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FISHING BOAT DISTRIBUTION ESTABLISHED BY COMPARING VMS AND VIIRS DATA AROUND THE ARU ISLANDS IN MALUKU INDONESIA

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Abstract. Marine protected areas (MPAs) and no take zones (NTZs) are essential for the preservation of marine ecosystems. However, these important areas can be severely harmed by illegal fishing. All vessels above 30 gross tons are required to use vessel monitoring systems (VMSs) that enable vessel tracking by sending geographic data to satellites in each specific time period. The Visible Infrared Radiometer Suite (VIIRS) is a sensor on the National Oceanic and Atmospheric Administration (NOAA)-20 satellite that can detect the light-emitting diode (LED) light used by fishing vessels from space during the night time. In this research, VMS and VIIRS fishery data were combined in order to identify fishing vessels that were detected by the VIIRS sensor of the NOAA-20 satellite. The research was focused on an area near the Aru Islands in the Arafura Sea in Indonesia. Data on LED light used by the fishing techniques of purse seine and bouke ami were obtained for the whole of 2018. The data were then processed using R software. An R package called LLFI (LED Light Fisheries Identifier) was created, containing several R-functions that calculate VMS vessel position during satellite overpass time and then combine the VMS and VIIRS data attributes, resulting in a dataset comprising vessels identified from the VIIRS dataset. Out of all the estimated VMS fishing vessel positions during the VIIRS satellite overpass, approximately 51% could be assigned to fishing vessels detected from the VIIRS dataset. For bouke ami, the identification rate was approximately 87%, while that for small purse seine was around 39%. Ultimately, the LLFI package created daily paths for each identified fishing vessel, displaying all its movements during the day of its'identification. These daily paths did not show any activity within MPA or NTZ. The LLFI package was successful in combining VMS and VIIRS data, estimating VMS vessel positions during the VIIRS satellite overpass, identifying a percentage of the vessels, and creating a daily path for each identified vessel.

Keywords: LED Light Fisheries, MPA, Vessel Monitoring, VIIRS, VMS

1 INTRODUCTION

Marine protected areas (MPAs) and no take zones (NTZs) are effective tools for ecosystem management and biodiversity preservation (Bennet & Daerden, 2014). They are therefore essential for maintaining sustainability and protecting biodiversity in marine ecosystems.

The Republic of Indonesia currently has 697 designated MPAs, containing approximately 82 NTZs. These constitute approximately 1.17% (MPAs) and 0.026% (NTZs) of Indonesia's total exclusive economic zone (EEZ) (KKP, 2019; Marine Regions, 2019).

One of Indonesia's most important regions for fishing is the Arafura Sea, located in southeast Indonesia, west of Papua (Resosudarmo, Napitupulu, & Campbell, 2009). In order to protect valuable fishing grounds in the Arafura Sea, Indonesia has designated areas

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around the Aru Islands in Maluku as MPAs, which contain NTZs.

Illegal fisheries form a threat to essential marine ecosystems within MPAs and NTZs. One way to monitor fishing activities is by vessel monitoring. Through vessel monitoring systems (VMSs), governmental and non-governmental organisations (NGOs) are able to trace fishery activities and detect possible illegal activities (Petrossian, 2015).

VMSs link actual fishery data with geospatial databases. Transponders aboard fishing vessels send out signals to satellites in each specific time period (usually hours or minutes). This period can vary based on the transponder's brand or settings. Some fishery techniques will also require more frequent measuring than others. (Petrossian, 2014 ; Russo D'Andrea, Parisi, A., Martinelli, Belardinelli, Boccoli, Cignini, I., Tordoni, Cataudella 2016 ; Detsis et al. 2012 ; Hintzen et al. 2012)

Indonesia is one of the front runners in gathering and sharing VMS data. All fishing vessels above 30 gross tons, fishing under the Indonesian flag, are required to have VMS transponders aboard. In combination with the NGO Global Fishing Watch, the country is publicly sharing VMS data of more than 5000 fishing vessels (Global Fishing Watch, 2019; Nugroho, Sufyan, & Akiwadi, 2013).

