Preliminary analysis on the abundance indices of neritic tuna species from Indonesian fleets in the north-eastern Indian Ocean 2012-2023

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Abstract

Indonesia is one of the world's largest tuna producers, with approximately 300,000 tons/year (equal to £35 billion in value in 2018) harvested from its archipelagic waters, Economic Exclusive Zone (EEZ), and high seas. About a quarter of the catch belongs to the neritic tuna group, e.g., eastern little tuna. Neritic tuna is caught mainly by artisanal fisheries using fish aggregating devices (FADs) and consumed and traded among coastal communities. However, given its importance, the available data, such as reported catches and effort alone, are insufficient for assessing the stock. Therefore, this study aims to present some preliminary historical trends of abundance indices of neritic tuna species from Indonesian fleets, with emphasize on estimating the number of FADs based on set-by-set logbook data from 2012-2023. The estimated number of FADs was used for generating catch-per-unit-of-effort (CPUE) in kg/FAD. A preliminary attempt at density-based spatial clustering of sets within trips gave satisfactory results, with clusters small enough to have plausibly come from single FADs. The next step is combining clusters that may represent the same FAD in data from different fishing trips and gears.

Keywords: Fish aggregating device (FAD), catch-per-unit-of-effort (CPUE), surface fisheries, density-based spatial clustering.

Introduction

Indonesia is recognized as a prominent global producer of tuna, accounting for up to 15% of the worldwide tuna catch (Miyake et al., 2010; Sunoko & Huang, 2014). The export volume of tropical, temperate and neritic tuna reached nearly one billion USD in 2022 (Pusat Data, Statistik dan Informasi, 2022), with Japan being the primary destination (Chodrijah et al., 2016). Notably, the Indonesian fleet accounted for about one- third (~210,000 tons) of the total neritic tuna catch in the Indian Ocean (IOTC-WPNT13, 2023). Despite the significance of these tuna species for local industries and household consumption, there is limited knowledge regarding their current dynamics and stock status, particularly at a regional level (Zhou et al., 2019).

Uncertainty in catch and effort data, particularly from small and medium-scale tuna fisheries, poses a significant challenge to fish stock assessment at a regional scale, including Indonesia

(Yuniarta et al., 2017). This issue has become a bottleneck in fisheries management within the country. The government's annual historical data has often been criticized by various stakeholders (Duggan & Kochen, 2016; IOTC-WPDCS14, 2018) due to its inconsistency and uncertainty. Many organizations, including NGOs, have been collecting similar data, driven by a lack of trust in the validity of existing data. However, most of these alternative data sources have not been considered when estimating national catch statistics. While some of these data sources could potentially be valuable for determining fish abundance from time series of catch and effort, further investigation is required, particularly when dealing with species like the neritic tuna group (Novianto et al., 2019).

Fish aggregating devices (FADs) are floating objects utilized by fishermen to attract and capture pelagic fish, including tunas, thereby increasing their fishing yield (Moreno et al., 2016). FADs come in two types: drifting FADs (DFAD), primarily utilized by European fleets in the western region of the Indian Ocean, and anchored FADs (hereafter: AFADs), which are equipped with attractors (such as coconut leaves) and secured to the sea floor with concrete blocks. Coastal countries in the eastern part of the Indian Ocean, notably Indonesia, extensively employ AFADs. In most cases, AFADs are used by surface fisheries, for which selectivity bias means that catch-per-unit-of-effort (CPUE) is not proportional to abundance (Bannerot & Austin, 1983). However, since the locations of most of AFADs are unknown (Widodo et al., 2023; Widyatmoko et al., 2021), we tried to divide CPUE by depth, under the assumption that sets conducted in waters deeper than 3000 m were free schooling, while those in waters shallower than 3000 m were AFAD-associated (Setyadji et al., 2023). The concept is supported by previous studies, which indicated that deep-sea anchored AFADs are typically placed at depths ranging from 1,000 to 2,500 meters (Priatna et al., 2017; Widodo et al., 2020), as it is economically unviable to place them in deeper water.

