HAZARD ASSESSMENT AND RISK ANALYSIS OF REEF FISH STOCKS IN BINTAN ISLAND WATERS, KEPULAUAN RIAU, INDONESIA

Thesis submitted to the Double Degree M.Sc. Programme,
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ABSTRACT

Overfishing or over exploited fishing in general defined as harvesting the fish resources faster than it natural replenishes. The amount of fish that can be produced from water areas have a strong link with the primary productivity of the waters. Therefore, chlorophyll serves as one indicator of aquatic primary productivity. Reef fish species is a kind of fish that is very popular and has a fairly high selling value in the world. Apart from the sizeable increase in the production of fish species is thought to have experienced symptoms of overfishing. Consequently, an effective monitoring and management are required to maintain a sustainable use of marine resources, admitting fish and its ecosystem. Remote sensing technology has been enabling continues monitoring ocean color properties. This study aim to find out the link between the dynamic of primary productivity in surrounding Bintan Island waters with the reef fish production. Apart, quantifying on reef fish production were done based on Total Allowable Catch (TAC) from Ministry of Marine Affairs and Fisheries. Measured ocean color properties shows relatively good performance. In general highest chlorophyll concentration occurs when sea surface temperature lower between 25 to 28 Celsius degree. Statistics informed strength linear relation between sea chlorophyll and primary productivity, r-squared 0,86 and very different from the relationship between these two parameters with sea surface temperature. Across eight years analysis on ocean color properties in area of study there is no indication about degradation of primary productivity from 2005 to 2012, in fact 2012 recorded the highest level of primary production. Despite having no real connection between the estimated value of primary productivity and distribution of reef fish production, this study find out that a comparison of three years of data from 2010 to 2012, production pattern of catches similar to the variation of primary productivity in a year. Reef fish fisheries production increased rapidly in Q2 to Q3 in one year and at the same time the estimation of primary productivity also increased in the same period.

Keywords: primary productivity, chlorophyll concentration, sea surface temperature, reef fish, Bintan, Kepulauan Riau.

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ABBREVIATIONS

BAPPEDA Regional Board for Planning and Development

BNPB National Disaster Management Agency

BPS National Statistics Agency

COREMAP Coral Reef Rehabilitation and Management Program

DKP Marine Affairs and Fisheries Office/Agency

GIS Geographic Information System

GPS Global Positioning System

IDR Indonesian Rupiah

IUU Illegal Unreported and Unregulated

KKP Ministry of Marine Affairs and Fisheries

MKP Minister of Marine Affairs and Fisheries

PP Primary Productivity

RBI Topographic Map

SST Sea Surface Temperature

Chapter 1. Introduction

1.1. Background

The amount of fish that can be produced from water areas have a strong link with the primary productivity of these waters, which are also limited by the abundance of feed in the waters. Phytoplankton depends on the nutrient concentration in the waters, because phytoplankton can only get that benefit from nutrient through photosynthesis which takes place inside the chlorophyll (Nontji, 2007) to provide nutrient and organic material for higher trophic organisms such as fish (De Vooys, 1979). Therefore, chlorophyll also serves as one indicator of aquatic primary productivity, particularly fisheries where waters with high chlorophyll concentrations would be preferred by the schools of fish.

Seafood, such as fish, crab, shrimp, squid, provides an important aquatic source of protein for humans. Yet at global scale fisheries are insistently facing human impact activities, namely population growth, overfishing, climate change, pollution and habitat degradations (Burke et al., 2011; Khemakorn, 2006). Over the past 40 years marine fisheries resources has been reaching Maximum Sustainable Yield (MSY) and about 80 percent of world fishing ground are overexploited (FAO, 2009). In 2014 (the latest report) FAO wrote that this number increased to 90 percent, only 10 percent were not optimally utilized. As world population continues to grow, the need of affordable high-protein intake also increased.

Overfishing or over exploited fishing is in general defined as harvesting the fish resources faster than it naturally replenishes (Gulland, 1983). In principle fishes is a renewable resource that can reproduce naturally, unless its breaking disrupted regeneration rate or reproduction cycles, the more that fish fails to proceed to rejuvenate staging, the higher danger that a species population becomes scarce and can become diminished (Bush, 2000). No fishing regulation, uncontrolled fishing fleets and its catching ability, fishing techniques, and unlimited fishing quota are among the driving factors of this phenomena. (Nasution, 2013).

Overfishing can lead to ecological and economical dangers. For example, in 1992, nearly 40,000 people lost their livelihoods when the cod fishery industry suddenly stopped in Newfoundland, Canada. The disaster caused by the deterioration of the state of aquatic ecosystems resulting absence of cod and after 15 years the fishers still expect the fish back into the water (Koster, 2014). According to Newton, et. al., (2007) coral reef area worldwide is fished in an unsustainable way or even overexploited. Moreover, in the Indo Pacific Ocean and South East Asia region the trading of live reef fish has further contributed to this overexploitation (Newton et al., 2007).

Effective monitoring and management are required to maintain a sustainable use of marine resources, admitting fish and its ecosystem (Brown, et al., 2005). Research vessels, as part of conventional monitoring approach, are limited in time and spatial area coverage of an aquatic environment (Longhurst, 2010; Platt, Sathyendranath, & Fuentes-Yaco, 2007). An alternative monitoring approach involves the use of remote sensing technology to observe marine ecosystem properties (Brown et al., 2005). When ocean colors data released into the public, all the limitations of access to the observation of aquatic ecosystems cover a vast area and the time period can be obtained from satellite imagery data (Platt et al., 2007). The use of satellite-based images also allow for routine and cost effective monitoring of large aquatic environments within a short period of time (Brown, et. al, 2005).

By utilizing satellite imagery and remote sensing technology expert can be estimating chlorophyll concentration, temperature of surface waters as well as environmental factors by predicting the aquatic primary productivity. Thus, in general, it can be estimate if the excess quantity of fish caught is affected by the declining quality of environmental parameters or not.

1.2. Fishery in Kepulauan Riau, Indonesia

Several fisheries management areas (FMA) in Indonesia are presumed to have been overexploited and to experience overfishing (KKP, 2009). This includes, for example, Kepulauan Riau waters which are part of the South China Sea. After 2008 the volume of fish production in this region is gradually decreased to a negative growth of more than 9% (KKP, 2013).

A majority of the fishers is only capable of operating within five miles from the coast (DKP, 2011). It is believed that almost two-third of catch reef fish is not recorded and to be considered as illegal, unreported and unregulated fishing, where the practices of vessel to vessel fish trade are also not marked and not logged. On Bintan Island there are only two public centers for fish landing, which also function as fish market; both are located on the west side of the island fish market of Tanjungpinang and fish landing port in Barek Motor, Bintan (DKP, 2011). However, most of the small fishermen unload their catch in private ports, port that owned by "*Tauke*" or trader/businessperson, who supply all their needs with some interest in return (Dirhamsyah, 2004). Those kinds of port couldn't be effectively monitored by fisheries authority.