Fishing activities can also be traced through satellite imagery. A commonly used technique, although still underdeveloped for pelagic fisheries, is to track fishing vessels through satellite imagery by using VIIRS (Visible Infrared Imaging Radiometer Suite) data. The VIIRS sensor on the NOAA-20 satellite detects light intensity from Earth during the night time, resulting in daily images displaying light intensity during the satellite's overpass (Ganggang et al., 2017; Xiong et al., 2013)

Indonesian fisheries are very diverse, ranging from large scale industrial trawler ones, to manual pots and fykes. With regard to Indonesia's pelagic fisheries, many purse seine fishing vessels make use of LED (light-emitting diode) lights, that light up on the vessel during the night to attract fish such as *engraulidae* and *cephalopods*. Other techniques for squid fishing, such as bauke ami, also make use of such lights (Susanto et al., 2017; Gumilang & Susilawati, 2020).

This research aims to track and identify LED light emanating from fishery activities in MPAs and NTZs around the Aru Islands in Maluku, Indonesia. This will be achieved by employing VMS and VIIRS data.

2 MATERIALS AND METHODOLOGY

2.1 VMS Data

Indonesian VMS data were obtained for all fishing vessels in 2018 in the region of interest around the southern Aru Islands. A geospatial ROI data file was sent to the Indonesian Ministry of Maritime Affairs and Fisheries (KKP) together with a data request. In response, KKP provided all the VMS data for the ROI in 2018.

The VMS data were filtered based on LED light using fishing gears used by the fishing methods purse seine and bouke ami. To filter out anchored and steaming vessels, all the data points with speeds over 1 knot were omitted. The resulting data on LED light used in fishing was then filtered based on local time. All the daytime data points were filtered out, leaving a dataset with night fishing activities only. The filtering process was conducted in R.

2.2 VIIRS data

All the VIIRS data were obtained from NOAA (National Oceanic and Atmospheric Administration) and NASA (National Aeronautics and Space Administration) using VIIRS boat detection (VBD), derived from DNB (day night band) VIIRS data.

The VIIRS data obtained had already been classified by vessel type by comparing the strength of various detected spikes (Elvidge et al., 2015). After downloading, the data were filtered for fishing vessels only ('QF = QF1). The QF1 data represent all VIIRS detected fishing vessels. All other light sources (e.g. marine platforms, other vessels, land-based light sources, etc.) were filtered out.

2.3 Data Combination

Before combining the VMS and VIIRS data, both datasets were set to the same temporal and spatial boundaries. The process was conducted in R, creating a reproducible script with various functions.

2.4 R Functions

An R package called LED Light Fisheries Identifier (LLFI) was created to gather together all the functions that were used in the research. Figure 2-1 shows these functions and their subsequent order.

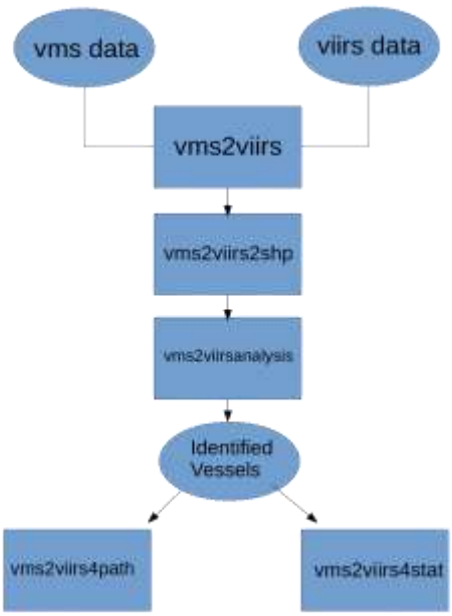

Figure 2-1: LED Light Fisheries Identifier Diagram

2.4.1 Function: vms2viirs

The vms2viirs function estimates the exact position at the NOAA-20 satellite overpass time for each data point in the VMS dataset. The calculation is made by linear regression between the VMS data points filtered between an upper boundary of a maximum of one hour after the local overpass time, and a lower boundary of a minimum of one hour before this time. This was done for every single day in 2018. The function output creates a file with 'vessel id', 'gear type', 'latitude', 'longitude', 'date', and 'MPA type' columns.

2.4.2 Function: vms2viirs2shp

The vms2viirs2shp function cleans the file that was created by the vms2viirs function by erasing rows with NA values (meaning 'no value available' in R), and then saving the output in Esri Shapefile format.

2.4.3 Function: vms2viirsanalysis

The vms2viirsanalysis function creates a 5,000 metre buffer around the position of each position that was estimated by the vmstoviirs function, filtered on the basis of day and vessel ID. Each VIIRS data point for that specific day and overpass time that is located within the buffer zone is then assigned to the vessel ID of the VMS data point. This assigned vessel ID is added to a new column for the VIIRS data points. If no vessel ID can be assigned to the VIIRS data, the column will set the VIIRS data point to 'unidentified'.