There have been several attempts to locate and count AFADs in Indonesia. Widodo et al. (2023) used satellite data interpretation for detecting suspected AFAD objects larger than 5 meters in length in the eastern part of Indonesian archipelagic waters, Satrioajie & Yuniarta (2018) used total enumeration method by interviewing local fishers in Maluku and Sulawesi Seas, and Widyatmoko et al. (2021) detected the potential FAD locations from small-scale fisheries tracking data in West Nusa Tenggara. Although these methods are promising, they are not suitable for larger scale implementation as acquiring raster data, conducting interviews and purchasing tracking devices across eleven Fisheries Management Areas (FMAs) would be too expensive. Combining density-based clustering (Widyatmoko et al., 2021) with set-by-set logbook data could be a cost-effective alternative for predicting the location and number of FADs for large-scale implementation.

The aims of this study were to examine temporal trends in CPUE for neritic tuna in Indonesia (with effort measured by the number of sets) from shallower locations (assumed to represent AFADs) and deeper locations (assumed to represent free-schooling), to estimate the number and location of AFADs across the western and southern parts of Indonesian archipelagic, Economic Exclusive Zones (EEZ) and high seas territories using density-based clustering, and to investigate the feasibility of developing an index of abundance using fisheries-dependent data on catch and the estimated AFAD locations

Materials and Methods

Data Sources

The set-by-set catch and effort data for this study were obtained from the Integrated Logbook Information System (SILOPI) for Fisheries Management Areas (FMA) 571, 572, 573 (Figure 1) and high seas, covering the period from January 2012 to December 2023. The data was provided by the Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, Indonesia. The logbook data provides a comprehensive record of commercial fishing activity, encompassing vessel information, trip identity, set number, time and location of each set, as well as species- specific estimates of the total catch. To ensure the reliability of the analysis, the data underwent a cleaning and filtering process prior to analysis. This step was crucial to deal with possible reporting errors that are commonly found in logbook data (Mendo et al., 2022; Sampson, 2011). The data cleaning process involved the following steps:

1. Fishing sets must be conducted between the departure and arrival dates.
2. Excluding sets with a depth of zero or more, assuming they were mistakenly marked as land.
3. Filtering out trips that contained sets below 20°S, assuming that was the farthest fishing ground for Indonesian purse seine based on VMS (Vessel Monitoring System) data (MMAF, 2022).

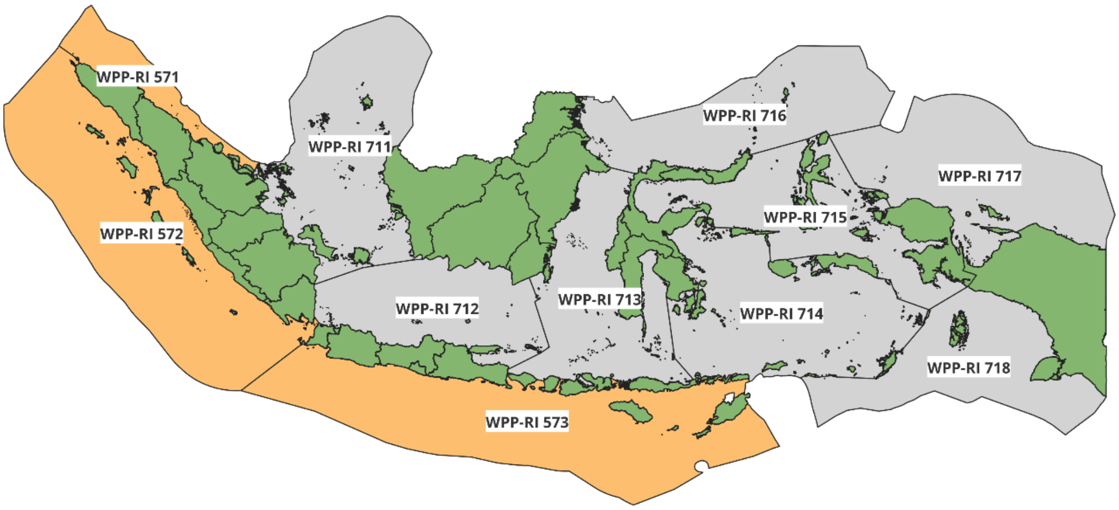

Figure 1. Map of the study area, highlighting Fisheries Management Areas (FMAs) 571, 572, and 573 in yellow.

Raw catch-per-unit-of-effort (CPUE)

Catch per unit of effort (CPUE) refers to the average catch of neritic tuna species per set, assuming a daily set frequency. To differentiate between different catch types (AFAD-associated and free schooling), a threshold of 3,000 meters depth was chosen. The depth of each set was established by intersecting logbook data with the General Bathymetric Chart of the Oceans (GEBCO) using R version 4.2.3 (R Core Team, 2023). The GEBCO_2023 GRID is a continuous, global terrain model for both ocean and land, providing a spatial resolution of 15 arc seconds (GEBCO Bathymetric Compilation Group, 2023). It is available for download at https://www.gebco.net.

