The Effect of ENSO (El Nino Southern Oscillation) phenomenon on Fishing Season of Small Pelagic Fishes in Indonesia Waters

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Abstract. The El Nino Southern Oscillation (ENSO) phenomenon causes changes in environmental conditions such as water temperature, salinity, and rainfall. In fisheries sector, the changing environment has affected the fishing seasons and Catch per Unit Effort (CPUE) of some pelagic species. This research was conducted by calculating CPUE and fishing season index for several small pelagic fishes in Makassar Strait, Bali Strait, and Aceh waters, then comparing the index value with the fishing season pattern in two extreme periods that are 2010-2011 and 2016-2017. An ANOVA test was conducted to assess the significant difference between normal and extreme conditions. The results of the analysis showed that there was a significant different in CPUE between average normal condition and ENSO period. Every single species showed different response to ENSO event, mostly decreased in CPUE relate to El Nino event, except for sardine in Bali and Makassar Strait and scad in Makassar Strait. ENSO affects shift in the fishing season of big-eye scad, scad, sardine, and neritic tuna in Makassar Strait, Bali Strait, and around Aceh waters. Indian mackerel in Makassar Strait showed no change in fishing season but the CPUE showed lower than normal condition. This study shows that ENSO was significantly affected fisheries in Indonesia waters.

1. Introduction

Indonesia’s territorial waters are geographically influenced by the dynamics of Indian Ocean and Pacific Ocean. The dynamic in the Pacific Ocean is complex, there is a large-scale oceanic warming event that occurs every few years called El Nino[1]. When El Nino combines with the southern oscillation which is related to the changes of sea level pressure, it causing the ocean-atmosphere interaction called ENSO[2]. ENSO phenomenon occurs in Pacific Ocean influence the oceanographic and atmospheric condition in Indonesia such as changes in seawater temperature[3] and rainfall[4]. Concerning temperature changes, ENSO phenomenon showed two phases that are warming phases in the Central and Eastern Pacific region called El Nino, and cooling phases called La Nina[2]. In Indonesia waters El Nino causing a decrease in seawater temperature while La Nina is an opposite condition[3].

ENSO has been reported to influence many sectors including fisheries both aquaculture and capture fisheries as well as a marine ecosystem[5]. Changes in aquatic environmental conditions caused by ENSO in Indonesia will certainly affect fish resources[6]. The results of previous studies showed that
which eventually affects the socio-economic conditions of the fishing community. Seawater temperature is a variable that is directly affected by ENSO causing anomalies conditions. Previous studies showed that the temperature anomaly in the Bali Strait associated with the ENSO phenomenon significantly affects sardine catches[7]. Temperature influences fish migration[5], at a certain level it increases predation rate as well. Changes in water temperature for several months continuously influence the fish stock abundance, then the fishing season shifting in the end. This study aims to analyze the effect of ENSO on the small pelagic fishing season in some fishing grounds around Indonesia water.

2. Material and methods

2.1. Data Collection

This research is conducted by collecting catch and effort data from National Fishing Port of Pengambengan Bali, Pekalongan Central Java, and Lampulo Aceh. A fishing vessel with purse seine gear landed in Pekalongan Fishing Port commonly has a fishing ground in Makassar Strait. Small pelagic data from Lampulo Aceh described landing data from a vessel operated around the West Coast and Northern Area of Aceh, not included vessel operated in Malaka Strait. ENSO Index used is Ocean Nino Index (ONI) collected from Climate Prediction Centre NOAA (https://origin.cpc.ncep.noaa.gov/). El Nino and La Nina events are determined by using ONI, El Nino indicated positive ONI for four consecutive months and La Nina indicated by the opposite condition.

2.2. Determination of CPUE

Catch per unit effort (CPUE) is determined by using monthly catch and effort data for 12 years (2009 – 2020), 9 years (2010 – 2018), and 6 years (2008 – 2013) for Bali Strait, Aceh waters, and Makassar Strait respectively. Calculating and arranging monthly CPUE (Y) was carried out by following the equation[8]:

\[ CPUE_i = \frac{C_i}{f_i} \text{ with } Y_i = CPUE_i \]  

Note: 
\[ i = 1, 2, 3, \ldots, n \]  
\[ C_i = \text{catch} \]  
\[ f_i = \text{effort} \]  
\[ Y_i = i-\text{CPUE} \]

The average of CPUE in normal years is compared to CPUE in the years in which ENSO occurs. A simple ANOVA analysis was performed to test the difference in significance of the two CPUE for the datasets that are normally distributed. When the data distribution was not normally distributed, the Kruskal Wallis analysis was performed.

