An Assessment of the Potential for Mapping Fishing Zones off the Coast of Ghana using Ocean Forecast Data and Vessel Movement

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Abstract

This research assessed the feasibility of mapping potential fishing grounds off the coast of Ghana using vessel trajectories and speeds as proxies for identifying migration patterns and fishing behaviour of inshore trawling vessels. The methods involved the extraction of data from Satellite Automatic Identification System comprising position and speed of the vessel from exactEarth Shipview. Daily oceanographic parameters i.e. sea surface temperature, sea surface height, sea surface salinity, and the current velocity between August 2015- January 2016 were obtained from Copernicus (www.marine.copernius.eu). Speed ranges and trajectories indicate that, the vessels steamed between 6.9 to 7.5 knots and fish aggregation mostly occurred closer to the shore predicated on favourable environmental ocean conditions. It was observed that the vessel depicted steaming behaviour in this study, characteristic of a recreational vessel with high speed, moving in straight paths rather than a trawling vessel whose movement occurs in slower and erratic trajectory patterns. The findings strongly suggest that the fishermen operating this trawl vessel have good knowledge of productive fishing grounds. The months with highest probability of catch aggregation were from October 2015 to December 2015, within the geographical locations of longitude -4° 2 ′ E and latitude 3.5° 6 ′ N. The highest probability of catch aggregation was observed in October 2015, probably due to upwelling that occurred during that month. It is concluded that, fishing efficiency of inshore trawling vessels in Ghana could be enhanced with maps indicative of probability of fish aggregation in the ocean.

Keywords: Marine fisheries, Potential Fishing Zones (PFZ), Vessel trajectories, Vessel speed, Catch per Unit Effort (CPUE), Automatic Identification System (AIS)

Introduction

Available scientific information indicates that the status of small pelagic fish stocks, particularly sardinella, are on the verge of collapse (Lazar *et al*., 2018). Annual fish landings have been on the decline for more than a decade primarily due to an open access regime, overfishing and overcapacity of fishing fleets (Fisheries Management Plan of Ghana, 2015). Illegal fishing activities also takes place in violation of the fisheries laws of the country because it provides high rate of economic return for the fishers and those who engage in the practice. The inefficiency of regulators to monitor or enforce the laws is attributed to low technical and financial capacity and poor fisheries governance structures in place (Afoakwa *et al*., 2018). Since no one is reporting catches of illegal fishers, their level of fishing cannot be accurately quantified. Therefore, reliable estimates of total fish landings cannot be guaranteed, undermining fish stock assessment records. These issues have weakened fisheries management measures directed at conserving fish stocks and ensuring their long-term sustainability for food security and employment generation.

The Government of Ghana is presently putting in place measures to reduce illegal fishing practices through several means including the strengthening of the fisheries regulation through legislative reforms and enforcement to impose sanctions on illegal fishers (Aheto, *et al.*, 2018). The introduction of new monitoring, control and surveillance (MCS) measures on Ghana-flagged vessels is also intended to provide information on real time position of fishing vessels at sea within the country's territory and neighbouring countries. Significant among the challenges

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is the lack of scientific and technical capacity to enforce the MCS measures for both the industrial and artisanal sectors. The use of nets of unapproved mesh sizes, dynamites, poisons and light for fishing and fishing in unapproved fishing grounds are major issues being addressed (Afoakwah *et al.*, 2018).

Fishers and stakeholders are being sensitized, amidst varying degrees of success, of the effects of these practices on the marine environment, fisheries resources and the sustenance of their fishery dependent livelihoods. One of the recent consequences of ineffective regulatory enforcement was the fisheries Yellow Card issued to Ghana in 2013 by the European Union (EU) as a result of illegal fishing practices in Ghana's waters (INTERPOL Environmental Security Sub-Directorate, 2014). Per the yellow card, Ghana was cautioned to put in place measures to forestall such illegal practices. The EU put in place this measure to improve the value of fishing activities as well as exported fish products. Presently, the Government of Ghana is putting in place measures to institute appropriate regulations and sanctions through the review of the Fisheries Act 625 of 2002, among others, to implement a closed season regime, strengthening monitoring and surveillance strategies by establishing the Marine Police Unit and the institution of management mechanisms and the introduction of supplementary livelihoods (Hen Mpoano, 2015).

The creation of such measures are steps in the right direction. Unfortunately, they do not address the full spectrum of mechanisms needed to address the problem of fishing illegalities at sea. The challenges are even more intense relative to monitoring or surveillance to combat illegal small-scale fisheries. The Monitoring, Control and Surveillance Division (MCSD) of the Fisheries Commission (FC) is under-resourced and the lack of MCS units are confounding challenges (Pramod, 2018). The high cost of acquiring a monitoring system is a major limitation although this is a requirement in the Fisheries Act of Ghana. Many accidents have also been reported at sea (Mbaga *et al.*,2008). Unfortunately, the weak monitoring services do not allow these fleets to communicate with land and in many cases, fishermen do not survive when in distress at sea (Mbaga *et al.*, 2008). Largely, monitoring has been limited to the industrial and tuna fishing fleets (Kwadjosse, 2009) which over the years have proven ineffective. The need to ensure a more comprehensive maritime security and improved surveillance over Ghana's fisheries resources by adopting technologically innovative means to monitor small fishing vessels is urgently needed.

Globally, vessel tracking technologies are providing opportunities to develop deeper insights into fishing activities and vessel movements both in national waters and on the high seas (McCauley *et al.*, 2016). A number of tracking systems exist, including Automatic Identification System (AIS) and Vessel Monitoring System (VMS). AIS is legally mandated by the International Maritime Organisation (IMO) for all fishing vessels of 500 gross tonnage and more to be fitted with transponders for tracking vessel trajectories (EU Dir 2011/15/EU). This could aid governments to track and assess the behaviour of vessels registered in their countries and foreign vessels poaching their territorial waters. This is also in compliance with the Safety of Life at Sea Convention (SOLAS) which expects vessels to ensure maximum safety at sea whiles their vessel positions are being tracked with little effort. AIS is a low-cost intervention compared to the VMS for tracking the trajectories of fishing vessels (Girard & Payrat, 2017). The technology could also be of immense benefit to fishers because locating fish in any fishing expedition is not an easy task and requires increased effort to achieve a successful fishing activity (Kamei *et al.*, 2014).

