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RESEARCH ARTICLE

Effect of ocean circulation and chlorophyll-a concentration on yellowfin tuna catch rates in Sri Lankan logline fishery

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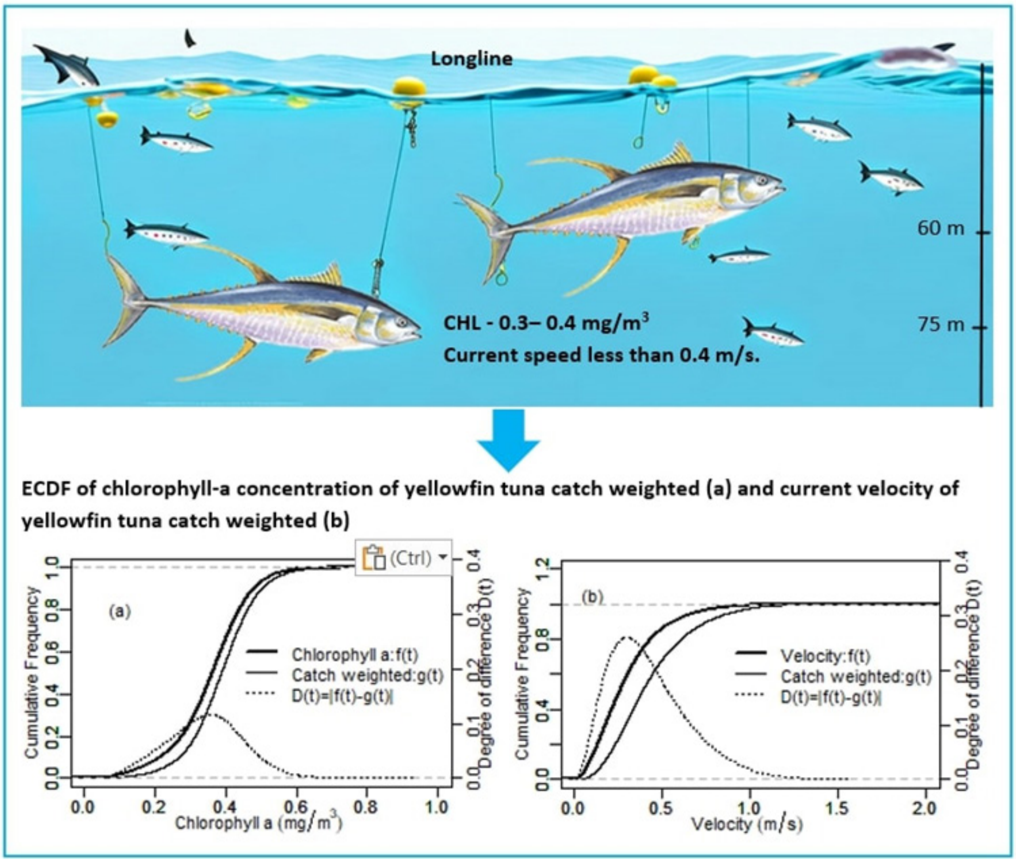

Highlights

- High yellowfin tuna catch rates can be obtained at 60 – 75 m depth.
- High yellowfin tuna aggregations related to chlorophyll-a concentration between 0.3 – 0.4 mg/m^3 and current speed < than 0.4 m/s.
- Yellowfin tuna fishable aggregations occur throughout the year, though their location varies with the oceanographic conditions.

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RESEARCH ARTICLE

Effect of ocean circulation and chlorophyll-a concentration on yellowfin tuna catch rates in Sri Lankan logline fishery

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Abstract: Sri Lanka has access to fishery resources in the Indian Ocean due to its location. While traditional fishing methods are still used in the Sri Lankan fishery industry, modern technologies such as remote sensing and GIS are employed to determine spatiotemporal distribution of tuna fish resources in the offshore fishery industry. However, due to uncertain catch rates, Sri Lankan fishers report low catch per unit effort, leading to increased fishing duration to meet targeted catch. Potential fishing areas can be identified based on oceanographic conditions to reduce search time and improve efficiency, particularly for highly migratory species like yellowfin tuna. Therefore, this study is focused on identifying the impact of subsurface ocean currents and chlorophyll-a concentration on yellowfin tuna aggregations. The study analysed fishery and oceanographic data from January 2018 to December 2019 within a latitudinal range of 0°N to 20°N and a longitudinal range of 70°E to 90°E. The data were gridded at a resolution of 0.25 degrees and then matched for analysis. The generalized additive model (GAM) and the empirical cumulative distribution function (ECDF) were applied to identify the nature of relationships between CPUE and the oceanographic conditions. The results showed high tuna aggregations occurred in chlorophyll-a concentration between 0.3– 0.4 mg/m^3 and current speed less than 0.4 m/s at a depth of 60 – 75 m of Sri Lankan longliners. Yellowfin tuna fishable aggregations were available throughout the year, although the spatial distribution of yellowfin tuna varied depending on the prevailing oceanographic conditions. Thus, searching for fishing locations based on oceanographic factors is essential for successful fishing operations. Hence, tuna harvest can be enhanced by maintaining fishing areas and the longline depth according to the oceanographic factors.