2.3. Determination of Fishing Season Index

The fishing season index was analyzed by moving average method[9] based on catch per unit effort data with the following steps of calculation:

- Arranging the moving average of 12 months of CPUE (RG)

\[ RG_i = \frac{1}{12} \times \sum_{i-6}^{i+5} Y_i \]  

Note: 
\[ i = 7, 8, 9, \ldots, n-5 \]  
\[ RG_i = \text{moving average of 12 months of CPUE i-order} \]

- Arranging the moving average of center CPUE (RGP)

\[ RGP_i = \frac{1}{2} \times \sum_{i-l}^{i+l} RG_i \]  

Note: 
\[ i = 7, 8, 9, \ldots, n-5 \]  
\[ RGP_i = \text{moving average of center CPUE i-order} \]
• Calculating the average ratio for RGP monthly data ($R_b$)

$$R_b^i = \frac{Y^i}{RGP^i}$$  \hspace{1cm} (4)

Note: $i = 6, 7, 8, \ldots, 12$

$R_b^i$ = average ratio for RGP monthly i-order

• Arranging the average value of matrix sized i x j by month, start on July ($R_{bij}$)

• Calculating the monthly average ratio, total monthly average ratio, correction factor, and the fishing season index:

(i) Monthly average ratio i-order (RBB$_i$)

$$RBB^i = \frac{1}{n} \times \sum_{j=1}^{n} R_{bij}$$  \hspace{1cm} (5)

Note: $i = 1, 2, 3, \ldots, n$

$R_{bij} = monthly$ average ratio in matrix sized I x j

RBB$_i$ = monthly average ratio for RGP monthly i-order

(ii) Total monthly average ratio (JRBB)

$$JRBB = \sum_{i=1}^{12} RBB^i$$  \hspace{1cm} (6)

Note: $i = 1, 2, 3, \ldots, 12$

JRBB = sum of monthly average ratio

(iii) Correction factor (FK)

$$FK = \frac{1200}{JRBB}$$  \hspace{1cm} (7)

(iv) Fishing season index (IMP)

$$IMP^i = RBB^i \times FK$$  \hspace{1cm} (8)

Note: $i = 1, 2, 3, \ldots, 12$

IMP$_i$ = fishing season index i-order

If IMP value > 100% that means the month is on the fishing season, on the other hand, if IMP value is < 100% the month is on the opposite side.

3. Result

3.1. CPUE and fishing seasons of small pelagic fishes in Bali Strait.

Four species were analyzed to figure out the effect of ENSO on small pelagic fishes, which are Bali sardine (Sardinella lemuru), scad (Decapterus spp), fringe scale scad (Sardinella fimbriata), and mackerel tuna (Auxis thazard). Bali sardine dominates the small pelagic catches in Pengambengan Fishing Port. However, another three species are economically important. Analysis of CPUE of four small pelagic species in Bali Strait shows a significant effect on CPUE of those four species (Figure 1). Catch data distribution of four small pelagic species was not normally distributed (Table 1), then the compare means analysis was conducted by using Kruskal Wallis analysis.

Comparing the CPUE of Bali sardine for all event periods shows that there is a significant difference in CPUE and fishing season between normal conditions and extreme periods occurred in 2010, 2011, 2016, and 2017 at a significant level of 5% (Kruskal Wallis Asym sign 0.000) as shown in Table 1. El
Nino event is related to an increase of CPUE, while the La Nina event is related to low CPUE (Figure 1). Bali sardine shows a sensitive tolerate to changing environments particularly seawater temperature [6]. The CPUE of neritic tuna shows a different response to El Nino in 2010 and 2016, the average CPUE in 2016 is 1.14 tons/trip, which was about three times higher compared to 2010. The lowest CPUE was in 2017 when extreme global conditions occurred (Figure 1). Scad and fringe scale scad showed a similar response to super-strong El Nino in 2016 affected on dropped of the catches to a minimum number, the catches start to increase when weak La Nina occurred in November.

