Spatio-Temporal Habitat Suitability Detection for Small Pelagic Fish Using Earth Observation Data on Nusa Penida Coast – Bali, Indonesia

RIZKI HANINTYO
February, 2019

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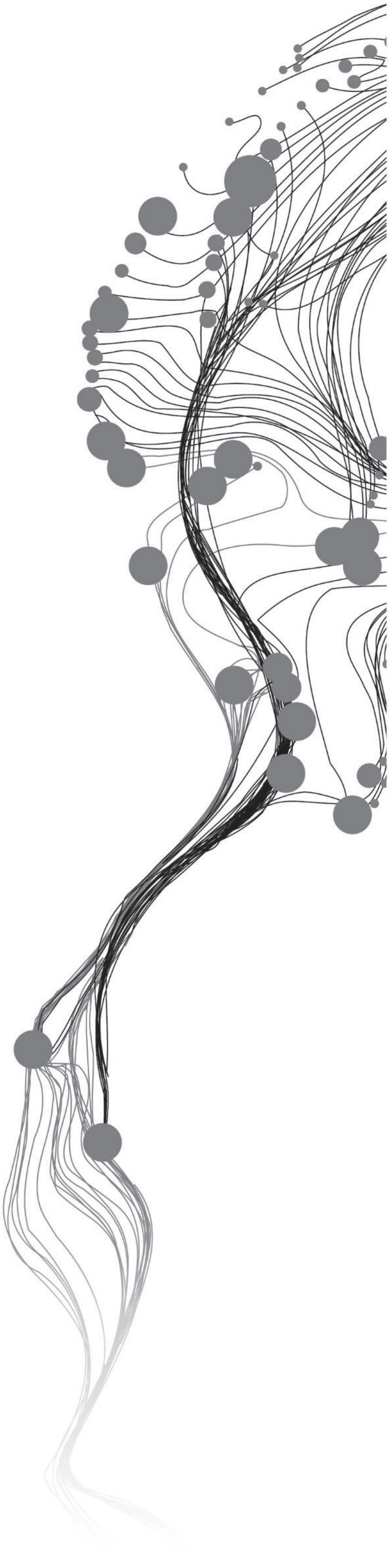

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RIZKI HANINTYO
Enschede, The Netherlands, February, 2019

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Water Resource and Environmental Management

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DISCLAIMER

ABSTRACT

Indonesia is one of the largest archipelagos, has a high fish stock in the open and coastal area. The United Nations has set where the ocean and the fish as one of the goals in their Sustainable Development Goals (SDGs). Map of Potential Fishing Ground (MPFG) can be utilized to catch and monitor small pelagic fish in a sustainable way. The MPFG for small pelagic fish in the coastal area has been developed using Earth Observation data and Marine Copernicus datasets. The habitat suitability index from Maximum entropy has been used to produce percent contribution and empirical relationship between potential fishing ground and EO data in Nusa Penida island in Indonesia. Sea Surface Temperature (SST), Front SST, Sea Surface Height (SSH), Sea Surface Current, Sea Surface Salinity and Chlorophyll-a have been observed using Sentinel 3 data and Marine Copernicus data to produce MPFG for small pelagic fish in the coastal area. The fish occurrence from acoustic measurement has been used as an input for Maximum Entropy model. Two empirical relationships based on multilinear equation has been produced, using Sentinel 3 datasets and using Marine Copernicus datasets. The empirical relationship equation using Sentinel 3 dataset has R^2= 0.9808 while using Marine Copernicus Dataset has R^2= 0.9865 for September 2018 dataset and R^2=0.9884 for October 2018 dataset. The percent contribution results from Sentinel 3 dataset showed incoherence with some literatures while the Marine Copernicus similar with previous literature. The SSH and chlorophyll-a is the main contributing parameter for detecting small pelagic fish. Based on weekly climatology MPFG from Marine Copernicus data since 2016-2018, the hotspot / high probability of fish occurs on the marine protected areas of Nusa Penida island. It means the MPFG information can be used not only for catching the fish but also monitoring the fish.

Keywords:
Small Pelagic Fish, Potential Fishing Ground, Habitat Suitability Index, Earth Observation, Maximum Entropy

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ACRONYMS

Maxent	= Maximum Entropy
MMAF	= Ministry for Marine Affairs and Fisheries
MPFG	= Map of Potential Fishing Ground
MPSFL	= Maps of Specific Fish Location
SST	= Sea Surface Temperature
SSH	= Sea Surface Height

1. INTRODUCTION

1.1. Background

As one of the largest archipelagos, Indonesia has a high fish stock in the open ocean and coastal area. In 2016, the UN has set the Sustainable Development Goals (SDG) where the SDG number 14 concerns about life below the water. This UN SDG number 14 is established due to overexploitation of fish stock/overfishing especially in unmanaged fisheries aspect and developing countries. One of the goals of SDG number 14 is "*By 2030, increase the economic benefits to Small Island Developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture, and tourism*" (UN, 2018). Based on Accountability Performance Report of Ministry for Marine Affairs and Fisheries (MMAF) of Republic Indonesia, the fisherman exchange value (FEV) has increased 3.5% from 2015 to 2017. The FEV is a value to determine the prosperity of fishers. The value calculated by the ratio of the fish price on the market and main basics needs including the cost to operate a fishing vessel. The FEV that has been increased from 2015-2017 due to the high amount of fish being caught and stable cost to operate a vessel (KKP, 2018). On the other hand, FEV from 2015-2017 shows increasing exploitation of fish stock. As the FEV increases, the income and prosperity of fisherman will increase. A way further increase FEV is to cut the cost of the operating fishing vessel, an optimum analysis to operate fishing vessel must be conducted, such as providing Potential Fishing Ground (PFG) maps that include fish stock management. PFG maps will guide fishers to make an efficient vessel planning to catch fish thus will reduce fuel consumption and other costs (ice, labor cost, etc.).

To determine the location of good fishing grounds, we need to understand the food chain of fish and environmental factors in the ocean, i.e., physical and biogeochemical parameters. Based on the food chain, the spawning habitat of fish can be determined based on food for larvae, which came from phytoplankton and zooplankton (Lehodey et al., 2012). The spawning habitat and distribution of fish are affected by biological parameters and physical parameters (Lehodey et al., 2008), such as sea surface temperature (Agenbag et al., 2003), sea surface height (Rivai et al., 2018; Zainuddin et al., 2017), sea surface current (Syah et al., 2016), and sea surface salinity (Daqamseh et al., 2013; Murase et al., 2009) to detect pelagic fish. The biological parameters, such as phytoplankton, act as primary producer (Robinson, 2010) in case-1 and case-2 water in term of biomass productivity (Ferguson et al., 1981). Phytoplankton can be measured in the form of chlorophyll-a using a passive sensor remote sensing data in case-1 (Tang, 2011) and case-2 water (Ambarwulan, 2010) spatially, in horizontal and vertical distribution/depth (Gholamalifard et al., 2013). One of the fish species that have high economic value and categorize as big pelagic fish is Thunnus, sp where adult Thunnus, sp mainly caught in case-1 water. Phytoplankton is one of the parameters in the food chain of *Thunnus, sp* (Olson et al., 2016). Model of the physical parameter and food chain of specific fish, such as *Thunnus, sp*, has been described and predicted in (Sukresno et al., 2015) using Empirical Cumulative Distribution Function (ECDF) for *T. obesus*, *T. alalonga*, *T. albacares*, and *T. maccoyii*. On the other hand, *Katsuwonus Pelamis* and *T.obesus* have been modeled using Spatial Ecosystem and Population Dynamics Model (SEAPODYM) (Lehodey et al., 2008) (SPC-CPS, 2014) in case-1 water. The SEAPODYM model using a food chain and environmental parameters to determine those species. The ECDF and SEAPODYM model can be used optimally in the case-1 water.

A study have been conducted to determine the location of the fishing ground area of small pelagic fish in the coastal /case-2 water area. Pacific Saury (*Cololabis saira, sp*) has been predicted using MODIS-Aqua and maximum entropy (Maxent) model to obtain environmental parameter (sea surface temperature/SST, eddy kinetic energy, and sea surface height anomaly/SSHA) and OLS satellite imagery to detect fishing vessel on north pacific region (Syah et al., 2016). Anchovy (*Stolephorus, sp*), sardine (*Sardinella fimbriata*), squid (*Loligo, sp*) and scads (*Selaroides leptolepis*) habitat has been analyzed in Kepulauan Seribu (Seribu Island) – Indonesia based on SST, SSH, chlorophyll-a, currents, bathymetry and total suspended solid / TSS using Generalized Additive Model /GAM. (Rivai et al., 2018). The Maxent model has been used to assess monthly habitat suitability maps for Atlantic Hering (*Clupea harengus*), Atlantic Mackarel and Butterfish based on SST, chlorophyll-a, bathymetry and climatic indices(Wang et al., 2018).

Ministry for Marine Affairs and Fisheries (MMAF) of Republic of Indonesia has been developing and publishing Maps of Potential Fishing Ground (MPFG) and Maps of Specific Fish Location (MPSFL) since 2004. Both maps are published by Institute for Marine Research and Observation (IMRO), a technical research unit of MMAF on a daily-basis for MPFG and as 10-day forecasts for MPSFL (IMRO, 2018e). The MPFG is published by IMRO for the Indonesian territorial waters. The MPFG divided into two scales, national and regional scale, where both MPFG maps have a different scale, coverage and temporal time of publishing. MPFG for national scale consists of 5 maps which contain 5 mains island of Indonesia (Sumatra, Java, Kalimantan, Bali and Nusa Tenggara, and Sulawesi and Papua)(IMRO, 2018c). The MPFG regional scale created in several case area where the MMAF requested to maps that area. There are 15 maps of a regional scale of MPFG (IMRO, 2018d). The type of fish that has been mapped in MPSFL is *T. Obesus* (Big Eye Tuna) in southern part of Java(IMRO, 2018b), *Katsuwonus Pelamis (Skipjack Tuna)* in northern part of Sulawesi and Papua (IMRO, 2018a), and *Sardinella Lemuru* (local name: *ikan lemuru*) in Bali strait (Susilo & Wibawa, 2016). These 3 MPSFLs are providing 10 days forecast and published every Thursday. These fishing ground maps published by IMRO are optimized for case-1 water. Based on MMAF Statistical report 2015, 65% of the vessels are small vessels (less than 30 gross tonnage) which is only operated on case-2 water (PUSDATINKP, 2015). These small vessels mostly owned by fishermen with lower income. A specific MPFG map for case-2 water is needed to help these fishermen. The maps also need to pay attention with several Marine Protected Areas / MPA where this area should be protected from any major destruction based on MMAF decree.

To obtain MPFG in case-2 water and a small pelagic fish, we need to understand the habitat suitability of small pelagic fish. A Maxent model has been introduced to understand the habitat suitability of species geographically. This model able to perform better to know the habitat suitability for a small pelagic fish. Maxent is a machine learning method, precise mathematical formulation, and number of aspects that have an excellent performance to see a species distribution modeling (Phillips et al., 2006). Several studies has been use maxent to map species, such as modelling of Piper *Aduncum,sp* in Philippines (Paquit & Rama, 2018), cetacean in Northeast Atlantic (Breen et al., 2017) Atlantic Hering (*Clupea harengus*), Atlantic Mackarel and Butterfish (Wang et al., 2018), Pacific Saury (Syah et al., 2016) and squid in Japan sea (Alabia et al., 2015). To obtain habitat suitability from Maxent Model, several environmental parameters and location information of species that will be mapped are needed. The location information of species is needed to calibrate and validate the Maxent model. The result of the Maxent Model is a percent contribution of each given parameter that contributes to the distribution of species location. In terms of PFG, habitat suitability from maxent can be related with the potential fishing ground (Alabia et al., 2015).

Chlorophyll-a has been used widely to determine fishing ground on the case-1 and case-2 areas. High-quality chlorophyll-a data is needed to determine the fishing ground of case-2 water. The coastal area has a complex and high variation at temporal and spatial scales (Elsdon & Connell, 2009). Several chlorophyll-a estimation methods have been introduced for coastal area. The 2SeaColor model(Mhd Suhyb Salama & Verhoef, 2015) has been able to retrieve a chlorophyll-a concentration on complex water in the coastal area(Arabi et al., 2016) using Sentinel 3 OLCI sensor (Arabi et al., 2018). The chlorophyll-a retrieval using 2SeaColor coupled with atmospheric correction method named Moderate Resolution Atmospheric

Transmission Model /MODTRAN have a reasonable result with RMSE 33.2% and R^2=0.88 where the validation of SeaWiFS global open ocean water with RMSE 58%(Arabi et al., 2016). In the other hand, the Case 2 Regional CoastColour / C2RCC has been introduced to estimate chlorophyll-a concentration using neural network method (Brockmann, 2016). The C2RCC is available in ESA SNAP toolbox where it uses a large database for radiative transfer simulations by neural network. The C2RCC originally created from the case 2 Regional Processor by Doerffer (2008). The neural network has been used by C2RCC to perform inversion of wavelength for atmospheric correction and inherent optical properties / IOP.

An accurate fishing ground information is needed for the coastal area. Research of detecting a potential fishing ground on case-1 and case-2 water mostly use Aqua/Terra-MODIS. A new Sentinel 3 remote sensing satellite developed by European Space Agency has been launched in February 2016 (3A) and April 2018 (3B). The Sentinel 3 satellites have good performance to retrieve physical and biological parameter to detect fishing ground. The Sentinel 3 satellite has Ocean and Land Color Instrument / OLCI and Sea and Land Surface Temperature Radiometer / SLSTR sensor. The OLCI sensor has 300m spatial resolution and SLSTR has 500m on VNIR/SWIR and 1 km on TIR. The OLCI sensor has 21 bands, ranging from visible to the near infrared (400 nm – 10200 nm). The SLSTR sensor has 9 bands, ranging from VNIR (554.27 nm – 868 nm), SWIR (1374.8 nm – 2255.7 nm) and thermal infra red (3742 nm – 10854 nm). Both spectral information is adequate to retrieve physical parameter and biological parameter to detect fishing ground information.

The study focused on generating potential fishing ground maps for small pelagic fish on the coastal area. The Maxent model is used for determining habitat suitability for small pelagic fish on the coastal area. The Sentinel 3 OLCI has been used to retrieve biological parameter and Sentinel 3 SLSTR is used to retrieve physical parameter. The C2RCC method has been used for retrieving chlorophyll-a in the coastal area using Sentinel 3-OLCI data. Based on the habitat suitability, the threshold from each parameter and empirical relationship for MPFG small pelagic fish can be retrieved. The validation of resulted potential fishing ground map will be conducted to assess the accuracy of the map.

1.2. Research problem

Indonesia coastal areas have a huge number of fisherman with a small boat (<10 GT), have less equity to operate the boat and mainly catch a small pelagic fish in the coastal area. They did not have enough information and technology to catch the fish efficiently. Earth observation data able to derive fishing ground information based on several oceanographic parameters. The fishing ground information will help the fisher to catch fish efficiently in the coastal area. On the other hand, retrieving biological parameters on the coastal area has several issues, such as spatial and temporal concentration variability that made retrieval process will not accurate. A statistical model has been developed based on the given parameters to obtain fishing ground area.

1.3. Research objectives and Questions

1.3.1. General Objective

The general objective of this study is to map potential fishing ground on coastal area in Bali, Indonesia using EO data.

The specific research objectives are formulated below:

1. To obtain a habitat suitability index for small pelagic fish from maximum entropy and contribution on each oceanographic parameter
2. To establish an empirical relationship between potential fishing ground and EO data
3. To validate the resulting potential fishing ground map on the coastal area.

1.3.2. Research questions

Based on Research Objective above, the research question is formulated below:

1. What is the best contributing environmental parameters from maximum entropy to map potential fishing ground for small pelagic fish?
2. Is there a relationship between EO data observed and PFG? And what is the empirical relationship to produce a potential fishing ground map for small pelagic on the coastal area?
3. What is the accuracy of resulting map of potential fishing ground?

2. METHODOLOGY

A physical and biological oceanographic parameter are required to obtain potential fishing ground, such as Sea Surface Temperature/SST, Front SST, Sea Surface Height/SSH, Sea Surface Current, Sea Surface Salinity, Bathymetry, and Chlorophyll-a. Moreover, not only physical and biological oceanographic parameters, but also a fish caught data is needed. A list of method and scientific article (Table 1) has been chosen to obtain parameters that support this research. The Maximum Entropy / Maxent model use those parameters to simulate the habitat suitability for small pelagic fish. A detailed step to obtain fish biomass shown in Figure 9. This figure have 1 sub-step, where the MPFG created for case-2 using Sentinel 3 data (Figure 10).

Table 1. Main Scientific Article and Methods

Parameter	Model/method	Scientific Article
Sea Surface Temperature/SST	Nadir-dual View SST (S3) Dual channel SST (L8)	(Embury & Merchant, 2012) (Aleskerova et al., 2017)
Front SST	Single Image Edge Detection / SIED	(Cayula & Cornillon, 1992)
Chlorophyll-a	Case 2 Regional Coast Colour / C2RCC	(Brockmann, 2016)
Bathymetry	Bathymetry maps from Navy Hydro-Ocean Center	-
Sea Surface Height	Global Ocean Physics Reanalysis GLORYS12V1	-
Sea Surface Current		-
Sea Surface Salinity		-
Fish prediction	Maximum Entropy	(Wang et al., 2018) (Phillips et al., 2006)

2.1. Physical Parameter

2.1.1. Sea Surface Temperature / SST

The SST data has been retrieved from Sentinel 3 – SLSTR. The ATSR Reprocessing for Climate / ARC procedure have been used for producing SST data. Further, this procedure is called ARC SST that can be used in ESA SNAP application. The ARC SST procedure for Sentinel 3 – SLSTR data are estimated using a coefficient-based retrieval scheme (Embury & Merchant, 2012) and give 2 output data, nadir view and dual view data. The ARC SST uses a new coefficient that obtained from numerical weather analysis. The coefficient reduces regional biases to <0.1 K compared to global biases of ~0.2 K. The nadir view data has been used because of it a low deviation of 0.2 K based on Embury & Merchant, 2012. The example of derived ARC SST nadir view of Sentinel 3 SLSTR in Figure 1.

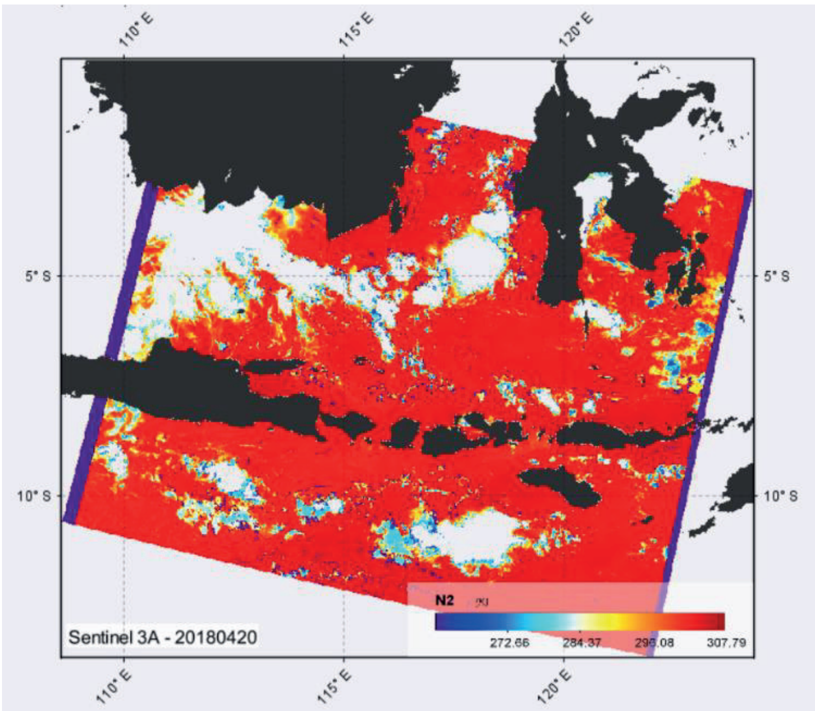


Figure 1 ARC SST Nadir View arrond Nusa Penida, Bali

2.1.2. Front SST

Upwelling is one of the important aspects in the ocean where the two different water masses met in the surface (Jing et al., 2012). The upwelling process is based on the lifting of water mass from deep water column to the sea surface. The upwelling can be indicated by lower SST from surrounding and resulted a higher chlorophyll-a because the lifting of the water mass carried a rich nutrient (Wirasatriya et al., 2018). The low SST differences from the surrounding area can be called front SST. The gradient zone or edge can be detected using SST imagery using histogram and edge detection method (Cayula & Cornillon, 1992). The edge detection method have been processed using Marine Geospatial Ecology Tools / MGET (Roberts et al., 2010). A 0.05^{0}C threshold have been used for the edge detection because of this value able to follow the seasonal temperature trends in tropical area (Jatisworo, 2017). The sample of front SST detection over Nusa Penida, Bali in Figure 2.

Based on Cayula & Cornillion (1992), the front SST has been calculated with respect of pixel window kernel with the strong edge. The kernel size should be determined to see the value in surrounding pixel area and the threshold value should be given to see the edge where the front SST is occurring. The moving pixel window kernel iterated through the image to check the location of front SST.

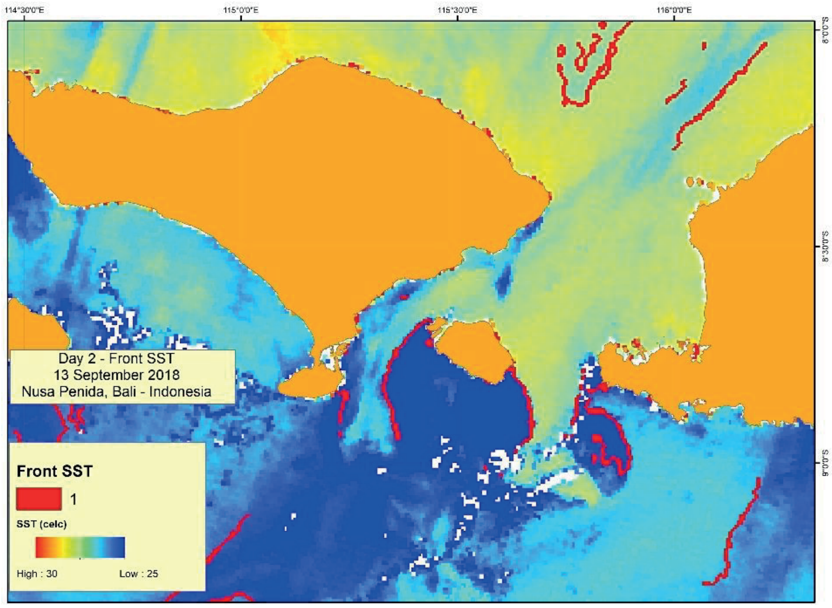


Figure 2. Front SST distribution

2.1.3. Sea Surface Current

The sea surface current data has been retrieved from Marine Copernicus Data (http://www.marine.copernicus.eu). The Marine Copernicus Data. The sea surface current dataset named "Global Ocean 1/12^0 Physics Analysis and Forecast". This dataset consists of a daily and monthly analysis of oceanographic physical parameters, such as sea surface current, sea surface height, and sea surface salinity. Those 3 parameters have been used in this study. This dataset has been processed by Marine Copernicus using the NEMO ocean model version 3.1 and use the bathymetry data of GEBCO8 and ETOPO1 (CMEMS, 2018). The altimeter data, in-situ temperature, vertical salinity profiles and satellite SST are jointly assimilated in the dataset. (CMEMS, 2016). The sea surface current dataset consists of 2 variables, a northward sea water velocity (V) and eastward sea water velocity (U). The sea surface current velocity has been calculated using simple Pythagoras equation where sea surface current velocity:

$$SSCV = \sqrt{U^2 + V^2}$$

The dataset is published daily and have a forecast for 10 days ahead. The dataset has a 9 km spatial resolution. The resampling has been used to up-sample the dataset that will be the same resolution with sentinel 3 SLSTR data. A northward and eastward sea surface current velocity of the dataset in Figure 3. In the figure, the data has a negative value for northward velocity and eastward velocity. It means both velocity direction is the opposite. For example, the northward velocity of -2 directed to south with velocity of 2 m/s.

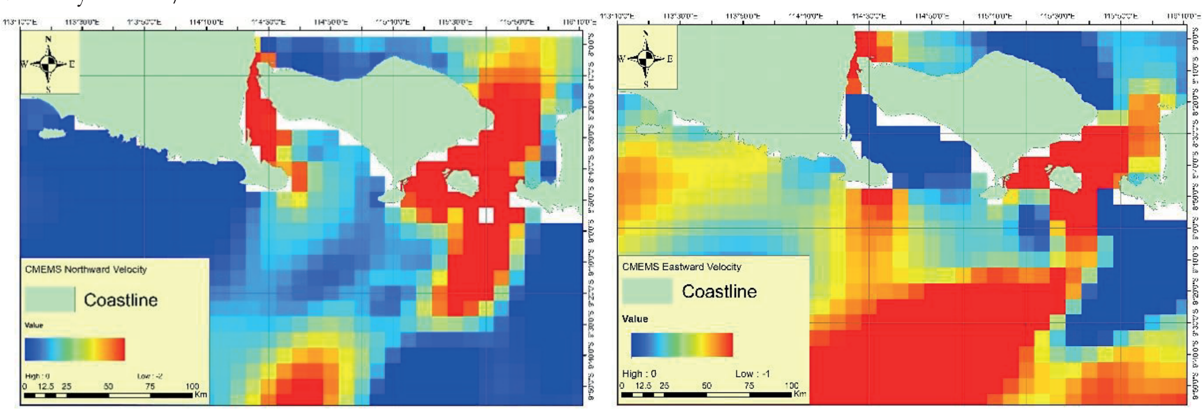


Figure 3. Marine Copernicus Dataset Northward (left) and Eastward (right) sea surface current velocity

2.1.4. Sea Surface Height

The sea surface height / SSH data has been retrieved from Marine Copernicus "Global Ocean 1/12^0 Physics Analysis and Forecast". The SSH data measured above the geoid surface. The geoid surface is a surface of constant geopotential with mean sea level. This dataset measured using altimeter satellite that measures SSH from ellipsoid. The NEMO ocean model represent SSH to the geoid based from altimeter satellite. (CMEMS, 2018). The dataset has three temporal option, an hourly, daily and monthly data. A daily dataset with 9 km spatial resolution has been used for this study (Figure 4)..