Keywords: Monsoon circulation; Chlorophyll-a; Yellowfin tuna; Longline

INTRODUCTION

Sri Lanka is located in the north-central part of the Indian Ocean, the Arabian Sea to the west and the Bay of Bengal to the east. This part of the Indian Ocean is influenced by two monsoon seasons, the southwest monsoon (SWM) and the northeast monsoon (NEM), leading to seasonal characteristics of the surface currents. The temporal variation was directly related to the monsoon climate, but the timing of the monsoon can vary by a few months depending on the onset of climatic events in the Bay of Bengal (Jayasiri *et al*., 2014). The major ocean surface currents are generated primarily by winds that are produced by convection due to variations of temperature with latitude and the Coriolis effect caused by Earth's rotation (Klemas, 2012). These ocean currents profoundly impact marine life, moving animals and plants around the ocean and redistributing heat and nutrients (Hays, 2017). Seasonal changes in currents can affect the abundance of chlorophyll-a concentration, a parameter to assess phytoplankton biomass which is the lowest link in the marine food chain (Hsu *et al*., 2020). Also, many fish species rely on currents to move them to breeding grounds, areas with more abundant prey and suitable water, thus forming good fishing grounds for the fishermen.

Being an island nation, Sri Lanka has abundant opportunities to access fishery resources that can be utilized for the socio-economic development of the country. Furthermore, tuna species such as yellowfin tuna (*Thunnus albacares*) are dominant species in the catch composition and have contributed a great amount to the total marine fish production of the country (National Aquatic Resources Research and Development Agency, 2019). Tuna is one of the world's most popular seafood products, associated with several forms of consumption, such as canned tuna and sashimi (Lecomte *et al*., 2017).

Sri Lankan fishery industry has been unable to meet the increasing demand for tuna fishery due to a persistent shortage in supply, primarily resulting from catch uncertainty. Sri Lankan vessels that use tuna longline for fishing spend about 2-4 weeks on a fishing trip. Most fishermen try to find locations for fishing based on their previous experience and traditional knowledge. This traditional knowledge and experience are not sufficient as it takes a long time to get the expected harvest, reducing the freshness of the fish and increasing the operational cost. Therefore, advanced methods for predicting fishing locations based on oceanographic factors are needed to overcome these difficulties.

Advanced techniques show great potential in supporting the successful exploitation of pelagic fishery resources and global fisheries management (Rajapaksha *et al*., 2010). Moreover, satellite remote sensing has become increasingly

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helpful in studying world oceans and their many biological and physical processes for which it is synoptic, repetitive, consistent, and cost-effective (Pu *et al.*, 2012; Yang & Yang, 2009; Yapa, 2011). Ocean feature analysis includes determining current strength and direction, amplitude and direction of surface winds, sea surface temperature, chlorophyll-a concentration and exploring the dynamic relationship and influences between ocean and atmosphere (Devi *et al*., 2015). Advances in remote sensing have made it possible to collect data on features and processes in the ocean over very broad scales. GIS technology has made it possible to organize and integrate this data, make maps and perform scientific analysis to increase understanding and help to make critical decisions.

Therefore, this study aims to find the relationship between subsurface current velocity driven by monsoon circulation and chlorophyll-a concentration on yellowfin tuna catch rates in Sri Lankan longline fishery which can help to find fishing grounds. This study examines the effect of the seasonal changes in ocean currents and chlorophyll-a concentration on tuna fish abundance. Because of the complexity of behaviour of currents in the Indian Ocean and the range of temporal and spatial scales of ocean surface currents and chlorophyll-a concentration, satellite remote sensing is an ideal tool for studying these ocean features (Dohan & Maximenko, 2011).

METHODOLOGY

The northern part of the Indian Ocean, confined to latitudes from 0° to 20°N and longitudes from 070° to 090°E where Sri Lankan offshore and coastal fishing activities take place was used for this study. The Indian Ocean's wind conditions and surface currents are influenced by the Asian continent's proximity to its northern border. During the northeast-monsoon season, cold air from the Himalayas sinks, affecting the wind patterns and surface currents. From April onwards, the continent begins to warm up, causing warm air to rise along the mountainsides and draw in air from the ocean, resulting in the southwest monsoon season. Therefore, the land climate also plays a significant role in shaping the weather patterns and ocean currents of the Indian Ocean (Odd Henrik & Aas, 2012).

The data used in the study mainly consisted of two types: oceanographic data obtained from the Copernicus marine environmental monitoring service and yellowfin tuna catch data obtained from the Department of Fisheries, Sri Lanka. Copernicus provides various oceanographic data, such as three-dimensional daily average temperature, salinity, and velocity in both the east-west and north-south directions, as well as two-dimensional representations of sea surface height, bottom temperature, and mixed layer depth. It provides improved data combining high-resolution Sentinel satellite data with in-situ data. These data were obtained from daily composites at a spatial resolution of 0.25 degrees (https://marine.copernicus.eu/). The dataset contained surface current information and chlorophyll-a concentration with the latitude, longitude and depth.

