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Climate variability impact on Bali sardine fishery: Ecology and fisheries perspective

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Abstract

The sardine fishery in Bali is influenced by fishing effort and environmental conditions including temperature and chlorophyll a (chl-a). Bali's sardine, *Sardinella lemuru* Bleeker, production decreased significantly during the extreme conditions that occurred in 2010 and 2016. This study assesses the impact of extreme conditions on the sardine fishery of the Bali Strait. Fisheries data were collected from two landing places: Muncar fishing port (Banyuwangi District, East Java Province) and Pengambengan fishing port (Jembrana District, Bali Province) between January 2007 and December 2017. Temperature and chl-a data were downloaded from satellite readings. Fishing locations were observed by an onboard observer to investigate shifts in fishing grounds. A modified Cobb–Douglas regression model and profile analyses were used to estimate the impact of environmental variables on sardine production and to assess how extreme periods affect the catch composition in the Bali Strait. Seawater temperature and chl-a concentration had significant impacts on sardine production, but temperature is likely to be less correlated with sardine production than chl-a concentration. To adapt to extreme weather, purse seiners prefer to modify the vessel type rather than change their fishing ground.

KEYWORDS
climate variability, Fisheries, impact, *Sardinella lemuru*

1 | INTRODUCTION

As the dominant species of small pelagic in the Bali Strait, *Sardinella lemuru* Bleeker (sardine) experiences fluctuations in its productivity (Tinungki, 2005) influenced by environmental conditions, such as temperature and chlorophyll a (chl-a) (Lumbangaol, Wudianto, Pasaribu, Manurung & Endriani, 2014). Puspasari, Rachmawati, Susilo, Wijopriono & Wiadnyana (2018) found that seawater temperature has a significant correlation with sardine CPUE (catch-per-unit-effort). Furthermore, regional climate also has an impact on the sardine production (Prasetyo & Natsir, 2010). Climate variability occurs around Indonesian waters, particularly in the Bali Strait where extremely high seawater temperature anomalies are observed. Due to its geographic position, the Bali Strait is highly impacted by the dynamics of the Indian Ocean through the Indian Ocean Dipole (IOD) and by the dynamics of the western Pacific Ocean through ENSO events (El Niño Southern Oscillation) (Puspasari, Rachmawati, Susilo, Wijopriono & Wiadnyana, 2018).

The intensity of impacts of climate variability on sardine catches has not been well studied due to the lack of available data. This research measures the impact of climate variability using temperature as an indicator of climate variability. The analysis includes changes in catch composition, shift of fishing grounds and changes of vessel type in the Bali Strait sardine fishery and explores any adaptation strategy that has been adopted by sardine fisher folk in Muncar, East Java and Pengambengan, Bali.

2 | MATERIAL AND METHODS

The research was conducted in Bali Strait and its surrounding area, including Muncar fishing port, Banyuwangi District in East Java Province and Pengambengan fishing port, Jembrana District in Bali Province (Figure 1) from April 2017 to March 2018. It was an extension of previous research on the impacts of climate variability on the sardine fishery (Puspasari, Rachmawati, Susilo, Wijopriono & Wiadnyana, 2018) with a broader scope and deeper analysis.

This study used fisheries data including time series (from January 2007 to December 2017) on sardine production, fishing trips and catch composition from Muncar and Pengambengan fishing ports. Onboard observers gathered data on the fishing ground exploited by sardine fishing fleets.

Climate-related data, such as seawater temperature, were extracted from the HYCOM + NCODA Global 1/12° model analysis. Seawater temperature was taken from 0–100 m depth. Data on chlorophyll a (chl-a) concentration were extracted from the Terra MODIS chl-a concentration and the OCI Algorithm, both downloaded from https://oceancolor.gsfc.nasa.gov. Chlorophyll a concentration is the concentration of total chl-a from the surface to the photic zone (about 80 m) that describes food availability to the sardines. Supporting information are provided in supplementary material.