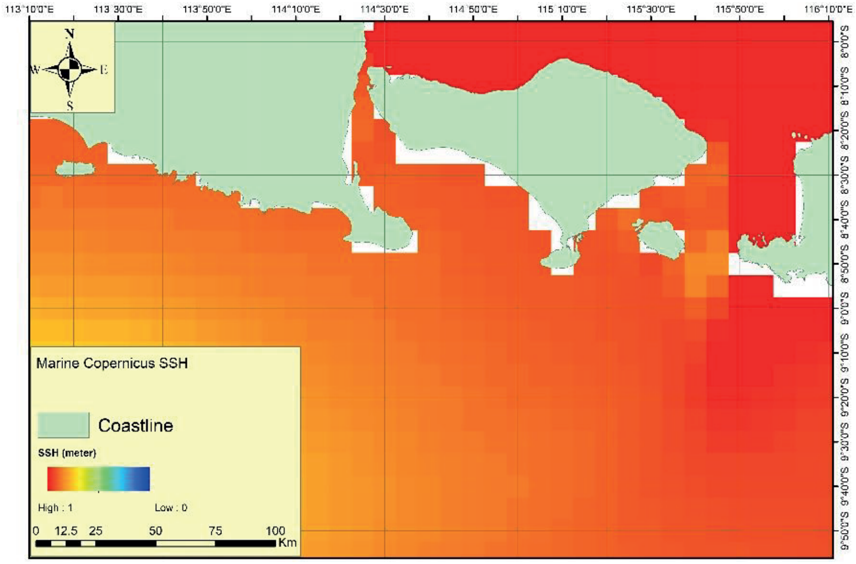


Figure 4. Marine Copernicus SSH dataset

2.1.5. Sea Surface Salinity

The sea surface salinity / SSS has been derived from the same dataset as the sea surface current and SSH. Based on the quality report in a global scale, the SSS dataset has 0.5 ppt RMSE while in the Indian Ocean has 0.2 RMSE on 0-5 m depth (CMEMS, 2016). The high accuracy SSS data due to the bathymetry used in the system from specific correction for Indonesian Sea (CMEMS, 2016; Tranchant et al., 2016). The resampling process has been performed to match with spatial resolution of Sentinel 3. The SSS dataset over Nusa Penida, Bali (Figure 5) showed a high variability of SSS range from 32-34 ppt.

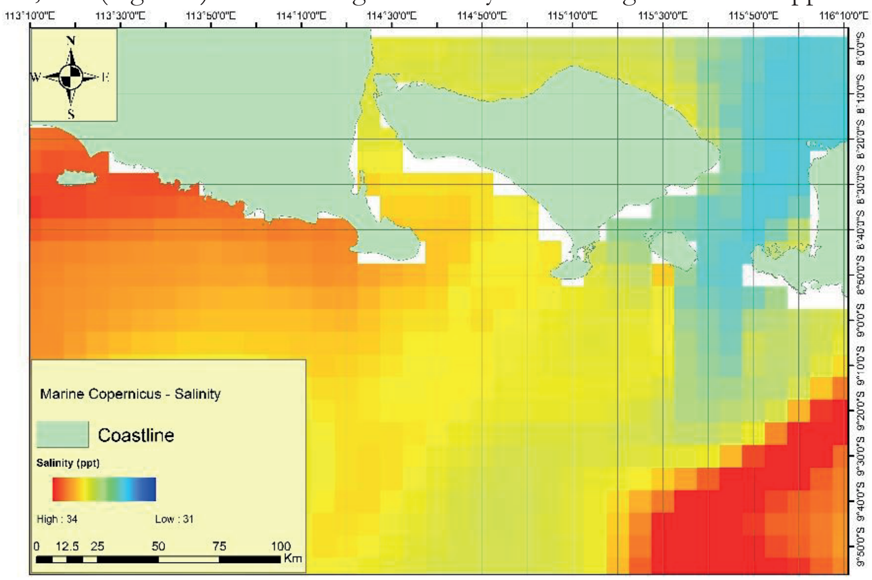


Figure 5. Marine Copernicus SSS Dataset

2.1.6. Bathymetry

The bathymetry map information has been retrieved from Navy Hydro-Ocean Centre. The bathymetry maps from Navy Hydro-Ocean Centre in hardcopy maps and has been digitized. Interpolation of this polyline data has been conducted to obtain a raster bathymetry data that has same spatial resolution with Sentinel 3 – SLSTR. For a quick overview of bathymetry condition in Nusa Penida, Bali, a GEBCO bathymetry data showed in Figure 6. A GEBCO bathymetry data has a 30-second resolution or 1 km spatial resolution near the equator. In the west part of Nusa Penida, a bathymetry has a maximum depth around 130 m while in the east (Lombok strait) has a maximum depth of 230 m.

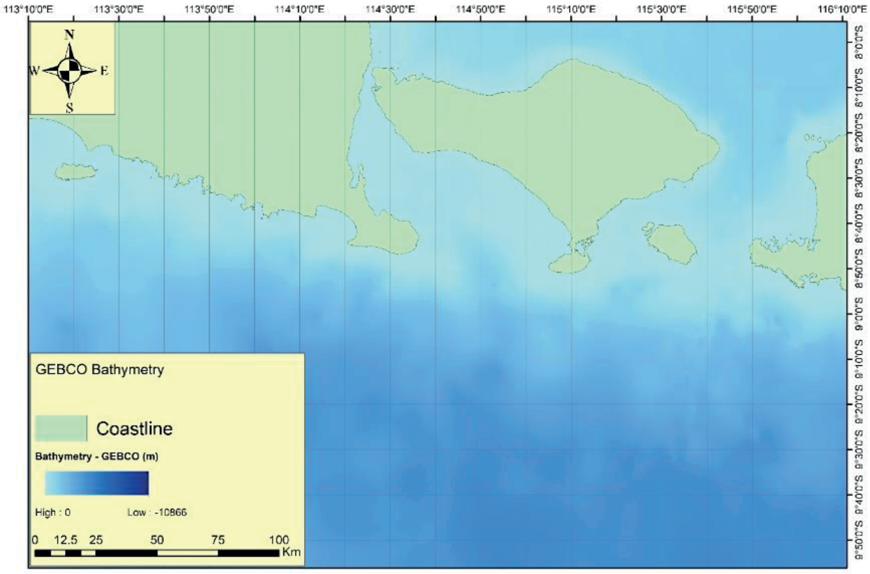


Figure 6. GEBCO Bathymetry of Nusa Penida, Bali

2.2. Biological Parameter – chlorophyll-a

A neural network / NN based processor called C2RCC has been used to obtain chlorophyll-a concentration over complex coastal area. The C2RCC processor using a large simulated database of water leaving reflectance and TOA radiances. NN has been used in C2RCC to inverse wavelength spectrum for atmospheric correction and retrieving inherent optical properties. The bio-optical model to retrieve Chlorophyll-a has been performed by C2RCC using 5 components for scattering and absorption to parameterise the model. All IOP are defined at 443 nm wavelength. Figure 7 below show the bio-optical model that has been used in C2RCC processor. The 5 components are abstraction from large data of IOP in natural water (Brockmann, 2016; Nechad et al., 2015).

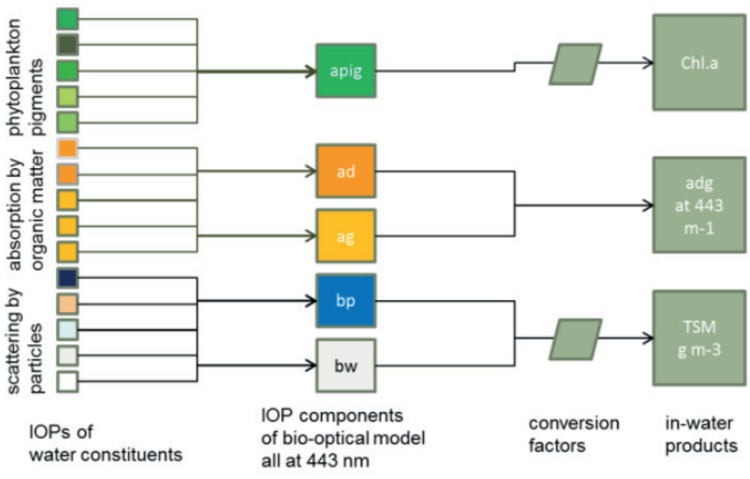


Figure 7. Bio- Optical model schematic from C2RCC (Brockman, 2016)

2.3. Fish Data

The fish data has been retrieved from hydro acoustic survey. The data has been retrieved using scientific acoustic sounder from Biosonics DT-X series. The device collects hydroacoustics data in the bottom of the vessel. The device and Visual Acquisition software (Figure 8) assess biological behavior, abundance and distribution of fish. The result is a number of echoes, target strength, depth and location of each transect. The data acquisition has been taken in a vessel with not more than 6 knots to obtain a good data.

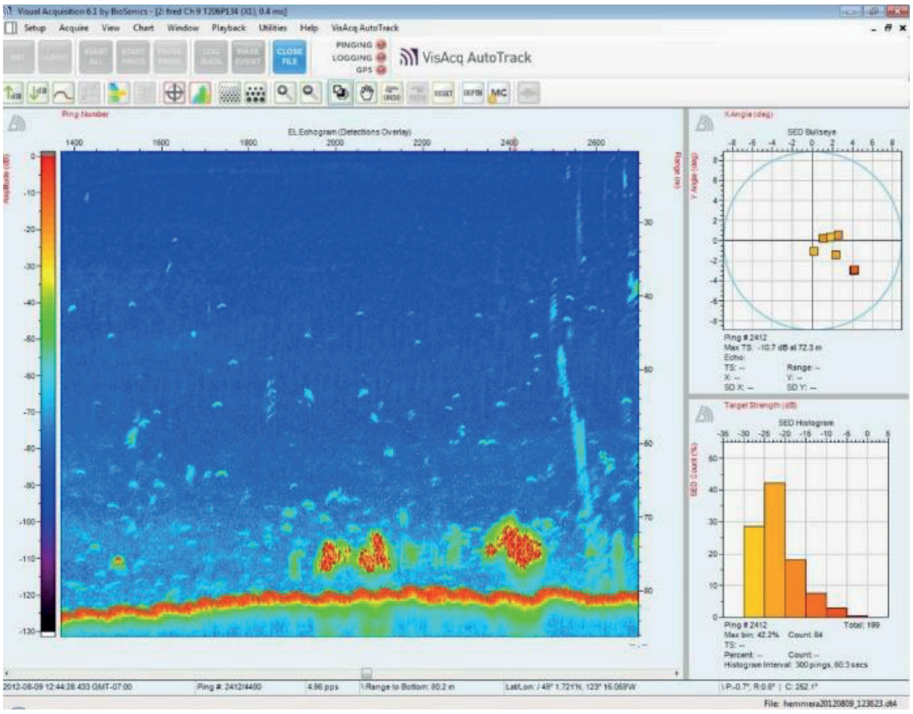


Figure 8. Visual Acquisition software (courtesy : www.biosonics.com)

2.4. Maximum Entropy

The main concept Maximum Entropy (Maxent) is to estimate a target probability distribution (geographic range) by finding the distribution that close to geographically uniform which has maximum entropy based on a number of constraints derived from the environmental condition at species occurrence location (Phillips et al., 2017; Phillips et al., 2006). Maxent estimate the spatial distribution by finding the distribution which has close to spatial uniform(Phillips et al., 2017). The entropy (H) from probability distribution P in the area X defined as

$$H(x) = -\sum P(x) \ln P(x)$$

To find the target probability distribution, a known distribution is required. In term of Species Distribution Modelling/SDM, a known distribution is a set of presence data of species. The complementary log-log (cloglog) transformation have been used to estimate species probability presence as:

$$probability\ presence = 1 - \exp\big(-\exp\big(H(x)P(x)\big)\big)$$

This cloglog probability transformation has been able to derive the probability of habitat based on environmental condition. Using cloglog, it has a good probability result on moderate to high probability compared to logistic transformation (1/(1+exp(H))) (Phillips et al., 2017). A primary goal of SDM is to understand the contribution of environment condition that suitable for specific species.

Maxent method for SDM has been published as a software package in Java and R package named Maxnet (Phillips et al., 2017; Phillips & Dudík, 2008). A maxent java package has been downloaded from https://biodiversityinformatics.amnh.org/open_source/maxent/. A Maxent package in Java has been used to analyse single temporal data while the maxent with R has been used to analyse multi-temporal data. The result of Maxent (Java or R) is a habitat suitability index /HSI of given species and a percentage contribution of each ocean physical (SST, front SST, sea surface current, sea surface height and bathymetry) and biological parameter (Chlorophyll-a). The percent contribution of each parameter has been calculated using the jackknife test in the software package. Where the jackknife test (leave-one-out procedure) provide performance information on each environmental parameter in term of variable importance to determine species distribution (Baldwin, 2009).

2.5. PFG Empirical Relationship and PFG map production

The multilinear regression has been used to develop empirical relationship for PFG where all X_n parameter given in maxent used to determine PFG. The multi-linear regression looks like this

$$PFG \approx HSI = \alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_n x_n$$

Where α_n is the coefficient from multi linear regression of each parameter. The result value normalized so the value will have range from 0 to 1. The validation process of resulted PFG have been performed based on fish caught data. Based on this empirical equation, regional MPFG can be calculated without any presence data of species. The MPFG production has been produced using given resulted equation.

2.6. Accuracy Assessment

The accuracy assessment has been conducted for SST, chlorophyll-a data and MPFG. RMSE, MAE and R^2 to measure the accuracy. The SST data has been calculated using Arc SST method from Sentinel 3 and the chlorophyll-a has been calculated using C2RCC method. Both parameters have been compared with point measurement from WQC TOA DKK and coastal buoy. The MPFG accuracy assessment has been conducted the accuracy of produced PFG map from developed empirical equation. The assessment of MPFG has been assessed using data from acoustic measurement.

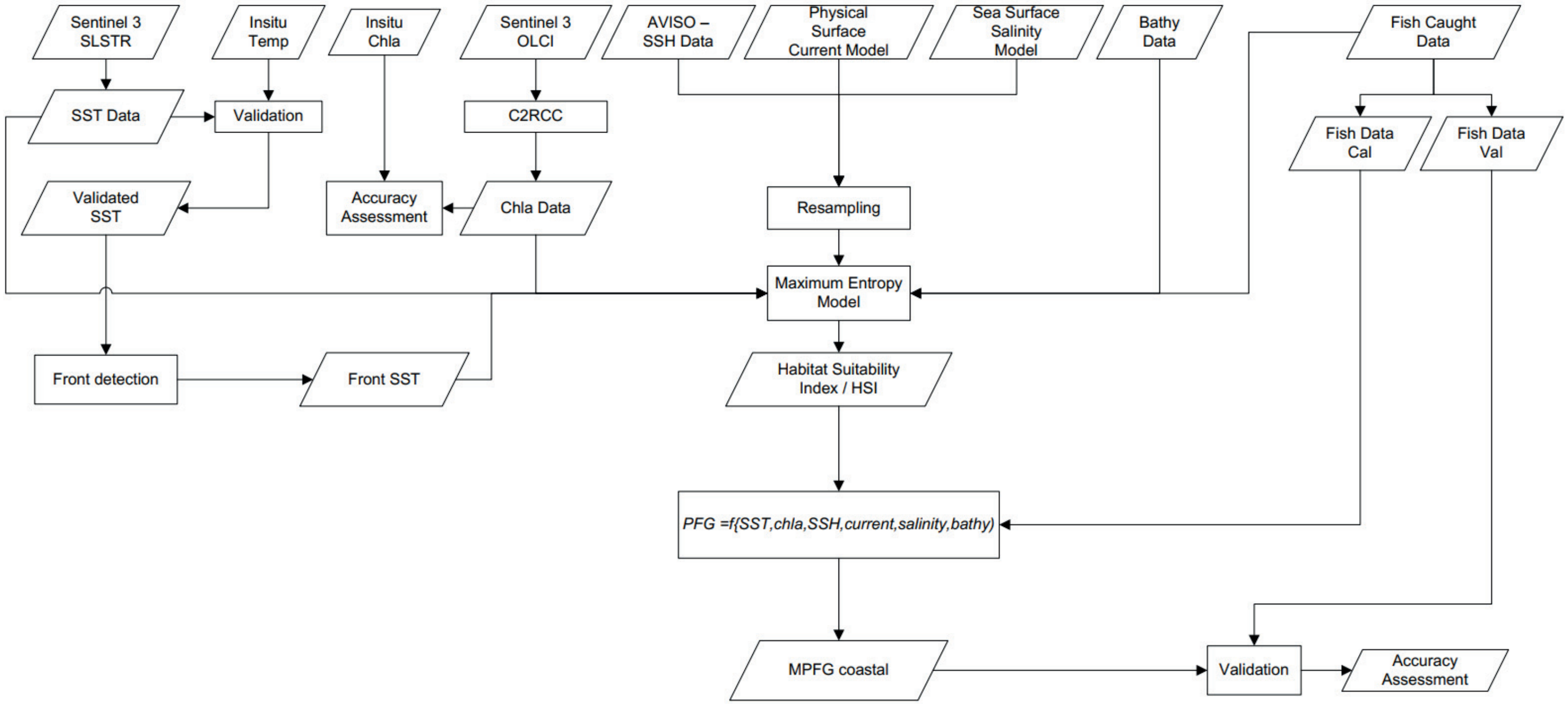


Figure 9. Main Research Schematic Diagram.

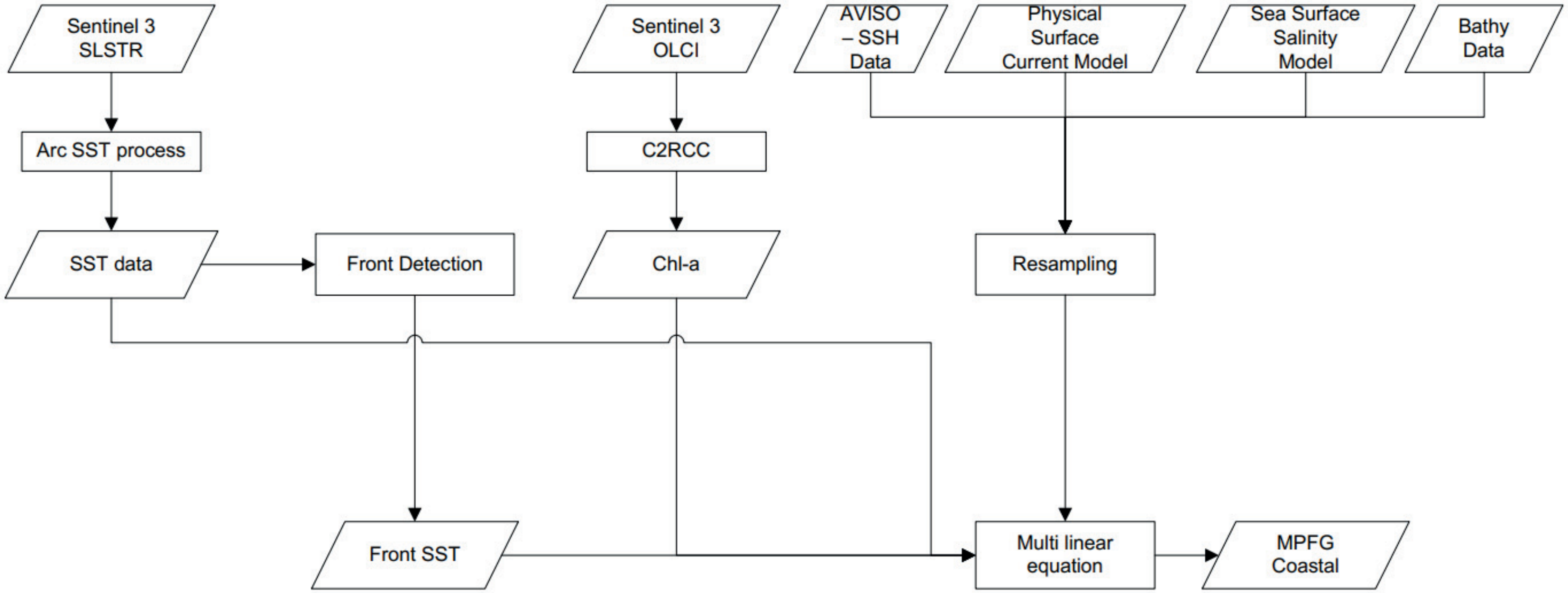


Figure 10. steps for case-2 MPFG

3. DATA COLLECTION

3.1. Field Measurement and Bathymetry maps

The field measurement has been conducted in two different time period. The first time period between September 10th 2018 – September 18th 2018 and the second time period between October 6th 2018 – October 15th 2018. There are 12 vessel track that correspond with satellite pass of Sentinel 2 and Sentinel 3. The survey track plan has been set according to the proposal plan. The survey plan has been changed due to local cultural act in Nusa Penida area where all vessel couldn't sail during 24-25 September 2018. The survey time changed into Table 2:

Table 2. Sentinel Dataset Collection

Satellite	Start (LT)	Satellite	Start (LT)
Sentinel-3B	2018-Sep-10 09:53:21.000	Sentinel-3A	2018-Oct-06 02:19:44.256
Sentinel-3A	2018-Sep-10 09:53:50.000	Sentinel-3B	2018-Oct-07 01:53:20.989
Sentinel-2B	2018-Sep-10 10:40:07.000	Sentinel -3A	2018-Oct-07 01:53:50.077
Sentinel-3B	2018-Sep-13 10:15:33.000	Sentinel-3B	2018-Oct-10 10:15:33.000
Sentinel-3A	2018-Sep-13 10:16:02.000	Sentinel-3A	2018-Oct-10 10:16:02.000
Sentinel-3B	2018-Sep-14 09:49:39.000	Sentinel-2B	2018-Oct-10 10:40:07.000
Sentinel-3A	2018-Sep-14 09:50:08.000	Sentinel-3B	2018-Oct-11 09:49:39.000
Sentinel-2A	2018-Sep-15 10:40:13.000	Sentinel-3A	2018-Oct-11 09:50:08.000
Sentinel-3B	2018-Sep-17 10:11:51.000	Sentinel-3B	2018-Oct-14 10:11:51.000
Sentinel-3A	2018-Sep-17 10:12:20.000	Sentinel-3A	2018-Oct-14 10:12:20.000
Sentinel-3B	2018-Sep-18 09:45:57.000	Sentinel-3B	2018-Oct-15 09:45:57.000
Sentinel-3A	2018-Sep-18 09:46:26.000	Sentinel-3A	2018-Oct-15 09:46:26.000
Sentinel-3B	2018-Oct-06 02:19:15.000	Sentinel-2A	2018-Oct-15 10:40:13.000

There are 6 survey tracks and each track repeated twice. The track map of each survey given in Appendix 1. The vessel track was not in the straight line due to safety reason because on some area of Nusa Penida Area has a high wave and current. All vessel track maps provided in appendix 1.

3.1.1. Fish Echo using Biosonic DT-X

The Biosonic DT-X has been used to determine the position of the target fish below the sea water. A 200 khz transducer has been used to detect the fish. Several parameters must be determined before Biosonics data acquisition started, such as initial temperature, salinity, pH and target strength. Target strength is a parameter to determine which kind of fish that has been detected.

On Figure 11, the Visual Acquisition application from Biosonics,inc used to record backscattering data from transducers. On the lower right image, we can see there are a huge fish occurrence on October 10th 2018 (day9) from the first track. We have been tried to fish to check the fish type using hand-line bottom fishing type with 3 hooks on each line separated ±20 cm on each hook. For 30 minutes fishing period, we caught 12 fishes (Figure 12). The size varying from 20 – 33 cm length. 10 Leather jacket fish (*Aluterus Monoceros,sp*), and 1 snapper. On day 10, we have been tried also to do the same during 30 minutes. We have been caught 4 snappers. Based on Biosonic reading, this target fish has a varying target strength from -48 to -60 db.