Cluster analysis.

In an attempt to identify the positions of AFADs, we followed Widyatmoko et al. (2021) and used the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm (Ester et al., 1996). Unlike other popular clustering methods, such as *k*-means and hierarchical clustering, which assume either convex or hyper-spherical cluster shapes (Jain et al., 1999), DBSCAN can capture clusters of arbitrary shapes, including non-convex shapes (Hahsler et al., 2019). The ability to capture non-convex clusters makes DBSCAN suitable for detecting the presence of AFAD from a group of concentrated points (e.g., set-by-set logbook data), in which strong current and wind speed can create irregular clustering patterns. DBSCAN also has the ability to handle noise (areas with very low density), which is useful when detecting erroneous data points caused by inaccuracies in GPS-enabled sensors (Chen et al., 2014).

The DBSCAN algorithm is available in the R package `dbscan` (Hahsler et al., 2019), and requires two parameters, the density threshold $minPts$ and the neighborhood radius ϵ (Ester et al., 1996). The value of $minPts$ is usually determined by the rule of thumb that it should be least the number of dimensions of the dataset plus one (Hahsler et al., 2019), in our case this is 3. The value of ε is determined as the radius through which an AFAD could move on the surface. Assuming that the length of the main rope anchoring the AFAD is twice the depth (Wudianto et al., 2019), then by Pythagoras' Theorem the radius is $\sqrt{3} \times \text{depth}$.

The DBSCAN algorithm was applied separately to each trip and each type of gears expected to interact with AFADs, such as purse seine, pole and line, hand line, troll lines, lift net and kite line fishing (Wudianto et al., 2019). To determine whether clusters plausibly represented single AFADs, we calculated the ratio of the diameter of each cluster to the maximum diameter through which an AFAD could move. The cluster diameter is defined as the maximum pairwise distance between any two points in the cluster, and the maximum diameter through which an AFAD could move (again using Pythagoras' Theorem and assuming the length of the main rope is twice the maximum depth for each trip) is $2\sqrt{3} \times \text{depth}$. Ratios much greater than 1 indicate clusters that could not plausibly represent single AFADs. The centroid of each cluster was identified as a suspected new AFAD location.

Results

The dataset contained 327,246 sets of purse seine gear data collected from January 2012 to December 2021. Around 122,112 sets (37.31%) were conducted in waters shallower than 3,000 m, indicating their association with AFADs, while the remaining 205,118 sets (62.69%) were performed in waters deeper than 3,000 m. The representation of known fishing grounds is depicted in Figure 1, illustrating the distribution of sets ranging from 10°N to 20°S and 75°E to 135°E. Notably, fishing activities have expanded towards the north-central Indian Ocean, particularly within the last five years. Annual landings of purse seine fleet showed a generally increasing trend over time (Figure 3).