2.1 | Data analysis

2.1.1 | Impact of sea water temperature on sardine production

A modified Cobb–Douglas production function was used to estimate the impact of environmental variables (Soylu & Uzmanoglu, 2010) on sardine production in Bali Strait. Sanz, Diop, Blanchard, and Lampert (2017) and Crentsil and Ukpong (2014) also used the Cobb–Douglas model to predict the effect of environment variables on fish production. Triharyuni, Wijopriono, Prasetyo & Puspasari (2012) used the model to assess the production and catch rate of stick-held, dip nets in Kejawanan fishing port, Cirebon District, West Java Province.

The basic equation of the Cobb–Douglas' production function is as follows:

$$\mathrm{Yi} = a\, E^{b1}\, t^{b2}\, C^{b3}\, e^{\mu} \tag{1}$$

where Yi = sardine production (in tons); a = intercept parameter; E = number of fishing trips (effort); t = deseasonalised seawater temperature (°C); C = chlorophyll a concentration (mg/m^3); e = base on natural logarithm; b1, b2, b3 = partial elasticity of production with respect to each input; μ = Error term; and i = 1,2,3.

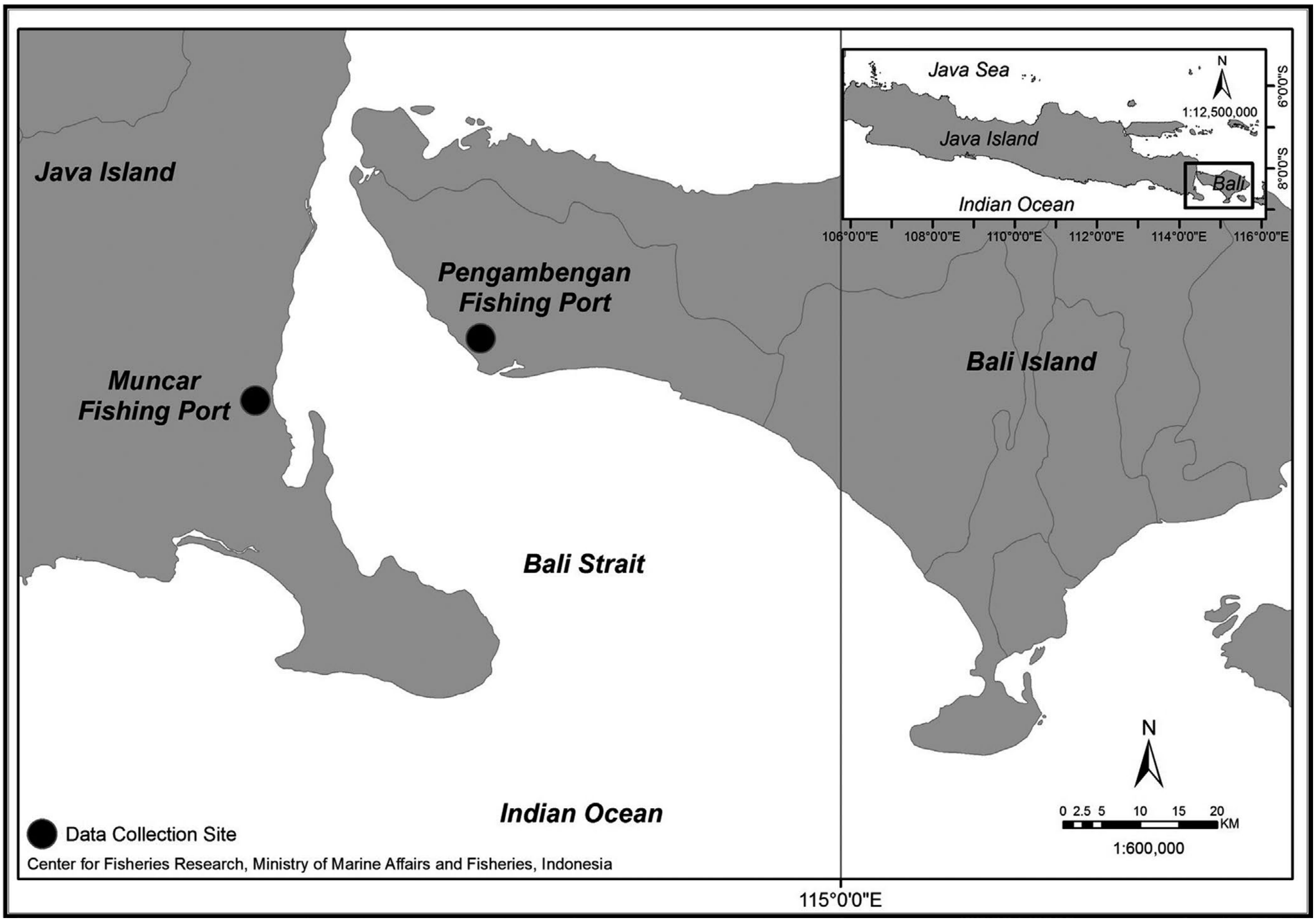

FIGURE 1 Study area

The number of the fishing trips (*E*), water temperature (*t*) and Chl-a concentration (*C*) was used to estimate sardine production (Yi). Water temperature was used to assess the effect of climate variability on production. The number of fishing trips refers to the total number of days in a month that the boat was fishing. The second environmental variable, Chl-a, is an indicator of food availability as it is a strong predictor of production (Lanz, Martinez, Martinez, & Dworak, 2009).

2.1.2 | Impact of periods of extreme temperature on the catch composition of purse seines

Profile analysis was used to estimate the effects of periods of extreme temperature on catch composition of purse seines. Extreme periods are caused by climate variability that creates different conditions of seawater temperatures. Profile analysis is a generalised linear model, specifically a multivariate equivalent of repeated measures. Repeated measures have been used by William and Taylor (2003) and Marchal (2008) for fisheries data analysis. Profile analysis uses plots of the data to compare visually across fish groups in different time sequences.

First, the time sequence characteristics to define climate variability were differentiated. Climate variability events were divided into normal, extreme and post-extreme periods based on the anomaly of sea surface temperature every year. The normal condition is when the water temperature is in the range of 8 years average water temperature (approximately 25.5°C); extreme conditions are when the average water temperature