Estimating catches with automatic identification system (AIS) data: a case study of single otter trawl in Zhoushan fishing ground, China

Wang Y.B.[1*]; Wang Y.[2]

Received: June 2014 Accepted: February 2015

Abstract

The sailing tracks of single otter trawl vessels were simulated using cubic hermite spline (cHs) interpolation method based on the automatic identification system (AIS) data of 6 sampled vessels that were fishing in the Zhoushan fishing grounds after the close of the fishing season from September 2012 to January 2013. The vessels' status (i.e. whether the vessels were fishing or not) were determined based on the integrated information of speed method and the simulated tracks. Generalized additive model (GAM) was built according to the logbook data of the 6 vessels in 2010, and then the GAM was applied to the AIS data of the same 6 vessels from September 2012 to January 2013 to estimate the monthly catches of these vessels in this period. The results show that the error of the simulated tracks increase with the increase in time interval, and the time interval of AIS data should be shorter than 30 minutes to prevent low accurate results. GAM can give viable estimates of catches when they do not greatly fluctuate over years. The step-by-step GAM analyses indicate that the factors, which affect catch, are ordered by their importance as date, sea surface salinity (SSS), latitude, sea surface temperature (SST), sea surface height (SSH) and longitude. This research is a new attempt for the study of fisheries resources in China using new data sources, which will be helpful for the improvement of fishery research in such data-poor countries as China.

Keywords: AIS, cHs interpolation, Sailing track, GAM

1 -School of Fisheries, Zhejiang Ocean University, No. 1 Haida south road, Zhoushan, 316022, China

2-Marine Fisheries Research Institute of Zhejiang, No. 28 sports road, Zhoushan, 316021, China

*Corresponding author's email: yingbinwang@126.com

Introduction

Stock assessment methods for quantifying the status of fishery resources are critical to effective fisheries management (Gobert, 1997; Aubone, 2003; Wang *et al*., 2011). Nowadays, stock assessment methods have become more and more complex because complex models are considered to give a clearer picture of stock status (Lapointe *et al*., 2012). Thus, more data from different sources have to be collected. Although only the traditional statistics, such as catch and fishing effort, cannot meet the needs of stock assessment, they are still one of the most important data that should be used in fisheries stock assessment (Wang *et al*., 2011; Anonymous, 2013).

In many countries, catch data reported by their fisheries management agencies are biased. They are under-reported by 100-500% in many developing countries and by 30-50% in developed countries (Zeller *et al*., 2007; Zeller *et al*., 2011). In China, the problem might be more serious for its over-reported catches have affected the trend of global catches (Watson and Pauly, 2001). Watson and Pauly (2001) pointed out that China's fishery data have distorted analyses provided by the FAO, and misled international fishery investment and management. In 2008, China revised the total fishery yield for 2006 based on the National Agriculture Census (NAC) of 2006 (FAO, 2010), and since 2009, China has treated the statistics as one of the most important works in fisheries management to improve the quality of data (FAO, 2012). In view of the efforts made by China, FAO did not separate the catches of China from those of other countries in the report of "The state of word fisheries and aquaculture 2012" (FAO, 2012). The quality of the reported catch data in China has improved a lot, but compared with the developed countries, the current data collection system in China is not sophisticated enough to ensure the data (catches) to be applied to stock assessment and management (Wang *et al*, 2015). Therefore, most of the fisheries in China still belong to data-poor fisheries, and other methods are needed to further improve the quality of fishery statistics.

Since the last 15 years, the vessel monitor system (VMS) has been considered by many fishery managers and scientists as an important technique for fisheries monitoring, management and surveillance (Chang, 2011). Now VMS is generally used to track vessel locations for fisheries which can be applied to deter illegal fishing activity (FAO, 1998; Wold *et al*., 2000) as well as to study the impact of fishing gear on the benthic communities (Piet *et al*., 2000; Deng, 2005; Hiddink *et al*., 2006 a, b; Hintzen *et al*., 2010). In addition, VMS data can also be used to provide independent estimates of fishing intensity (Gulin, 2005; Murawski *et al*., 2005; Mills *et al*., 2007), analyze the dynamics of fisheries (Kourti *et al*., 2005.), and describe fish distribution (Bertrand *et al*., 2005). It can be expected that many potential functions of VMS in fisheries studies will be developed.

In 2008, Zhejiang became the first province in China that installed AIS on fishing vessels. It is required that fishing vessels with main engine power larger than 44kW install AIS, and those with main engine power larger than 136kW install the terminal equipment of satellite position information. AIS is an automatic tracking system used on ships for identifying and locating vessels by electronically exchanging data with other nearby ships and AIS base stations. It can provide essential information about the sailing of fishing vessels, including the vessel's name, position (longitude and latitude), speed, navigation heading, date and time. Although VMS and AIS are quite different on the technical level, sometimes VMS is used as an informal synonym for AIS, because both of them can be applied to marine oversight and navigation. In China, AIS only plays a role in monitoring or surveying the illegal fishing activities when the fishing season is closed (each year from June 1st to September 15th, the otter trawls are forbidden to fish in the East China Sea) and for safety command when there is extreme weather conditions. It has not been used as an assistant tool, like the VMS does in some developed countries, in the research of fisheries science.

