Habitat characteristics and distribution of flyingfish in Fak-Fak and surrounding waters

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Habitat characteristics and distribution of flyingfish in Fak-Fak and surrounding waters

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Abstract. In Indonesia, flyingfish are abundant and distributed in Makassar Strait, Flores Sea, Banda Sea, Sulawesi Sea, Maluku Sea, Arafura, Northern Sea of Papua, and Halmahera. The aims of this study were to analyse and describe the characteristics of flyingfish habitat, based on oceanographic conditions and eggs catches, and to visualize the variability in spatial and temporal patterns of predicted potential spawning grounds. The research was conducted in Fak-Fak and adjacent seas in the Indonesian Fisheries Area WPP 715, from 130°–134° E and 2°S–5° S. Data were collected during 2018 for selected months: June, July, August and September. Remote sensing data used in this study included chlorophyll-a concentration (Chl-a) OCI-Algorithm, Sea Surface Temperature (SST) 11µ daytime, Absolute Dynamic Topography (ADT), Significant Wave Height and Ocean Surface Current (meridian and zonal components). Fishery data were collected from fishermen's GPS units, and through participatory mapping. Based on the mapping of fishing locations of flyingfish fishermen, there were four locations where fishing frequency was high. The potential fishing grounds were approximately 5-40 miles from mainland of Fak-Fak. Chlorophyll-a concentration in Fak-Fak waters ranged from 0.201–2.13 mg/m3. The temperature was estimated to be in the range of 27-31°C, with an average temperature of 27.1°C. ADT only changed by 0.01 cm in height each month with a range between 0.88–1.02 cm. Wind was one of the driving forces of geostrophic current. The waves reached a peak in August, with heights ranging from 0.70 to 1.6 metre. Flyingfish were predominantly found in oceanic zones.

1. Introduction

Flyingfish (Family *Exocoetidae*), known locally as *torani* or *tuing-tuing*, comprise at least 50 species globally. They are found in almost all tropical and subtropical seas, living offshore in waters with oceanic characteristics [1,2]. In many tropical regions, flyingfish are an important fishery resource, utilized by small scale fisheries [3]. In Indonesia, flyingfish are abundant and distributed in the eastern part of Indonesia along the Makassar Strait, in the Flores Sea, Banda Sea, Sulawesi Sea, Maluku Sea, Arafura Sea, Northern Papua Seas, and around Halmahera [4,5]. In the eastern Indonesian seas, flyingfish are believed to migrate from the north of Sulawesi Island around February, entering the Makassar Strait [6]. They swim and move to the southern part of Makassar Strait and Flores Sea from about April through August, in concurrence with their spawning season. Then, the flyingfish may continue eastward, some moving north to the Maluku Sea and others south to Banda Sea [6].

In Makassar Strait and Flores Sea, about 11 species that have been found, while only 2 species have been reported from the Sulawesi Sea and Halmahera, and 5 species from Central Maluku. Based on species identification carried out in early August 2007 [3], *Hirundichthys oxycephalus* (Bleeker,

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1852), family Exocoetidae, is the species most exploited for their eggs in the waters of western Papua. This species is said to be the dominant species from the Makassar Strait to the Flores Sea [7] and Central Maluku [8]. In some parts of the Makassar Strait, there has been a decline in flyingfish production, with some fishermen losing their fishing grounds and having to travel further afield [9].

Flyingfish in southern Papua are targeted by fishing fleets from other provinces including vessels from Makassar, South Sulawesi Province. Based on the catch data of the Department of Marine Affairs and Fisheries of Fak-Fak Regency in 2002, production of flyingfish eggs in Fak-Fak was estimated around 33 tons. The flyingfish egg harvesting season usually lasts for five months, from May to September, with a peak between July and August [10]. This seasonal pattern follows the spawning season of flyingfish in these waters, which it is believed could be associated with increased biological productivity in the area due to upwelling which occurs during the southwest monsoon [11]. Flyingfish are concentrated around the spawning area and will be attracted to floating objects as spawning habitat.

Flyingfish are a widely distributed offshore pelagic species. One of the characteristics of flyingfish is a tendency towards separate geographical distributions based on their life cycle, interspecies as well as intraspecies [1]. However, there was a lack of reliable data on fish migration and abundance in Fak-Fak. Surveys on fish distribution are important to understand their population dynamics and to provide a basis for sustainable flyingfish fishery management strategies. The lack of data from the fishermen and related agencies raised questions regarding the potential spawning locations and ecological characteristics of flyingfishes. In this context, it is important to establish baseline data on flyingfish distribution to better understand their population movements and dynamics. Several previous studies have suggested that environmental factors such as SST and ocean currents play a role in determining flyingfish geographical distribution and abundance, and spawning areas [12,13]. However, which oceanographic factors control the distribution and abundance of the flyingfish was still unclear. Characterizing distribution, abundance and habitat of flyingfish can provide understanding about environmental parameters linked to flyingfish abundance, but as yet there were no studies analysing the oceanographic patterns that describe flyingfish habitats in the seas around Fak-Fak.