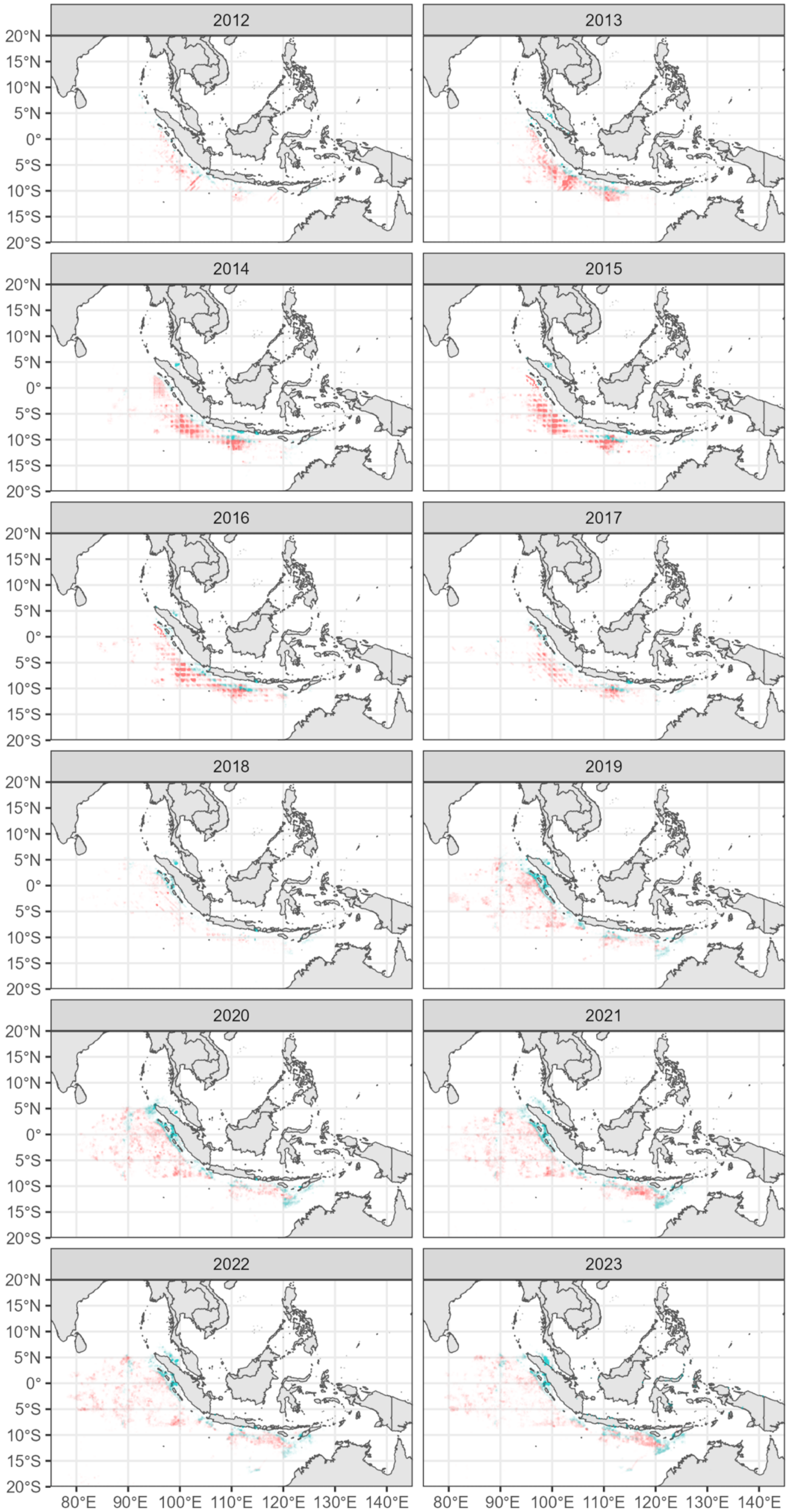
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Figure 2. The spatial distribution of purse seine activities, represented by the number of sets, from January 2012 to December 2023. Sets performed in waters with depths exceeding 3,000 m are in red, while sets conducted in waters with depths less than or equal to 3,000 m are in blue.

