



Spatial distribution of fishing intensity of canvas stow net fishing vessels in the East China Sea and the Yellow Sea

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ABSTRACT

Present study used the position data of BeiDou Vessel Monitoring System (VMS) in 2018, with respect to motorised fishing vessels in the East China Sea and the Yellow Sea to construct a fishing vessel operating status classification model based on threshold, deep neural network and DBSCAN density clustering algorithm. The geographic grid was divided into cells of $0.1^{\circ} \times 0.1^{\circ}$ and the average fishing time per square km (h km^{-2}) in each grid was calculated to obtain the spatial distribution of fishing intensity in the study region in 2018. The results showed that the threshold method could classify fishing vessel sailing, anchoring and other states with an accuracy of more than 95%. The deep neural network and DBSCAN algorithm could classify the two states of netting and closing with an accuracy of 94.7%. By classifying the status of fishing vessels, quantitative monitoring can be carried out to better serve the management of marine fishery resources and marine ecological protection

Keywords: China, DBSCAN, Deep neural network, Fishing intensity, Spatial distribution, VMS, Voyage extraction

Introduction

China is a country having considerable fisheries resources, with a large number of offshore fishing vessels. According to the 2018 China Fisheries Statistical Yearbook, by the end of 2018, Liaoning, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian and other coastal provinces (and cities) in the East China Sea and the Yellow Sea had 88,852 offshore fishing vessels, with an annual output of 7,943,082 t (CFB, 2018). Stow nets are China's most widely distributed traditional fishing equipment with the largest number of species caught and the most stringent control (Chen *et al.*, 2009; Xu *et al.*, 2019).

The canvas stow net is a single-anchor net, which belongs to a passive filtering fishing equipment. It uses net anchors to fix the net underwater and use floats and sinkers to extend the net vertically, stretch the entire net under the action of seawater flow and use the seawater flow to force the fishing object into the net (Zheng *et al.*, 2016). The fishing vessels usually carry 5 to 10 nets, arrange the nets after arriving the operating area, deploy anchor and wait for fish to be caught. The cod ends of canvas stow nets are picked every 12 h until the high tide subsides, after which the fishing vessels retrieve all the nets and return to the fishing port (Pei *et al.*, 2019).

Vessel Monitoring Systems (VMS) are now a decisive tool for studying fishing operations in the ocean. Speed thresholds have been set for different types of fishing boat operations, but since some of them overlap, it is impossible to accurately distinguish the type of fishing boat operation (Lee *et al.*, 2010). Several studies have used Hidden Markov's Bayesian hierarchical model to predict the fishing status of boats; however the requirement of high data continuity in this model has a certain impact on the results (Vermard *et al.*, 2010; Walker and Bez, 2010). According to different fishing methods, authors have used different classifiers to obtain the operating status of various types of fishing vessels at each moment of the voyage and to calculate the distribution of fishing effort and fishing intensity (Chang *et al.*, 2010; Chang, 2011).

Most of the studies carried out so far calculated the fishing effort for a single fishing vessel, determined the type of operation based on the year-round position data of the fishing vessel and ignored the situation in which the fishing vessel changes the fishing method. Fishing intensity of refined fisheries are mainly obtained through field surveys of scientific research vessels, which are used to form dynamic fishing networks (Liu *et al.*, 2013; Liu *et al.*, 2017). This survey method is inefficient and has a

small coverage area and it can not visualise the fishing situation across the sea. Hence the present study attempted to use VMS data to determine the operating status of fishing vessels and to extract the spatial distribution of fishing intensity of canvas stow net fishing vessels.

Materials and methods

Data collection

The BeiDou Civil Division Service Provider, shared China's 2018 VMS position data, which included the fishing vessel ID, latitude, longitude, dispatch time, speed and course of the fishing vessel. Ship location data was captured every 3 min on average, with a spatial resolution of around 10 m (Zhang *et al.*, 2018). By the end of 2018, the Chinese mainland had around 60,000 offshore fishing vessels with BeiDou navigation and positioning systems and roughly 24,000 vessels with BeiDou VMS systems operating from coastal provinces (municipalities) in the East China Sea and the Yellow Sea. The 1.123×10^9 BeiDou VMS position records generated by 23,879 offshore fishing vessels in the provinces along the East China Sea and the Yellow Sea were used in this study.

