Vulnerability analysis of capture fisheries to climate change based on the Province Scale (exposure and sensitivity analysis)

V Mandhalika¹, A B Sambah¹, D O Sutjipto¹, F Iranawati², M A Z Fuad², C A Intyas¹, F Rochman⁵

¹Fisheries Resources Utilization Study Program, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Jalan Veteran Malang, East Java 65145 Indonesia

²Marine Science Study Program, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Jalan Veteran Malang, East Java 65145 Indonesia

³Marine Resources Exploration and Management Research Group, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Jalan Veteran Malang, East Java 65145 Indonesia

⁴Fisheries Agribusiness Study Program, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Jalan Veteran Malang, East Java 65145 Indonesia

⁵Tuna Fisheries Research Workshop, Research and Human Resources Agency-Marine and Fisheries, Ministry of Marine Affairs and Fisheries. Jalan Mertasari No. 140 Denpasar, Bali 80224, Indonesia

*Corresponding author: absambah@ub.ac.id

Abstract. Fisheries has a major contribution for the Indonesian economy both on a local and national scale. However, the phenomenon of climate change can threaten the sustainability of this sector. Therefore, a scientific approach is needed to determine the level of risk and adaptation strategies for fisheries, one of which is through vulnerability analysis. Vulnerability is the final analysis resulted from the analysis of sensitivity and exposure. Both of these analyses are important to determine the parameters that will affect the value of the fishery vulnerability to climate change. This research is focused on sensitivity and exposure analysis with the coverage limit is the province area to determine the sensitivity and exposure index that exists in the study area. The result will be important input in further research for the vulnerability of capture fisheries to climate change. Three provinces in Indonesia were selected through purposive sampling method. The source of data for indices variables were using recorded data in 2009-2020 from relevant sources. Result described that SST variability in the three provinces has the same pattern. In the exposure analysis, the SST is linked to the catch resulting in different exposure statuses in each province. It also illustrated those areas with a very high number of fishermen and catches will have very high sensitivity. The research will support in the sustainable management of capture fish at the province scale.
1. Introduction
Climate change has affected all aspects of life, including the environment. This phenomenon can also indirectly threaten the capture fisheries sector. Extreme conditions with rising water temperatures, low dissolved oxygen concentrations and changes in pH values, can result in the death of fish. Environmental conditions that are not optimal can reduce the metabolic rate, growth, metamorphosis, reproductive ability of fish, and affect the endocrine system and crocodile patterns [1]. All of these changes will directly or indirectly affect fishery production [2].

The impact of climate change on fisheries can be analyzed using vulnerability analysis. Vulnerability is the degree to which climate change is capable of damaging or endangering the system, depending on the sensitivity of the system and the ability of the system to adapt to new climatic conditions. Vulnerability analysis can be used as a scientific basis for determining climate change risks and the adaptation strategies needed to reduce these risks. Research on capture fisheries vulnerability in general has covered discussions on the coastal community scale to the national scale. In Indonesia, not many have conducted research on the vulnerability of capture fisheries. This research still revolves around small islands and certain animal species, or vulnerabilities due to climate change at the village scale [2].

Vulnerability is the final analysis obtained through a sensitivity and exposure analysis approach. Both of these parameters are important to be analyzed early in order to be able to determine the parameters that will affect the value of the vulnerability of a water to climate change. This research is focused on sensitivity and exposure analysis with the coverage limit is the province area to determine the sensitivity and exposure index that exists in the study area which can later be used as important input in further research, namely mapping the vulnerability of capture fisheries to climate change.

2. Methods
2.1. Research Area
This research was conducted in three provinces, namely East Java, Bali, and West Nusa Tenggara (Figure 1). East Java Province is limited to coordinates 6°–9° South Latitude and 111°–114° East Longitude, Bali is limited to coordinates 7°–9° South Latitude and 114°–115° East Longitude, and West Nusa Tenggara is limited to the coordinates of 7°–9° South Latitude and 115°–119° East Longitude. The three provinces have different Fisheries Management Areas (FMA). According to the Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 18 of 2014, the northern waters of East Java Province are part of FMA-712, the northern waters of Bali and Nusa Tenggara Provinces West is included in FMA-713, and southern waters of the Provinces of East Java, Bali, and West Nusa Tenggara are included in FMA-573.