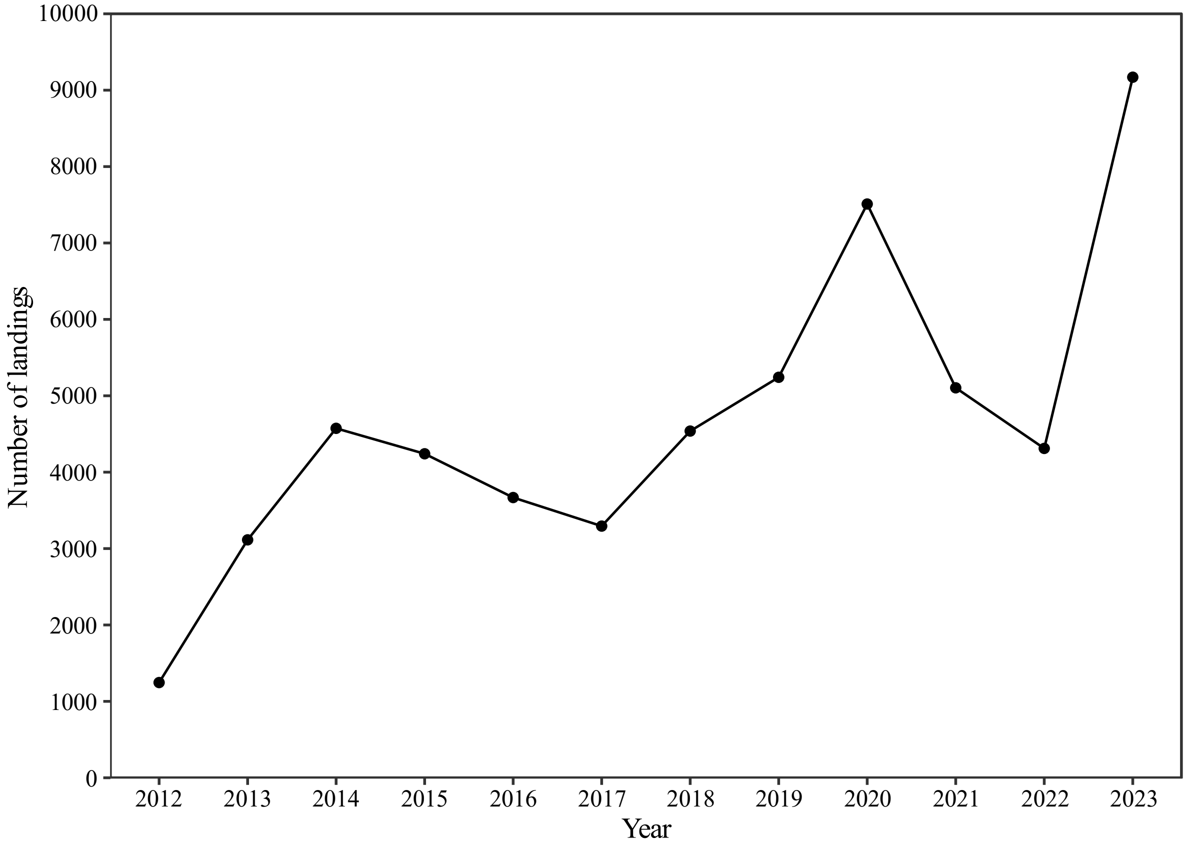

Figure 3. Number of landings in logbook data from January 2012 to December 2023.

The historical CPUE based on fishing type is shown in Figure 4. Overall, the CPUE derived from free-schooling fishing (sets deeper than 3,000 m) exhibited relatively low variability, possibly due to the prevalence of industrial-type purse seiners. However, the CPUE trend associated with AFADs (sets at depths less than or equal to 3,000 m showed substantial variability for frigate and longtail tuna, with exceptionally high catches in certain years.

Except for a large spike in 2017, the abundance of bullet tuna (BLT) exhibited minor discrepancies between AFAD-associated and free schooling. A similar pattern was observed for frigate tuna (FRI), apart from a very large CPUE from AFADs in 2018. The challenge in distinguishing between these two species could impact the overall estimation of abundance, as they are often caught together and grouped as a single entity for sale. For longtail tuna (LOT), there was little difference between the temporal patterns for AFAD- and free-schooling sets, apart from a large CPUE from AFADs in 2014, even though the purse seine catch for this species has increased in the past five years (IOTC-WPNT13, 2023). The CPUE of eastern little tuna (KAW) showed similar temporal trends for both cases which could be the base for further analysis.

