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ECONOMIC CONSEQUENCES OF CLIMATE VARIABILITY ON SARDINE FISHERIES IN THE BALI STRAIT

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Applied Economic Research on Fisheries Management
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ABSTRACT

The sardine fishery contributes around 60% of fish landings in the Bali Strait via its two main gateway ports, Pengambengan and Muncar. Sardine populations go through seasonal fluctuations, and are influenced by variations in temperature and chlorophyll-a, both important for sardine distribution. Extreme changes in climate conditions could drastically alter those two variables, and by association, sardine populations. This study aims to assess the impact of a changing environment on the sardine fishery in the Bali Strait by looking at both the ecological and socio-economic effects of climate variability.

This research was conducted in the Bali Strait from April 2017 to April 2018. Data were collected from two landing sites, Muncar and Pengambengan ports. Temperature and chlorophyll-a data was downloaded from satellite data, and fishing ground location was determined by on-board observers. Data samples are then analyzed to explain the impact of climate variability on changing seawater temperature. After that, we looked at the impact of sea water temperatures on sardine production, catch composition of purse seine nets, and choice in fishing ground and vessel type. The socio-economic impact analysis focused on the fluctuation of revenue per unit effort (RPUE) due to changes in catch per unit effort (CPUE) in both normal and extreme conditions. Economic analysis was also done to understand the operational costs of different types of vessels. We interviewed fishers to collect information on their adaptation strategies during extreme conditions.

Our results showed that climate variability affected the temperature dynamic of Bali Strait and positively correlated with fluctuations in sardine production. Seawater temperature significantly affected the production of sardines; however temperature impacts were less correlated compared to the impact of fluctuations in chlorophyll-a on sardine production. We also noted that a drop in sardine production was associated with an increase of some other small pelagic species. Catch composition in purse seine nets in the extreme period was similar to catch during normal conditions, yet there was a delayed impact (1 – 3 years) of extreme conditions on catch composition. Extreme conditions did not influence fishing ground location of purse seine vessels, however we did note a trend of changing vessel type, from a two-vessel system to a one-vessel system.

The value of RPUE is directly proportional to CPUE. Sardine fish prices follow market conditions, a decrease in catch leads to an increase in fish price. The estimated economic loss due to climate variability ranges from IDR 24,461 million/year to IDR 242,691 million/year, during the period from 2009 to 2016, due to disappearance of the sardine. The dominant adaptation strategies used by fisher during this period were: (1) not fishing for a certain period (almost one year); and/or (2) switch to other temporary jobs (not related to fisheries) as an alternative livelihood.

The detailed research results are explained in the following two chapters. The first chapter focuses on the ecological impacts of climate variability on the sardine fishery, and the second chapter is focuses on the socio-economic impacts.

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CHAPTER 1: CLIMATE VARIABILITY IMPACT ON SARDINE FISHERIES: ECOLOGY AND FISHERIES PERSPECTIVE

1. INTRODUCTION

Since the 1970s, sardine fisheries have dominated small pelagic fisheries in the Bali Strait (Merta, 1992), contributing more than 60% of total fish landings at Muncar port, and more than 90% at Pengambengan port. More than 12,000 fishers depend on the sardine fishery for their livelihood. Ninety-two fish canning and fishmeal industries in the Banyuwangi District of East Java Province and the Jembrana District of Bali Province use sardines as a raw material input. As effort to catch sardines increased, sardine populations decreased, with reductions in sardine production detected starting in the early 2000s, and a sudden and significant decline in 2010. Generally, fluctuations in sardine production occur in a 5 - 10 year pattern, with low seasons indicated by low numbers of sardines caught (Tinungki, 2004).

Lumbangaol, et al. (2014) found that the fluctuations in sardine catch in Bali Strait were influenced by environmental conditions such as temperature and chlorophyll-a. Previous research showed that seawater temperature has a significant correlation with sardine CPUE (Puspasari et al., 2018, in process). Regional climate phenomena also have an impact to sardine production patterns (Prasetyo & Natsir, 2010). The 2010 production drop could potentially be correlated to high seawater temperatures caused by a strong El Niño in 2010 and 2011's La Niña.

Due to its geographic position, Bali Strait is highly impacted by conditions in the Indian Ocean via the Indian Ocean Dipole (IOD), and by the dynamics of the Western Pacific Ocean through the El Niño Southern Oscillation (ENSO) (Puspasari et al., 2018 in process). Positive IOD will result in a decrease in seawater temperature, and negative IOD gives the opposite effect. El Niño leads to lower temperatures in Bali Strait. ENSO and IOD could both act as a synergistic or antagonistic effect to seawater temperature. When El Niño occurs simultaneously with positive IOD, it will decrease seawater temperature in a larger scale compared to the El Niño effect alone.

The degree to which climate variability affects sardine catch is not well studied due to lack of data. In this study, we attempt to measure any impact of climate variability using changing temperature as an indicator of sardine production. Our analysis of the impact of climate variability on sardine fisheries will look at catch composition, and changes in fishing ground and vessel type by fishers in the Bali Straight. To date, there have been no findings on how extreme climate variability will impact catch composition.

Environmental changes not only affect the number of sardines, but also impact the welfare of fishers, as seen through their profits. Fishers adapt to environment changes and we will explore the strategies used by sardine fishers in Muncar and Pengambengan. Instability in sardine catch and production decreases lead to economic losses for coastal communities. We will estimate losses from increasing seawater temperatures in an effort to estimate the economic consequences of climate variability on sardine fisheries.

2. TOOLS AND METHODOLOGY

2.1 Study Site

This research was conducted in the Bali Strait, particularly in Muncar fishing port in the Banyuwangi District of East Java Province and Pengambengan fishing port in the Jembrana District of Bali Province (Figure 1), from April 2017 – 2018. This research is an extension of our previous research on a similar topic, but with a broader scope and deeper analysis.

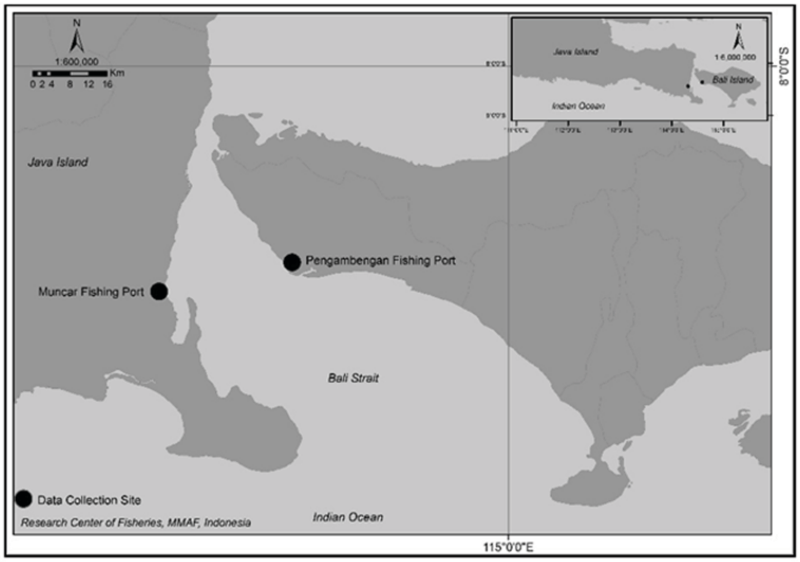

Figure 1. Study site

2.2 Data Collection

Fisheries data was collected from Muncar and Pengambengan fishing ports, which are the dominant landing sites for sardines harvested in the waters of Bali Strait. The production data is the catch landed from purse seine vessels, which represents more than 95% of sardine landing data. The effort data is the number of trips and number of vessels. Sardine fisheries activity is often one-day making the number of trips similar to the days at sea. Catch composition of the purse seines was also collected. However, data was only available for dominant species. Fishing ground data was collected through observation by on-board observers in purse seine vessels in December 2017.

Shifts in fishing grounds were also analyzed using on-board observer data. On-board observers joined fishing vessels to pinpoint the exact location where fishers catch sardines. This data was compared to the usual pattern of sardine fishing grounds, derived from historical information provided by fishers during focus group sessions.

Seawater temperature data was extracted from the HYCOM + NCODA Global 1/12^{o} model (Hybrid Coordinate Ocean Model and Navy Coupled Ocean Data Assimilation) and chlorophyll-a data came from the Terra MODIS (Moderate Resolution Imaging Spectroradiometer) chlorophyll concentration and OCI (Ocean Color Instrument) Algorithm, both of which were provided by the National Aeronautics and Space Administration (NASA). Seawater temperature was taken for the depth from 0 – 100 meters, and chlorophyll-a concentration is measured from the surface to the photic zone (about 80 m).

