 6). There is also a title and credits section. The summary section is a summary of the results of the Banggai Sea fish density analysis which consists of survey track length, horizontal bin acoustic survey value settings, total density, small fish density (<21 cm), large fish density (>21 cm), summary of the most potential depth (per -50 m) and its density, and the most potential fish categories. In the map display, there are several layers that can be shown, by default the initial layer displayed is the fish density map in the Banggai Sea. There are also layers of small fish density maps, large fish density maps, and fish density maps per 100 m depth. An explanation of the symbols on the map will be explained in the legend panel with the display will adjust to the active layer.

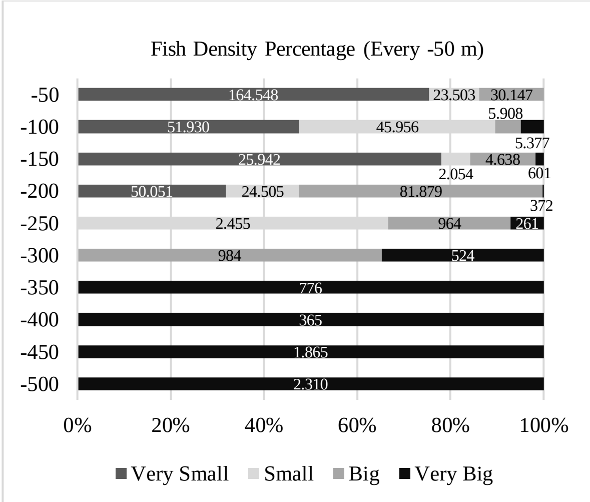

Fig. 5. Percentage Chart of Fish Density for Every -50 m.

In the other three panels, data is displayed in the form of tables and graphs. The first panel displays a bar graph of total fish density per 10 m. The arrow keys available for change one graph to another. Each graph displays depth strata every 100 m for a total of five bar graphs. In the next panel, a bar graph of fish density is also displayed but simplified to every -50 m depth and displayed in just one graph. The last panel is the part that explains the TS value. The relationship between TS value and depth is depicted with a scatter plot. Then the distribution of maximum and minimum TS values per -10 m of water column is displayed in a table. The information displayed on this dashboard page is the most valuable information in the analysis output of fish density distribution in an area. This dashboard is published online, and access is open to the public.

Fig. 6. The Banggai Fish Density GIS-Dashboard.

3.2 Discussion

Acoustic data calculations show that the Banggai Sea area has a fish density of 527,913.56 fish km^{-2}. The results of this research produce fish density in individual units per area; fish km^{-2}. However, if samples are caught using trawls during the survey, estimates can be made up to eight units per area; kg km^{-2} [2]. The highest fish density was in the depth strata [0 m to -100 m] and [-100 m to -200 m] with a total density of 327,368 fish km^{-2} and 190,041 fish km^{-2}, respectively. The TS Mean values detected during measurements in the Banggai Sea ranged from -54.84 dB re 1 m^{2} to -20.42 dB re 1 m^{2}. The highest density was found at a TS

Mean value of <-50 dB re 1 m^2 with a total of 313,645 fish km^{-2}, followed by a TS Mean in the range of -44 dB re 1 m^2 to – 41 dB re 1 m^2. It can be concluded that fish in the Banggai Sea are dominated by small fish (<21 cm). The results of this calculation are supported by research on the distribution of pelagic fish in WPP NRI 715 [2] which states that the highest density of small pelagic fish is found in the Maluku Sea.

Spatially, the distribution of small fish is very large and evenly distributed along the measurement track with a high density. The presence of many small fish in an area indicates the presence of phytoplankton which is their food there. Indirectly, this condition will attract large fish because it is related to the food chain [2]. The spatial distribution of small and large fish, when overlayed, also shows a strong relationship, when the estimated density of small fish is high in an area, there will also be large fish there (see Figure 10). The spatial distribution of these fish is dynamic and depends on several factors such as water temperature [3]. However, the main factors that influence the spatial distribution of fish are environmental factors such as food sources (plankton), seawater temperature, seawater salinity, and dissolved oxygen [7, 8].

