Dissemination of angling vessels in the eastern Indian Ocean: a remote sensing perspective

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Abstract. Dissemination of angling vessels extracted from Vessels Monitoring System (VMS) platform and the Visible Infrared Imaging Radiometer Suite (VIIRS) boat detection (VBD) data in the eastern Indian Ocean. The data of angling vessels derived VMS platform and VBD data was provided by Ministry of Maritime Affairs and Fisheries Indonesia and Earth Observation Group, respectively. The results showed the number of angling vessels that operated during southeast monsoon was higher than others monsoon. The dissemination of angling vessels originating from the VMS platform with VIIRS-VBD has a similar pattern, especially from Bali – Nusa Tenggara. In the general, the dissemination variety of angling vessels from VMS showed that angling vessels mostly appeared in the waters of Bali – Nusa Tenggara while the angling vessels from VBD appeared from West Java - Nusa Tenggara. The VMS and VBD data opening up a variety of possible future applications for more calculable data analysis of fisheries.

1. Introduction

The supply of global fish continues to decline. Therefore, supervision of fishing vessels is very much needed. This is to produce a basis for enforcement of fishing regulations and against illegal, unreported, and unregulated (IUU) fishing activities. In addition, [1] states that monitoring and mapping fishing activities are important components in the planning and management of fisheries and marine resources. Fishing location data has long been used for various things such as to help assess fisheries resources [1, 2], identify and describe fishing areas [3] evaluate the impact of external factor interventions in resource management marine and fisheries resources [4] and estimated fishing efforts [5]. However, monitoring and mapping of fishing activities still face many problems such as high costs in collecting fishing data, poor quality of fishing data, and fishermen’s perceptions of fishing data. Actually, the log book has recorded the date range, location, and weight of the catch in a particular location. However, these reports are not normally sent until the ship returns to its landing site and there is no unified mechanism for exchanging these documents. To solve this, the location of the vessel can be monitored using remote sensing technology.
Remote sensing technology has the potential to detect position and supervise angling vessels. With weather conditions that are slightly clouded, optical sensors that have high resolution, the satellite is able to detect the position of the ship. One satellite that is able to detect ships and has the ability to operate in all weather conditions is Satellite synthetic aperture radar (SAR). In addition, several high-resolution optical images have also been used to detect ship activity [6, 7, 8]. However, these sources have drawbacks including the general costs associated with data access, it takes several days to access data and global reach is not currently available every day.

Satellite meteorological sensors have many benefits including having a very wide area coverage, open access data and near real time. In addition, this satellite also has a long data archive that can be used to temporarily understand the condition of an area. The disadvantage of meteorological satellites is the low spatial resolution. An exception to this is the detection of electrical lighting on ships at night. Low light imaging on these sensors is designed to detect moonlight clouds in the visible, but also allows the detection of electric lights present on the surface of the earth [9]. One of the technologies currently used to detect the position of lighted vessels is VIIRS Boat Detection (VBD) and Vessel Monitoring System (VMS). The exception here is the identification of artificial lighting on ships at night. Low light imaging on these sensors is designed to detect clouds of moonlight in the visible, but also to detect electrical lights on the earth's surface [9]. VBD and VMS are two of the technologies currently used to detect the position of lighted vessels.

Night-time satellite imagery provides an alternative source of spatial data in marine and fisheries studies, particularly for vessels using lights as fish aggregates (FADs) to attract fish [10]. [11] established the ability of VBD as the position of a vessel derived from the visible infrared imaging radiometer series, day / night band (VIIRS DNB) image data to provide an innovative solution for vessel monitoring activities. The light intensity used in this method of fishing allows it to be identified through a night-time image [12].

The use of VMS in Indonesia is officially enforced by the issuance of Ministerial Regulation No. 42 in 2015. VMSs are installed on fishing vessels and 30 tonnage (GT) or larger fishing vessels, representing about 10% of the domestic fishing fleet. Besides having advantages, VMS also has weaknesses. For vessel surveillance, operators can avoid detection by deactivating their devices, reporting false identification, or reporting a series of fake locations. Among maritime law enforcement agencies, there is a great deal of interest in identifying "illegal ships" that do not have an accurate VMS signal. This is a clue about the possibility of illegal fishing in certain fishing areas. The only way to identify "dark ships" is to combine VBD and VMS. Therefore, this study aims to understand the distribution of lighted vessel positions both spatially and temporally by using VBD and VMS in the eastern Indian Ocean (EIO).