![Figure 1. Research location](image)

2.2. Dataset
Data applied in the study include Sea Surface Temperature (SST), the number of fishermen, fish catches, the number of fish landing sites (fishing base/fishing port), and the number of fishery instructors (Table 1). The SST data used in this study is the result of processing monthly SST data from Aqua MODIS
level 3 satellite imagery with a spatial resolution of 4 km. SST level 3 data is SST level 2 data that has been collected/projected onto a defined spatial grid over a certain period of time [3].

| Data                                        | Year     | Source                                                                 |
|---------------------------------------------|----------|------------------------------------------------------------------------|
| SST                                         | 2009-2019| https://oceancolor.gsfc.nasa.gov/data/aqua/                             |
| Landing sites (fishing base/fishing port)   | 2018     | Decree of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 6 of 2018 concerning the National Fishery Port Master Plan. |
| Fishery instructors                         | 2017     | Minister of Marine Affairs and Fisheries of the Republic of Indonesia (http://kkp.go.id) |
| East Java                                   |          |                                                                        |
| Fish catch                                  | 2009-2019| Department of Marine Affairs and Fisheries of East Java Province       |
| Number of fishermen                         | 2010-2018|                                                                        |
| Bali                                        |          |                                                                        |
| Fish catch                                  | 2009-2019| Department of Marine Affairs and Fisheries of Bali Province            |
| Number of fishermen                         | 2010-2018|                                                                        |
| West Nusa Tenggara Barat                    |          |                                                                        |
| Fish catch                                  | 2009-2013| Central Bureau of Statistics of West Nusa Tenggara Province (https://ntb.bps.go.id) |
|                                             | 2014-2019| One data of West Nusa Tenggara Province (https://data.ntbprov.go.id)    |
|                                             | 2010-2012| Ministry of Marine Affairs and Fisheries Statistics report (https://statistik.kkp.go.id) |
| Number of fishermen                         | 2013-2017| Book of Business Potential and Investment Opportunities for Marine and Fisheries of West Nusa Tenggara Province by the Directorate General of Strengthening the Competitiveness of Marine and Fishery Products, Ministry of Marine Affairs and Fisheries |
|                                             | 2018     | One data of West Nusa Tenggara Province (https://data.ntbprov.go.id)    |

2.3. Data Analysis

2.3.1. Exposure
Exposure in this study is a level that indicates the magnitude of the impact received by the capture fisheries system due to climate change. This level is indicated by an exposure index value between 0 and 1 (a value of 0 indicates low exposure and 1 high exposure). SST was chosen as the exposure variable due to its changes have an impact on capture fisheries both directly and indirectly [2]. The following are the steps for calculating the Exposure Index (EI):

a) SST linear regression to get the linear regression coefficient value per province.

\[ y_i = a + bx_i \]  \hspace{1cm} (1)

b) Standardization of provincial linear regression coefficient values

\[ EI_i = Sb_i = \frac{b_i - \min b}{\max b - \min b} \]  \hspace{1cm} (2)

In which;

\[ y_i \] : The catch in area i
\[ x_i \] : SST in area i :
\[ a \] : Intercept
\[ b \] : SST regression coefficient value
\[ b_i \] : The regression coefficient value of SST in area i
\[ Sb_i \] : Standardization of SST regression coefficient in area i
\[ EI_i \] : Exposure index in area i
2.3.2. Sensitivity
The sensitivity variable of capture fisheries to climate change in this study is the catch landed (number of fishing base/fishing port) and the number of fishermen. The sensitivity index is from 0 to 1, a value of 0 indicates low sensitivity and a value of 1 indicates high sensitivity. The formulation of the sensitivity index at the provincial scale based on [2] are as follows:

a) Average of each variable per province
\[ \bar{x}_{JN_i} = \frac{\sum JN_i}{t} \]  
\[ \bar{x}_{HT_i} = \frac{\sum HT_i}{t} \]  

