1 INTRODUCTION

Background Information

Nearly 67% global fish stocks were classified as being exploited in 2015 (FAO, 2018). Marine ecologists are concerned that humans are fishing down the food web (Pauly and Palomares, 2005). One of the measurements to tackle depleting fish stocks is by applying Fisheries Management Areas (FMA). This can be done through Marine Protected Areas (MPA).

In MPA fisheries and other activities are managed in order to protect key species, habitats, and ecosystems (Bennet and Daerden, 2014). One of the measurements within MPA are No Take Zones in which fishing is (temporary) prohibited. No Take Zones are proven to be effective in the preservation of biodiversity and fish abundance (Bennet and Daerden, 2014). A study by Lester *et al.* (2003) found that No Take Zones can increase species biomass up to 446%, species density up to 166%, and species richness up to 21%. Even the size of organisms can increase up to 28% when No Take Zones are implemented. The main benefit of No Take Zones in Marine Protected Areas is that they happen to cause species spillovers to neighboring areas and thus stimulate species density (Halpern, Lester and Kellner, 2010). The larger the MPA No Take Zone, the bigger the impact on neighboring areas (Bennet and Daerden, 2014).

The Republic of Indonesia is one of the world's largest producers of fish products. Approximately 5.8 million tons of fish are landed in Indonesia each year (World Atlas, 2019).

Indonesia has a coastline of approximately 100,000 kilometers (World Resources Institute, 2019). Its' Exclusive Economic Zone (EEZ) makes up a total area of 6,051,529 km^2. Indonesia has 70,819 km^2 on marine protected areas which means that only 1.17% of Indonesia's EEZ is currently managed with MPA. These protected areas contain 81 No Take Zones (Zona Inti in Indonesian) with a total area of 1,461 km^2, which means that approximately 2.07% of Indonesia's MPA and 0.026% of Indonesia's total EEZ area are No Take Zones for fisheries (KKP, 2019 ; Marine Regions, 2019)

However, poverty levels in the Indonesian fisheries sector seem to be increasing (Stanford *et al*. 2013). This can be caused by various reasons. Overfishing, global warming, and coral bleaching are known to form a big threat to Indonesian marine ecosystems and thus to its fish stocks (FAO, 2018). Therefore, proper management of Indonesia's fisheries areas will be essential for both marine ecosystems and coastal communities. However, illegal fisheries can heavily disturb this process. (Petrossian, 2014)

Besides taking large amount of fish from No Take Zones and marine reservation areas, illegal fisheries are also harmful because they often make use of illegal fishing techniques like dynamite and dangerous chemicals (e.g. cyanide) that affect the entire ecosystem. Illegal fisheries also tend to have much higher by-catch rates than regular fisheries. (Caldwell and Fox, 2006 ; Petrossian, 2014)

Indonesia has a zero-tolerance policy towards illegal fishing vessels in its' EEZ. This has resulted in a few conflicts with China after Chinese fishing vessels were caught fishing illegally in Indonesian waters. The crew usually gets arrested and the fishing vessel is often blown up to scare off other other offenders. (Suryadinata, 2016 ; Weatherbee, 2017)

One of the determining factors for offenders to take part in illegal fisheries is "the risk of being caught". The lower this risk, the more likely the offender will take part in illegal fisheries. (Petrossian, 2014 ; Wright, Caspi and Moffitt, 2004).

The larger a county's Exclusive Economic Zone (EEZ), the harder it will be to control, monitor, and prevent illegal fisheries since more patrol boats are needed. Besides this, a countries financial status also plays a role in its capability to prevent illegal fisheries. (Petrossian, 2014)

With its' enormous EEZ (+- 6 million km^2) and +- 15.000 islands, Indonesia has a very large and difficult area to manage. Therefore remote sensing and vessel monitoring are essential for Indonesia in order to prevent illegal fisheries.

Vessel monitoring is a widely used strategy to prevent illegal fisheries. It enables governments and NGO's to monitor the activity of fishing vessels and these systems will make it able to identify single fishing vessels (Petrossian, 2014).

Vessel Monitoring Systems (VMS) are a tool that can be used to detect the impact of fisheries and its spatial extent (Russo *et al.* 2016). VMS systems work through transponders aboard vessels that send out signals to receivers on global navigation satellites. The amount of pings (signals) per time period can vary based on the transponder and its settings. (Detsis *et al*. 2012 ; Hintzen *et al.* 2012)

VMS data can be used for multiple purposes. It links several attributes like vessel number, fishing gear, speed, and course to a spatial component. VMS data can also be linked with catch data. This all enables the researcher to get an insight in fishing effort, the impact of fisheries, and fisheries management in a certain area. (Gerritsen and Lordan, 2011 ; Gerritsen, Minto and Lordan, 2013 ; Hintzen *et al*. 2012 ; Russo *et al.* 2016) VMS data can also be used to detect a vessels' fishing gear (Marzuki *et al*. 2015).

Another famous tracking system is the Automatic Identification System (AIS) which can be used for fishing vessel identification. However AIS focuses more on navigation than on monitoring. Vessels use AIS to avoid collusion with other vessels. (Russo *et al.* 2016)

When it comes to VMS data, Indonesia is one of the world's pioneers in sharing and researching VMS data. The country has publicly shared VMS data of approximately 5000 vessels through the NGO Global Fishing Watch (Global Fishing Watch, 2019). Indonesia requires all fishing vessels in its EEZ above 30 Gross tons to make use of VMS data (Global Fishing Watch, 2019 ; Nugroho, Sufyan and Akiwadi, 2013).

However, transponders can be switched off, and many illegal fishing vessels do not use VMS or AIS. To make sure whether illegal fisheries occur in a certain area, one cannot rely on VMS data only. One must take into account that illegal fishing vessels might not have a (working) satellite tracking system transponder aboard.

Another method to remotely sense fisheries activities is through Visible Infrared Imaging Radiometer Suite (VIIRS) (Ganggang et al. 2017). VIIRS is positioned on a satellite and collects 22 spectral bands of data that are calibrated aboard the satellite. With the results light intensity during night time can be obtained (Xiong *et al*. 2013)

The usage of VIIRS data for researching pelagic fisheries is still underdeveloped since there is no proper algorithm yet that can detect pelagic fisheries on the open ocean (Ganggang et al. 2017). However, many Indonesian fisheries make use of LED lights to attract fish and squid during night time (Susanto *et al*. 2017). This makes fishing vessels fairly easy to trace through VIIRS data.

Fishing vessels can be detected through VIIRS day and night (DNB) bands. Several algorithms are able to detect lights from fishing vessels even when there is cloud coverage. (Elvidge, Zhizhin and Hsu, 2013 ; Elvidge *et al*. 2015)

These algorithms can even be used to measure the exact number of light fishing vessels in an area over a certain period of time (Ganggang *et al*. 2017).

In order to track both large- and small scale fisheries activities in MPA and No Take Zones, a combination of VMS and VIIRS data will be required. This research focuses on combining VMS and VIIRS data sets and identifying vessels that were captured by the VIIRS satellite.

Problem Statement

Even though it could be very useful in tackling illegal fisheries within fisheries management areas, there is currently no proper working method to identify LED light using fishing vessels that were captured by VIIRS satellites.

Research Objective

This research aims to compare the yearly distribution of LED light using fisheries based on both VMS and VIIRS data in and around Indonesia's Marine Protected Areas and No Take Zones and to combine these data sources in order to identify LED light using fishing vessels that were captured by the VIIRS satellite.

Research Benefit

The output of this research will give a proper view on fisheries activities in and around Indonesian Marine Protected Areas and No Take Zones. If this will point out differences between VMS and VIIRS data in certain area, this can lead into recommendations for better management techniques in these areas.

2 MATERIALS AND METHODS

Research Time and Place

This research has taken place from April 2019 until March 2020 The work has been carried out in Bogor at the Department of Marine Science and Technology, IPB University campus Dramaga, Bogor

The scope of this research project is Indonesia's Exclusive Economic Zone. Within this area the study focuses on Indonesia's Marine Protected Areas, No Take Zones, and areas that lie just outside these zones. Figure 1 displays the scope of this research.

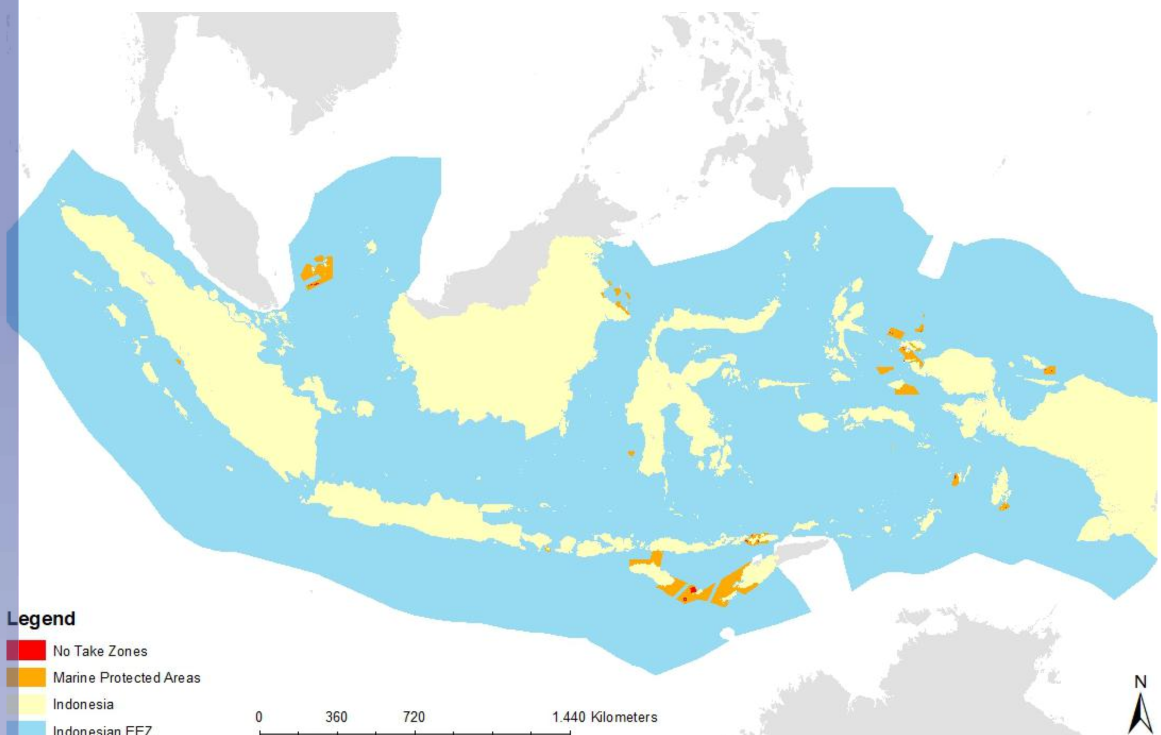


Figure 1 The location of Indonesia's Marine Protected Areas and No Take Zones within its EEZ

Materials

VMS Data

The VMS data of Indonesian fisheries vessels >30 gross tons was obtained at Kementrian Kelautan dan Perikanan (KKP), the Indonesian ministry of maritime affairs and fisheries. The data was provided for the entire year of 2018. The spatial limit is displayed by the Regions of Interest in Figure 2. These ROI were used in the VMS data application process at KKP.