Therefore, technological innovations beyond the use of sonar and echo sounders to maximize fish catch and aid identification of areas of fish aggregations is crucial. The AIS technology reduces search time and cost of fishing by reducing effort through provision of timely and reliable forecasts based on earth observation and vessel trajectory data to locate sites of productive waters and areas conducive to fish aggregation (Santos, 2000).

This study being the first of its kind, made use of ocean forecast data to assess the feasibility of monitoring trajectories of fishing vessels and forecasting potential fishing zones in Ghanaian waters. The specific objectives were to document migration patterns and fishing behaviour of the investigated fishing vessel to predict potential fishing routes of inshore vessels and map potential fishing grounds off the coast of Ghana.

Materials and Methods

Determination of vessel trajectories and fishing behaviour

The study deplored the use of an inshore trawling vessel fitted with Advanced Class B Satellite Enabled AIS ABSEA transponder (with a Mobile Maritime Service Identifier Number: 627999980) at the Elmina fishing harbour (5°08’ 36’ N 1°32’ 24’ W), located in the Central Region of Ghana from August 2015-January 2016. Satellite Automatic Identification System (Sat-AIS) data comprising times of vessel operation, positions, and speed the fishing vessel studied, were extracted from exactearth Shipview for the Gulf of Guinea from August 2015 to January 2016. The Sat-AIS signals collected by a network of ground-based receivers at the ECOWAS Coastal and Marine Resources Management Centre, University of Ghana. A database was created using DOS command and Sqlite for the AIS data. These tools helped merge AIS navigational information such as latitude (lat), longitude (lon), speed over ground (sog), course over ground (cog). The data was initially filtered to exclude all duplicate pings. AIS positions were isolated and separated into several subsets based on time and geographical distances and then interpolated into unique trajectories. An algorithm was implemented to compute fishing speeds from the trajectories from the AIS observations. The detection of changes and frequency of speed of the vessel helped to determine the fishing or steaming behaviour of the vessel. The density of trajectories was then computed on a geographical grid at a spatial resolution of 0.1^{o} latitude by 0.1^{o} longitude to derive a presence/absence map of fished and non-fished areas. Bathymetric information of the area fished, and path travelled from the General Bathymetric Chart of the Oceans (GEBCO) website (www.gebco.net) within 1 nautical mile distance covering the extent of the Gulf of Guinea. The presence/absence map was used as a logical index to extract environmental data to setup the predicting model.

Defining optimal ranges for oceanographic parameters to mapping potential fishing zones

Daily oceanographic parameters i.e. sea

surface temperature (SST), sea surface height (SSH), sea surface salinity (SSS), geostrophic current (derived from u- and v- components of surface velocity) were obtained from Copernicus (www.marine.copernius.eu) from August 2015-January 2016. These parameters were used as proxies for determining the optimal conditions where fishes aggregate to feed. The potential fishing zone maps are created as a response or the output (y) of the combined effects of oceanographic and fish catch data, as follows:

$y = \alpha + f\,(SST, SSH, UV, SSS) + catch + \varepsilon$

where y is the response or output variable, α is a constant and ε is the error term.

The outputs allow for an analysis of the visual interpretation of potential fishing zones that are created, as a result.

Results

Fishing vessel behaviour

The trawling vessel operated within the central portions of the coastal waters of Ghana (Figure 1). It confirmed that the vessel operated throughout the study period within Ghana's coastal waters at a depth of 30-100m depth at geographical location of latitude 5.3° 4.7' N and longitude -1.5° 0.2' E.

The speed profile of the trawling vessel showed a bimodal distribution (Figure 2). The speeds ranged between 2 to 8 knots. The vessel travelled mostly within a speed range 6.9 to 7.5 knots at a mean speed of 7 knots. The trawling vessel sped continuously within 6.9 to 7.5 knots and maintained a specific course during that period.

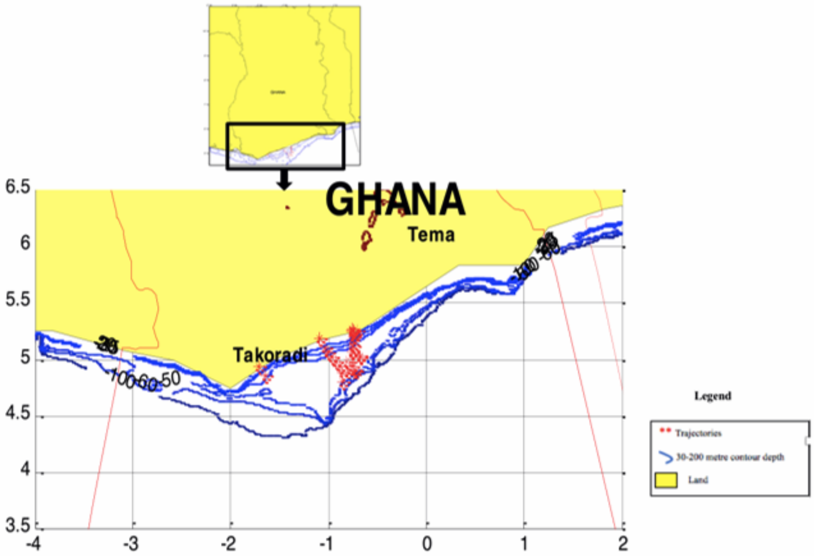

Figure 1: Vessel trajectories and movement patterns of the vessel from August 2015- January 2016