Reef fishes are one of the main economic fisheries catch product in Riau Archipelago, especially in Bintan and Tanjungpinang. These species are on the market the whole year, especially for use in restaurants. Reef fish generally live in groups on the reef and not far from the nearby island of about 1 to 3 miles at a depth of 0 to 50 meters (Froese & Pauly, 2014), and have a higher sale value if alive (Mak, Yanase, & Renneberg, 2005).

In Table 1.1 presents commonly reef fishes species for consumption and traded in Bintan and the surrounding area.

Table 1.1. Common species of reef fish with high economic value in Bintan Island (source: DKP, 2011)

No	Common Name	Market name	Species
1	Ekor kuning	*Yellowtail fish*	*Caesio cuning*
2	Lencam	Spangled emperor	*Lethrinus nebulosus*
3	Kakap merah	Mangrove red snapper	*Lutjanus argentimaculatus*
4	Bambangan	Crimson snapper	*Lutjanus erythropterus*
5	Kerapu karang	Sea basses	*Cephalopholis cyanostigma*
6	Baronang	Golden-lined spinefoot	*Siganus lineatus*

1.3. Problem statement

The increasing trade in live reef fish and its economic value are putting pressure on reef fisheries by the increased number of catches (Mak et al., 2005). Unfortunately, the lack of public (and government controlled) fishing ports complicates the recording and monitoring of fishing trends; this is further complicated by the presumed trade of live catch between fishers directly at sea (Detik, 2014). According to Mak et al., (2005) and Lau (2014) Hong Kong is the biggest importer of live marine fish and the largest consumer of reef fish. Groupers (*Serranidae*), wrasses (*Labridae*) and snappers (*Lutjanidae*) are in highest demand on the market. Of the top-ten exporters of live reef fish in Hong Kong, Indonesia contributed almost 45% of the total.

A number of parties have indicated a decline in water quality in the Kepulauan Riau in general and more specifically in Bintan. Various causes are believed to have prompted a decline, among other illegal mining activity, tourism, and litter and increased sediment in the water intrusion. The issue of illegal mining activities has been rising since the mid-2009 where mining activity is directly adjacent to the coastal region of Bintan Island, so the side effects are certainly not small (Adriman et. al., 2012; BatamToday, 2014; HaluanKepri, 2015; Tribunnews, 2010). Bintan is also an icon of maritime tourism destination in the region, the widespread establishment of building hotels and resorts around the coast and even up to 1 km from the beach. Trash on the islands, sometimes is a problem that is not inevitable, especially after a large enough tide to the mainland region. According to Adriman et al., (2012), sedimentation rate in these waters into the category of mild to very severe.

On the other hand alleged occurrence of overexploited reef fish due to the decreased quality and carrying capacity of the marine environment, pollution of the water environment could cause the decline in the carrying capacity of the environment to sustain life in the fish habitat, whether it is caused by pollution from industrial and household waste, excesses of mining which are not environmentally friendly and global climate change (Supriharyono, 2007). Through an analysis of the changes in water parameters; chlorophyll concentration, the temperature of the surface waters and aquatic primary productivity is expected to provide information link between the presences of these parameters with symptoms of overfishing on reef fish species in the study area.

Remote sensing technology allows the analysis of whether there has been a change in the quality of the ocean environment parameters from the time the disaster occurred or even a few years earlier. Because of the remote sensing products can store data on past events with coverage (Butler, et. al., 1998).

1.4. Research Objectives and Questions

The main objectives of this study is to measure the exploitation of reef fisheries in Bintan Island waters and compare with primary productivity of Bintan Island waters, using a remote sensing-based approach. Sub objectives are followed by research question:

a. To map the spatial distribution of sea surface temperature in Bintan island waters from 2005 to 2012.
   - Are there any major differences in dynamic of sea surface temperature distribution during 2005-2012?

b. To map the spatial distribution of chlorophyll concentration as an indicator for fish potential in Bintan island waters from 2005 to 2012.
   - Are there any major differences in the dynamic of chlorophyll concentration distribution during 2005-2012?
   - What kind of relationship exists between SST and chlorophyll concentration distribution in Bintan island waters during 2005-2012?

c. To estimates aquatic primary productivity in Bintan island waters and its relationship with the catch data from 2005 to 2012.
   - What kind of the relationship between primary productivity and chlorophyll concentration?

d. To determine the exploitation level of reef fish based on fish regulation (total allowable catch) and its link with the variety of aquatic primary production in the study area.
   - Is there any relation between exploitation of reef fish with aquatic primary production?
   - What are the alternatives to maintain a sustainable reef fishery?

1.5. Benefit of the Research

The result of this study is expected to give preliminary input towards sustainable reef fisheries, especially in Bintan island waters, based on descriptive analysis on the relationship between primary productivity and the volume trend of production.

Chapter 2. Literature Review

2.1. Primary Productivity

Primary productivity declares as the fixation carbon rate (material, organic synthesis) within the water column that state as gram carbon that can be produced within a time period (Molles, 2002). Moreover, primary productivity is the production of complex organic compounds from the photosynthesis performed by plants using carbon compounds and water molecules in the pigment greener plants, and with the help of sunlight (De Vooys, 1979). Photosynthesis produced an organic complex, which placed inside its green pigment (chlorophyll), is a multi-stakeholder operation that involved carbon dioxide, water molecule and sunlight (Behrenfeld & Falkowski, 1997a; De Vooys, 1979). So phytoplankton plays an important role in photosynthesis, as primary production in the ocean that can only be processed in the chlorophyll, but extreme temperature generally reduce the rate of photosynthesis by plants (Molles, 2002). Mackey et al., (2013) compiled that marine pico-cyanobacteria (the most abundant phytoplankton) able to tolerate sea temperatures up to 30^{0}C, depending on its geographical distribution in the oceans.

Remote sensing technology based on its energy source divided into passive and active remote sensing. Passive sensors detected sunlight reflected from the surface of the earth in the form of solar radiation and thermal radiation, in the form of visible light and infrared, this sensor does not emit energy but catch the reflection of the sun from the earth's surface. In contrast to passive sensors, active sensors emit energy to the earth's surface and then re-record the reflections of objects from earth’s surface (Comiso, 2010; Lillesand, Kiefer, & Chipman, 2004).