2.3 Data Analysis

2.3.1 Impact of seawater temperature on sardine production

A Cobb-Douglas regression model used to measure the influence of a changing environment on sardine production in the Bali Strait. We used number of trips, water temperature, and chlorophyll-a concentration to predict sardine production. The variable used for capturing the effect of fishing effort is a number of total days per month in which the fishing fleets are offshore. Chlorophyll-a is a variable that functions as indicator of food availability, a strong predictor of production (Lanz et al., 2009). The relationship between water temperature and production is the focus of this part of our analysis. The basic equation of Cobb-Douglas formulas is:

$$Yi = a\ E^{b1}\ t^{b2}\ C^{b3}\ P^{b4}\ e^{\mu}$$

Yi = Sardine production (in tons);
E = Number of effort (fishing trip);
t = Deseasonalized seawater temperature (^{o}C);
C = Chlorophyll-a concentration (mg/m^{3});
a = Intercept parameter;
b1, b2, b3, b4 = Partial elasticity of production with respect to each input;
e = Base on natural logarithm;
μ = Error term;
I = 1, 2, 3….

2.3.2 Impact of extreme periods on the catch composition of purse seine

Profile analysis was used to determine the effect of extreme periods on the catch composition of purse seines. Profile analysis is a generalized linear model (GLM), which is the multivariate equivalent of a repeated measure. The use of repeated measure in ecology/fisheries data analysis has been applied by William & Taylor (2003) and Marchal (2008). Profile analysis uses data plots to compare visually across groups. In this case, the treatment was not a real experimental treatment, but refers to different environmental conditions that affect fish populations.

First, we differentiated the event sequence characteristics to define climate variability. We divided the climate variability event into normal, extreme, and post extreme periods based on annual sea surface temperature data. The normal condition is when water temperature is within the range of the 8 year average (approximately 25,5^{o}C); the extreme condition is when the average water temperature is more than 1^{o}C higher than the normal condition; the post extreme condition is the 1 – 3 years after a period of extreme condition[1]. Post extreme is separated because we needed to evaluate the impact of extreme condition on the fishery for several years after the event (Table 1). After grouping, the data were plotted against time. These plots were then made into profile lines representing the scores across time for each group. There are four groups of species observed: sardine, scads, neritic tuna, and other small pelagic species. Their response to the extreme condition is demonstrated by their population fluctuations.

Table 1. The grouping of event sequence

Normal	Extreme	Post Extreme
2007	2010	2011, 2012, 2013
2008	2016	N/A
2009		
2014	2016	
2015	2017	N/A

2.3.3 Impact of extreme periods on the decision to shift fishing grounds

On-board observation was carried out to investigate the shift of fishing grounds during extreme periods compared to normal conditions. We deployed two observers to follow the fishing activity of 4 vessels during December 2017. The

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[1] The post extreme period are defined base on production data performance, that showed the low number of sardine production in 2011 continued to 2013, and start to increase in 2014, indicating that extreme period impact of the year 2010 impacted the 3 years forward after.

fishing grounds at that time were then tagged and compared to the common pattern of purse seine fishing grounds. Common pattern of purse seine fishing grounds has been defined by previous research based on the literature and interviews and focus group discussions with fishers (Puspasari et al., 2016).

2.3.4 Impact of extreme periods on the shifting vessel type

There are three types of vessels arrangements used by purse seiners in the Bali Strait, namely (1) two boats – one day fishing (*slerek*), (2) one boat - one day fishing (*gardan*), and (3) one boat - several days fishing (*kapalan*). Vessel data was collected from Muncar fishing port during from 2014 to 2017, and the number of vessels then plotted by time to describe the shifts in vessel operation.

3. RESULTS AND DISCUSSION

3.1 Sardine production patterns in the Bali Strait

Sardines are a dominant small pelagic species landed in Pengambengan and Muncar. In recent years, sardines experienced a significant decrease in production. In 2011 alone, production of sardines at both landing sites decreased up to 90%, the largest decline ever recorded in Bali. After its dramatic decline, sardine production slowly increased from 2012 to 2016. In 2017, sardine production collapsed again (0.1 – 0.2 % compared to production of 2009 conditions) (Figure 2). Therefore, we consider 2011 and 2017 to be extreme conditions in terms of sardine production.

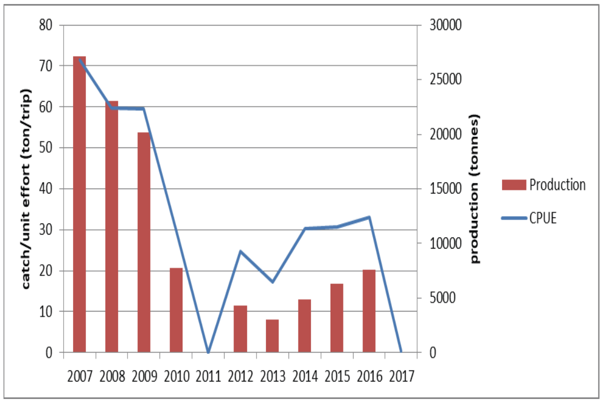

Figure 2. Sardine production pattern in Pengambengan Fishing Port (left) and Muncar Fishing Port (right)

According to Tinungki (2005), the long-term production of sardines in the Bali Strait shows a fluctuating pattern. Sardine production experiences a low season every 5 – 10 years. Production stayed low after the 2010 collapse occurred, compared with previous periods.

3.2 The effect of temperature and chlorophyll-a on sardine production

Previous research results showed that anomalies in sea surface temperature have a positive correlation with CPUE of sardines landed in Muncar and Pengambengan. Another factor that influences sardine CPUE is chlorophyll-a concentration (Puspasari et al., 2018 in process), as it is related to food supply. Sardines tend to form schools in areas with elevated chlorophyll- a levels, i.e. concentrated food sources.

Overlaying sardine production data with water temperature anomaly data indicated that there is a correlation between those variables. Decreases in production coincide with significant increases in water temperature (Figure 3). Sardine production started to decrease significantly in June 2010, which was 2 months after water temperature increased more than 1°C, in April 2010. In September 2010, water temperature reached 28.5°C (an increase of 2.7°C) and warmer water temperatures were felt for more than 3 months after that. Four months of continuously warmer temperatures contributed to the dramatic decrease in sardine production in 2011, indicating that the impact of increased water temperature was delayed for several months.

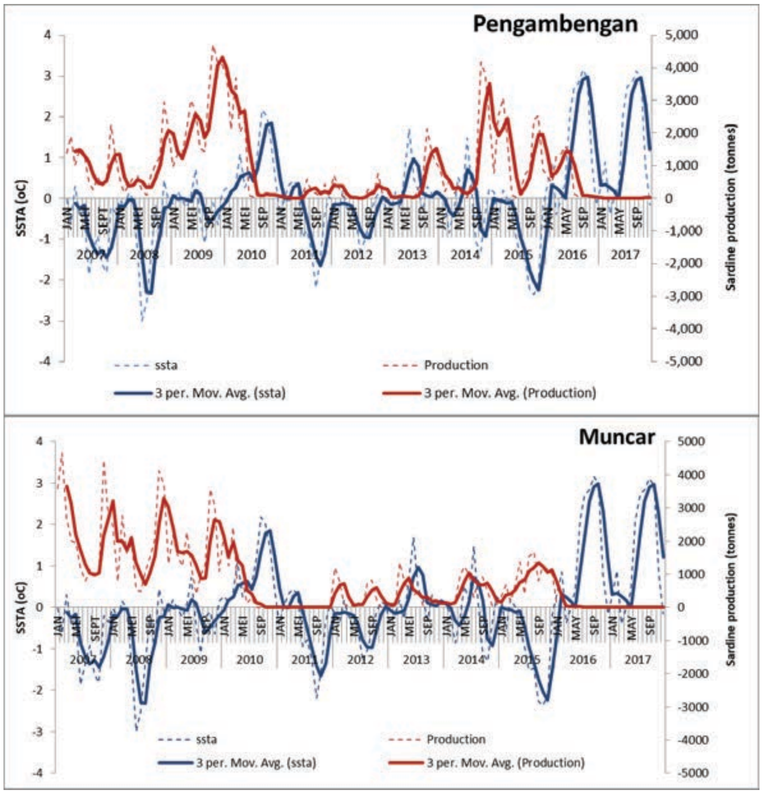

Figure 3. Overlay graph of sardine production with water temperature.

Effort is the most important variable in defining sardine production; it is highly affected by number of vessels, gear quantity, and number of trips. In the Bali Strait, the dominant fishing gear used to catch sardines is the purse seines, which account for more than 90% of the gear used. The number of vessels and gear tends to be the same, while effort fluctuates seasonally. Fishers commonly go fishing for 20 days per month, with effort decreasing during the full moon.

Sardine production was determined by using a basic Cobb-Douglas formula. Some tests of the regression analysis had been conducted to find the most accurate formula to express the impact of temperature on sardine fisheries. We used production as a dependent variable. Independent variables were effort (fishing trips), temperature, chlorophyll-a concentration, and prior production levels[2]. The best equation of sardine production function is as described in equation (f2) and the result of statistical analysis is described in Table 2.

$$\text{PROD} = 1.7951(\text{EFFORT}) - 35.4120(\text{SUHU}) + 50.3651(\text{CHLA-5})) + 0.6125\,(\text{PROD-1}) - 29.0307 \qquad \text{(f2)}$$

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[2] Regression models of time series data commonly have residual autocorrelation. Including the lag of the dependent variable (Prod-1) is a method to fix the residual autocorrelation problem in the model, so that we do not have to interpret the lag of the dependent variable (Prod-1) in the result (Firdaus, 2004; Durbin & Watson, 1951).