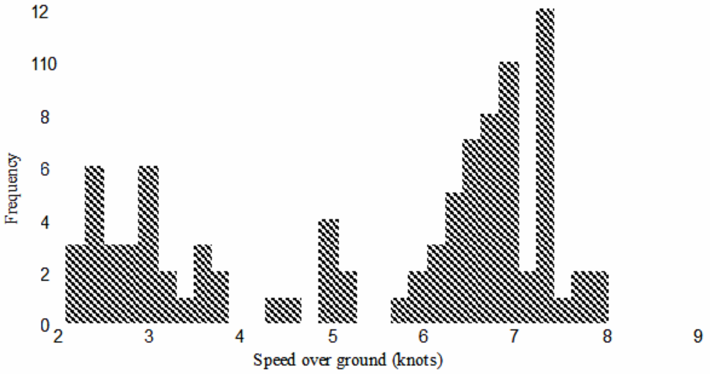

Figure 2: Frequency distribution of speed profile of the inshore vessel from August 2015 to January 2016

Optimal range of oceanographic parameters for fish distribution and abundance from Generalized Additive Models (GAM)

Figures 3-6 shows Generalized Additive Models of sea surface height (SSH), sea surface salinity (SSS), current velocity (UV) and sea surface temperature (SST) from August 2015 to January 2016 within Ghana's coastal waters. The solid line shows the non-linear relationship between the parameters and the distribution of fish and dash line represents 95% confidence-interval of the values. The positive values in the model in each case represent the preferred environmental values whereas the negative values also indicate range of condition parameters not suitable for fish aggregation. The daily composite of SSH values ranged from 1.8 cm to 2.15 cm with a standard deviation of 3.93. The optimum SSH values from the study are 1.88 cm and 2.15 cm (Figure 3).

Distribution of high catch in relation to SSH indicates that fish are likely to be found in areas where sea surface height ranged from 1.88 cm to 2.15 cm. SSS values obtained from the plot were 32.5, 33.5 and 35 psu at a standard deviation of 3.84. These are values noted to influence fish aggregation. The observed current velocity values preferred for fish distribution and abundance is within the ranges of 0.3m/s to 0.65 m/s (Figure 5) whereas 18.5°C to 29°C (Figure 6) provided the best thermal condition that influenced catch distribution.

Potential fishing zones in the coastal waters

Figures 3-8 show maps of zones in the coastal

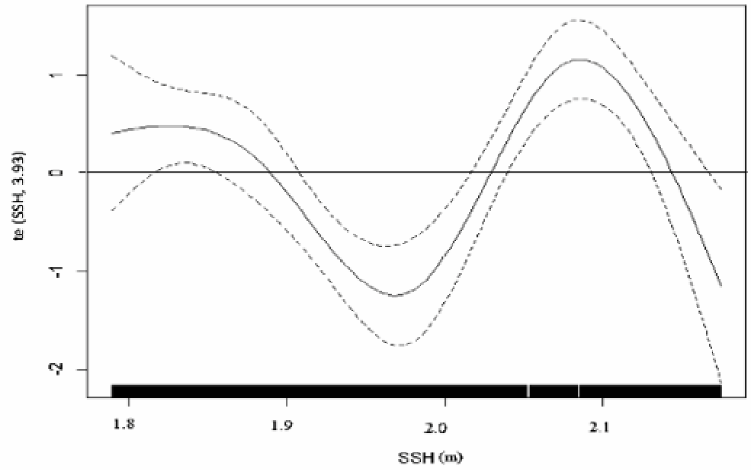

Figure 3: A generalized additive model (GAM) of optimum sea surface height (SSH) range for preferred for fish distribution off the coast of Ghana

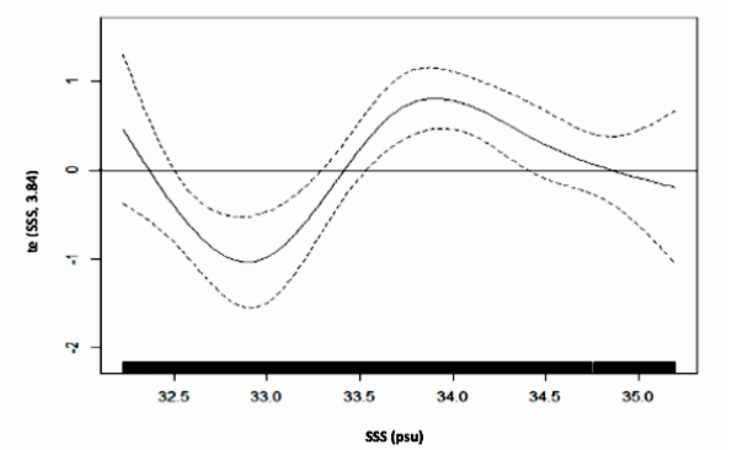

Figure 4: A generalized additive model of optimum sea surface salinity range for fish distribution off the coast of Ghana

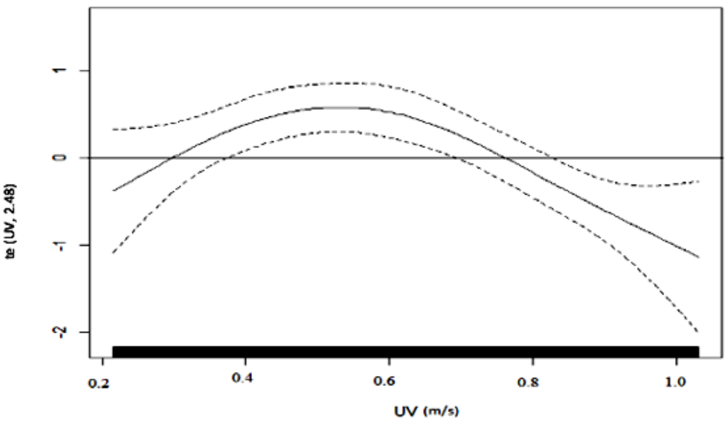

Figure 5: A generalized additive model of optimum current velocity (uv) range for fish distribution off the coast of Ghana

