Impact of El Niño Southern Oscillation (ENSO), variability on skipjack tuna (*Katsuwonus pelamis*) catches in the fisheries management area (FMA) 715, Indonesia

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Abstract. Marine and fishery resources have trans-boundary nature and have great potential to be affected by the global climate change. Tuna is one of the main export commodities from Indonesia. Patterns of fish life can not be separated from the environmental conditions, whose fluctuations influence the seasonal fish migration and residence period. This study aimed to determine the tuna catch variability in the peak season, under regional climate change constraints, such as El Niño and La Nina, with the aim to optimize the utilization of *Katsuwonus pelamis*. A descriptive qualitative study was conducted to investigate the direct correlation between *K. pelamis* catches during 2015 to 2019 and regional climate changes that occurred in those periods, i.e., El Niño (2015 to 2019) and La Nina (2015 to 2019). Sampling and measurement sessions were performed at the end of the East season, from September to December 2019. The results of this study show that regional climate change affected inter-monthly variation of the peak seasons of *K. pelamis* fishing in the fisheries management area (FMA) no. 715. During El Niño, the FMA 715 was an ideal place for *K. pelamis* fishing. During the period from September to November, the fishing peak season was in October. The regional climate change originating from the Pacific Ocean caused unsuitable water conditions in the FMA 715, regarding the *K. pelamis* fishing. The variability of the climate changes triggered by La Nina in the Pacific Ocean did not provide a favorable environment for the fish migration to the FMA 715 waters.
Key Words: La Nina, salinity, sea surface temperature, climate change, tuna fishing.

Introduction. Indonesia is an archipelagic country that has a strategic position and its waters are part in the oceanic movement known as the Great Ocean Conveyor Belt. The changes occuring in the pattern of the global water mass movement affect the world's climate (Trenberth 2007). The global warming that hits the world today causes global climate change that is irregular and has an impact on the environment as a whole (Blunden et al 2018). This global change affects life in the territorial area and negatively impacts the potential quality and quantity of the marine and fisheries resources (Yáñez et al 2017). The impact of the global warming increased temperatures with 0.5°C throughout the 20th century (Church & White 2011; Masson-Delmotte et al 2018).

Marine and fisheries resources have a trans-boundary character (Song et al 2017) making them vulnerable to the global climate change (Barange et al 2014; Monnereau & Oxenford 2017). Environmental changes that occur and have an impact on the water resources in a particular area can cause environmental changes in other areas (Duran-Encalada et al 2017). Changes in the global environment emerge due to the climate changes characterized by the atmosphere warming. Tuna is one of Indonesia's main export commodities (Hidayat et al 2019; Ningsih 2018). Fish life patterns cannot be separated from the various environmental conditions.

Fluctuations in the environmental conditions have major influences on the period of seasonal migration (Taylor et al 2013) and the presence of fish in certain places (Enders & Boisclair 2016). The main problems faced in the effort to optimize fish catches, especially *Katsuwonus pelamis*, are the availability of data sources for fishing catches and for site characterization. There is very limited data and information about oceanographic conditions that are closely related to potential fishing areas. The early availability of this information is essential for the *K. pelamis* fishing community, so that fishermen can direct their fishing activities effectively and efficiently.

This study aimed to determine the variability of *K. pelamis* catch season to regional climate changes, i.e. El Niño and La Nina. This study investigated the water sensitivity of FMA 715 towards the regional climate changes that affected the monthly variability of *K. pelamis* catches, with the aim to optimize the *K. pelamis* fishing.