**Figure 1.** CPUE of sardine (top left), scad (top right) neritic tuna (bottom left), and fringe scale scad (bottom right) in average normal condition compare to ENSO periods in 2010, 2011, 2017, and 2018.

**Table 1.** Kruskal Wallis test results on significant differences for four species of small pelagic fishes.

| Species                  | Sardine | Scad  | Fringe scale scad | Macakarel tuna |
|--------------------------|---------|-------|-------------------|----------------|
| Chi-square               | 56.51   | 22.57 | 8.672             | 14.410         |
| df                       | 5       | 4     | 2                 | 4              |
| Asymp. sign              | .000    | .000  | .013              | .006           |

**Bali sardine (Sardinella lemuru)**

In normal condition, the fishing season for Bali sardine start in October to February, showing two peaks seasons occur at November and February. From 2010 to 2011, there is a unique phenomenon when strong El Nino suddenly changes into strong La Nina, which impacted Bali sardine fish catch directly. When El Nino occurred, sardine catch increase significantly over three months at a time when catches are usually low under normal conditions (Figure 1). However, sardine catches were drastically dropped
when La Nina occurred in the middle of 2010. Then, the La Nina period continued to 2011 and occurred all over the year causing a low catch of Bali sardine in 2011. The next extreme condition period occurs in 2016 coincided with super-strong El Nino (ONI > 2) and 2017 when the increase of water temperature was not related to ENSO, but global warming phenomenon. The same with previous El Nino in 2010, strong El Nino in 2016 generates a drastic increase in sardine catches. The peak season of sardine catch shifted three months later after super-strong El Nino occurred at the end of 2015. Super-strong El Nino at the end of 2015 continues to the beginning of 2016 then follow by weak La Nina at the end of 2016 and continue with global warming in 2017 lead to a significantly dropped in sardine catches in Bali Strait.

Scad (Decapterus spp.)
Scad showing dynamic seasons in a year, three peak seasons take place every year at February, April and August shows the highest. In the period of El Nino 2010 scad showed delays in peak season, the catches tend to be flat over the year, the increase in scad catches occurred in July then slowly decrease in August to December. In 2011 that relates to the La Nina year, the catches seem to be normal in number, but the peak of fishing season was delayed for one to three months so that in 2011 peak season of fishing scad occurs in March, June, and November. Super-strong El Nino in 2016 impacted a significant decrease in scads catches, indeed it almost zero catch for over 2016, then continue to the beginning of 2017. The catches of scads drastically increase in July then reach the maximum number in August (Figure 2). Response of scad fishing season on ENSO seems to shows that scad is sensitive to low water temperature relate to the El Nino phenomenon. Scad shows an opposite response with sardine to El Nino events, Scad CPUE was low when El Nino events occurred, the stronger El Nino (2016) the lower the CPUE value (Figure 2).

Group of neritic tuna
A neritic tuna is a group of fish composed mostly of three species namely Auxis thazard, Auxis rochei, and Euthynnus affinis. The landing data on those three species are not separated from one another. Fishing season index shows that there is two peak season of fishing mackerel tuna in Bali Strait that is February and May, the real peak season that reaches over 200%. El Nino period in 2010 causing lost in mackerel tuna catches and delayed in peak season. At the beginning of 2010, the catches of neritic tuna were significantly decreased; the catches start to increase slowly in July then reach the maximum number in October (Figure 2 left). Super-strong El Nino 2016 showed a different impact on neritic tuna catches, the peak fishing season occurred in March and October, meaning that there was a delay in fishing season for about one to five months.

Fringe scale sardine (Sardinella fimbriata)
Landing data on fringe scale sardine (Sardinella fimbriata) in Bali Strait start in 2014, therefore we cannot analyze the response of 2010 – 2011 extreme periods. The fishing season index shows that peak season occurs twice a year in February and September (Figure 2). In 2017 the dynamic of Fringescale sardine follow the normal pattern but then delayed in the second peak season for two months. The fishing season pattern of fringe scale sardine in Bali Strait shows a negative response to the El Nino phenomenon.
Figure 2. Fishing season of neritic tuna, in normal condition compare to the extreme period of 2010-2011 (left) and 2016–2017 (right); sardine fishing season (top), scad fishing season (second line), neritic tuna fishing season (third line) and fringe scale scad (bottom).