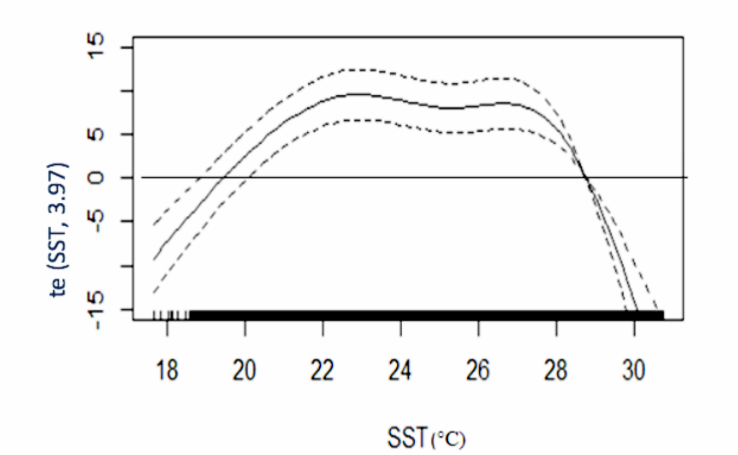

Figure 6: A generalized additive model (GAM) of optimum sea surface temperature (SST) range for fish distribution off the coast of Ghana

waters of Ghana predicting areas of fish aggregation for the period of August 2015 – January 2016. The colour scale on the side of the charts shows the percentage probability of finding fish. The least to greatest chances of finding fish lies within 0 to 50% as indicated on the chart in the open waters of Ghana. The areas of highest fish aggregation in August 2015 was located within the range of longitude of -0.5° -2.5’ E and latitude 4° to 4.5’ N (Figure 3a). The other areas of high fish aggregation occur at longitude 0° -1.5’ E and latitude 4° 4.5’ N and longitude -4° 1.5′ E and latitude 5° 5.5′ N (Figures 3d-h). These results show that fish aggregation along the shore occurred at probability of between 2 and 8%. In September 2015, the probability of locating fish in Ghana’s inshore marine waters was estimated at 0-8%. However, the probability of fish aggregation was higher within the geographical range of longitude -2.5° 3.5’ E and latitude 5° 5.2’ N (Figure 4b). In October 2015, the probability of aggregation of fish was within 0-40% yet, the probability of finding fish was 2-8%. A 20-40% probability was found within longitude -3.5° 2’ E and latitude 4.5° 6′ N, close to shore. In November 2015 a 2-30% probability of locating fish schools was observed and the highest probability of 30%, occurring shoreward within longitude -3° 2’ E to latitude 4.5° 6’ N. In December 2015, the five maps produced showed a general decline in percentage probability of catches (Figure 7 a-e). The decline in probability manifested along the shore as compared to November 2015 from 10 to 30%. The locations of drastic decline in probabilities occurred at longitude -4° 1’ E to latitude 4° 5’ N estimated at 0-2% (Figure 7 a and e). Finally, in January 2016, there was the least probability (0-8%) of fish

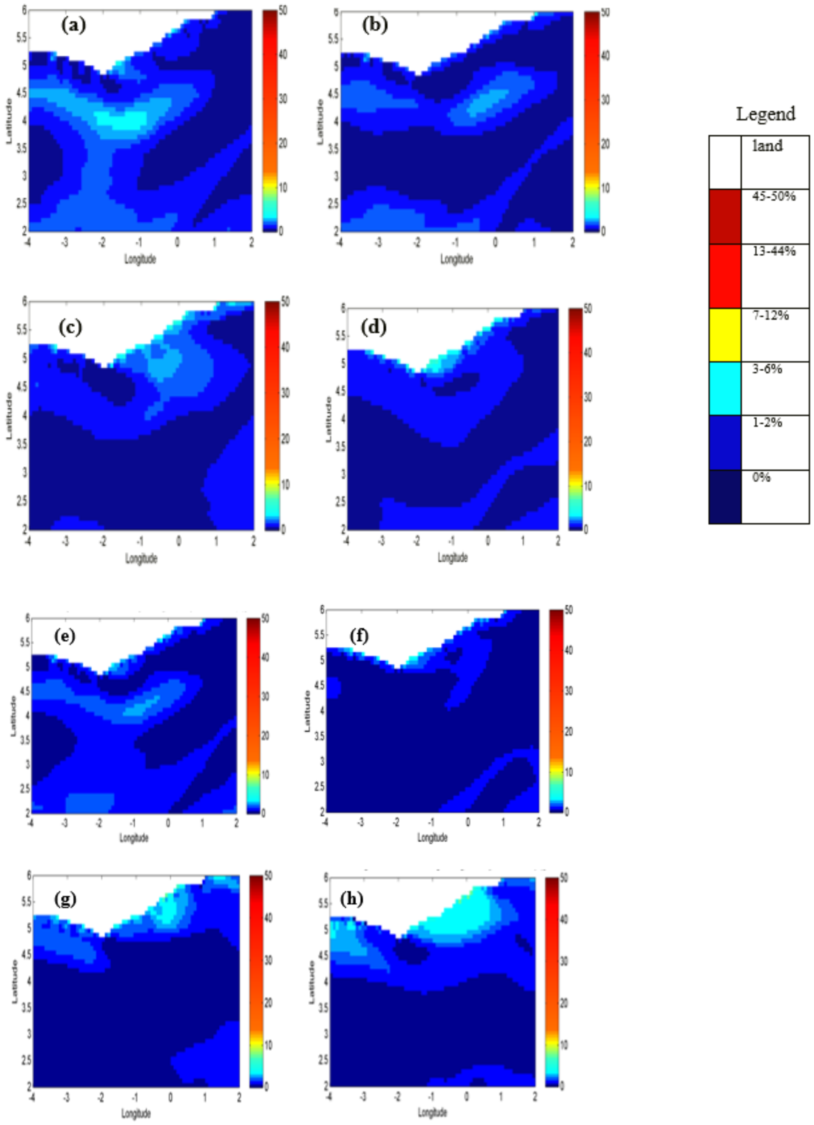

Figure 7: Maps of potential fishing zones off the coast of Ghana showing percentage probability of fish aggregation in August 2015 (a-h)