Remote sensing technology can also be used to estimate primary productivity in the marine environment using a spatial model of ecological primary productivity. These mathematical models use spatial ecological approach of surface chlorophyll concentrations and phytoplankton biomass in relation to the carbon or nitrogen, as input (Behrenfeld & Falkowski, 1997a, 1997b).

In marine waters, primary productivity is highly dependent on the presence of phytoplankton organisms as a producer and as a primary autotrophs organism that contain chlorophyll pigments. Chlorophyll pigment serves to absorb sunlight as a source of energy for photosynthesis. There are three kinds of chlorophyll in phytoplankton, chlorophyll a, b and c. Chlorophyll a is a pigment that is important in prose photosynthesis in marine phytoplankton (Strickland, 1960). Judging from plant physiological, spectrum light absorbed by phytoplankton in the wave range of 400-700 nm known as a PAR spectrum (Tripathy, Raman, Chauhan, & Ajai, 2014) which is similar to the spectrum of visible light is 360-780 nm. Pigment chlorophyll-a have a high absorbance properties in blue and red channels. While the chlorophyll-a will reflect green channel and near infrared because it does not absorb radiation of electromagnetic waves in this channel. So the waters with high a phytoplankton abundance will look more green than blue (Robinson, 2010).

2.2. Sea Surface Temperature

Sea surface temperature (SST), is one of the important parameters of geophysics in the ocean contains information about the limits that are used to measure the heat flux at the air-sea interface. This information can be used on a global and local scale. On a global scale, this information is used for weather modeling and measuring interaction between atmosphere and ocean and their anomalies (such as ENSO). SST, on a local scale, used to measure the biological productivity, eddies, fronts and upwelling in the ocean (Comiso, 2010).

Satellite technology in measuring SST is far more advanced than the conventional technology using ships and buoys, making it easier for global observations and periodically. Sea surface temperature can be estimated in two ways, namely thermal infrared remote sensing and passive microwave radiometry (Robinson, 2010).

SST from of thermal infrared (TIR) method has the advantage of high resolution and better accuracy and coverage availability is quite long, the drawback of this product is very influenced by atmospheric effects, such as the cloud so that atmospheric corrections need to be applied. Among TIR satellite using current technology are NOAA, Aqua and Terra (with MODIS sensor) and Meteosat. While SST from passive microwave is almost completely free of atmospheric disturbances (cloud-free) and are relatively insensitive to atmospheric effects, shortcomings have low resolution and accuracy and surface roughness and precipitation affected. Application among others on the Aqua satellite (with sensor AMSR-E) and Coriolis (Kuenzer & Dech, 2013; Robinson, 2010).

Traced of light has a strong vertical precedent in the ocean temperature. Unlike in the dark bottom water temperature stand cool, sunlight keeps the surface environment warmed, (Bush, 2000) this happen because the blender and mix of water mass by wind. Sea surface temperature in the shoreline is higher than offshore. The mean temperature in Indonesian surface waters about 28^0 to 31^0C (Nontji, 2007).

Sea surface temperature affects the rate of photosynthesis and distribution of phytoplankton in the water column. The optimal temperature range for the breeding of phytoplankton in the tropics, range 25-32^0C (Kemili & Mutiara, 2012; Nontji, 2007). According to Nybakken, (1992) temperature of sea water is very high in the surface layer will be resulted in mixing of water masses with the underlying layer (down welling) so that phytoplankton also carried over into the water column and the waters become less productive. At the upwelling location, sea surface temperature can go down to 25^0C due to the cold water under elevated to the upper layer (Nontji, 2007).

Water temperature and its variation are the most frequently used environmental indicators to investigate the environment and fish behavior and abundance relationships (Kellogg & Gift, 1983). In marine fisheries potential fishing ground can be predicted by overlaying data on lake surface temperature and chlorophyll concentration in Lake Malawi (Chavula, Sungani, & Gondwe, 2012). Many fish species easily adapted temperature fluctuation as small as 0.1^0C and temperature can impact fish in many different ways, for example, fishes metabolisms will be increased at higher temperatures, but the availability of oxygen decreases as the temperature rises, causing the fish to stress (Helfman, et. al, 2009).

The extreme temperature raised can caused coral bleaching and increasing the coral mortality rate (Cinner et al., 2012) which will lead into declining of the reef fish stocks in the coastal waters. In 1998 the increase in sea surface temperature between 2-30C triggered by the El-Nino phenomenon, has led to extensive coral bleaching from Kepulauan Riau (East Sumatra) to the Kepulauan Seribu (off Jakarta), Bali and Lombok, where nearly 90- 95% of affected coral reefs flat down to depths of 25 m (UNESCO, 2000).

2.3. Chlorophyll-a

The green pigment of plant or chlorophyll not only available in typical plant organisms. In aquatic environment also has plantlike organisms that float as the wave move the water, knows as phytoplankton while zooplankton for an animal like organisms. Phytoplankton, as well as land plant, needs nutrients, carbon dioxide, water and sunlight to life and growth. It is the chlorophyll that catches the sun’s energy for photosynthesis (Sverdrup, Duxburry, & Duxburry, 2006).

Chlorophyll as high plant level divided into chlorophyll-a and chlorophyll-b. The molecule structure and type of light absorb are the main different. Chlorophyll-a chemical compound as $C_{55}H_{72}MgN_4O_5$ and $C_{55}H_{70}MgN_4O_6$ for chlorophyll-b. Blue, violet and red light catch by chlorophyll-a and chlorophyll-b traps blue and orange and reflect yellow-green light (Nybakken, 1992).

The ocean color shows general information on marine environment. The blue water informs short of nutrient availability, limited gross primary productivity and scarcity of the feed source (Bush, 2000). Phytoplankton needed sunlight and nutrient to growth and regeneration. Therefore they need to be remain in the upper layer of the sea surface to get benefit from sun’s energy. Even throughout year tropical regions washed with high-intensity of solar energy, nutrient are limited in the tropical water. Only at the equator, where upwelling nourish the environment continually, giving the high rates of primary productivity (Sverdrup et al., 2006).

The capability of remote satellite to recorded sea surface chlorophyll measurement has allowed the measurement of primary productivity on global scale affordable in time and research grant. It was expensive and took a long time period when using oceanographic and fisheries research fleets (Sverdrup et al., 2006).

The Coastal Zone Color Scanner (CZCS) is the first satellite-borne sensors were created to predict the biological productivity of the ocean waters. Ocean color data provides access to the characteristics of spatial and temporal variability of chlorophyll structure so as to provide a breakthrough in the study of the relationship between the tropic levels in the ocean (Comiso, 2010; IOCCG, 1999).