Table 2. Statistical analysis of production function (f2)

Variable	Coefficient	Prob.	VIF
EFFORT (trips)	1.7951	0.0000**	1.60
SUHU (temperature)	-35.4120	0.0292**	1.26
CHLA(-5) (chlorophyll-a)	50.3651	0.0791*	1.18
PRODUKSI (-1) (prior production)	0.6125	0.0000**	1.51
C (control)	-29.0307	0.5556	
R-squared	0.7480		
Adjusted R-squared	0.7377		
Durbin-Watson stat	2.3898		

Based on the results of our assumption tests on the regression analysis i.e., data stationarity, homoscedasticity, autocorrelation, and multicollinearity (Appendix 1), we can accept that the regression equation (f2) was the best equation to express the sardine production in the Bali Strait by using effort, temperature, and chlorophyll-a concentration as predictor variables.

Equation (f2) shows that chlorophyll-a concentration is the most important variable in predicting sardine production in the Bali Strait. Lanz et al. (2009) reported the same result, showing that chlorophyll-a concentration has a significant effect on Pacific sardine catch in the Gulf of California. Chlorophyll-a concentration is a measure of the standing stock of phytoplankton and higher concentrations are associated with productive feeding grounds for plankton-feeding fish, such as sardines. Chlorophyll-a concentration levels affect sardine production over a 5-month period, which indicates a delayed effect of chlorophyll-a concentration on production (Sartimbul et al., 2010, and Rintaka, et. al., 2016). This delayed effect is related to the time needed for material transfer at the trophic level, as sardines feed mainly on zooplankton (Gaughan & Mitchell, 2000), which in turn feed on phytoplankton.

Temperature is less likely to be correlated with sardine production than chlorophyll-a concentration, however it does have a significant negative effect. Equation (f2) showed that increasing water temperature can significantly decrease production. Unlike chlorophyll-a, temperature gives an immediate effect, indicating that temperature plays a role as a limiting factor for sardine production.

3.3 Effect on catch composition

Sardinella sardine dominated the catch composition of purse seines in the Bali Strait in the period of 2007 – 2009. Decreases in production number influenced the proportion of sardines in catch composition. The proportion of *S. sardine* suddenly decreased in June 2010, two months after the water temperature increased over 1^{o}C. In May 2010, sardines were 98.3% of the total small pelagic landings, yet the production decreased significantly in June, while other species' production remained the same (Figure 4).

In 2011, sardine production dropped about 90%, while scads and neritic tuna landings increased up to 100% from 2009. Overall, sardine production experienced a major fluctuation from 2011 – 2016. Tragically, sardine catches almost disappeared in 2017, both in Muncar and Pengambengan ports. Using profile analysis, we found that there is a correlation between water temperature and species composition of catch. Our analysis, with a Greenhouse Geisser correction, showed a significant difference in species composition among event sequences (normal, extreme, and post extreme) [F(1.820; 254.816) – 17.632; p < 0,001]. Figure 5 shows the profile analysis plot.

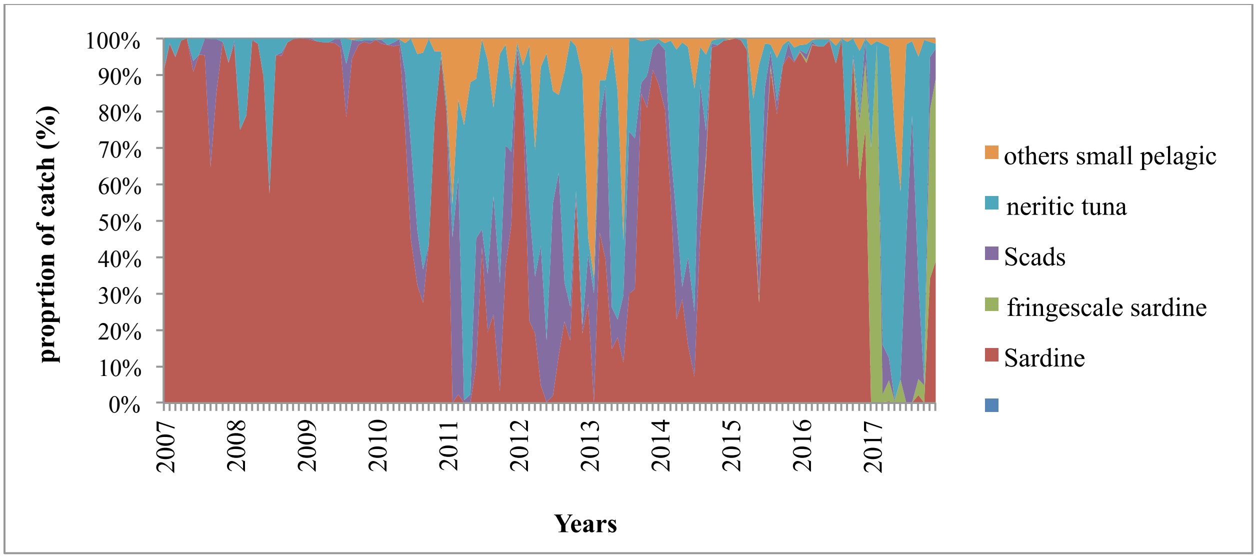


Figure 4. Time series catch composition of purse seine landed in Muncar fishing Port

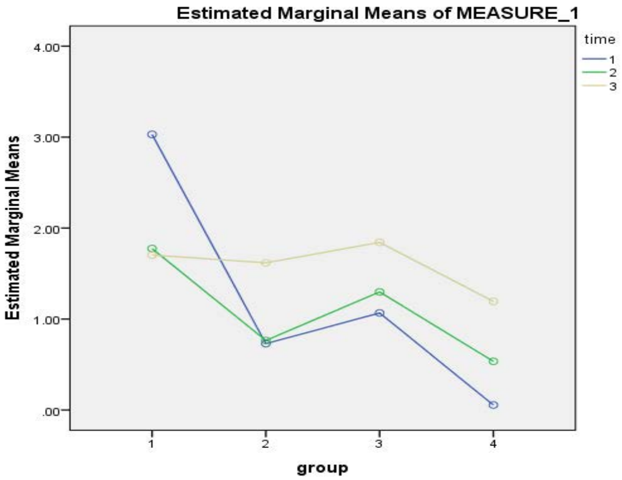


Figure 5. Plot profile of species groups composition in each event sequences (normal, extreme and post extreme)

We then did a pairwise comparison test among event sequences to determine whether there is a significant difference in catch composition. We found no difference between normal and extreme events, but a significant difference between normal and post extreme, as well as between extreme and post extreme (Table 3).

Table 3. Pairwise comparison between event sequences

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	0.127	0.084	**0.403**	-0.077	0.332
	3	-.369*	0.076	0	-0.553	-0.186
2	1	-0.127	0.084	**0.403**	-0.332	0.077
	3	-.497*	0.099	0	-0.736	-0.257
3	1	.369*	0.076	0	0.186	0.553
	2	.497*	0.099	0	0.257	0.736

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

We then tested subject effects to see the impact of event type on species group. We found a significant difference among group of species [(F: 81.472; df: 3); p<0.001] on all three events. This indicates that every group of species has a different response to each event sequence.

Our profile analysis shows that the species composition of purse seines operated in the Bali Strait was impacted by extreme climate variability. Increasing water temperature did not show any immediate impact on species composition; impacts happened 1 – 3 years after the extreme period. In this case, species composition changes were the result of the disappearance of sardines, particularly in 2010. Since sardines were the main target of purse seine fishers, they instead caught other small pelagic fish, but in small quantities compared to sardines.

3.4 Effect on fishing ground

Puspasari et al. (2018, in process) found that purse seines operating in the Bali Strait have a certain distribution pattern. Sardine fishing grounds are located in two distinct areas: South Java, and Southwest Bali (Figure 7). Puspasari et al. (2018 in process) identified similar fishing locations with ones found by Wudianto et al. (2013). In this study, we identified the fishing grounds used by purse seiners with on-board observers.

Our observations in extreme periods (no sardines, December 2017) show that purse seiners did not change their fishing grounds. Purse seiners continued to operate in areas that were productive sardine fishing grounds in normal conditions. In December 2017, purse seiner from Muncar fished around the Alas Purwo – Blambangan waters in Banyuwangi (Figure 6), which were the same sites identified by Puspasari et al. (2018 in process) and Wudiyanto, et al.(2013).