Material and Method

Description of the study site. The position of the each observation station was recorded using the Global Positioning System (GPS) in FMA 715, West Papua. Fishing ground location was located in yellow colour area (Figure 1).
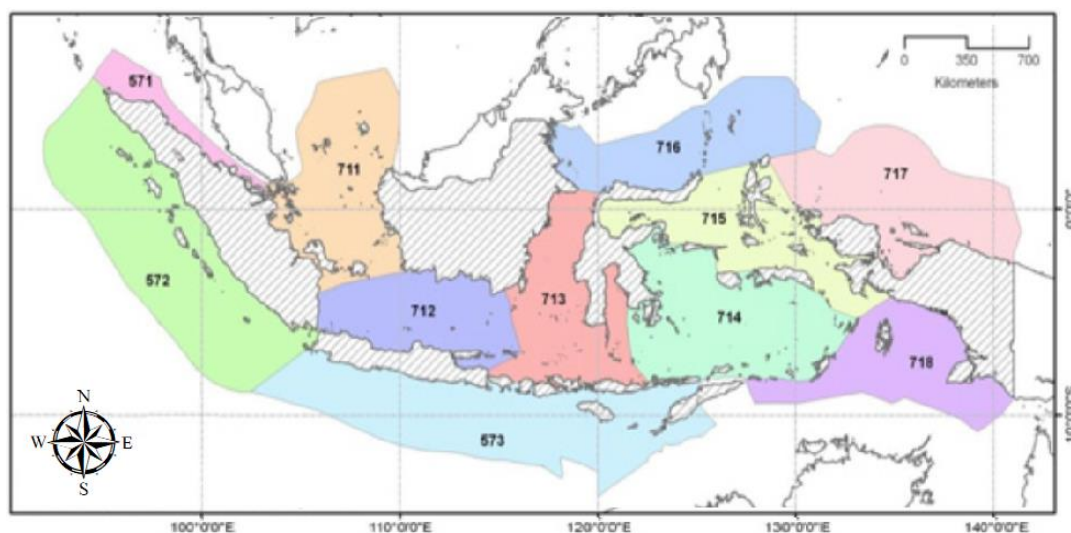

Figure 1. Map of sampling site (MMAF 2018).

Data collection. Observations and data collection on oceanographic variable factors (SST and salinity) in the FMA 715 area were carried out using satellite data and in situ data from September to December 2019, where the West Papua Province was still in the transition season from the East season (Figure 2). The study was conducted using qualitative and descriptive methods by investigating the direct correlation between *K. pelamis* catches during 2014 to 2019 and the regional climate change events that occurred during those periods, i.e., El Niño (2014 to 2019) and La Nina (2004 to 2019) using data from the Indonesian Meteorology, Climatology and Geophysical Agency, Jefman Sorong Station.

Sampling and measurement sessions were carried out at the end of the East season, which was between September and November 2019. Simultaneous measurement methods of the Sea Surface Temperature (SST) in the FMA 715 waters area were performed using satellite imagery and Triton buoy data.
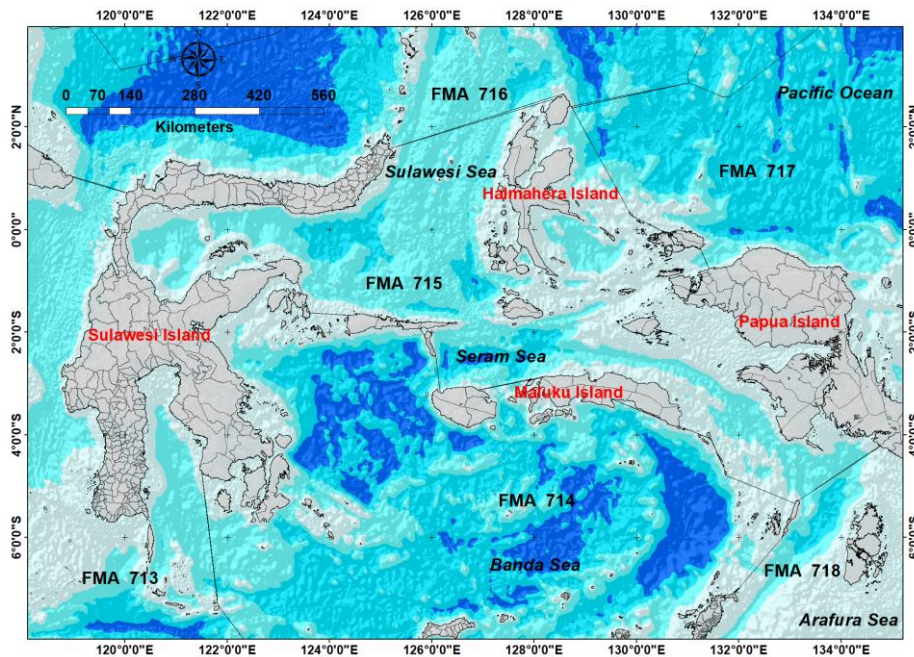
Figure 2. Indonesia Fisheries Management Area (FMA) 715 (MMAF 2018).

Data analysis. Data analysis using descriptive qualitative analysis was conducted to investigate the direct correlation between *K. pelamis* catches during 2014 to 2019 and the regional climate changes that occurred in those periods, i.e., El Niño (2015 to 2019) and La Nina (2015 to 2019).