b) Standardize the value of each variable per province
\[ S_{JNi} = \frac{\bar{x}_{JN_i} - \min \bar{x}_{JN}}{\max \bar{x}_{JN} - \min \bar{x}_{JN}} \]  
\[ S_{HTi} = \frac{\bar{x}_{HT_i} - \min \bar{x}_{HT}}{\max \bar{x}_{HT} - \min \bar{x}_{HT}} \]  

c) Adding up the variables
\[ S_{\text{total}} = S_{JNi} + S_{HTi} \]  

d) Standardize the sum of the two variables to produce a sensitivity index
\[ SI_i = SS_{\text{total}} = \frac{S_{\text{total}} - \min S_{\text{total}}}{\max S_{\text{total}} - \min S_{\text{total}}} \]  

In which:
- \( \sum JN_i \): Total number of fishermen in area \( i \)
- \( \sum HT_i \): Total number of catches in the area \( i \)
- \( t \): Number of years of data collection
- \( \bar{x}_{JN_i} \): Average number of fishermen in the area \( i \)
- \( \bar{x}_{HT_i} \): Average catch in the area \( i \)
- \( \bar{x}_{JN} \): Average number of fishermen
- \( \bar{x}_{HT} \): Average catch
- \( S_{JNi} \): Standardization of the number of fishermen in the area \( i \)
- \( S_{HTi} \): Standardization of catches by area \( i \)
- \( S_{\text{total}} \): Total sensitivity to the area \( i \)
- \( SS_{\text{total}} \): Standardization of total sensitivity in the area \( i \)
- \( SI_i \): Sensitivity index on area \( i \)

3. Result and Discussion

3.1. Exposure Analysis

3.1.1. Sea Surface Temperature Analysis
The SST analysis in this study is limited to the coordinates of 6°-9° South Latitude and 111°-119° East Longitude. The spatial distribution of SST is shown through color degradation as shown in Figure 2. This color degradation shows the difference in the value of the sea surface temperature in each pixel. In general, the SST in the northern waters of East Java to West Nusa Tenggara has a higher temperature than the southern waters. However, this did not happen in 2016. The northern waters of East Java-West Nusa Tenggara also experienced an increase in SST in 2010. The high SST in 2010 was allegedly related to the Indian Ocean Dipole Mode (IODM) phenomenon. In 2019, there was a significant decrease in SST in the southern part of East Java-Bali, especially in coastal areas [4].

The results of the SST spatial variation are in accordance with [5], which states that in general the SST in the waters of the northern part of Bali Island has a higher temperature than the southern waters of Bali [6,7,8]. [9] also stated that the SST in the southern and central parts of the Alas Strait was dominated by low temperatures, while the northern part of the Alas Strait was dominated by high temperatures.
The decrease in SST in parts of Java Island to the south of West Nusa Tenggara Province is related to upwelling events that occurred in the waters south of Java to Timor Island around April to November. Upwelling in the waters south of Java to East Nusa Tenggara is the upwelling with the longest duration and highest intensity compared to other locations in Indonesia with a decrease in SST reaching 2°C below the average during the east monsoon.

Based on the analysis that has been carried out, the temporal variability of SST conditions in East Java Province in 2009-2019 can be explained that the SST in 2016 tends to be the highest with temperature values ranging from 29.1-31.7°C. The maximum SST average value in 2009-2019 occurred in March 2016 with an average monthly temperature of 31.7°C, while the minimum SST average occurred in August 2019 with an average monthly temperature of 26.39°C. Based on the graph, it can also be seen that there are differences in trends in the east and west monsoons. In the west season the SST has an average value of 29.94°C, while in the east season the sea surface temperature has an average value of 27.97°C.

![Figure 2. SST variability of 2009-2019](image)

In 2016 the condition of SST variability in the Province of Bali tends to be the highest with values ranging from 28.73-31.52°C. The highest SST trend occurred in March 2016 with an average monthly temperature of 31.52°C, while the lowest occurred in September 2019 with an average monthly temperature of 26.607°C. The highest SST average value in 2009-2019 occurred in March 2016, while the lowest occurred in August 2015. In the west season the SST has an average value of 29.94°C, while in the east season the sea surface temperature has an average value of 27.97°C.