is 1°C higher or more than normal condition; and post-extreme conditions are the 1–3 years following extreme condition. The post-extreme period is defined based on production data performance. In this study, sardine production was low in 2011–2013, which indicated that the extreme period of 2010 impacted the following 3 years. Post-extreme is classified as a separate group to evaluate the impacts following extreme condition (Table 1).

The data were then plotted against the group. These plots are then made into profile lines representing the point scores (using repeated measure analysis in SPSS and called estimated marginal means) against the group. Groups of species observed were sardine, scads, neritic tuna and other small pelagic species, which showed responses through fluctuations in production. The target species were identified in 4 groups in a repeated measurement analysis; sardine (group 1), scads (group 2), neritic tuna/tongkol (group 3) and others small pelagic species (group 4).

2.1.3 | Impact of extreme periods on the shifting fishing ground

Onboard observations were carried out to investigate changes in fishing ground during the extreme period compared to normal condition. Two observers followed the fishing activity of four vessels during December 2017. The fishing grounds were then tagged and compared with the common pattern of purse seine fishing grounds. The common pattern of purse seine fishing grounds was defined by previous research based on a literature study and fisherfolk interviews, then validated through focus group discussions (Puspasari, Wijopriono, Wiadnyana, Rachmawati & Sulaiman, 2016).

TABLE 1 Grouping of event sequences in 2007–2015 for sardine fishery in Bali Strait

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

2.1.4 | Impact of extreme periods on the shifting vessel type

Three types of purse seine operate in the Bali strait: (a) purse seines using two boats—one-day fishing (*slerek*); (b) purse seines using one boat—one-day fishing (*gardan*); and (c) purse seines using one boat—several days fishing (*kapalan*). Data on the number of vessels operating from Muncar fishing port were collected between 2014 and 2017. The numbers of vessels were then plotted against time to describe changes in proportions of the different types of operation in Bali Strait.

3 | RESULTS

3.1 | Sardine production pattern in Bali Strait

Catches of sardine landed in Pengambengan and Muncar have declined by about 90% since 2011. In 2017, sardine production collapsed for the second time and achieved only 0.1%–0.2% of 2009 production (normal condition) (Figure 2). These two years (2011 and 2017) were considered as extreme conditions in this analysis.