Remotely sensed satellite observations of the ocean may provide oceanographic information to explore potential spawning grounds and habitat of flyingfish during the spawning season. [14] used satellite images of surface temperature (SST), chlorophyll-a concentration, fishing depth and absolute geostrophic current together with catch data to detect highly productive flyingfish fishing areas in the Flores Sea. The author concluded that potential fishing grounds correspond to the occurrence of oceanographic features such as upwelling and frontal zones which could be responsible for concentrating the fish schools. Therefore, a combination of all these variables may provide important mechanisms for detecting habitat preference and potential spawning locations of flyingfish population in Fak-Fak waters.

The aims of this study were to analyse and describe the characteristics of flyingfish habitat based on oceanographic conditions and eggs catch, and to visualize the variability in spatial and temporal patterns of predicted potential flyingfish spawning grounds, abundance and distribution in Fak-Fak waters during spawning season. The results were expected to provide data and information as inputs to develop holistic management plans for this fishery, considering the flyingfish together with their habitat and ecosystem.

Management policies and conservation require a scientific approach as a basis for responsible management. In particular, the estimation of flyingfish habitat preference and characteristics will provide an improved understanding of the distribution and potential spawning ground of flyingfish in Fak-Fak. This initial information is needed to determine fisheries management areas and approaches to improve fisheries sustainability using an EAFM strategy. Therefore, the outputs should contribute to flyingfish management strategy through spatial planning to ensure sustainable catches and maintain this resource so that it can provide more benefit to fishermen and local communities in the long term.

2. Methods and Materials

2.1. Time and Location

This research was conducted in Fak-Fak and adjacent seas in the Indonesian fisheries management area WPP715, between 130°-134° E and 2°-5° S, during the southwest monsoon (July to September) in 2018. This period was selected based on the peak egg harvesting and flyingfish fishing season. Ground truthing and observation were conducted in September 2018.

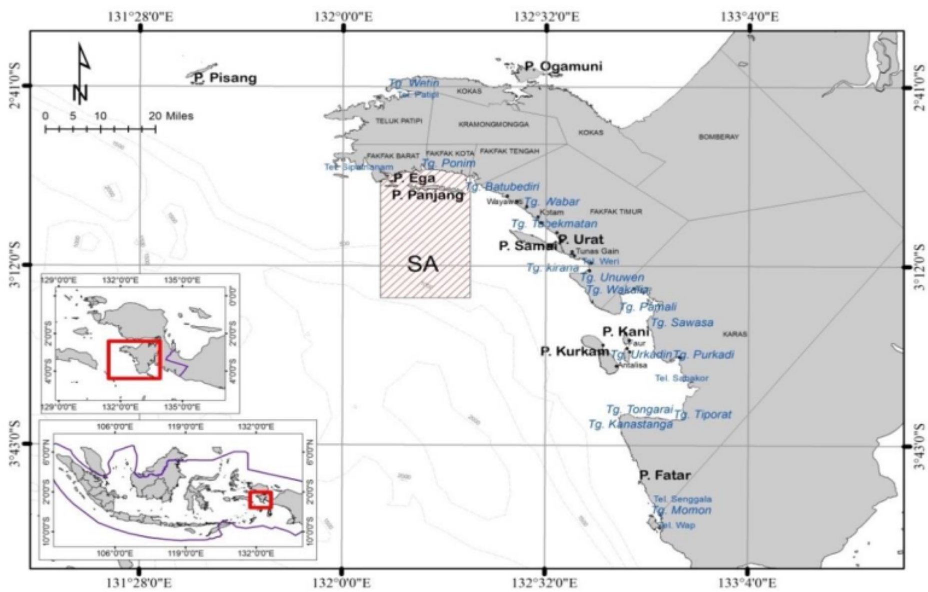

Figure 1. Location of the sampling area (SA) for oceanographic parameters in Fak-Fak and adjacent waters (about 20-30 miles offshore) during September 2018.

2.2. Satellite Data

Remote sensing data used in this study included chlorophyll-a concentration (Chl-a) OCI-Algorithm, Sea Surface Temperature (SST) 11μ daytime, Absolute Dynamic Topography (ADT), Significant Wave Height and Ocean Surface Current (meridian and zonal components). Data were obtained for four months in 2018: June, July, August and September. These months were selected based on the flyingfish spawning and fishing season in Fak-Fak offshore waters. These data provided information for analysing oceanographic patterns in relation to potential fishing ground locations. Chl-a (OCI algorithm) and SST (11μ daytime) were obtained from Aqua MODIS level 3 with 4 km spatial resolution, while data on Absolute Dynamic Topography was derived from the AVISO dataset. Significant Wave Height was derived from ERDDAP using the WaveWatch-III model with an 0.5 degree resolution, while Ocean Surface Current data were derived from the OSCAR database. Data was extracted in NetCDF format and gridded using the kringing method to smooth the pixels and estimate neighbouring values. SEADAS 7.5.1, ODV 5.1, ArcGIS 10.2 and Excel were used to compute, analyse and display remote sensing data.