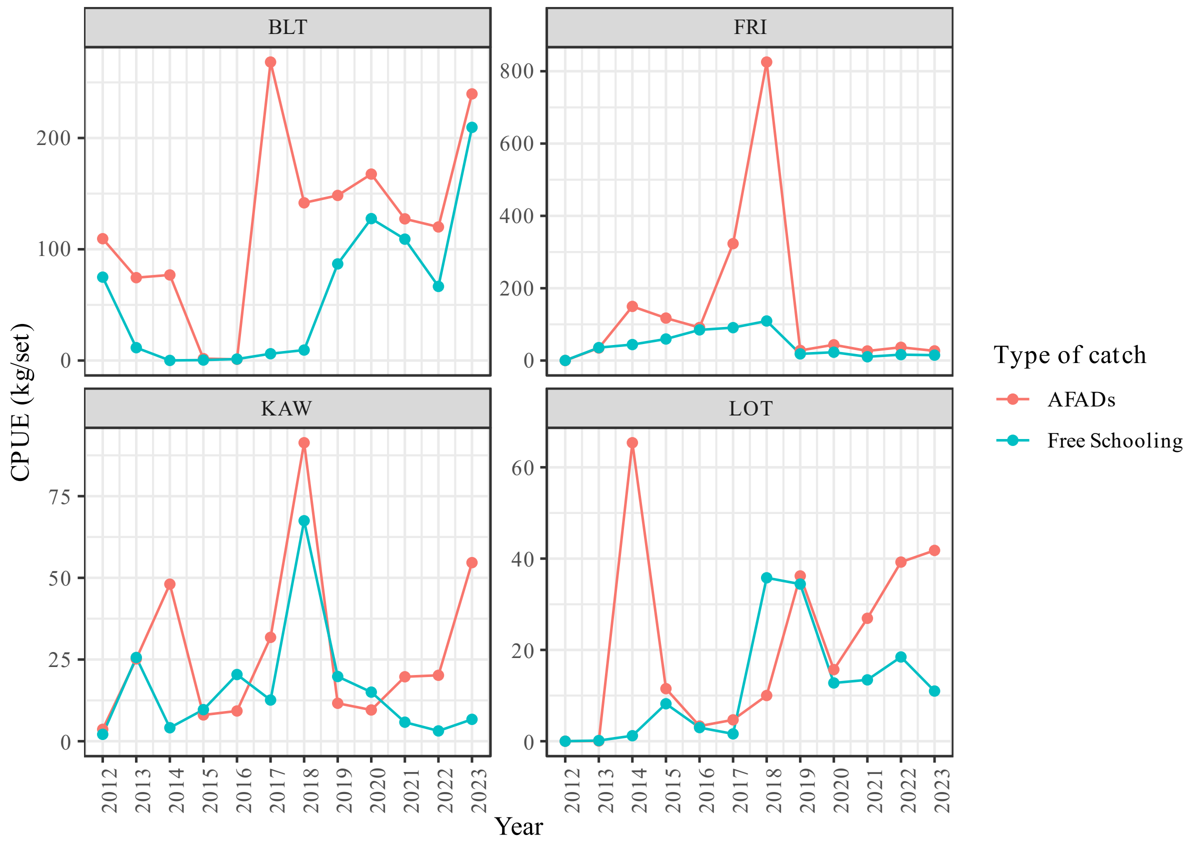

Figure 4. Catch per unit of effort (CPUE) series of some neritic tuna species derived from logbook data from January 2012 to December 2023. AFADs refer to sets conducted from depth shallower than 3,000 m, whereas Free Schooling refers to sets conducted deeper than 3,000 m.

The DBSCAN algorithm identified 24,488 potential AFADs from a total of 34,696 trips across fishing gears from 2012 to 2022, however, only result for purse seine fleet in 2022 displayed in this paper (Figure 4). There was a large concentration of potential AFADs in the south of Java, Bali, and Nusa Tenggara (FMA 573, refers Figure 1). However, one-third of the clusters were located in waters deeper than 3000 m, suggesting that they are unlikely to represent AFADs. It is possible that these clusters indicate transshipment activities, vessels acting as logistical supply, or the presence of AFADs at depths greater than 3000 m.