Results and Discussion

Resources. West Papua is one of the Provinces in the Papua Island that has a considerable fish resource potential and has good prospects for capture fishery activities, especially pelagic species, among which fishery commodities with important economic value such as tuna, *K. pelamis* and small fish groups. It was recorded in 2019 that 15,825 tons of tuna were caught (MMAF 2012). Fishing season occurs throughout the year and moves according to food availability and temperature that can be tolerated by the fish body (Brucet et al 2012; O'Gorman et al 2016).

K. pelamis in eastern Indonesia waters are available throughout the year, especially in the Maluku Sea, Halmahera Sea, Banda Sea, Seram Sea and Sulawesi Sea (Tadjuddah et al 2017; Hidayat et al 2019). The abundance of *K. pelamis* is very dependent on the oceanographic conditions of waters, especially on the water temperature (in accordance with the tolerance of body temperature of *K. pelamis*) and abundance of food. The potential fishing catch zone is strongly influenced by oceanographic physical, chemical and aquatic biology factors, including the SST (Zainuddin 2011), distribution of horizontal (Zainuddin et al 2017) and vertical temperature, salinity, chlorophyll-a concentration and front or up welling phenomena (Putri et al 2018).

Climate conditions. The waters of FMA 715 are areas of a tropical zone, in a region with rainfalls above 3,000 mm year^{-1}, located to the west of Irian and Mindanao. It is the center of a warm water pool, which results in intensive convection accompanied by high velocity currents (Wyrtki 1961). During the period of 2019 in September-November, data collected from Jefman station, Sorong, showed the average rainfall decrease, both in number of rainy days and in rain intensity. This indicates the occurrence of the seasonal transition process in the FMA 715 waters, from the rainy season to the summer (transition season).

Oceanographic conditions. In the eastern part of the Indonesian archipelago flow important ocean currents, known as Arus Lintas Indonesia (Arlindo). This current flows from the Pacific Ocean to the Indian Ocean and falls on the surface and the thermocline zone. In general, the waters of the West Papua Sea and FMA 715 are directly influenced by the Pacific water mass, from the entrance of the main area consisting of the Indonesian waters to the Indian Ocean. The effect of oceanic water mass from the Pacific Ocean is dominant in the East season.

The upwelling process in the waters of North Papua is generally caused by the flow of westward water mass from the Pacific, in the form of warm water mass towards the Halmahera Island, which spreads in many directions, including towards the equator and Indonesian waters, through the waters gate between the Halmahera and the Papua Islands (Hartoko 2007). Pelagic fish are organisms that have the ability to move, so that they do not depend on ocean currents or the water movements caused by wind. However, the ocean currents form areas known as upwelling and fronts. The horizontal surface temperature pattern in North Papua comes from the mass flow temperature of the water originating from the Northwest. This event is known as the lower current in New Guinea Coastal under Current (NGCUC). The transfer of water mass from the Pacific (inflow) into the Eastern islands such as Papua occurs along the Northwest monsoon and outflows to the Indian Ocean, during the Southeast monsoon wind (Hartoko 2007). The NGCUC water mass flows from a depth of 100 m in the North Papua, then continues to the surface of the water in the South Halmahera and becomes upwelling as shown in Figure 3. Upwelling brings nutrients from deeper water to the surface, causing nitrification and phytoplankton bloom (Kämpf & Chapman 2016).
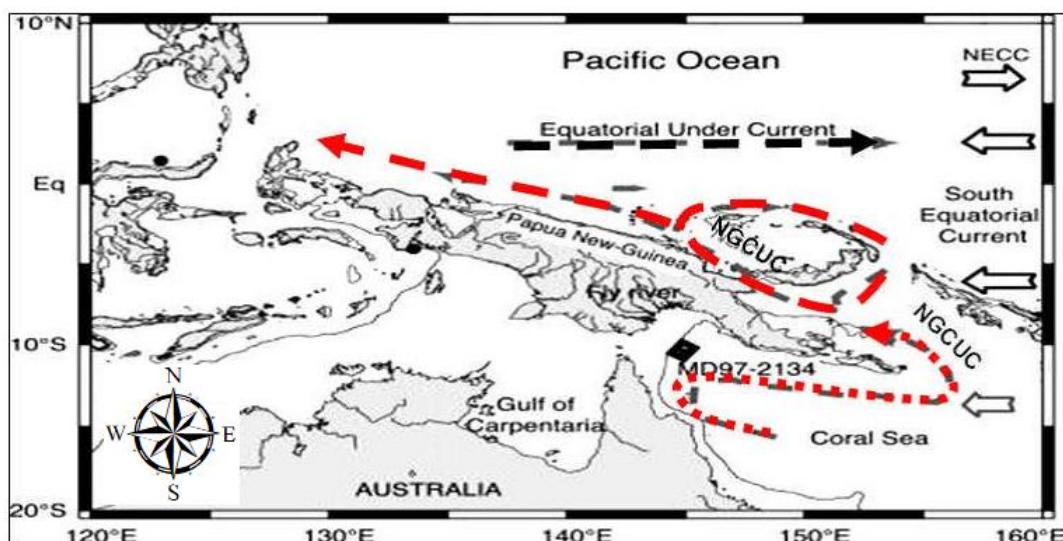