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

Sardine production was overlaid with water temperature to determine the correlation between water temperature anomalies and sardine production (Figure 3).

Effort (number of trips), water temperature and chlorophyll a concentration were significant variables affecting sardine production. No correlation found between Chl-a concentration and temperature. The explanation for sardine production function was expressed by equation (2), and the result of the statistical analysis is in Table 2.

$$\begin{aligned}\text{Prod} = {} & 1{,}7951(\text{Trip}) - 35{,}4120(t) + 50{,}3651(\text{Chl} - a - 5) \\ & + 0{,}6125(\text{Prod} - 1) - 29{,}0307\end{aligned} \tag{2}$$

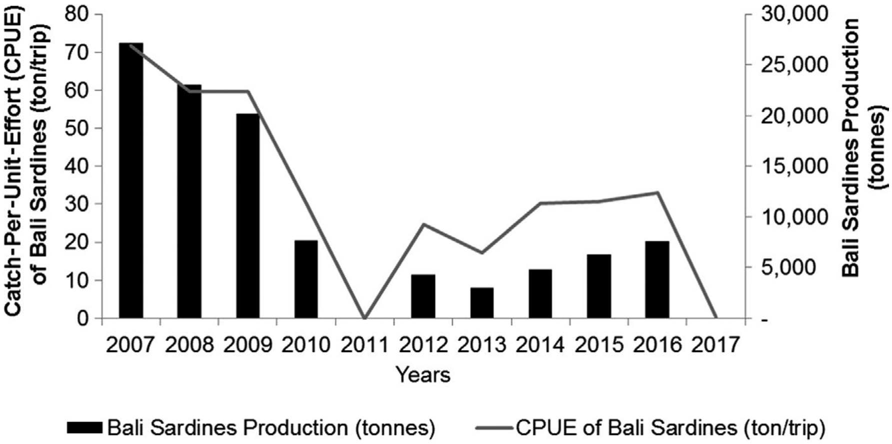

FIGURE 2 Time series sardine production in Muncar fishing port, East Java Province, Indonesia in 2007–2014

where Trip = fishing effort; t = deseasonalised average of sea water temperature at 0 – 100 metres depth; Chl-a = concentration of chlorophyll a; and Prod-1 = lag of production as a solution to overcome the autocorrelation of the model (Durbin & Watson, 1951).

3.3 | Effect on changes of catch composition

Sardine dominated the catch composition of purse seines in the Bali Strait in 2007–2009. Many instances confirmed that the drop in overall production from the Bali strait was due to the decrease in sardine production. The sardine catch decreased significantly in June 2010, two months after a water temperature increase of over 1°C in April. In May 2010, sardine contributed 98.3% of total small pelagic landings. However, in June 2010, the sardine catch decreased significantly while catches of other species of fish remained the same (Figure 4). Again in 2011, the sardine catch dropped by about 90%, but scads and neritic tuna catches increased by up to 100% from 2009. Overall, sardine catches fluctuated in 2011 to 2016 and then almost disappeared in 2017, in both Muncar and Pengambengan fishing ports.