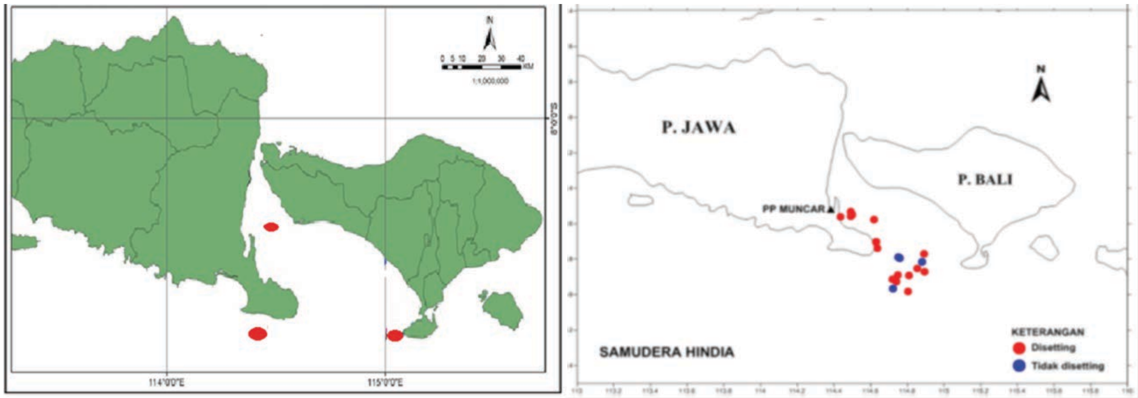


Figure 6. Common fishing grounds of purse seiners in December according to Purpsari (2017) (Left); Purse seine fishing grounds in December 2017 according to on-board observers (Right)

We find that purse seiners did not go further to find fish, which we confirmed with fishers through non-formal interviews. This pattern indicates that the extreme climate phenomenon did not impact the choice of fishing ground. However, significant declines in sardine production (catch) indicate the absence of sardines in the usual fishing grounds.

3.5 Effect on boat composition

In Muncar, there are 3 types of sardine fishing vessels. They are (a) a two boat with one-day fishing system (*slerek*) which uses one large vessel for capturing, and one smaller vessel for hunting and herding; (b) a one boat with one-day system (*gardan*) which behave the same as the *slerek*, but using only one small vessel; (c) a one boat multi-day system (*kapalan*) which uses asmall vessel but spends 2 – 4 days fishing per trip.

Based on 2014 and 2017 data, there is a significant difference in boat type operated in Muncar (Figure 7). In 2014 and 2015, *slerek* was the dominant vessel type for purse seine fishers, operated by more than 40 crews. However, as sardine catch decreased, the fishers suffered losses, making *slerek* operation no longer cost effective. Fishers then switched to *gardan* and *kapalan* systems, which, due to smaller size of vessel and crew, have lower operating costs. Figure 8 shows the shifting of boat systems in Muncar from 2014 – 2017.

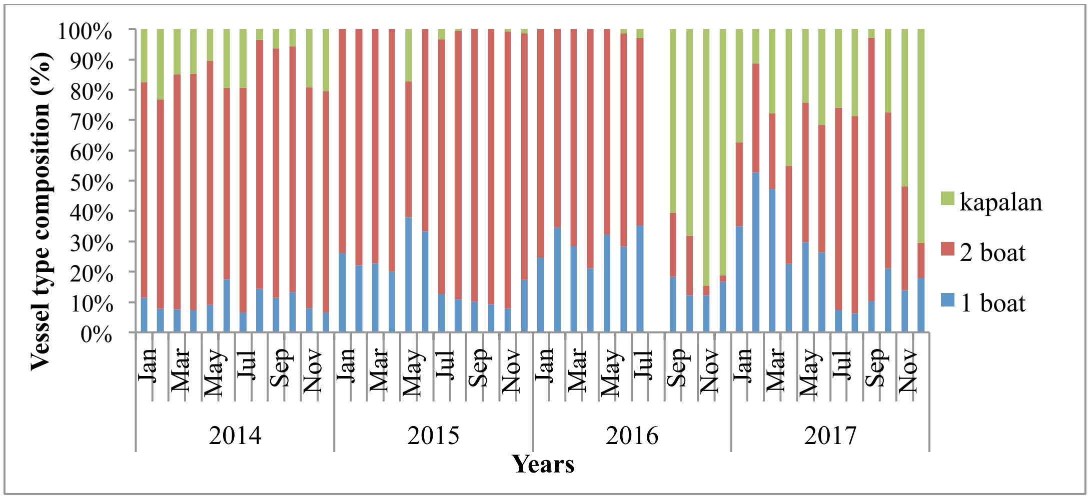


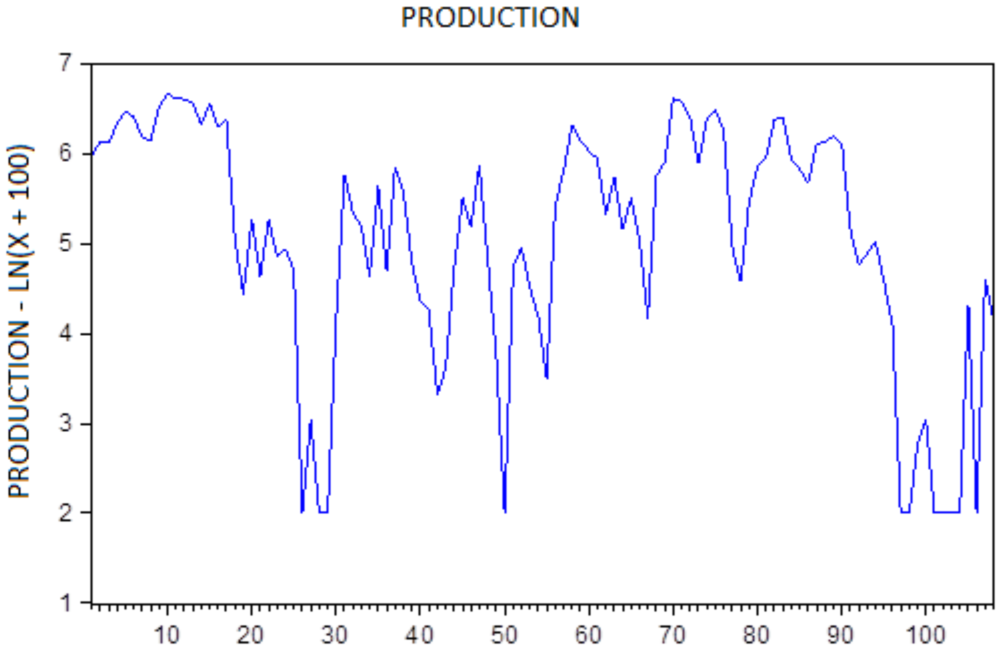
Figure 7. The composition of purse seine vessel type landed in Muncar Fishing Port.

Extreme climate variability provided opportunities for local fishers to adapt. However, according to Suryawati et al. (2018, in process), the cost of a one-boat system is not significantly different from two-boat systems, and the revenue from other species cannot be substituted for the revenue from sardines.

4. CONCLUSION

Climate variability is the phenomena-causing anomaly in seawater temperature in the waters of the Bali Strait. Water temperature anomalies have a significant negative impact on sardine production as observed in Muncar of Pengambengan ports. However, temperature has less of an impact on sardine production than that of chlorophyll-a, an indicator of plankton conditions. The impact on sardine production of increased chlorophyll-a concentration will only be seen 5 months after the increase. Increased water temperature significantly impacts the catch composition for purse seine fishers. Catch of sardines, scads, neritic tuna, and other small pelagic fish changed significantly 1 to 3 years after an extreme period of climate variability occurred. Purse seiner fishers changed their vessel type during extreme periods, but operated at the same fishing grounds.

APPENDIX 1: Stationarity test for time series data

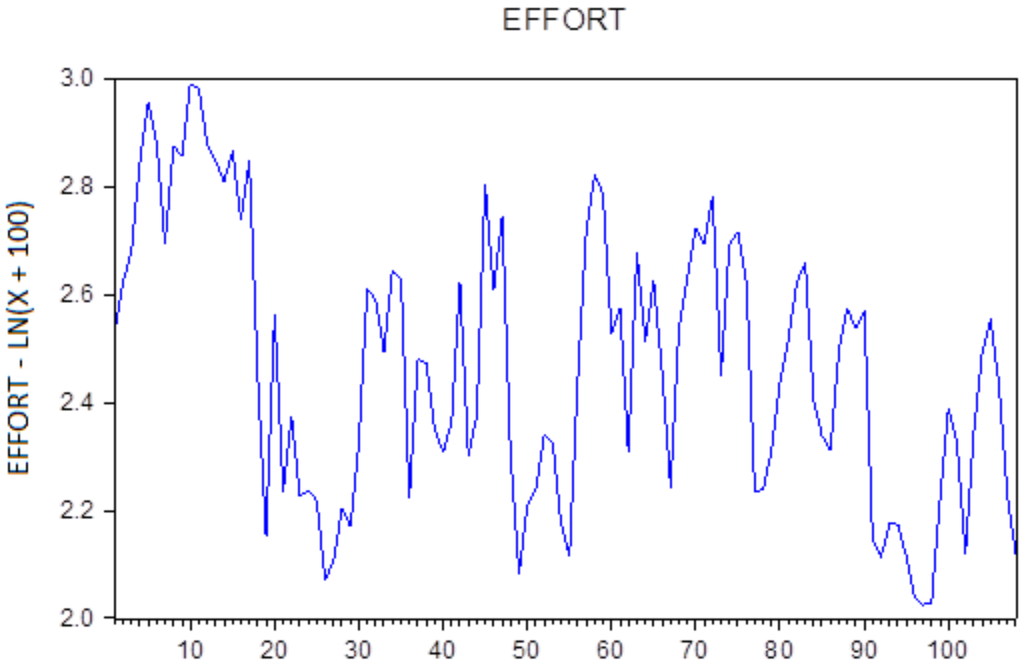


ADF test

H_0 : data stasioner on the level
H_1 : data not stasioner on the level

```
Null Hypothesis: PRODUKSI has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=12)
=======================================================================
                                               t-Statistic    Prob.*
=======================================================================
Augmented Dickey-Fuller test statistic          -3.486186     0.0102
-----------------------------------------------------------------------
Test critical values:        1% level           -3.492523
                             5% level           -2.888669
                            10% level           -2.581313
=======================================================================
*MacKinnon (1996) one-sided p-values.
```

Prob. value (0.0102)<alpha 5% ; H0 rejected; the data is stasioner on the level.