3.2. Fishing season of pelagic fishes in western Aceh waters

Analysis on the response of pelagic fishes in western Aceh waters was carried out on three species are Scad (*Decapterus* spp.), yellow-striped scad (*Selaroides leptolepis*), and skipjack (*Katsuwonus pelamis*), even though skipjack is included in a large pelagic group, but catches were dominated by small size fishes. All three species showed a significantly different response to ENSO periods based on ANOVA analysis (Table 2).

Table 2. Compare mean analysis results of ANOVA on three species of pelagic fishes response to ENSO periods.

| Species          | Scad   | Yellowstriped scad | Skipjack |
|------------------|--------|--------------------|----------|
| F value          | 20,698 | 222,207            | 11,037   |
| df               | 4      | 4                  | 4        |
| Asymp. sign      | 0.000  | 0.000              | 0.000    |
Compare mean of CPUE shows the different responses of small pelagic species on ENSO events. Scad data has a normal distribution, therefore the compare means analysis then continues by using ANOVA and Tukey test for post hoc test. ANOVA test showed that all the data compare is significantly different (sig: 0.05%), and Tukey test shows the year that significantly different from the normal average condition is 2010 (Figure 3) when there was shifting on strong El Nino to strong La Nina leading to extreme condition at that time. CPUE scad in Aceh showed a different response to the ENSO event in two extreme periods that occurred in 2010-2011 and 2016-2017. In the period 2010-2010, CPUE scad was lower than normal, but in the period 2016-2017 CPUE scad rose significantly, even though it occurred in the same ENSO event, namely El Nino (Figure 3).

![Figure 3. Compare mean of CPUE in average normal condition and ENSO events for scad (top left), yellow-striped (top right), and skipjack (bottom).]

**Scad (**Decapterus spp.**)**

Scad fishing season in Aceh water comes about once a year occur in October when catches reach about 150% from the normal condition. When El Nino 2010 occurred, scad catches seems to fluctuate, and the peak fishing season came one month earlier. La Nina period in 2011 showed a similar effect on fluctuation on catches, however, the peak season come delayed for one month. Different response on El Nino occurred in 2016 showed that peak season of scad came two months earlier (Figure 4).

**Yellow striped scad (Selaroides leptolepis)**

Yellow striped scad in Aceh waters showed five months of fishing seasons start in February to June indicated by CPUE is approximately 1.4 higher than normal condition. In 2010 there was a delay in fishing season for one month, then followed by a continuous decrease in CPUE with small fluctuation in May and June (Figure 4). When strong La Nina occurred in 2011, the CPUE of yellow striped scad was significantly increased to 1.87 times higher than the normal average condition and there was a fluctuation in the fishing season.
The strong El Niño period in 2016 affected the CPUE that showed a decrease in value to reach about 0.0358 tons/unit. It seems related to decreased number of CPUE in March to May, when it should be in high value. Extreme global conditions in 2017 caused the decrease in CPUE to the lowest number of decades, the fishing season changed, fluctuated with the peak season in June. ANOVA analysis shows that there is a significant difference among the period of the fishing season, unless for 2016 and 2017 that showed a similar pattern in CPUE (Figure 4).

**Skipjack (Katsuwonus pelamis)**

The fishing season index of skipjack in Aceh waters shows that skipjack starts to increase in number in June, then reaches the peak number in September. Extreme conditions in 2010 reduced the CPUE to half of the normal condition. The abundance of skipjack was fluctuating and affected the fishing season, the highest CPUE occurred in August, it comes one month earlier compared to the normal average condition. Strong La Nina in 2011, caused a decrease in skipjack CPUE and delayed the peak fishing season by about two months (Figure 4).

Figure 4. Fishing season of scad (top), yellow striped scad (middle), and skipjack (bottom) in normal condition compare to the extreme period of 2010-2011 (left) and 2016 – 2017 (right).
A similar pattern of CPUE showed by super strong El Nino in 2016, which caused the fluctuation of CPUE throughout the year and the peak season occurred in August. In 2017, the pattern of CPUE showed that the peak of the fishing season occurred in October, about one month delayed compared to normal conditions.