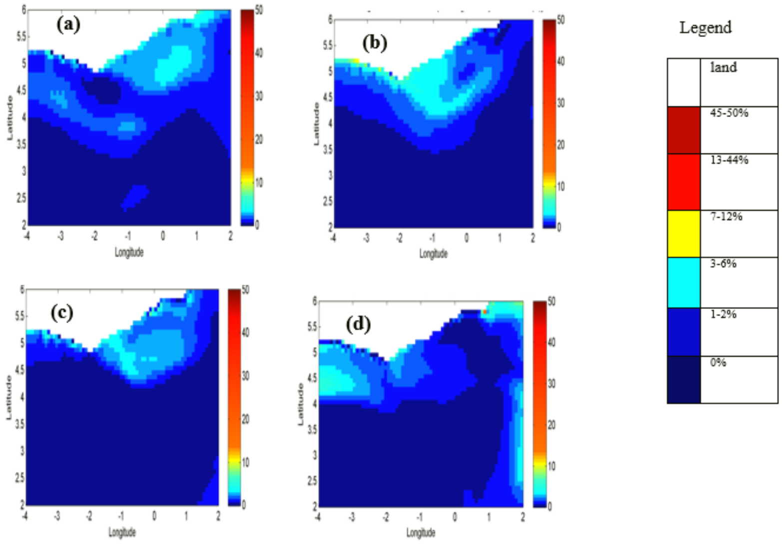

Figure 8: Maps of potential fishing zones off the coast of Ghana showing percentage probability of fish aggregation in September 2015 (a-d)

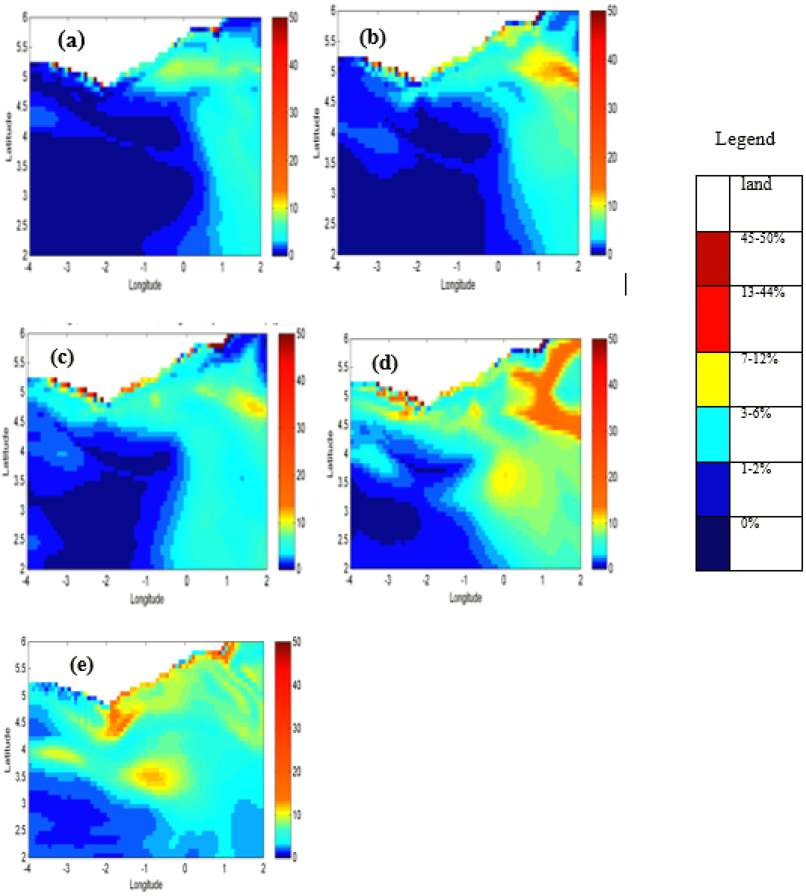

Figure 9: Maps of potential fishing zones off the coast of Ghana showing percentage probability of fish aggregation in October 2015 (a-e)

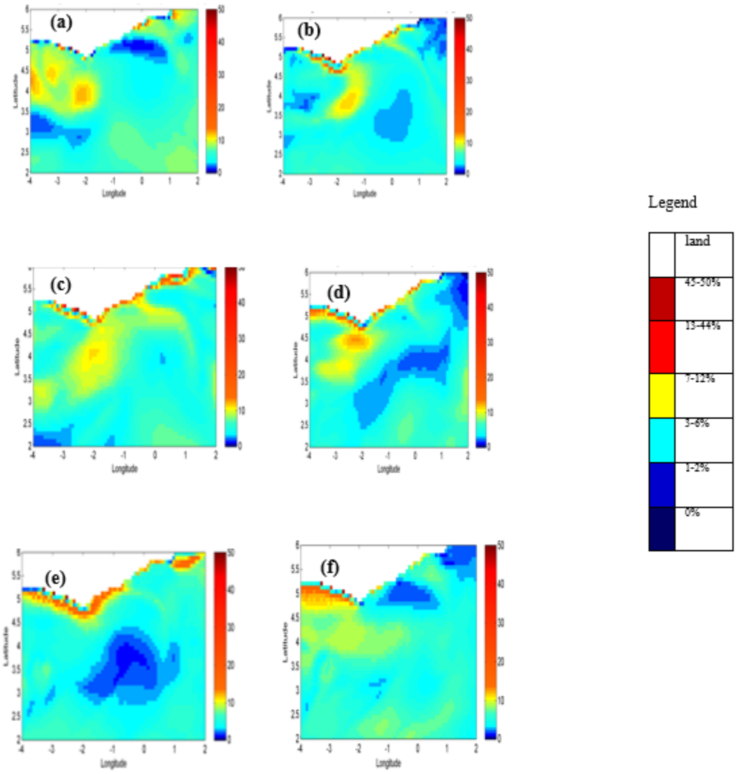

Figure 10: Maps of potential fishing zones off the coast of Ghana showing percentage probability of fish aggregation in November 2015 (a-f)