In general, the increase in SST occurred in 2016. According to [5], the El Nino-Southern Oscillation (ENSO) phenomenon is one of the factors that causes the increase and decrease in SST in waters [10].
El Nino with a strong intensity occurred in 2015. In 2016, the El Nino weakened and started a La Nina phase. During El Nino, SST tend to be cooler, while during La Nina, SST tend to be warmer [11]. This is evidenced by the results of processing SST data which shows that 2016 was the year with the highest average monthly sea surface temperature during 2009-2019.

The SST in the three provinces observed experienced seasonal variations. The existence of seasonal variations in Indonesian waters is influenced by the phenomenon of the Indonesian Monsoon Current (Armondo) [5] which moves from the west (South China Sea, Natuna Sea, Karimata Strait, and Java Sea) to the east (Bali Sea, Sea Flores, and the Banda Sea) and south (Indian Ocean through straits in the Eastern Islands including the Bali Strait) or vice versa [12]. In the east monsoon, SST tend to be cooler than in the west monsoon. The decline began in April and continued to decline until August. In September, the temperature increases until it enters the west season and reaches its highest temperature in March.

3.1.2. Sea Surface Temperature to Fish Catch Analysis
The correlation analysis between SST and fish caught in the study area showed that the coefficient of determination of SST on the catches of the three provinces ranged from 7% - 13%. The highest coefficient of determination value is found in the Province of Bali, while the lowest coefficient of determination is found in the Province of West Nusa Tenggara. This shows that the magnitude of the effect of SST on the catch in each province is different. The SST affects 13% of the total catch in Bali Province. In the Provinces of West Nusa Tenggara and East Java, the catch which is affected by SST is only 7% and 11%, respectively. According to [2], changes in temperature do not always have the same effect on fish stocks and other organisms. For example, in small pelagic fish (lemuru fish/sardine) whose existence depends on plankton so that SST is not directly related to these two types of fish [13, 14].

3.2. Sensitivity Analysis
3.2.1. Fisheries Resources
The sensitivity analysis of capture fisheries resulted in an average number of fishermen. The average number of fishermen in East Java Province reached 6.5 times more than the average number of fishermen in Bali Province. The number of fishermen in East Java Province every year is able to reach 225,168 people. Meanwhile, the number of fishermen in West Nusa Tenggara Province and Bali Province were 66,631 people and 34,606 people, respectively. East Java Province is the area with the highest number of fishermen compared to Bali and West Nusa Tenggara Provinces. [15] stated that the largest distribution of fishermen on the north coast of East Java is in Sumenep Regency as much as 18% of the number of fishermen in East Java, while the highest number of fishermen on the South coast of East Java is in Banyuwangi Regency as much as 11% of the number of fishermen in East Java. The decrease and increase in the number of fishermen in East Java Province is the most volatile. In contrast to the Province of West Nusa Tenggara which has a fairly stable number of fishermen every year. The increase in the number of fishermen in East Java and Bali provinces occurred in 2016. The decrease in the number of fishermen in East Java, Bali and West Nusa Tenggara Provinces occurred in 2018.

According to [16], 90% of Indonesian fishermen are small-scale fishermen with under 30 Gross Tonnage of fishing vessel. The main problem faced by fishing communities is climate change. This phenomenon causes fishermen to find it difficult to determine the fishing season due to the erratic weather. Climate change does not only have an impact on weather conditions but also has an impact on reducing fishery resources which causes fishermen to have to search for fish at longer distances [17].