Based on the geographic distribution of material dissolved and suspended material in the water Morel & Prieur (1977) introduced two approaches remote sensing to measure chlorophyll content as an index of phytoplankton biomass are Case 1 and Case 2 waters. Case 1 waters characterized when watercolor is a real phytoplankton concentration and higher than other particles, usually applied in open waters. In Case 2 waters inorganic particles predominate over the chlorophyll concentration, generally applied in coastal waters with a large runoff inputs and high human activity (Martin, 2014) .

2.4. Overfishing

Fisheries can be divided into small-scale and large-scale or artisanal fishing operations. A small-scale fishery could be typified by an individual's or community's effort to harvest fish using small boats or pulling nets by hand, whereas a large-scale fishery could be a fully mechanized industrial trawler fleet supported by a mother ship (Bush, 2000).

According to SEAFDEC (2001) small-scale or artisanal fisheries is fishery with removable engine < 10 DK or 5 GT and operate in path 1; or boat (with engine) below than 50 DK or 25 GT and operate in path 2. Industrial fishery which has vessel with more than 200 DK or 100 GT and operate in path 3.

Fishers is not the only single player to be condemned for damage in fisheries. Mangroves or wetlands provided shelter for spawning and protection for from predation, as well the habitats supply high nutrients that let the young fish grow rapidly (Bush, 2000). Development of coastal area, deforestation and conversion of mangrove to shrimp-farming ponds has wiped out almost half of this perfect nursery ground and make fish yet vulnerable to overfishing (Adriman et al., 2012; Bush, 2000; Supriharyono, 2007).

Fishery management needs to be changed if its goal is to maintain a sustainable harvest and a balanced ecosystem. Wherever possible, the fishers must be given control over on local fisheries so that these areas may be "owned" rather than treated as "a commons". By monitoring fish populations and landings, warning signals of a future population crash can be seen and action can be taken at an early stage to reduce fishing pressure (Bush, 2000).

2.5. MODIS

Moderate-Resolution Imaging Spectrometer (MODIS) is part of National Aeronautical Space Agency Earth Observing System (NASA EOS) program to observe the earth from outer space. MODIS censor that launch with satellite Terra and Aqua designed to collect and measure physical atmosphere characteristics also land and ocean characteristics. MODIS designed to record data continuously as it successor AVHRR NOAA with a better sensor and technology such spatial resolution, radiometric sensibility, geometric rectification, and more accurate radiometric calibration (Danoedoro, 2002).

Table 2.1. Details information in each band of MODIS sensor (after Mather, 2004; Aronoff, 2005; Jensen, 2007 in Danoedoro, 2002)

Band	Bandwidth (μm)	Spatial Resolution	Primary Use
1	0,620 – 0,670	250 x 250 m	Land cover classification, chlorophyll absorption detection, mapping of leaf area index (LAI)
2	0,841 – 0,876		
3	0,459 – 0,479	500 x 500 m	Land, cloud and aerosol related study
4	0,545 – 0,565		
5	1,230 – 1,250		
6	1,628 – 1,652		
7	2,105 – 2,155		
8	0,405 – 0,420	1 x 1 km	Ocean color, phytoplankton and biogeochemistry study
9	0,438 – 0,448		
10	0,483 – 0,493		
11	0,526 – 0,536		
12	0,546 – 0,556		
13	0,662 – 0,672		
14	0,673 – 0,683		
15	0,743 – 0.753		
16	0,862 – 0,877		
17	0,890 – 0,920	1 x 1 km	Water gas in atmosphere study
18	0,931 – 0,941		
19	0,915 – 0,965		
20	3,600 – 3,840	1 x 1 km	Land surface temperature and cloud surface
21	3.929 – 3,989		
22	3,929 – 3,989		
23	4,020 – 4,080		
24	4,433 – 4,498	1 x 1 km	Atmosphere temperature measurement
25	4,482 – 4,549		
26	1,360 – 1,390	1 x 1 km	Cirrus cloud study
27	6,535 – 6,895	1 x 1 km	Water gas study
28	7,715 – 7,475		
29	8,400 -8,700		
30	9,580 – 9,880	1 x 1 km	Ozone study
31	10,780 – 11,280	1 x 1km	Land surface temperature and cloud surface measurement
32	11,770 – 12,270		
33	13,185 – 13,485	1 x 1 km	Study on top of cloud characteristic
34	13,485 – 13,785		
35	12,785 – 13,085		
36	14,085 – 14,385		

To study the biological characteristics of the ocean, from table 2.1 informs that the channel with the ability to recognize these characteristics is the band 8 (405 – 420 nm) until band 16 (862 – 877 nm). Common information could be intercepted is associated with ocean color, chlorophyll waters, phytoplankton and ocean biogeochemical. Various levels of MODIS products which are available to date are presented in Table 2.2.

Table 2.2. MODIS product level specification (source: NASA Ocean Color web, at http://oceancolor.gsfc.nasa.gov)

Product Level	Spatial Resolution (m)	Description
0	250 , 500, 1000	Raw format data, unprocessed instrument/payload data at full resolution, no geocorrection
1A	250, 500, 1001	Radiance data and georeferencing parameter, no geocorrection
1B	250, 500, 1001	Radiance data and georeferencing parameter (Level 1A data) with calibrations applied
2	1000	Data consist of derived geophysical variables with calibration and atmosphere correction applied
3	4630, 9000	Aggregated/projected geophysical variables (Level 2) spatially and temporarily, georeferencing applied
4	9000	model output or results from analyses of lower level data, for example ocean primary productivity (http://www.science.oregonstate.edu/ocean.productivity/)

Products Ocean Color Level 3 SMI is generated image of the binned data product and derived from SeaWiFS, MODIS, or OCTS. This product has a two-dimensional image with an Equidistant Cylindrical projection or also known as the Plate Carre. Products Ocean Color Level 3 SMI presented in a composite image based on the time for example daily, 3 days, 8 days, monthly, and seasonal, with spatial resolution 4 km and 9 km (Ocean Biology Processing Group, 2003).

In connection with the sea surface temperature measurements, MODIS using five spectral bands in the infrared atmospheric window, band 31 and band

32. These bands correspond roughly with the band AVHRR channels 4, 5 and 20. In addition MODIS also has two additional, band 22 and 23, narrow band in the mid- infrared window. Band in mid infrared window is generally cleaner than the thermal infrared, but measurements of short wave susceptible to solar radiation reflected from the sea surface. A number of researchers have been through a series of tests, atmospheric testing algorithm with different coefficients on the algorithm, as well as compared and validated the model results with measured data of highly accurate ship-based infrared radiometers and buoys data, and at last they managed to extract the value of sea surface temperature that is useful to a wide range of research and operational applications (Minnett et al., 2004).