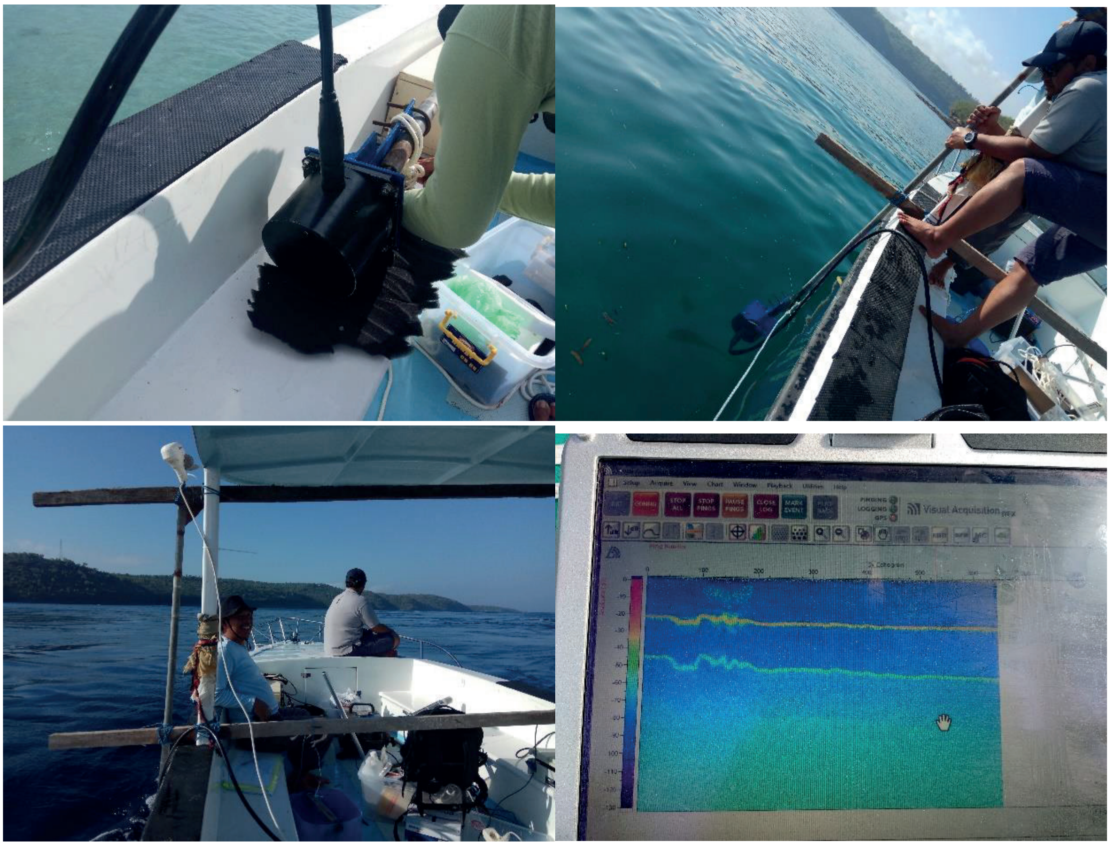


Figure 11. Biosonic DT-X Preparation on Vessel

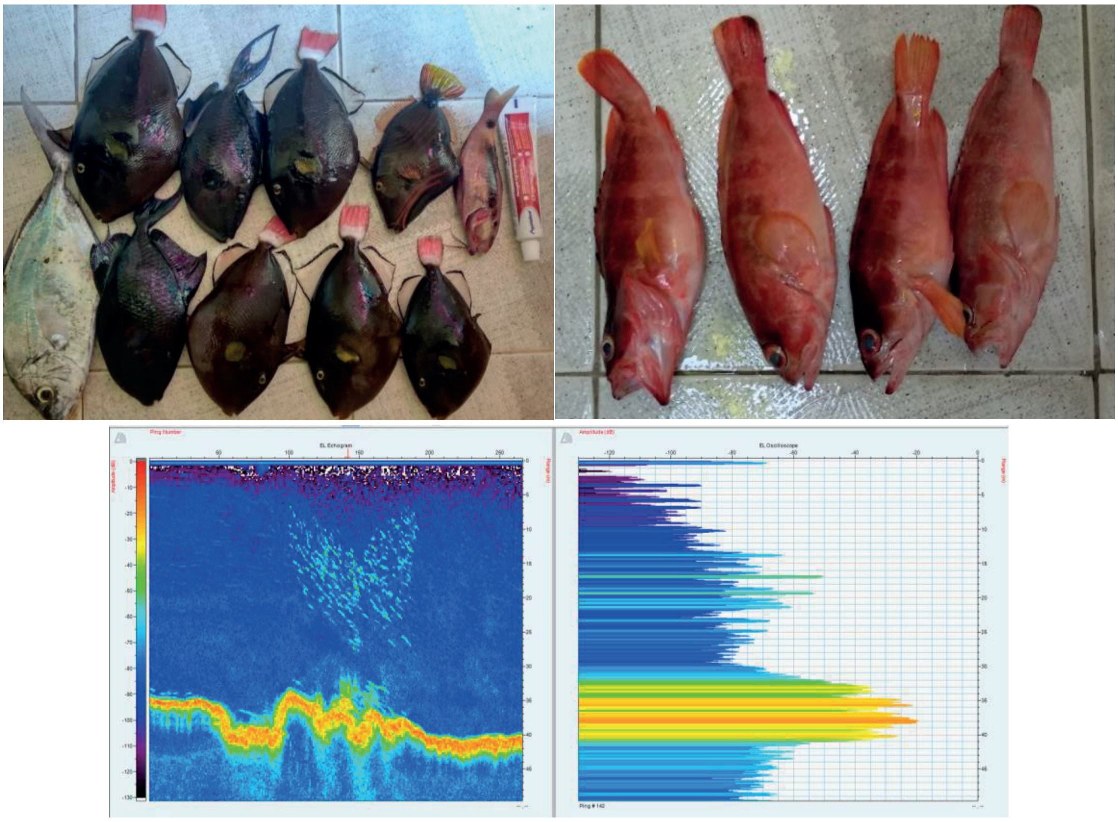


Figure 12. Fish Catch on day 9 & day 10 (above) and Biosonic reading on day 9 (below)

Based on dataset on Day1 (September 10th, 2018), several fishes have been detected from Station no.1 to Station 4 and Station 5 to Station 6 (Figure 13). The fish that has been detected on day 1 located on 5 to 100 meters depth. On the field measurement, locations where several fishermen did fished nearby our track survey are recorded.

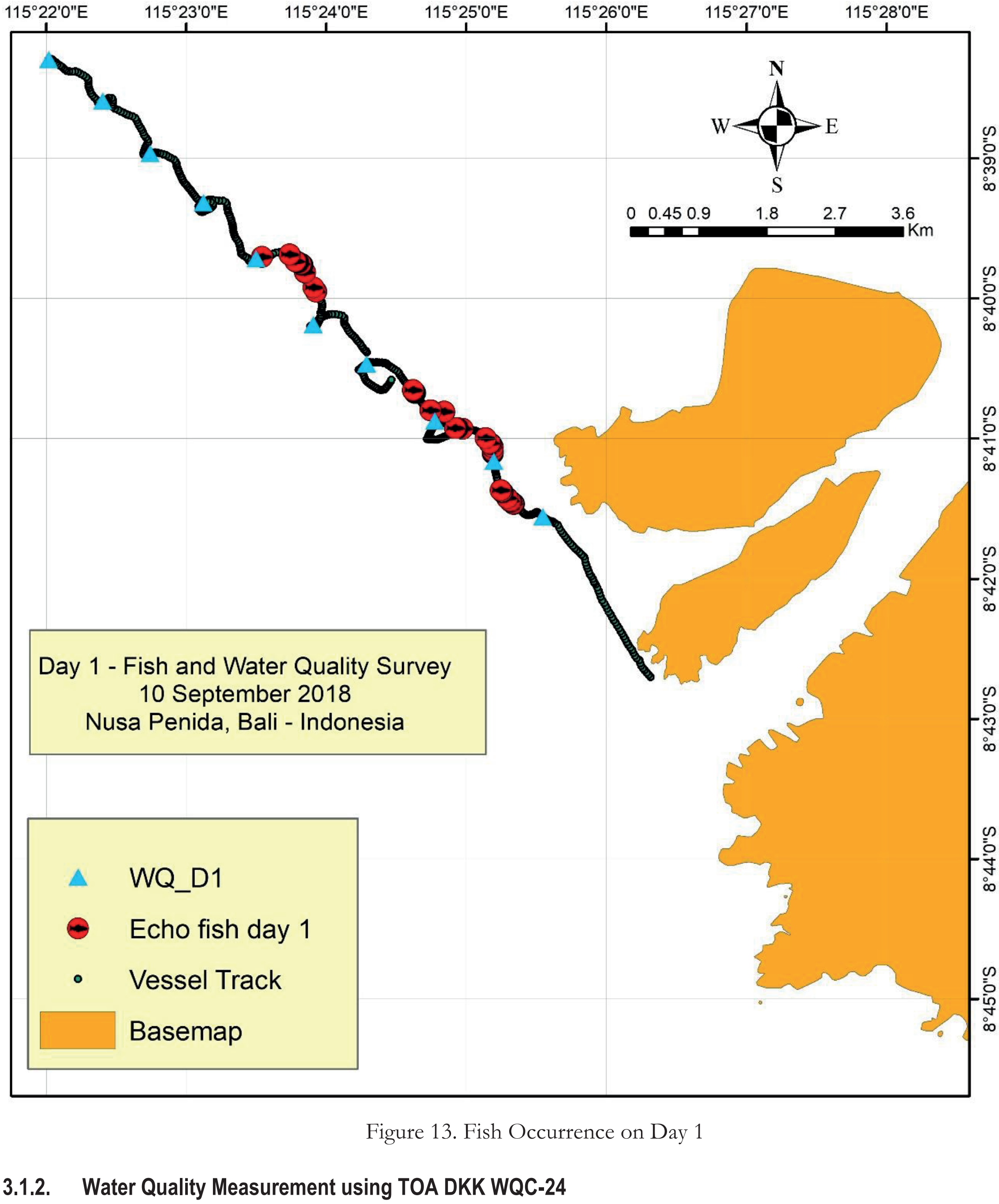


Figure 13. Fish Occurrence on Day 1

3.1.2. Water Quality Measurement using TOA DKK WQC-24

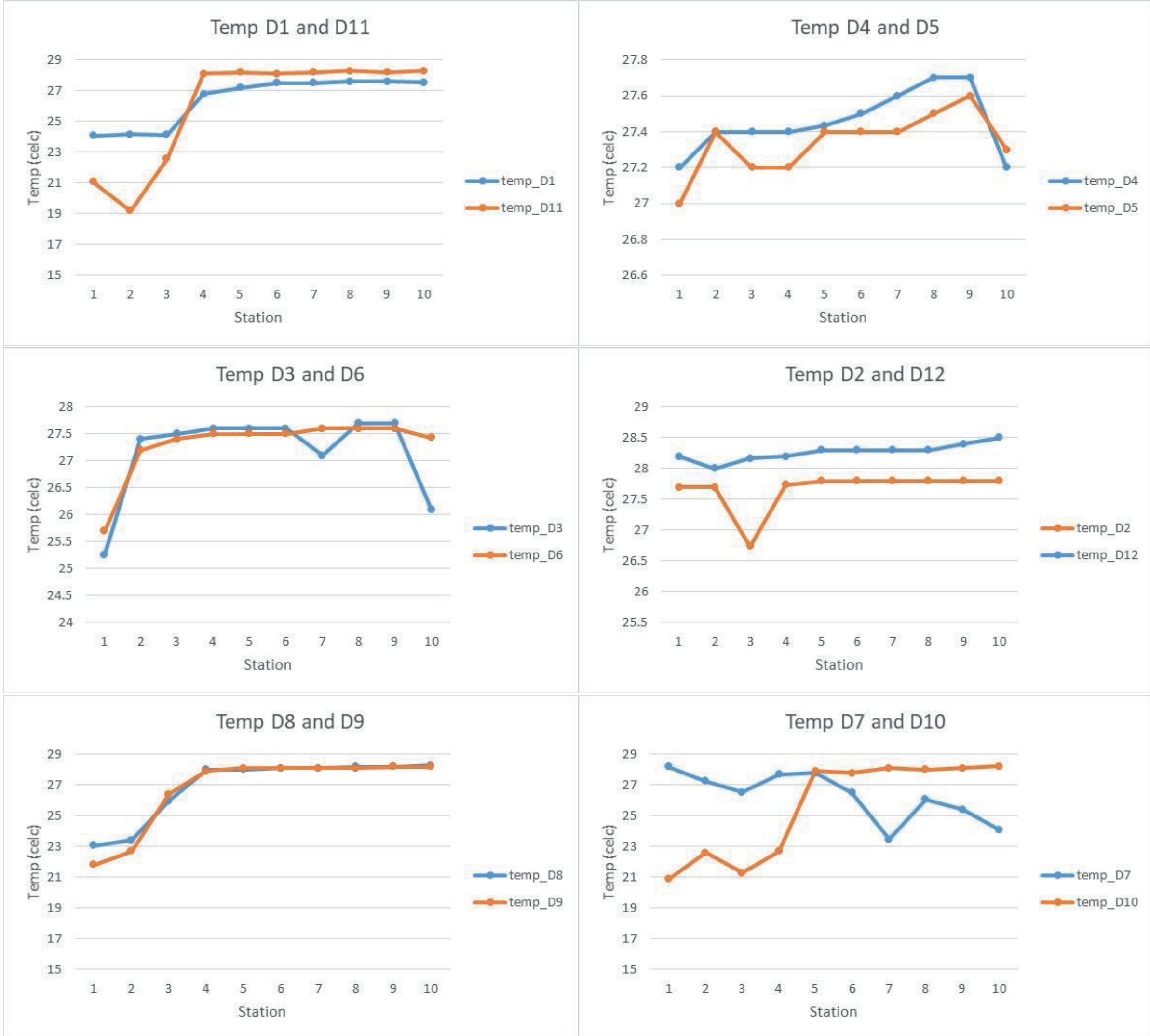
The measurement of SST and chlorophyll-a has been conducted using TOA DKK WQC-24. The measurement has been taken three times in the same position to obtain a valid value. The instrument place directly in the ocean where the sensor immersed near the ocean surface (Figure 14). There are eight parameters from the instrument. On day 7 to 10, there is a problem on salinity probe on WQC, so the salinity was measured using handheld refractometer.

Figure 14. Measurement using WQC

The TOA DKK WQC-24 has been calibrated on August 29^{th} 2018, two weeks before the field measurement time, by Accredited Calibration and Analytical Laboratories Committee. The uncertainty for Temperature, pH, and Salinity sensor are $0.2^{0}C$, 0.02 and 0.2 ppt, respectively. The temporal variability of temperature, chlorophyll-a and salinity from WQC measurement shown in Figure 15. The chart has been grouped by the day where the points of measurement was the same.

For temperature data, almost all measured data has the same pattern in spatial term, except the measurement of day 7 and day 10. It means, there is less variability on the temperature measurement in spatial term. The temperature measurement has a low temperature on the station measurement number 1 on almost each day. Furthermore, if we compare the point measurement number 1 in day 1,11, 8 and 9 with Front SST occurrence and Sea surface current data, the point 1 located on the front SST area with a medium-high sea surface current velocity (>1m/s). The low temperature condition can be described as the effect of the Indonesian Throughflow that flowing in Lombok strait from north to south that affect the physical water condition near Nusa Penida area.

For the salinity data, the value range stable around 33-34 PSU. On day 7 to day 10, the value is 34 because the salinity sensor on WQC-24 was broken and changed using handheld refractometer. The trend pattern on each track is the same. It means there are less variability on the measurement. In the other hand, for Chlorophyll-a measurement, there are no same pattern on each measurement. It means, there are a lot of chlorophyll-a measurement variability, thus can be caused by the coastal variation on daily basis.


Temp D1 and D11
Temp (celc)
Station
temp_D1
temp_D11
Temp D4 and D5
Temp (celc)
Station
temp_D4
temp_D5
Temp D3 and D6
Temp (celc)
Station
temp_D3
temp_D6
Temp D2 and D12
Temp (celc)
Station
temp_D2
temp_D12
Temp D8 and D9
Temp (celc)
Station
temp_D8
temp_D9
Temp D7 and D10
Temp (celc)
Station
temp_D7
temp_D10


Sal D1 and D11
Salinity (ppt)
Station
sal_D1
sal_D11
Sal D2 and D12
Salinity (ppt)
Station
sal_D2
sal_D12
Sal D3 and D6
Salinity (ppt)
Station
sal_D3
sal_D6
Sal D4 and D5
Salinity (ppt)
Station
sal_D4
sal_D5
Sal D7 and D10
Salinity (ppt)
Station
sal_D7
sal_D10
Sal D8 and D9
Salinity (ppt)
Station
sal_D8
sal_D9

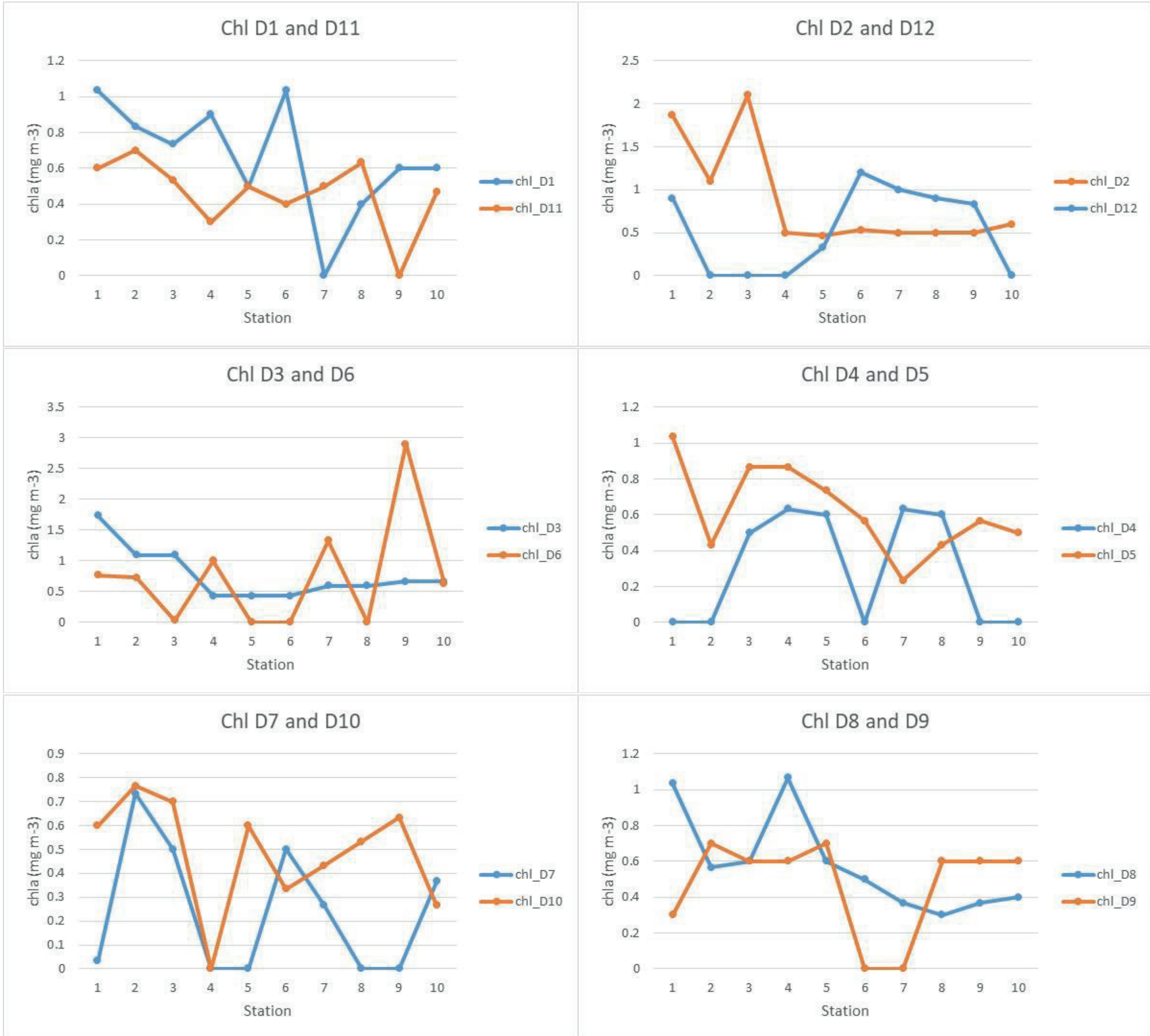


Figure 15. temporal variability of temperature, chlorophyll-a and salinity from WQC measurement

3.1.3. Radiance and irradiance measurement

The Trios Ramses device was used to determine radiance, irradiance and CDOM concentration. For each station, the measurement has been done 3 -5 times for radiance, irradiance and CDOM. The more measurement on each station due to high wave and high tide condition. Instrument setup on the vessel showed on Figure 16. The position of radiance and irradiance sensor has been placed outside shadow area. On the first 3 point from first day, CDOM instrument did not show a satisfying value. Radiance and irradiance value on the last 4 points from last day didn’t show a good value due to high tide and wave and late departure of vessel.

Figure 16. Trios Ramses Measurement

3.1.4. Bathymetry maps data from Hydro-Ocean Navy Center

A hardcopy bathymetry maps number 291 sheet "Selat Lombok" has been retrieved from Hydro-Ocean Navy Center of Indonesia. A manual image registration from scanned maps has been conducted. A manual digitation of each point depth has been conducted with 1410-point depth from one map sheet. Based on the maps, Nusa Penida, Nusa Ceningan and Nusa Lembongan area has varying depth from 19 – 500 meters. From the depth point data, an interpolation was performed to create a raster bathymetry maps (Figure 17) with the same spatial resolution as Sentinel 3 datasets.

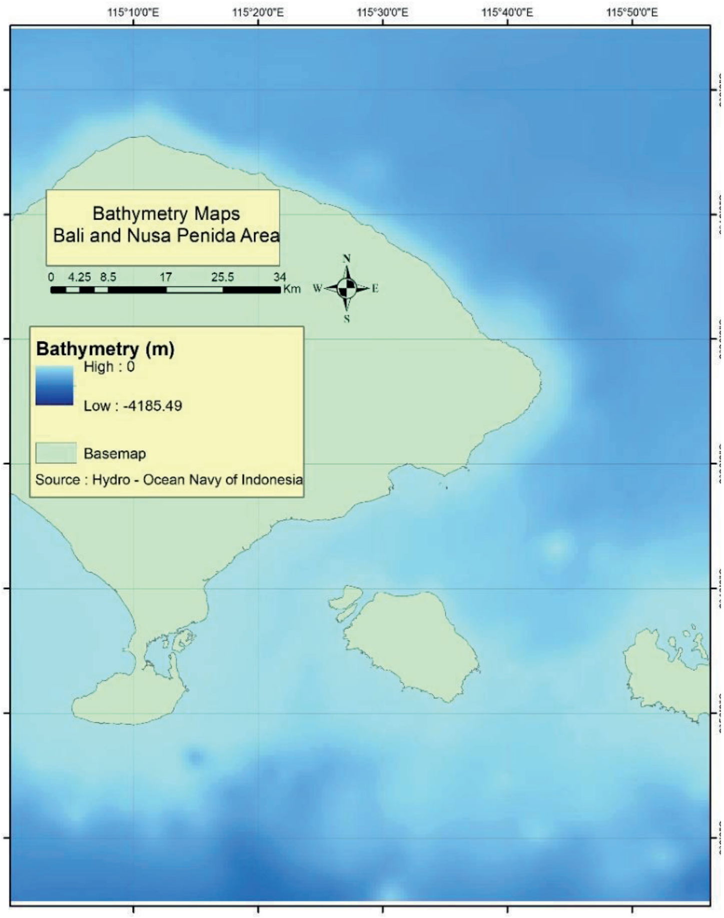


Figure 17. Bathymetry Maps from Hydro-Ocean Navy Center

3.2. Satellite and Ocean Numerical Model Datasets

3.2.1. Sentinel 2 Datasets

4 Sentinel 2 -MSI datasets has been retrieved with the same date of field measurement. The list of datasets given in Table 3 below.

Table 3. Sentinel 2 dataset

No	Dataset	Acq date
1	S2B_MSIL1C_20180910T021559_N0206_R003_T50LLR_20180910T063247	20180910
2	S2A_MSIL1C_20180915T021601_N0206_R003_T50LLR_20180915T063856	20180915
3	S2B_MSIL1C_20181010T021649_N0206_R003_T50LLR_20181010T074252	20181010
4	S2A_MSIL1C_20181015T021641_N0206_R003_T50LLR_20181015T064421	20181015

The Sentinel 2 datasets used to compare chlorophyll-a retrieval from C2RCC using Sentinel 2 MSI and Sentinel 3 – OLCI. The comparison not only between 2 satellite datasets but also with insitu measurement.

3.2.2. Sentinel 3 Datasets

Sentinel 3 dataset is one of the main satellite datasets. Two sensors of Sentinel 3 have been downloaded from scihub Copernicus (https://scihub.copernicus.eu/s3/#/home). There are 11 OLCI datasets and 10 SLSTR datasets. The OLCI datasets used to retrieve chlorophyll-a concentration using C2RCC and the SLSTR datasets used to retrieve SST and front SST. The list of datasets given in Table 4 below.

Table 4. Sentinel 3 OLCI and SLSTR dataset

No	Dataset OLCI	Acq date
1	S3A_OL_1_EFR_20180910T015148_20180910T015448_20180910T034344_0179_035_288_3060_SVL_O_NR_002.SEN3	20180910
2	S3A_OL_1_EFR_20180913T021415_20180913T021715_20180913T040335_0179_035_331_3060_SVL_O_NR_002.SEN3	20180913
3	S3A_OL_1_EFR_20180914T014804_20180914T015104_20180914T033526_0179_035_345_3060_SVL_O_NR_002.SEN3	20180914
4	S3A_OL_1_EFR_20180917T021031_20180917T021331_20180917T035235_0179_036_003_3060_SVL_O_NR_002.SEN3	20180917
5	S3A_OL_1_EFR_20180918T014421_20180918T014721_20180918T032904_0179_036_017_3060_SVL_O_NR_002.SEN3	20180918
6	S3A_OL_1_EFR_20181006T021803_20181006T022103_20181006T040826_0179_036_274_3060_SVL_O_NR_002.SEN3	20181006
7	S3A_OL_1_EFR_20181007T015152_20181007T015452_20181007T033454_0179_036_288_3060_SVL_O_NR_002.SEN3	20181007
8	S3A_OL_1_EFR_20181010T021419_20181010T021719_20181010T035955_0180_036_331_3060_SVL_O_NR_002.SEN3	20181010
9	S3A_OL_1_EFR_20181011T014808_20181011T015108_20181011T033420_0179_036_345_3060_SVL_O_NR_002.SEN3	20181011
10	S3A_OL_1_EFR_20181014T021035_20181014T021335_20181014T040151_0179_037_003_3060_SVL_O_NR_002.SEN3	20181014
11	S3A_OL_1_EFR_20181015T014424_20181015T014724_20181015T033714_0179_037_017_3060_SVL_O_NR_002.SEN3	20181015

No	Dataset SLSTR	Acq date
1	S3A_SL_1_RBT_20180910T015148_20180910T015448_20180911T064422_0179_035_288_3060_LN2_O_NT_003.SEN3	20180910
2	S3A_SL_1_RBT_20180913T021415_20180913T021715_20180913T040219_0179_035_331_3060_SVL_O_NR_003.SEN3	20180913
3	S3A_SL_1_RBT_20180917T144226_20180917T144526_20180917T155816_0179_036_010_5760_SVL_O_NR_003.SEN3	20180917
4	S3A_SL_1_RBT_20180918T014421_20180918T014721_20180918T033249_0179_036_017_3060_SVL_O_NR_003.SEN3	20180918
5	S3A_SL_1_RBT_20181006T021803_20181006T022103_20181006T040731_0179_036_274_3060_SVL_O_NR_003.SEN3	20181006
6	S3A_SL_1_RBT_20181007T015152_20181007T015452_20181007T033804_0179_036_288_3060_SVL_O_NR_003.SEN3	20181007
7	S3A_SL_1_RBT_20181010T021419_20181010T021719_20181010T040239_0180_036_331_3060_SVL_O_NR_003.SEN3	20181010
8	S3A_SL_1_RBT_20181011T014808_20181011T015108_20181011T033909_0179_036_345_3060_SVL_O_NR_003.SEN3	20181011
9	S3A_SL_1_RBT_20181014T021035_20181014T021335_20181014T035914_0179_037_003_3060_SVL_O_NR_003.SEN3	20181014
10	S3A_SL_1_RBT_20181015T014424_20181015T014724_20181015T033403_0179_037_017_3060_SVL_O_NR_003.SEN3	20181015

3.2.3. Marine Copernicus Ocean Numerical Model Datasets

The "Global Ocean $1/12^0$ Physics Analysis and Forecast" model from Marine Copernicus has been used to retrieve Sea Surface Height, Sea Surface Salinity and Northward and Eastward Velocity to obtain Sea Surface Current. 12 datasets have been retrieved based on field measurement date on the surface layer of the model. The statistics of the models given in the Table 5 below

Table 5. Marine Copernicus data statistics

date	env	Min	max	mean	sd	date	env	Min	max	mean	sd
	SSH	0.16	0.33	0.25	0.03		SSH	0.12	0.34	0.23	0.05
20180910	Salinity	34.22	34.32	34.27	0.02	20181006	Salinity	34.30	34.45	34.35	0.03
	Current	0.82	2.51	1.84	0.36		Current	0.76	2.94	2.02	0.42
	SSH	0.12	0.30	0.23	0.03		SSH	0.12	0.34	0.24	0.05
20180913	Salinity	34.21	34.35	34.26	0.03	20181007	Salinity	34.28	34.43	34.33	0.03
	Current	0.68	2.62	1.79	0.37		Current	0.77	2.90	2.01	0.41
	SSH	0.12	0.30	0.22	0.03		SSH	0.15	0.33	0.24	0.04
20180914	Salinity	34.19	34.35	34.25	0.04	20181010	Salinity	34.26	34.42	34.33	0.03
	Current	0.59	2.69	1.80	0.40		Current	0.75	2.66	1.88	0.38
	SSH	0.12	0.31	0.23	0.03		SSH	0.14	0.33	0.23	0.04
20180915	Salinity	34.19	34.34	34.24	0.04	20181011	Salinity	34.26	34.43	34.33	0.04
	Current	0.72	2.74	1.89	0.40		Current	0.73	2.70	1.88	0.39
	SSH	0.13	0.32	0.24	0.04		SSH	0.20	0.33	0.27	0.03
20180917	Salinity	34.24	34.36	34.28	0.03	20181014	Salinity	34.24	34.38	34.29	0.03
	Current	0.75	2.76	1.90	0.39		Current	0.55	2.39	1.66	0.35
	SSH	0.14	0.33	0.24	0.04		SSH	0.24	0.34	0.30	0.02
20180918	Salinity	34.24	34.37	34.28	0.03	20181015	Salinity	34.24	34.35	34.28	0.02
	Current	0.79	2.67	1.92	0.37		Current	0.40	2.17	1.51	0.34

3.3. Other Insitu Measurement.

Institute for Marine Research and Observation (IMRO) has been deployed 10 coastal buoys on 2017. 2 of the coastal buoys located in coastal area of Bali. Buoy unit 1 located in Perancak estuary and buoy unit 2 located in Gondol coastal area. The location of the buoy shown in the figure 20 below. The buoy has been deployed ±1 km from the coastal line. The buoy measure SST and chlorophyll-a concentration. The fluorescence method used to retrieve chlorophyll-a concentration. The buoy sensor located on 1-meter depth from the sea surface. Schematic diagram of the coastal buoy shown in the Figure 18 below.