ADF test

H_0 : data stasioner on the level

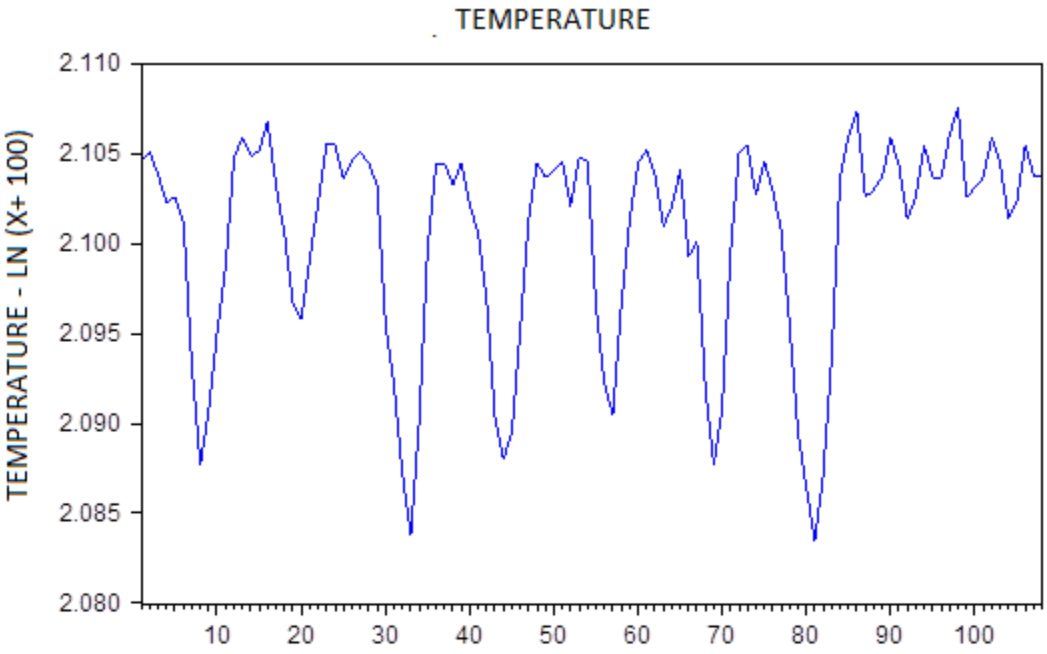
H_1 : data not stasioner on the level

Null Hypothesis: EFFORT has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=12)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.845254	0.0034
Test critical values:	1% level	-3.492523	
	5% level	-2.888669	
	10% level	-2.581313	

*MacKinnon (1996) one-sided p-values.

Prob. value (0.0034)<alpha 5% ; H0 rejected; data is stasioner on the level.



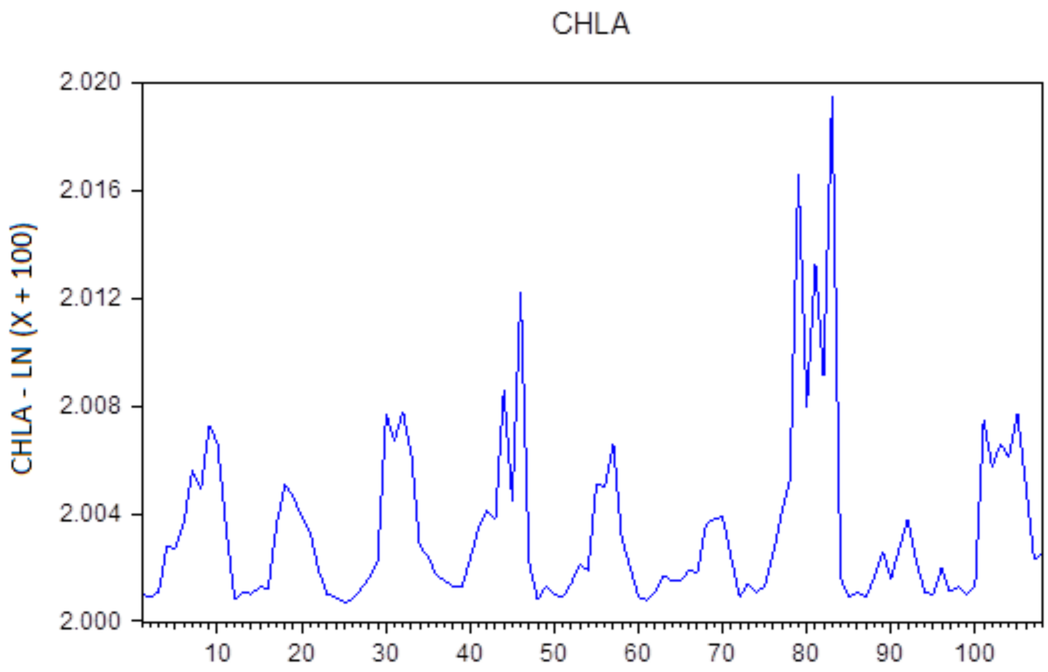
ADF test
H_0 : data stasioner on the level
H_1 : data not stasioner on the level

Null Hypothesis: SUHU has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=12)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-6.562864	0.0000
Test critical values:	1% level	-3.493129	
	5% level	-2.888932	
	10% level	-2.581453	

*MacKinnon (1996) one-sided p-values.

Prob. value (0.0000)<alpha 5% ; H0 rejected; data is stasioner on the level



ADF test

H_0 : data stasioner on the level
H_1 : data not stasioner on the level

Null Hypothesis: CHLA has a unit root
Exogenous: Constant
Lag Length: 2 (Automatic - based on SIC, maxlag=12)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.764045	0.0001
Test critical values:	1% level	-3.493747	
	5% level	-2.889200	
	10% level	-2.581596	

*MacKinnon (1996) one-sided p-values.

Prob. value (0.0001)<alpha 5% ; H0 rejected; data is stasioner on the level

APPENDIX 1. Linear regression model

```
Dependent Variable: PRODUCTION
Method: Least Squares
Date: 03/01/18 Time: 09:18
Sample (adjusted): 6 108
Included observations: 103 after adjustments
====================================================================================
        Variable          Coefficient   Std. Error   t-Statistic     Prob.       VIF
====================================================================================
         EFFORT             1.985165     0.350080     5.670610      0.0000      1.60
      TEMPERATURE          -30.73293     12.68667    -2.422459      0.0173      1.26
        CHLA(-5)            53.74619     22.89106     2.347912      0.0209      1.18
     PRODUCTION(-1)         0.551060     0.061656     8.937636      0.0000      1.51
            C              -45.78202     44.84468    -1.020902      0.3098
====================================================================================
R-squared                   0.750893  Mean dependent var        4.975873
Adjusted R-squared          0.740725  S.D. dependent var        1.366851
S.E. of regression          0.695987  Akaike info criterion     2.160355
Sum squared resid           47.47104  Schwarz criterion         2.288255
Log likelihood             -106.2583  Hannan-Quinn criter.      2.212159
F-statistic                 73.85128  Durbin-Watson stat        2.247189
Prob(F-statistic)           0.000000
====================================================================================
```

Test of Classic Assumption

1. Autocorrelation test

Hypotesis

H_0 : no autocorrelation

H_1 : autocorrelation exist

```
Breusch-Godfrey Serial Correlation LM Test:
======================================================================
F-statistic                 1.572184  Prob. F(2,96)             0.2129
Obs*R-squared               3.266650  Prob. Chi-Square(2)       0.1953
======================================================================
```

P value (0.1953)>alpha 5%; accept H0; no autocorrelation

2. Multicollinearity test

VIF value in the regression model is < 10; no multicollinearity.

3. Homoscedatisity Test

Hypothesis:

H_0: Homoscedastisity

H_1 : Heteroscedastisity

```
Heteroskedasticity Test: ARCH
======================================================================
F-statistic                 6.977493  Prob. F(1,100)            0.0096
Obs*R-squared               6.652841  Prob. Chi-Square(1)       0.0099
======================================================================
```

P value (0.0099)<alpha 5%; H0 rejected means that the model is not fulfilled the assumption of homoscedastisity , therefor we should continue the test using **ARCH(1) model** .