A large number of researchers and scientists have contributed greatly to the research and development of algorithms that are used to obtain the value of chlorophyll concentration from satellite imagery. O’Reilly et al., in 1998 informs the released of ocean chlorophyll 2 encryption (OC2), which is derived from the modified cubic polynomial (MCP) function that uses Rrs490/Rrs55, as the operational logarithm for chlorophyll-a concentration. This algorithm was developed from the ocean chlorophyll 4 algorithm (OC4) based on four bands, band 9 to 12 (443, 490, 510, 555 nm). The NASA Ocean Biology Processing Group as the authorities in the development of chlorophyll algorithm and ocean color satellite imagery, manages a local repository of in-situ marine data bio-optical to be used in the development of bio-optical algorithms on a large scale for the coincident radiometric observations and chlorophyll concentration, known as NASA bio-Optical Marine Algorithm Data (NOMAD) and available to the public. This data includes more than 3400 stations in the form of spectral water - leaving radiances, surface irradiance, and down-welling diffuse attenuation coefficients, and a large range of chlorophyll a concentration (Werdell & Bailey, 2005).

2.6. Remote Sensing

Remote sensing ordinarily differentiated corresponding to their spatial, temporal, and spectral resolution (Campbell, 2007). The spatial resolution determines the pixel value of the satellite image, and the oftenest returning to a certain of earth’s surface determines the temporal resolution. In the last two decades, many papers have been highlighted remote sensing as the fast, reliable and cost effective tools for fisheries management and monitoring.

Remote sensing technology based on its energy source/sensor function divided into passive and active remote sensing (as illustrated in figure 2.1.). Passive sensors detected sunlight reflected from the surface of the earth in the form of solar radiation and thermal radiation, as visible light and infrared, this sensor does not emit energy but catch the reflection of the sun from the earth's surface. In contrast to passive sensors, active sensors emit energy to the earth's surface and then re-record the reflections of objects from earth’s surface (Comiso, 2010; Lillesand et al., 2004).

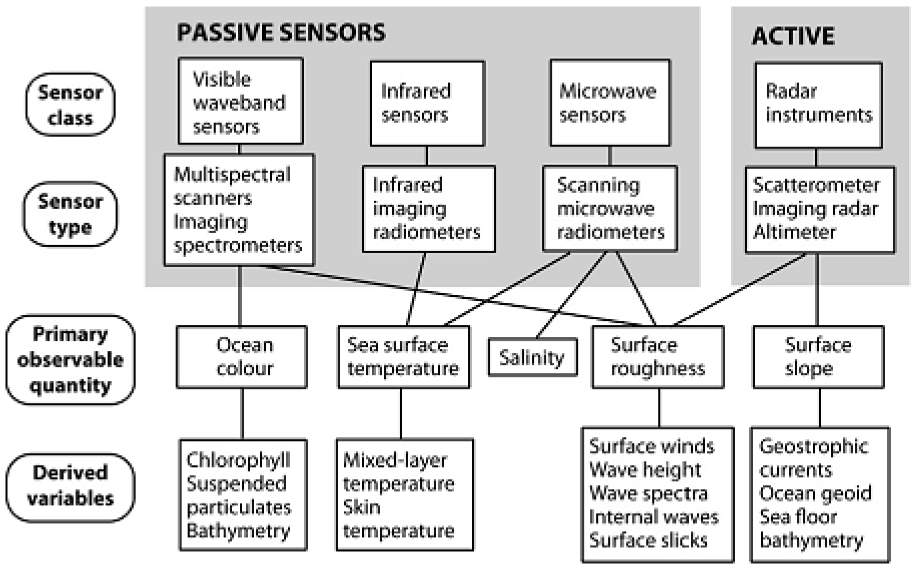


Figure 2.1. Different remote sensing methods and sensors used in satellite oceanography (from Robinson, 2010)

The specific marine ecosystem parameters most commonly measured by remote sensing technique include; sea surface temperature, ocean color (chlorophyll concentration), salinity, up-welling (vertical and horizontal circulation), oil pollution, winds and sea state. Information about these environmental indicators helps to predict mobile fish schools, distribution and behavior (Chen, Lee, & Tzeng, 2005). Remote sensing of ocean color and temperature has enable the global monitoring and management advantage (Butler et al., 1998). Distribution of marine's chlorophyll and sea surface temperatures of satellite imagery interpretation have been used to define regions or aquatic provinces on similar biological and physical characteristics (Oliver & Irwin, 2008). Brown, et al., (2005) defined ocean color as:

> "*the spectrum of water-leaving radiance (L_w) or reflectance ($\rho=\pi L_w/F_o \cos \theta_o$, where F_o is the extraterrestrial and θ_o is the solar zenith angle exiting the water column*."

All bio-optical measures of interest, like chlorophyll concentration, are inferred from these values. Ocean color reflections are produced by valuating the radiances of dissimilar visible wavelengths at the sensing element, processing and converting into significant geophysical parameters, such as chlorophyll and suspended sediment concentration (Brown, et al., 2005).

The concentration of chlorophyll pigments, which are the photosynthetic pigment of phytoplankton, is frequently conceived an index of biological productivity. Chlorophyll concentration over 0.2 mg/cm^3 is showing the front of adequate planktonic activity to sustain a viable commercial fish (Butler et al., 1998).

Factors that affect the rate of photosynthesis process will also affect the primary production are sunlight, temperature, nutrient and water environment quality factors such as turbidity, salinity (Falkowski & Raven, 2007; Steeman Nielsen, 1975). Sunlight, will undergo attenuation with increasing water depth as reflected, and absorbed at a certain depth in the water (Barale & Schlittenhardt, 1993). Nutrients are also an important factor affecting the primary productivity, especially for the growth of phytoplankton (Fasham & Ducklow, 2003). The existence of nutrients in waters affected by currents and upwelling, which flows upward movement which brings regeneration of nutrients into the surface layer, resulting in increased fertility waters in these locations (Feldman, 1986).

Primary production is one of the vital chain in global carbon cycle, it is basically provided organism in the form of organic substance as nutrient sources (Odum, 1971). Measurements of primary productivity on a global scale had limited by financial budget, time tighten, and less-information on ocean dynamic globally, which rapidly changes due to presence of tidal, heat up, salinity and sediment concentration (Tomczak & Godfrey, 2001) but using remote sensing it's become possible (Klemas, 2013).