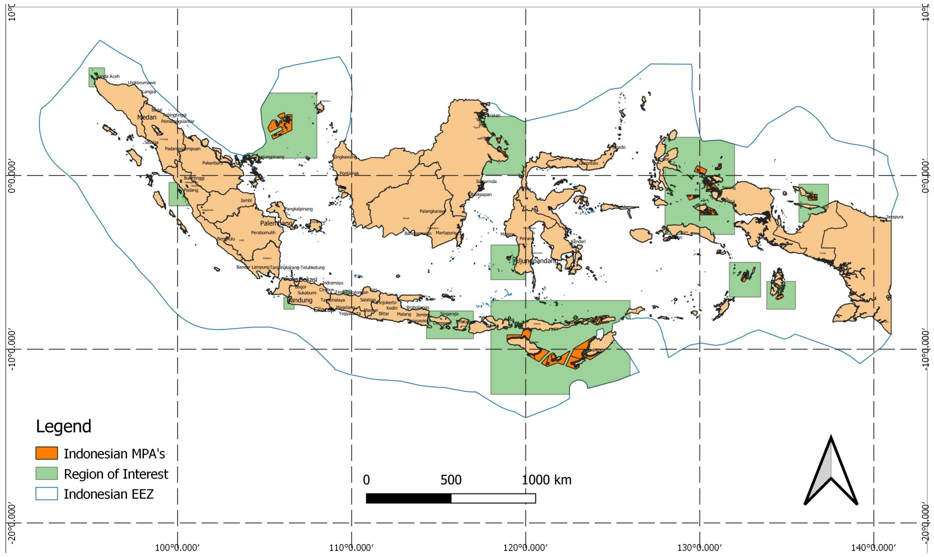


Figure 2 The Regions of Interest for the VMS data

To select fishing vessels with LED light using fishing techniques, the VMS data were filtered on fishing gear. In order to obtain Led light using fishing vessels, the gear type was filtered on ‘Bouke ami’ and ‘Purse Seine’. The data was filtered on speed between 0 and 1 knots to filter out non-fishing (e.g. steaming) vessels. Data located in any harbour was filtered out.

At last the data was filtered on a temporal scale. Because the focus of this study is on LED light fisheries which is usually taking place at night, the data was filtered on the hour when the VIIRS satellite overpasses for each region. This was done through an algorithm that calculated the mean overpass time for each region of interest and filtered the VMS between an upper boundary of one hour before the overpass time and a lower boundary of one hour below the overpass time. This is further explained in the vms2viirs function.

The processing and filtering of the VMS data sets was done in R programming language. The code that was used can be found in Appendix I-IV.

VIIRS data

The VIIRS data that was used for this research has been obtained from NOAA and NASA (VBD). This VBD data has been derived from Day Night Band (DNB) VIIRS data on which algorithms were run that detect spikes that can be identified as fisheries activities (Elvidge *et al*. 2015).

In order to download all VIIRS data from the year 2018, a Python script was created that mines data from the VBD geoportal for the entire year of 2018. The downloaded data was then combined into one large file that obtains year round VIIRS data for 2018.

The VIIRS data that was downloaded through VBD already contained classification on vessel type. This was done through comparing the strength of various detected spikes (Elvidge *et al.* 2015). With this vessel type data the newly created VIIRS 2018 file could be filtered on containing fishing vessels only ('QF = QF1') in which QF1 data represents all VIIRS detected fishing vessels and thus filters out any other light source (e.g. marine platforms, other vessels, land based light sources, etc.) based on the light intensity known for various Indonesian LED light using fishing techniques.

Figure 3 displays the captured VIIRS vessel data (QF1) for the entire year of 2018 within Indonesian waters. As can be seen, the majority of led light fisheries activities take place outside of the 12 ROI and thus rather far from any MPA or No Take Zone. However, the ROI near Natuna (ROI 1) seems to be an exception. The ROI near Southeast Maluku (ROI 4) also has some VIIRS activity but the ROI at the Savu Sea (ROI 6) is nearly empty.

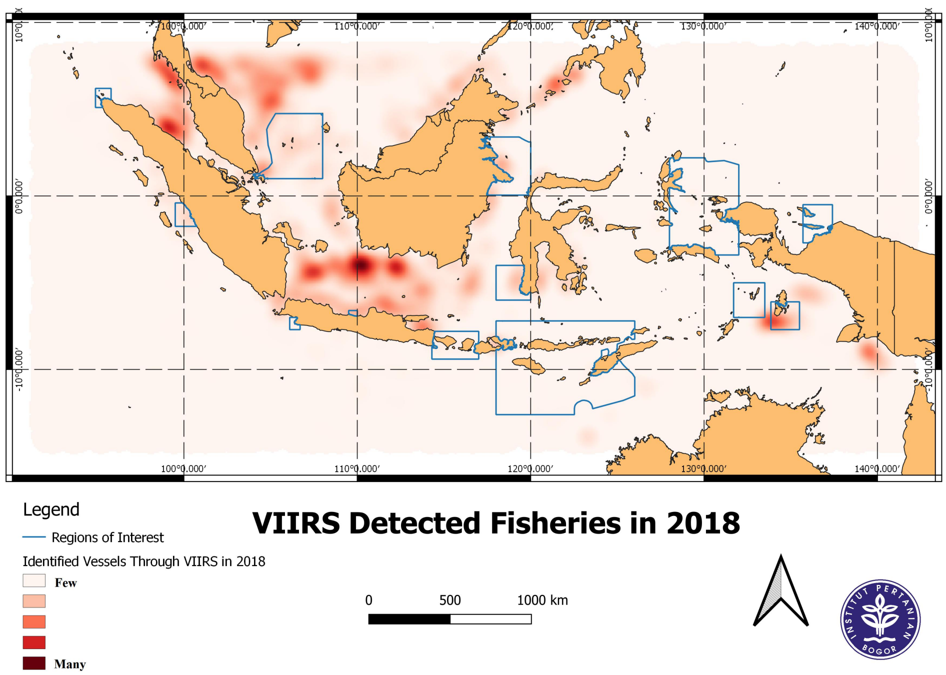


Figure 3 Viirs Detected Fisheries in 2018.. (Heatmap: Resolution= 10k x 10k meter. Scale= 100k meter)

Data Tools

Various computer programs were used to carry out the analysis. The following programs were included:

QGIS – For data display

This program was used because it is Open Source and relatively easy to work with.

PostgreSQL – For data storage

After the data was processed in R, the data was stored in a PostGIS database, using PostgreSQL. In this way it was possible to do SQL scripting on the output which can be integrated with QGIS.

R Studio – For data analysis

R language was used because R, an Open Source statistical programming language, is a more suitable for statistic issues than other programming languages such as Python. Besides that, R is already commonly used for research on VMS data (Hintzen *et al*. 2012). R was run in the R Studio IDE (Integrated Development Environment).

Anaconda/Spyder – For data analysis

The automatic download of VMS data was done in Python programming language, in an Anaconda environment, run from a Spyder IDE.

Research Methods

Combining the Data

Figure 4 displays how the data was processed in order to combine, compare and analyse the data. When both VMS and VIIRS data sets were set to the right spatial and temporal boundaries, they were compared and combined. This process was done in R and various R scripts and functions were made in order to make it reproducible. R makes it possible to handle large data sets at once. An algorithm was developed for quickly analyzing and displaying fisheries activities in all of Indonesia's MPA and No Take Zones.

The total area of fisheries activities for both VMS data and VIIRS data were measured for each Region of Interest, MPA, and No Take Zone. To further process the data, a number of R functions were created.

R Functions

The following scripts and functions have been created in order to make this research reproducible. The functions were then combined in the R the package "LLFI" (Led Light Fisheries Identifier). Figure 3 illustrates the various functions of the LLFI package and displays these functions in their subsequent order. Appendix I-IV display the raw code for each of these functions.