### 3.3. Fishing season of pelagic fishes in Makassar Strait

Fishing season analysis in Makassar Strait was carried out into six species of small pelagic, are Indian mackerel (*Rastrelliger kanagurta*), big-eyed scad (*Selar crumenophthalmus*), scad (*Decapterus spp*), sardine (*Amblygaster sirm*), neritic tuna (*A. rochei, A. thazard, and Euthynnus affinis*) and torpedo scad (*Megalaspis cordyla*). Catch and effort data in Makassar Strait are only available for 4 years are 2008 up to 2013. In this case, we can only analyze the response of extreme periods in 2010 and 2011. ANOVA analysis was conducted after all CPUE data were transformed by using log transformation. The results of the ANOVA analysis showed that only CPUE of four species that were significantly different between normal conditions and the ENSO period, those species are Indian mackerel, big-eyed scad, neritic tuna, and torpedo scad. Scad and sardine showed similar fishing season and CPUE values with the normal condition when the ENSO period occurred (Tabel 3).

| Species               | Indian mackerel | Big-eyed scad | Scad | Sardine | Neritic tuna | Torpedo scad |
|-----------------------|-----------------|---------------|------|---------|---------------|--------------|
| F                     | 5,974           | 10,799        | 1,194| 0,531   | 8,870         | 2,579        |
| Df                    | 2               | 2             | 2    | 2       | 2             | 2            |
| Sig                   | 0,006           | 0,000         | 0,316| 0,593   | 0,001         | 0,091        |

Small pelagic fishes in Makassar strait show different responses to ENSO event, two species of small pelagic that are scad and sardine did not indicate any significant changed in CPUE compare to normal conditions. CPUE of Indian mackerel showed a different response to El Nino and La Nina, when El Nino occurred, CPUE of Indian mackerel decreased significantly, but strong La Nina did not show any significant difference with normal condition (Figure 5). The ENSO, both El Nino and La Nina event resulted in a significant decrease in CPUE for big-eyed scad, torpedo scad, and neritic tuna (Figure 5).

**Scad (*Decapterus* spp.**)

Fishing season for scad fishery in Makassar Strait occur for six months respectively, start in August to January. The average CPUE of normal years is 12,189 tons/trip/year. Extreme condition in 2010 seems did not shift the fishing season peak, but more fluctuate in fish abundance. Scad CPUE dropped into approximately 60% than normal condition. When strong La Nina occurred in 2011, scad fishing season comes about one month earlier, CPUE seems to decrease to only 80% from normal condition (Figure 6). There is no significant difference in the fishing season of scad when extreme conditions occur in 2010 and 2011 (sig: 5%).

**Sardine (*Amblygaster sirm***

Sardine fishery in Makassar Strait was unaffected by extreme conditions neither in 2010 nor 2011. Fishing season in 2010 and 2011 showed no different pattern with the normal condition unless it comes one month earlier in 2010 and one month delayed in 2011 (Figure 6). The CPUE in 2010 and 2011 did not show any significant difference with normal conditions (sig: 5%).

**Indian mackerel (*Rastrelliger kanagurta***


Indian mackerel in Makassar Strait has a fluctuate pattern; the pattern shows that May has become the first start as fishing season. However, the abundance of mackerel drops in June and increased gradually from July to October as the second peak of the fishing season. The extreme period of 2010 caused the first peak of the fishing season in May to disappear and dropped in CPUE throughout the year to less than half of normal conditions (Figure 6). Strong La Nina in 2011 did not show any difference in fishing season seems La Nina gave no significant impact on mackerel fishing season in Makassar Strait (sig: 0.05%).

Figure 5. Compare mean of CPUE in average normal condition and ENSO events for scad (top left), sardine (top right), Indian mackerel (middle left), big-eyed scad (middle right), torpedo scad (bottom left), and neritic tuna (bottom right).

**Big-eyed scad (Selar crumenophthalmus)**

Big-eyed scad in Makassar Strait shows two periods of the fishing seasons, are in May to June when season index reach 130 to 170% higher than normal condition and the second season come about November to December when season index reach 110 – 130% than normal. In normal conditions, CPUE
start to increase gradually from March to May, extreme conditions in 2010 caused CPUE to decrease significantly from January to April, caused the dropped of CPUE. Strong La Nina in 2011 caused a delay in fishing season for two months and dropped CPUE to a half of normal condition throughout the year (Figure 6). Both extreme conditions in 2010 and strong la Nina in 2011 affected fishing season and CPUE of big-eyed scad in Makassar Strait significantly (sig: 0.05%).