ARCH(1) MODEL

```
Dependent Variable: PRODUKSI
Method: ML ARCH - Normal distribution (BFGS / Marquardt steps)
Date: 03/01/18 Time: 09:26
Sample (adjusted): 6 108
Included observations: 103 after adjustments
Convergence achieved after 76 iterations
Coefficient covariance computed using outer product of gradients
Presample variance: backcast (parameter = 0.7)
GARCH = C(6) + C(7)*RESID(-1)^2
==========================================================================
      Variable       Coefficient   Std. Error   z-Statistic   Prob.    VIF
==========================================================================
       EFFORT          1.795149     0.298701     6.009855    0.0000   1.60
    TEMPERATURE       -35.41204     16.23412    -2.181334    0.0292   1.26
      CHLA(-5)         50.36509     28.68168     1.756002    0.0791   1.18
   PRODUCTION(-1)      0.612542     0.050413     12.15038    0.0000   1.51
         C            -29.03070     49.25881    -0.589350    0.5556
==========================================================================
                          Variance Equation
==========================================================================
         C             0.307555     0.053733     5.723824    0.0000
    RESID(-1)^2        0.358871     0.173896     2.063708    0.0390
==========================================================================
R-squared              0.748010  Mean dependent var       4.975873
Adjusted R-squared     0.737725  S.D. dependent var       1.366851
S.E. of regression     0.700002  Akaike info criterion    2.100859
Sum squared resid      48.02033  Schwarz criterion        2.279918
Log likelihood        -101.1942  Hannan-Quinn criter.     2.173384
Durbin-Watson stat     2.389773
==========================================================================
```

Homoscedatisity Test by using ARCH(1) model

Hypothesis:

H_0: Homoscedastisity

H_1 : Heteroscedastisity

```
Heteroskedasticity Test: ARCH
================================================================
F-statistic            0.201373  Prob. F(1,100)            0.6546
Obs*R-squared          0.204988  Prob. Chi-Square(1)       0.6507
================================================================
```

P value (0.6507)>alpha 5%; H0 accepted due to the model has already fulfilled the homoscedasticity assumption.

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CHAPTER 2: SOCIO-ECONOMIC IMPACTS OF CLIMATE VARIABILITY IN THE BALI STRAIT SARDINE FISHERY

1. INTRODUCTION

Indonesia is the world's largest archipelago comprising over 17,500 islands, and Indonesians rely on coastal resources for their livelihoods. As such, the fisheries sector has a significant role socially and economically, and is strongly affected by changing environmental conditions, some of which are reducing catch. Both climate and non-climate factors are at play in this dynamic, including but not limited to: weather uncertainty, extreme weather conditions, sea surface temperature rise, changes in wind direction, and fluctuations in fuel prices. These factors can contribute to decreasing levels of fishing productivity, which can, in turn, cause fishers to lose their livelihoods.

Fishing communities depend on natural resources in coastal areas for their livelihoods, and the distribution and productivity of these are known to be influenced by climate variability (Allison *et al.* 2005). According to Allison *et al.*(2009), small-scale fishers in developing countries are more vulnerable to climate variability due to their high reliance on fisheries and poor adaptive capacity.

The sardine fishery is a dominant small pelagic fishery in the Bali Strait, making up almost 60% of the total fish landings from two fishing ports in the Bali Strait (Muncar and Pengambengan). There are more than 12,000 fishers who depend on the sardine fishery for their livelihood, and about 92 fishery industries in Banyuwangi and Jembrana require sardines as a raw material. However, total production of sardines in Muncar has decreased significantly since 2010. In 2009, sardine production was 28.5 tons, decreasing to 17.7 tons in 2010, and only 1.7 tons in 2011. These sudden declines were not associated with increased effort, suggesting that there are other factors affecting sardine production in the Bali Strait. This study examined the impact of climate variability, specifically changes in sea surface temperature, on fishing activities, and estimated the economic losses and examined the adaptation strategies of sardine fishers in the Bali Strait.

1.1 Potential Climate Variability Impact

Climate variability can impact fisheries in multiple ways. Changes in water temperature, precipitation, wind velocity, wave action, and rise in water level, can bring about significant ecological and biological changes to marine and freshwater ecosystems and the fish populations therein (Cheung et al., 2009; Brander, 2009; Drinkewater et al., 2009). Extreme weather events may also disrupt fishing operations and land-based infrastructure (Westlund et al., 2007), while fluctuations in fishery production and other natural resources can have an impact on livelihood strategies and outcomes of fishing communities (Coulthard, 2008; Iwasaki et al., 2009). Indirect impacts arising from adaptive strategies pursued by different groups may also be significant and compound the effects of direct climate impacts on fish production and dependent livelihoods. Additionally, loss of revenues can be the result of closure or reduction of fisheries activities during weather anomalies (Lum, 2002; Siung-Chang and Lum 2001; and Nagy et al., 2006).

1.2 Adaptation Strategies Toward Climate Variability

Global climate change may cause seawater to warm by 2-3 °C. As a result, algae that are a source of food for corals may die. We saw an example of this during the El Niño of 1997-1998 that led to rising sea temperatures, triggering the largest coral bleaching event in western Indonesia. Coral bleaching takes place in the eastern part of Sumatra, Java, Bali and Lombok. According to Wilkinson, there has been 30% coral bleaching events in Indonesia (Murdiyarso, 2003).

In order for communities to be resilient to climate change, adaptation is key to withstand current weather anomalies and anticipate future impacts. Climate change mitigation through adaptation is a priority for most developing countries as it becomes obvious that the impacts can no longer be avoided, let alone prevented. Adaptation efforts must be undertaken to anticipate impacts, and to mitigate risks early and effectively, in order to minimize losses. Therefore, the first step is to identify vulnerable populations and the regions in which they live (Hadad, 2010).

Various types of adaptation include anticipatory (proactive), autonomous (spontaneous), and planned. Anticipatory adaptation is done before the impacts of climate change occur. Autonomous adaptation is not a conscious response to climate change, but is triggered by ecological changes in the natural system and by market or welfare changes in the human socioeconomic system. Planned adaptation is the result of a deliberate policy decision, based on the realization that conditions have changed or will change (McCarthy et al., 2001).

Spearman and McGray (2011) stated that climate change has three dimensions of adaptation namely (1) adaptability (adaptive capacity); (2) adaptation actions (adaptive actions); and (3) sustained development. The dimensions of adaptability encourage future thinking, planning, and implementation of work that will avoid disaster and benefit. An intervention is said to have dimensions of adaptability when improving the quality and availability of resources to adapt or the ability to utilize resources effectively. The indicator that can be used is the institutional function (an activity that enables an institution in accordance with applicable laws or norms) and the available (social, cultural, economic, environmental, and technological) resources, which are used as the foundation for the application of adaptation action (Spearman and McGray 2011).

2. METHODOLOGY

2.1 Research Design

Our research was based on a survey of fishers on their adaptation strategies. We conducted household and in-depth surveys with 100 sardine fishers from Muncar and Pengambengan fishing ports. The data were then analyzed using statistical descriptive analysis.

2.2 Study Site

Our study was carried out among the sardine fishers in the Bali Strait, specifically in the fishing ports of Muncar, in east Java, and Pengambengan in western Bali (Figure 1).

2.3 Conceptual Framework

The Bali Strait has been a major sardine fishery since the mid-1990s. However, sardine landings in the Bali Strait have decreased drastically, some might even claim the fishery has collapsed. At the same time, climate variability fluctuates with physical/ecological, economic, and social changes. Coastal communities, and particularly sardine fishers, have suffered economic losses from the disappearance of the sardines, but they have several forms of adaptation that reduce the negative impacts to their fishing business activities.

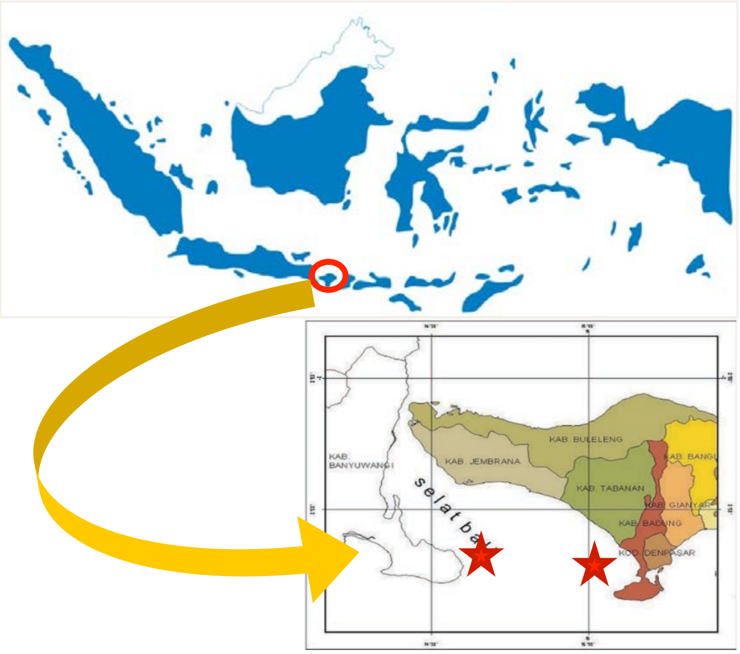

Figure 8. Study Area

2.4 Data Type

This study used both primary and secondary data, collected from available documents and field surveys using structured questionnaires. These data were used to examine the effects of weather and climate variability on fishing activities and adaptive strategies of fishers in the Bali Strait. We had 100 respondents consisting of 70 fishers from Muncar and 30 from Pengambengan.