Both AIS and VMS are powerful instruments. In China, the VMS data consists of two parts: AIS data and maritime satellite data. Because the cost of maritime satellite is high, the recording frequency of maritime satellite data is low. Therefore, the VMS data mainly come from AIS. However, neither AIS nor VMS can provide the catch, which is the key information in stock assessment as mentioned above. If the information, including catch data, from logbooks can be combined with the AIS data, the usefulness of AIS can be increased. The spatial distribution of catch, effort and stocks at high resolution can be explored, and the fishing activity that cannot be clearly figured out from AIS data may be verified based on logbooks (Palmer and Wigley, 2009; Gerritsen and Lordan, 2011).

The Zhoushan fishing grounds, located in the East China Sea, is the largest near-shore fishing grounds in China (Fig. 1). Mainland rivers (including the Yangtze River) continually flow into the East China Sea, which bring a large amount of nutritive salts into Zhoushan fishing grounds and its adjacent waters. The favorable geographical and hydrological conditions make this sea area a suitable habitat for fish reproduction, growth, feeding, and overwintering (Yu, 2011; Wang *et al.*, 2012). Thus, it is one of the most important fishing areas in China, and over thousands of vessels are fishing in this area, which makes it also one of the most representative fishing zones in China.

In this paper, we firstly judge the status of every single otter trawl vessel fishing in the Zhoushan fishing grounds, i.e. whether a vessel is fishing, steaming, or inactive based on AIS data. Then, we build a generalized additive model (GAM) based on the data of logbooks and environmental factors, from which we estimate the monthly catch of the vessels. Thus, the fishing behavior of the otter trawl vessel will be identified and the catches will be estimated independent of the traditional statistical data. These will be useful for the improvements of fisheries stock assessment and fisheries management under the data-poor conditions in China.

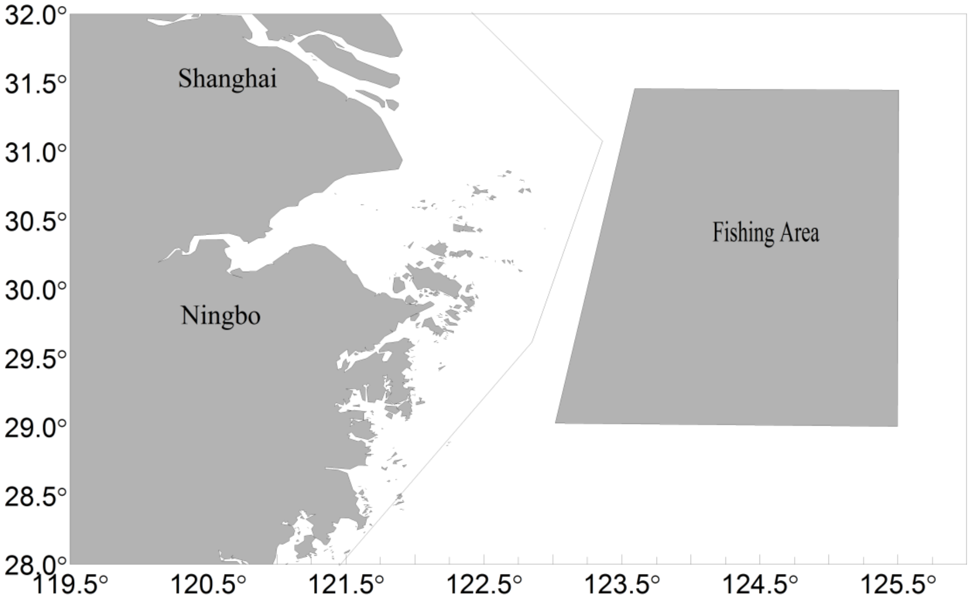

Figure 1: Fishing area of the six sampled single otter trawl vessels.

Materials and methods

The AIS data of 6 single otter trawl vessels from September 2012 to January 2013 were obtained from the monitoring center of Ocean and Fisheries Bureau of Zhoushan. The data set includes longitude, latitude, speed, navigation heading, date and time for each vessel. The dates are standardized to 360 days. Over 3000 data can be received for each vessel per month, and totally we obtained about 100,000 sets of data for the 6 vessels.

The data that come from the logbooks are also used, which can not only provide catches but also serve as the verification of vessels' fishing status deduced from the AIS data. Logbook data of those 6 commercial single otter trawl vessels were recorded in each month of 2010 (except when the fishing season was closed) and from September 2012 to January 2013 when the vessels were out at sea. We paid the fishermen who completed the logbook to improve the accuracy of the data. One logbook page typically corresponded to a single fishing day, providing a record of the catch, time, latitude, and longitude of each shooting and hauling the net per day as well as commercial species-specific catch and total catch in weight. The single otter trawls were primarily fishing in the area of 29.00°N–31.33°N and 122.50°E–125.30°E (Fig. 1).

Usually the AIS data are not sent back to the base stations in accordance with the fixed frequency. Sometimes data are received every few seconds, but sometimes more than half an hour apart. When the time interval between two registration points is short, straight lines can be used to describe the sailing track. However, when the time interval is large, the straight line will not be viable since the headings of the vessel on the two successive registration points are not in the same direction (Hedin *et al*., 1996; Jeffrey *et al*., 2001; Hijmans *et al*., 2005; Tremblay *et al*., 2006; Hedger *et al*., 2008). Thus, we used cubic Hermite spline (cHs) interpolation method for the estimation of sailing tracks. It can pass through all the registration points, and use more information (like heading and speed) at the same time, which will estimate the sailing tracks with less deviation (Hintzen *et al*., 2010). The cHs method is based on four polynomials and it considers heading and speed as two points. Its interpolation curve passes all the data points, and constructs a simulative trajectory. (For more detailed descriptions, refer to Hintzen *et al*. (2010) and Wang *et al*. (2015).