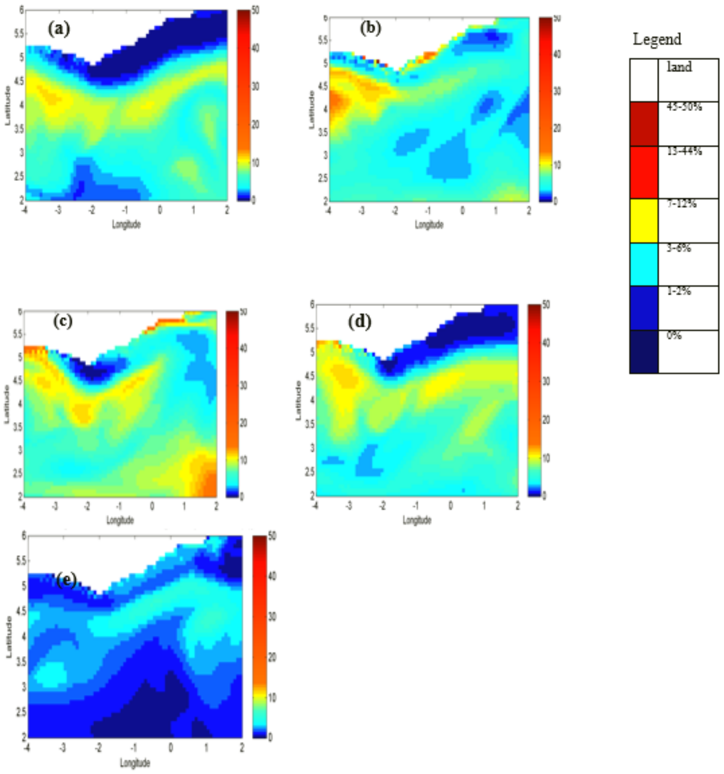

Figure 11: Maps of potential fishing zones off the coast of Ghana showing percentage probability of fish aggregation in December 2015 (a-e)

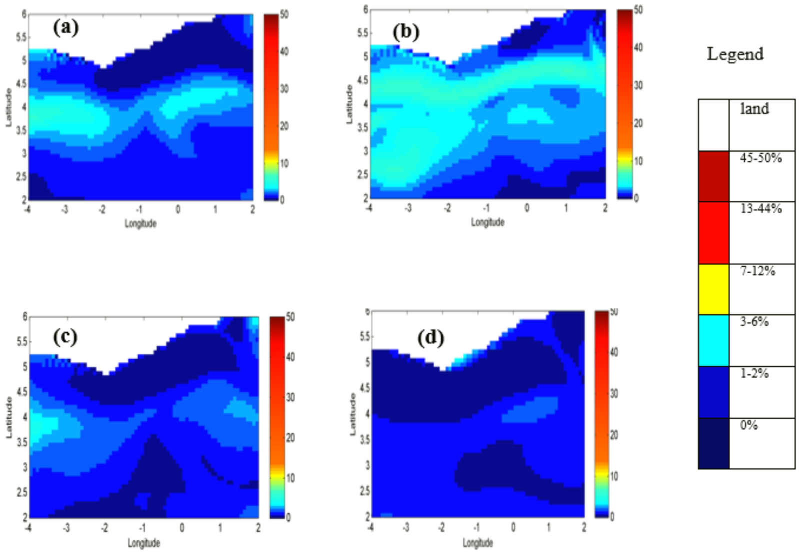

Figure 12: Maps of potential fishing zones off the coast of Ghana showing percentage probability of fish aggregation in January 2016 (a-d)

aggregation (Figure 8 a-d).

Discussion

Fishing behaviour and movement patterns of trawl vessel

Fishing behaviour describes the movement pattern or trajectories and fishing habits of vessels at sea (Vermard, 2010). Monitoring of sailing tracks is one of the important applications of AIS and speed is noted to define the fishing behaviour and effort of vessels (Vernard *et al.* 2010). Speed has been used to classify fishing and non-fishing activities in fisheries studies (Lee et al. 2010).

Mullowney & Dawe (2009) confirmed this observation based on the behaviour of the vessel described as actively fishing or trawling, speeding (steaming) or anchoring (mooring). The lower and upper speed limits of 2 and 8 knots respectively are important determinants of fishing behaviour.

According to the speed rule, a trawling vessel will actively fish or trawl with an estimated speed range of 2-5 knots and steam within 5-8 knots (Skaar *et al.* 2011). This speed range suggests a fishing speed where the fishing boat steamed to the fishing ground. Invariably, it can be deduced that the speed range of 2 to 5 knots (Figure 2) was associated with periods when the fishing vessel was engaged in fishing. Findings from the study showed that the vessel spent most of its time steaming progressively within a speed range of 6.9 to 7.5 knots and fished or trawled less frequently within the range of 2-5 knots. These activities were detected at the location of longitude -1.5° 0.2′ E and latitude 5.5 ° 4.5′ N within 30-100m depth. This result is contrary to the findings of Gerritsen & Lordan (2011), which showed that trawlers spend more time fishing than steaming.

The steaming behaviour observed from the inshore trawl vessel in this study is very characteristic of a recreational vessel where movement is seen at a high speed and in straight path rather than a trawling vessel whose movement occurs in slower and erratic trajectory patterns (Sampath, 2012). Such vessel behaviour strongly suggests that the fishermen operating this trawling vessel have good working knowledge of specific areas where they could find fish. However, such a finding also means that they seem not to have precise information on other potential fishing grounds and so fishing expeditions are limited to the same fishing grounds previously visited. Another important factor that may be attributed to speeding behaviour relate to occasional mechanical challenges of vessels encountered by the fishermen during the study. They speed to their destination without wasting time searching for other productive areas to avoid engine failure (pers. comm, Debrah *et al.*, 2015). Further to that, challenges in accessing premix fuel is another factor to consider because fishermen had to focus on getting their catches from productive locations, they are already familiar with as a strategy to avoid fuel wastage and prevent unproductive fishing outcomes.