2. Methods
2.1 Study area
This investigation was located in the eastern Indian Ocean (104° – 123°E and 5.8° – 15°S) (see Figure 1). The area is affected by prevailing wave and currents system, for example 1) South Java Current (SJC) [13]; 2) Indian Ocean Kelvin Waves (IOKWs) [14]; 3) the Indonesian Through Flow (ITF) [15, 16]; 4) Rossby Waves (RW) [17, 18]; and 5) the Indian Ocean South Equatorial Current (SEC) [19].
2.2 Location of angling vessel from VMS and VBD data

In this study, the VMS data was obtained from the Ministry of Maritime Affairs and Fisheries Indonesia (http://integrasi.djpt.kkp.go.id). We were focusing on the angling vessels for Bigeye tuna. The speed of angling vessels and type of angling gear are provided by the VMS data. Therefore, for analysis, the information was picked depending on the speed of angling vessels and the kind of angling equipment. Vessel speeds of less than 3 bunches were viewed as guiding angling exercises, while vessels were expected to speed multiple bunches that would not lead angling exercises. However, longline is a popular angling gear used for having Bigeye tuna in EIO [14, 20]. Therefore, in this analysis, we chose vessels fitted with longline tuna angling gear and vessel speeds below 3 bunches and operated at night as the Bigeye tuna angling vessels area within the EIO. The location of the angling vessels was then believed to represent the Bigeye tuna angling region within the EIO.

The DNB data were obtained from the Earth Observation Group website (https://eogdata.mines.edu/vbd/). The dissemination of angling vessels data in csv format was processed on the basis of Elvidge's algorithm [11]. In this study, only Quality Flag (QF1) was used to detect the angling fishing with strong light intensity in the EIO. Furthermore, both VMS and VBD data were carried out using the Geographical Information System (GIS) to understand the spatial distribution of angling vessels in the EIO.

Spatial distribution of angling vessels has been evaluated using spatial indicators i.e. (1) spatial dispersion, and (2) directional dispersion [21]. The spatial dispersion of angling vessels was determined using a "standard distance tool" that represents the degree to which the operation of spatial angling vessels is spatially dispersed around the central pattern. The greater the size of the circle radius, the more the fishing operation has been spread, or vice versa. In addition, directional dispersion was measured using the "standard deviation ellipses tool" that represents the direction of vessels coordinate distribution in the x and y directions.

\[
SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} + \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}}
\]

(1)

\[
SD_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \quad SD_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}}
\]

(2)
where $SD$ is spatial dispersion, $SD_x$ is directional dispersion of x axis and $SD_y$ is directional dispersion of y axis.

3. Results and discussion

3.1. Fishing vessel distribution

VBD and VMS are two practical and economic tools for monitoring the success, surveillance and control of fishing activities. The number of angling vessels collected from the VBD and VMS was fluctuating in the EIO (see Figure 2). In general, the number of angling vessels collected from VMS was more than VBD data. We collected with total of 11411 VMS and 7580 VBD data from January – December 2017. Furthermore, the number of angling vessels collected from VMS during southeast monsoon (April – September) (6160 unit) was more than northeast monsoon (October-March) (5251 unit). The same conditions occurred for angling vessels obtained from VBD. During southeast monsoon the number of angling vessels (4714 unit) extracted from VBD was more than northwest monsoon (2866 unit). The results was consistent with results of [22] who reported that angling vessel operated during southeast monsoon was more than during northeast monsoon. In addition, they also reported that high potential fishing zone during southeast monsoon was larger than northeast monsoon. [23] reported that during the southeast monsoon, the potential fishing zone was closer to the shoreline of Java, while in the northwest monsoon the potential fishing zone was shifted south to near 13°S. This situation was increasingly positive for tuna as a result of the upwelling activity [24], which produced subsurface temperatures along the coast of Java, which was increasingly favorable for tuna, particularly in the southeast monsoon.