Figure 3. Current flow patterns in North Papua (Hartoko 2007).

Water temperature. The temperature of the FMA 715 waters is directly affected the Pacific Ocean. Water temperature based on vertical sea temperature data from Triton buoy was obtained at various depths 1.5 m. Temperature data from Triton show an average of the SST variations ranging from 28.4 to 30.6°C (Figure 4). The largest catch of *K. pelamis* occured in the SST range of 29 to 30°C (Nugraha et al 2020).
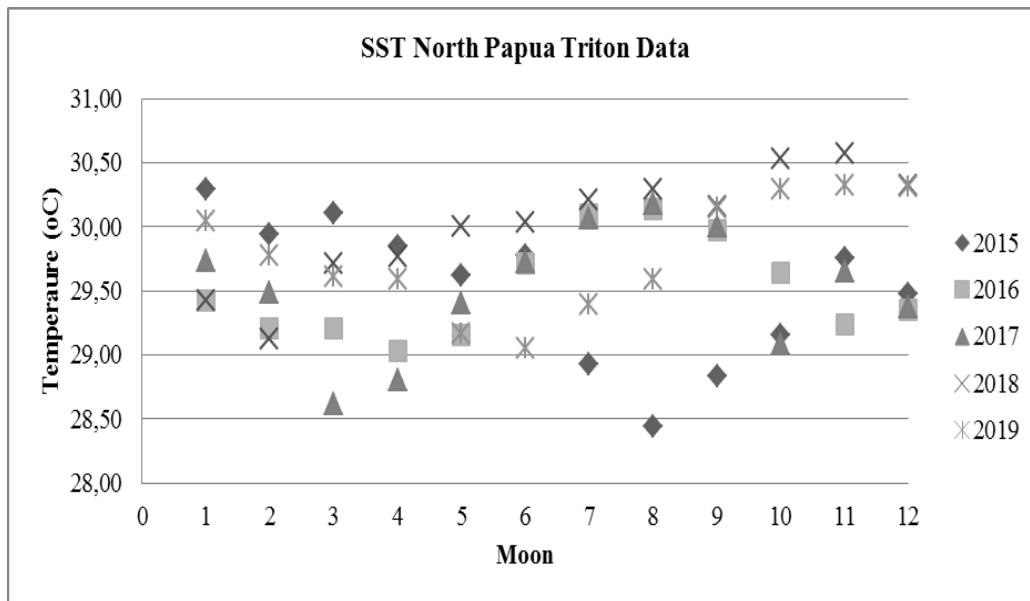
Figure 4. Sea Surface Temperature (SST) in the FMA 715 waters.

Salinity. The water surface layer's salinity is influenced by wind and monsoon current. In the east monsoon, a high salinity value occurs due to Arlindo currents, which transfer water masses from the Pacific Ocean into Eastern Indonesian (Bahiyah et al 2019). The vertical salinity data of the TRITON buoy shows the temperature data obtained at each depth of 1.5 m. During the period from 2015 to 2019, the salinity profiles at certain coordinate points in North Papua show values ranging from 33.3 to 34.6 psu (Figure 5).
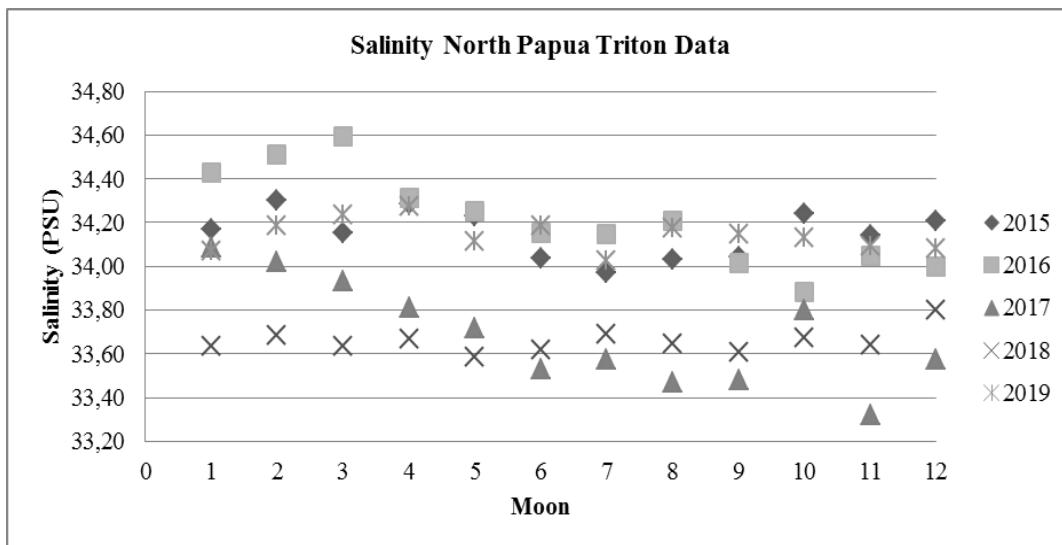