Behrenfeld & Falkowski (1997a) has developed a *Vertically Generalized Production Model* (VGPM) as the standard logarithm in measuring primary production in certain locations. It was developed based on measurement of sea surface chlorophyll concentration with organized approach and advances in forecasting the productivity (Behrenfeld & Falkowski, 1997a). The VGPM model defines as:

$$PP = 0.66125 x P^{B}_{opt} x \frac{E_0}{E_0 + 4.1} x Chl_a x Z_{eu} x D_{irr} \quad \ldots\ldots (1)$$

with input parameter as follow (Nor et al., 2013):

Table 2.3. VGPM Input Parameter

Input parameters	**Symbol**	**Units**
Chlorophyll concentration	*Chl-a*	mg/m^3
Sea surface daily PAR (solar irradiance)	E_0 *(PAR)*	Enstein/m^2/day
Euphotic depth	Z_{eu}	Meter
Optimal carbon fixation rate	P^{B}_{opt}	mgC/mg Chl/ h
Photoperiod (day length)	D_{irr}	Decimal hours

Chlorophyll concentration and PAR are derived from the MODIS standard product, whereas euphotic depth also from MODIS product from diffused attenuation coefficient (Kd) as given expression:

$$Z_{eu} = \frac{4.65}{Kd} \quad \text{….. (2)}$$

The optical carbon fixation rate can't directly extracting from MODIS sea surface temperature product, in this study the correlation of temperature-dependent with other environment variable are used to define the P^B_{opt} value with a certain condition as follows:

$$P^B_{opt}\begin{cases} 1.13, if T < -1.0 \\ 4.00, if T > 28.5 \\ P^B_{opt}, otherwise \end{cases} \quad \text{….. (3)}$$

From expression (3) value of optical carbon fixation rate equal to 4 if the temperature higher than 28,5^oC and 1,13 if less than -1^oC. For the temperature between this interval , determine using seven polynomial equations (Behrenfeld & Falkowski, 1997b) which estimated from temperature-dependent relationship, with T as sea surface temperature, as given expression:

$$P^B_{opt} = 1{,}2956 + 2{,}749xT + 6{,}17x10^{-2}T^2 – 2{,}0462x10^{-2}T^3 + 2{,}462x10^{-3}T^4 – 1.348x10^{-2}T^5 + 3{,}4132x10^{-6}T^6 – 3{,}27x10^{-8}T^7 \quad \text{….. (4)}$$

Chapter 3. Research Methodology

3.1. Study Area

Bintan Island geographically is located between 0°40'00" North Latitude - 1°15'00" North Latitude, and 104°10'00" East Longitude on the West to 104°50'00" East Longitude in the East, it has an area about 4.800 km^2, about 1.250 km^2 land and 3.550 km^2 seas.

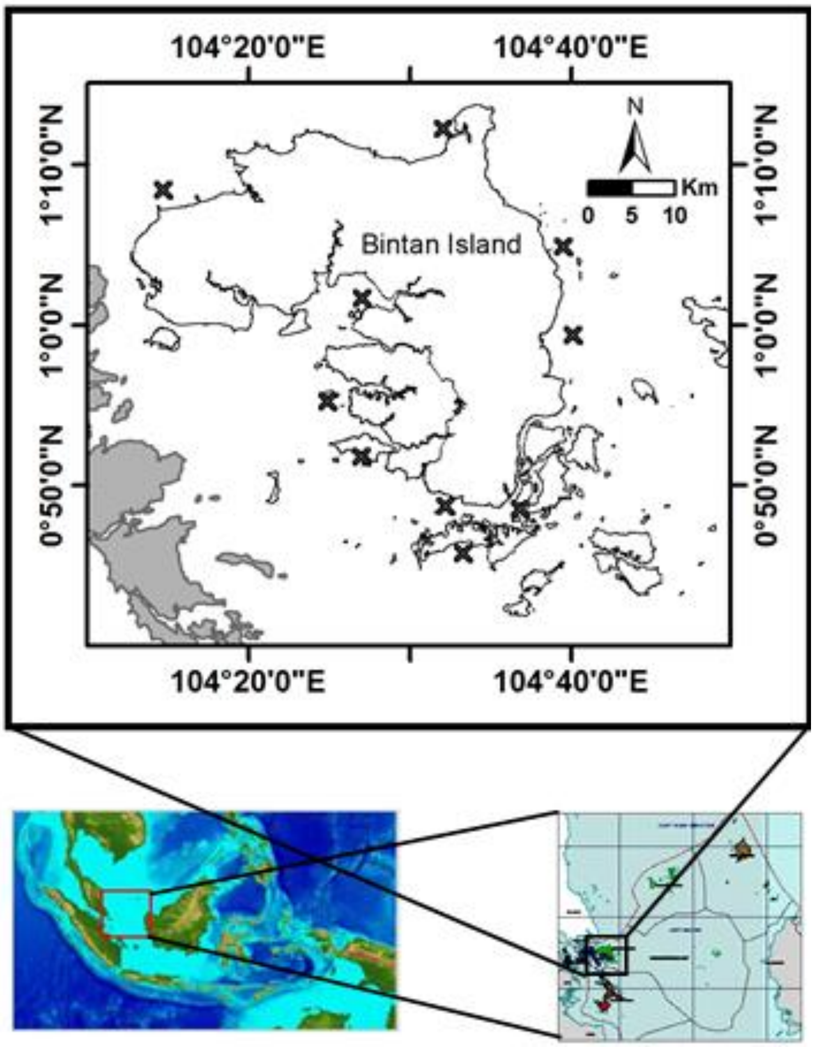


Figure 3.1. Location of study area, Bintan Island waters, Province of Kepulauan Riau (source: Government of Kepulauan Riau)

In the northbound by Natuna sea, Lingga regency in the South. Batam and Tanjungpinang municipality in the west and Tambelan Island in the eastern border. As the archipelago area marines and fisheries sub sector has become a new economic awakening to speed up the economic growth. Bintan Island occupied by Bintan regency and Tanjungpinang municipality.

Oceanography Characteristics of Bintan Islands Waters

Bintan Island, geographically, surrounding by high valuable coastal ecosystem, namely mangrove forest ecosystem, coral reef ecosystem and sea grass ecosystem. As the un-integrated path of local development, especially in coastal and marine resources will give impact if the environmental condition decreased. Any effort to reduce the risk pollutant in are significant considering the ecosystem that vulnerable from environmental pollution (Pranowo & Husrin, 2003).

Coral Reef Management and Rehabilitation Project phase II (COREMAP II) has initiated marine area conservation in Bintan waters with hope to keep the coral reef protected and growing gradually along 35 km in east part of Bintan Island. Kinds of coral reef are located in Malang Rapat village to Kijang village, approximately 100 to 1000 m width. Total coverage area by coral reef, including Mapur Island and small islands about 6.066 ha (CRITC-COREMAP-II, 2007).