When the sailing tracks are determined, we still cannot clearly know the fishing status (i.e. whether the vessel is dragging or not) until some features or the speed range of fishing activity are known. It is important to know this to avoid assigning catches or effort to locations where the vessel was not actually engaged in fishing (Gerritsen and Lordan, 2011). We firstly used the vessels' speeds coming from AIS to detect the fishing activity (Eastwood, 2007; Mullowney and Dawe, 2009; Lee *et al*., 2010). But sometimes the speed method may underestimate a vessel's activity, especially in the case of long intervals between data. Thus we also relied on the fishing features of the otter trawl vessels at the same time to judge their dragging behavior. Generally speaking, when the single otter trawls are fishing, they will show certain features, i.e. they drag back and forth within a certain range when they are fishing. Then, if the sailing tracks, fishing features and fishing speeds are estimated with less deviation, we will get more accurate spatial distribution characteristics of fishing behaviors. At last, the status of vessels are also validated by checking the records in logbooks (Palmer and Wigley, 2009). The percentage frequency distributions of AIS speed and the corresponding records in the logbooks are compared to determine whether and when a vessel is fishing.

With the criteria for judging the characteristics of fishing status, we can tell the locations where the net is shot and hauled. Then we build a GAM to predict the monthly catch total based on the AIS and the environmental data. Catch is log-transformed with errors being assumed to be normally distributed in the GAM (Tian *et al*., 2009; Wang *et al*., 2012):

$$\ln(cacth) = s(date) + s(trawling\ \ time) + s(longitude) + s(latitue) + s(SST) + s(SSS) + s(SSH) + \varepsilon$$
(1),

where *s* is the spline smoother function, and the variables in the brackets are the factors that may have effects on catch (Wang *et al*., 2012). Analysis of deviance for the above GAM will be done to screen the optimized model. By using the optimized GAM we estimate the catches of the 6 otter trawl vessels from September 2012 to January 2013 using the AIS data of the 6 vessels in 2010 and the corresponding environmental data that come from the Coriolis program of EU (http://www.coriolis.eu.org/) and Colorado Center for Astrodynamics research (http://eddy.colorado.edu/ccar/ssh/nrt_global_grid_viewer). The spatial resolution was $1^{\circ} \times 1^{\circ}$. To verify the accuracy of the estimates, we compared the estimated catch with the recorded catches in logbooks. R (Version 3.1.0) was used for the analyses in the research.

Results

When the time interval increases from 10 minutes to 120 minutes the difference between a real track and the simulated track also increases. Fig. 2 indicates that the relative difference between the real track and the estimated track increases from about 5% to about 25% when the time interval increases from 10 minutes to 30 minutes. When the time interval is longer than 30 minutes, the relative difference will exceed by 30%, which may result in an unacceptable cHs simulated track.

The frequency distribution of speed recorded by AIS is plotted as Fig. 3, and the frequency of speed at 2.5-5.0 kn is about 15%. According to the features of the sailing behavior, when a vessel is fishing, it will go back and forth in an area frequently. It will not leave for another area until the catch becomes low. The tracks in Fig. 4 can be separated into two parts: dragging and steaming. A single line on the left side, which is not overlapped, represents the track when the vessel is steaming. When most tracks overlap in the rectangle part it means the vessel goes back and forth frequently indicating the vessel is dragging.

Fig. 5 shows the frequency distribution of speed recorded by logbooks. According to the logbook data, the speed recorded during the periods of fishing mainly concentrates in the interval of 2.5-5.0 kn (Fig. 5). Comparing the results of Fig. 3 and Fig. 5, we can infer that when speed is between 2.5 kn and 5.0 kn, a vessel can be considered as trawling. Furthermore, by using the sailing feature of the vessels as auxiliary information (Fig. 4), we can finally determine the status of a vessel at a certain location and a certain time.

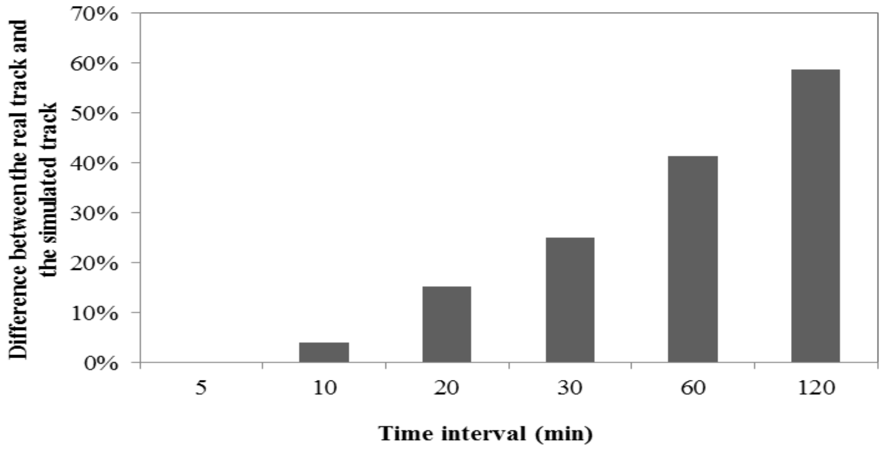

Figure 2: Differences between a real track and the simulated track for different time intervals.