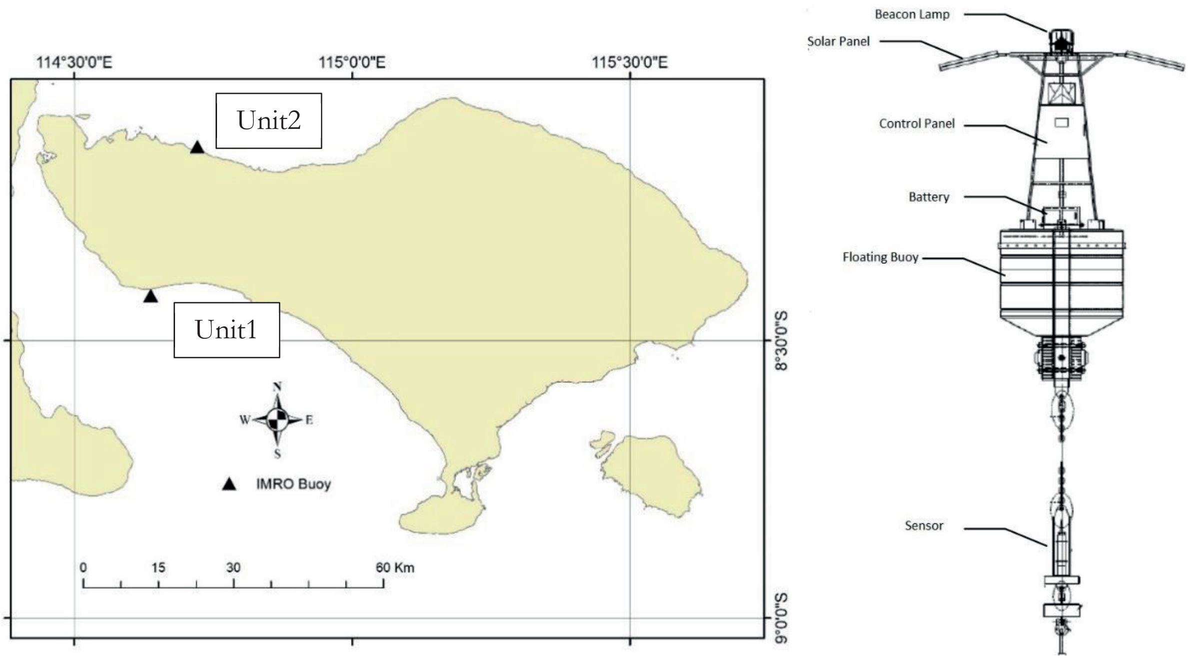
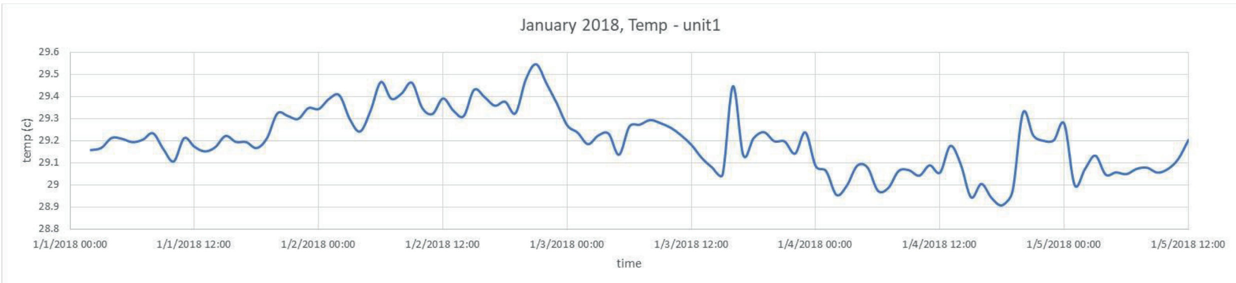
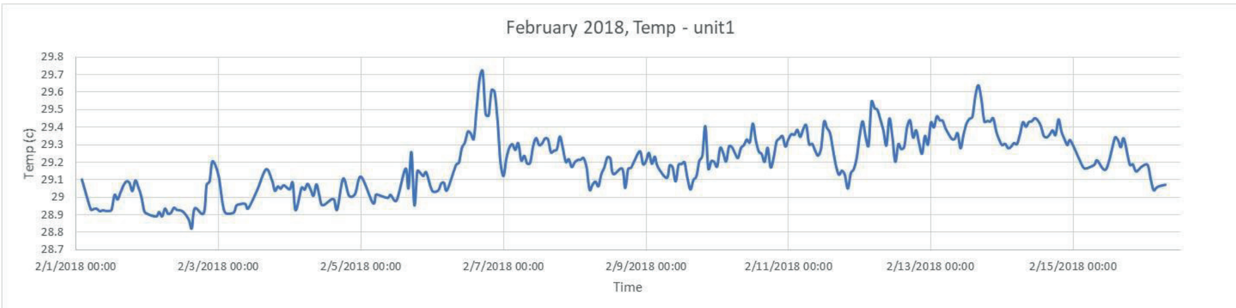


Figure 18. Location of coastal buoy and schematics of coastal buoy

This coastal buoy was used to check the consistency retrieval between satellite and field measurement using TOA DKK WQC-24. The buoy was retrieved on 10-minute basis and was averaged in hourly basis to have a matched with satellite pass. On unit 1, it only has 5 months data on January, February, May, November and December 2018. In the other hand, on unit 2, it only has 2 months data on November and December 2018. Based on satellite acquisition time, the match up only use buoy data 2 hours before satellite acquisition and 2 hours after acquisition. Figure 19 show us the variability of temperature data on buoy unit 1 and unit 2





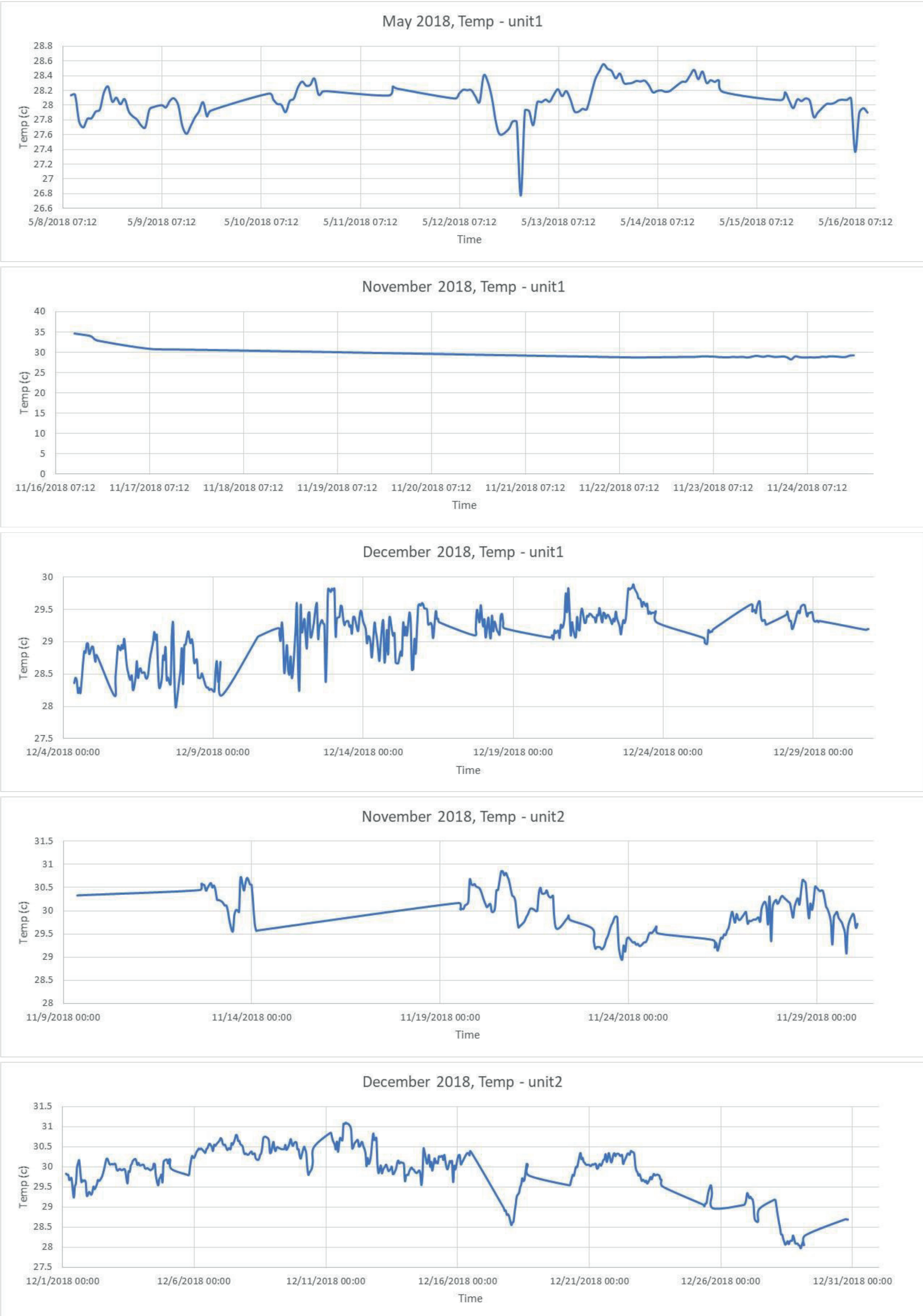


Figure 19. temperature variability from coastal buoy

4. DATA ANALYSIS

4.1. Hydro accoustics data analysis

Visual Analysis has been conducted to retrieve the fish occurrence information using Visual Acquisition software from Biosonics. Based on trial fishing on day 10, we can identify the target strength of the target fish lies between -48 to – 60 db. (Wilson, 2008) in mentioned that there are relation between target strength and length of the fish,

$$TS = 20\ log_{10}L - 70.9$$

Where TS is target strength in db and L is the length of the target in cm. The target fish in the coastal area has the length between 5-15 cm then the target strength lies between -48 to -60 db.

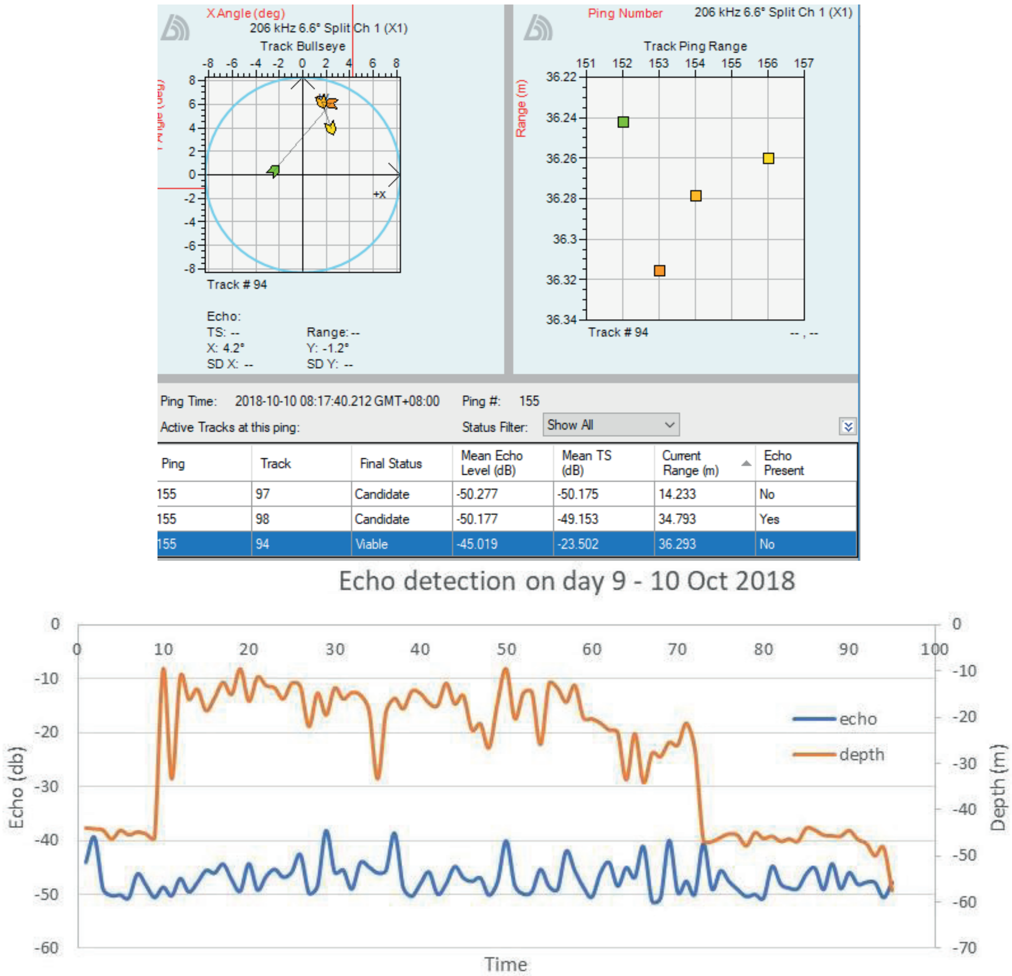


Figure 20. Echo track display (above) and echo detection on day 9

The EchoTrack tools has been applied during the field measurement of hydro acoustics on Visual Acquisition Software. The EchoTrack help to find echo / target fish based on predefined target strength. During analysis, EchoTrack result (Figure 20) has been used to help the visual analysis of the fish echo. Based on EchoTrack, it needs to be confirmed manually on the visual window of the data and record all the position (latitude and longitude), depth and target strength value. The example of hydro-acoustic analysis shown in Figure 20. From all echo detection, we can conclude that most of echo detected on depth 0 to 100 meter. This detection confirms with all literature that small pelagic fish located on those depth range. All the data analysis saved in csv file format contain information of time, ping number, position, target strength, and depth value.

4.2. Environmental Parameter

4.2.1. Sea Surface Temperature

The SST has been retrieved using ArcSST as mentioned by (Embury et al., 2012) and nadir view has been chosen to obtain a vigorous SST retrieval. The SST retrieved (Figure 21) using ArcSST validated using in-situ data from field measurement using WQC-24 and coastal buoy data.

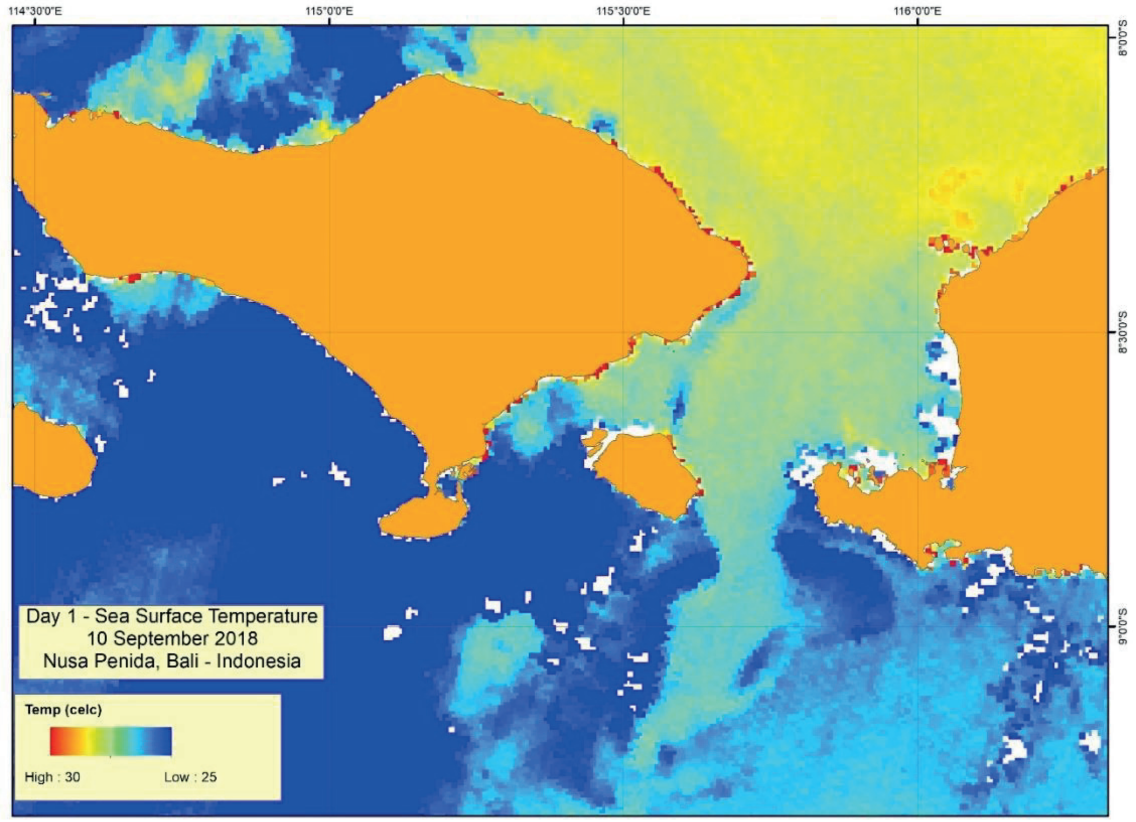
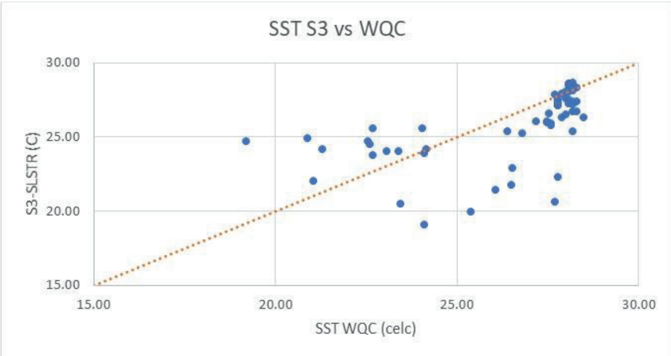


Figure 21. SST retrieval using Arc SST on September 9th 2018

The validation between SST and field measurement using WQC-24 show a low relation with the R^2=0.3 with RMSE = 2.28^{o}C (Figure 22). Several value of satellite SST has lower than field measurement data and has been neglected from the comparison. Due to low relation, coastal buoy data has been used to validate the SST retrieval. The validation process has been conducted in 2 ways, without filter and with filter. The 3x3 filter has been used to aggregate and smoothness surrounding SST pixels value. The result of non-filter method has a low relation with the R^2=0.0774 with RMSE = 3.9^{0}C and the result of filter method has a better relation than non-filter method with the R^2=0.1197 with RMSE = 4.723^{0}C (Figure 23). Based on the Figure 23, on filtered data, we can see that there are grouping of buoy no 1 (blue colour) and no 2 (yellow colour).

Table 6. SST Sentinel 3 Comparison

	R^2	RMSE (^{0}C)	MAE (^{0}C)	Slope	Intercept
SST S3 (non filter) vs WQC-24	0.3	2.28	1.56	0.5854	10.31
SST S3 (non filter) vs Buoy	0.077	3.90	2.62	1.7759	236.26
SST S3 (filter) vs Buoy	0.119	4.72	3.22	2.2947	393.86
SST cop vs WQC	0.00001	2.86	1.63	-0.0004	28.152
SST cop vs buoy	0.56	0.67	0.53	0.6952	9.4878
SST S3 (non filter) vs MODIS - VIIRS	0.075	2.8354	2.0728	0.2677	19.049



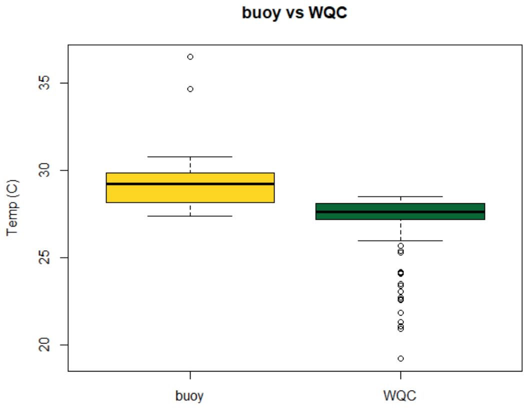


Figure 22. Validation between S3 Arc SST and WQC

Based on the box plot between WQC-24 measurement and Coastal buoy on Figure 22, we can find several outliers on WQC measurement and also the WQC-24 measurement is comparatively short than buoy measurement. Both measurements didn't have the same minimum and maximum range. The comparison has been conducted between non-filtered Sentinel 3 SST and SST data from MODIS – VIIRS sensor. The comparison shown that there is no relation between Sentinel 3 SST and SST MODIS-VIIRS with R^2= 0.0747, RMSE = 2.8354^{0}C and MAE = 2.0728^{0}C.

Marine Copernicus Datasets has been used to compare the retrieval of SST from Sentinel 3 SLSTR using ArcSST. The Marine Copernicus dataset "Global Ocean 1/12^0 Physics Analysis and Forecast" has been used to compare with SLSTR retrieval. Surface layer of those data has been selected based on acquisition time of field measurement using WQC-24 and coastal buoy and IDW interpolation has been chosen to match the spatial resolution of SLSTR. There is a low correlation between WQC measurement and Marine Copernicus data and Marine Copernicus data show a good correlation with buoy then SST from SLSTR (Figure 24 and Figure 25). The buoy and Marine Copernicus data has the same histogram pattern (diagonal box) while SLSTR data doesn't have the same histogram pattern.