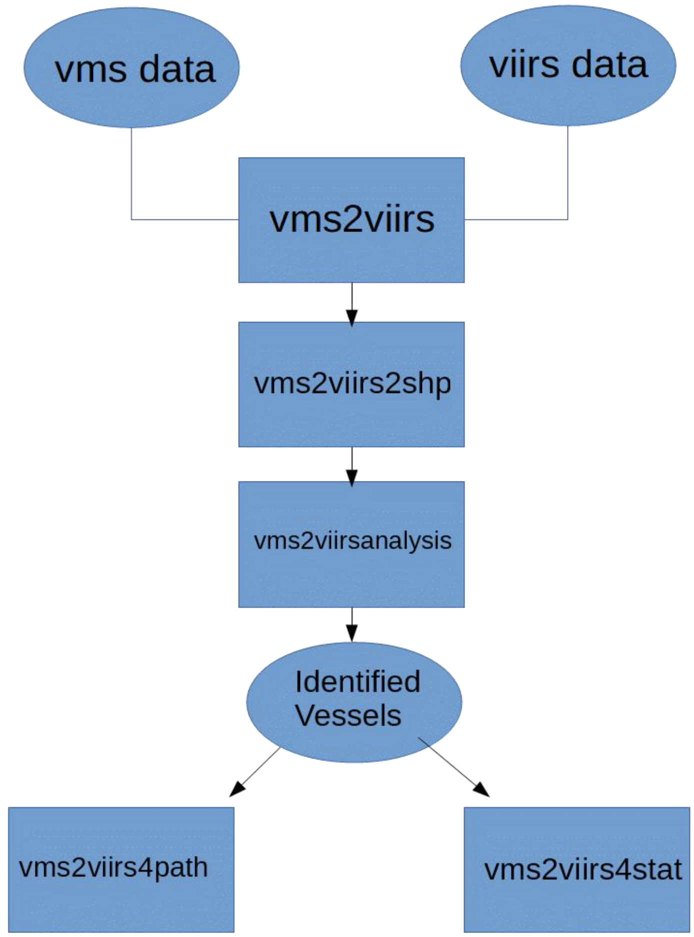


Figure 4 LLFI Diagram

Function: vms2viirs

This R function was written to calculate the position (by latitude and longitude) of each vessel in the filtered VMS data set at the time of the VIIRS satellite overpass. This was done through linear regression between the upper and lower boundaries that were set one hour before and after the VIIRS satellite overpass time. Because the satellite overpass time varies per day, the function splits the large VMS file per day and vessel id and then creates a single output for each vessel per day. When the function is done running it combines each single output and saves it to a larger file that contains all VMS data of fishing vessels at the VIIRS satellite overpass time. The output file contains columns for vessel id, gear type, latitude, longitude, date (provided by the original VMS file), ROI, and MPA type (derived by overlaying the point file with ROI and MPA shapefiles).

Function: vms2viirs2shp

This function cleans the vms2viirs output from NA values and it saves the output in Esri shapefile format for both each ROI and for the total combined data set. This makes it easy to export the output to GIS programs for display (per gear type). The output contains the same columns as the vms2viirs function output.

Function: vms2viirsanalysis

The vms2viirsanalysis function takes the output of vms2viirs2shp as input and creates a 500 meter buffer around each linear-regression-based estimated vessel position. This is done separately again for each day, ROI, and vessel id. The function then also filters the VIIRS data by day and overlays VIIRS and estimated VMS data for each day. The function then traces VIIRS data points inside the buffer zones that were laid around of the estimated VMS data. The output of this function writes a new column for the VIIRS data set that either displays the vessel id of the buffer it has been found in, or it gets marked as ‘unidentified’. Thus eventually vessel id’s of the VMS data set with a location that is matching the VIIRS data set at VIIRS overpass time are added to the VIIRS data set.

The vms2viirsanalysis function can be run with varying buffer distances. For this research three different distances were chosen.

- Class A output gives the results of identified vessels within a range of 500 meters from each estimated vessel position at VIIRS overpass time. Vessels that were hauling for two or more hours should be identified within this buffer.
- Class B output gives the results of identified vessels within a range of 1,000 meters from each estimated vessel position at VIIRS overpass time. Vessels that were both hauling and then steaming around the VIIRS overpass time should be identified within this buffer.
- Class C output gives the results of identified vessels within a range of 5,000 meters from each estimated vessel position at VIIRS overpass time. Vessels that were only hauling for a short period of time and then started steaming should be identified within this buffer.

A “Class D” output with a buffer distance of 10,000 meters gave the exact same result as Class C and was therefore disposed. The output file includes all columns from the original VIIRS file plus new columns for vessel id, gear type, latitude, longitude, date, ROI, and SZNKKP (MPA type), derived from the vms2viirs output that was found in the buffer zones.

Function: vms2viirs4path

This function filters the VMS file on the vessel id and day of each identified vessel in the vms2viirsanalysis function. The output contains VMS data for each day on which a certain vessel id was identified in the vms2viirsanalysis function. The output file contains the same columns as the regular VMS file, but it also generates a new column ‘sepprtr’ that creates a new unique id for each vessel on each specific day. This data can later be converted to a path to visualize the daily track of a fishing vessel that was identified by both VMS and VIIRS data. This path will connect all the dots for each identified vessel, per day. Non matching days and vessel id's will not be connected because the 'sepprtr' column has generated unique id's for each vessel. This connecting of points cannot be done in R, but the output makes it possible to easily do this in SAGA GIS (possible through QGIS) by the 'Convert points to line(s)' tool, with 'VMS ping time' as 'order field' and 'sepprtr' as separator.

<u>*Function: vms2viirs4stat*</u>

The vms2viirs4stat function calculates the amount and percentage of identified vessels within MPA's and their sub areas such as No Take Zones.

Data Display

The results of all functions were displayed in QGIS. Most results were displayed as a heat map. For all heat maps a standard scale of 10.000 meters and a grid size of 1.000.000m^2 was used.

Regions of Interest

The VMS data request was done for 12 different ROI. After analyzing VIIRS activities in these areas, ROI 1, 4 and 6 stood out as the areas with most fisheries activities through VIIRS satellite data. The VMS data also pointed these areas out as areas with high activities of led light using fisheries (Purse Seine and Bouke ami). Therefore these areas were chosen to put extra focus on.

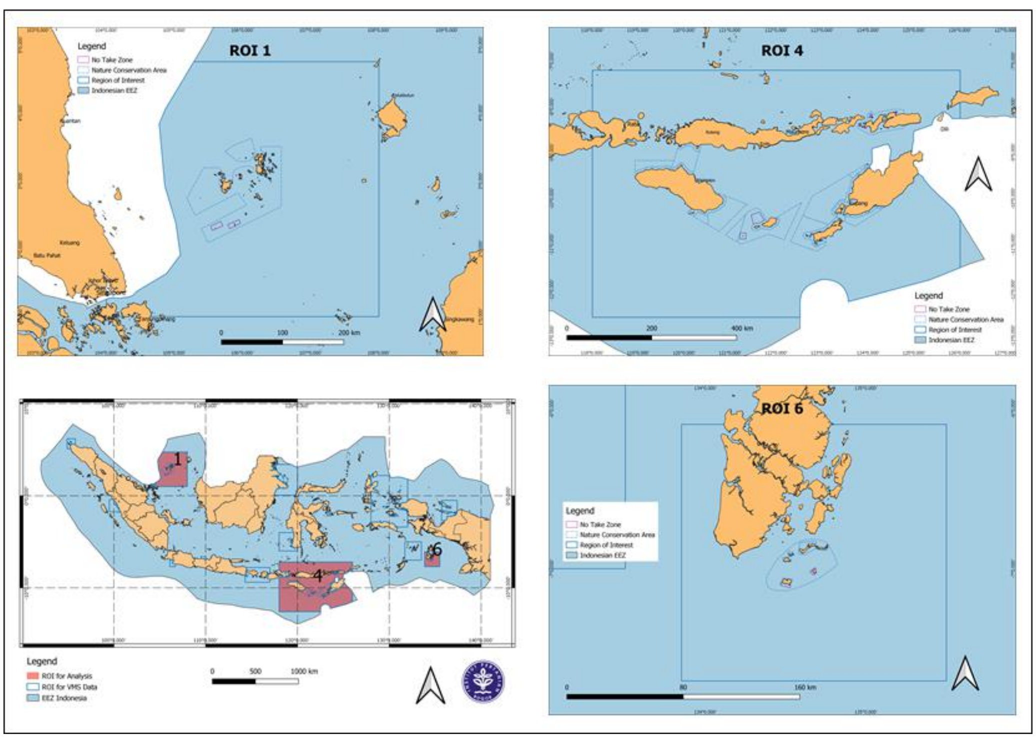


Figure 5 Regions of Interest for VMS2VIIRS

Figures 5 display ROI 1, 4, and 6. ROI 1 is located near Natuna Island. This area is known to have high fisheries activity from Indonesia’s small purse seine fleet, as well as some bouke ami fisheries activities. ROI 4, located near the Savu Sea, is known to have high levels of larger purse seine fisheries. ROI 6, located southeast Maluku, also has activities of small purse seine and bouke ami fisheries.

3 RESULTS AND DISCUSSION

Results

vms2viirs

The function “vms2viirs” gives the opportunity to view the linear-integrated position of vessels with a VMS transponder at the overpass time of the VIIRS satellite. The function also creates a “date” column to the VMS data set. In this way the estimated VMS positions at VIIRS overpass time can be viewed for any given day.

Figure 6 displays the number of estimated vessel positions (through vms2viirs) in ROI 1, 4, and 6. As can be seen, the majority of estimated vessels can be found in ROI 1. Figure 7 displays the estimated vessel positions within MPA.