Data pre-processing

The original VMS data describes the navigation attributes of only a single ship point and lacks continuity. Therefore, pre-processing of the data is required. Fishing boats with nets do not frequently change their fishing status. Therefore, ship speed is an important indicator for distinguishing fishing status. The speed in the sailing state was $2\text{--}6 \text{ m s}^{-1}$ and the speed change rate was -0.04 to $+0.04$; while speed during net setting and hauling was mostly $0\text{--}2.5 \text{ m s}^{-1}$ and the speed change rate was -0.96 to 0.7 . The speed during netting operation was $0\text{--}3 \text{ m s}^{-1}$ and the speed change rate was -0.84 to 0.37 . The speed at anchor was 0 m s^{-1} and the speed change rate was -0.38 to 0.5 . The coordinates of the fishing boats were the main data for positioning. The cumulative deflection angle of the vector was calculated based on the ship position point. The semi-positive vector formula was used to calculate the distances between consecutive ship positions on the time series. The average deflection angle and accumulated time of each ship were calculated separately.

The operational status classification model

The entire operation voyage of a canvas stow net fishing vessel can be divided into four states viz., sailing status, fishing status, net hauling status and anchoring status. The visualisation of an operation voyage of a canvas stow net fishing vessel is shown in Fig. 1a. Here, yellow indicates trip to the fishing ground, green depicts fishing operation in the fishing ground and pink indicates return trip to the fishing port. The red in Fig. 1b-e are the four states of the fishing vessels, *i.e.*, sailing, fishing, net

hauling and anchoring status during the voyage, Fig. 1c-e depicts enlarged areas of fishing operations.

Canvas stow net fishing vessels adopt passive fishing. The position data characteristics of fishing vessels in sailing status and anchoring status are significantly different and the number of these two statuses were the largest, usually accounting for more than 80% of the total position records of each voyage (Zheng, 2016).

The sailing status includes the position of the fishing boat between the fishing port and the fishing ground. The speed is greater than 1.5 m s^{-1} , the vector deflection angle is less than 30° and the distance between two adjacent positions in time-series is greater than 100 m. The fishing vessel waits for the catch to enter the net when it is in anchoring status. The average speed of the boat is less than 0.2 m s^{-1} within 2 h and the distance between adjacent ships is less than 25 m. The position data characteristic during fishing and net hauling status are between the above two conditions (Pei *et al.*, 2019). By setting the threshold, the ship position is classified into sailing status and anchoring status (Zong *et al.*, 2016).

The position data which do not pass the threshold classification are mainly composed of fishing status and net hauling status. Characteristics of these two statuses are similar which need to be further tapped for classification. After removing the sailing status and the anchoring status, the continuous vessel positions in the time-series form a group and the time between the groups is not continuous. Each group of records contains only one state. We calculated the duration of each set of data using equation (1), the average deflection angle using equation (2) and the average cumulative displacement per minute using equation (3).

$$t = T_j - T_k \# \dots\dots\dots(1)$$

where T_k is the start time in a group of fishing vessels position, T_j is the end time and t is the duration in the group of operational status, in minutes.

$$\theta = \frac{1}{n} \sum_{i=1}^n \theta_i \# \dots\dots\dots(2)$$

where θ_i represents one of the n vector deviation angles generated in one group and θ is the average vector deviation angle in the current group.

$$x = \frac{1}{t} \sum_{i=1}^n 2R \cdot \arcsin \sqrt{\sin^2 \left(\frac{y_i - y_1}{2} \right) \cos(y_1) \cdot \cos(y_i) \cdot \sin^2 \left(\frac{x_i - x_1}{2} \right)} \dots\dots\dots(3)$$

where x_1 , y_1 , x_i and y_i represent the latitude and longitude of the first ship position point and any ship position point in the time-series in a group of ship positions respectively. R represents the radius of the earth and is equal to 6371 km, which is used to calculate the distance between each