2.5 Analysis Method

Data obtained through the questionnaires were analyzed using quantitative methods such as frequencies, total, percentages, and cross-tabulation, as well as Cost Benefit analysis (CBA), and Catch per Unit Effort (CPUE) and Revenue per Unit Effort (RPUE) analysis.

3. RESULTS AND DISCUSSION

3.1 Characteristic of samples

The sardine fishers that we interviewed were boat owners, captains, and crew. The types of fishing gear used by respondents are purse seines, gillnets, fishing lines, charts, and traps. The majority of fishers, 84%, use purse seine fishing gear. The majority of fishers in Muncar and all fishers in Jembrana District are purse seiners.

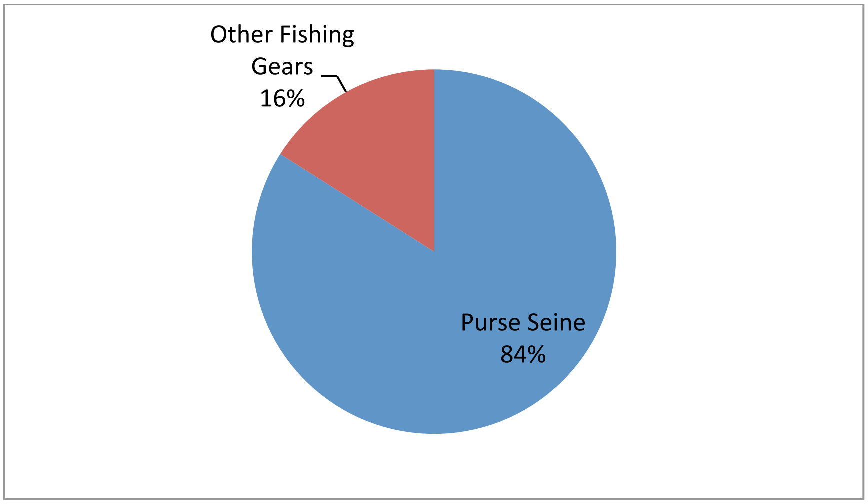

Figure 9. Gear composition of surveyed respondents (Source: primary data (2017))

We found 68% of respondents to be between 20 - 50 years old, with 31% aged 41-50 years. Age can be used as a proxy for business experience as the majority of respondents have worked in the fishing sector from a young age.

Table 4. Respondents Age Group in Muncar District, Banyuwangi Regency, 2017

Age Group	***Respondents***	
	Number (person)	***Percentage (%)***
20 – 29	5	7
30 – 40	21	30
41 – 50	22	31
51- 60	10	14
> 60	12	17
Total	**70**	**100**

Source: Primary data analysed (2017)

We found that most fishers have a low level of education, the majority having only graduated from elementary school. Sixteen percent of respondents never attended school at all. Low education levels usually correlate with the low skills in capture technology, catch handling, cultivation of catch, and use of environmentally friendly fishing gear.

Table 5. Respondents' education level in Muncar Fishing Port, 2017

Education Level	***Respondents***	
	Number (People)	***Percentage (%)***
No school	11	16
Elementary School	36	51
Junior High School	8	11
Senior High School	13	19
University	2	3
Total	**70**	**100**

Source: Primary data analyzed (2017)

For those who only enrolled in elementary school, many only passed grade 2, 3, or 4, and the ‘no school’ group was dominated by respondents over 50 years of age. In the past, young fishers were less interested in going to school and went fishing with their parents instead. In some cases, the children were needed to help their parents earn money from fishing. This phenomenon is still happening in Indonesia, albeit to a lesser extent than in previous generations.

3.2 Sardine Fishing Season

Based on previous research on the characteristics of small pelagic fishing businesses, fish species production is influenced by fish stocks and seasonal cycles (Taeran, 2007; Abdullah, 2011). Seasonal cycles are crucial to the sustainability of fisheries. In Indonesia, the fishing season is divided into four parts that affect catching activities, namely the west season, the east season, the beginning of the year transition season, and the year-end transition season. The four seasons are influenced by monsoons and winds periodically blowing over Indonesian territory (Gunawan, 2004).

Generally, sardine fishing in the Bali Strait can be divided into 3 seasons: peak, transition and low season. There is no definite reference to the timing of the parts of the fishing season. In this study, we attempted to define the catching season based on the results of interviews, which are supported by production data from each respondent. Table 3 shows the time of fishing season in the Bali Strait based on respondents’ survey.

Table 6. Fishing Seasons in Bali Strait (from Sept 16 until Augs 17)

No	Main catches	Time of Fishing (Month)											
		9[b]	10[b]	11[b]	12[b]	1[a]	2[a]	3[a]	4[a]	5[a]	6[a]	7[a]	8[a]
1	Tembang/ Sardine (*Sardinela fimbriata*)	c	c	c				c	c				
2	Layang / Scad	c	c	c	c		c	c				c	c
3	Tongkol/ Mackarel Tuna			c	c			c		c	c		
4	Kembung / Mackarel	c							c	c	c		

Description: [a]January – August is 2017 periods
[b]September – December is 2016 periods.
[c] The dark colored columns are the higher production frequency of catches than any other month

Source: Primary data analyzed (2017)

There are two types of fishing gear used by fishers in the research location to catch small pelagic fish species, namely purse seines and gillnets. Peak fishing season varies based on the type of fish caught. Gillnet fishers generally catch sardine, while crayfish, tuna, and bloat are the main targets for purse seiners when it is not sardine season. In addition to the two types of fishing gear, fishers in the study sites also use the local net *kejer*, trammel nets, and lift nets to catch crustaceans like shrimp, crabs, and anchovies.

Peak season for sardines in the Bali Strait is in September, October, November, and April. Sardine fishing season is open from in February, March, and from July – November. Tuna fishing season is in March, May, June, November, and December. Bloated fish season in April-June and September. In general, fishers in the Bali Strait only use one type of fishing gear throughout the year. The pattern of gear usage is presented in Table 4.

Table 7. Pattern of Use of Fishing Gears by Fishers in Bali Strait, 2017

No	Types of Fishing Gears	Using Time of Fishing Gears (Month)											
		9[b]	10[b]	11[b]	12[b]	1[a]	2[a]	3[a]	4[a]	5[a]	6[a]	7[a]	8[a]
1	Purse Seine	c	c	c	c							C	
2	Gillnet	c	c			c	c	c	c				

Description : [a]January – August is 2017 periods
[b]September – December is 2016 periods.
[c] Dark colored columns are the higher frequency of use of fishing gear from other Months based on trips.

Source: Primary data analyzed (2017)

Based on the results of our research, we divided the season for purse seiners into two parts: peak season and famine season. The following table presents details on the fishing season and average number of trips per month for purse seine and gillnet fishers. However, given unpredictable weather changes in recent years, it is likely that the seasons will change in subsequent years.

Table 8. Calendar of Fishing, Average Number of Trip / Month Fishing Activity Using Purse Seine and Gillnet Purse in Bali Strait, 2017

Category	Purse Seine		Gillnet	
	Fishing Time (Month)	Average Trips/Month	Fishing Time (Month)	Average Trips/Month
Peak Season	July, September, October, November, December	15	January, February, March, April, September, October	19
Famine Season	January, February, March, April, May, June, August	11	May, June, July, August, November, December	15

Source: Primary data analyzed (2017)

During peak season, fish production from purse seines per trip reaches more than 1 ton, with the majority of fish being overpass and cob. In famine season, the maximum catch is around 200 Kg / trip, but also often experience empty catch (zero) during the low season. Not all fleets get results no matter the season. For gillnet fishers, catch is relatively even for each fleet at around 50 - 100 Kg / trip.

3.3 CPUE and RPUE analysis

Revenue per unit effort (RPUE) analysis, also referred to as profit forecasts (Simarmata, 2014), determines if fishers allocate their catch effort based on the profit they will earn. The value of RPUE for sardines is determined based on the catch per unit effort (CPUE) data and the price. The dynamics of CPUE and RPUE of sardines in the Bali Strait for the period 2009 - 2017 are shown in Figure 4.