To calculate geostrophic current velocity and direction, we extracted and calculated data containing zonal (u) and meridional (v) values from the Ocean Surface Current Analysis (OSCAR) database using the following formula:

- Velocity (V) $= \sqrt{u^2} + \sqrt{v^2}$
- Direction (θ) $= 90 - \ tan^{-1}\frac{v}{v}; u > 0, v > 0$

$$90 + \ tan^{-1}\frac{v}{v}; u > 0, v > 0$$

$$270 - \ tan^{-1}\frac{v}{v}; u > 0, v > 0$$

$$270 + \ tan^{-1}\frac{v}{v}; u > 0, v > 0$$

2.3. In-situ Survey

Fishery data were collected from fishermens GPS units and through participatory mapping. A total of 30 respondents were sampled randomly from several fishing villages (Figure 2). The respondents consisted of captain and crewmembers form vessels operating in Fak-Fak during the flyingfish egg harvesting season (June-September). The fishery data we collected consisted of fishing location based on their coordinate position (latitude and longitude), egg production or catch and fishing effort (days of fishing operation). The CPUE used was defined as the total volume of eggs harvested in kilograms per day for each fishing trip. Flyingfish fishermen usually operated 2-3 trips in a season. A single trip could last 20-50 days, depending on the catch, food and logistics, vessel and gear condition.

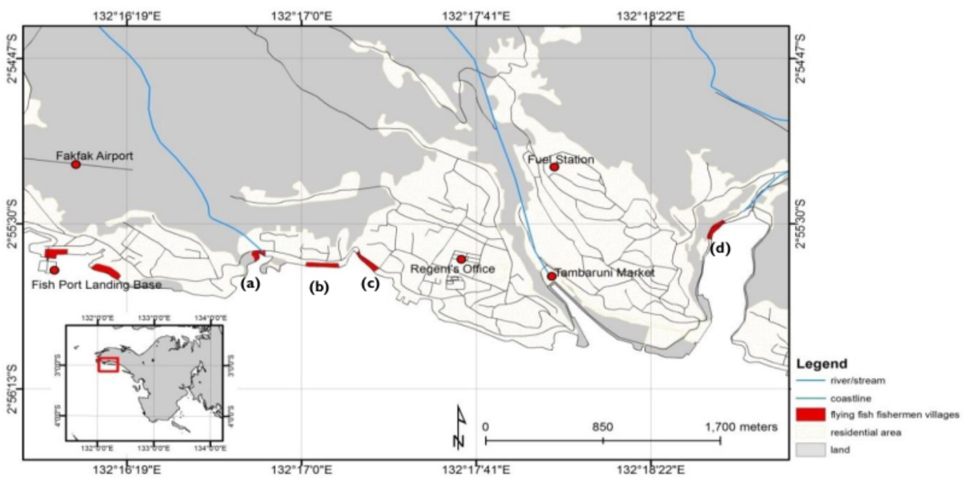

Figure 2. Flyingfish fishing villages in Fak-Fak Regency where data and information were obtained on fishing grounds, catch and effort during the fishing season: (a) Torea, (b) Tanama, (c) Prabu and (d) Sungai.

For groundtruthing, oceanographic parameters collected in the field included SST, salinity, DO (dissolved oxygen) and surface current velocity. Each parameter was measured three times to determine the mean values. Geographic positions of the samples taken were recorded using GPS. The purpose of water quality sampling was to verify the satellite measurements and to provide data on other environmental variables that might influence flyingfish distribution.

2.4. Data analysis

Fishing location data from 2018 was overlaid with 2017 data to determine fishing frequency using a Point Density Analysis method. In addition, remote sensing data was extracted from fishing/CPUE data using the Extract Values to Points tool in ArcGIS. Data were displayed in terms of fishing frequency in response to oceanographic parameters.

3. Results

3.1. Environmental Variability of Flyingfish Habitat

3.1.1. Chlorophyll-a concentration (Chl-a). Chlorophyll-a concentration in Fak-Fak waters ranged from 0.201 to 2.13 mg/m3. The high concentration of Chl-a during the southwest monsoon was presumably due to wind and waves offshore bringing nutrients to the water surface. There is a possibility of frequent upwelling occurring during this season, causing vertical water mass mixing. Upwelling is predicted to occur frequently 5-20 miles offshore from Karas, making the area very productive for fishing.

The chlorophyll-a concentration in Fak-Fak during June-September 2018 can be seen in Figure 3. During the observation period, high chlorophyll-a concentration was observed in several areas close to the Fak-Fak shore (<5 miles) such as in Teluk Nusalasi, Samai, Batu Putih, and Air Kiti-Kiti (Karas). These areas are known as potential fishing grounds not only for flyingfish but also other pelagic fishes. In Pulau Panjang, the high chlorophyll-a concentrations were located further from the shore, over 20 miles to the south. Chlorophyll-a concentrations tended to move north, a phenomenon which may be caused by ocean currents.