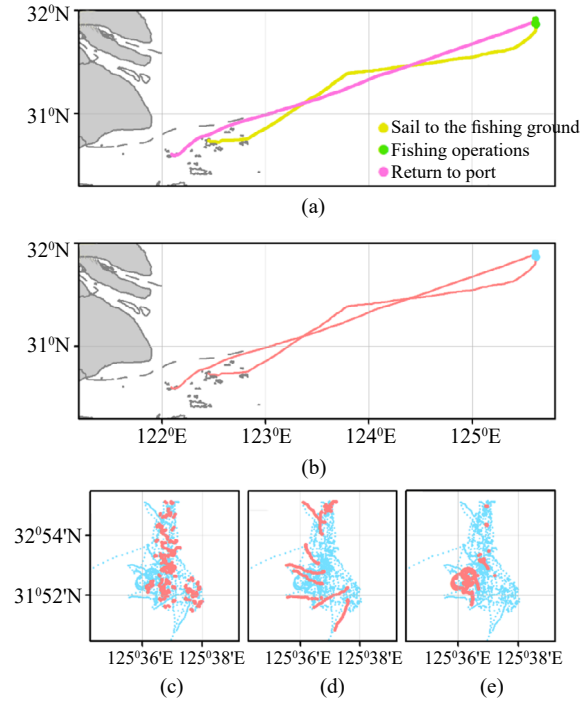


Fig. 1. Overview of a fishing vessel's voyage trajectory and position record distribution of operational status. (a): Overview of one voyage of a canvas stow net vessel; (b-e): The position record distribution of the fishing vessel in sailing status, fishing status, net hauling status and anchoring status

position in this group of positions and the first position. The symbol t is the duration of the operation stage and x represents the average cumulative displacement per minute.

According to the position characteristics of canvas stow net fishing vessels operational status (Pei *et al.*, 2019), we manually classified the operation status of 28,770 position records, after removing the sailing status and anchoring status and calculated the following 9 attributes of the remaining position: the distance between adjacent ships in time-series, average displacement distance per minute, the average distance of each group in the same operational statuses, speed at each location, average speed in each group data, the proportion of 0 m s⁻¹ in each group, vector deflection angle for each position, average vector deflection angle within each group and duration of each group. The correlation between the characteristics of fishing status and net hauling status is shown in Fig. 2. The kernel density curve is shown diagonally on the subgraph. The smaller the overlapping part of the kernel density curve, the more obvious the difference between different states, which is beneficial to neural network classification. The smallest attribute of the overlapping part of the nuclear density curve was: average displacement distance per minute, vector deflection angle for each position and duration of each group. The difference between these three attributes is obvious in fishing status and the net hauling

status, so they can be used as the classification basis of the statuses classification model.

We established a 4-layer deep neural network with 3 neurons in the input layer, 10 neurons in the first hidden layer, 6 neurons in the second hidden layer and 2 neurons in the output layer. The ReLU function was used as the activation function in equation (4), using the Adam optimiser, the classification cross-entropy function is used as the loss function in equation (5). The 28,770 position data marked with the operation statuses were divided into a training set and a test set at 4: 1. The training set data was used as input into the neural network and iterated for 100 rounds to train the fishing vessels' operational status classification model (Wang *et al.*, 2022; Zhang *et al.*, 2022).

$$f(x) = \max(0, x) \# \dots\dots\dots(4)$$

where x is the input vector.

$$f(x) = - \sum_{i=1}^n (p(x_i) \log q(x_i)) \# \dots\dots\dots(5)$$

where $q(x_i)$ is the value, $p(x_i)$ is the corresponding probability value.

Extraction of the fishing intensity distribution

When canvas stow net fishing vessels arrange the net, the anchor of the net is first sunk into the water, then the net body is released and rely on the tide force to stretch the net. Arranging net status is usually completed within 24 h after the fishing vessel arrives in the operating area (Yan *et al.*, 2015). The position records during the first 24 h were screened with the fishing status classification to determine the position of fishing operation. The DBSCAN algorithm was used to group the position points from fishing status of the same net into a cluster and were grouped into different clusters (Yuan *et al.*, 2020). Since the position points were expressed as the longitude and latitude coordinates, we used the spherical half vector formula to calculate the distance between two position points. Equation (6) was used to replace the Euclidean distance formula in the traditional DBSCAN calculation. The dispatch time of the first position record in the time-series of the cluster was the time when the net was released. The dispatch position was the net distribution position, namely, the net anchor sinking position.