The distance of 5,000 metres was chosen in order to correct possible errors in the vmstoviirs function, since it uses linear regression within a maximum time period of two hours. In an ideal situation, in which fishing vessels are constantly hauling, with no wind to alter their course, a buffer zone of 500 metres would be sufficient. However, since fishing vessels tend not to always navigate in a straight line, a buffer distance of 5,000 metres was chosen. In this way, at an overpass time of 12.00pm, vessels that had been hauling and steaming between 11.00pm and 01.00am were also included. During various experiments with varying buffer zones, the distance of 5,000 metres also returned the maximum number of identified vessels.

2.4.4 Function: vms2viirs4path

The vms2viirs4path function takes all identified vessels from the vms2viirsanalysis function each day and adds a sepprtr column that assigns each vessel with a unique ID. This output can then be converted into a path in GIS programs such as SAGA GIS and QGIS. In this research, the dots were combined by the 'Convert points to lines(s)' tool in SAGA GIS in a QGIS software instance. 'VMS ping time' was selected as the order field, and 'sepprtr' as the separator, so that each line only represented one vessel for one day.

2.4.5 Function: vms2viirs4stat

The vms2viirs4stat function gives the number and percentages of identified vessels for each MPA and NTZ.

2.5 Data Display

Before combination, all the heatmaps were set at a standard grid size of 1,000km^2 and a scale of 10 km.

2.6 Region of Interest

The area around the southern Aru Islands in the Arafura Sea was designated as a region of interest for the research, mainly because of the importance of the Arafura Sea region to Indonesian fisheries (Resosudarmo, Napitupulu, & Campbell, 2009).

Figure 2-1 shows the ROI near the Aru Islands. The area is located in the Arafura Sea, a region of special interest for the Indonesian fishing sector.

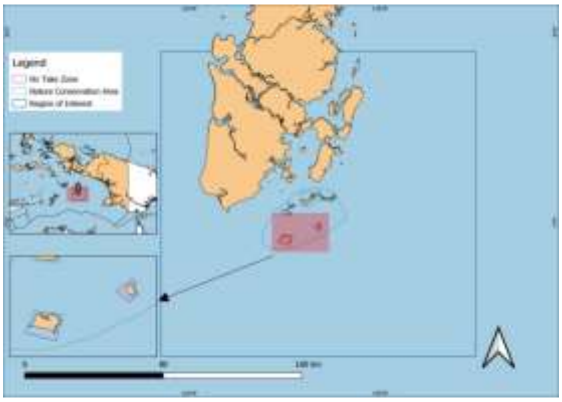

Figure 2-1: Region of interest near the Aru Islands, Maluku, Indonesia

3 RESULTS AND DISCUSSION

In total, 37,723 vessels with VMS transponders, using either bouke ami or purse seine fishing techniques, were located within the boundaries of the ROI in 2018, as shown in Figure 3-1. Meanwhile 24,902 fishing vessels were detected by the VIIRS satellite in the ROI during the year of 2018. Figure 3-2 displays these fishing vessels that were captured by the VIIRS satellite.

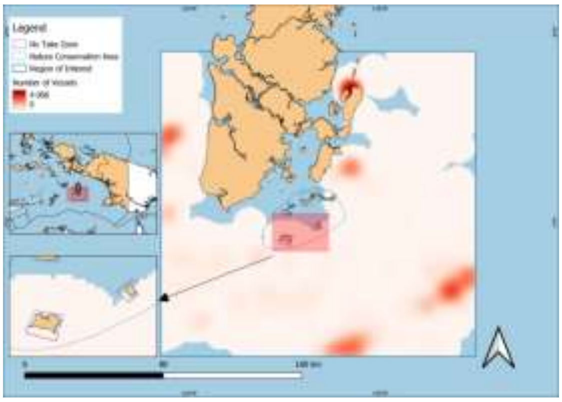

Figure 3-1: LED light using fishing vessels captured through VMS in 2018.