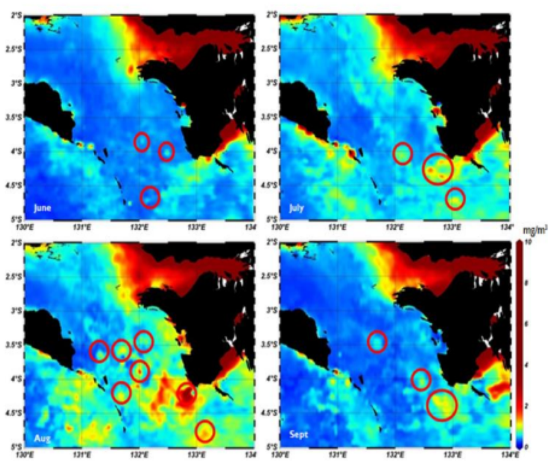

Figure 3. Chlorophyll-a concentration in Fak-Fak waters during the southwest monsoon varied over the observation period. High chlorophyll concentration and distribution occurred in August. Upwellings (indicated by red circles) tended to occur from June to September in areas where chlorophyll-a concentration was higher than surrounding area.

3.1.2. Sea Surface Temperature (SST). Temporal distribution of sea surface temperature (SST) between June and September shows variability leading to an overall decrease in sea surface temperature (Figure 4). Each month the temperature changed by between 0.8 and 10C. SST in the southern Fak-Fak waters was higher than in the northwest during the southwest monsoon. The estimated temperatures were in the range of 27-310C, with an average temperature of 27.10C. Cooler water masses from northern Australia were carried by geostrophic currents accompanied by strong winds to the Arafura Sea and Fak-Fak waters, causing mixed temperatures.

In June the mean temperature was estimated at 29.1°C, then decreased to 26.2°C in August, and gradually rose to 27.8°C in September. The monsoon wind caused mixing and distribution of water masses from areas with warmer temperatures to cooler waters. The groundtruthing, in September 2018, recorded SST ranging between 27.57 – 28.15 °C, while dissolved oxygen ranged between 6.53 – 7 ppm. Near the shore and in the bay the temperature was slightly higher than offshore, presumably due to heat transfer from land to water.

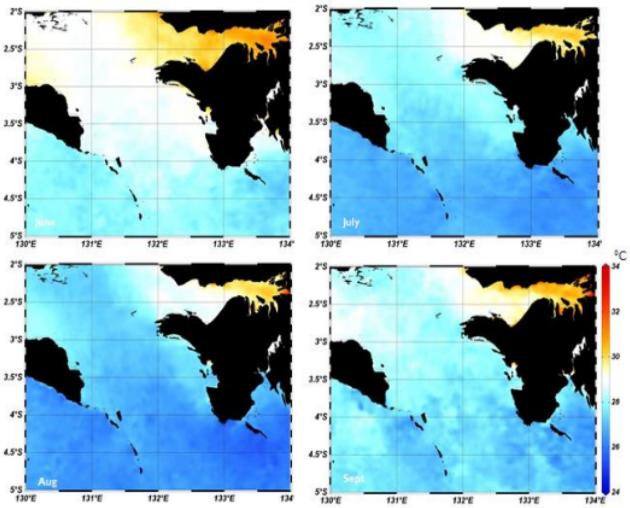

Figure 4. Sea surface temperature variability during southwest monsoon. Cooler water moved northwest from Australia to the Seram Sea from June to August, then gradually increased in temperature by September.

3.1.3. Absolute Dynamic Topography (ADT). Absolute dynamic topography is one parameter that can be used to detect movement of geostrophic current and eddies. ADT is obtained by subtracting the geoid height from altimetry Mean Sea Surface Height above the reference ellipsoid. ADT change only by 0.01 cm height each month with the range between 0.88 – 1.02 during southwest monsoon. ADT starting to decrease from June to August and increase slightly in September. During this season upwelling began to occur from June to August, as the current move from Arafura Sea to Banda Sea due to monsoon wind moving from Australia to Asia.

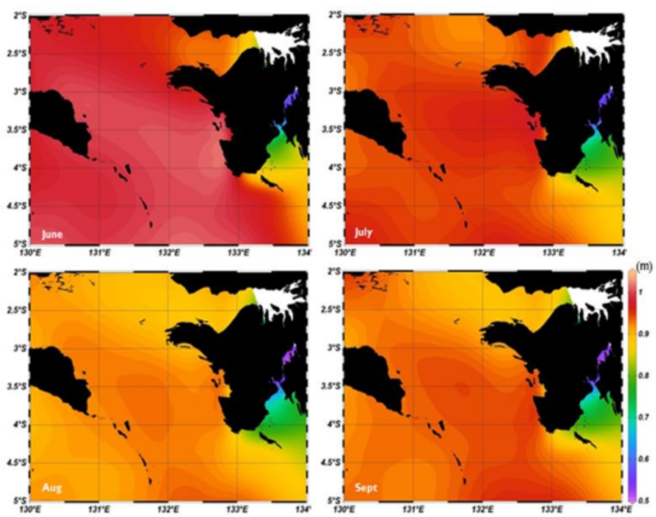

Figure 5. Absolute dynamic topography (ADT) decreased during the southwest monsoon from July to September. The lower ADT in Fak-Fak waters tended to create upwellings in the area, and to cause geostrophic current movement from higher to lower slopes.