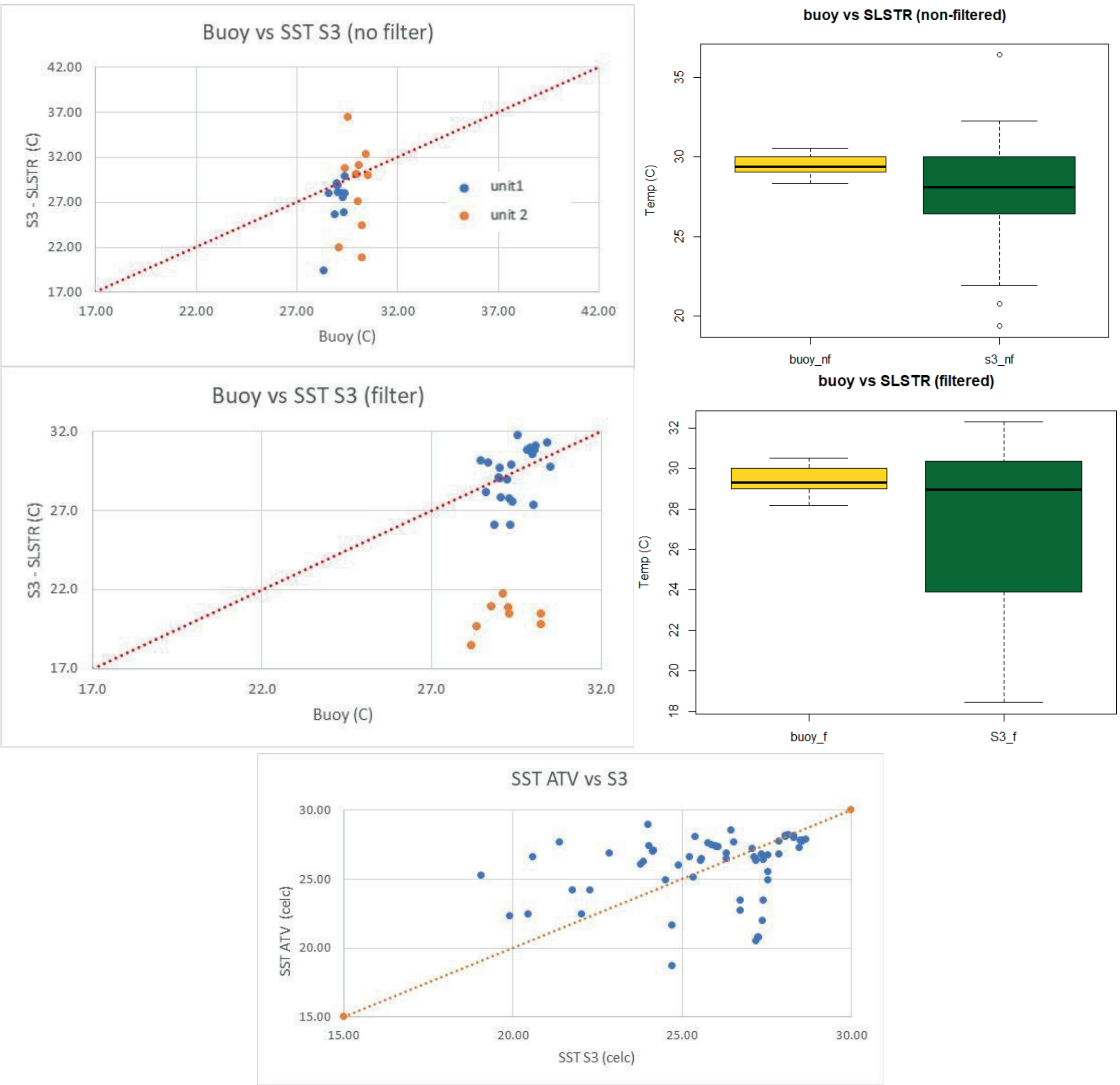


Figure 23. Buoy and S3 SST comparison on filter and non-filtered data and with SST MODIS-VIIRS

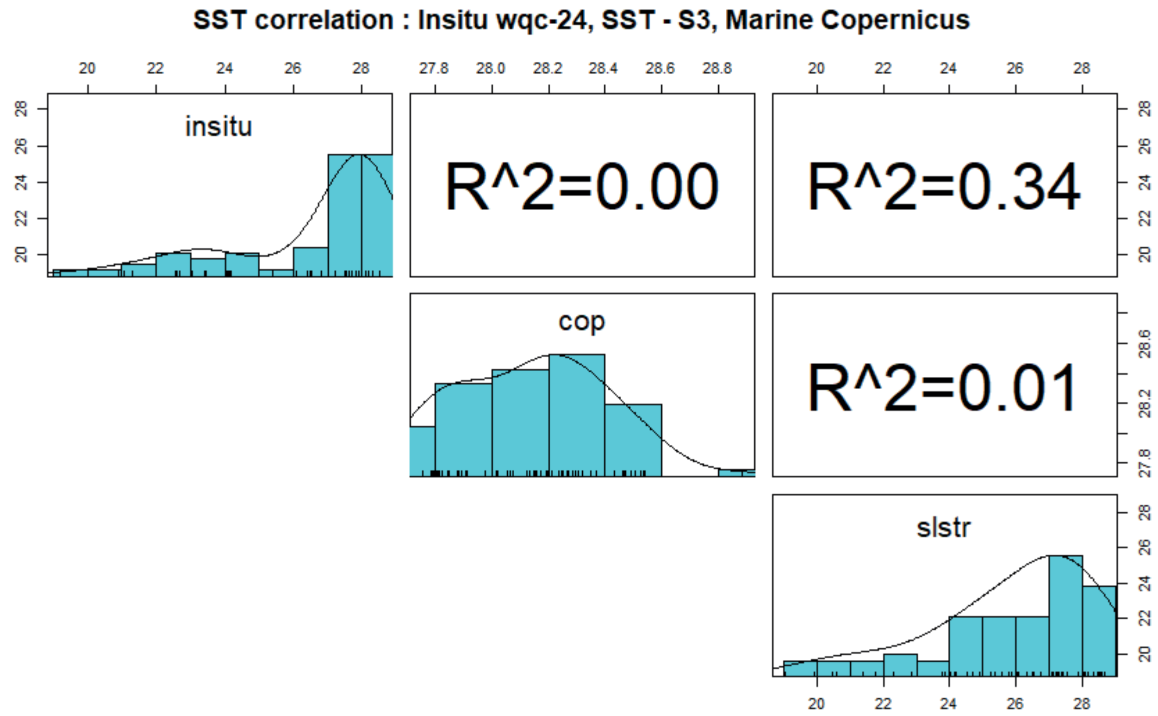


Figure 24. SST correlation: insitu WQC, Arc SST, Marine Copernicus

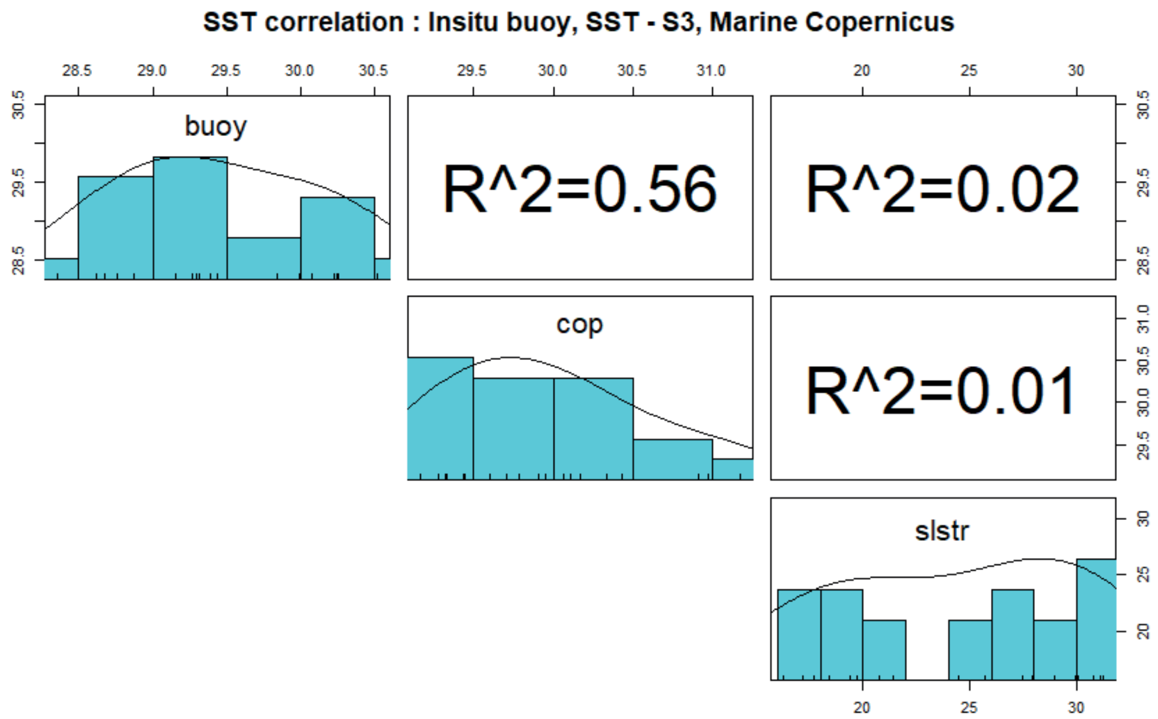
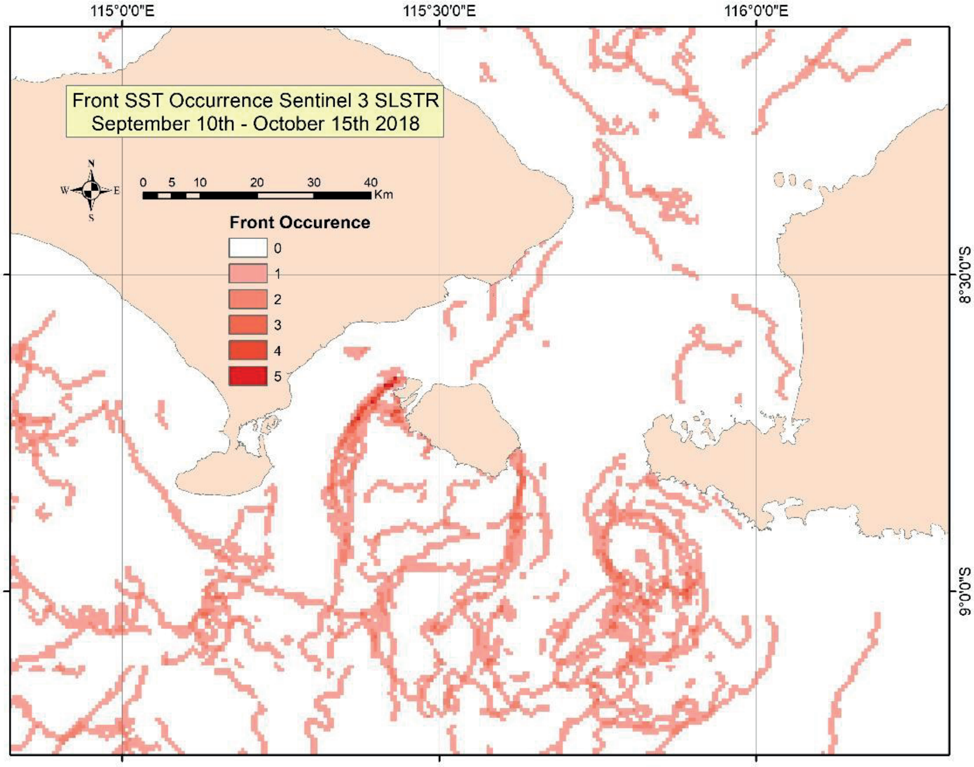


Figure 25. SST correlation: insitu buoy, Arc SST, Marine Copernicus

4.2.2. Front SST

The Front SST has been calculated based on Cayula & Cornillion Single Image Edge Detection method. A 0.5°C threshold has been used to define the front SST. Based on the result, we can see in Figure 26 that front SST always occur on the north side between Bali island and Nusa Penida island and lies from north to south. Based on (Susanto et al., 2007), in southeast monsoon, the geostrophic transport direction in Lombok strait from north to south due to Lombok throughflow where Nusa Penida is close to Lombok strait. This geostrophic transport explains us why the direction of front SST lies from north to south. Based on several literature for pelagic fish, Front SST is the indication where a lot of nutrient and the fish located. On figure 26 below, it shows us that most of fish detection from Bisonics occur on front SST location.



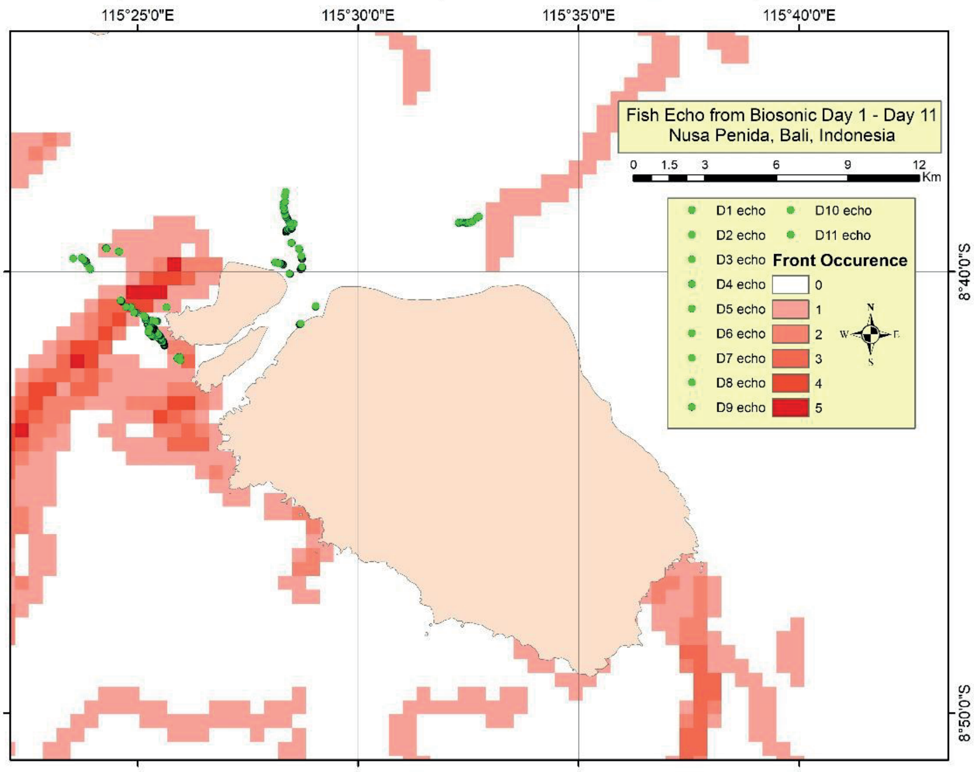


Figure 26. Front SST detection occurrence (above) and echo detected on front SST

4.2.3. Depth

Depth is one of the parameters to differentiate between small pelagic and large pelagic fish. Based on Hydro-Ocean Navy Centre maps, the depth in 10 km area of Nusa Penida island lies between 0 to 1047 m where the maximum depth located near Indian Ocean and in the center of Lombok Strait. The bathymetry maps around Nusa Penida island showed on Figure 27.

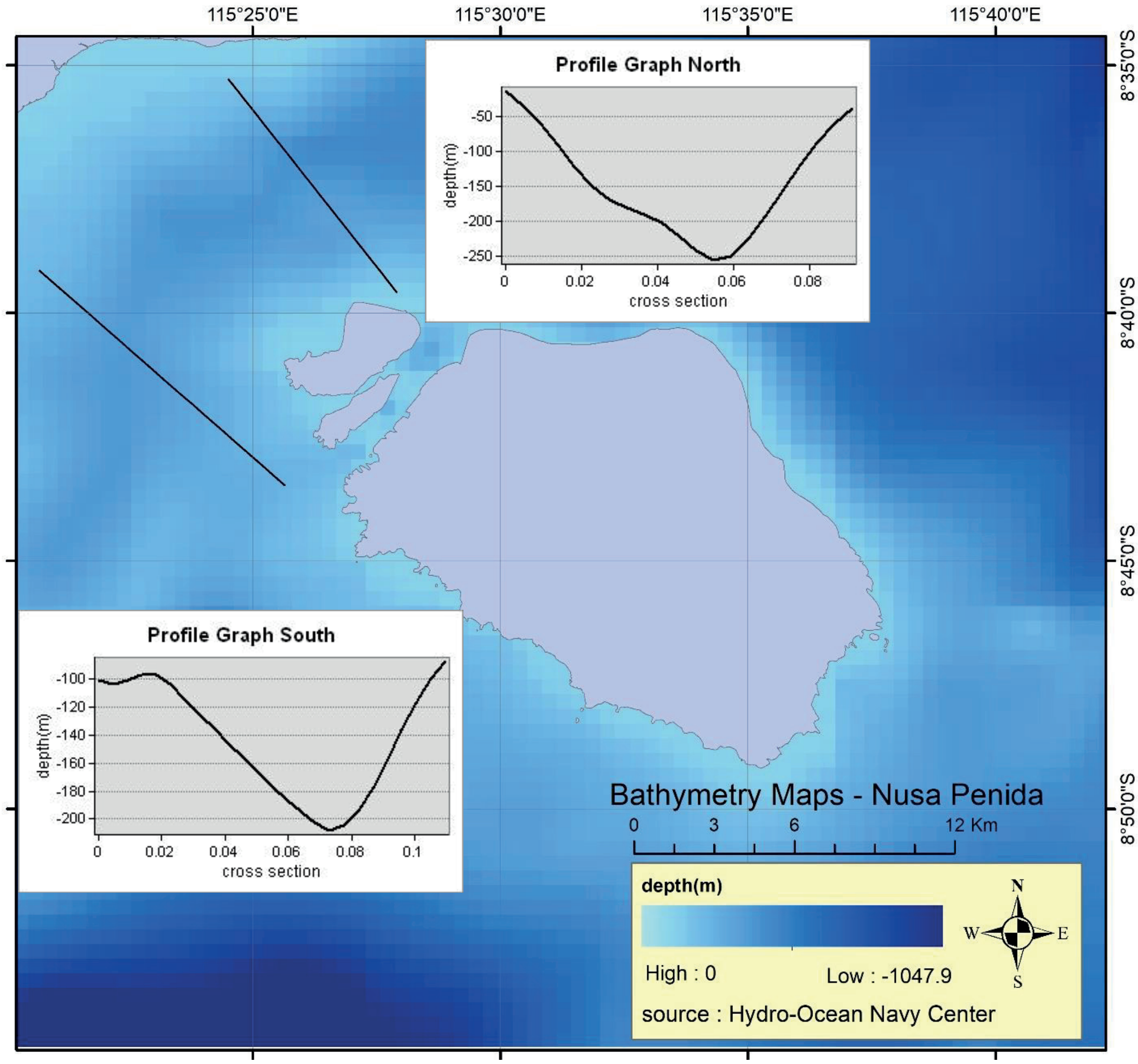


Figure 27. Bathymetry and cross section of depth

4.2.4. Chlorophyll-a

Chlorophyll-a concentration has been retrieved using Case-2 Regional Coast Colour /C2RCC (Brockmann, 2016) that has been provided in SNAP software. The C2RCC processor using neural networks method to train the data to perform the inversion of RRS dataset and retrieval of IOP of water body. Parameters that has been used to obtain chlorophyll-a concentration listed in Table 7 below. The temperature and salinity parameters must be the same with average value in the area.

Table 7. Parameters on C2RCC

Salinity	35 PSU	Chl exponent	1.04
Temperature	27^0 C	Chl Factor	21.0

The chlorophyll-a exponent and chlorophyll-a factor value based on (Bricaud et al., 1995). The result of chlorophyll-a dataset from C2RCC have been resampled to match the spatial resolution of SLSTR dataset. To validate the chlorophyll-a retrieval using C2RCC, match up process between field measurement using WQC-24 and chlorophyll-a retrieval has been conducted. The match up process not only using field measurement, but also using coastal buoy data. The match up result has a low relation between field measurement using WQC-24 and chlorophyll-a retrieval from Sentinel 3 data with R^2 =0.009, RMSE = 4.0707 mg/m^3 and MAE= 2.7565 mg/m^3 (Figure 29). Furthermore, there is a low relation also with the coastal buoy with R^2 = 0.0013, RMSE =11.27 mg/m^3 and MAE = 8.5124 mg/m^3 (Figure 29). This can be caused by a fluorescence method that used in WQC-24. Fluorescence method has a high discrepancy than spectrophotometer and HPLC method (Jacobsen & Rai, 1990). The chlorophyll-a retrieval using Sentinel 2 C2RCC show a better response than sentinel 3 with R^2=0.1147, RMSE = 0.5644 mg/m^3 and MAE =0.4971 mg/m^3 due to better spatial resolution (Figure 28).

In the other hand, the Marine Copernicus data with dataset of "Global Analysis Forecast BIO 001 014" with 0.5-degree spatial resolution has been used to compare the result of C2RCC. The Marine Copernicus data has a coarse spatial resolution with 0.25^0 (27.5 km in equator). The IDW interpolation has been used to interpolate this data to match with Sentinel 3 OLCI spatial resolution. In Figure 29 and Figure 30, we can see that correlation between insitu (buoy and WQC-24) with Marine Copernicus data show a better result than Chlorophyll-a retrieval using C2RCC. The R^2 = 0.027for WQC-24 with Marine Copernicus data and R^2=0.5284 for Buoy with Marine Copernicus data

Table 8. Sentinel 3 Chlorophyll-a Comparison

	R^2	RMSE (mg/m^3)	MAE (mg/m^3)	Slope	Intercept
Chlorophyll-a S3 vs WQC 24	0.009	4.0707	2.7565	0.6858	2.6176
Chlorophyll-a S2 vs WQC 24	0.114	0.5644	0.4971	-0.3017	0.4718
Chlorophyll-a S3 vs buoy	0.001	11.2755	8.5124	0.0128	2.6262
Chlorophyll-a Copernicus vs WQC 24	0.027	0.4919	0.3386	-0.0221	0.4201
Chlorophyll-a Copernicus vs Buoy	0.528	12.7300	9.6330	0.0099	0.0514
Chlorophyll-a MODIS vs S3 OLCI	0.005	0.1679	0.1050	0.0447	0.2042
CHLOROPHYLL-A OC PML vs S3 OLCI	0.383	0.1335	0.1210	-1.3389	0.4498

Other data set has been used to understand the retrieval of chlorophyll-a using C2RCC. The datasets are the level 2 chlorophyll-a data from Aqua MODIS, Terra MODIS and VIIRS that has been downloaded from http://oceancolor.gsfc.nasa.gov and the other dataset is Ocean Colour Climate Change Initiative (OC-CCI) datasets from Plymouth Marine Laboratory (PML). The OC-CCI dataset downloaded from ftp.rsg.pml.ac.uk . The datasets created by band-shifting and bias-correction from MERIS, MODIS, and VIIRS data to match SeaWiFS. Based on match up comparison (Figure 31), the chlorophyll-a from Sentinel 3 has very low relation with MODIS and VIIRS data (R^2=0.0045) and a better relationship with OC-CCI (R^2=0.383). the relation with OC-CCI dataset is better due to the same characteristics between Sentinel 3 OLCI with MERIS sensor that has been used in OC-CCI processing and the OC-CCI spatial resolution is coarse.