$$L_{nm} = 2R \cdot \arcsin \left(\sqrt{\sin^2 \left(\frac{y_n - y_m}{2} \right) \cos(y_n) \cdot \cos(y_m) + \sin^2 \left(\frac{x_n - x_m}{2} \right)} \right) \# \dots(6)$$

where (x_n, y_n) and (x_m, y_m) are the latitude and longitude coordinates of the adjacent position points N_n and N_m , respectively, where x is the longitude and y is the latitude. R stands for the radius of the earth. The value of 6371 km is entered into the formula to calculate the actual distance between N_n and N_m . The unit is m.

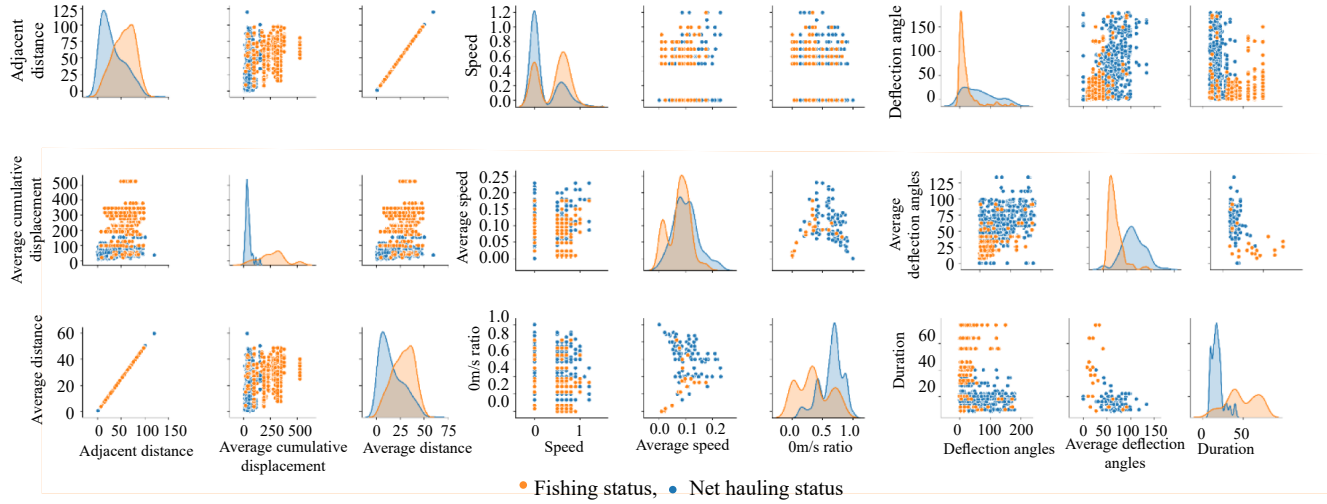


Fig. 2. Bivariate scatter plot and univariate histogram of the ship position feature during the non-sailing status and non-anchoring status

The position records of the net hauling status were arranged according to the dispatch time. The dispatch time of the first position record of the net hauling status was taken as the net retrieval time and the dispatch position was taken as the net receiving position, namely, the anchor retrieval position (Pei *et al.*, 2019). Since the net anchor is submerged on the bottom and its position is relatively fixed, the nearest group from the list of arranging nets positions and the list of retrieving nets positions is selected as the retrieval position of the same net. The period from the moment when each nets are arranged to the moment when the nets are retrieved is taken as the length of time as fishing time. Equation (7) was used to calculate the fishing time of each net and the net retrieval position was taken as the coordinate of the net.

$$T_k = E_k - B_k \quad \# \quad (7)$$

where E_k and B_k are the times of the net hauling status and fishing status of the k th net. T_k is the duration of the fishing status of the k th net. The unit is h.