Fishery and oceanographic data were matched in 5-day composites of 0.25-degree resolution for a two-year period (January 2018- December 2019). Catch per unit of effort (CPUE) was calculated as kg/100hooks/day. The output records are consisted of fishing locations, and catch rates with corresponding oceanographic parameters (Swarnamalie *et al*., 2021). Output data were statistically analysed using R statistical packages.

The association between the chlorophyll-a concentration and currents with CPUE were analysed by empirical cumulative distribution function (ECDF). In this analysis, functions were used as follows (Andrade & Garcia, 1999; Zainuddin, 2011),

$$f(t)=\frac{1}{n}\sum_{i=1}^{n} l(x_i) \tag{1}$$

With the indication function

$$l(x_i)=\begin{cases}1 & \text{if } x_i \leq 1\\ 0 & \text{otherwise}\end{cases} \tag{2}$$

$$g(t)=\frac{1}{n}\sum_{i=1}^{n}\frac{y_i}{\bar{y}} l(x_i) \tag{3}$$

$$D(t)=\max|f(t)-g(t)| \tag{4}$$

Where f(t) was the empirical cumulative frequency distribution function, g(t) was catch-weighted cumulative distribution function, l(xi) was the indication function, and D(t) was the absolute value of the difference between the two curves f(t) and g(t) at any point t and assessed by the standard Kolmogorov-Smirnov test.

In addition to ECDF, generalized additive model (GAM) was applied to identify the relationships between CPUE and the three oceanographic parameters. The relationships between two variables and the CPUE are mostly non-linear. GAM is a non-parametric generalization of multiple linear regressions which is less restrictive in assumptions of the underlying statistical data distribution. The GAM has no analytical form but explains the variance of CPUE more effectively and flexibly (Rajapaksha *et al*., 2013).

RESULTS AND DISCUSSION

The results of the study suggest that there is a relationship between two oceanographic variables and higher catch frequencies of yellowfin tuna. Specifically, the highest catch rates were observed in areas with a chlorophyll-a concentration between 0.3 – 0.4 mg/m^3 and a current speed less than 0.4 m/s (Figure 1). Further, the study found that the correlation between CPUE and oceanographic factors was strongest at a current velocity of approximately 0.2 m/s and a chlorophyll-a concentration of around 0.4 mg/m^3.

The significant correlation between CPUE and the environmental factors was confirmed by the ECDF analysis ($P < 0.05$) within the ranges of 0.2 - 0.4 m/s for current velocity and 0.3 - 0.4 mg/m^3 for chlorophyll-a concentration (Figure 2). The results of the GAM analysis further supported the significant influence of current velocity and chlorophyll-a concentration on CPUE (Figure 3.) These findings suggest that variations in current velocity and chlorophyll-a concentration can substantially impact CPUE.

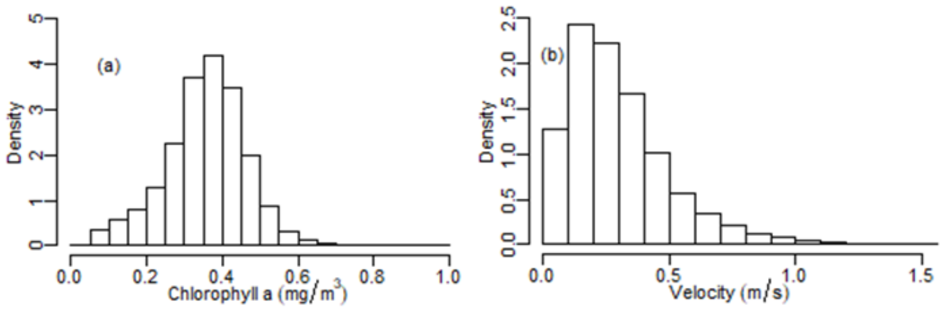

Figure 1: (a) Histogram showing frequencies of yellowfin tuna CPUE with chlorophyll-a concentration and (b) histogram showing frequencies of yellowfin tuna CPUE with current velocity (January 2018 – December 2019).

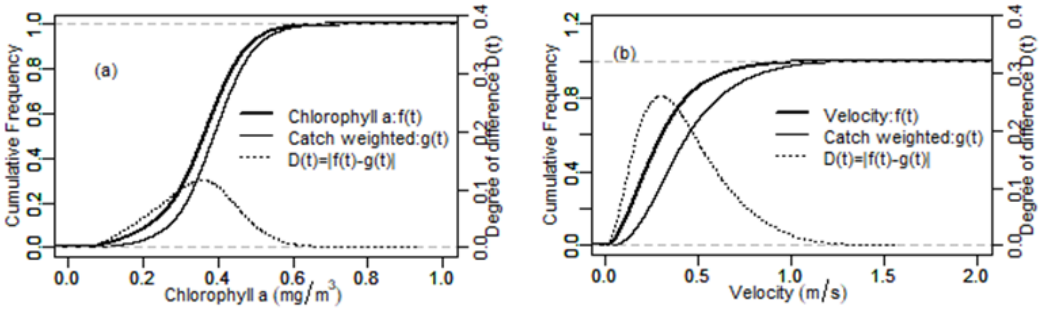

Figure 2: (a) Empirical cumulative distribution frequencies of chlorophyll-a concentration of yellowfin tuna catch weighted and (b) Empirical cumulative distribution frequencies of the current velocity of yellowfin tuna catch weighted (January 2018 – December 2019). The dashed lines show the degree of differences between the two curves.