Within three years monitoring, between 2007 and 2009, on coral reef ecosystem COREMAP-II-LIPI (2009) reported that there is an increased in the number of fish in same species but the kind of species that have been found are decreasing over time. In general the condition of environment in Bintan waters relatively suitable for coral reef and other marine life.

3.2. Material

Materials needed for this research consist of Aqua MODIS image, statistics of fisheries, in situ data from the field, spatial planning from local government (Bintan and Tanjungpinang Districts, and reef monitoring report on the study area. The table 3.1 shows the required material in this research.

Table 3.1. Satellite images, maps and data used in the study

No.	Data	Data Sources
1	Aqua MODIS Sea Surface Temperature 11 μ daytime from 2005 to 2012 (level 3 SMI, 4 km spatial resolution, monthly basis)	Downloaded from http://oceancolor.gsfc.nasa.gov/cgi/l3
2	Aqua MODIS Chlorophyll Concentration from 2005 to 2012 (level 3 SMI, 4 km spatial resolution, monthly basis)	Downloaded from http://oceancolor.gsfc.nasa.gov/cgi/l3
3	Aqua MODIS Sea surface temperature from 2005 to 2012 (level 3 SMI, 4 km spatial resolution, monthly basis)	Downloaded from http://oceancolor.gsfc.nasa.gov/cgi/l3
4	Aqua MODIS Photosynthetically available radiation from 2005 to 2012 (level 3 SMI, 4 km spatial resolution, monthly basis)	Downloaded from http://oceancolor.gsfc.nasa.gov/cgi/l3
5	Aqua MODIS Diffused attenuation coefficient (KD 490) from 2005 to 2012 (monthly level 3 SMI, 4 km spatial resolution)	Downloaded from http://oceancolor.gsfc.nasa.gov/cgi/l3
6	Fisheries statistic on catch number and fishing facilities in Bintan Island	Ministry of Marine Affair and Fisheries, Marine Affairs and Fisheries Agency
7	Spatial planning of Bintan and Tanjungpinang Districts, related with fishing area development	BAPPEDA Bintan and Tanjungpinang
8	Rupabumi Indonesia Map, scale 1:50000	BAPPEDA Bintan and Tanjungpinang

3.3. Equipment and Software

A set of equipment and software are used in this research to analysis satellite imagery and field data from in situ measurement. The table 3.2 shows the required equipment and software for detail.

Table 3.2. Equipment and software needed in this research

No.	Equipment and Software	Utility
1	Notebook (Microsoft Windows 8 and MS- Office Professional 2013)	Image acquisition, image processing device and preparing report
2	Environment for Visualizing Images (ENVI) 4.5	Image processing tools
3	ArcGIS 10.2	Map analysis, processing and final result
4	Laboratory Pigment analysis with spectrophotometric determination of chlorophylls (for details see Appendix 3)	Estimates in situ water sample for chlorophyll concentration and sea surface temperature

3.4. Methods

The methods in this research were divided into six steps as follows. In brief flowchart of this research illustrates in Figure 3.2.

3.4.1. Image Preprocessing

3.4.1.1. Image cropping

Aqua MODIS level 3 SMI products cover the entire surface of the earth/ global scale so that needs to be done cutting research based position location specified latitude, longitude is $0^0$40'00" North - $1^0$15'00" North, and $104^0$10'00" to $104^0$50'00" East Longitude. Since the original product applied geographical projection, the cropping process will be easier. Aqua MODIS level 3 SMI Products which has been cropping then stored in a standard format image processing application, ASCII format or ERDAS Imagine. To facilitate subsequent image processing is recommended to be stored in a standard format.

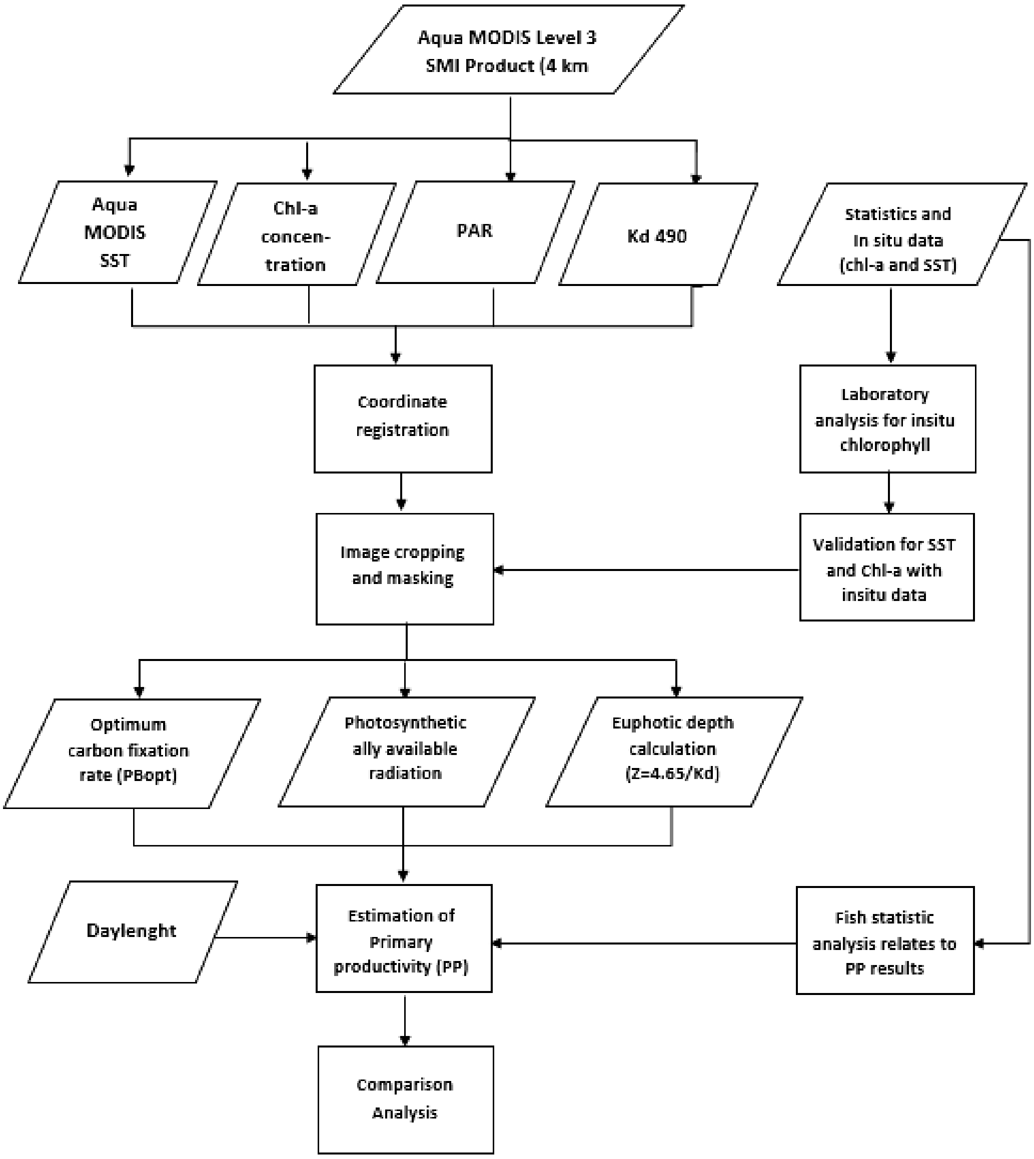
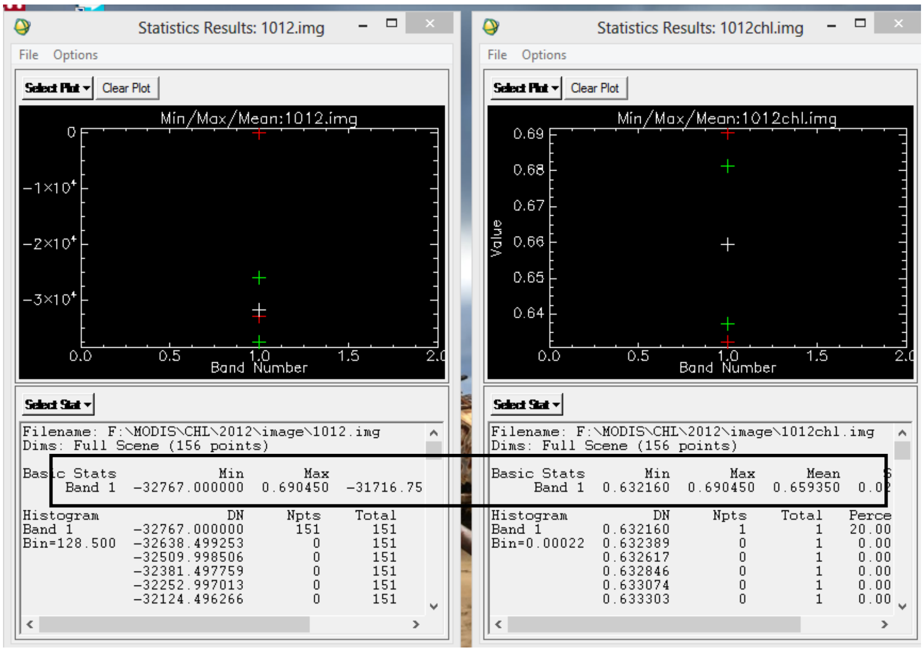