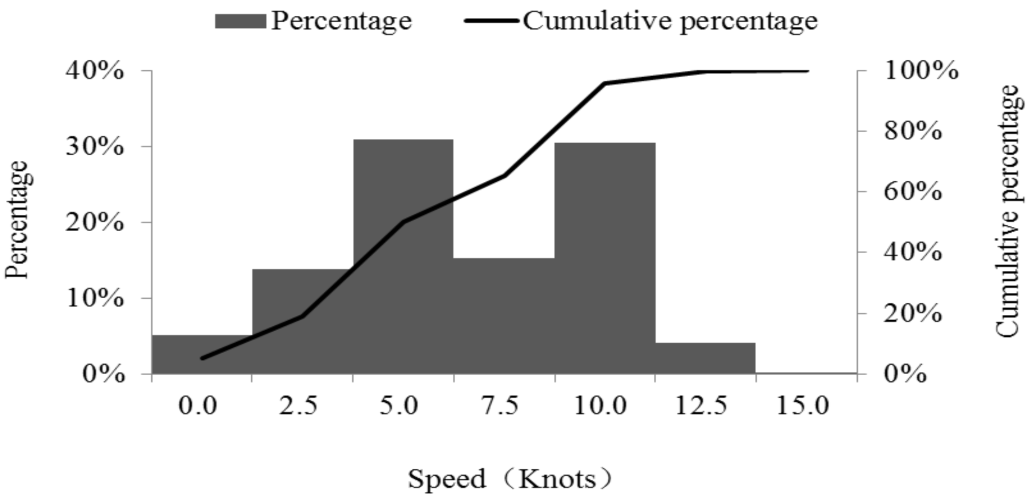

Figure 3: Frequency (bars) and cumulative percent (line) distributions of the vessel's speed obtained from AIS.

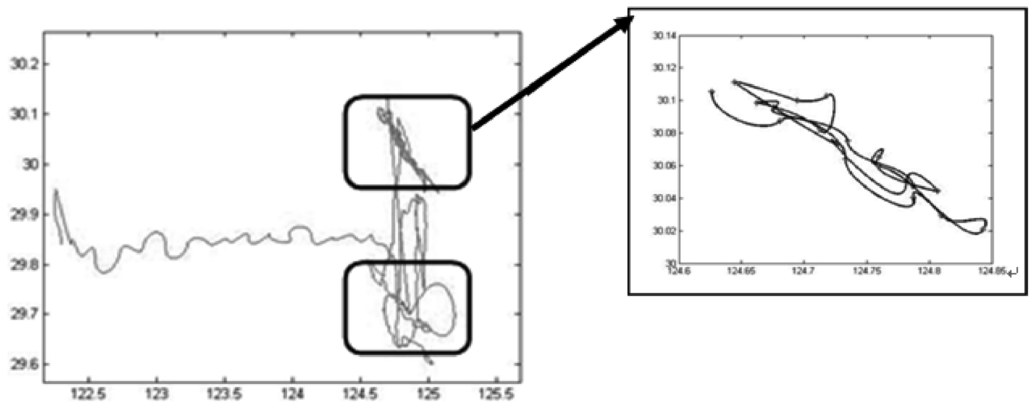

Figure 4: Features of the vessel's track when dragging and steaming.

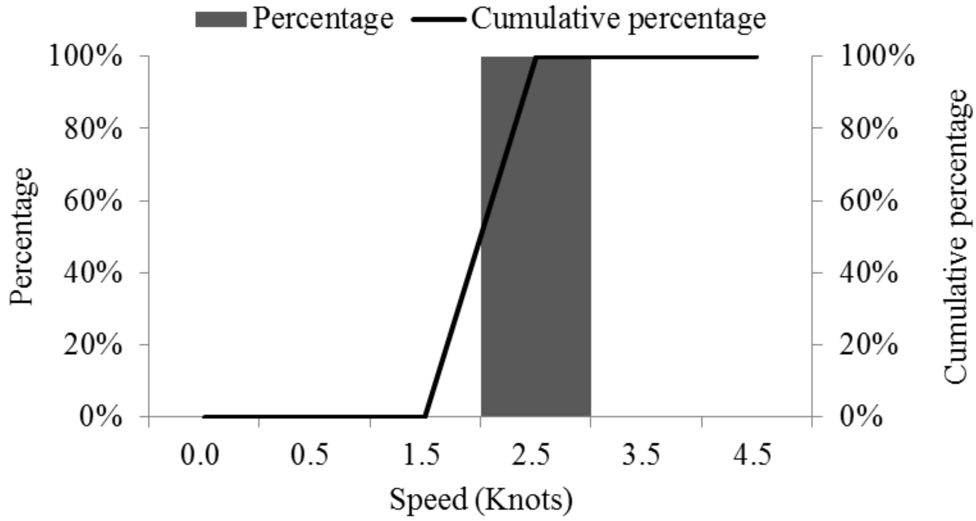

Figure 5: Frequencies (bar) and the cumulative (line) distribution of vessel's speed obtained from logbook.

Table 1 shows the results of analysis of deviance of Eq. (1). The rate of deviance explanation for catch is 53.80%. Our results of step-by-step GAM analyses suggests that the factors which affect catch can be ordered according to the importance as follows: date, sea surface salinity (SSS), latitude, sea surface temperature (SST), sea surface height (SSH), longitude and duration of hauling. For each factor, the explained deviance rate is 35.40%, 7.30%, 4.40%, 3.00%, 1.80%, 1.40% and 0.50%, respectively.