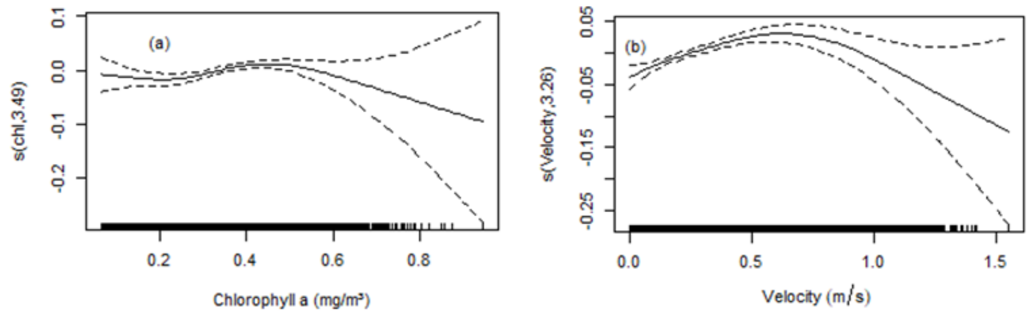

Figure 3: (a) GAM derived from the effect of chlorophyll-a on yellowfin tuna CPUE (log-transformed) and (b) GAM derived from the effect of current velocity on yellowfin tuna CPUE (log-transformed). Dashed lines indicate 95% of the confidence intervals. The relative density of data points is shown in rug plots along the x-axis.

Catch overlay maps for two distinct seasons and for two inter-monsoon seasons were generated using monthly averaged chlorophyll-a concentration data and CPUE data based on four categories *viz*., $0 \leq$ CPUE < 50, $50 \leq$ CPUE < 100, $100 \leq$ CPUE < 150 and $150 \leq$ CPUE.

The distribution pattern shows that yellowfin tuna abundance is not random. Tuna longline activities are mainly concentrated in the north-eastern part and southwest of the island. Yellowfin tuna fishable aggregations are available during both northeast and southwest monsoon seasons, although their distribution varies depending on the prevailing oceanographic conditions and the northeast part of the island is more promising for tuna harvest. This study was based on available logbook data which has maximum longline depth penetration about 100 m. Most catches have been concentrated to the depth range of 60 m to 75 m depths (Figures 4 and 5).

The monsoons are strong, often violent winds that change direction with the season by affecting the current direction (He *et al*., 2007). Since currents influence so many marine-related activities and processes, marine-related agencies, including fisheries managers, need up-to-date information on ocean and coastal currents, as many fish species rely on currents to move them to breeding grounds and areas with more abundant prey (Klemas, 2012).

These monsoon currents reverse their direction twice a year and directly influence the seasonal circulation variability (Schott *et al*., 2009). NEM occurs from December to April and the SWM between June to October, along with two inter-monsoon periods in May and November (Su *et al*., 2021). During the NEM, currents flow from east to west (Figure 6). Currents originate from the eastern coast of India flow towards the west after passing the eastern and southern coasts of Sri Lanka (Figure 6).