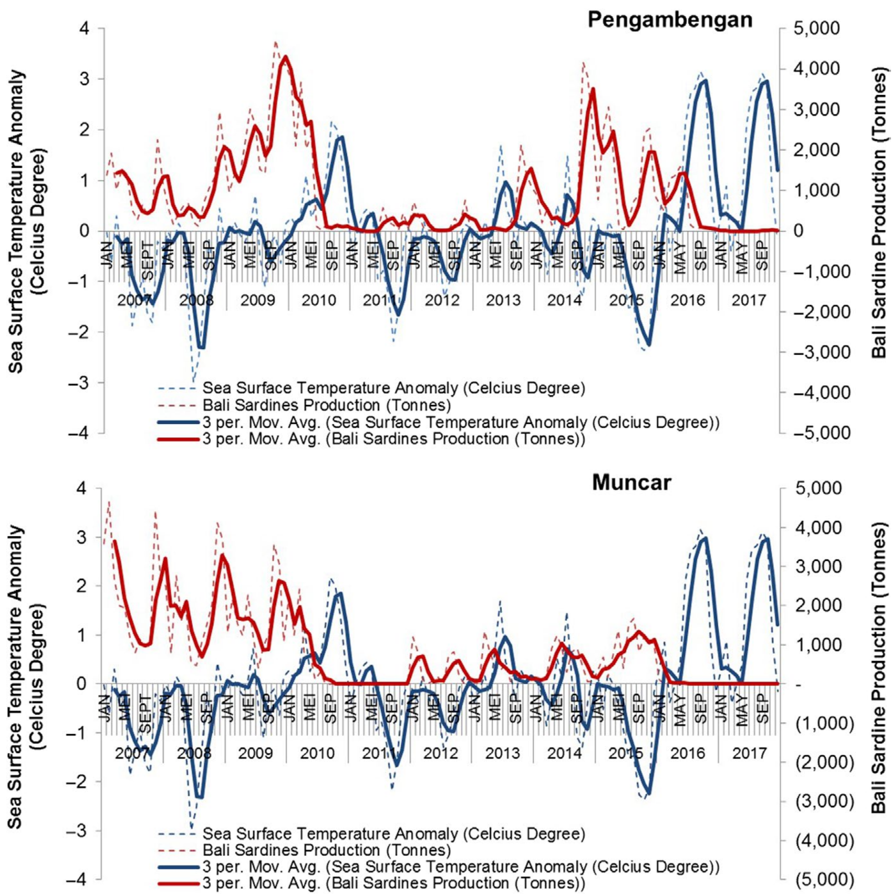

FIGURE 3 Overlay graph of sardine production with sea surface temperature anomaly (SSTA)

TABLE 2 Regression of Cobb–Douglas production function (2) for Sardine Production

Variable	Coefficient	Prob.	VIF
Effort	1.7951	.0000**	1.60
Sea surface temperature	−35.4120	.0292**	1.26
Chlorophyll a (−5)	50.3651	.0791*	1.18
Production (−1)	.6125	.0000**	1.51
C	−29.0307	.5556	
R-squared	.7480		
Adjusted *R*-squared	.7377		
Durbin–Watson Coefficient	2.3898		

*Siginificant at level 10%.
**Siginificant at level 5%.

Profile analysis of the three-time sequence groups (normal, extreme and post-extreme) using the Greenhouse–Geisser correction showed a significant difference in species composition among the event sequences [F(1,820; 254,816)–17,632; p < 0.001] (Figure 5). Pairwise comparison tests between event sequences indicated no significant difference between the normal and extreme events. However, they showed a significant difference in catch composition between normal and post-extreme as well as between extreme and post-extreme (Table 3).

3.4 | Effect on changes of fishing ground

Onboard observations of fishing ground showed that purse seiners did not switch their fishing grounds in extreme periods (in this case December 2017), despite sardine production being low or absent (Figure 6). Purse seiners continued fishing at locations that used to be sardine fishing grounds in normal condition (Wudianto et al., 2013; Puspasari, Wijopriono, Wiadnyana, Rachmawati & Sulaiman, 2016).

3.5 | Effect on boat composition

The fishing systems operated in Muncar changed significantly in 2014–2017 (Figure 7). In 2014 and 2015, *slerek* was the dominant vessel type operated by more than 40 fishers. However, as the sardine catch decreased, the *slerek* system became less cost-effective and fishers switched operations to one-boat systems (*gardan and kapalan*), which have lower operating costs because they are smaller in size and crew number. In 2014 and 2015, *slerek* formed more than 75% and 82%, respectively, of purse seine boats, but in 2017, the number of *slerek* decreased to 42% of the total.

4 | DISCUSSION

Sardine catches have a pattern showing a low season every 5–10 years (Tinungki, 2005). However, after 2010 sardine production was very low compared with previous years. Previous research found that extreme climate conditions affected the production and CPUE of sardine (Prasetyo & Natsir, 2010; Puspasari, Rachmawati, Susilo, Wijopriono & Wiadnyana, 2018). The present study confirms their conclusion that a sea water temperature anomaly impacted sardine production; an anomaly that has a strong correlation with climate variability.