Table 1: Analysis of deviance for GAM fitted to the catch data.

Model factors	Residual degree of freedom	Residual deviance	Deviance variation	Cumulative deviance explanation rate	Akaike information criterion (AIC)	F test Pr (F)	Chi-square test Pr (Chi)
Initial status	1370	564.9			2679		
Date	1361	364.8	300.1	35.40%	2097	0.000	0.000
Hauling duration	1356	362.2	2.6	35.90%	2096	0. 267	0. 267
Latitude	1348	337.4	24.8	40.30%	2016	0.000	0.000
Longitude	1343	329.3	8.1	41.70%	1993	0.000	0.000
SSS	1341	288.1	41.2	49.00%	1813	0.000	0.000
SST	1338	271.0	17.1	52.00%	1734	0.000	0.000
SSH	1328	260.8	10.2	53.80%	1702	0.000	0.000

Note: Pr (F) is the *p*-value from an ANOVA F-ration test between the model for that row and the model for the previous row; Pr (Chi) represents the score that used to evaluate the non-linear contribution of non-parametric effects, and the smallest value meant the best.

The F test indicates that all the factors significantly correlate with catch (p<0.05) except for the duration of hauling (p=0.267) (Table 1). As the factors add to the GAM the AIC value continuously decreases, indicating an increase in the goodness of fit of the model. Therefore, we retained all the factors except for the duration of hauling, and the final optimized GAM becomes:

$$\ln(cacth) = s(date) + s(longitude) + s(latitue) + s(SST) + s(SSS) + s(SSH) + \varepsilon \quad (2),$$

where PCf = 0.54, suggesting the optimized GAM has good fit.

Fig. 6a shows that date has great impact on the catch. Before the closing of the fishing season the catch increases with date, and reached the maximum value in September. After the end of the fishing season the catch decreases with date. Catch inversely decreases with the increase in latitude (Fig. 6b), and increases with the increase in longitude (Fig. 6c). Figs. 6d, 6e and 6f show the relationships between environmental factors and catch. Among these environmental factors, the SSS has the greatest impact on catch. When SSS increases, the catch also increases. The suitable SST is in the range of 6-29 °C, and catch generally decreases with the increase in SST. The range that SSH can affect catch is between -0.2 m and 0.2 m, but it has less effect on catch in comparison with the other factors.

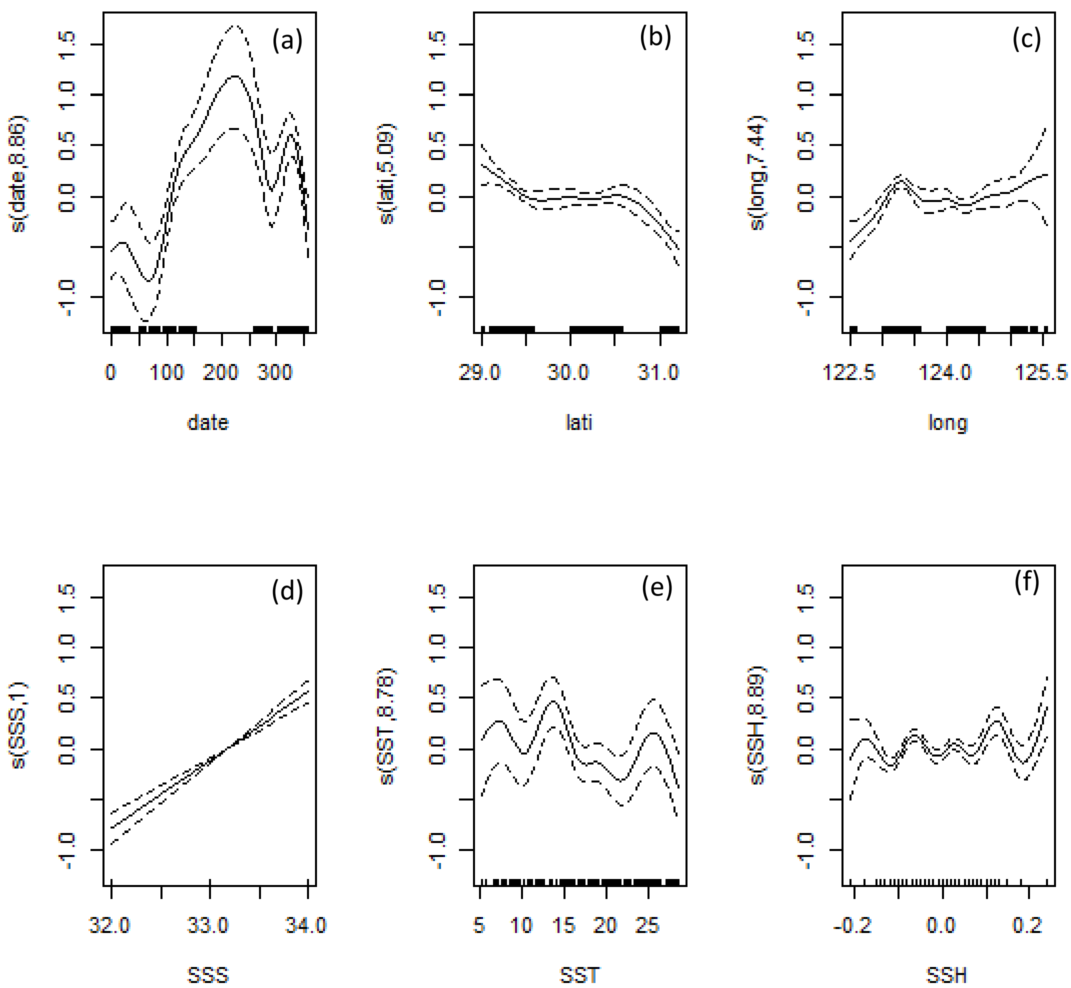

Figure 6: Effect of date (a), latitude (b), longitude (c), Sea Surface Salinity (SSS) (d), Sea Surface Temperature (SST) (e), Sea Surface Height (SSH) (f) on catch.