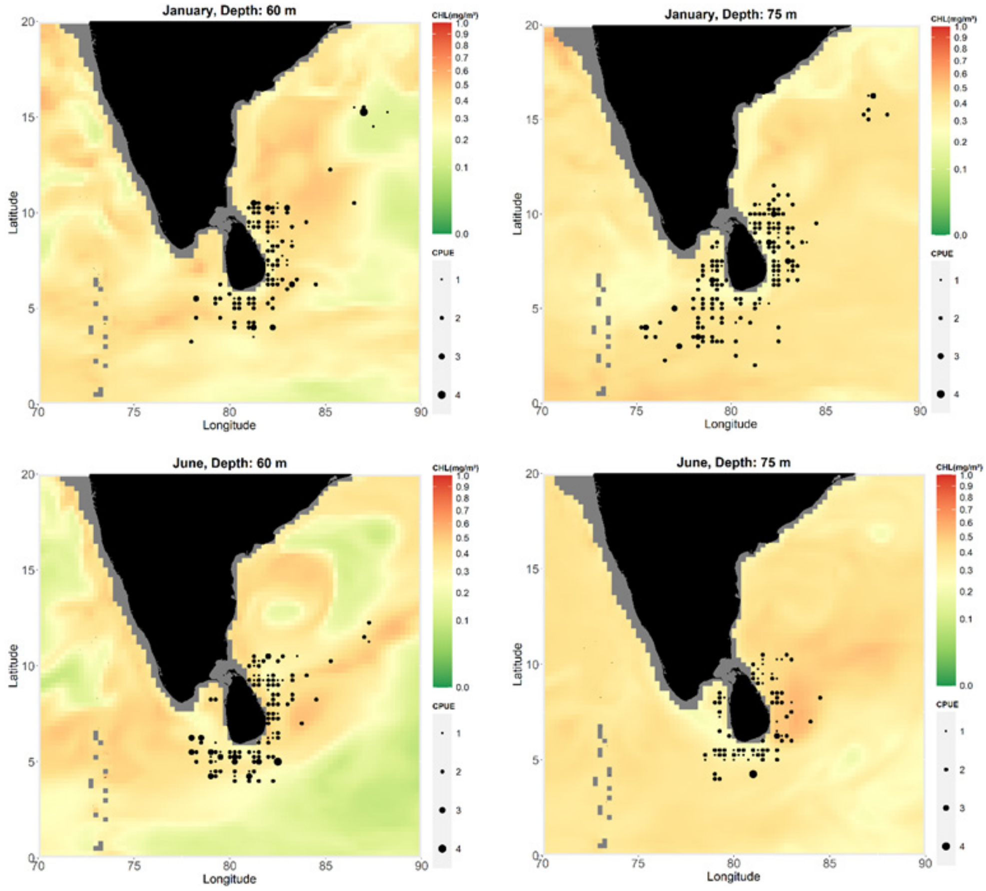

Figure 4: Monthly mean CPUE overlay (black circles) on monthly mean chlorophyll-a concentration map during the NEM (January 2018) and SWM (June 2018) at 60 m and 75 m depth levels.

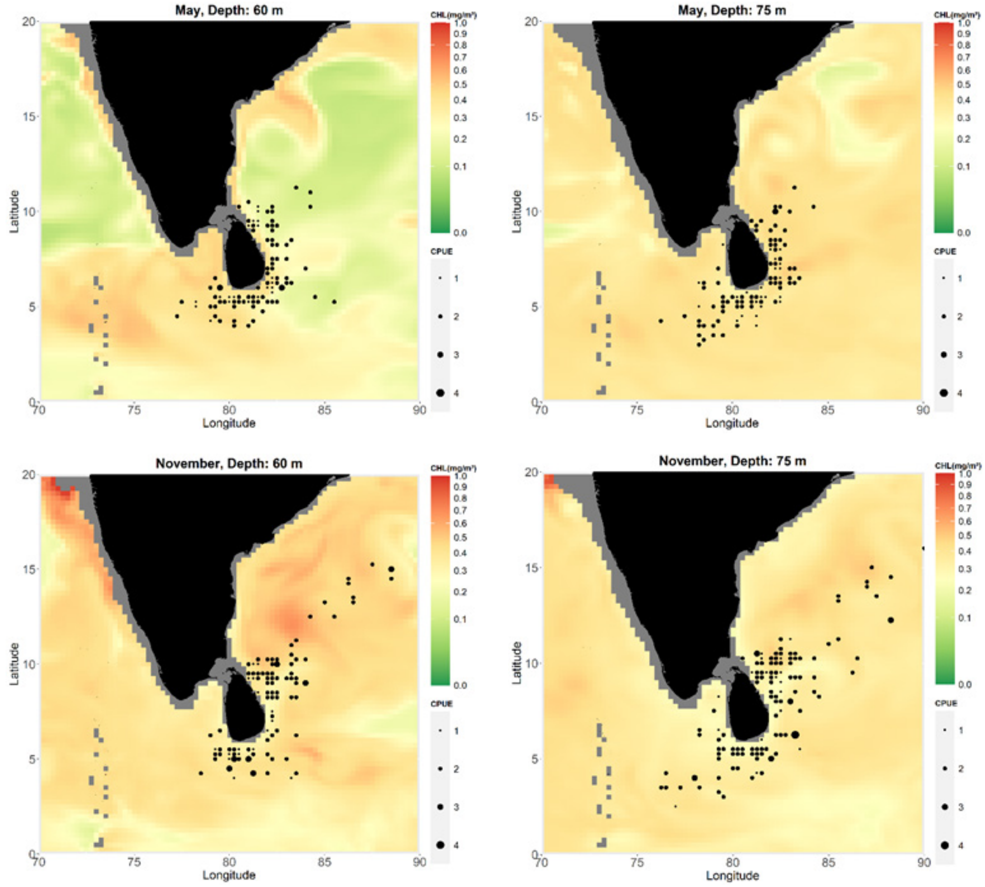

Figure 5: Monthly mean CPUE overlay (black circles) on monthly mean chlorophyll-a concentration map during the first inter-monsoon (May 2018) and second inter-monsoon (November 2018).