**Torpedo scad (Megalaspis cordyla)**
Torpedo scad fishery in Makassar Strait showed fluctuation in abundance throughout the year, the high abundance starts in April to July as the peak of fishing season for torpedo scad. ENSO changes in the peak of the fishing seasons, that in extreme period peak in fishing season delayed for about two months (Figure 6).

![Graphs showing fishing season patterns](image)

**Figure 6.** Fishing season of scad (top left), sardine (top right), Indian mackerel (middle left), big-eyed scad (middle right), torpedo scad (bottom left), and neritic tuna (bottom right) in normal condition compare to the extreme period of 2010-2011 (left), CPUE in normal average condition, El Nino 2010 and La Nina 2011 (right).

**Neritic tuna**
The fishing season of neritic tuna shows fluctuate pattern, there are three periods of fishing season in a year, the first season come about May then fish abundance dropped in the next month. The second fishing season comes about July to September when fish abundance increases gradually, and the season
index reaches over 100%. The last period of fishing season for neritic tuna came in November (Figure 6). The extreme period of 2010 and 2011 caused a significant decreased in CPUE and delayed the peak of the fishing season for about two months (sig: 5%). In 2010 CPUE of neritic tuna decreased to 29% than the normal condition, while in 2011 CPUE decreased to 36% compared to normal condition.

4. Discussion
ENSO phenomenon in Indonesia waters follows by changes in oceanographic features that are sea surface temperature[3], vertical thermal structure, and upwelling current[10]. Temperature is one of the important limiting factors for organisms. Temperature changes can directly affect biological processes such as metabolisms[11] and migration[5]. Some studies show that an increase in water temperature influences the increase of the metabolism rate of fishes that leads to predation rate increase[11]. Some causes of a sudden decrease in fish abundance are related to changes in water temperature, Coldwater species move into deeper water when warm water associated with the El Nino event comes[5]. Bali sardine experienced dropped in production for some periods associated with the La Nina event, some studies indicate that increase in water temperature generates vertical migration of sardine which makes the fish difficult to catch[7].

Changes in the fishing season as a consequence of the ENSO event experienced by almost all small pelagic fishes in Bali Strait, Makassar Strait, and Aceh waters, all showed a different response. Geographically, Bali Strait is located in the south latitude and directly facing the Indian Ocean. The influence of the Indian Ocean water mass and changes Southern Java Sea are strong. Makassar Strait is located in North latitude and passed by Indonesia Trough Flow which brings warm water mass from the Pacific Ocean to the Indian Ocean. ITF passes through Makassar Strait in deeper water about 150 – 250 meters[12] cause no significant effect on pelagic ecosystems. However, the ENSO effect strongly influences the changes of SST in Makassar Strait[3]. Aceh waters are a part of the Indian Ocean, which is not directly influenced by Pacific water mass. ENSO influencing the SST dynamic of the Indian Ocean through a tropical atmospheric process[13] and ENSO influences the sea level rise in Western Sumatera Waters[14]. According to previous studies, ENSO effects all around Indonesia waters.

Small pelagic species showed different responses to ENSO events in different areas. Response showed by small pelagic fisheries are changes in CPUE and fishing seasons. Among all species analyzed in three waters areas, Indian mackerel and scad in Makassar Strait did not show a significant response to the ENSO event, while others are changed. The same species in the different areas showed a different response, it might be related to the different oceanographic effects of ENSO in Bali Strait, Makassar Strait, and Aceh Waters. Different species showed a different response to the ENSO effect as they may have a different level of tolerance to temperature changes. Disperse migration and vertical migration is a possible mechanism to avoid drastic temperature changes that generate fish stock decreased and changes in the fishing season.

5. Conclusion
ENSO events affect the small pelagic fishery in Indonesia waters through changes in CPUE that generate changes in the fishing season. Response of every species is different among three studies area, ENSO commonly causes fishing season to delay or come earlier and decrease or increase in CPUE except for Indian mackerel and scad in Makassar Strait.

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