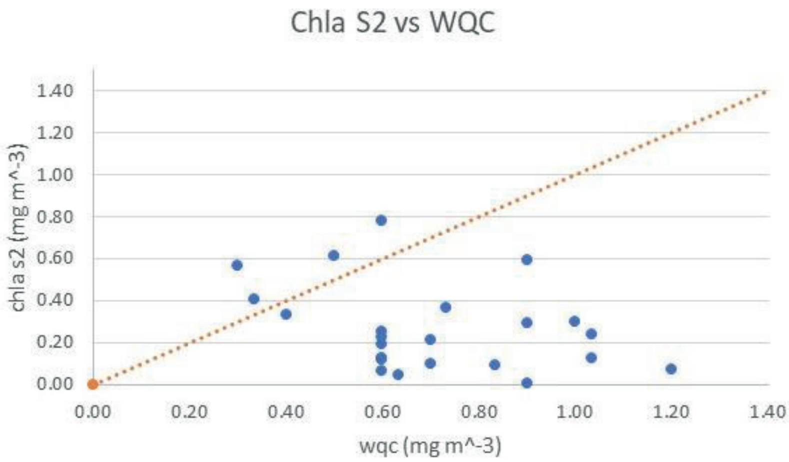


Figure 28. Chlorophyll-a from Sentinel 2 vs WQC-24

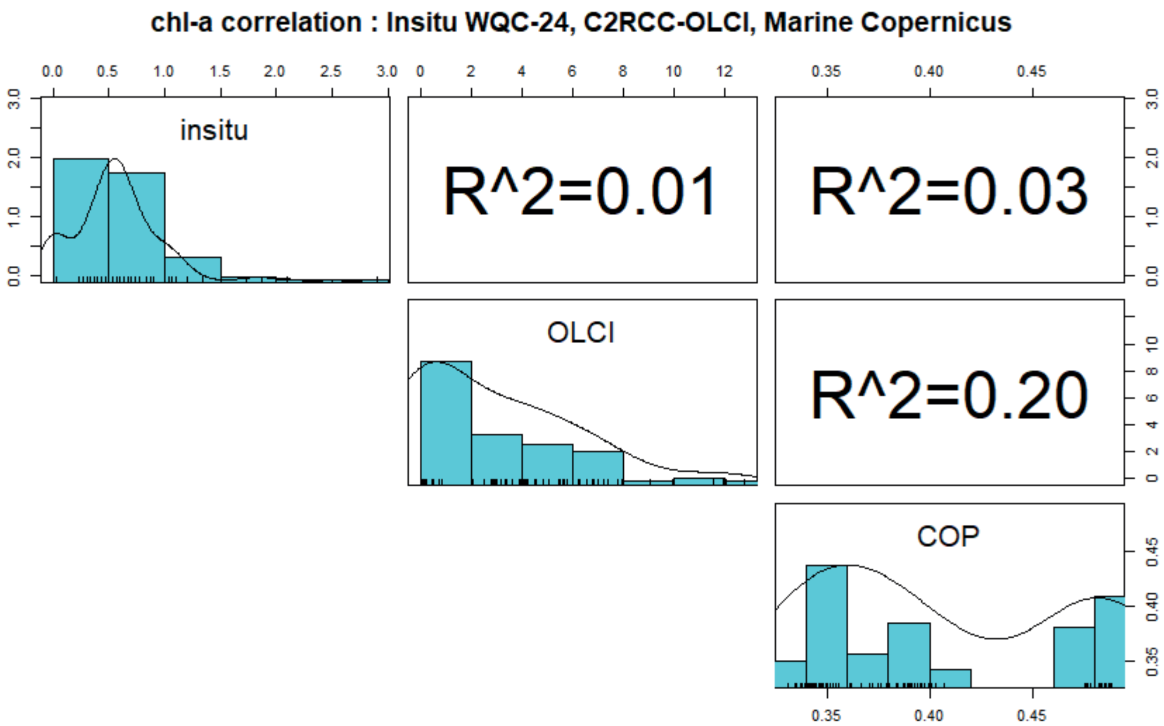


Figure 29. chlorophyll-a correlation: insitu WQC, S3 C2RCC, Marine Copernicus

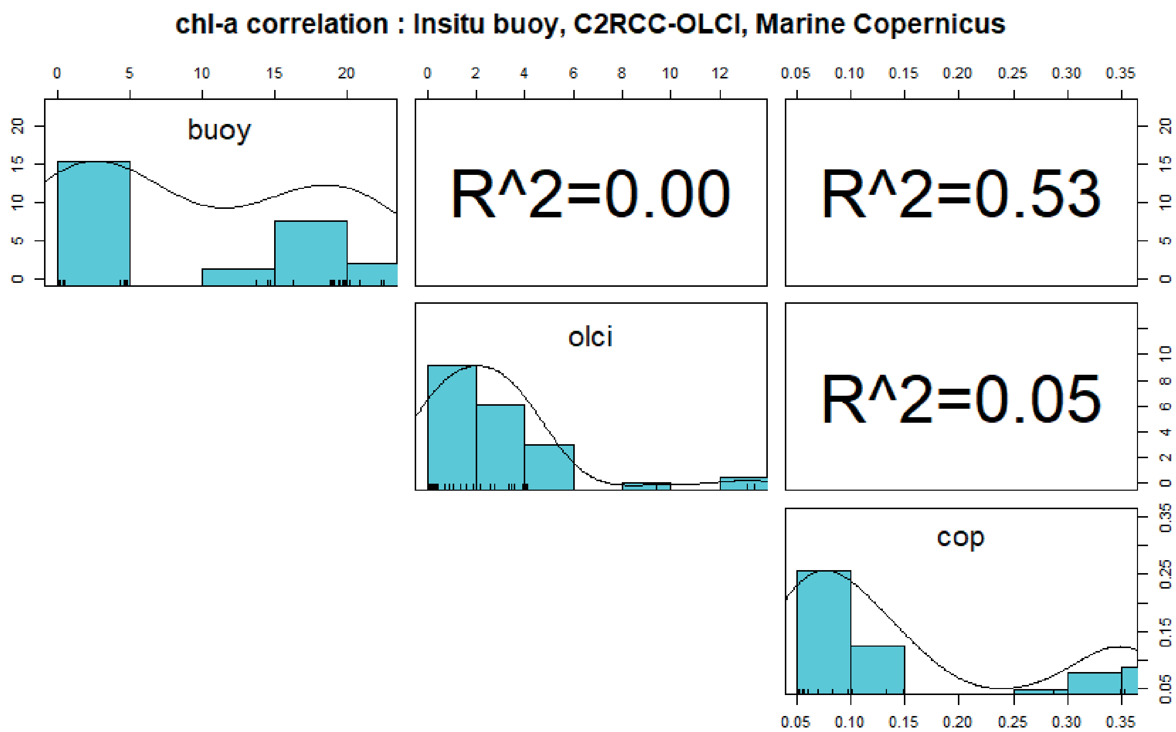


Figure 30. Chlorophyll-a correlation : insitu buoy, S3 C2RCC, Marine Copernicus

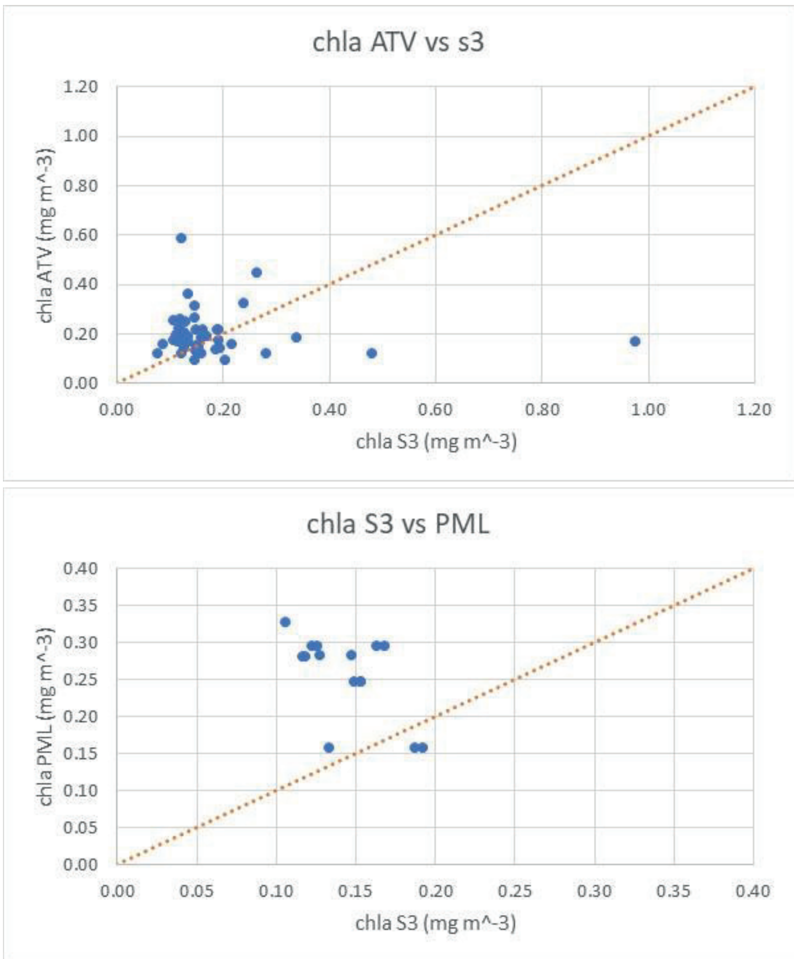
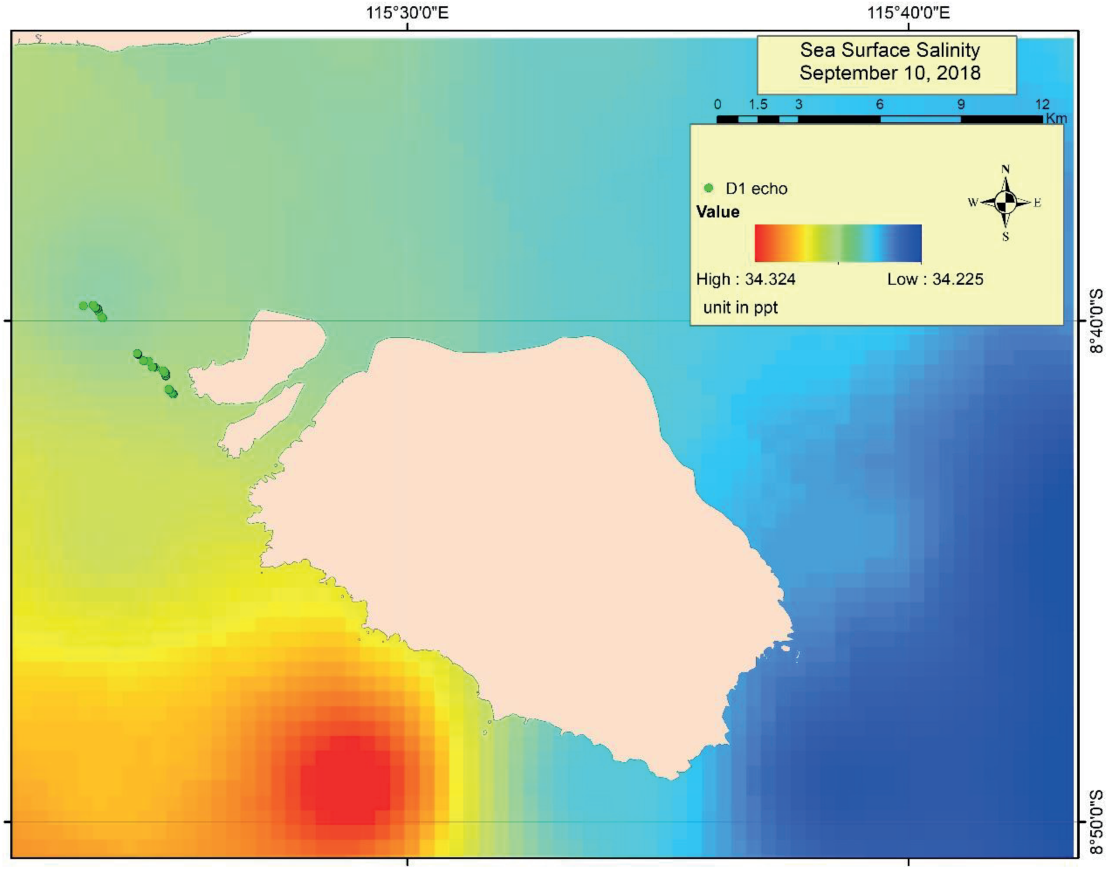
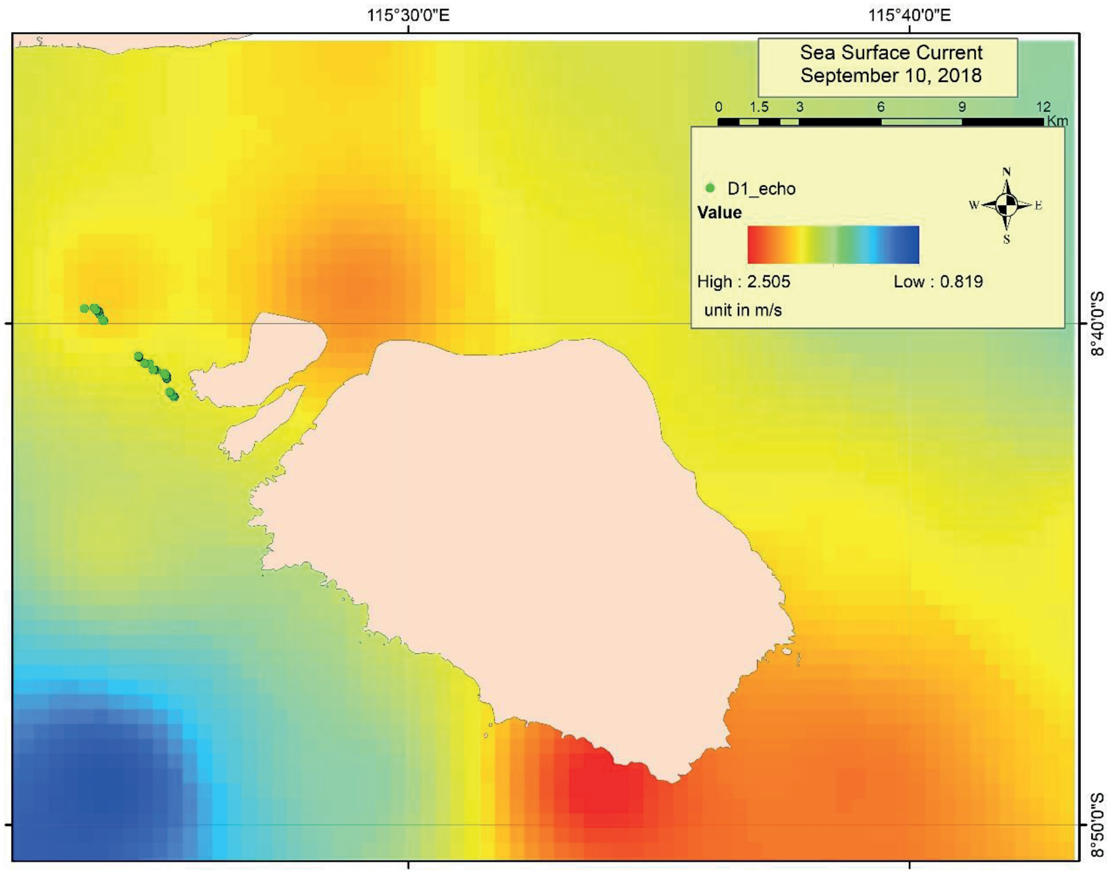


Figure 31. chlorophyll-a comparison between Aqua Terra VIIRS, S3 C2RCC and OC-CCI PML

4.2.5. SSH, Sea Surface Salinity and Sea Surface Current.

The SSH, Sea Surface Salinity and Sea Surface Current datasets has been downloaded from Marine Copernicus using Motu-Python client. The Motu-Python client has been used to automatically download, select and subset (position and time) the product from Marine Copernicus. All datasets from Marine Copernicus have a netCDF format. The netCDF format have been converted into a point data in CSV format. The point dataset from netCDF have been interpolated using Inverse Distance Weight/ IDW method. Pixel size of interpolated data has the same size with the SST dataset. The interpolated SSH, Salinity and Sea Surface Current for 10 September 2018 in Figure 32 below where detected fish echo located on low SSH (0.16-0.23 m), salinity value around 34.2 psu and medium sea surface current speed between 1.8 to 2 m/s.





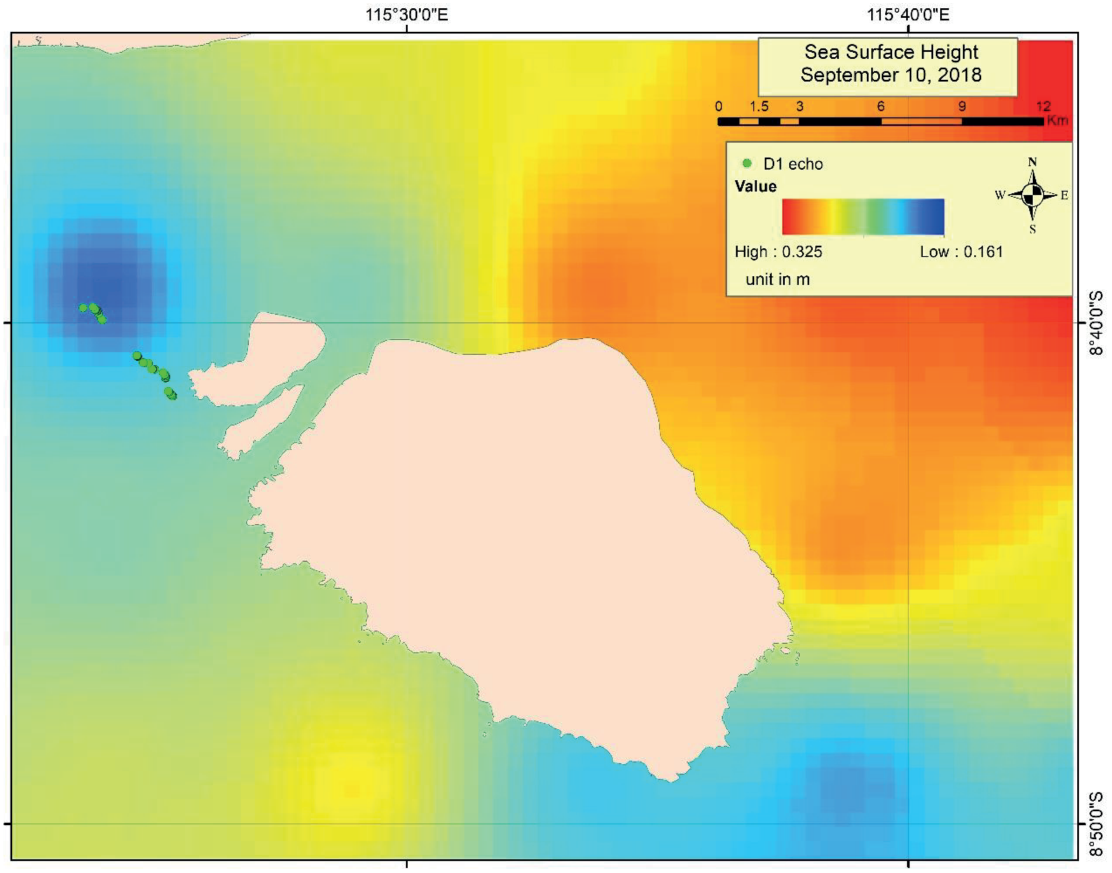


Figure 32. Sea surface salinity, current and height using Marine Copernicus dataset

4.3. Maxent Processing

The maximum Entropy has been intensively used to obtain small pelagic fish habitat prediction. The maxent runs in the apps that has been developed by (Phillips et al., 2006)in JAVA based application. Maxent version 3.4.1 has been used in this research to detect small pelagic fish species distribution. The newest Java Development Kit is needed to run the maxent application. We construct the model using default value for parameter with 500 iteration and cloglog transformation.

There are 2 input for the maxent, the species occurrence and environmental parameters. The species occurrence has the information of species name and the coordinate of the species. The species occurrence should be in the CSV file format. The environmental parameters consist of all parameters needed for detecting small pelagic fish in this research, such as SST, front SST, depth, SSH, salinity, current and chlorophyll-a. The environmental parameters must be in ASCII format and the same dimension (column, row, and size). To develop a multi linear equation based on the maxent, the environment parameters has been averaged based on available temporal datasets on day 1, 2, 7, 8, 9, 10, and 11 of field measurement.

The result of maxent is the species distribution of small pelagic fish based on the input data and the information of percent contribution from each parameter. The species distribution result is a probability of the occurrence of small pelagic fish based on cloglog transformation used in maxent. The combination of environmental input file from satellite imagery (SLSTR and OLCI) data and Marine Copernicus dataset has been used in the maxent. The combination of input data reveal the accuracy of both input data.

The result of Maxent using satellite imagery has been showed in Figure 33. Table 9 show us the percentage contribution on each environmental parameter based on Maxent calculation using satellite imagery. Based on the result, SSH is the main contributing parameter while the biological parameter (chlorophyll-a) is less contributed.

Table 9. Percent contribution using Sentinel imagery

Parameters	% Contribution	Parameters	% Contribution
SSH	56	Front	2.8
Depth	15.9	Salinity	0.4
SST	12.8	Chlorophyll-a	0
Current	12		

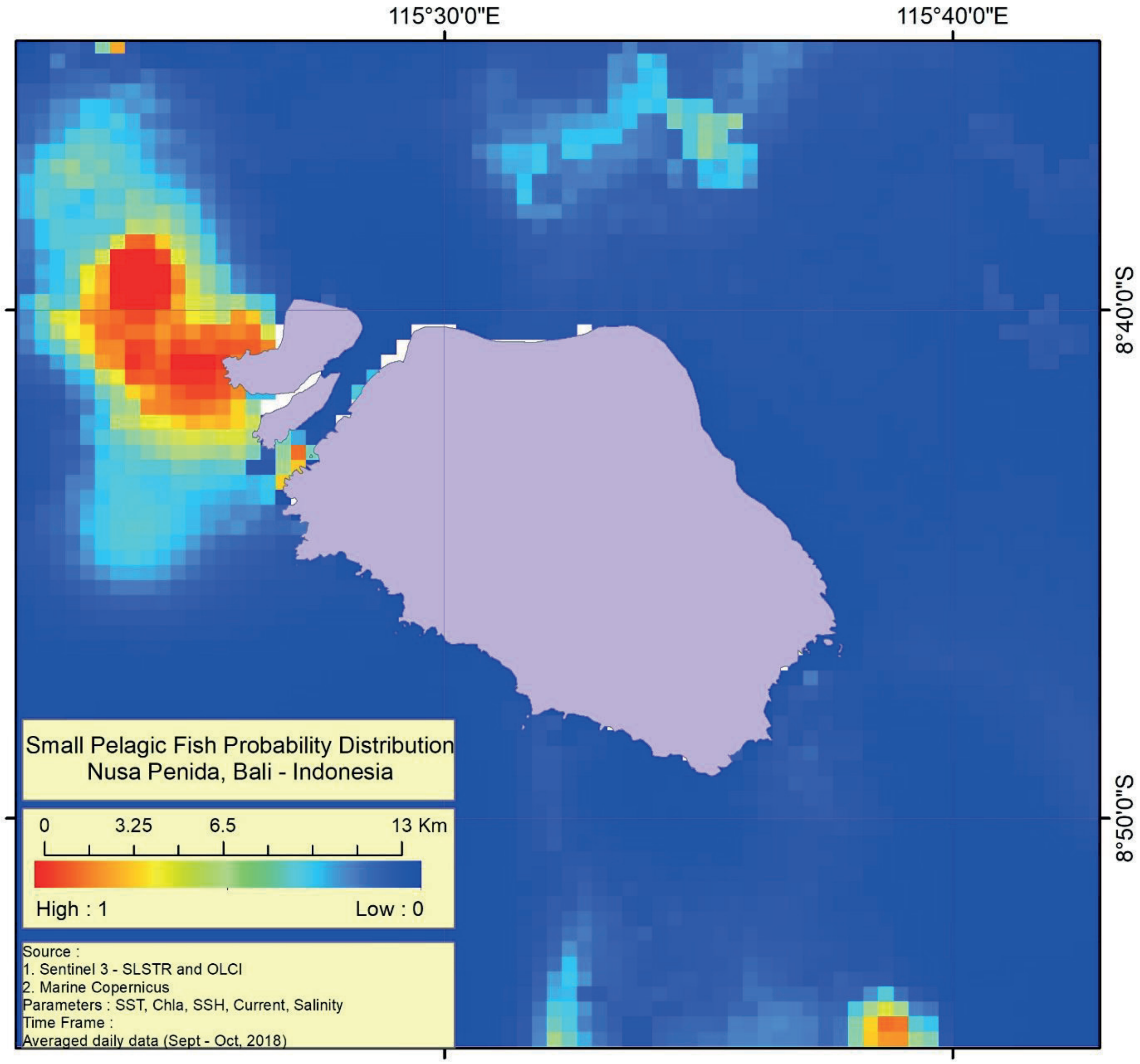


Figure 33. Maxent result using Sentinel imagery

Based on the result of maxent, the multi linear equation has been developed in 2 steps. First, the fish occurrence has been sorted based on db strength and divided into two part where this method based on Geo-Cal-val from(M. S. Salama et al., 2012). Second, the first part of fish occurrence has been used to develop the multi linear equation and the second part has been used for validating the equation. The equation shown in equation below. The validation shows a good fit of the model (Figure 34) where the R^2 = 0.9808 with RMSE = 0.051 and MAE = 0.047.

$$Fish_{probability} = 0.087025chla + 0.493826cr + 7.039077sal + 0.021381sst + 0.085624front + 0.001633depth - 1.60771ssh - 246.694$$

Where chlorophyll-a, cr, sal, sst and ssh are chlorophyll-a in mg/m^3, current in m/s, salinity in psu, sea surface temperature in Celsius and sea surface height in meter, respectively.

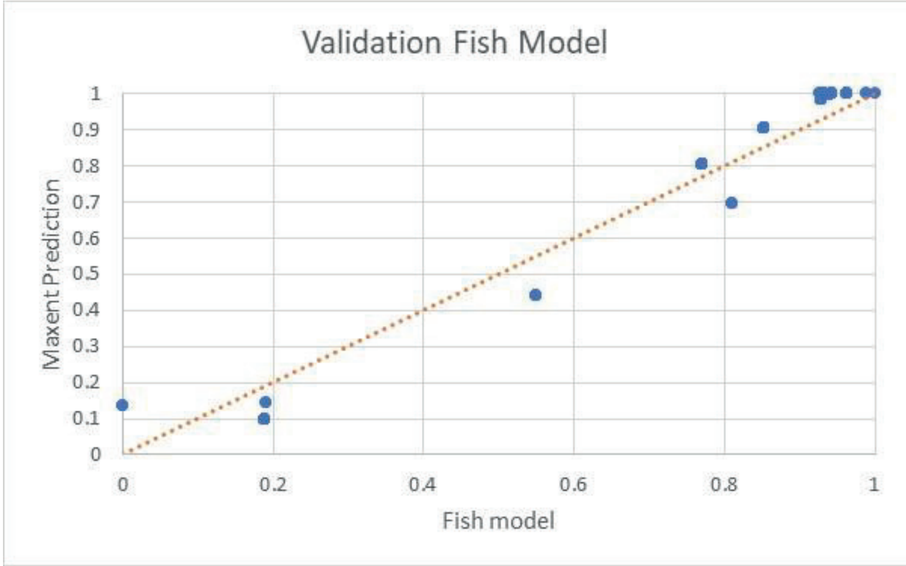


Figure 34. Fish model validation using satellite imagery

Maxent using Copernicus dataset

Based on SST and chlorophyll-a comparison between insitu and Sentinel 3 and Marine Copernicus data, the Marine Copernicus data show a better result on chlorophyll-a and SST retrieval. The Marine Copernicus data has been used in Maxent to compare the result of maxent with Sentinel 3 data. Due to temporal resolution of Marine Copernicus data, the Maxent has been performed based on monthly basis data on September 2018 and October 2018. The multi linear equation using Marine Copernicus data shown below.

$$fish_{probability} = -13.0345chl + 0.147954cr - 1.34853sst - 28.6916sal + 0.272665front + 0.0018331depth - 6.41697ssh + 1029.099$$

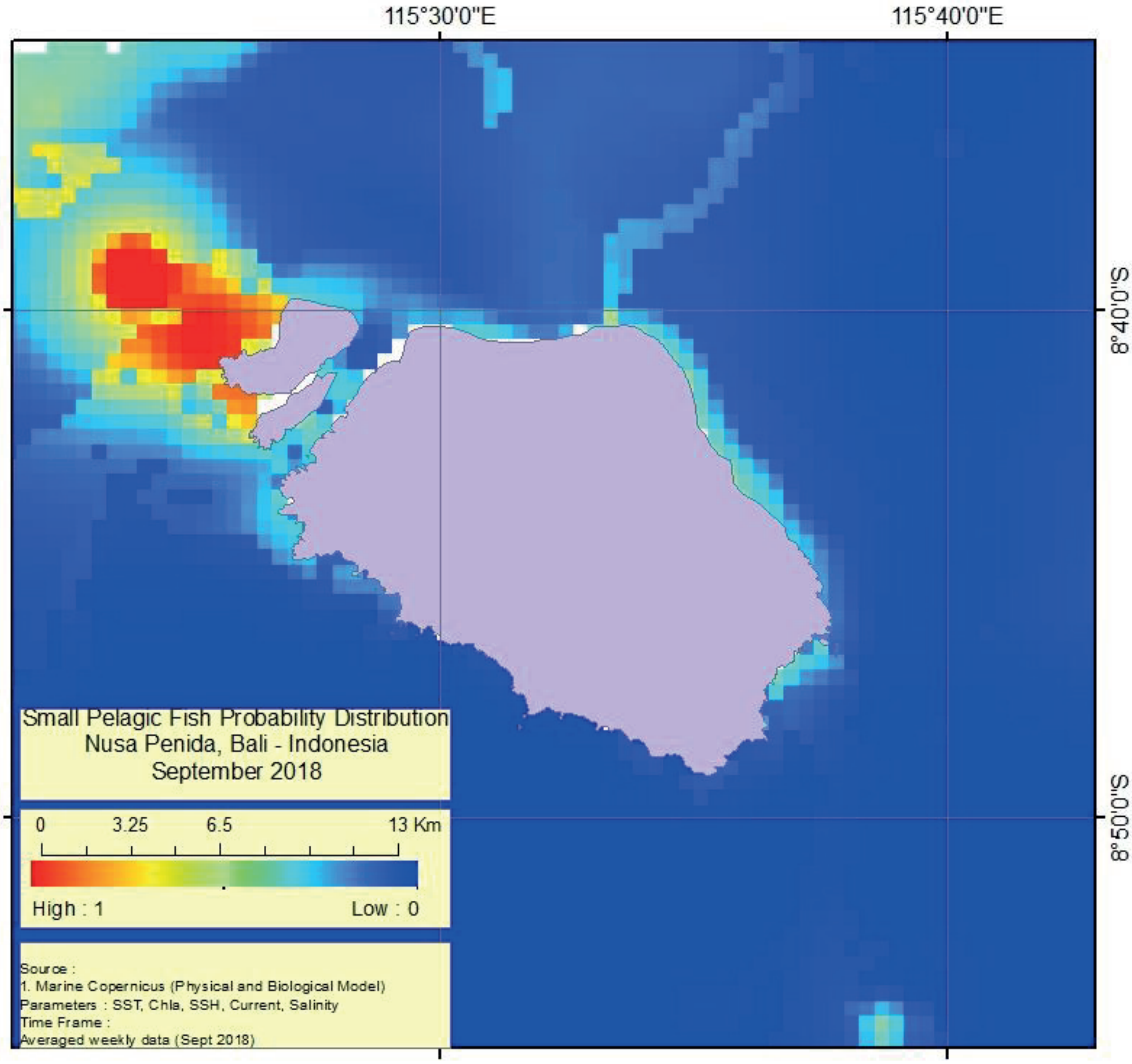
The Maxent Result on September 2018 (Figure 35) has a good fit where the R^2=0.9865 with RMSE = 0.221 and MAE = 0.219. on October 2018 (Figure 36), the maxent result (Table 11) show a good fit with R^2=0.9884 with RMSE = 0.199 and MAE = 0.197. The percent Contribution of each month showed in Table 10 below. The best contributing parameter on both months is SSH and chlorophyll-a.