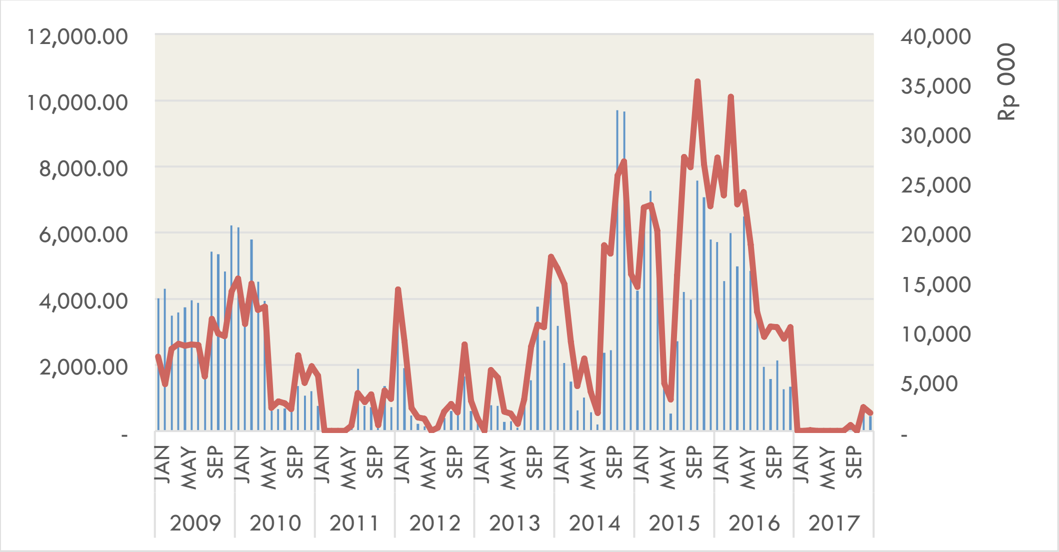

Figure 10. Dynamics of CPUE and RPUE Sardine Fish in Bali Strait, 2009 – 2017

Based on Figure 3, we can see that CPUE and RPUE are directly proportional. There is a constant high demand for sardines, but prices are unstable - decreases in catch lead to an increase in the price. The high price of fish caused by decreased in catch and high market demand will trigger the fishers to try to catch more fish. But, such conditions can in fact lead to an imbalance in the profit gain. Big revenues due to high selling prices will not necessarily result in high profits, as costs are also high due to high fishing effort. In addition, the sustainability of fish resources will also be threatened by overfishing.

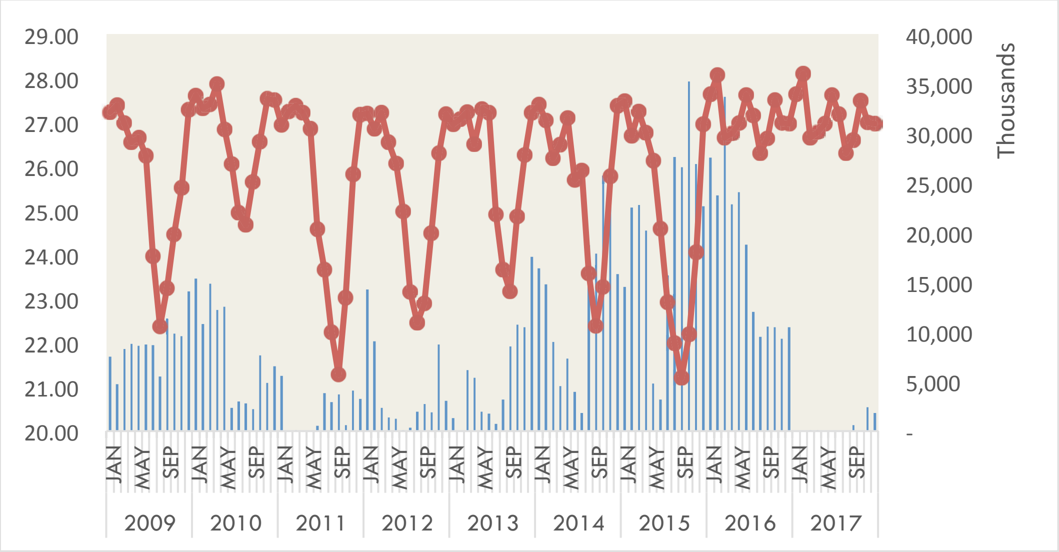

Figure 11. Temperature Dynamics (SST) and RPUE Sardine Fish in Bali Strait, 2009 – 2017

Interview data shows that, since 1974, there has been a phenomenon of sardine catch collapse. However, what has happened since 2016 is quite remarkable – no sardines have been caught for more than 1.5 years. The fleet of purse seine and gillnet fishers in the Bali Strait can catch other fish, namely cob and kite, but the results are not as expected by fishers. The purse seine fleet is the dominant fishing fleet and can catch several species such as sardine (77.12%), tuna (8.60%), overpass (5.09%), bloat (0.63%), and other species (8.56%). There is a perception among fishers in the Bali Strait that if they are able to catch sardines, then they 'got fish', if they do not catch sardines, the fishers assume that they 'did not get fish.'

3.4 Local context of climate variability for sardine fishers

Objective observation data from Meteorology Climatology and Geophysics Council (BMKG) shows that seasons are no longer predictable in the study area. This has been confirmed by focus group discussions conducted at the study sites, where people do not see significant changes in temperature, rainfall, or other climate parameters, but there is a common message that their local knowledge of seasons is no longer relevant as the climate has changed.

The welfare of coastal communities, especially fishers in the Bali Strait, depends on fishery resources, especially sardines. Increasing economic activity and population in coastal areas creates competition for limited resources, and as a result, pressure on those resources is higher. This condition is exacerbated by climate variability and its direct impact on fishing patterns and activities. We know that there have been extreme climatic conditions as many as 3 times in the past decade - in 2010, 2011, and 2017. In this study, we look at six factors affecting sardine fishing in the Bali Strait: (1) no sardines due to famine season; (2) bad weather; (3) damage to fishing equipment; (4) business opportunities in the fishery sector (other than as sardine fishers); (5) promising business opportunities in a non-fishery sector; and (6) changes in water temperature.

We look at the phenomenon of no sardines due to low season to find out how fishers behave when there is no main target fish. We found that most purse seine fishers choose not to go to sea during the low season, but instead spend time repairing fishing gear. Some of crewmembers temporarily switch to other jobs in the fishery sector like harbor laborer, or gillnet crew.

Weather is a very influential factor for a fisher's income, especially when the weather is so bad they cannot go fishing. Under these conditions, fishers must adapt to meet their family's needs. We found five types of adaptation done by purse seiners, which can be grouped into two basic adaptation patterns, namely: (1) stopping the activity of purse seine fishing for a certain period of time; and (2) switching livelihoods. In the first pattern, fishers reduce costs by not going fishing, and instead spend time repairing their fishing gear and vessels. In the case of changing livelihoods, captains often do other business such as fish processing and selling basic foods, crews switched to other fleets or became laborers at the port, and some took work outside the fishery sector. However, these adaptations are usually temporary because, when it is high season for fishing again, they will return to the purse seine fleet.

In weather that prevents operation of purse seine fishing gear, some fishers will switch their fishing gear. Purse seine owners who use a one-boat system generally choose this strategy. In this case, captains choose to operate a fishing gear that can still catch fish amid bad weather and can catch enough fish to still yield a profit.

The percentage of crews who are unemployed because they have no options other than fishing is about 54%. During their time off, these fishers depend on the captain for fulfillment of their daily needs, or spend their savings from previous seasons.

Some boat owners choose to reduce the number of fishing trips, rather than stop fishing altogether. In this case, purse seine fishers will reduce their time on the water from daily to a few days per month, depending on the weather and information obtained from other fishers about the presence of overpass or cob. All respondents in this study reduced the number of trips in order to reduce costs. Details on purse seiner adaptation strategies are shown in Tables 6 and Table 7.

Table 9. Fisher Adaptation Strategy Purse Seine One Boat System on Climate Change Phenomenon and Factors Affecting Fishing Activity in Bali Strait

No	Phenomenons	Adaptation Strategy								Total
		1	2	3	4	5	6	7	8	(%)
1	There is no sardine (Famine Season)	10	-	62	28	-	-	-	-	100
2	Bad Weather	-		7	86	7	-	-	-	100
3	Water Temperatur Changing	-	10	-	90	-	-	-	-	100

Description :
1. Changing fishing gear
2. Reduce the number of trips
3. Fixed fishing gear
4. Do not go to sea within a certain period of time
5. Switch to other livelihoods in the fisheries sector temporarily
6. Switch to other livelihoods in the non-fishery sector for a while
7. Switch to other livelihoods in the fisheries sector permanently
8. Switch to other livelihoods in the non-fishery sector permanently

Table 10. Adaptation of Purse Seine Two Boat System Fisher to Climate Change Phenomenon and Factors Affecting Fishing Activity in Bali Strait

No	Fenomena	Adaptation Strategy								Total
		1	2	3	4	5	6	7	8	(%)
1	**Phenomenons**	-	20	12	40	28	-	-	-	100
2	Fenomena cuaca buruk	-		4	76	8	12	-	-	100
4	There is no sardine (Famine Season)	-	44	-	-	-	-	-	-	44

Description :
1. Changing fishing gear
2. Reduce the number of trips
3. Fixed fishing gear
4. Do not go to sea within a certain period of time
5. Switch to other livelihoods in the fisheries sector temporarily
6. Switch to other livelihoods in the non-fishery sector for a while
7. Switch to other livelihoods in the fisheries sector permanently
8. Switch to other livelihoods in the non-fishery sector permanently

4. CONCLUSION

There is a decline in sardine fish production in the Bali Strait. When the climate is not good, fishing effort declines, and fishing profits become negative. The form of adaptation for non-fishing in a certain period of time is done in an effort to reduce costs in purse seine fishing effort. Commitment and collaboration among fishers, the sardine industry, and the government are required to maintain sustainability in the sardine fishery.

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