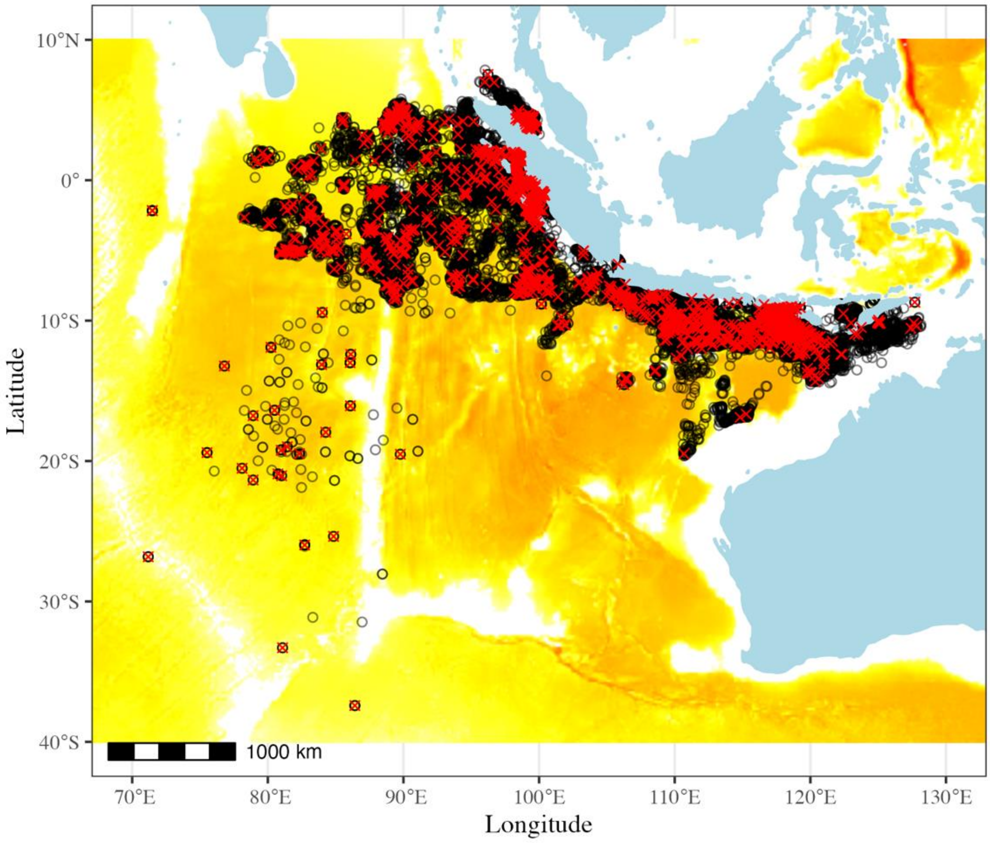

Figure 4. Potential AFAD locations at trip level (red mark) across gears in 2022, generated by the DBSCAN algorithm. Grey points are reported set locations. Gradient color represents depth more than 3,000 m.

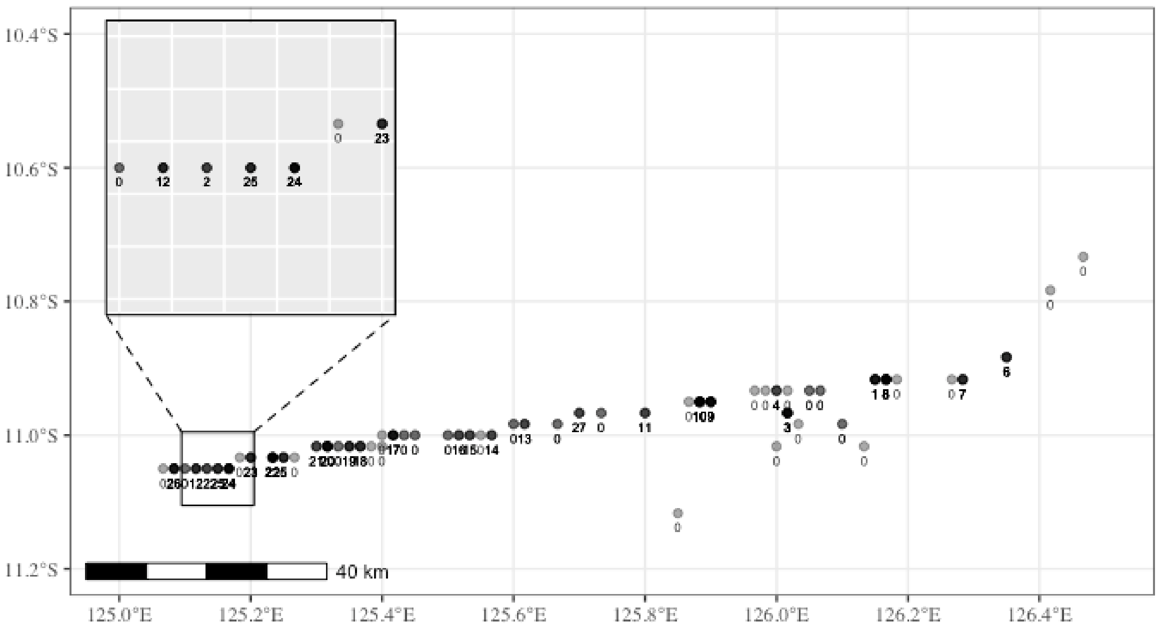

Figure 5. Clusters within a single trip of handline vessel. Each point represent a set. Points labelled with 0 are "noise" not associated with any cluster. Other numbers identify cluster. Points are semi-transparent, so that multiple sets at the same location appear as darker points.

Figure 5 showed an example of clustering result from a typical trip of handline vessel. Where sets were often conducted relatively close together. The proportion of cluster diameter to twice radius ratio less or equal with one was more than 99%, whereas only small number of cluster beyond 1 (Figure 6). Thus, most clusters could plausibly be identified as single AFADs. Clusters with zero diameters, indicated successful sets were recorded on top of each other, resulting in stacked points (e.g., Figure 5: darker points indicate multiple sets at the same location). This behavior might be relevant for handline, troll line, and liftnet fisheries, where sets are usually repeated in the same area when the yield is satisfactory. However, for other gears, we might expect fewer zero values in diameter because sets are typically done once per day.