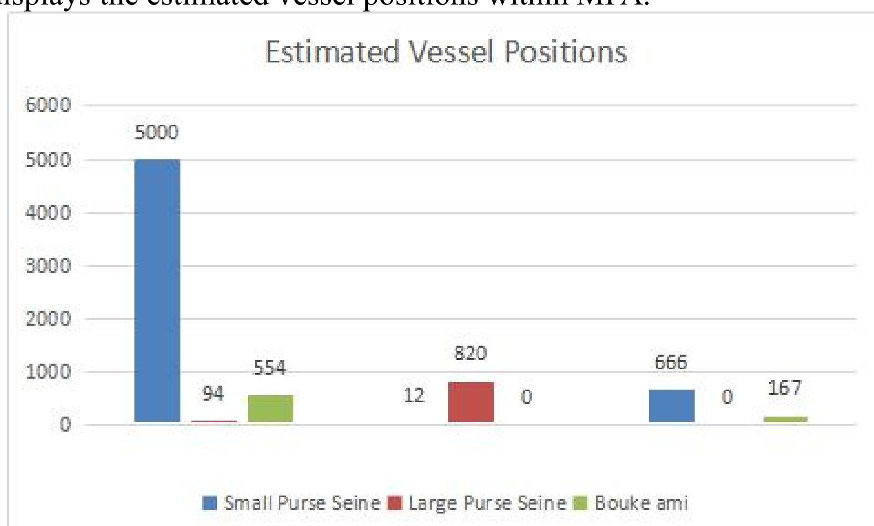


Figure 6 Estimated Vessel Positions in ROI 1, 4, and 6

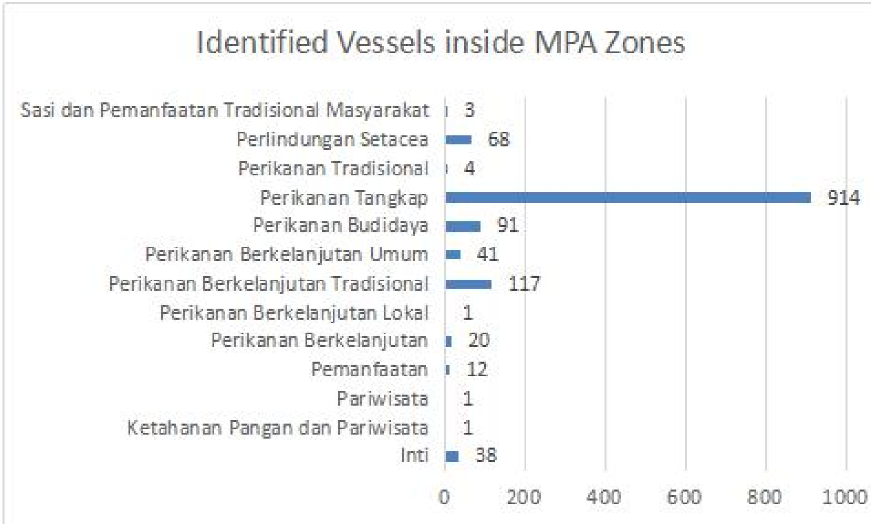


Figure 7 Estimated Vessel Positions in MPA

Figures 8-10 display the result for Led Light, Small Purse Seine, and Bouke ami fisheries of the vms2viirs function in ROI 1,4, and 6. As can be seen in Figure 8 small Purse Seine fisheries are expected to be found all over ROI 1 but Bouke ami is most likely to be found in the southwest corner of ROI 1.

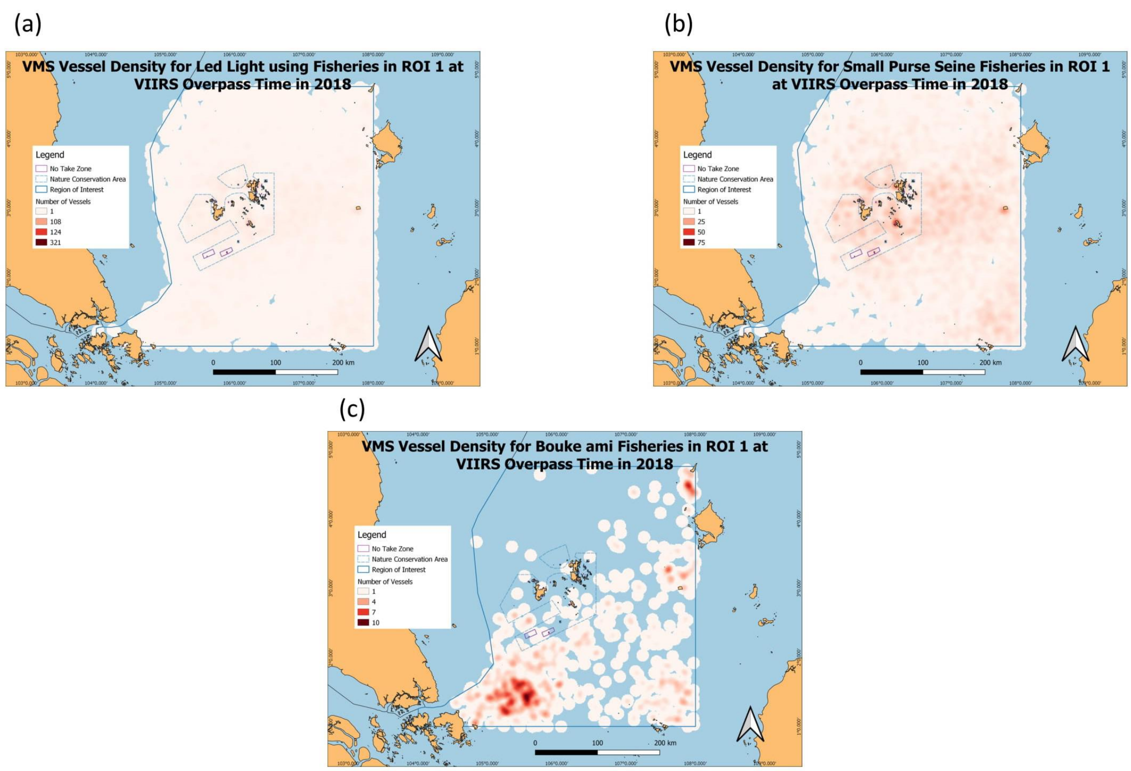


Figure 8 VMS Vessel Density for (a) Led Light (b) small Purse Seine Fisheries (c) for Bouke ami Fisheries in ROI 1

Figure 9 illustrates the expected identified vessels in ROI 4. As was previously illustrated in Figure 6, mainly Purse Seine fisheries can be found in this region. Figure 9(b) shows that this type of fisheries are mainly expected to be found in the south and center of the region.

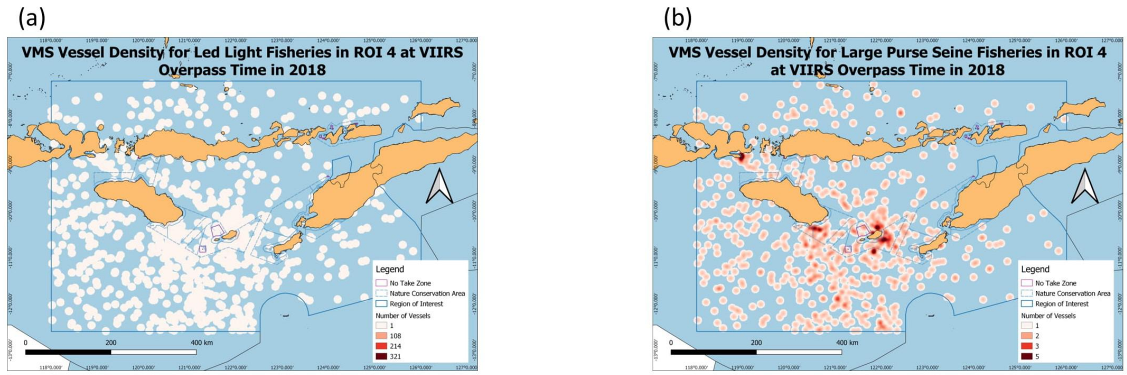


Figure 9 VMS Vessel Density for (a) Led Light (b) large Purse Seine Fisheries (c) in ROI 4

Figure 10 indicates that small Purse Seine and Bouke ami fisheries are both expected to be found all over ROI 6.

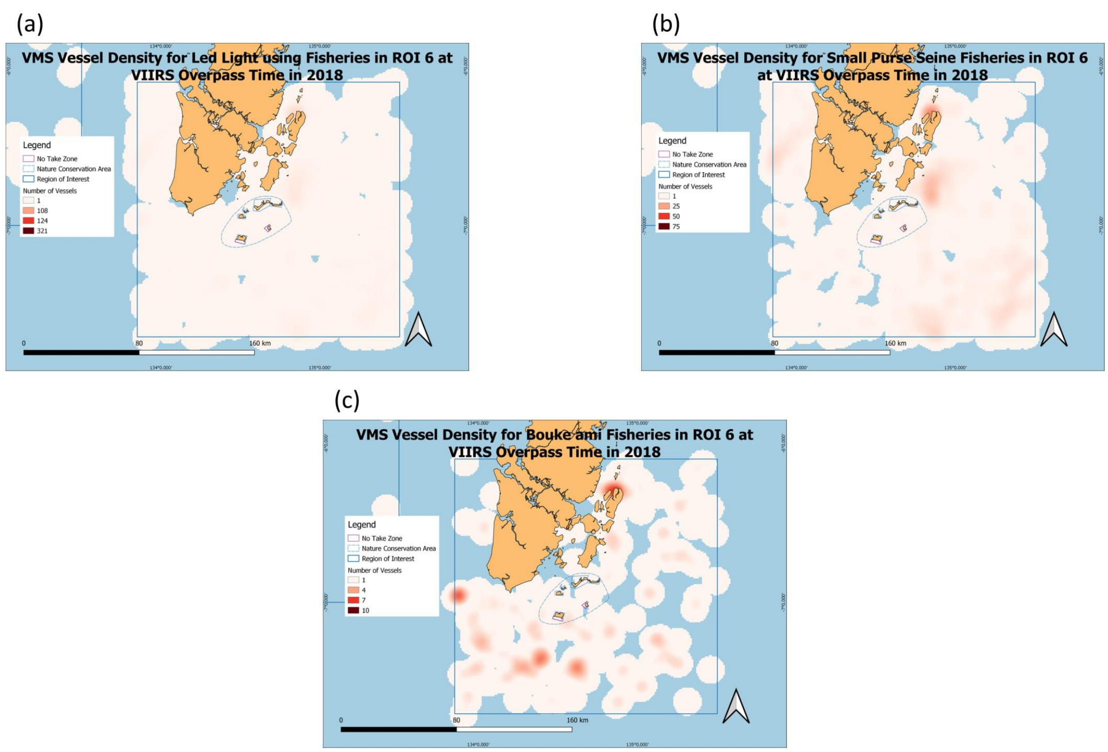


Figure 10 VMS Vessel Density for (a) Led Light (b) small Purse Seine Fisheries (c) for Bouke ami Fisheries in ROI 6

vms2viirsanalysis

Figure 11-13 display the number of identified vessels, through the "vms2viirsanalysis" function in class A, B, and C in ROI 1, 4, and 6. As can be seen in these figures, for each buffer class most identified vessels are found in ROI 1. These figures also show that almost no vessel could be identified in ROI 4. Therefore further results of ROI 4 will not be shown in the results section.

Based on the numbers showed in Figure 11, the number of identified vessels for Class A (500 meter) buffer zones in ROI 4 and 6 does appear to be more than 10. In ROI 1 however, almost 200 vessels were identified with Class A buffer zones.