The $0.1^\circ \times 0.1^\circ$ geographic grid as a cell was divided under the projection coordinate system of WGS1984, statistics the fishing time of all nets in each grid. The fishing intensity of each grid was calculated with equation (8) (Zhang *et al.*, 2014; Zhang *et al.*, 2016a).

$$E_i = \frac{1}{S_i} \sum_{k=1}^n T_k \quad \# \quad (8)$$

where S_i represents the geographic area of each cell. n is the number of extracted nets on the grid. T_k is the duration of fishing for each cell. E_i represents the fishing intensity of the grid and the unit is h km^{-2} .

Results

The extraction of voyages from the fishing vessels was based on the offshore distance and voyage duration

of the fishing vessels, voyages longer than 5 days were interpreted as valid voyages and their trajectory maps were drawn. The deep neural network model was used to classify the operational statuses of the fishing vessels and the classification accuracy of each status was expressed with a confusion matrix. Finally, the fishing effort in the area was calculated and displayed in the form of pictures.

Extraction of valid voyages

The provinces (municipalities) along the East China Sea and the Yellow Sea include Liaoning, Shandong, Jiangsu, Shanghai, Zhejiang and Fujian. The 2018 VMS data provided by the BeiDou Civil Division Service Provider had missing data from Fujian Province. In 2018, Liaoning, Shandong, Jiangsu, Zhejiang and Shanghai had a total of 23,878 fishing vessels with VMS records and a total of 125,502 operation voyages were extracted, of which 54,120 were valid voyages.

Classification of the operational statuses of the canvas stow net vessels

According to the operating characteristics of the canvas stow net fishing vessels, 28,770 VMS records were manually classified into four statuses. Among them, 9770 records were marked as sailing status, 3781 records were marked as fishing status, 2098 records were marked as net hauling status and 13121 records were marked as anchoring status. Each operation status was divided into a training set and test set according to 4:1. Thresholds were set in the training set of 23,016 records, from which 7,746 records were judged into sailing status and 10,374 records were judged into anchoring status. A total of 4704 records were marked in the training set as the fishing status and net hauling status. The training set and the test set were divided again at a 4:1 ratio and the training set was used

as input in to the operational statuses classification model and iterated through 100 rounds. The training iteration loss and the accuracy of the test set, are shown in Fig. 3.

A total of 5754 records in the test set were used to test the accuracy of the model. The accuracy of classification by this model is shown in the confusion matrix in Fig. 4.

Calculation of fishing duration and extraction of the fishing intensity distribution

The operation status classification model was used to identify the operation status of each VMS record and the DBSCAN density clustering algorithm was used to determine the fishing and net retrieving position of each canvas stow net based on the fishing status and net retrieving status. Taking the time when the nets were arranged as the fishing start time and the time when the

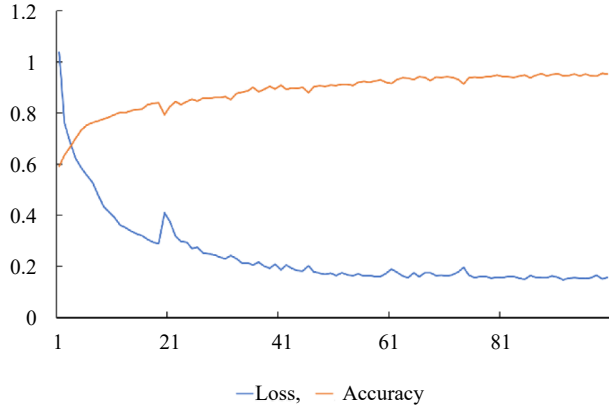


Fig. 3. Visualisation of the deep neural network model for the training process of fishing status and net retrieving status classification

True label	Sailing status	0.9910	0.0042	0.0005	0.0042
	Fishing status	0.0162	0.8429	0.1097	0.0312
	Net retrieving status	0.0080	0.0258	0.9662	0
	Anchoring status	0.0003	0	0.0114	0.9883
		Sailing status	Fishing status	Net retrieving status	Anchoring status
		Predicated label			

Fig. 4. Accuracy confusion matrix of the canvas stow net operational status classification model

nets were retrieved as the fishing end time, we calculated the time difference between the two as the fishing duration of each net.