In addition to these arguments, the observed fishing habit by the operators of the canoe may also suggest that the fishing vessel could have engaged in other activities such as illegal transhipment, other than regular fishing. The fishing the behaviour of the trawling vessel is markedly unusual of trawling vessels, and contravenes Ghana's Fisheries Act 625 (2002), Sub Part 81(5) which states that, a towing or trawling gear shall not be used in a 30-metre zone or depth of the Inshore Exclusive Zone (IEZ) as prescribed by the regulation. Obviously, trawling was undertaken within the IEZ by the vessel under study.

To confirm the accuracy of speed threshold in this study, the speed range (2-5 knots) established as trawling speed was compared with other findings elsewhere. For Scottish trawling fleets, speeds between 0.5 and 5 knots are indicative of fishing (Deng, 2005). Norwegian otter trawls estimated 80% of fishing activity at a speed range of 2-5 knots comparable with the 88% of that in Gerritsen & Lordan (2011). Notwithstanding, these are markedly less than the 99% success rate reported by Mills et al. (2007) for beam trawlers in the North Sea, whose fishing speeds were in the range 2–5 knots. The difference between these studies is probably a consequence of unrelated fishing patterns between the fleets. In the Barents Sea, stern trawlers often take large catches that require long processing times, and the trawl cannot be shot again before a good part of the previous catch has been processed (Skaar *et al*., 2011). In such circumstances, vessels often sail to the next fishing position, or conduct searches for good fish registrations, at low speeds like that used during trawling.

This speed concept has proven to be ideal for monitoring vessels fishing close to the oil rig platforms of Ghana. The Petroleum Exploration Act of Ghana, Act 2016 (Act 919) establishes safety zones up to 500m in relation to fisheries. This measure limits access to fishing areas and avoids the entanglement of fishing gears to rig installations as well.

Speed classification, aside its usage for predicting fishing and non-fishing activities, can also be used as first-hand information for determining the most frequently visited location of a vessel. The method is also useful for detecting vessels exhibiting suspicious fishing behaviours including other maritime crimes such as piracy. The data from this study clearly showed that the vessel was found fishing within the Inshore Exclusion Zone (IEZ) which supports the observation that AIS technology is an effective tool to support decision making based on monitoring and surveillance of local and foreign vessels which may be fishing illegally in Ghana's territorial waters.

The procedure therefore has also proved useful for mapping marine protected areas as part of fisheries management efforts because areas of productive fish aggregation zones have been clearly demarcated in this study. The data indicates potential areas within the maritime space where navy or marine police may increase their efforts towards fisheries enforcement measures to combat IUU.

Oceanographic parameters influencing aggregation of fish

SST determines which fish species or aquatic life will thrive and which will diminish in numbers and size. The results of this study showed that fish tend to aggregate in marine environment with SST values ranging from 18.5 °C- 29.5 °C. Generally, SST recorded were high with very smooth fluctuations. Changes in the SST could be linked to alterations in circulation patterns of the ocean, which is influenced by the direction and speed of the winds (Henson *et al.,* 2010). These winds drive the ocean currents and mix the nutrient rich deep column water with the surface waters which affect the abundance and the distribution of the planktons (Vivekanandan & Jeyabaskaran, 2010). NOAA (2016), has recorded increase in temperature from 1880 to 2015 on the world's ocean which can be linked to anthropogenic activities. The effect of these activities can be attributed to the SST results observed in this study. Variations in SST impact the productivity of marine fisheries and also alters the species composition, changes the structure, function of the ecosystem and the net primary productivity. Studies have revealed that in response to climate change, marine fishes and invertebrates tend to move their distributions toward higher latitudes and deeper waters which affect the relative abundance and aggregation of species (Cheung *et al.* 2009). Similar results of preferential SST have also been recorded for some pelagics by other researchers whose work has been done in other tropical areas. As indicated by Stretta (1991), yellowfin tuna inclines towards warmer waters and the abundance of this species was higher with temperature limits between 18 °C and 31.0 °C. He further reported that in the tropical Atlantic, most of the catches of yellowfin tuna occur with temperatures between 22.0oC and 29.0°C, and preferentially above 25.0°C. Semedi & Hadiyanto (2012) also established SST of about 26 °C to 30 °C as favourable for pelagics in the Makassar Strait of Indonesian waters. Fish species must have adopted an adaptation mechanism to survive in this high condition because fish species are likely to face challenges and extinction in the extremes of SST as stated by Perry *et al.* (2005).

According to Lalli & Parsons (1997), sea surface height (SSH) provides insight into ocean currents, sea level rise and ocean circulation and influences the geographical distribution of pelagic and benthic marine species. SSH differences in the ocean tend to occur from high to low regions contributing to form the ocean currents. This study established SSH ranges of 1.88cm to 2.15cm as optimal for fish aggregation. The range favours fish species in undertaking vertical diel movements, inhabiting water depths in the day and night. Chen et al. (2010) reported that *Ommatrephes bartramii* of the Northwest Pacific Ocean prefers SSH of 0–40m during night and 1.50–3.50cm during the day. The SSH range in this present study proved to be consistent with a finding by Rajapaksha (2009) in Sri Lanka. He noted that distribution of high CPUEs in relation to SSH indicated that yellowfin tuna was found in areas where sea surface height SSH ranged from 1.85cm to 2.35cm in Sri Lankan waters. Another study by Rajapaksha et al. (2013) states that the optimum SSH ranges for the abundance and distribution of yellow fin tuna in the northeast Indian Ocean was estimated as 2.05-2.15m. They came up with SSH range of 20cm to 50cm as optimum and preferential range for this species from August to October 2008 in the Northwest Pacific Ocean. Understanding how fish species respond to regional/local environmental variations and predicting the dynamics of the fish population are therefore essential for the effective management of marine resources (Botsford *et al*. 1997).