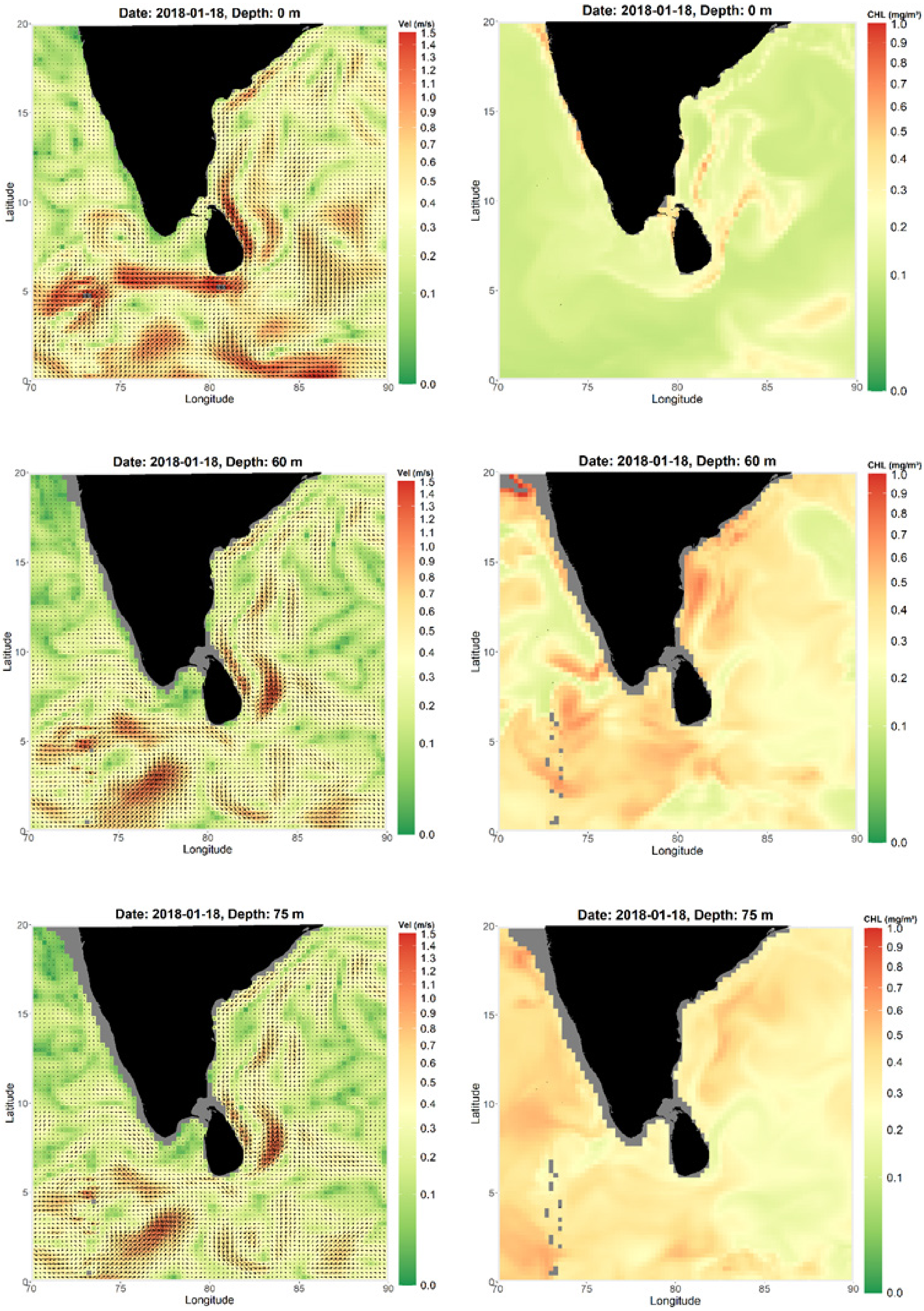

Figure 6: Currents (left) and chlorophyll-a concentration (right) maps for different depth levels, during NEM (18 January 2018).