The provinces (municipalities) along the East China Sea and the Yellow Sea strictly manage the operation of canvas stow net vessels. There are fishing moratoria for some vessels. Therefore, the operation of canvas stow net fishing vessels were closed from 12:00 hrs on 1 May to 12:00 hrs on 16 September 2018. Table 1 lists the numbers of canvas stow net fishing vessels, voyages, the number of fishing nets and the cumulative fishing duration of each month in the East China Sea and the Yellow Sea in 2018.

The $0.1^\circ \times 0.1^\circ$ geographic grid was created under the projection coordinate system of WGS1984. The geographical areas of the grid cells were the same at the same latitudes and the geographic area of the grid cells at the same longitudes decreased with increasing latitude. According to each specific grid area, the fishing duration of the canvas stow net vessels per square kilometre was calculated for each month and the results were taken as the fishing intensity of the canvas stow net fishing vessels (Perera *et al.*, 2012; Murray *et al.*, 2013). Fig. 5 shows the spatial distribution of the fishing intensity of canvas stow net vessels in each production month of 2018 in the East China Sea and the Yellow Sea.

Discussion

This study was based on the 2018 ship position records of the vessels belonging to 5 provinces (municipalities) along the East China Sea and the Yellow Sea. A range of $0.01^\circ \times 0.01^\circ$ was used as the cell size for the characteristic trajectory map. The number of ship positions, mode of the speed of the ship position and the mean value of the ship position vector deviation angle in each cell were used as the basis for each cell's 3 RGB channels. Trajectory maps were drawn for every valid operational voyage. A deep neural network model was used to determine the statuses of the classified canvas stow net vessel's operation voyage records. The DBSCAN density clustering algorithm was used to determine the operation position, thus, fishing duration based on operation position and the spatial distribution of the fishing intensity of the canvas stow net fishing vessels in the East China Sea and the Yellow Sea was extracted.

Some studies have proposed the use of BP neural network models to extract the voyage information of canvas stow net vessels to determine the operational statuses at each vessel position (Pei *et al.*, 2019). Due to the large difference in the number of positions in the different operation states of the canvas stow net fishing vessels, BP neural networks may not be suitable since they have a poor ability to discriminate the statuses with a

Table 1. Production statistics of the canvas stow net fishing vessels in the East China Sea and the Yellow Sea in 2018

Month	No. of stow net vessels	No. of voyages	No. of nets operated	Cumulative fishing duration
January	519	600	2126	232459 h
February	382	424	1677	201402 h
March	481	708	2803	324809 h
April	451	628	2528	402963 h
September	488	511	1952	247010 h
October	605	831	5349	567741 h
November	515	692	3245	549793 h
December	456	580	2416	368027 h
Total	1661	4974	22096	2894204 h

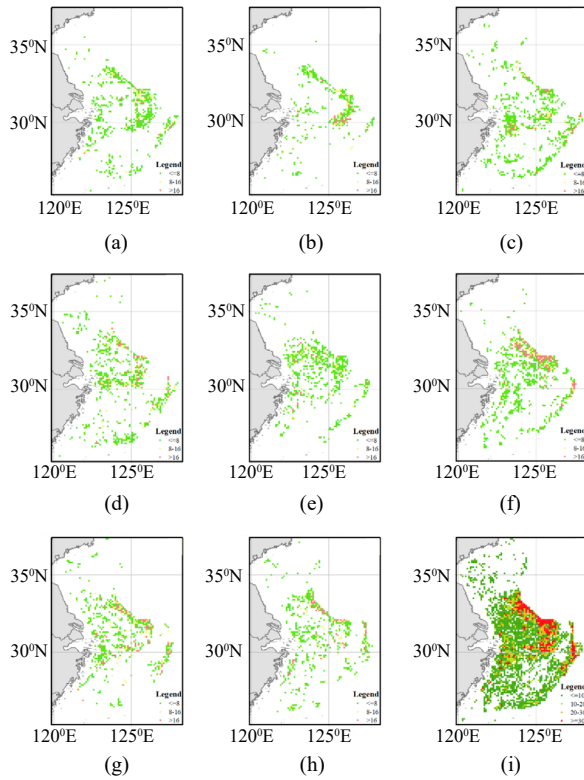


Fig. 5. Spatial distribution of fishing intensity in the annual and production months in 2018. (a-d): Distribution of fishing intensity from January to April; (e-h): Distribution of fishing intensity from September to December; (i): Spatial distribution of the annual fishing intensity in 2018