Class B buffer zones (1000 meter) results are shown in Figure 12. When compared to the results of Figure 11, it can be stated that numbers do not seem to be much higher than results of Class A buffer zones.

However, Figure 13 displays that Class C (5000 meter) buffer zone results tend to be much higher than those of Class A, and B. Nearly 800 vessels were identified in ROI 1 alone, and approximately 300 vessels were identified in ROI 6 when using Class C buffer zones.

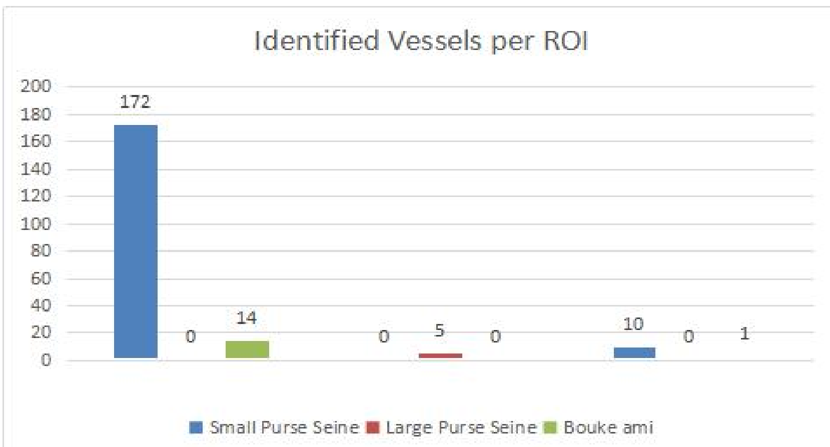


Figure 11 **Class A** Identified Vessels for Led Light using Fisheries in ROI 1, 4, and 6

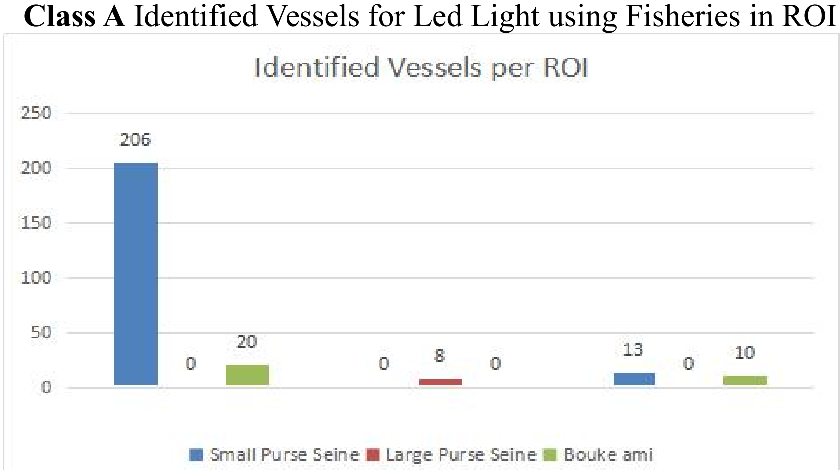


Figure 12 **Class B** Identified Vessels for Led Light using Fisheries in ROI 1, 4, and 6

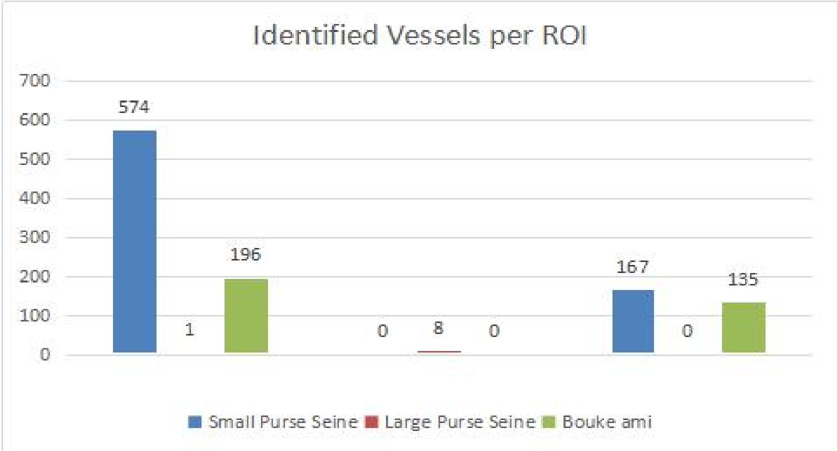


Figure 13 **Class C** Identified Vessels for Led Light using Fisheries in ROI 1, 4, and 6

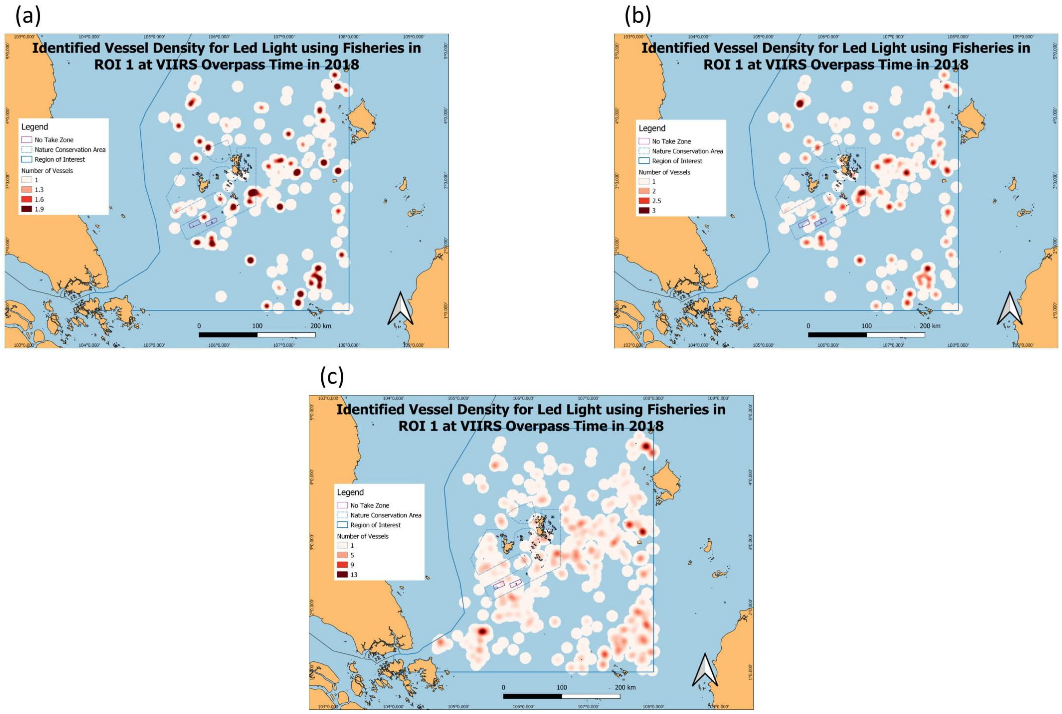
Figure 14-19 display identified vessels through the "vms2viirsanalysis" function for Class A, B, and C led light using fisheries in ROI 1 and 6. Because ROI 4 has such low numbers of identified vessels, it has not been included in the following maps.

In Figure 14 all identified LED lights using fishing vessels in ROI 1 are shown. It appears that while Class A and B buffer zone results merely display activities in several hot spots spread over the eastern and central part of the region, Class C buffer zone results also display identified vessels in the southwestern corner of ROI 1.

As can be seen in Figure 15, identified small Purse Seine vessel results are quite similar to all LED light fishing vessels combined (Figure 14). This makes sense since by far the highest amount of identified vessels were indicated as small Purse Seine fishing vessels (Figure 11-13).

However, Figure 16 indicates that identified vessels in the southwest corner of ROI 1 that could also be seen in Figure 14 mainly consist out of Bouke ami fishing vessels.

Figure 17-19 indicate that, as could be seen in Figure 11-13, not many vessels were identified by Class A, and B buffer zones. The majority of identified vessels for both small Purse Seine and Bouke ami (and thus for all identified LED light using fishing vessels) could be found in Class C buffer zones, consisting of several hot spots, mainly in the southern part of the region.



.Figure 14 Identified Vessels for Led Light using Fisheries in ROI 1 for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance

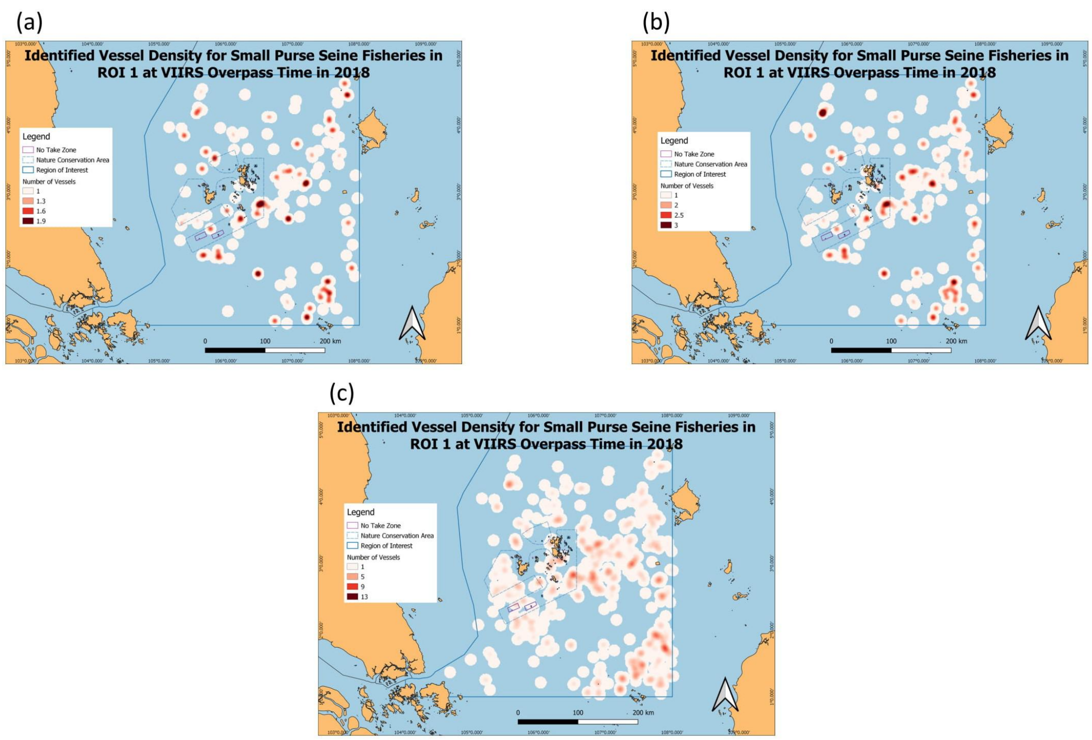


Figure 15 Identified Vessels for small Purse Seine Fisheries in ROI 1 for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance

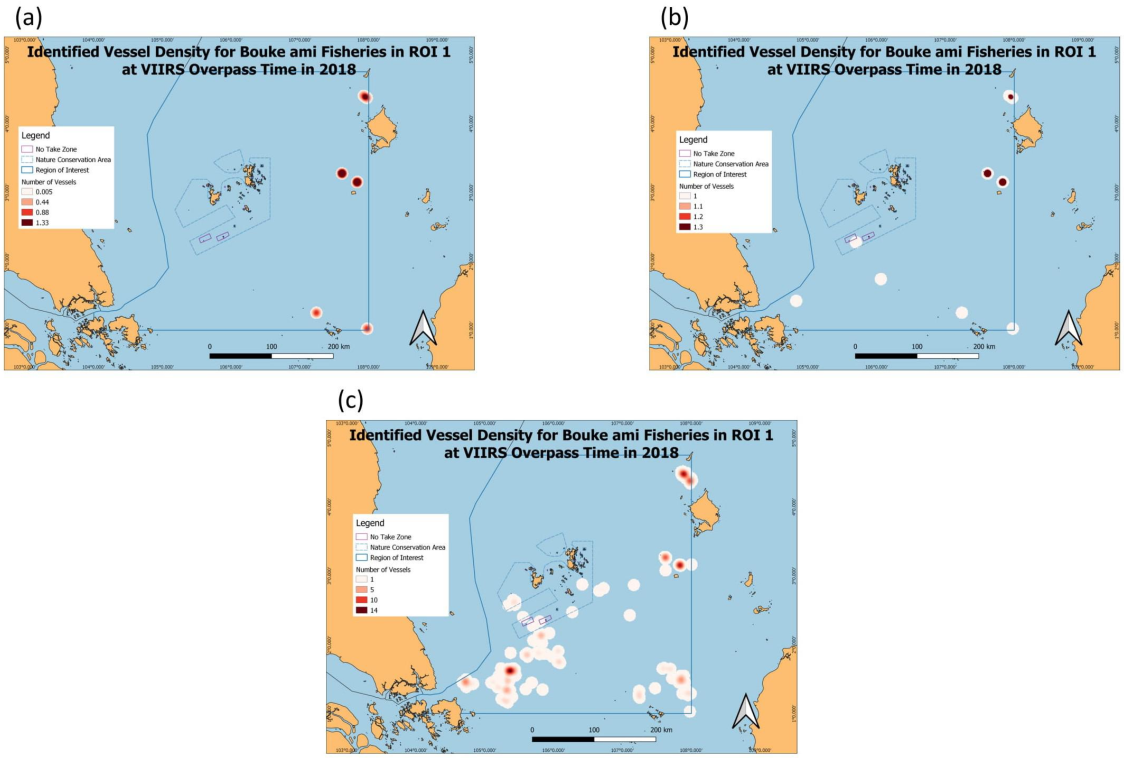


Figure 16 Identified Vessels for Bouke ami Fisheries in ROI 1 for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance

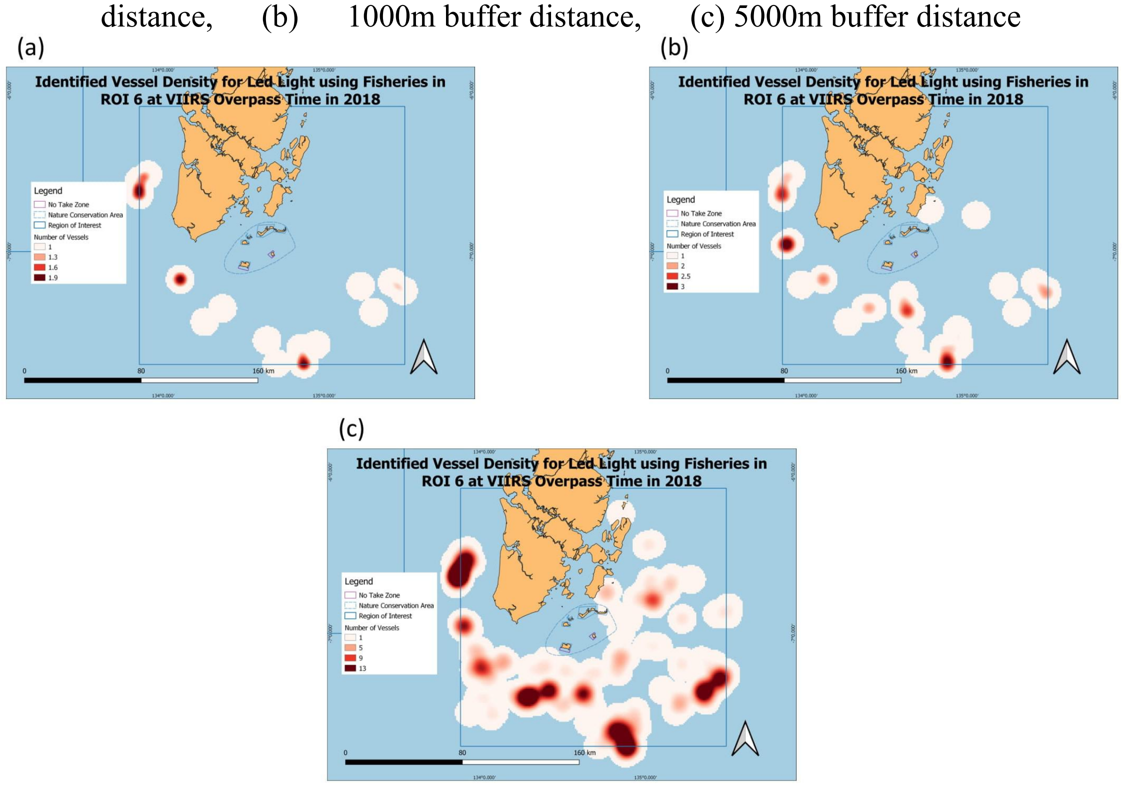


Figure 17 Identified Vessels for LED Light using Fisheries in ROI 6 for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance

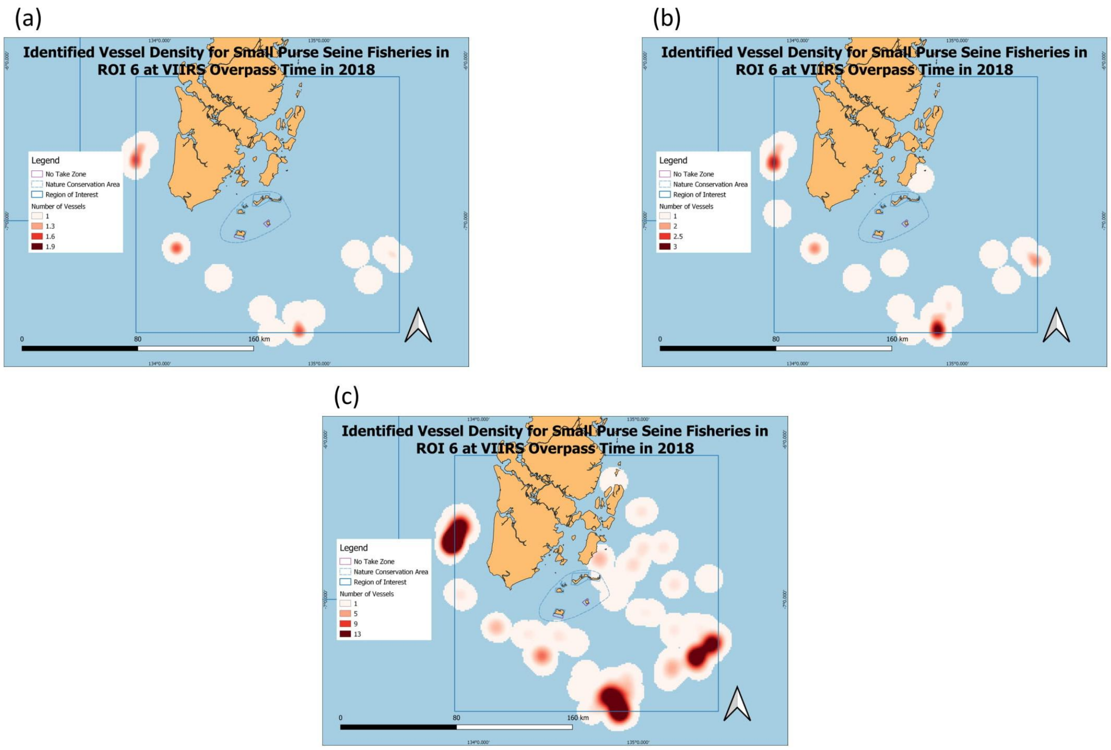


Figure 18 Identified Vessels for small Purse Seine Fisheries in ROI 6 for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance

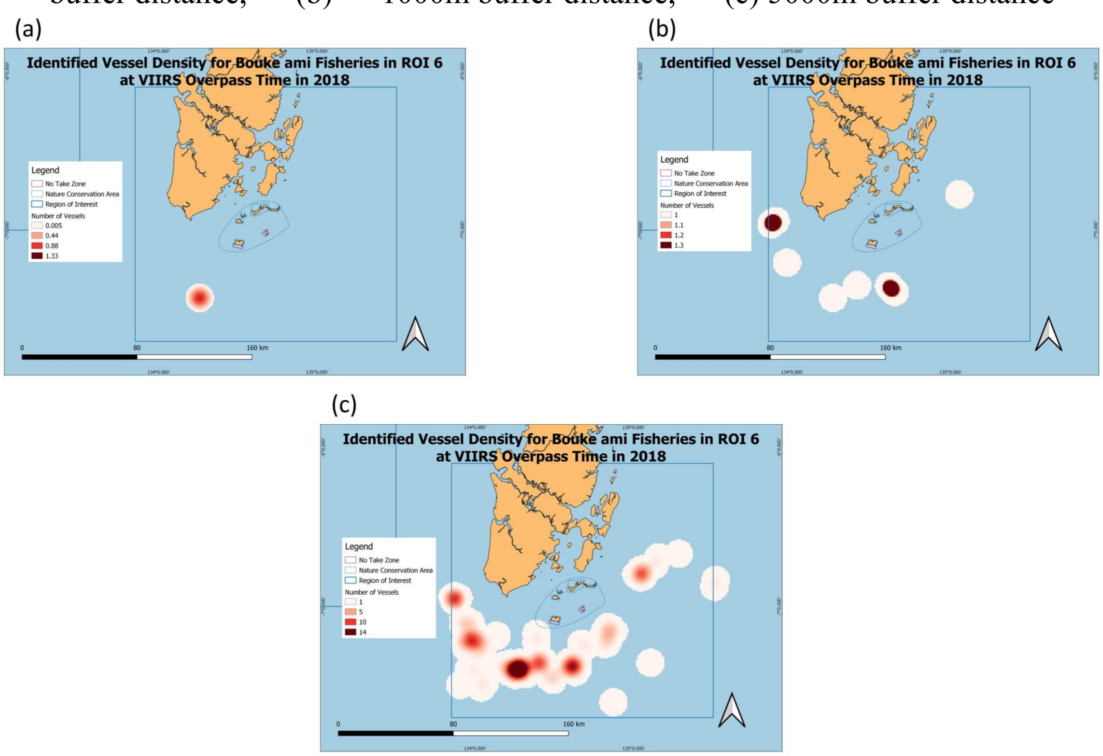


Figure 19 Identified Vessels for Bouke ami Fisheries in ROI 6 for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance

vms2viirs4path

Figure 20-21 display the results of the function “vms2viirs4path” in ROI 1 and 6. These figures indicate that the most and longest track lines could be found in Class C buffer zone results. However, even these Class C buffer zone results do not indicate a lot of activities within MPA and No Take Zones.

As can be seen in Figure 20, most tracks of identified fishing vessels can be found near the outer corners of ROI 1. Class C buffer zone results indicate a lot of activities in the south and southwest corner of ROI 1. However, some tracks can still be found crossing and MPA.

In ROI 6 however, no track lines of identified vessels seem to cross any MPA at all. Most identified activities can be found far from the shore and thus far from any MPA or No Take Zone. This is backed up by Figure 17-19 that also display many activities in the southern part of the area.

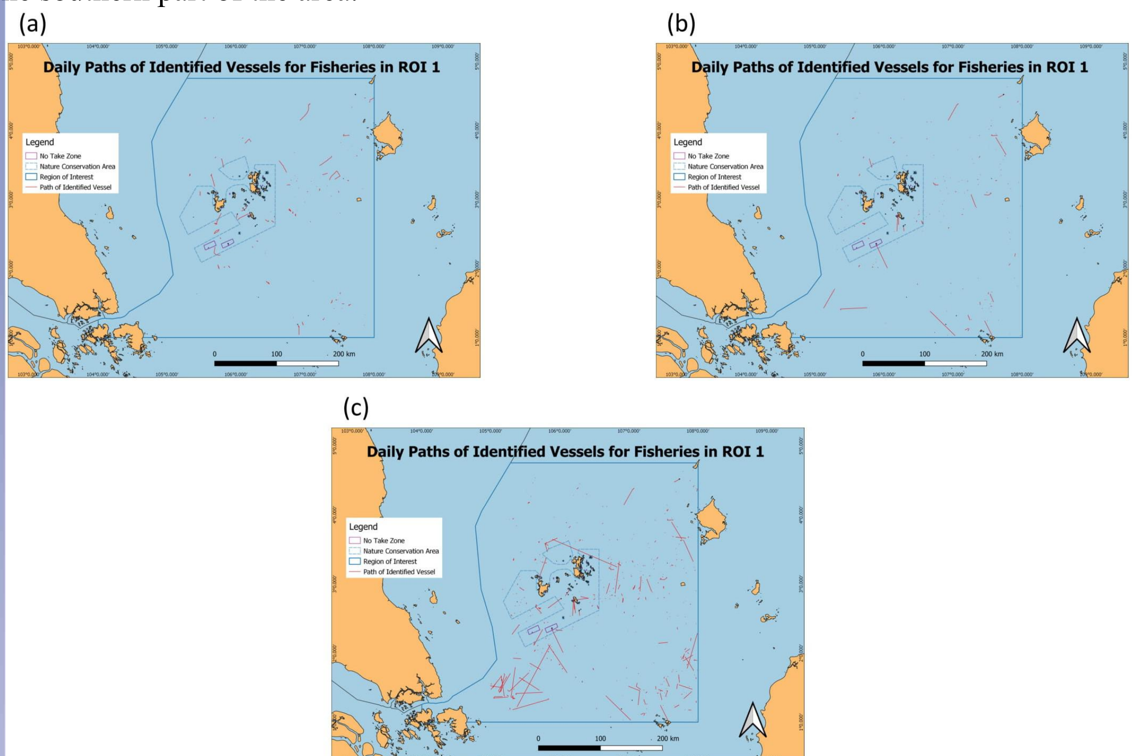


Figure 20 Daily paths for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance of identified vessels in ROI 1

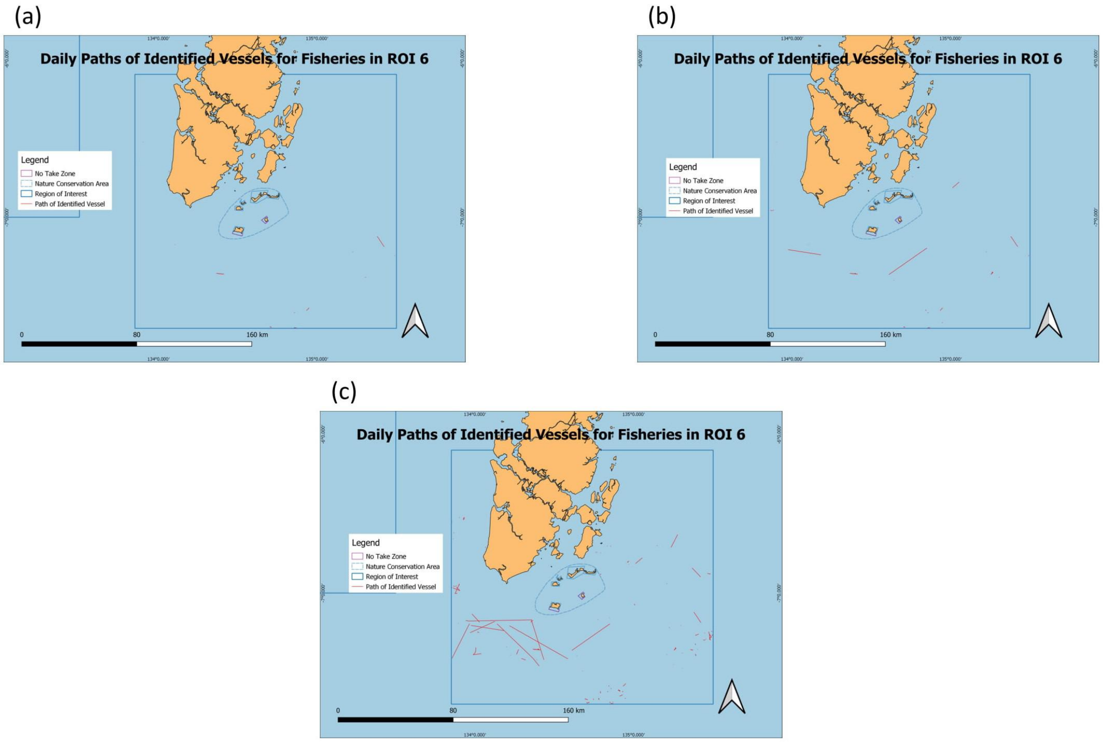


Figure 21 Daily paths for (a) 500m buffer distance, (b) 1000m buffer distance, (c) 5000m buffer distance of identified vessels in ROI 6

vms2viirs4stat

The “vms2viirs4stat” function indicated that for Class C identified vessel data, three vessels were identified within No Take Zones of ROI 1. This means that 3.09% of identified vessels within KKP MPA were located within No Take Zones, while 8.25% (count 8) could be found in traditional fishing areas and roughly 88.66% could be found in designated areas for fisheries within the MPA. Both Class A and Class B did not identify any vessels within No Take Zones. Figure 22 displays the identified vessels within one of ROI 1’s No Take Zones.

For ROI 4, Class A and B also did not identify any fishing vessels within No Take Zones either. While Class C also identified 3 (3.37%) vessels within No Take Zones.

In ROI 6 all identified vessels were located outside MPA.