Figure 5. Salinity profiles in North Papua waters.

Catches of K. pelamis. January, May to June and September to December are not the appropriate seasons for *K. pelamis* fishing in the area of Papua. The five years catches of *K. pelamis* originating from the headwaters of Papua and landing at Radios Apirja Co. Ltd. reached their highest levels in March. It can be assumed that in March, the waters to the north of Papua (FMA 715) were in a suitable condition, with food available in abundance, and it was convenient for *K. pelamis* to migrate into (Mugo et al 2010).

The graph from Figure 6 of *K. pelamis* catches shows decreasing trends in the fishing periods of February to May and September to December and increasing catches in June to August, November and January, without considering other factors that affect production, such as fishing fleet, size and number of catches.
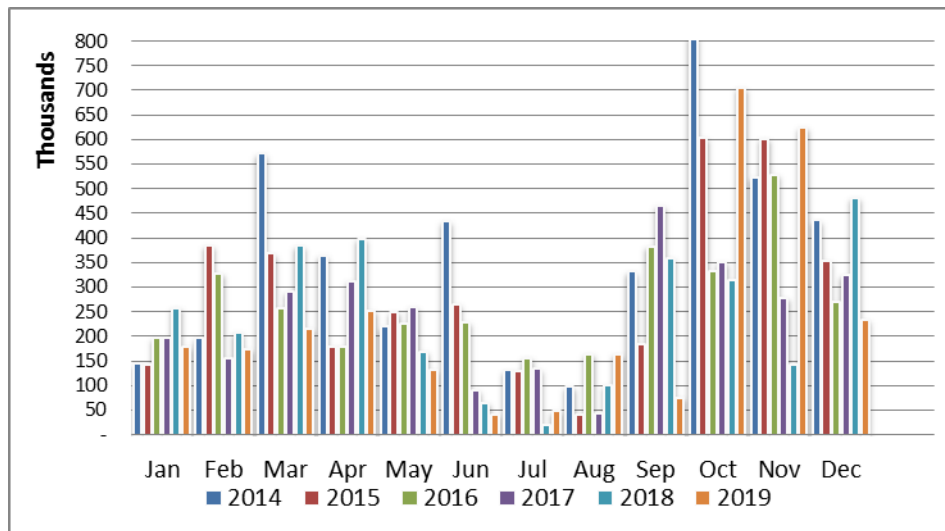
Figure 6. Catches of *Katsuwonus pelamis* from 2014 to 2019.

Correlation analysis of K. pelamis catches and regional climate change. The conditions of Indonesia's oceanography are influenced by global climate change factors, for example by the condition of rainfall on land and at sea, the sea surface temperature (SST) and the sea level height. Rainfall is influenced by the El Niño phenomenon which is predicted to affect sea surface temperature. Global warming will increase sea level (Mimura 2013) and water temperature (Brown et al 2019). The impact of the ozone layer is expected to affect the performance of chlorophyll synthesis.

El Niño. El Niño is characterized by a SST decrease in the Indonesian waters and increase (of more than 0.5°C) in the eastern tropical Pacific Ocean (Sofian et al 2011). From March 2014 until April 2016, the regional climate experienced one of the longest dry seasons in History, due to El Niño. The year and intensity of El Niño can be seen in Figure 7 (NOAA-NWS 2019).