small number of samples and have a poor ability to extract the net position. Alternately the use of k-means clustering algorithms has also been proposed (Zen, 2021). This method does not classify the operational statuses of vessels but rather extracts the network position coordinates from the position in the fishing stage and estimates the fishing duration. K-means clustering algorithms may ignore the time-series relationship of the ship position, resulting in large deviations in the fishing times of some network extractions. In this study, a deep neural network model

was used to classify the four operational statuses of the canvas stow net fishing vessels with high classification accuracy. The DBSCAN density clustering algorithm was used to extract the network position, which was used to accurately extract the position of each net and calculate the fishing duration of each net. Table 2 shows the accuracy of extracting net and extracted fishing duration from three randomly selected operational voyages (each operation had 10 operational nets) using different methods and the performance of the different methods was compared.

Canvas stow nets are passive fixed nets with low technical difficulty and low energy consumption. Each canvas stow net fishing vessel carries several pairs of nets. After arriving the fishing area, nets are arranged to wait for the catch to enter. Fishing with canvas stow nets is strongly dependent on the force of the current. Each voyage usually arrives at the operation area before the start of the spring high tide (*i.e.* the first and 15th day of each lunar month) and arranges the nets. After the start of the spring low tide (5th and 20th day of the lunar month), the nets are retrieved in batches and returned according to the time. During the period of spring high tide, fishing vessels cruise among the nets and collect the catch from the cod ends every 12 h. When there are no operation tasks, the fishing vessels anchor. Canvas stow net fishing vessels' voyages usually last more than 5 days. The operation voyages of offshore fishing vessels were extracted from the BeiDou VMS position records and voyages with operation times exceeding 5 days were screened as valid trips. According to the longitude and latitude of the position record, $0.01^\circ \times 0.01^\circ$ grid squares were used as the cells and the position record number, speed mode and mean vector deviation angle in each cell were used as the three channel values of the corresponding cell to draw a characteristic trajectory map for each valid voyage. The geographical size of the $0.01^\circ \times 0.01^\circ$ grid in the WGS1984 coordinate system was equivalent to a 1×1 km grid (Perera *et al.*, 2012; Murray *et al.*, 2013). The use of a $0.01^\circ \times 0.01^\circ$ grid to merge the ship position records for the whole voyage can clearly depict the fishing vessel's

Table 2. Comparison of the accuracies of the extraction of the network coordinates and fishing duration with different methods

Methods	Voyages	Classification status accuracy	Cumulative fishing time (h)	No. of nets operated
BP Neural Network	Voyage A	89.39%	992	8
	Voyage B	89.83%	1010	9
	Voyage C	91.88%	1211	10
K-means	Voyage A	None	1082	8
	Voyage B	None	992	8
	Voyage C	None	894	7
DNN+DBSCAN	Voyage A	93.87%	1259	9
	Voyage B	95.23%	1387	10
	Voyage C	94.90%	1366	10

operational trajectory and highlight the trajectory features of the different fishing types (Zhang *et al.*, 2016b).

Normally, the sailing status and anchoring status accounted for more than 70% of the total ship position records in a voyage and the sailing status and anchoring status records that met the set threshold conditions accounted for more than 95% of the total ship position records for each voyage. By setting a threshold, the sailing status and anchoring status could be quickly and accurately extracted from the voyage records and the remaining position records could be divided into fishing status and net retrieving status by using the deep neural network model. By using the method of combining a threshold and a deep neural network, the comprehensive classification accuracy of the four operational statuses of the canvas stow net fishing vessels was 94.7%. The number of position records for the canvas stow net fishing vessels in different operational statuses varied greatly. There may be considerable differences in features among positions under the same operational statuses. Thus, the model overfits seriously if only the neural network is used to identify the different operational statuses. The accuracy of the models trained only with thresholds or other machine learning methods cannot meet the practical requirements.