In June, the coastal waters of Fak-Fak had higher ADT while other waters such as the Banda and Arafura Seas had lower ADT. In August, higher ADT was detected between Seram Island and Fak-Fak, while lower ADT spread along Fak-Fak waters. Geostrophic currents tended to move from higher to lower slopes and were deflected to left in the south hemisphere, moving counter-clockwise.

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3.1.4. Ocean Surface Currents. In June, a current moving at speeds of 0.5-1.3 m/s passed from Pulau Panjang through the Seram Sea, while between June and September, water masses move consistently from the Arafura Sea to the Banda Sea with speeds between 0.1-0.7 m/s (Figure 6). Between June and July, about 50 miles offshore from Fak-Fak the current diverged in two directions, with one branch heading to the Banda Sea and the other heading to Karas; this divergence brought water masses to the surface and increased ADT in the area. In August, there was increase in current velocity to about 1.7 m/s heading towards the Seram Sea due to an increase in the velocity of winds blowing north from Australia. Eddies were detected on the west of Bintuni Bay in July and September moving clockwise. Eddy is a large vortex or circular mass of water formed in the ocean. The presence of eddy in the area could be associated with rich nutrient water stir up to the surface.

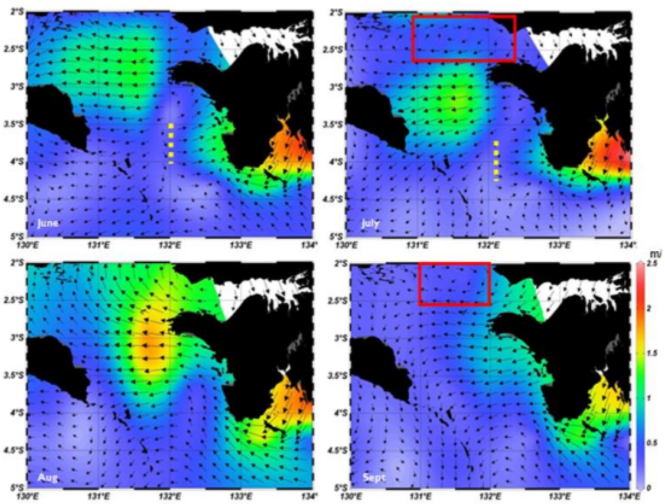

Figure 6. Geostrophic velocity and direction in Fak surrounding waters duri southwest monsoon from September. Eddies (red re occured in July and Septemb west of Bintuni Bay. divergence (yellow line: observed in June and July ab miles west from Fak-Fak.

3.1.5. Significant Wave Height. The wave height reached a peak in August, ranging from 0.70 to 1.6 metres. Significant wave height is the average of the highest 1/3 or 33% of the waves (trough to crest) over a period of time. This means that there could be individual waves that would probably be much higher; for example, in August some individual wave heights reached 4.6 metres due to strong winds. The wave height generally increases away from the shore and decreases close to the shore. Both wind direction and topography also affected the intensity of wave heights. For example, during the southwest monsoon the wind was blowing from the Arafura Sea to the Seram and Banda Seas, thus wave intensity was higher along the exposed coastal area between Kaimana and Fak-Fak. Wave heights were lower from Pulau Panjang to Pulau Kurkam with heights ranging from 0.25 to 0.95 metres. Even though the flyingfish spawning season started in May, the wave magnitude in July was lower compared to September (Figure 7).

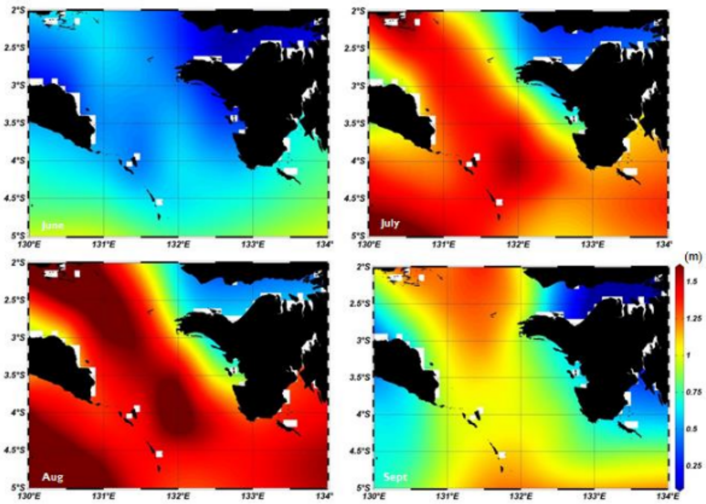

Figure 7. Significant wave height during the southwest monsoon from June to September. The intensity of the wave height increased and reaches a peak in August due to waves driven by strong winds from the Arafura to Banda and Seram Seas.