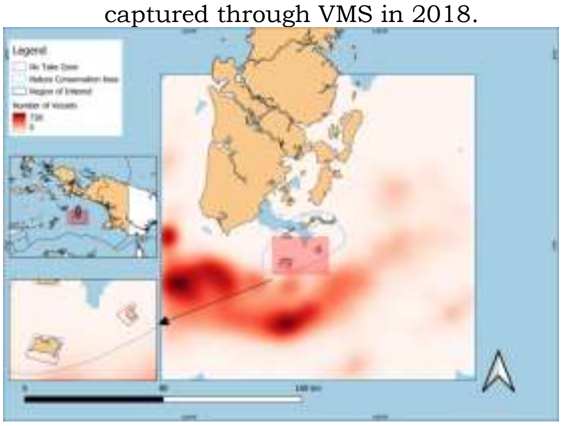

Figure 3-2: LED light using fishing activities captured through VIIRS in 2018.

The vms2viirs function calculates the approximate position of vessels that are present in the VMS dataset during the time of the VIIRS satellite overpass. Figure 3-3 shows the total number of fishing vessels in the ROI detected by the VIIRS compared to the VMS transponders. Figure 3-4 shows the number of vessel positions estimated by vm2viirs in the ROI of the Aru Islands, while Figure 3-5 shows the distribution of these.

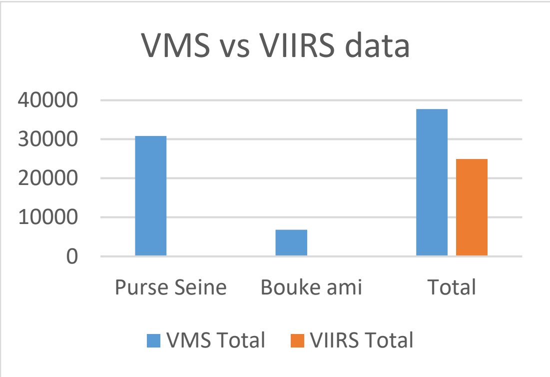

Figure 3-3: VIIRS and VMS data quantities in the ROI used by fishing vessels.

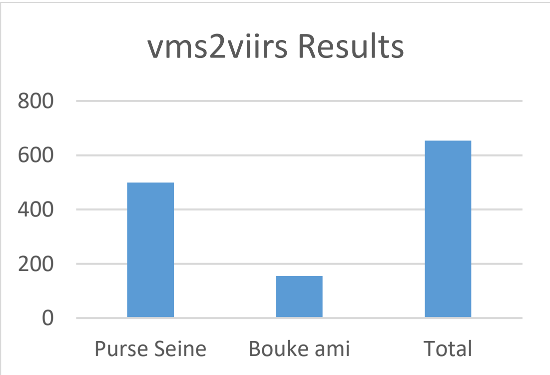

Figure 3-4: Number of fishing vessels in the VMS dataset estimated at the VIIRS overpass time by the vms2viirs function.

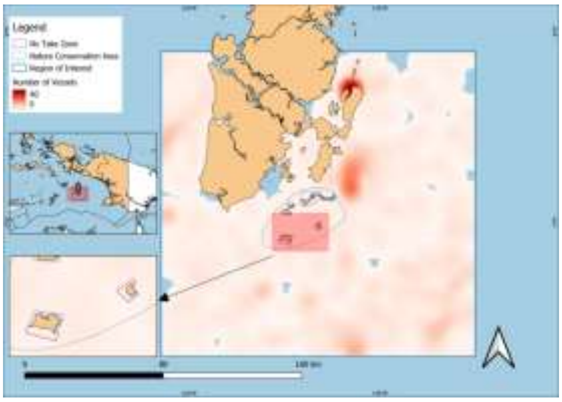

Figure 3-5: Distribution of fishing vessels in the VMS dataset estimated at the VIIRS overpass time by the vms2viirs function.

As indicated by Figures 3-3 and 3-4, the location of only a small proportion of the vessels in the VMS database could be estimated. However, this is logical since the original VMS database that was used has yet to be filtered based on time.

3.1 Vms2viirs analysis

Vms2viirsanalysis returns an output with all the identified vessels found when combining the VIIRS and VMS data. Figure 3-6 shows the distribution of the identified bouke ami vessels in the ROI, while Figure 3-7 shows the distribution of the identified purse seine vessels. Figure 3-8 shows the distribution of all the identified LED light-using vessels in the ROI.