Chl-a concentration appears to be the most important variable predicting sardine production in the Bali Strait (Equation 2). A result comparable with Lanz et al. (2009) who showed that chl-a concentrations 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; therefore, a higher concentration is associated with productive feeding grounds for planktivorous fish.

The current research showed there is a 5-month delay between the high abundance of chl-a and high sardine production. As a secondary consumer, sardine abundance increases with zooplankton abundance, as zooplankton is the food source for the sardine and will attract them to school around the Bali Strait. The delayed effect of chl-a on sardine production has also been reported by Sartimbul, Nakata, Rohadi, Yusuf, and Kadarisman (2010) and Rintaka, Setiawan, Susilo & Trenggono (2014), which seems to be related to the time needed for material transfer between trophic levels.

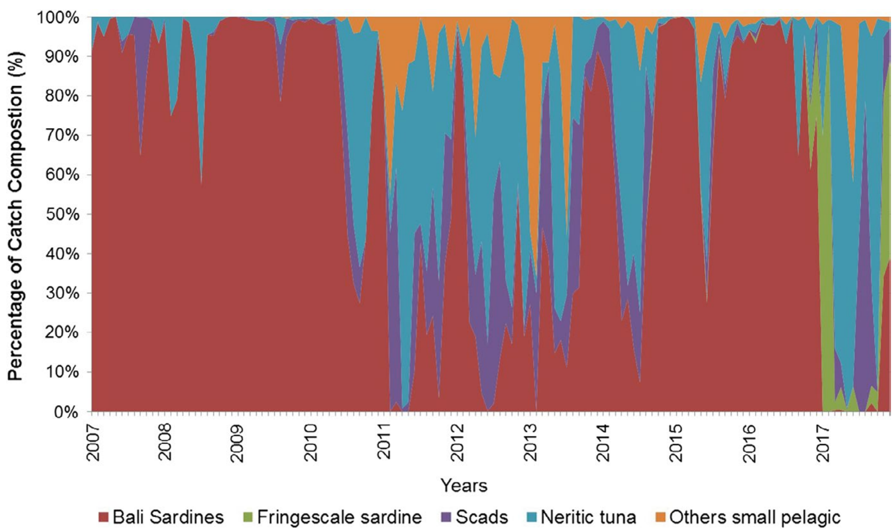

FIGURE 4 Time series of the contribution of catches of sardine to total landings (%) of purse seiners in Pengambengan fishing port, Bali Province, Indonesia

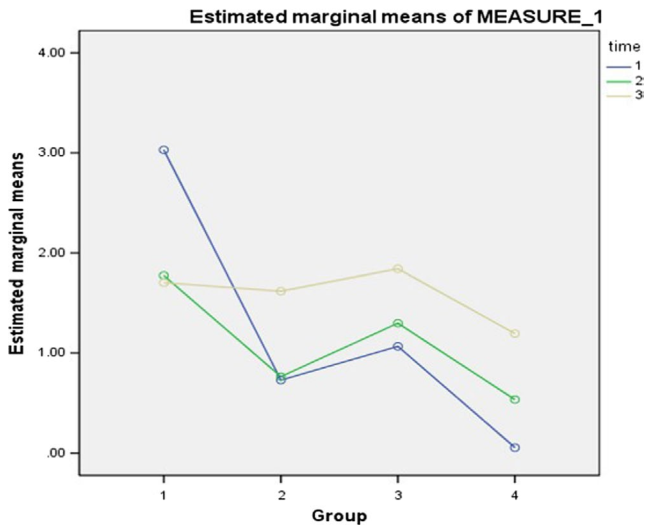

FIGURE 5 Plot profile of species groups composition in each event sequences (normal, extreme and post-extreme)

Temperature is likely to be less correlated with sardine production than chlorophyll a concentration. Equation 2 showed that increasing water temperature can significantly decrease production. Unlike chlorophyll a, temperature has an immediate effect on sardine production suggesting that temperature is a limiting factor for sardine production.