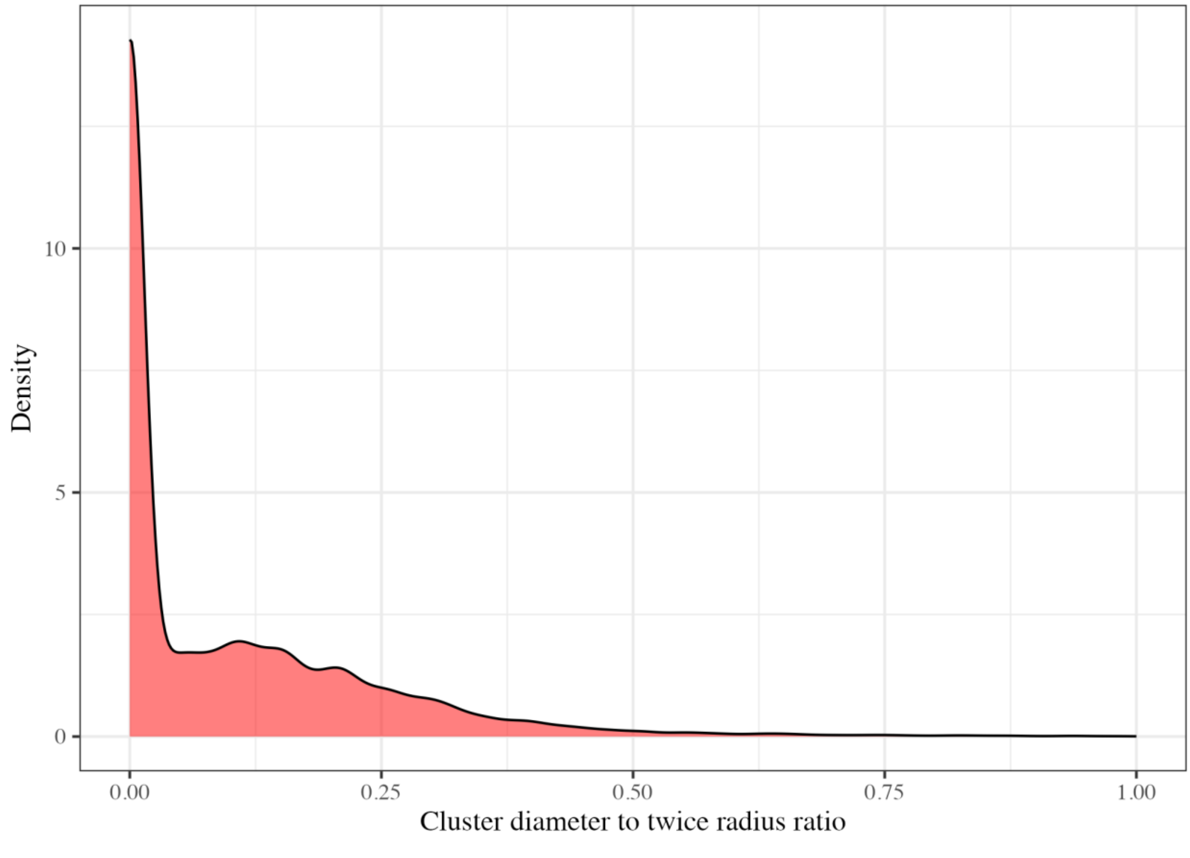

Figure 6. Distribution of cluster diameter ratios, where a ratio of 1 (red line) indicates that the cluster diameter equals twice the radius through which an AFAD could move.

Further study

Following Widyatmoko et al. (2021), the total number of suspected AFADs was determined by plotting the coordinates of each suspected AFAD from each trip. If the distance between two suspected AFADs was less than the value of ε for each centroid, they were classified as a single suspected AFAD. This classification indicates that the same suspected AFAD was visited by more than one vessel or on multiple trips. Since the original method wasn't clearly explained, we propose using agglomerative clustering to mimic their approach to solve this issue. The total number of AFADs for each year was then used to determine an alternative abundance index for neritic tuna species, expressed as kilograms per AFAD. Then, the total number of AFADs can be used to determine an alternative abundance index for neritic tuna species, expressed as kilograms per AFAD.

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