3.2.2. Fish Catch Analysis
Capture fisheries production in East Java Province annually reaches 400,230.95 tons. Capture fisheries production in this province is 3.87 times greater than capture fisheries production in Bali Province. The Provinces of West Nusa Tenggara and the Provinces of Bali have average catches of 166,923.44
tons/year and 103,420.60 tons/year, respectively. The value of capture fisheries production in East Java Province is the highest when compared to Bali and West Nusa Tenggara Provinces. Bali Province as the area with the lowest capture fishery production value. In 2015-2016 there was a decline in catches in the provinces of East Java and West Nusa Tenggara. The increase in catches in the Provinces of East Java and West Nusa Tenggara occurred from 2016 to 2019. The decrease and increase in catches in the Province of West Nusa Tenggara was the most volatile when compared to the Provinces of Bali and East Java Provinces.

The increase and decrease in catches as one of the capture fisheries variables that are influenced by the phenomenon of climate change. Generally, climate change that impacts on the interaction between the sea and the air can cause a decrease in fish production or the number of fishermen catches. In addition, climate change which is marked by an increase in SST also has consequences for shifting habitats to the loss of marine species [18].

3.3. Exposure and Sensitivity Analysis to Climate Change

3.3.1. Exposure

Further analysis of SST resulted in the exposure index as shown in Table 2. In general, SST variability in the three provinces has the same pattern. However, in the exposure analysis, this SST is linked to the catch resulting in different exposure statuses in each province. The province that is under very high pressure from climate change is Bali. The level of exposure to climate change in the Provinces of West Nusa Tenggara and East Java is still relatively low.

| Province                | EI         | Exposure Status |
|-------------------------|------------|-----------------|
| Bali                    | 1.00       | Very High       |
| West Nusa Tenggara     | 0.03       | Low             |
| East Java               | 0.00       | Low             |

3.3.2. Sensitivity

The sensitivity of capture fisheries to climate change for each province is shown in Table 3. [2] assume that the greater the number of fishermen or catches in an area, the greater the opportunity for climate change to affect fishery activities in the area. This is evidenced by the results of research showing that areas with a very high number of fishermen and catches will have very high sensitivity, for example, East Java Province. Areas with a low number of fishermen and catches will also have low sensitivity, for example the Provinces of Bali and West Nusa Tenggara.

| Province       | Variable ($) | S Total | SI  | Sensitivity Status |
|----------------|--------------|---------|-----|--------------------|
|                | Number of Fishermen | Fish Catch |     |                    |
| East Java      | 1.00         | 1.00    | 2.00| Very High          |
| West Nusa Tenggara | 0.17     | 0.21    | 0.38| Low                |
| Bali           | 0.00         | 0.00    | 0.00| Low                |

4. Conclusion

Sensitivity and exposure analysis was applied in the current study to investigate the effect of climate change to the capture fisheries at the province scale. The result of the study is important for the study of vulnerability of capture fisheries to climate change. SST is one of the climate change indicators that applied in the calculation of exposure index. The result describes here also confirmed the variability of SST that shown the specific pattern of variability due to the global phenomena event like ENSO and
IOD. SST variability in the three provinces has the same pattern. The result of exposure calculation showed the SST is linked to the catch resulting in different exposure statuses in each province. It also illustrated those areas with a very high number of fishermen and catches will have very high sensitivity. The recommendation also can be state as the result of the study which describe that a short-term policy strategy is implemented to reduce the impact on the most vulnerable area, namely Bali Province. Medium-term policies are implemented to reduce sensitivity in East Java Province and to increase adaptability in West Nusa Tenggara and Bali Provinces. The long-term policy is implemented to reduce exposure to the Province of Bali.

Acknowledgments
This research is a part of Hibah Penelitian Unggulan from the Universitas Brawijaya, under the funding of Research Institutions and Community Service of Universitas Brawijaya Number: DIPA-042.01.2.400919/2021. Authors thank to Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, Department of Marine Affairs and Fisheries East Java, Bali, and West Nusa Tenggara province. We also thanks to Central Bureau of Statistics for the data support.