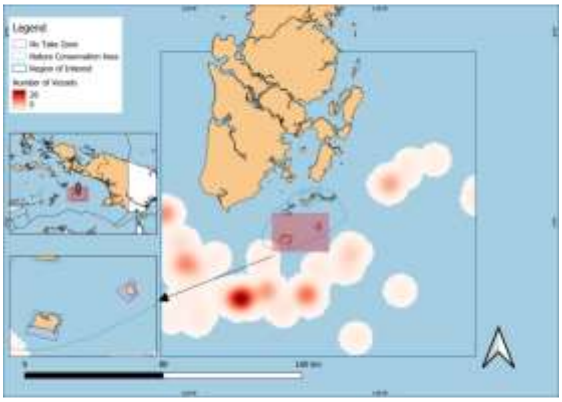

Figure 3-6: Bouke ami fishing vessels identified through vms2viirsanalysis in the ROI.

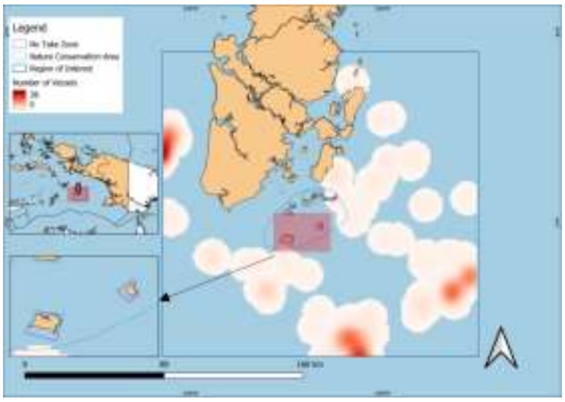

Figure 3-7: Purse seine fishing vessels identified through vms2viirsanalysis in the ROI.

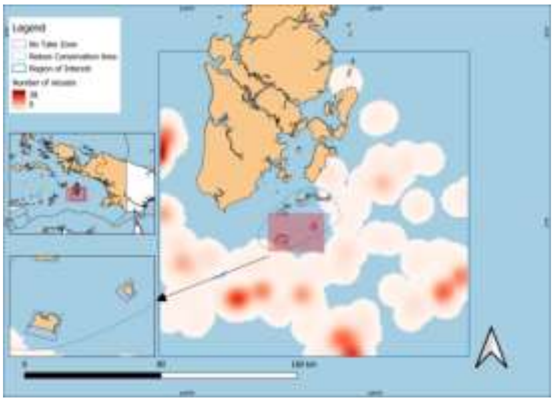

Figure 3-8: LED light-using fishing vessels identified through vms2viirsanalysis in the ROI.

As can be seen in Figures 3-6 - 3-8, nearly all the identified fishing vessels were identified outside the MPA. However, a fair number could be identified outside the MPA.

The 5,000 meter buffer that was used by the vms2viirsanalysis function was set at this distance in order to include vessels that were partially hauling or partially steaming during the hours before and after the VIIRS satellite overpass. However, the greater the buffer distance, the higher the possibility of error; e.g., multiple vessels are located within the buffer zone.

3.2 Vms2viirs4path

The vms2viirs4path function output displays the daily path of each vessel identified through the vms2viirsanalysis function. Figure 3-9 shows the daily paths of all the identified vessels within the ROI.

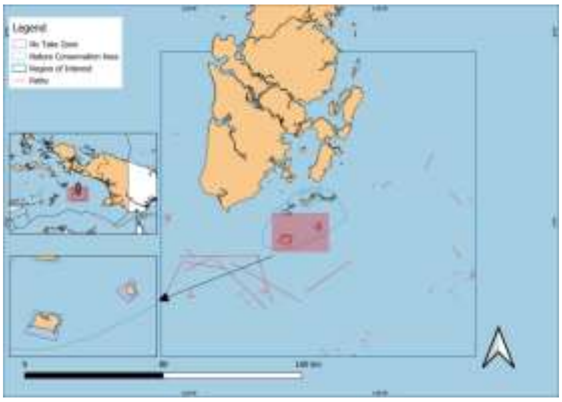

Figure 3-9: Daily paths of each identified LED light-using vessel in the ROI.

In Figure 3-9, it can be seen that none of the daily paths appears to cross the MPA. This means that none of the vessels that were identified through the vms2viirsanalysis function was crossing the MPA on the same day.

A reason for this might be that vessels above 30 gross tons are required to use VMS, and thus can be live-tracked when they enter an MPA or NTZ (Nugroho, Sufyan, & Akiwadi, 2013). The VMS dataset does not include data for fishing vessels <30 gross tons (e.g. traditional fishing boats) or vessels that have switched their VMS transponders off.