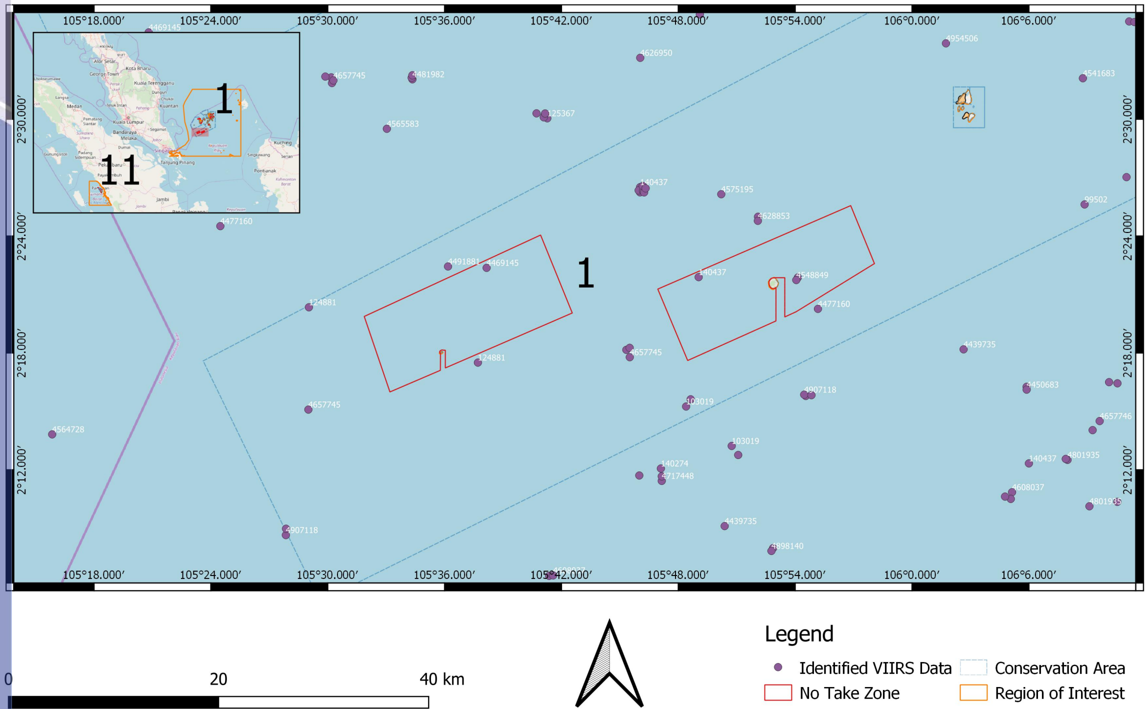


Figure 22 **Class C** Identified Vessels within ROI 1's No Take Zones

Discussion

Buffer Zones

Earlier research on VIIRS and VMS data in the Java Sea by Hsu et al (2019) indicates that from all fishing techniques, purse seine has the highest identification rate. The same was found to be true in this research, where the large majority of identified vessels were vessels using purse seine fishing techniques.

Class C identified vessels (buffer of 5.000 meters) include a lot more vessels than Class A and B (500 and 1.000 meter buffers). However, a Class D with a buffer zone of 10.000 meters identified the exact same amount of vessels as Class C. This indicates that at Class C the maximum number of captured vessels is reached since it is highly unlikely that hauling vessels (with speeds around 0 knots) are more than 10.000 meters away from their interpolated position within one or two hours. However with increasing buffer distances, the possibility of errors increases as well since there is an increasing chance that non identical vessels are being captured.

Percentage of Identified Vessels

In the research of Hsu et al. (2019), the ratio of obtained VIIRS fishing activity to VMS fishing vessel activity was nine to one. This number seems corresponding with the 10% identification rate (Class C) of the vms2viirsanalysis function in this research.

Other studies on VIIRS and VMS data for pelagic trawlers indicate that identification of VIIRS data has a higher accuracy when lunar illumination is weak. This even lead to a success rate over 92% on certain days. (Ganggang et al. 2017) This could also be a reason why some vessels could not be identified.

Since LLFI is dependent on VIIRS data input, it is depending on lunar illumination. When lunar illumination is weak this can affect the accuracy of LLFI results.

Illegal Fisheries

In the case of ROI 1, a part of the non-identifiable vessels could be illegal foreign vessels. The Natuna-Batam region is known for illegal fisheries that are taking place (Permana, Indra, & Erdiansyah, 2016). One of the reasons for illegal fisheries taking place in this region can be because this region is a part of a border conflict between several nations including Indonesia, Vietnam, and China (Suryadinata, 2016). Since the VMS database that was used for this research did not include any foreign vessels, these vessels will not be identifiable with this database. However, this is most likely not a cause for non identified vessels in ROI 4, and 6, since these regions are not located near any border zones with other countries' EEZ.

Vessels under 30 Gross Ton

Traditional Indonesian fishing vessels (below 30 Gross tons) are not required to have a VMS transponder (Nugroho, Sufyan and Akiwadi, 2013). There is a high probability that many captured fishing vessels by the VIIRS satellite were traditional vessels and could thus not be identified with VMS data.

LLFI is currently not capable to track fishing vessels <30 GT since Indonesian VMS data only contains vessels > 30 GT.

Lack of Identified Vessels in ROI 4

For ROI 4 it is highly unlikely that unidentifiable vessels are either foreign or traditional vessels because the region is not located close to a region where illegal fisheries usually occurs, and because, based on the VMS data, we can assume that large purse seine vessels are the most prominent type of vessels in this area. A possible reason for the lack of identified large purse seine vessels could be that these vessels usually do not haul during mid night. Various studies (Potiet, Petigas & Petit, 1997 ; Arcos & Oro, 2002) seem to indicate that some Purse Seine fisheries take place during day time. However, to be certain of this, more research on Indonesia's Large Purse Seine fleet is needed.

This could indicate that LLFI is not suitable for tracking Large Purse Seine fishing vessels.

Fisheries in MPA and No Take Zones

The results of vms2viirs4stats show that most activity inside MPA and could be found in ROI 1. In ROI 6 no fishing activity was located within MPA or No Take Zones at all. A possible explanation for this difference is that ROI 1 and ROI 6 differ in area size of both the ROI and the MPA. The MPA of ROI 6 also seem to be located in coastal waters only, while ROI 1 also contains some MPA that are located further offshore. Since VMS using vessels (> 30 GT) tend to be larger vessels, they are more likely to operate further offshore. This seems to be backed up by Naamin, Mathews, & Monintja (1995) who state that fisheries in Indonesian coastal areas are usually done by fishing vessels below 30 Gross tons.

While some activity could be detected in ROI 4, the amount of identified vessels in this ROI is too low to make a statement on fisheries within MPA in this region.

Even though almost all identified vessels within MPA were found in ROI 1, only approximately 3% was found within a No Take Zone when applying the Class C (5000 meter) buffer zone. A possible explanation for the low amount of identified fishing vessels in No Take Zones can be because VIIRS satellites only capture fishing vessels once per 24 hours. If a vessel would have been fishing in a No Take Zone at another time, it would not be traceable through VIIRS data. Another possible reason for the lack of identified vessels within No Take Zones is that fishermen are able to switch off their VMS device manually. In this way they would not be traceable through a VMS database.

However, if many of the identified vessels would have been fishing at another time during the day, the vms2viirs4path function output would have shown a lot more activity in MPA. This however, is not the case. And while the vms2viirs4path output does show some more activity in MPA, one cannot be certain that these fishing boats were hauling. These vessels could also have been steaming.

Besides that, not many activities were expected to be found in No Take Zones in the first place. As can be seen in Figure 7, nearly all expected vessels to be identified in MPA were expected to be found in ‘Zona Perikanan Tertangkap’ which means that these specific areas with MPA are designated for the capture of fish. Therefore it is not illegal when fishermen enter these areas. There might be some restrictions though, but that is something to look further into in following research projects on this subject.

4 CONCLUSION AND SUGGESTIONS

Conclusion

Although VIIRS and VMS data sets on fishing vessels differ in size, range, and content ,it is possible to combine both for analyzing LED light using fishing vessels in Indonesian waters. The vms2viirs function made it possible to estimate the position of hauling led light using fishing vessels during the daily overpass time of the VIIRS satellite in 2018. In this way the position of each vessel of the VMS data set was known at the time of the VIIRS satellite overpass.

In some cases approximately 10% of VIIRS captured fishing vessels could be identified by the vms2viirsanalysis function. However, these numbers could only be reached in the Natuna and southeast Maluku regions with a buffer of approximately 5000 meters (Class C) applied to small Purse Seine and Bauke ami fisheries. Smaller buffer distances (Class A : 500m & Class B: 1000m) resulted in a significantly lower amount of identified vessels. Large Purse Seine fishing vessels could not be detected by the algorithm.

The vast majority of identified vessels was found outside of any MPA. Only approximately 3% of all identified vessels within MPA for ROI1 were located in No Take Zones when applying Class C (5000m) buffer zones around estimated vessel positions. For all other buffer zone classes and ROI none of the identified fishing vessels were found within No Take Zones. For ROI 6, near southeast Maluku, no fisheries activities were found within MPA at all. An increase in VMS usage for smaller or traditional fishing vessels could increase the accuracy of the analysis

Eventually daily paths could be created for each identified fishing vessel. This was done by the vms2viirs4path function. For Class C identified fishing vessels paths were generated all over ROI 1, while in ROI 6 only certain parts of the area were covered. But these daily paths also do not seem to indicate many fishing activities within MPA.

Thus, it is possible to combine VMS and VIIRS fishing vessel data and to track and identify VIIRS detected anonymous fishing vessels through merging the data with VMS data sets by using the LLFI package in R. However, not all vessels are identifiable and not many fishing vessels within MPA could be identified. This could indicate that fisheries in MPA is not frequent.

Suggestions

A wider usage of VMS transponders among the Indonesian fishing fleet and more research on various LED light using fishing techniques could greatly increase the accuracy of the LLFI package.

To properly run LLFI for detection of foreign vessels, it should be run with VMS data input from various countries.

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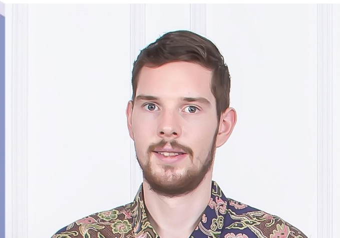
BIOGRAPHY



The author was born at Obtober 28th in Almelo, The Netherlands, as second of five children to Jacob van Beek and Joland van Beek Ter Harmsel. He is currently married to Etania Simamora. Together they have a one year old son named Kenzo Emmanuel van Beek. Ruben did his Bachelor studies in Integrated Coastal Zone Management with a Major in Marine Biology at Hogeschool Van Hall Larenstein in Leeuwarden, The Netherlands, starting in September 2012 until May 2016. Following this he has worked as a project employee for the Dutch Fisheries Association for a while before moving to Indonesia in September 2017 to participate in the BIPA Indonesian language course of Universitas Indonesia in Depok. After finishing BIPA in August 2018, Ruben enrolled for a Marine Technology Master study at Institut Pertanian Bogor. Meanwhile Ruben is working as data specialist and map maker on a freelance base.