3.1.6. Water depth. Another parameter that characterizes flyingfish distribution is water depth. Flyingfish are known as oceanic species which means they are distributed offshore. Based on the bathymetry map overlaid with fishing locations, flyingfish were dominantly found in oceanic zones between 7 and 40 miles offshore. This pelagic species was found along continental slope to ocean basin (Figure 8). They swam at depths between 2-15 metres, and during the spawning season they rise to the surface attracted by bale-bale (a kind of fish aggregating device) deployed by fishermen. The waters near Batu Putih and Pulau Panjang have wider neritic zones stretching 7 to 22 miles from the land, while Tanjung Tonggarai and Air Kiti-Kiti have narrower neritic zones, only stretching 5-6 miles from land. These bathymetric features were reflected in the fishing locations, with fishermen from Pulau Panjang tending to go farther offshore than those from Air Kiti-Kiti.

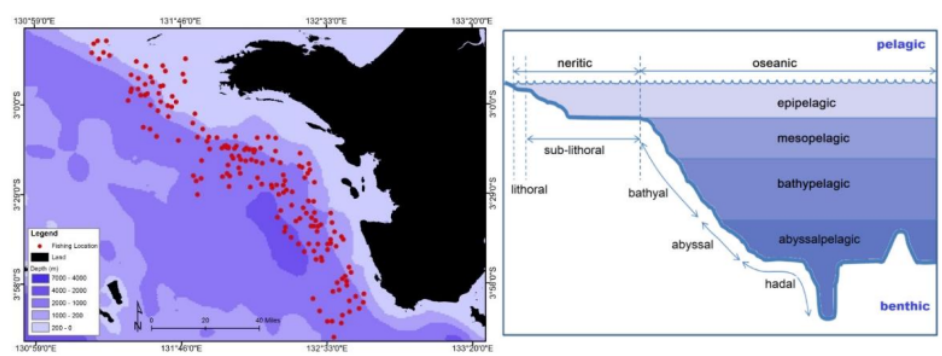

Figure 8. Bathymetry map overlaid with fishing locations in Fak-Fak Waters (left). This map shows that most fishing locations were in oceanic zones between 6 – 40 miles offshore. The right-hand figure shows ocean zones to illustrate flyingfish distribution offshore.

3.2. Distribution of Flyingfish in Fak-Fak

3.2.1. Fishing Ground Based on Fishing Locations. Based on the mapping of fishing locations by flyingfish fishermen, there are four locations with high fishing frequency values: Batu Putih, Pulau

Panjang, Nusalasi and Air Kiti-Kiti. According to the fishermen, these areas are potential fishing grounds (hotspots) for flyingfish. The closest distances from the Fak-Fak mainland were approximately 5-40 miles, with about 70% of fishing activities occurring outside of the Papua Barat provincial administrative border, and thus in waters under central government jurisdiction. Fishers could move 0.67 - 2.7 miles away from their initial fishing ground due to ocean surface currents moving as speeds of 0.3 - 1.2 m/s. They tended to go back to the same fishing locations if the result was good. Based on the fishing ground locations obtained from the fishermen, the total fishing ground area was estimated at around 638,798 hectares (Figure 9).

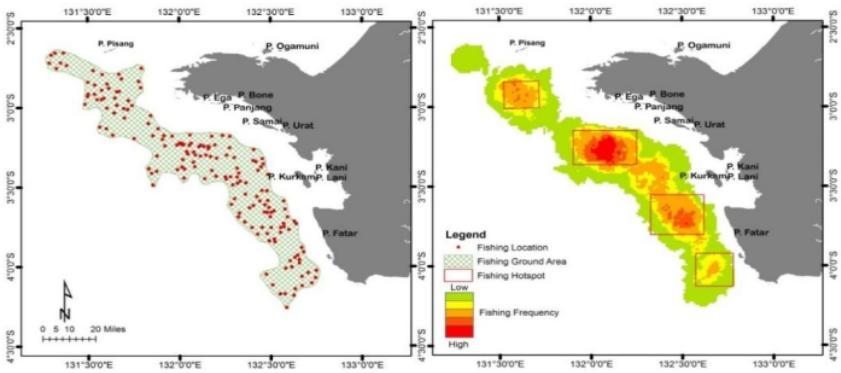

Figure 9. Map of fishing frequency (right) in 2018 overlaid with 2017 data based on fishing location (left). Fishing location was obtained from fishermen's GPS units, survey (participatory mapping) and direct observations at the fishing grounds.

*3.2.2. CPUE of Flyingfish Eggs on Spatial and Temporal Scales***.** Flyingfish abundance in the area may be associated with the egg catch collected by fishermen during spawning season. According to the catch data sampled from 30 respondents total egg production was at its peak in June with 5,369 kg with a total fishing effort of 1,002 days (Figure 10).

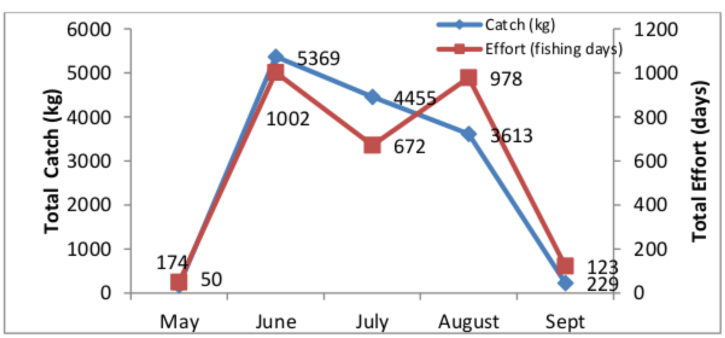

Figure 10. Catch production of flyingfish eggs and fishing effort (days of operation) in Fak-Fak. The peak season started early in June with a total catch of 5369 kg (based on 30 respondents).