In November 2018, the authors went onboard a canvas stow net fishing vessel in Zhejiang Province to learn the operation principles and modes. There was no uniform standard for the inlet areas that were fished with canvas stow nets, so it was difficult to quantify the water volume filtered through the net and the fishing intensity of each net. Therefore, we calculated the fishing duration of each net set in each voyage and took the average fishing duration per unit area as the quantitative standard of canvas stow net fishing intensity. This was based on the actual fishing method of the canvas stow net fishing vessel, which was then combined with the operational statuses classification results of the model. The first position record of the retrieving nets status of each net was taken as the coordinate position of that net. The first

position record of the fishing status that was closest to the net's coordinate position was taken as the beginning of fishing with the net. Thus, the net fishing duration was calculated. The fishing duration of all nets in the $0.1^\circ \times 0.1^\circ$ grid in the WGS1984 coordinate system was calculated for each month and the average fishing duration per square kilometre was calculated to obtain the spatial distribution of canvas stow net fishing intensity.

By analysing the spatial distribution of the canvas stow nets fishing intensity for each month of 2018, it was found that the areas with high fishing intensities were mostly concentrated in the waters within 100 nautical mile (nm) of the shore. The continental shelf of China extends farther and the sea bed slope increases gradually. Additionally, the average depth of the East China Sea is 370 m, while the average depth of the Yellow Sea is 44 m. Therefore, shallow waters are not suitable for canvas stow nets because they cannot completely stretch, so canvas stow net fishing operations are mostly concentrated in far offshore areas.

The distribution of fishing intensity in each month was analysed individually. The distribution of fishing intensity in January and February was similar, but the fishing intensity in February was the lowest. The 2018 China Spring Festival was on 16 February of the Gregorian calendar and most offshore fishermen chose to return home for the holiday, which may be the main reason that the lowest fishing intensity was in February. The distribution of fishing intensities in March and April were similar. The reason for the scattered distribution of high-intensity fishing grounds may be that towards the end of the production cycle, high-density fishing resources are distributed in a dispersed manner. In September, the distribution of sea areas with high fishing intensities was relatively dispersed, which may be because the stow net fishing vessels in the provinces (municipalities) along the East China Sea and the Yellow Sea were closed to fishing until 12:00 hrs on 15 September and hence the fisheries resources were relatively rich. However, the fishers' production periods were only within 15 days, so the spatial

distribution of the sea areas with high fishing intensities was relatively dispersed. In October, November and December, the fishing intensity was high and the distribution of high-intensity fishing areas was concentrated. The reason may be that 15 days after the end of the fishing moratoria, the areas with rich fisheries resources were relatively fixed and the fishing areas were relatively concentrated.

Canvas stow nets are passive fixed fishing methods and the fishing duration of every net becomes the most important parameter for evaluating fishing intensity. The longer the cumulative fishing duration in per unit area, the greater is the fishing intensity. When the fishing intensity is greater than the natural recovery capacity, excessive fishing of fishery resources leads to ecological degradation; when the fishing intensity is less than the natural recovery capacity, insufficient development of fishery resources leads to a waste of resources. Therefore, a reasonable allocation of fishing intensity is conducive for healthy and sustainable development of fishery resources.

In 2018, the fishing intensity of the canvas stow nets in the East China Sea and the Yellow Sea was widely distributed and the distribution of high-intensity fishing areas was more concentrated in the south of the Yellow Sea and the north of the East China Sea. Overall, the distribution of fishing intensities in all months highly correlated with the fishing off seasons and production cycles and the high-intensity fishing areas were mostly distributed between 50 and 200-350 nm offshore. When fishing operation is within 50 nm offshore, the input cost of fishing vessels is low. The water is deep in the range of 200-350 nm offshore, which is conducive for operation of canvas stow nets and the catches are abundant. Unreasonable fishing methods will have irreversible impacts on the conservation of marine fisheries resources, fisheries safety and the marine environment. In the long run, this will inevitably lead to the depletion of fisheries resources and degradation of marine ecosystems. Therefore, it is urgent to undertake quantitative supervision and management of fishing vessel operations. With the use of the BeiDou VMS data for analysis of spatial distribution of fishing intensity of canvas stow net fishing vessels, the fishery can be quantitatively monitored and managed. Our research will continue to improve the accuracy of identification and extraction, to better serve the management of marine fisheries resources and marine ecosystem protection.

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