In this study, the preferred sea surface salinity (SSS) and current velocity (UV) for designating an area as favourable for fish aggregation ranged between 32.5 to 35 psu and 0.3 to 0.65 m/s respectively. These values can be ideal for influencing zooplankton and phytoplankton bloom, to boost fish aggregation and abundance. So far, very few research works have been encountered to justify the preference of current velocity and salinity ranges by fish schools. Wang & Wang (2015) estimated SSS between the ranges of 32 psu to 34 psu in Zhoushan waters in China after the close of the fishing season from September 2012 to January 2013 as optimal for fish species. Chen et al. (2010) had SSS of 33.3 psu – 34.3 psu as favourable for *Ommastrephes bartramii* in Northwest Pacific Ocean. Investigations carried out by Tian (2006) reported that the monthly favourable SSS for squid distributions were 33.8–34.3, 33.3–34.4, 33.0–34.2, 33.0–33.7, 33.0–33.8 and 33.3–33.8 psu from June to November, respectively, in the north Pacific. Chen et al. (2005) discussed the impacts of large-scale oceanic phenomena such as the Kuroshio Extension and El Niño Southern Oscillation (ENSO) events on squid distribution and recruitment. They concluded that these phenomena influence squid by affecting the SST and SSS of the spawning and feeding grounds. Each fish species has a salinity preference and congregates at vertical salinity breaks, as horizontal salinity "fronts" (Chen *et al.* 2010).

Maravelias & Reid (1995), also proposed sea surface salinity > 35 psu as ideal value for herring abundance off the shores of Scotland. They elaborated that during summer in the northern North Sea, small *Calanus* species, which represent up to 99% of the biomass, form patches in areas with the higher salinities, influencing herring abundance. Generally, SSS ranges observed in this study were in optimal ranges (32.5 psu to 35 psu) for fish tolerance and aggregation. Changes in salinity of the marine ecosystem could be due to high and low tides and on seasonal basis, as salts are diluted in the rainy season due to the influx of fresh water. Once the rains end and the fresh water flow decreases, temperature increases, and the salinity rises causing shifting of habitats within it by various faunal species, particularly the highly mobile fishes; they migrate to adjacent estuaries to either feed, transit and breed and nurse their young ones who are unable to tolerate the increasing sea salinity regime.

Potential fishing zones (PFZ) off Ghana's coastal waters

Potential fishing zones (PFZs) are areas of reliable fish aggregations in the ocean. The results demonstrated that fish aggregation was found to be high along the shores of Ghana. Aggregation of fish is determined by favourable ocean conditions such as salinity, depth, temperature and nutrient availability for boosting phytoplankton distribution and fish growth (Kizhakudan *et al.* 2014). From this study, it was observed that the potential fishing grounds with high catch probabilities occurred along the coast of Ghana's territorial waters (Figures 3-8). This is explained by the productive and nutrient rich coastal waters, resulting from river discharges and frequent upwelling (Henson *et al.* 2010). This finding is in accordance with Mustapha *et al.* (2010), Nurdin *et al.* (2014) and Zainuddin (2007) where they established potential fishing zones of Indian Ocean. In this study, the months with the highest probability of catch aggregation were from October 2015 to December 2015 and within the geographical locations of longitude -4° 2 ′ E and latitude 3.5° 6 ′ N. The high probability of catch aggregation especially, in October 2015 is due to upwelling that occurred during that month (Figures 5a-e).

Ghana's coastal waters experience two seasons of upwelling; a major one, occurring from July to October and a minor one from November to January (Quaatey,1997). This phenomenon could be the reason for the high fish abundance and distribution from October 2015 to December 2015. A research by Dayaker (2003) also indicated that high fish aggregations occur close to the shorelines because of the water properties: high temperatures and increased chlorophyll reflectance due to the low water depth. The ocean conditions observed in the study from December 2015 to January 2016 informs that no significant upwelling took place and could not influence fish aggregation. Changes in the SST marked from the effect of dry atmospheric conditions can be linked to alterations in circulation patterns of the ocean affecting the direction and speed of the winds (Henson, 2010). These winds contribute to mixing nutrients locked in the deep-water layers with the surface waters and affect the abundance of the planktons to attract fish stocks (Vivekanandan & Jeyabaskaran, 2010). On the contrary, some fish species may change their location, moving toward colder latitudes which they find favourable (Perry *et al.* 2005), thus reducing fish stock aggregations. Obstructions by high suspended particulate by the north-east trade winds (high sediment load coming from the land) also affects the accurate estimation of ocean parameters from satellite data (Han, 1994). As indicated by Kupschus & Tremain (2001), managing fish stocks sustainably require that resource managers understand and consider the factors that influence the distribution and abundance of the species of interest. For instance, understanding how fish species respond to environmental variations is essential for managing the fish stocks (Botsford *et al.*, 1997). This knowledge is required for best fishery management decisions and to develop efficient harvesting mechanisms for marine fisheries resources. This study has shown that potential fishing fish aggregation zones can be represented as charts for fishermen, stakeholders and government officials for fish forecasting. The use of the charts could aid to improve upon catches, maximize profits of fishermen and reduce search time at sea. It can also possibly reduce fishing effort and reduce fuel consumption.

Conclusions

This research sought to use ocean forecast data and vessel movement to map fishing zones off the coast of Ghana. The observed steaming behaviour of the vessel studied is characteristic of a recreational vessel, moving in straight path rather than a trawling vessel whose movement occurs in slower and erratic trajectory patterns. The findings strongly suggest that the fishermen operating this trawl vessel have good knowledge of productive fishing grounds. The months with highest probability of catch aggregation were from October 2015 to December 2015, within the geographical locations of longitude -4° 2 ′ E and latitude 3.5° 6 ′ N. The highest probability of catch aggregation was observed in October 2015, probably due to upwelling that occurred during that month. It is concluded that, fishing efficiency of inshore trawling vessels in Ghana could be enhanced with maps indicative of probability of fish aggregation in the ocean. This study marks a first step to convey the practicality of AIS data for fisheries research and highlights the need for the increased use of science and technology for the work of the Ministry of Fisheries and Aquaculture Development and the Fisheries Commission of Ghana. Fish aggregation mostly occurs closer to the shore predicated by favourable ocean conditions than otherwise. The most appropriate period of fish aggregation coincided with the upwelling season. Therefore, the need for fishers to base their fishing expeditions on more precise locations guided by maps of potential fishing zones showing percentage probability of fish aggregation to maximize their efficiency.

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