Based on the catch per unit effort data (Figure 11), there was an increase in CPUE in June where, in a single trip, fishers could harvest around 214.8 kg of eggs. There was a slight decline of CPUE in the following month. A steep reduction occurred in August and September where fishermen only harvested between 45 and 139 kg/trip. This decline was unlike the previous year when fishers had higher yields in August. Based on the number of operating days, a similar trend is also seen in CPUE, where a fishing vessel could collect 5.4 kg of eggs/day in June and the yield increased to 6.6kg/day in July. This increase was due to the higher egg production rather than longer fishing days. However, the CPUE value declined in August and September with average catches per day of 3.4 and 1.9 kg, respectively.

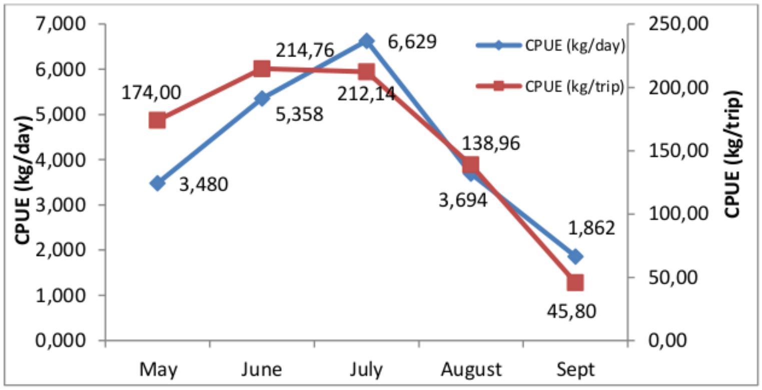

Figure 11. Catch per unit Effort (kg/day) of flyingfish in Fak-Fak. The figure shows a decline in CPUE both per day and per trip from August to September 2018.

The fishing locations and the relative size of the CPUE per location and month can be seen in Figure 12. The CPUE values varied across different spatial scales. In June, most of the fishing locations were concentrated close to the fishing bases and few spread far from Batu Putih and Air Kiti-Kiti, with CPUE between 5.7 and 8.3 kg/day. CPUE was higher closer to the shore (<10 miles), and lower further away from shore (>20 miles). In June and August, the fishing grounds were scattered around Batu Putih, Pulau Panjang, Samai and Air Kiti-Kiti. Other areas where fishermen set their gears included the waters around Pulau Pisang and Pulau Panjang.

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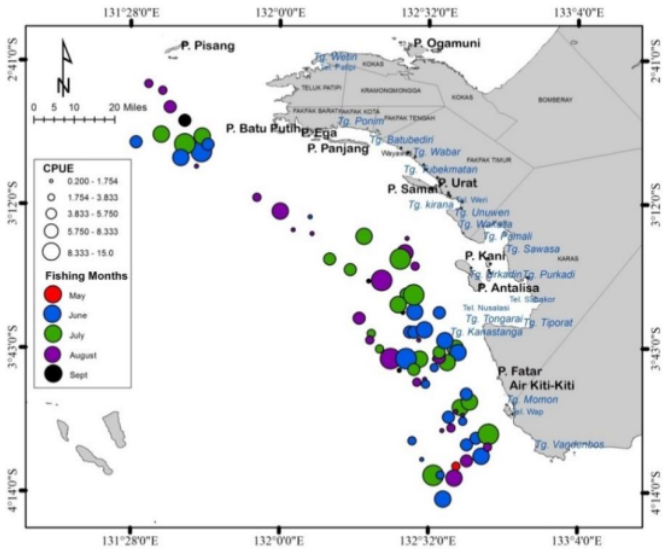

Figure 12. CPUE map based on flyingfish fishing ground locations over the study period in 2018. The map illustrates changes in terms of location and CPUE during the southwest monsoon in Fak-Fak. Changes in CPUE could be related to favourable values of environmental parameters corresponding to flyingfish habitat

In July, high CPUE values were found near coastal areas in Karas. Meanwhile in August, CPUE was lower to the south of Pulau Panjang and Pulau Fatar. In September, fishermen set their fishing gears near Antalisa but their CPUE was also lower, 0.2 -1.75 kg/day. However in Batu Putih, the CPUE was higher again in September, with 5.8 – 8.3 kg/day. The spatial and temporal data based on CPUE values in Figure 12 shows that there was a shift in the location of fishing area from the waters around Karas to Batu Putih towards the end of the fishing season. This shifting of fishing grounds may have been associated with changes in oceanographic pattern in the area. Flyingfish may migrate northwards in conjunction with warmer ocean surface currents flowing towards the Seram Sea.