Table 10. Percent contribution using Marine Copernicus dataset

Parameters	% Contribution Sept 2018	% Contribution Oct 2018
SSH	52	55.5
Chl	26	24.5
Depth	12.2	12.3
Front SST	6.3	5.1
SST	3.1	0.7
Current	0.4	1.8
Salinity	0	0

Table 11. Fish Model Performance Comparison

	R^2	RMSE	MAE	Slope	Intercept
Fish Model – Satellite	0.9808	0.051	0.047	1.1552	-0.087
Fish Model – Copernicus 201809	0.9865	0.2216	0.219	1.1305	0.143
Fish Model – Copernicus 201810	0.9884	0.1992	0.197	1.1073	0.129



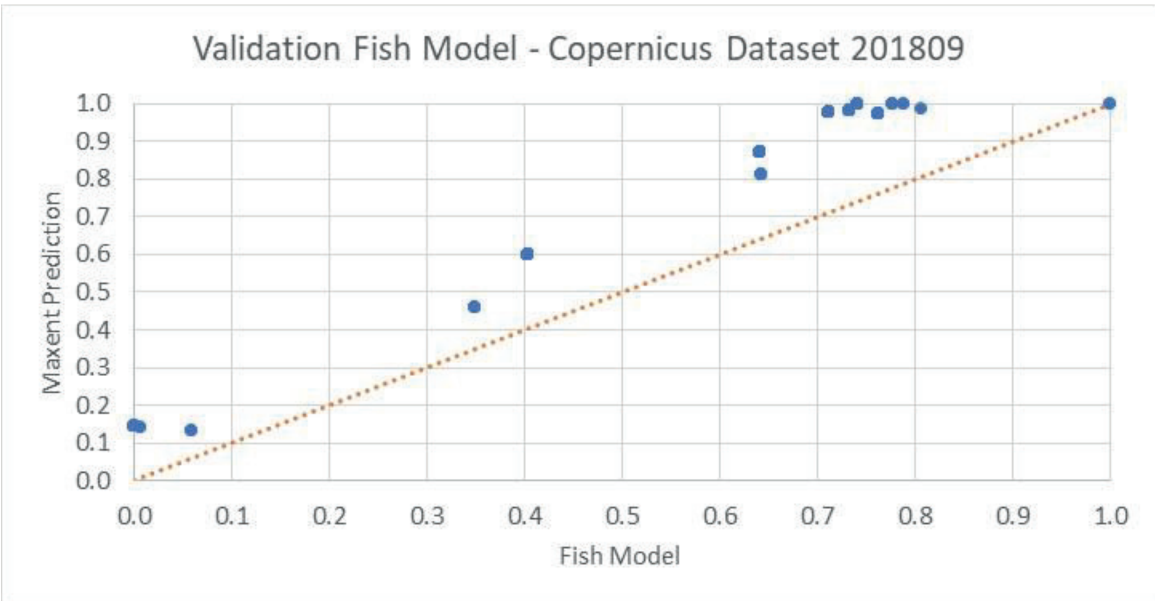
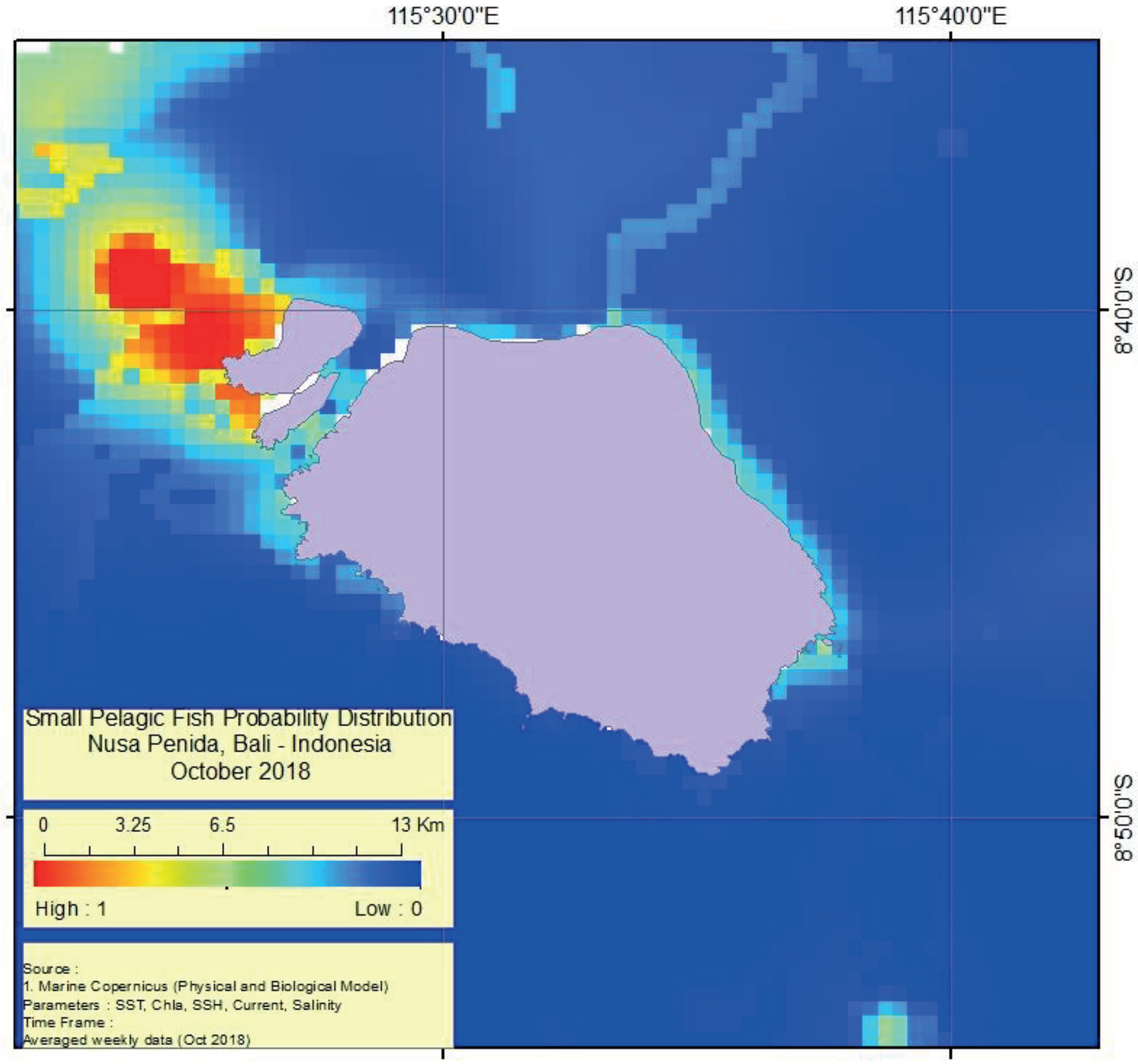


Figure 35. Maxent result using Marine Copernicus dataset - September 2018 (above) and fish model validation (below)



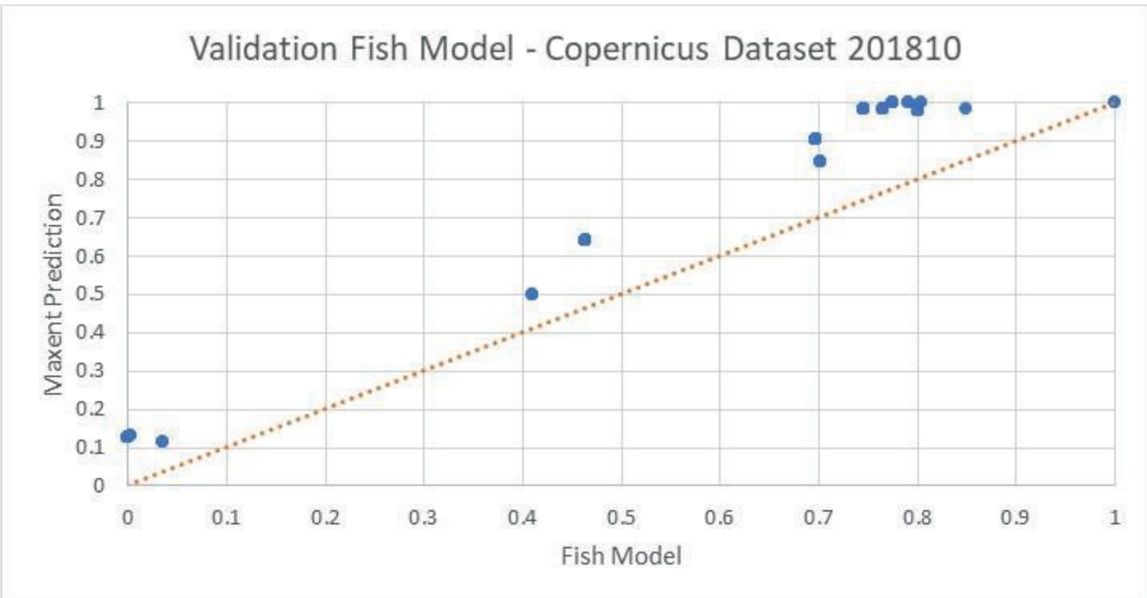


Figure 36. Maxent result using Marine Copernicus dataset - October 2018 (above) and fish model validation (below)

4.4. Map of Potential Fishing Ground / MPFG generation

Based on the result, we can conclude that Marine Copernicus dataset with IDW interpolation is able to describe the location of small pelagic fish over Nusa Penida area. The Map of Potential Fishing Ground / MPFG has been generated based on the result using Marine Copernicus data. A daily physical data (SST, SSH, salinity and current) has been averaged on weekly basis and interpolated using IDW from 9 km resolution to 500 m resolution. The weekly biological data consist of chlorophyll-a has been interpolated using IDW from 0.5 degree to 500 m resolution. The Front SST has been calculated based on Single Image Edge Detection on weekly dataset. The bathymetry data has been used the same dataset from Hydro-Navy Ocean Center. The MPFG generation result shown in Figure 39 and Figure 40.

On the first semester of 2018, the high probability of small pelagic fish occurs from west in Nusa Penida strait and move to the northern part of Nusa Penida. Compared to the second semester of 2018, the high probability stays in the north part of Nusa Penida and the probability lower on December 2018. Compared to fish probability from Maxent result on September and October 2018, the location of hotspot of the fish in northern area of Nusa Penida have the same pattern with MPFG from Marine Copernicus. The hotspot based on Marine Copernicus MPFG occur on August to November 2018.

Based on the overall statistic of MPFG 2016 to 2018, the mean of probability is stable during 2016 to 2018 (Figure 37). The maximum and minimum value has a variation but there's no sign of seasonal / monsoon pattern. Meanwhile in the averaged 3 years climatology has been processed using the weekly dataset of Marine Copernicus (Figure 38). The monthly average climatology has a variation and no sign of seasonal pattern as the monthly statistics. The monthly average climatology MPFG has been depicted in Figure 41 and Figure 42. On the other hand, a map that consist of high probability PFG (>0.7) has been created and averaged from weekly data of 2016-2018 (Figure 43). The map show us where is the location of fish hotspot that occur during the whole season. The Marine Protected Area has been informed in the depicted map.