![Figure 2](image_url)

**Figure 2.** Number of fishing vessel for period January – December 2017 derived from VMS and VBD.

Figure 3 showed the spatial and temporal distribution of angling vessels extracted from VBD (green) and VMS platform (blue) and overlap of VMS and VBD (red). In general, the angling vessels from VMS more concentrated in the waters south of Bali – Nusa Tenggara archipelago. This result was consistent with the findings of [22] who reported that the waters south of Bali – the Nusa Tenggara archipelago are more suitable for Bigeye tuna than the waters south of Java Island. Meanwhile the angling vessel from VBD was more spread more than VMS. The angling vessels extracted from VBD spread from West Java – Nusa Tenggara archipelago. This condition was suspected because the VBD data not only captured the lights vessels from those catching Big eye tuna but also caught the lights vessels that caught other fishes such as Albacore, Skipjack tuna, Yellowfin tuna and other pelagic fishes [23, 25, 26].
**Figure 3.** Spatial and temporal distribution of angling vessels collected from VBD and VMS in the eastern Indian Ocean in period of January - December 2017.

Figure 4 exhibited the spatial dispersion (circle) and direction of dispersion (ellipse) of VBD and VMS during northwest and southeast monsoon. In general, an elliptical and circle of VMS and VBD has identical impression, both during northeast monsoon and southeast monsoon. However, the spatial dispersion and direction of dispersion of VMS was more east and smaller than the dispersion and direction of dispersion of VBD. This condition is indicated that the angling vessels derived from VMS more concentrated in the eastern part of study compared with VBD.

**Figure 4.** Spatial dispersion (circle) and direction of dispersion (ellipse) of angling vessels in the eastern Indian Ocean during the (a) southeast monsoon, and (b) northwest monsoon.
Table 1 revealed the seasonal values of measures for the geographical distribution of fishery vessels i.e. center X, center Y, directional dispersion, spatial dispersion and directional trends. For angling vessels from VBD, the distribution center of it in southeast monsoon is at 113.12°E and 09.87°S, while in the northwest monsoon is 113.50°E and 10.13°S. Spatial dispersion of it in the southeast monsoon is 574.55 km, shorter than in the northwest monsoon which is 603.69 km, demonstrated that the distribution of angling vessels in the southeast monsoon is smaller than in the northeast monsoon. Moreover, for angling vessels from VMS, the distribution center of it in southeast monsoon is at 115.71°E and 10.71°S, while in the northwest monsoon is 115.76°E and 10.55°S. Spatial dispersion of it in the southeast monsoon is 514.50 km shorter than in the northwest monsoon which is 529.91 km, indicated that the distribution of angling vessels in the northeast monsoon is wider than in the southeast monsoon.

Finally, VMS and VBD data were seen as accommodating to review the appropriation of fishing vessels – an outcome that supports prior investigations [27, 28, 29, 30, 31]. The results of the VMS and VBD can be accumulated within a few days, while the reported data may set aside an all-inclusive effort to gather. In any event, the lack of a VMS signal and cover by cloud for VBD could constrain the use of VMS and VBD data; therefore, logbook data is still essential to confirm the legitimacy of fish existence in the future.

| Table 1. Values of angling vessels seasonally distributed geographically |
|-----------------------------|---|---|---|---|---|
|               | Seasonal                  | center X (°) | center Y (°) | Directional dispersion x (km) | Directional dispersion y (km) | Spatial dispersion (km) | Directional trends (°) |
| VBD            | Southeast Monsoon         | 113.12       | -9.87        | 795.07                          | 167.55                          | 574.55                  | 103.62                |
|                | Northwest Monsoon        | 113.50       | -10.13       | 834.68                          | 179.44                          | 603.69                  | 104.61                |
| VMS            | Southeast Monsoon        | 115.71       | -10.71       | 706.34                          | 174.69                          | 514.50                  | 99.99                 |
|                | Northwest Monsoon        | 115.76       | -10.55       | 726.76                          | 182.85                          | 529.91                  | 99.93                 |

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