References
[1] Syahailatua A 2008 Impact of climate change on fishery *Oseana* 33 25–32
[2] Cintra A K A, Setyobudiandi I, and Fahrudin A 2017 Province scaled fisheries vulnerability on climate change *Marine Fisheries* 8 223-233
[3] Satriaojie W N 2012 Teknologi Citra Satelit MODIS untuk Pengukuran Suhu Permukaan Laut. *Oseana* 37, 1-9
[4] Yuniarti A, Maslukah L, and Helmi M 2013 Studi Variabilitas Suhu Permukaan Laut Berdasarkan Citra Satelit Aqua MODIS Tahun 2007-2011 di Perairan Selat Bali *Jurnal Oseanografi* 2, 416-421
[5] Nuryana J, Hendrawan I G, and Karim W 2018 Pendugaan Kejadian Pemutihan Karang Berdasarkan Analisis Suhu Permukaan Laut (SPL) Tahun 2015-2016 di Perairan Bali *Journal of Marine and Aquatic Sciences* 4, 286-296
[6] Sambah A B, A Wijaya, N Hidayati, and F Iranawati 2021 Sensitivity and Dynamic of *Sardinella lemuru* in Bali Strait Indonesia *Journal of Hunan University (Natural Sciences)* 48, 97-109
[7] Setyohadi D, U Zakiyah, A B Sambah and A Wijaya 2021 Upwelling Impact on *Sardinella lemuru* during the Indian Ocean Dipole in the Bali Strait, Indonesia *Fishes* 6, 1-9
[8] Wijaya A, A B Sambah, D Setyohadi, and U Zakiyah 2021 Model of Habitat Characteristics of *Sardinella lemuru* in The Bali Strait, Indonesia *Journal of Southwest Jiaotong University* 56, 229-240
[9] Santoso D 2019 Sebaran Suhu Permukaan Laut (SPL) secara Spasial dan Temporal di Perairan Selat Alas Provinsi Nusa Tenggara Barat *Jurnal Bologi Tropis* 19, 34–41
[10] Sambah A B, Wijaya A, Iranawati F, and Hidayati N 2021 Impact of ENSO and IOD on Chlorophyll-A Concentration and Sea Surface Temperature in the Bali Strait *IOP Conf. Series: Earth and Environmental Science* 674, 1-7
[11] Nabilah F, Prasetyo Y, and Sukmono A 2017 Analisis Pengaruh Fenomena El Nino dan La Nina terhadap Curah Hujan Tahun 1998 - 2016 menggunakan Indikator ONI (Oceanic Nino Index) (Studi Kasus: Provinsi Jawa Barat) *Jurnal Geodesi UNDIP* 6, 402-412
[12] Cahya C N, Setyohadi D, and Surinati D 2016 The influence of Oceanographic Parameters on Fish Distribution *Oseana* 41, 1-14
[13] Putra E, Gaol J L, and Siregar V P 2012 Relationship Chlorophyll-A Concentration and Sea Surface Temperature with Primary Pelagic Fish Catches In Java Sea From Modis Satellite Images *Jurnal Teknologi Perikanan dan Kelautan* 3, 1-10
[14] Sambah A B, T D Oktavia D W Kusuma, F Iranawati1, N Hidayati, and A Wijaya 2020 Oceanographic Variability and Its Influence on Pelagic Fish Catch in the Bali Strait *Berkala Penelitian Hayati* 26, 8-16
Huda H M, Purnamadewi Y L, and Firdaus M 2014 Strategi Pengembangan Perikanan dalam Pembangunan Ekonomi Wilayah di Jawa Timur. *Ekuitas: Jurnal Ekonomi dan Keuangan* 18, 387–407

Retnowati E 2011 Nelayan Indonesia dalam Pusaran Kemiskinan Struktural (Perspektif Sosial, Ekonomi, dan Hukum) *Perspektif* 16, 149-159

Ulfa M 2018 Persepsi Masyarakat Nelayan dalam Menghadapi Perubahan Iklim (Ditinjau dalam Aspek Sosial Ekonomi) *Jurnal Pendidikan Geografi: Kajian, Teori, dan Praktik dalam Bidang Pendidikan dan Ilmu Geografi* 23, 41-49

Moegni N, Rizki A, and Prihantono G 2014 Adaptasi Nelayan Perikanan Laut Tangkap dalam Menghadapi Perubahan Iklim. *Jurnal Ekonomi dan Studi Pembangunan* 15, 182-189