From Fig. 7 we can see that the estimated catches from Eq. 2 are similar to those recorded in the corresponding logbooks in September and October, and the relative estimate errors (*REEs*) are 29% and 24%, respectively. While, the *REE* of catch in November is about 32%, meanings the catch in November is significantly underestimated. The reason is possibly that the fishing areas in 2012, which are mainly concentrated at 31°00′-31°30′N, 124°00′E-125°00′E, have moved further to the northern part as compared to those in 2010. Additionally, in November 2012 the catch of swimming crab (*Portunus trituberculatus*) is much higher than ever in this area (Anonymous, 2013; Private communication with Prof. Ji Zheng). In December, GAM performs well and the *REE* of the estimated catch is about 20%. While in January 2013, the *REE* of the estimated catch increases to about 26%.

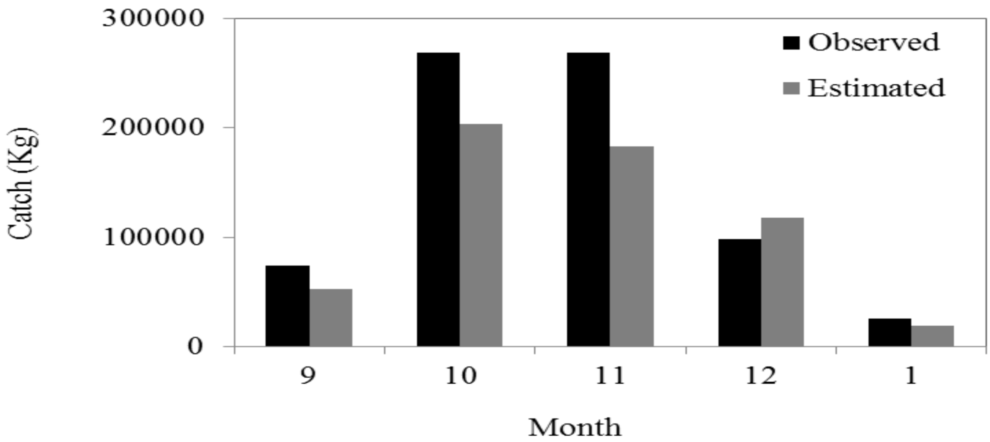

Figure 7: The observed and the estimated monthly catches from GAM of the sampled single otter trawl vessels from September 2012 to January 2013.

Discussion

Estimation of sailing tracks is one of the important applications of AIS or VMS data, and several methods have been proposed for this (Hintzen *et al*., 2010; Russo *et al*., 2011). In this study, we determined the sailing track using cHs interpolation method to accurately judge the spatial and temporal characteristics of dragging, which belongs to the second type of usage of trawl track summarized by Hintzen *et al*. (2010). Thus, the relationship between space/time and catch are established. However, the sailing track cannot be directly used to indicate whether a vessel is fishing or not, which is a key factor to estimate fishing effort and catch (Bastardie *et al*., 2010). Speed method is firstly used to classify fishing and non-fishing activities (Eastwood, 2007; Mullowney and Dawe, 2009; Lee *et al*., 2010), and the data from AIS have the same locations as those recorded on logbooks. However, because AIS records larger areas than logbooks, if we just rely on speed, we may underestimate a vessel's activity. For instance, sometimes when a vessel slows down after steaming, its speed may be between 2.5 kn and 5.0 kn. This situation may be easily treated as fishing if we only read the speed from AIS. The fishing feature of the single otter trawl (sailing back and forth) can also be used to determine whether the vessel is fishing or not (Fig. 3). Therefore, the accuracy of the determination of fishing status of the vessel can be improved by combining the above two methods. The fishing feature may be easily judged for the active fishing gears like trawls, while for the passive fishing gear, like gill net or stow net, etc., the feature is not obvious. So, other features have to be considered for these gears to improve the accuracy.

The results of the estimation of monthly catch indicated that date is the most important factor influencing catch among other factors (Table 1), and the highest catch appeared in the month following the closed fishing season, which is in close agreement with the research results of Wang *et al*. (2012).

The high catch may indicate the increased abundance. This may owe to the closed fishing season, which makes the fisheries resources recover temporarily. Duration of hauling is not significantly correlated with catch, which is inconsistent with previous studies (Wang *et al*., 2012).