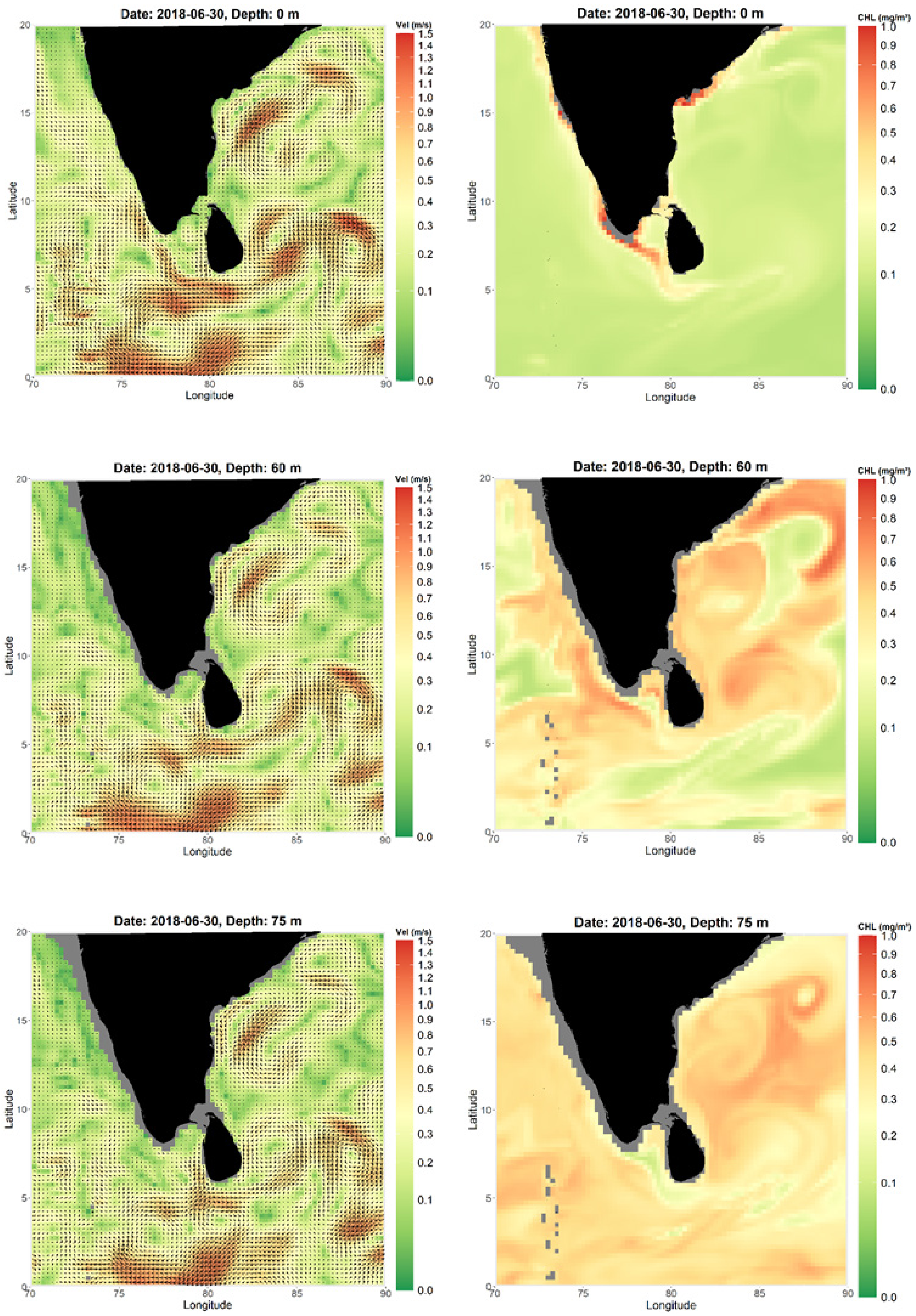

Figure 7: Currents (left) and chlorophyll-a concentration (right) maps for different depth levels, during SWM (30 June 2018).