The lag of the dependent variable (Prod-1) in Equation 2 is included as a solution to correct the residual autocorrelation problem in the model. Therefore, no interpretation is needed for the lag of the dependent variable (Prod-1) in the result (Durbin & Watson, 1951; Firdaus, 2004). Finally, sardine production will be impacted by the simultaneous response to environmental changes and fishing effort by the fishery.

4.1 | Effect on the changing on catch composition

Profile analysis showed some delayed effects of extreme climate conditions on catch composition. Catch composition begins to change 1 to 3 years after the extreme period. Changes in temperature directly impact sardine production; although sardine still dominates the catch, its proportion in the catch decreased and ultimately reduced the total catch. In other words, the composition of the total fish catch changes due to low catches or disappearance of sardine, particularly in 2010. In response to this phenomenon, purse seiners

TABLE 3 Pairwise comparison between event sequences

(I) time	(J) time	Mean difference (I–J)	Std. Error	Sig.[a]	95% Confidence Interval for differences[a] Lower bound	Upper bound
1	2	0.127	0.084	**.403**	−0.077	0.332
	3	−0.369[b]	0.076	0	−0.553	−0.186
2	1	−0.127	0.084	**.403**	−0.332	0.077
	3	−0.497[b]	0.099	0	−0.736	−0.257
3	1	0.369[b]	0.076	0	0.186	0.553
	2	0.497[b]	0.099	0	0.257	0.736

Note: Based on estimated marginal means.
Bold means not significant difference, because the values are >5% significant level.
[a]Adjustment for multiple comparisons: Bonferroni.
[b]The mean difference is significant at the .05 level.

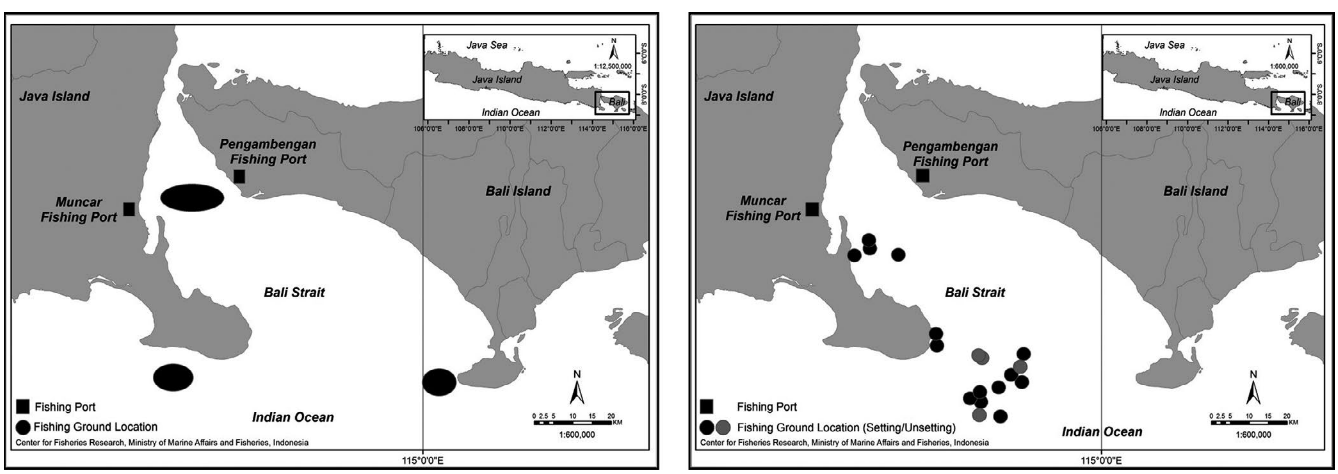

FIGURE 6 Location of purse seine fishing ground in the Bali Strait in December 2016 (left, Puspasari, Wijopriono, Wiadnyana, Rachmawati & Sulaiman., 2016) and purse seine fishing grounds in the Bali Strait in December 2017 (right, from onboard observers)