The GIS-Dashboard that was successfully created displays all data and information from analysis of the distribution and density of Banggai Sea fish. On the dashboard that is created, a map of the analysis results is displayed which can be selected based on theme, along with several graphs and tables which provide more detailed information on the results of the analysis of fish density distribution, all of which can be found on just page. Apart from displaying maps, GIS-Dashboard also displays non-spatial data in diagrams, plots, histograms, and other graphic formats [14]. This is in line with [15] that GIS-Dashboard can display spatial data along with non-spatial data. Apart from that, there is also a summary section that briefly explains the main points of the analysis results so that the information displayed is easier to understand [27]. Dissemination of the results of fish density distribution analysis will indeed be more interesting and easier to understand if visualized using a dashboard rather than using conventional methods.

The information on this GIS-Dashboard can help policy makers around the Banggai Sea to plan fisheries resource management. The Banggai Regency Fisheries Service in its 2021-2026 Strategic Plan states that one of the obstacles in developing the marine and fisheries sector is the lack of data and information on natural resource potential in Banggai Regency [28]. This obstacle becomes a big problem when it is discovered that the fisheries sector has good development opportunities. Banggai Regency has opportunities in the form of high market demand for fishery commodities, quite high interest in consumption, and good export prospects [28]. The analysis results displayed in the GIS-Dashboard in this research can be a solution to obstacles for planning development strategies to take advantage of this fantastic opportunity.

Visualization with GIS is very helpful in understanding the spatial distribution of fish in water. The data resulting from the analysis of fish density distribution using the hydroacoustic method consists of quite a lot of rows and columns. Usually, this information will be visualized with simpler tables or various graphs to represent the distribution and density of fish. However, map visualization provides a stronger view of understanding the spatial distribution of fish in waters. Distribution and density can be represented by a variety of colours and symbols that are attractive and easy to understand. With the interpolation method, points whose values are not measured can be assigned statistical values.

An example of interpolation is visualization using the inverse distance weighting (IDW) method [29]. The results from IDW provide a better and more comprehensive spatial visualization of fish density distribution for the study area, although they are not suitable for predicting the actual values from unmeasured points. The role of GIS can also be developed further than just as a visualization tool in understanding analysis results. With GIS, it is possible to map environmental factors that influence the distribution and density of fish.

Temperature, salinity, dissolved oxygen values, and sunlight intensity can be mapped using certain methods [26]. So apart from knowing the spatial distribution and density of fish, the environmental factors that influence them can also be mapped.

These environmental factor maps can be overlaid on each other to provide a better visual understanding [26]. The relationship between the information on each map can also be better understood. Even with these maps, relationship analysis can be conducted using geostatistical methods and spatial modelling to fill in points whose value cannot be measured. Spatial modelling can help predict the distribution and density of fish not only at unmeasured points but also predict the distribution and density of fish in the future [30]. However, this kind of analysis requires quite high temporal resolution with large numbers. So, the continuity of hydroacoustic measurements is very important.

4 Conclusion

The spatial distribution of fish tends to be in the waters east of Banggai Island and the waters north of Taliabu Island. Fish tend to be found in depth strata from 0 to -200 m. The greatest potential in the Banggai Sea area is in the epipelagic layer (0 to -200 m) and based on size the greatest potential is in very small fish, then large fish, and then small fish. The results of the analysis of the distribution and density of Banggai Sea fish are summarized into a GIS-Dashboard where all map and graphic information is displayed on one page published online to provide a more interesting and easier-to-understand visualization.

5 Recommendation

In this study, the result of fish density not shown using weight units per area, and validation of the number of catches was not conducted. To do this, next research need to correlate the TS Mean value with the sample unit weight of the dominant fish species caught as in several previous studies. However, limitations are caused by the unavailability of sample data because no fishing was conducted during the voyage in the field. In future research, it can be developed by using more complete data in addition to hydroacoustic data, namely information from caught fish samples such as type and weight for more detailed analysis and validation of estimation results.

The existence of fish is influenced by environmental conditions such as temperature, salinity, food sources, and others. Collecting data related to environmental conditions along the hydroacoustic measurement track in future research allows research to be developed. Analysis of the relationship between fish density distribution and environmental factors can be conducted so that potential areas can be determined based on environmental conditions.

Considering that fish as the main subject in fisheries resources is a dynamic subject, continuity of data measurements must be conducted so that fish potential data is always available. With temporal data, research can be developed into broader topics, especially in understanding the distribution of fish at certain times or seasons, along with the continuity of data on environmental conditions.

The role of GIS can be developed to understand the distribution and density of fish with various spatially related information. With fish density distribution data, a relationship analysis can be conducted with various information so that spatial modelling of fish potential for the future can be carried out. Data integration data from spatial modelling and remote sensing can also be integrated with field data to understand fish density distribution better.

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