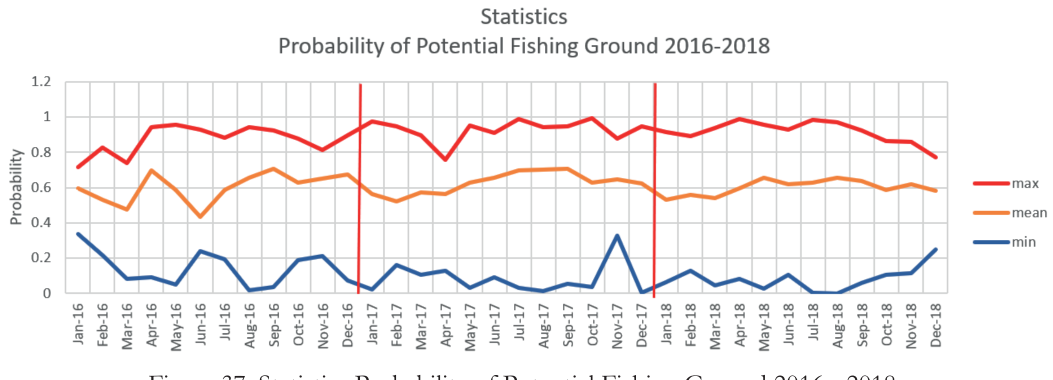


Figure 37. Statistics Probability of Potential Fishing Ground 2016 - 2018

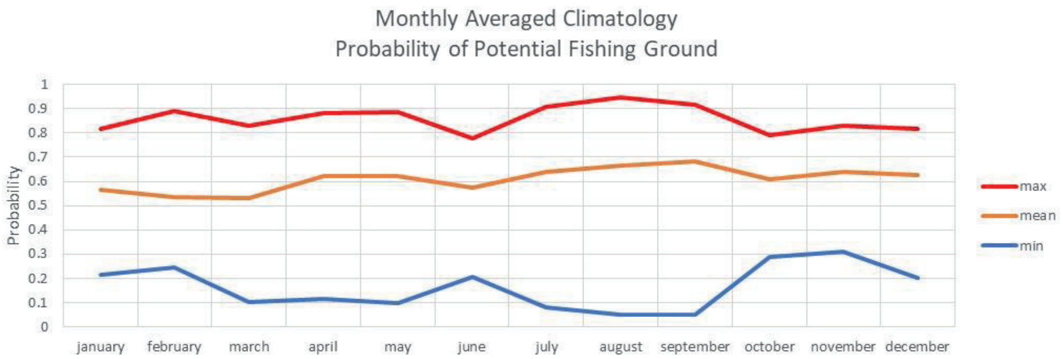


Figure 38. Monthly Average Climatology Probability of Potential Fishing Ground

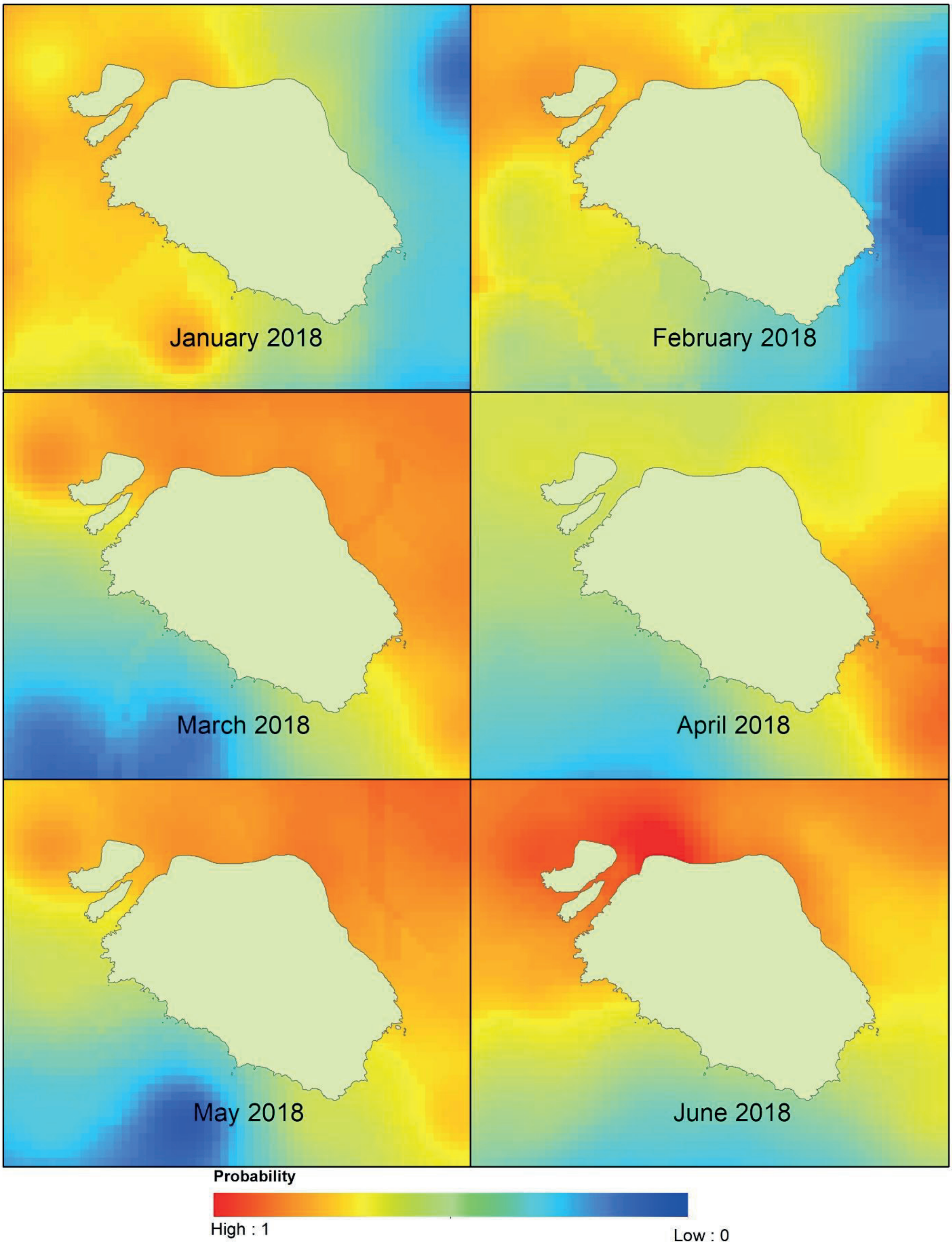


Figure 39. MPFG for January to June 2018

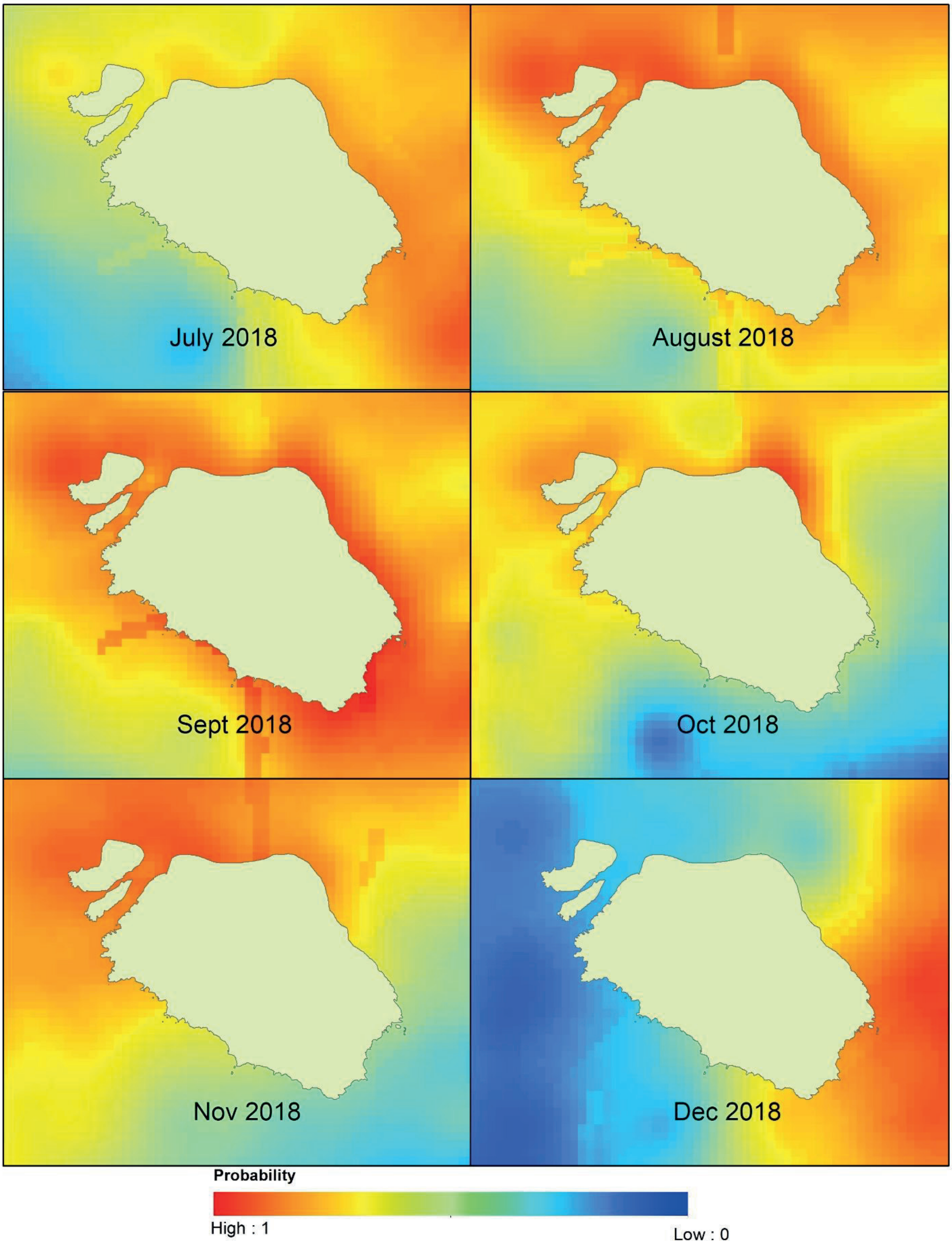


Figure 40. MPFG for July to December 2018

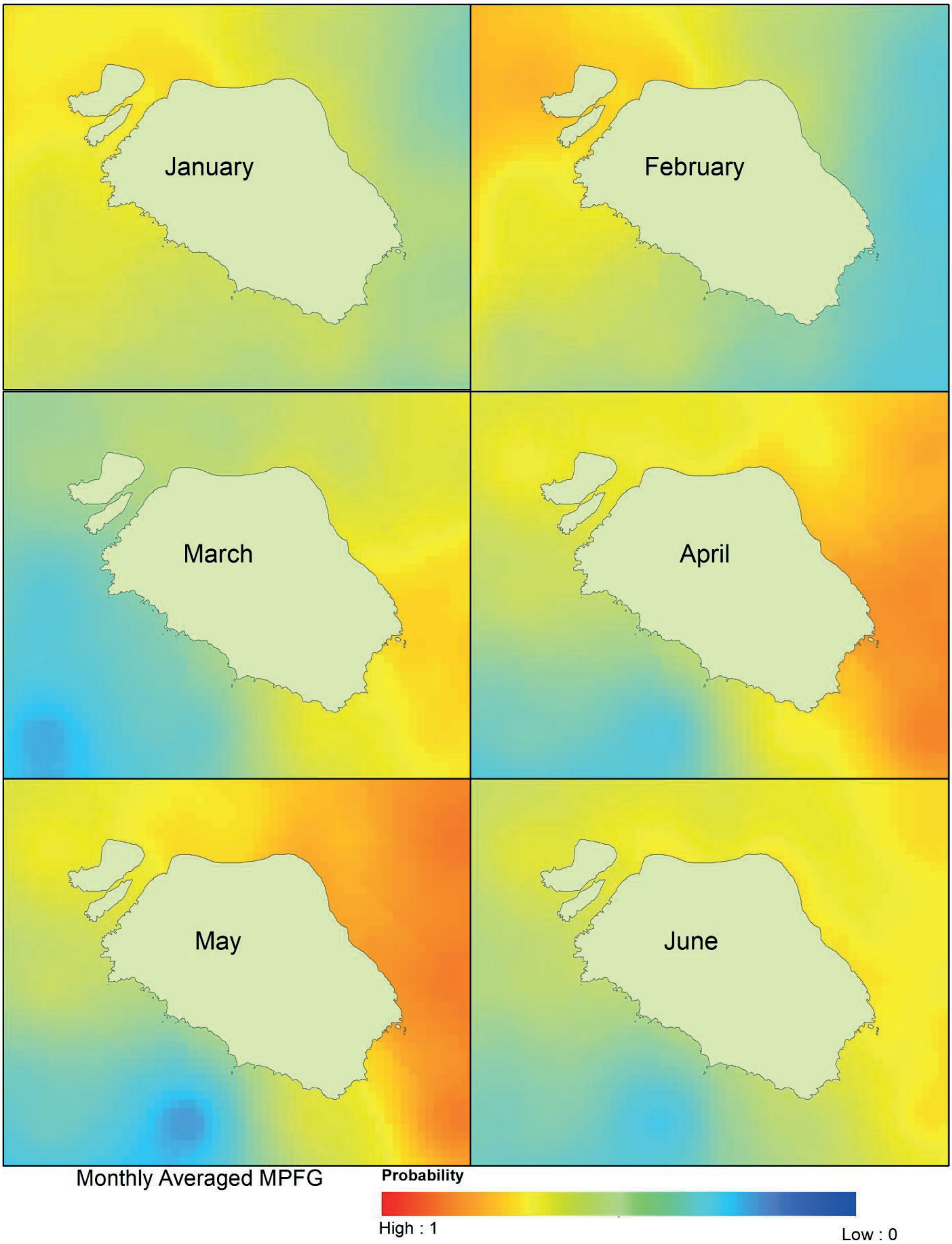


Figure 41. Monthly Average MPFG January to June 2016-2018

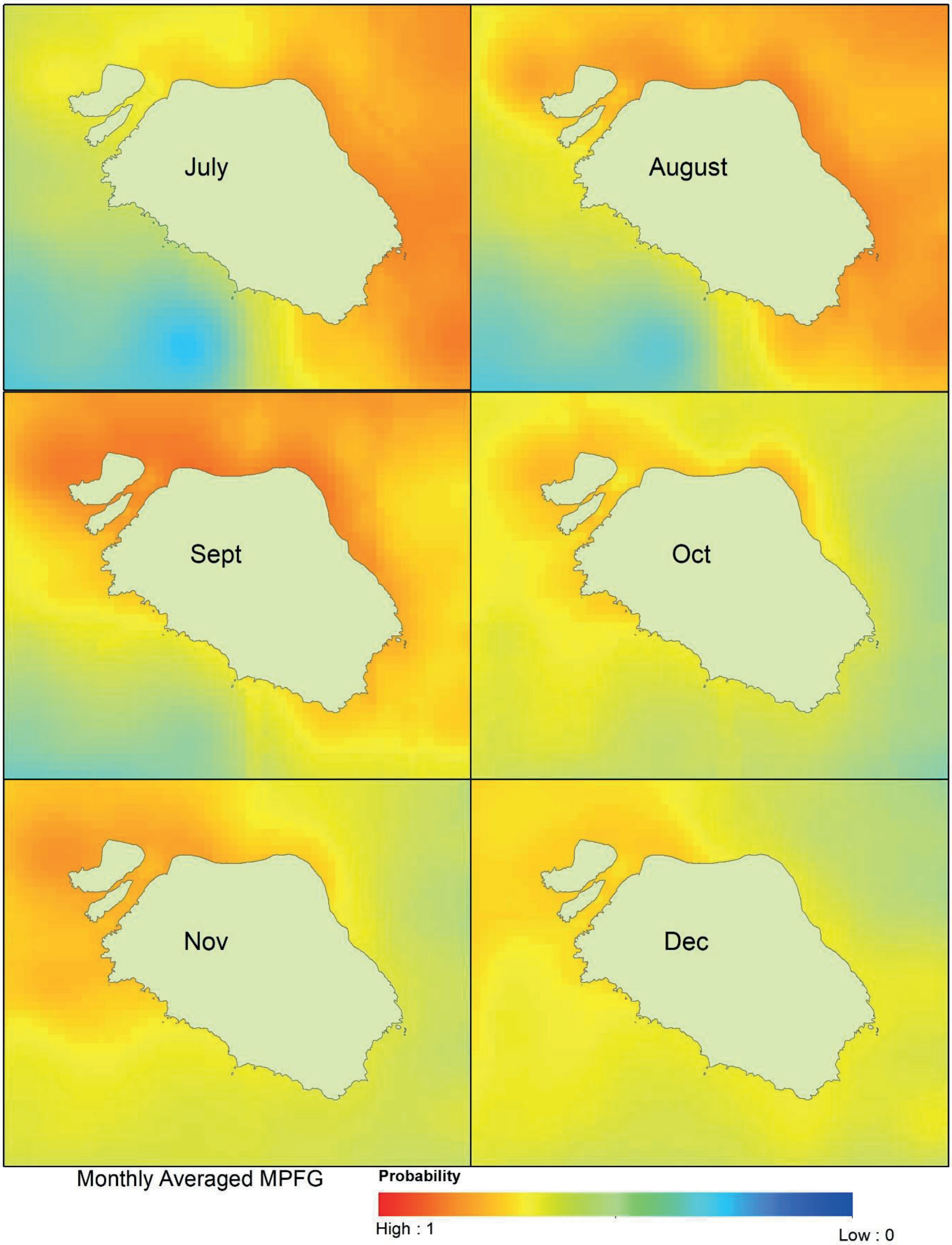


Figure 42. Monthly Average MPFG July to December 2016-2018

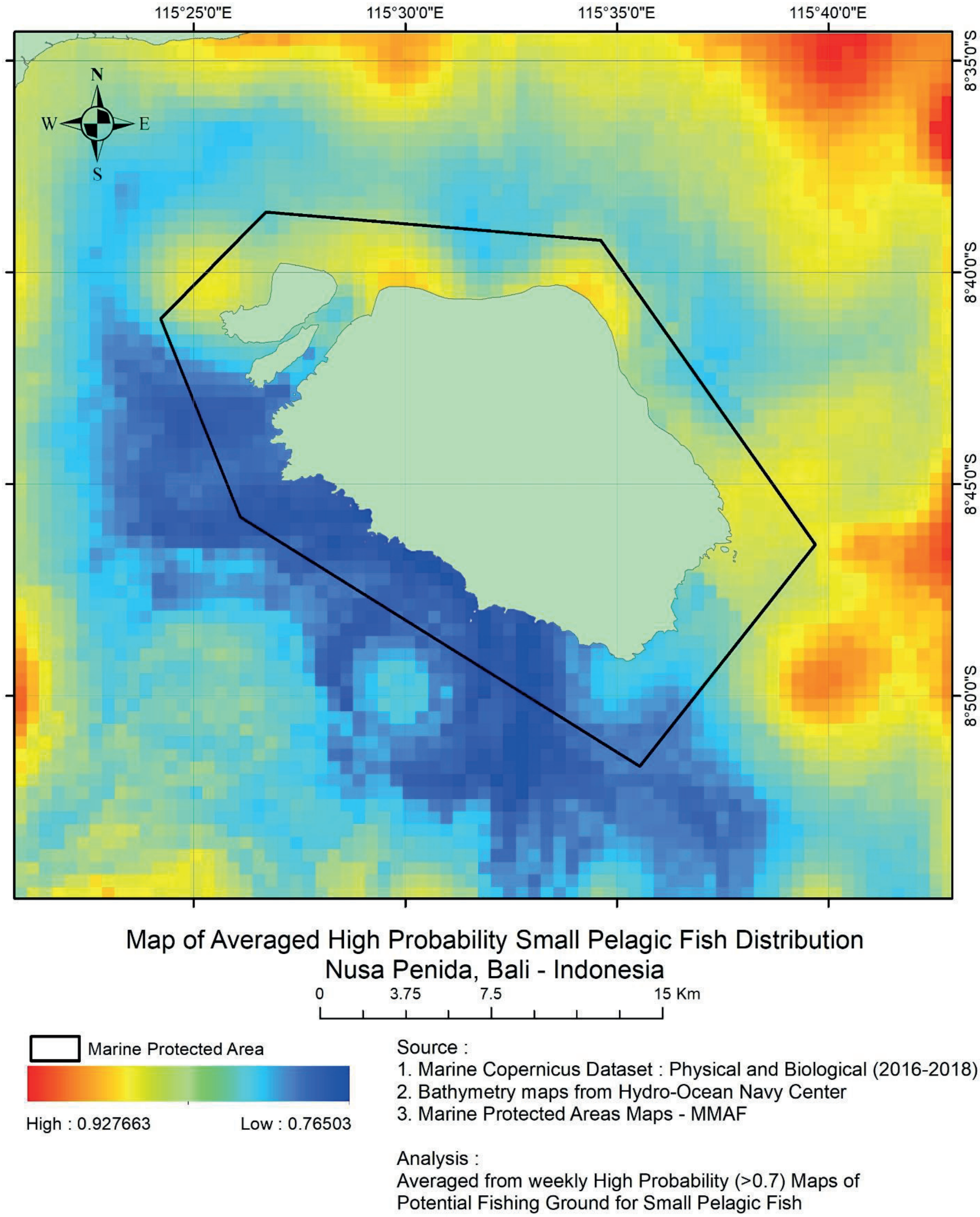


Figure 43. Averaged High Probability Small Pelagic Fish Maps

5. DISCUSSION

Satellite remote sensing data has shown a satisfactory performance to observe physical and biological environmental parameters on open ocean and coastal area. A Sentinel 3 dataset has been used in this research to obtain SST, Front SST and Chlorophyll-a information. A Sentinel 3 SLSTR sensor has been used to obtain SST and Front SST information and Sentinel 3 OLCI sensor has been used to obtain chlorophyll-a information.

The ATSR Reprocessing for Climate SST (ArcSST) has been used to retrieve SST information from Sentinel 3 SLSTR sensor. The ArcSST based on coefficient-based retrieval scheme to estimate SST information. Based on (Embury & Merchant, 2012), a N2 approach show a better bias value on tropical condition. The ArcSST N2 method has been used to retrieve SST information in this research. The ArcSST has been compared to insitu measurement using WQC-24 and coastal buoy measurement. In the other hand, ArcSST retrieval compared with another SST product from Marine Copernicus data. Based on the result, ArcSST retrieval compared with WQC-24 measurement and coastal buoy show a low correlation value. Several outliers have been found on WQC-24 insitu measurement. A Marine Copernicus data with IDW interpolation have a strong correlation with coastal buoy compared with ArcSST retrieval. The performance of ArcSST show a good response compared with the insitu measurement.

The front SST calculated based on ArcSST N2. The threshold $0{,}5^0$C has been used based on (Jatisworo, 2017) to determine front SST. Based on time window of field measurement, the Front SST occur on the strait between Nusa Penida and Bali island. The front SST is an indicator of upwelling and mass transport in the ocean where the cold water rises toward the surface. The front SST is one of indicator of pelagic fish. If we compare the front SST with sea surface current, the front SST mostly located in the direction of current from the north in Lombok strait goes to the strait between Nusa Penida and Bali Island (figure 38). It means the water that has been transported from north to south carried a cold water through Indonesian Throughflow in Lombok Strait (Susanto et al., 2007).

The Chlorophyll-a parameter has been retrieved from Sentinel 3 OLCI using C2RCC method. The comparison has been performed using insitu measurement from WQC-24 and coastal buoy. The retrieval of chlorophyll-a using C2RCC show a low correlation on both insitu measurement. Contrary on Marine Copernicus dataset with IDW interpolation, the chlorophyll-a retrieval shows a better correlation than C2RCC retrieval. The adjacency between insitu and coastal line is the main factor of low correlation. Based on several literature, C2RCC didn't show a good performance. A research has been conducted in Farm Strait (Liu et al., 2018) show that there is underestimation of chl-2 retrieval using C2RCC where RMSE = 0.282 and R^2= 0.0169 using spectrophotometry insitu data. In Baltic Sea, C2RCC did not correlate with insitu measurement (Toming et al., 2017).

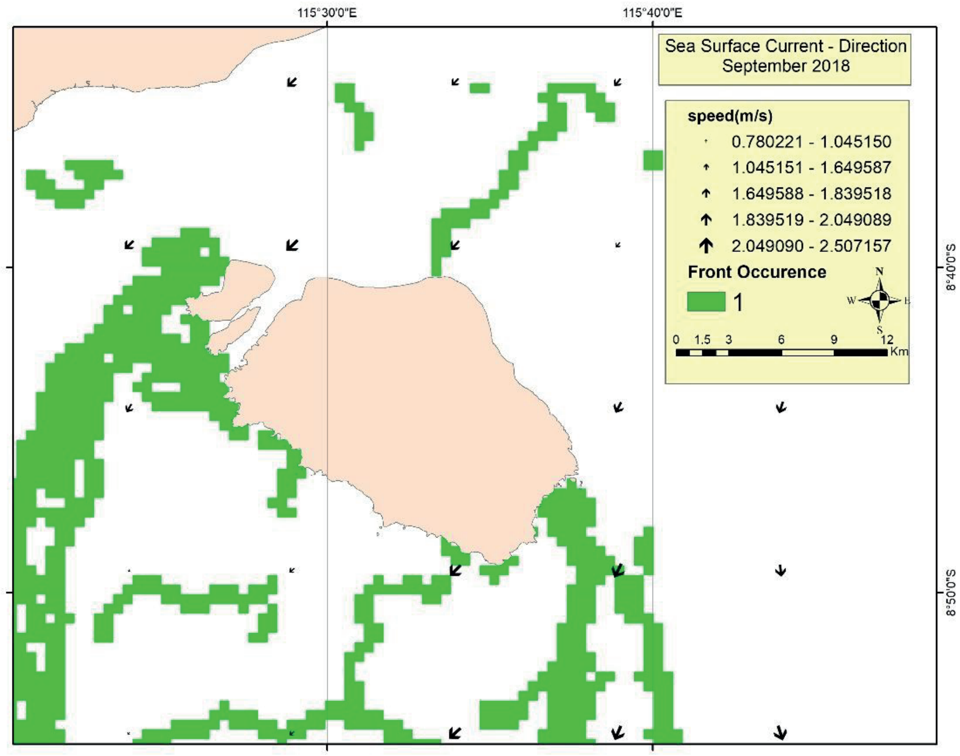


Figure 44. Front SST occurrence and sea surface current speed and direction

The 1/12^0 ocean numerical data from Marine Copernicus dataset has been used retrieve the other parameter such as SSH, current and salinity. The inverse distance weighted / IDW interpolation has been used to calculate and resample the image with the same spatial resolution as Sentinel 3. The IDW interpolation has been perform well on oceanographic parameters (Kusuma et al., 2018). Based on quality report from Marine Copernicus(CMEMS, 2016), the salinity data has RMSE = 0,199, surface current data with mean bias of 0,2 m/s and RMSE = 4,9 cm for SSH data.

The Maximum Entropy has been applied using two different datasets to test the result of the model. Based on maxent result and multi linear equation, the Marine Copernicus dataset has shown a better performance and the percent contribution result similar with literature of small pelagic fish. The percent contribution result from Marine Copernicus has met with several literature of pelagic fish detection where the most contributing parameter is SSH, chlorophyll-a and depth. The percent contribution of maxent from Sentinel 3 show a different way while SSH, depth and SST are the most contributing parameter. The differences between both results is chlorophyll-a parameter where chlorophyll-a is the indicator of food of small pelagic fish. The bad performance retrieval of C2RCC to show chlorophyll-a is the main problem of incoherence of percent contribution result. Several literatures show that the SSH, chlorophyll-a, depth and SST is important to detect a fish. Zainuddin (2017) has shown the pelagic hotspot in Gulf of Bone where SST, SSH, and chlorophyll-a is the main parameters. Atlantic Herring fish on Wang (2017) has the most related with SST on all month, chlorophyll-a has strong influence on several month and depth 1-17% of contribution. Rivai (2018) has shown the same result as maxent to detect Fish Catch per Unit Effort (CPUE) on coastal area of Seribu Island Jakarta. The total suspended solid and SSH has shown a high influence on CPUE value in Seribu Island Jakarta. The fish probability equation based on Marine Copernicus dataset show the same result as mentioned literature.

Fish occurrence has been collected on September and October 2018 where it just covers one monsoon time. In the other hand, the resulted equation only works on the same monsoon time due to seasonal effect and migration pattern of fish in tropical area. A large temporal and different location of fish occurrence is needed to develop a monsoon or generalized fish probability equation based on season or monsoon. A large and sparse dataset of fish occurrence will enhance the quality and accuracy of developed equation. The acoustics-based fish occurrence or a vessel detection can be used as the input of maxent. Syah (2016) has been used vessel detection based from Defence Meteorological Satellite Programme / DMSP – Operational Linescan System / OLS. The other vessel dataset that can be used for the fish input in maxent is Vessel Monitoring System / VMS data from regional authorities and Automatic Identification System / AIS data that has been installed on large fisheries vessel.

The monthly climatology of MPFG has been produced based on weekly data from 2016 to 2018 on Figure 41-42. The fish probability distribution has been moved according to monthly climatology. On west monsoon, between November to March, the high probability didn't occur much compared to east monsoon between April to September. The high small pelagic fish probability occurs in Lombok strait during east monsoon and shifted a little bit to the west in Nusa Penida strait. This can be explain due to the water masses sources changes annually on Lombok strait where during April – June there is large mass flow from Java Sea to Lombok Strait (Atmadipoera et al., 2009). This water masses bring a high nutrient and the fish attracted to move toward high nutrient area. Furthermore, the hotspot consistently occurs in the north-west part of Nusa Lembongan island from August to November. A high probability composite map has been created to gain more understanding of the hotspot occurrence. The high probability composite map created by filtering probability value more than 0.7 from each weekly map and combined those maps by averaging the value (Figure 43). The map show that on average, the hotspot probability value near 0.9 which is high probability of small pelagic fish occurrence. Based on acoustic data analysis, we can find that fish that has been detected on the hotspot area has target strength echo from -50 to -56 db or the fish has length from 5 to 11 cm. The fish length can be one of indication that the area can be the spawning area of fish. *Sardinella Lemuru,sp* , where usually occur in Bali Strait, has 14-18 cm length during spent stage (Wujdi et al., 2013). In the other hand, Figure 43 show us a boundary of Marine Protected Areas of Nusa Penida area. Based on the maps, we can see that most of the area of Marine Protected Areas has a high probability of fishing ground of small pelagic fish and the indication of spawning ground of the small pelagic fish. Based on Marine Protected Areas, we can know that by producing Map of Potential Fishing Ground able to support fishing efficiency on fishing management and Sustainable Development Goals.

6. CONCLUSION

The Maximum Entropy model has been successfully applied to detect habitat suitability for small pelagic fish in coastal area and able to map the potential fishing ground of small pelagic fish. Satellite imagery and Marine Copernicus dataset has been used in maximum entropy as environment parameter and fish occurrence from acoustics measurement has been used as occurrence data. The multi linear regression equation based on environmental parameters and maxent result has been developed to obtain potential fishing ground location. The result from the equation show that maxent using Marine Copernicus dataset has a better performance than maxent using Sentinel 3 dataset.

SSH, depth and SST are the first 3 high percent contribution from maxent using Sentinel 3 dataset and SSH, chlorophyll-a and depth is the first 3 high percent contribution from maxent using Marine Copernicus datasets. The multi linear equation from maxent using Marine Copernicus dataset is the best performance with R^2=0.981, RMSE = 0.199 and MAE = 0.197 while using Sentinel 3 dataset with R^2= 0.981, RMSE = 0.051 and MAE = 0.047. In the other hand, percent contribution result from Marine Copernicus data show a coherence with other literature. The percent contribution result from Sentinel 3 is incoherence with literature due to inferior performance of chlorophyll-a retrieval. Inadequate retrieval of chlorophyll-a can causes faulty percent contribution result from Maxent.

6.1. Limitation

The limitation has been foreseen based on this research

1. This research has been performed on September and October. The equation only performs better on specific month and season.
2. The equation only works on specific dataset and need to be adjusted and work using other datasets.

6.2. Recommendation

1. To obtain a satisfactory equation with seasonal variation, the insitu measurement of small pelagic fish presence should be retrieved on monthly or seasonal basis. This monthly or seasonal basis fish presence data will help to create better equation to obtain potential fishing ground for small pelagic fish.
2. A vessel logbook catch and fishing vessel location can be used to obtain fish presence data to perform Maximum Entropy model.

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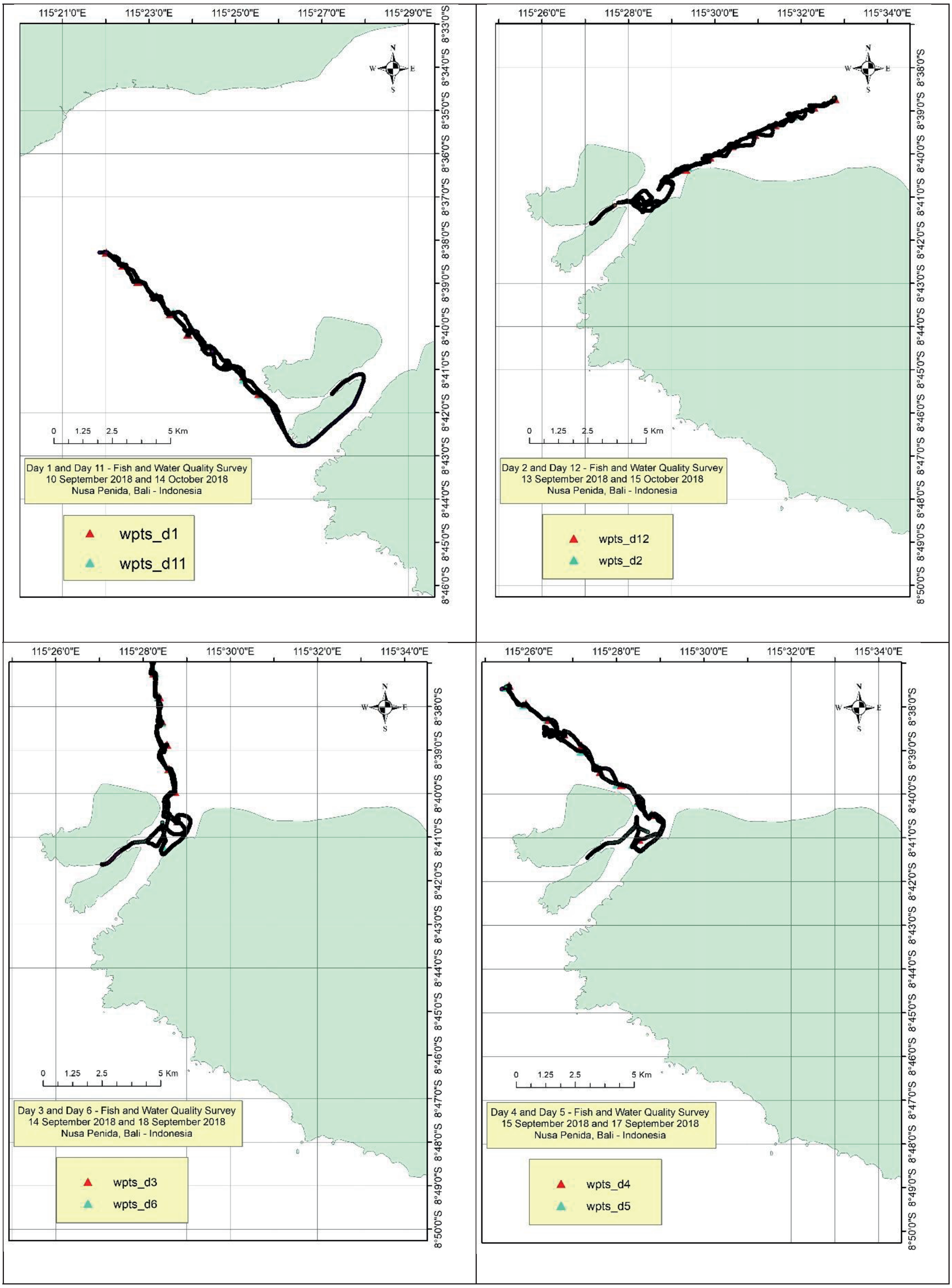
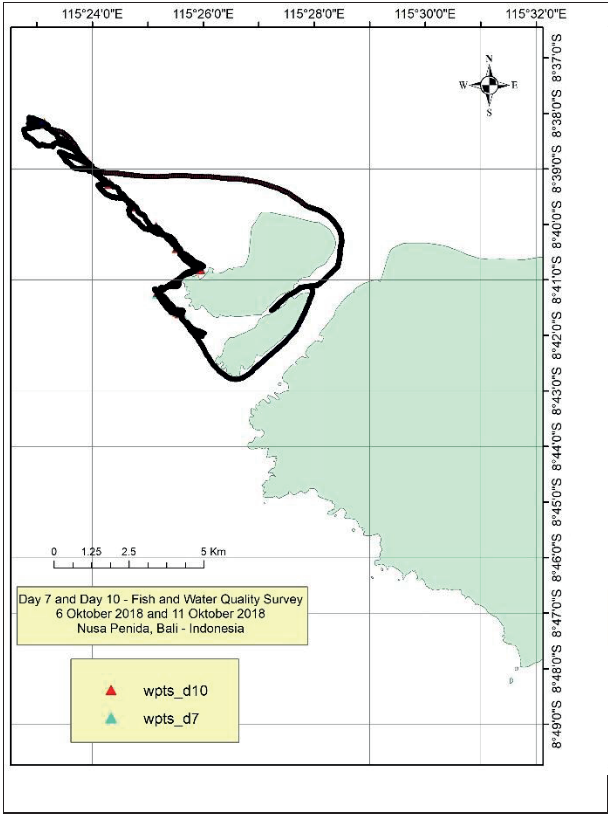
Appendix 1 – Track of survey Maps.

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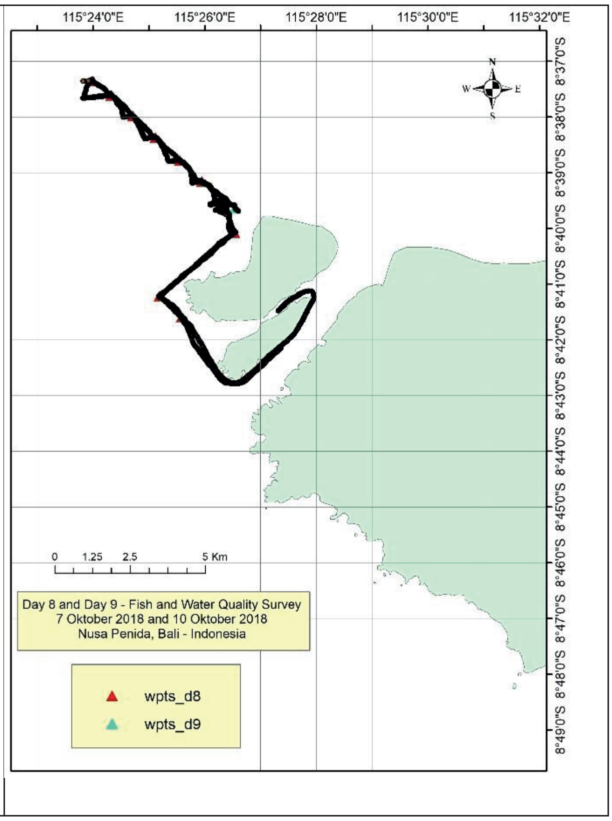
Day 7 and Day 10 - Fish and Water Quality Survey
6 Oktober 2018 and 11 Oktober 2018
Nusa Penida, Bali - Indonesia
wpts_d10
wpts_d7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Day 8 and Day 9 - Fish and Water Quality Survey
7 Oktober 2018 and 10 Oktober 2018
Nusa Penida, Bali - Indonesia
wpts_d8
wpts_d9