The criterion that is frequently used to classify the vessel's fishing and non-fishing activities is speed (Eastwood, 2007; Mullowney and Dawe, 2009; Lee *et al*., 2010). Unlike the previous study that totally used logbooks, in this study we used both the logbook and AIS data to determine the fishing status by analyzing the sailing speed and trawling feature of the vessel. The range of the duration of hauling determined by AIS data is from 2.5 to 5 hours, which is consistent with the observation that the speed of bottom trawler is usually lower than 3.6 kn (6.5 Km/h) (Murawski *et al*., 2005) and the speed of fishing activities falls within a narrow range (Palmer and Wigley, 2009). But this is narrower than those based on logbooks (from 0.5 to 6 hours). The narrow range results in similar catches, and then their correlation may not be significant. Although the range became small, it still covers the optimal range for catch and retention (Wang *et al*., 2012). The spatial factors also affect catch amounts (Figs. 6b and 6c). Catch decreases with increasing latitude and decreasing longitude. Catch is higher in the southern area, most likely because of the influence of the Taiwan warm current and the upwelling caused by complex submarine topography (Wang *et al*., 2012). A greater number of fish are captured in the eastern region of the study area, most likely because of declines in abundance in coastal and inshore waters because of overfishing, pollution, and habitat loss (Wang *et al.*, 2012). Environmental factors are usually important when GAM is applied to fisheries research (Zhou *et al*., 2004; Walsh *et al*, 2005; Chen and Tian, 2006; Tian *et al*., 2009). The catches fluctuated under the impacts of SST and SSH (Figs. 6e and 6f), indicating the seasonal variations in catch is obvious. Catch increases with increasing SSS, which is consistent with the effects of longitude since the SSS in the eastern region of the study area is usually high (the west region of the study area is affected by the diluted water of Yangtze River).

Acknowledgements

This work was supported by the National Natural Science Foundation of China (grant number 40801225 and 31270527); the Natural Science Foundation of Zhejiang Province (grant number LY13D010005); Young academic leaders climbing program of Zhejiang Province (grant number pd2013222). We wish to thank Ji Zheng, who gave us great help in renting sampled vessels and collecting the AIS data.

References

Anonymous, 2013. China fishery statistical yearbook. China

Agriculture Press, Beijing.

Anonymous, 2013. Does catch reflect abundance? *Nature,* 494, 303–306.

Aubone, A., 2003. Threshold for sustainable exploitation of an age-structure fishery. *Ecological Modelling*, 173, 95–107.

Bastardie, F.J., Nielsen, R., Ulrich, C., Egekvist. J. and Degel H., 2010. Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite recorded vessel geo-location. *Fisheries Research,* 106, 41–53.

Bertrand, S., Burgos, J.M., Gerlotto, F. and Atiquipa, J., 2005. Levy trajectories of Peruvianpurse-seiners as an indicator of the spatial distribution of anchovy (*Engraulis ringens*). *ICES Journal of Marine Science*, 62, 477–482.

Chang, S., 2011. Application of a vessel monitoring system to advance sustainable fisheries management—Benefits received in Taiwan. *Marine Policy,* 35, 116–121.

Chen, X.J. and Tian, S.Q., 2006. Temp-spatial distribution on abundance index of nylon flying squid *Ommastrephes bartrami* in the Northwestern Pacific using generalized additive models. *Journal of Jimei University,* 11, 295–300.

Deng, R., 2005. Can vessel monitoring system data also be used to study trawling intensity and population depletion? The example of Australia's northern prawn fishery. *Canadian Journal of Fisheries and Aquaculture Science,* 62, 611–622.

Eastwood, P., 2007. Human activities in UK offshore waters: an assessment of direct, physical pressure on the seabed. *ICES Journal of Marine Science*, 64, 453–463.

FAO., 1998. Fishing operations. Vessel monitoring systems. FAO technical guidelines for responsible fisheries–Fishing Operations–1 Suppl. 1–1. Vessel Monitoring Systems. Rome. FAO. pp.4–10.

FAO., 2010. The state of world fisheries and aquaculture 2010. FAO Fisheries and Aquaculture Department, Rome. pp.5–6.

FAO., 2012. The state of world fisheries and aquaculture 2012. FAO Fisheries and Aquaculture Department, Rome. pp.6–7.

Gerritsen, H. and Lordan, C., 2011. Integrating vessel monitoring systems (VMS) data with daily catch data from logbooks to explore the spatial distribution of catch and effort at high resolution. *ICES Journal of Marne Science,* 68, 245–252.

Gobert, B., 1997. Evaluating mortality using length-frequency data when growth parameters are poorly known. *Naga*, *the ICLARM Quarterly,* 20, 46–51.

Gulin, D., 2005. Fishing vessels monitoring systems. In: ELMAR, 2005. The 47th international symposium, 8–10 June, 2005, Zadar, Croatia; 2005. pp. 369–372.

Hedger, R.D., Martin, F., Dodson, J.J., Hatin, D., Caron, F. and

Whoriskey, F.G., 2008. The optimized interpolation of fish positions and speeds in an array of fixed acoustic receivers. *ICES Journal of Marine Science,* 65, 1248–1259.

Hedin, A.E., Fleming, E.L., Manson, A.H., Schmidlin, F.J., Avery, S.K., Clark, R.R., Franke, S.J., Fraser, G.J., Tsuda, T., Via, F. and Vincent, R.A., 1996. Empirical wind model for the upper, middle and lower atmosphere. *Journal of Atmospheric and Solar-Terrestrial Physics,* 58, 1421–1447.

Hiddink, J.G., Jennigs, S. and Kaiser, M.J., 2006a. Indicators of the ecological impact of bottom-trawl disturbance on seabed communities. *Ecosystems,* 9, 1190–1199.

Hiddink, J.G., Jennigs, S., Kaiser, M. J., Queiros, A.M., Duplisea, D.E. and Piet, G.J., 2006b. Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. *Canadian Journal of Fisheries and Aquaculture Science,* 63, 721–736.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A., 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology,* 25, 1965–1978.