4. Discussion

Chlorophyll-a concentration in Fak-Fak and surrounding waters varied from June to September during the east monsoon. Chlorophyll-a can be used as an indicator or proxy to evaluate phytoplankton biomass. Furthermore, studies have indicated that pelagic fish catch is high in the areas with high phytoplankton abundance [15]. Highly productive waters have high phytoplankton abundances and high chlorophyll-a concentrations. Chlorophyll-a concentration therefore represents the magnitude of phytoplankton biomass in the water column. Phytoplankton are primary producers which play an important role as a source of food for fish. The chlorophyll-a concentrations in Fak-Fak waters were consistently high in coastal areas and bays (near shore), presumably due to high nutrient input (mainly phosphate) from land and river discharges. Further away from the shore, moving towards the open ocean, chlorophyll-a concentration tended to decrease. Chl-a concentration and distribution increased from June, and then decreased in September. Peak concentration and wide distribution of Chl-a was observed in August, mainly located in the southern Fak-Fak waters.

The season for catching flyingfish eggs generally peaks in July and August, when SST reaches an average of 27.1°C. The temperature offshore (>20 mils) was cooler by between 0.5-0.8 °C. In August, cooler water masses move north to the Seram Sea. Upwellings can also be detected in tropical areas where there are slight drops in temperature of about 2°C as cooler water masses rise up from depths of 40-100 metres. The research report from [13] explains that the sea surface temperature of the Flores Sea during the peak flyingfish spawning period in June ranges from 28-29°C with an average temperature of 29.50°C, higher than the SST in Fak-Fak waters.

Water mass transport in Fak-Fak can occur both near the coast and in the open sea where the main driver is the wind. The winds are a major driving force of geostrophic currents in Fak-Fak and surrounding waters. During the southwest monsoon, high wind energy is transferred to the surface of the water column, creating a surface current that flows from the Arafura Sea towards the Banda and Seram Seas. In the southern hemisphere, water mass movement is deflected to the left of the wind direction due to the Coriolis Effect.

According to fishermen the presence and abundance of flyingfish depends on the wave height. Large wave height during southwest monsoon is associated with flyingfish rising up to the water surface to spawn. Large wave heights with shorter wave lengths may increase the risks for fishermen and their vessels. Smaller vessels usually travel less than 20 miles, while larger vessels can travel further to collect flyingfish eggs. Based on the map model, significant wave height tends to increase starting from June to August, then drop in September. The spatial analysis shows spatial and temporal variability in CPUE (kg/day).

During the southwest monsoon, most fishers operate in Karas waters. They also define this area as a potential fishing ground for pelagic and reef fish. Satellite images also indicated that this area should be a highly productive fishing ground mainly because of the Chl-a concentration, lower SST compared to others region in Fak-Fak, and nutrients discharged from several rivers. This area has potential upwellings with relatively high current velocity during August and September.

Egg production in May was lower because only a few vessels operate during this time of year. Similarly, in September, there was a sharp decline in the catch because the fishing season ended early with only a few vessels continuing to operate. This was marked by a drop in fishing effort in terms of fishing days. In July, the catch dropped to 4,455 kg due to a decline in fishing effort. This decline could be related to a delay in issuing fishing permits. These were issued late because the Fak-Fak government rejected the MoU between the Provincial Governments of Sulawesi and Papua Barat regarding Andon fishermen. In August, fishing effort increased but the catch dropped due fishing ground competition between fishermen. Based on the catch data obtained from fishermen, we could estimate the total catch or egg production in Fak-Fak during one year fishing season; however the samples (respondents) would need to be increased for better representativeness.

5. Conclusion

Several areas in Fak-Fak were classified as favourable habitats for flyingfish, including Air Kiti-Kiti, Tanjung Tonggarai, Pulau Antalisa and Pulau Batu Putih. These areas had high concentrations of chlorophyll-a, related to frequent occurrence of upwellings and ocean fronts. This research also provides scientific evidence corroborating fishers beliefs regarding good fishing grounds in highly productive upwelling areas. The habitat preference of flyingfish does not only relate to food availability but also to habitat suitability for larval development to sustain the population.

This study highlights several oceanographic parameters that characterize favourable ranges of flyingfish habitat including Chl-a, SST, significant wave height, ocean depth, water current velocity and Absolute Dynamic Topography (ADT). These parameters are useful to indicate potential upwelling locations that may attract flyingfish and increase their abundance. The rich nutrients that stimulate phytoplankton productivity may provide flyingfish with forage habitat as well as spawning grounds. The increase in chlorophyll-a concentration and significant wave height, and decline in SST and absolute dynamic topography starting from June to August were good indicators of high flyingfish CPUE, with an opposite pattern in September also marking a decrease in CPUE, where CPUE is used as a proxy to describe flyingfish abundance during the spawning season.

Another parameter that describes flyingfish distribution is depth. The fish live and spawn in oceanic zones, which is why most fishing catches in Fak-Fak are located in waters more than 200 metres deep beyond the continental shelf. These preferred environmental ranges can be used as information to predict the spatial distribution and potential fishing grounds of flyingfish in other tropical waters with similar characteristics to Fak-Fak.

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