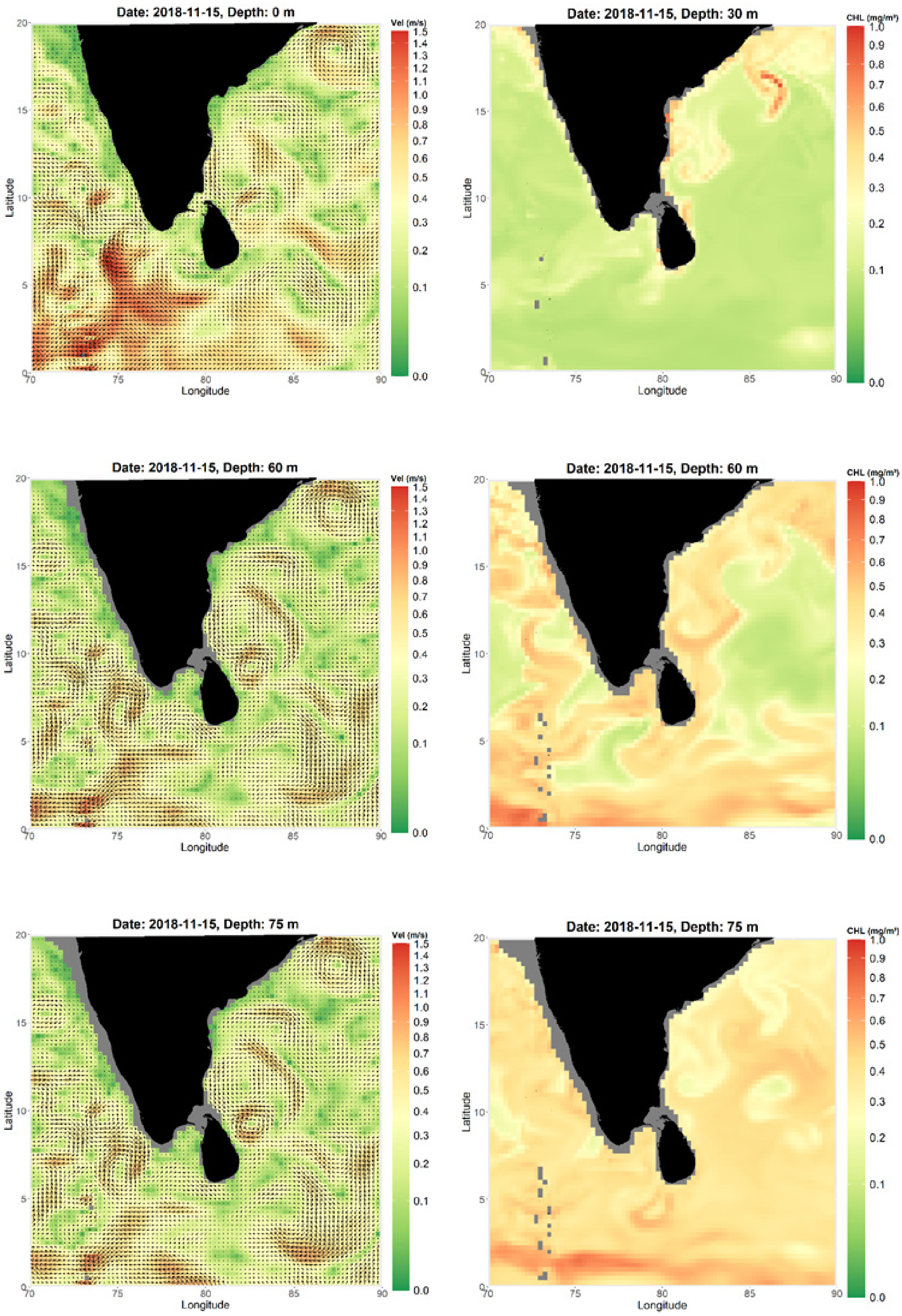

Figure 8: Currents (left) and chlorophyll-a concentration (right) maps for different depth levels, during the second inter-monsoon (15 November 2018).

During the SWM, currents flow from west to east. As in Figure 7, by the end of June, after passing Sri Lanka's southern coast, these currents form an anti-clockwise eddy circulation known as the Sri Lanka Dome (SLD) that is located in the southwest Bay of Bengal (De Vos *et al*., 2014; Thushara *et al*., 2019). During this period, high chlorophyll-a patches develop in the south and southeast coasts as a result of upwelling phenomenon (Yapa, 2011). Upwelling occurs when surface currents diverge or move away from each other. As the surface waters diverge, deeper water must be brought to the surface to replace it, creating upwelling zones (Webb, 2017). Therefore, comparatively higher chlorophyll-a concentration can be evident during the SWM than in the NEM (Figure 7). Because the deep water brought to the surface is often rich in nutrients, coastal upwelling supports the growth of phytoplankton, creating one of the world's most fertile ecosystems. These, in turn, provide food for fish, marine mammals and birds and provide prey for predatory fishes such as yellowfin tuna (Dabuleviciene *et al*., 2023; Yapa, 2011). Therefore, these upwelled waters create good fishing grounds for the fishermen.

In the meantime, north of Sri Lanka SWM currents forms a cyclonic eddy circulation known as the Bay of Bengal Dome (Figure 7) (Vinayachandran and Yamagata, 1998). After the SWM, both the Sri Lankan dome and Bay of Bengal dome position shift further northward before moving out of the region during the second inter monsoon period (Figure 8). Currents change their direction and speed over time and depth and generally diminish in intensity with increasing depth.

According to Swarnamalie *et al*. (2021), the seasonal variability of the vertical temperature of the thermocline fluctuates between 60 to 160 m depth around Sri Lankan waters and yellowfin tuna prefer warmer temperatures between 22.0 – 27.0 °C where the depth ranges 60 – 75 m. Further, Brill *et al*. (1999) have found that the large adult yellowfin tuna spend nearly 60% to 80% of their time in or immediately below the relatively uniform temperature surface layer, above 100 m. The results of the current study are also consistent with these findings. More fish aggregations can be evident at the depth levels between 60 – 75 m depths as this depth range provide favourable oceanographic conditions for yellowfin tuna (Figures 4 and 5).

The yellowfin tuna is one of the fastest, strongest predators and is known to be highly migratory and widely distributed important fishery species everywhere that it lives. These migrations likely correspond with their spawning behaviour and with their food needs (Zagaglia *et al.*, 2004). Changes in ocean circulation can determine the fish movements along the coastal areas. The above results show that the yellowfin tuna fishable aggregations are available throughout the year and are related to the prevailing oceanographic conditions. Ocean currents greatly influence the distribution of chlorophyll-a in the study area. Therefore, identifying the behaviour of yellowfin tuna in relation to ocean currents and chlorophyll-a concentration is essential to predict productive fishing grounds.

CONCLUSION

The study confirms that the tuna is more likely to be caught around 60 – 75 m depth by the Sri Lankan longliners and the current speed is less than 0.4 m/s and chlorophyll-a concentration is around 0.4 mg/m^3. Prediction of fishing locations based on these oceanographic parameters is essential for successful fishing operations. Hence tuna harvest can be enhanced by maintaining the longline depth according to the oceanographic conditions such as currents and chlorophyll-a concentration.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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