3.3 Vms2viirs4stat

Table 3-1 displays the total number of identified fishing vessels in the ROI near the Aru Islands. From the total amount of identified VIIRS data points, around 1.3% were identified. However, from all the 654 VMS data points at the time of the VIIRS satellite overpass, approximately 51% of all vessels could be connected to a VIIRS data point. From all the estimated bouke ami-using vessels at the time of the VIIRS satellite overpass, roughly 87% were connected with the VIIRS captured data points, while the corresponding figure for the purse seine vessels was around 39%.

Table 3-1: Total number of identified vessels in the ROI from raw VMS data (VMS total), VIIRS data (VIIRS total), vms2viirs output (VMS at time of overpass), and vms2viirsanalysis output (VIIRS identified)

Data Type	Purse Selne	Bouke ami	Total
VMS Total	30861	6862	37723
VIIRS Total			24902
VMS at overpass	499	155	654
VIIRS identified	196	155	331

In a studiy on VMS and VIIRS data in Indonesian waters by Hsu et al. (2019), purse seine and bouke ami fishing techniques were identified as having high identification rates for VIIRS-captured fishing vessels. Table 3-2 compares the rates obtained by Hsu et al. and those obtained during this research. It is unclear why there is a difference in small purse seine identification of 20%. However, it should be noted that the research by Hsu et al. was conducted over a longer time period in a larger area including the Java Sea, while this research only focused on the ROI in the Arafura Sea. More research will be needed to establish whether this difference in identification rate will also occur in other areas during other years.

Table 3-2: Identification rates for bouke ami and small purse seine fishing vessels while actively fishing during the NOAA-20 satellite overpass.

Gear Type	Hsu et al.	This research
Bouke ami	81%	87%
Small purse seine	59%	39%

The research by Hsu et al. (2019) also gives a nine to one ratio for VIIRS fishing vessels to VMS data points. In this research, only around 1.3% of all VIIRS data points were identified. A possible reason for this is because the ROI near the Aru Islands is located near the shore, so it is likely that many vessels using LED lights in this area are below 30 gross tons, and therefore not required to use VMS transponders (Nugroho, Sufyan, & Akiwadi, 2013).

Another study by Ganggang et al. (2017) suggests that weak lunar illumination can result in higher accuracy for VIIRS vessel detection. Such strong lunar illumination might have also affected the identification process in 2018. A possible way to tackle this in future projects is to include local weather data.

Another possible reason for unidentifiable data points is illegal fisheries. Illegal fishing vessels often do not carry VMS transponders; it is known that such fishing does occur in the Arafura Sea region (Resosudarmo, Napitupulu, & Campbell, 2009). However, it does not seem likely that the VIIRS dataset contains many illegal vessels, since Table 3-1 shows that more vessels were detected through VMS data than through VIIRS sensor data during the satellite overpass. In addition, foreign vessels are not included on the VMS database provided by KKP, so these will not be traceable, although the region around the Aru islands is not located in an area where Indonesia has any border conflicts with neighbouring countries (Suryadinata, 2016; Permana, Indra, & Erdiansyah, 2016). Therefore, if illegal fishing is taking place in this area, it will probably be domestic.

4 CONCLUSION

Despite the various differences between the VMS and VIIRS data, it is possible to combine them and identify VIIRS-captured fishing vessels through the VMS data. The LLFI vms2viirs function enabled the estimation of LED light-using fishing vessel locations through linear regression of their coordinates before and after the VIIRS satellite overpass.

The vms2viirsanalysis function was able to connect around half of all the estimated vessel positions at the time of the VIIRS satellite overpass (vms2viirs output) with VIIRS-captured fishing vessels. Through the vms2viirs4path function, daily paths could be created for each identified VIIRS data point. None of these paths crossed MPA or NTZ boundaries.

Overall, it is possible to combine VIIRS and VMS data on fishing vessels for VIIRS vessel identification and to create daily paths through the LLFI package in R. However, not all vessels were identifiable and no fishing vessels within the MPAs could be identified. This could indicate that fishing in MPAs and NTZs is not frequent, but it is also possible that illegal and <30 gross ton fishing vessels are being missed in the VMS data.

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AUTHORS CONTRIBUTION

All authors contributed to the study conception and design, material preparation, data collection, analysis and manuscript. All authors read and approved the final manuscript.

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