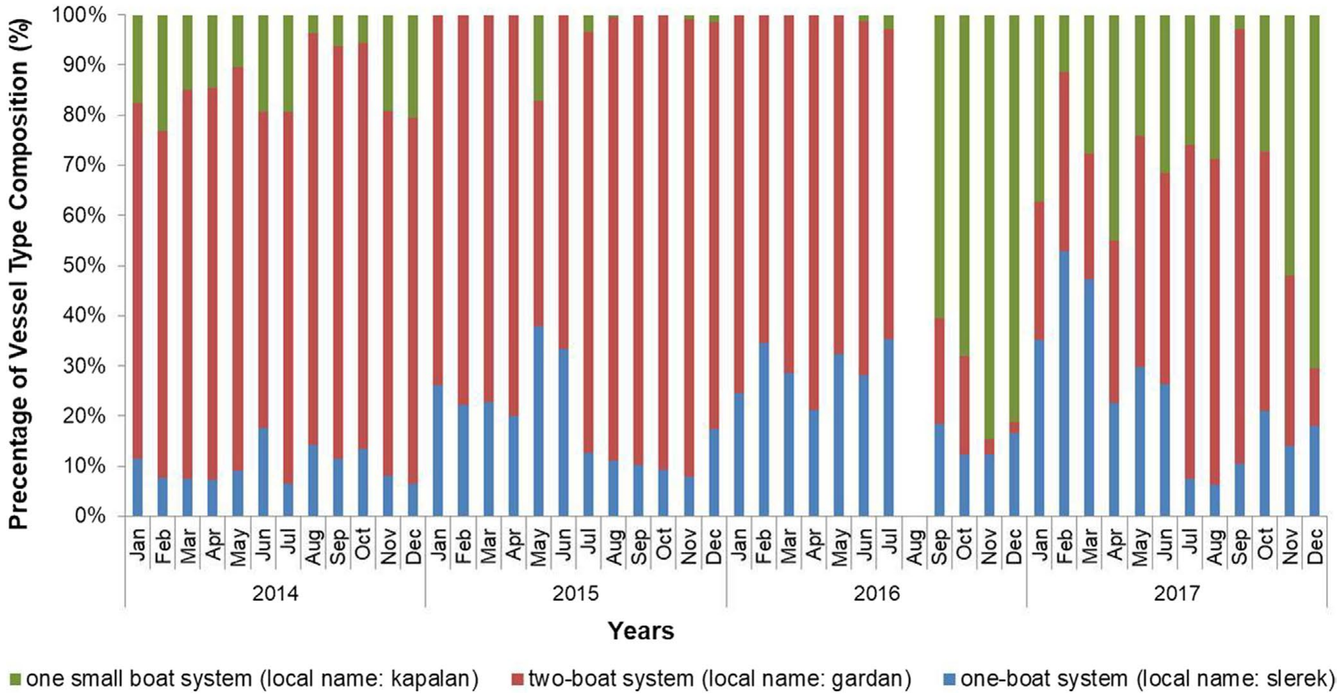

FIGURE 7 The composition of purse seine vessel types operated and landed their catches in Muncar Fishing Port, East Java Province, Indonesia

usually catch other small pelagic fishes (although in smaller quantities) to increase their total catches.

4.2 | Effect on the changing of purse seine fishing ground and fleet type

Declines in sardine catches indicate the absence of sardine in their usual fishing grounds. There is no certainty as to whether they migrate vertically or horizontally or whether there are other causes (McFarlane, MacDougall, Schweigert, & Hrabok, 2005; Puspasari, Rachmawati, Susilo, Wijopriono & Wiadnyana, 2018). During the extreme period, purse seiners did not travel further to fish and did not shift fishing grounds, a situation confirmed by fisher folk through non-formal interviews. This pattern indicates that the extreme climate did not induce the purse seiners to change fishing grounds, a possible explanation being that changing fishing ground would cost the purse seiners more.

Extreme climate variability leads to adaptations in fisher's strategy to cope with the change. Adaptation by changing the fleet into one-boat systems does not appear to be cost-effective. According to Suryawati and Firdaus (2018), the cost of one-boat systems is not significantly different from two-boat systems and the revenue from another group of species does not substitute for the revenue from the sardine catch.

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SUPPORTING INFORMATION

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