Running 3-Month Mean ONI values
https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php
WE=Weak El Niño, ME=Moderate El Niño, SE=Strong El Niño, VSE=Very Strong El Niño
WL=Weak La Niña, ML=Moderate La Niña, SL=Strong La Niña

ENSO Type		Season		JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
	2013	-	2014	-0.4	-0.4	-0.3	-0.2	-0.2	-0.3	-0.4	-0.4	-0.2	0.1	0.3	0.2
WE	2014	-	2015	0.1	0.0	0.2	0.4	0.6	0.7	0.6	0.6	0.6	0.8	1.0	1.2
VSE	2015	-	2016	1.5	1.8	2.1	2.4	2.5	2.6	2.5	2.2	1.7	1.0	0.5	0.0
WL	2016	-	2017	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6	-0.3	-0.1	0.1	0.3	0.4	0.4
WL	2017	-	2018	0.2	-0.1	-0.4	-0.7	-0.9	-1.0	-0.9	-0.8	-0.6	-0.4	-0.1	0.1
WE	2018	-	2019	0.1	0.1	0.4	0.7	0.9	0.8	0.8	0.8	0.8	0.8	0.6	0.5
WE	2019	-	2020	0.3	0.1	0.1	0.3	0.5	0.6	0.5	0.6	0.5	0.3	0.0	-0.3

Figure 7. El Niño years and intensities (NOAA-NWS 2019).

El Niño began to be felt in October 2014, with a moderate intensity, when the western Pacific equatorial hot pool moved from the west to the central Pacific. This caused Indonesia's internal waters to obtain a mass supply of water that is relatively cooler than the The Indonesia through Flow (Arlindo) coming from the western Pacific Ocean. This condition continued to grow with the strengthening of El Niño signals, which became extreme in November 2015 and returned to normal conditions in May 2016 (Figure 7). From August 2015 to April 2016, El Niño was a stronger category, even reaching its peak in January 2016 (Figure 7), and during this phase, *K. pelamis* catches increased (Figure 6).

Normal phase. The oceanographic conditions of FMA 715 returned to normal and upwellings began to form. The formation of warm water masses in the internal waters of

FMA 715 is an ideal condition for the *K. pelamis* environment. The normal phase can be observed from March to September 2014 and from March to August 2018, with increasing yield catchment, but not as significant as in the El Niño phase.

La Nina phase. During La Nina (from June 2016 to January 2017 and from June 2017 to April 2018), *K. pelamis* catches were decreased when observed in the fishing area of the western Pacific, compared to the eastern and central Pacific regions. Correlations between *K. pelamis* catches in FMA 715 waters and regional climate change could be observed, using SST and depth temperature data from the Triton buoy. Within the transition season (September to November), the *K. pelamis* catches showed a decrease.

K. pelamis migrated in the La Nina period, moving from the Pacific to the East (including Indonesia). These conclusions proved the observation of a shift in the fishing season, caused by climate change, reported by the fishing communities active in the FMA 715. This weather deviations can have a positive impact on the fisheries sector, triggering migrations of tuna to the territorial waters of Indonesia. Turkington (2019) reported that El Niño and La Niña have the potential to occur periodically, every 2 to 3 years.

A possible impact of the climate change on fisheries is a decrease in the catch results, which can occur due to the migration of the targeted fish species. The migration from temperate (sub-tropical) to tropical climate regions (and not vice versa), due to the climate change, will decrease the fish stocks. Climate change will greatly affects the physiology and behavior of individuals, populations and communities (Walther 2010; Butler 2019). Extreme conditions with rising water temperatures, low dissolved oxygen concentrations and water pH can result in fish death. Environmental conditions that are not optimal can reduce metabolic rate, growth and ability of fish to lay eggs, and can also change metamorphosis, endocrine systems and patterns of the fish skin (Roessig et al 2004).

Conclusions. This study suggests that the peak season of *K. pelamis* fishing in the waters of FMA 715 can be predicted based on information on the area's climate conditions. The study also shows that regional climate change greatly affects the inter-monthly variation and the peak of the *K. pelamis* fishing season, in the FMA 715 waters. During El Niño, these waters are an ideal place for catching *K. pelamis*. In normal climatic conditions, the peak of the fishing season occurs from October to November. Regional climate change triggered from the Pacific Ocean does not provide a suitable environment for *K. pelamis* migration to the FMA 715 waters. Therefore, the regional climate change triggered from the Pacific Ocean can also make these waters unfavorable for the *K. pelamis* environment.

Conflict of interest. The authors declare no conflict of interest.

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