Hintzen, N.T., Piet, G.J. and Brunel, T., 2010. Improved estimation of trawling tracks using cubic Hermite spline interpolation of position registration data. *Fisheries Research*, 101, 108–115.

Jeffrey, S.J., Carter, J.O., Moodie, K.B. and Beswick, A.R., 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modeling and Software*, 16, 309–330.

Kourti, N., Shepherd, I., Greidanus, H., Alvarez, M., Aresu, E., Bauna, T., Chesworth, J., Lemoine, G. and Schwartz, G., 2005. Integrating remote sensing in fisheries control. *Fisheries Management and Ecology,* 12, 295–307.

Lapointe, G., Mercer, L. and Conathan, M., 2012. Counting fish 101, an analysis of fish stock assessments. *Center for American Progress*, 9(2012), 15.

Lee, J., South, A.B. and Jennings, S., 2010. Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data. *ICES Journal of Marine Science,* 67, 1260–1271.

Mills, C.M., Townsend, S.E., Jennings, S., Eastwood, P.D. and Houghton, C.A., 2007. Estimating high resolution trawl fishing effort from satellite-based vessel monitoring system data. *ICES Journal of Marine Science* 64, 248–255.

Mullowney, D.R. and Dawe, E.G., 2009. Development of performance indices for the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery using data from a vessel monitoring system. *Fisheries Research,* 100, 248–254.

Murawski, S.A., Wigley, S.E., Fogarty, M.J., Rago, P.J. and Mountain, D.G., 2005. Effort distribution and catch patterns adjacent to temperate MPAs. *ICES Journal of Marine Science,* 62, 1150–1167.

Palmer, M.C. and Wigley, S.E., 2009. Using positional data from vessel monitoring systems to validate the logbook-reported area fished and the stock allocation of commercial fisheries landings. *North American Journal of Fisheries Management,* 29, 928–942.

Piet, G.J., Rijnsdorp, A.D., Bergman, M.J.N., van Santbrink, J.W., Craeymeersch, J. and Buijs, J., 2000. A quantitative evaluation of the impact of beam trawling on ben-thic fauna in the southern North Sea. *ICES Journal of Marine Science,* 57, 1332–1339.

Russo, T., Parisi, A. and Cataudella, S., 2011. New insights in interpolating fishing tracks from VMS data for different métiers. *Fisheries Research,* 108, 184–194.

Tian, S.Q., Chen, X.J., Chen, Y., Xu, L.X. and Dai, X.J., 2009. Standardizing CPUE of *Ommastrephes bartramii* for Chinese squid-jigging fishery in Northwest Pacific Ocean. *Chinese Journal of Oceanography Limnology,* 27, 729–739.

Tremblay, Y., Shaffer, S.A., Fowler, S. L., Kuhn, C.E., McDonald, B.I., Weise, M.J., Bost, C., Weimerskirch, H., Crocker, D.E., Goebel, M.E. and Costa, D.P., 2006. Interpolation of animal tracking data in a fluid environment. *Journal of Experimental Biology,* 209, 128–140.

Walsh, W.A., Ito, R.Y., Kawamoto, K.E. and McCracken, M., 2005. Analysis of logbook accuracy for blue marlin (*Makaira nigricans*) in the Hawaii-based longline fishery with a generalized additive model and commercial sales data. *Fisheries Research,* 75, 175–192.

Wang, Y.B., Zheng, J. and Wang, Z., 2011. The effects of distorted fishery statistical data on fisheries stock assessment. *Chinese Journal of Oceanography Limnology,* 29, 270–276.

Wang, Y.B., Zheng, J., Wang, Y. and Zheng X.Z., 2012. Spatiotemporal factors affecting fish harvest and their use in estimating the monthly yield of single otter trawls in Putuo district of Zhoushan, China. *Chinese Journal of Oceanography Limnology,* 30, 580–586.

Wang, Y.B., Wang, Y. and Zheng, J., 2015. Analyses of trawling track and fishing activity based on the data of vessel monitoring system (VMS): the single otter trawl vessels in Zhoushan fishing ground as a case. *Journal of Ocean University of China*, 14, in press.

Watson, R. and Pauly, D., 2001. Systematic distortions in world fisheries catch trends. *Nature*, 414, 534–536.

Wold, C., Arrigotti, S., Johnson, L., Horn, A.V. and White, L., 2000. A review of monitoring, control, and surveillance programs of international fisheries agreements with a view to the IWC's inspection and observation scheme of the RMS. International Environmental Law Project, Northwestern School of Law of Lewis & Clark College, 2000.

Yu, C.G., 2011. Zhoushan fishing ground fishery ecology. Science Press, Beijing, 2011.

Zeller, D., Booth, S., Davis, G. and Pauly, D., 2007. Re-estimation of small-scale fishery catches for U.S. flag-associated island areas in the western Pacific: the last 50 years. *Fishery Bulltein*, 105, 266–277.

Zeller, D., Rossing, P., Harper, S., Persson, L., Booth, S. and Pauly, D., 2011. The Baltic Sea: estimates of total fisheries removals 1950–2007. *Fisheries Research*, 108, 356–363.

Zhou, S.F., Fan, W., Cui, X.S. and Cheng, Y.H., 2004. Effects of environmental factors on catch variation of main species of stow net fisheries in East China Sea. *Chinese Journal of Applied Ecology*, 15, 1637–1640.