Figure 3.2. Flowchart of research methodology

3.4.1.2. Image masking

An image that has been cropped to the boundary of study area proceed to image masking stage. The objectives in to adjust the central tendency values which outside the normal range (-32767) of Aqua MODIS products. This processes should be applied to chlorophyll concentration, photosynthetically available radiation, and diffused attenuation coefficients. Masking result, with adjusted values shown in Figure 3.3.



(a) (b)

Figure 3.3. Tendency central information of chlorophyll concentration image, before (a) and after masking applied (b). (Source: Image processing, 2015)

3.4.2. Image Processing

3.4.2.1. Image processing for sea surface temperature

Image Aqua MODIS sea surface temperature can be directly processed after the cut to the boundary area of research, where the value of its central tendency is representative of sea surface temperature that has been captured by the MODIS sensor. The tendency central information used to highlight then maximum-minimum and mean value of the image in Celsius degree. The value of the central tendency of these products as in the Figure 3.4.

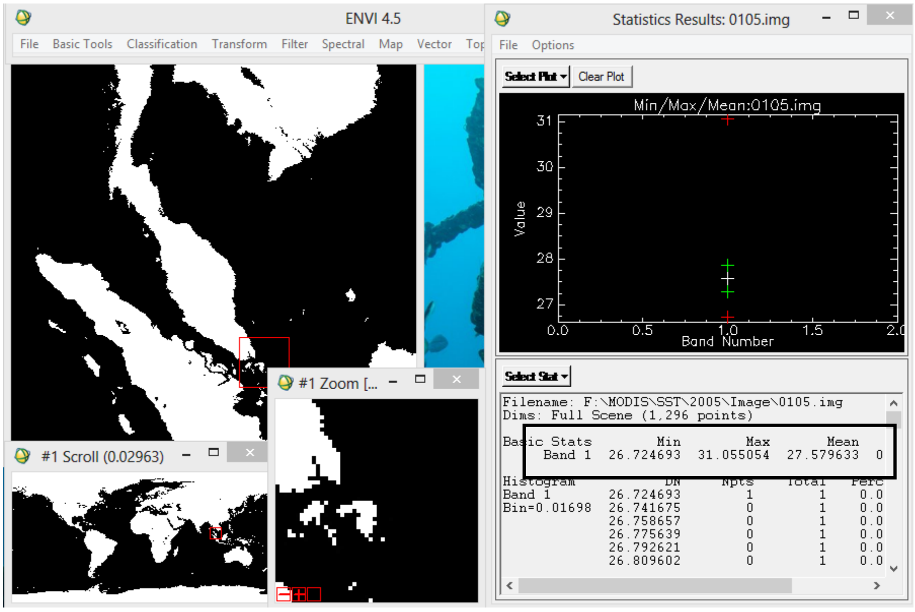


Figure 3.4. Tendency central information of sea surface temperature image (source: Image processing, 2015)

3.4.2.2. Image processing for optimum fixation carbon rate

Aqua MODIS sea surface temperature image is also used to obtain value of the optimum carbon fixation rate ($P^B{}_{opt}$) through seventh polynomial equation from Behrenfeld & Falkowski (1997b) with condition as follows:

$$P^B_{opt} \begin{cases} 1.13, if T < -1.0 \\ 4.00, if T > 28.5 \\ P^B_{opt}\ 'otherwise \end{cases}$$

For temperature between -1^{0}C and 28,5^{0}C will estimates using seventh polynomial equation as given by:

$$P^B{}_{opt} = 1{,}2956 + 2{,}749xT + 6{,}17x10^{-2}T^2 – 2{,}0462x10^{-2}T^3 + 2{,}462x10^{-3}T^4 – 1.348x10^{-2}T^5 + 3{,}4132x10^{-6}T^6 – 3{,}27x10^{-8}T^7$$

3.4.2.3. Image processing for euphotic depth

Euphotic depth is a pelagic waters that still getting sunlight. The lower limit of this zone depends on the depth limit translucent, and usually varies according to the level of water clarity. Generally, the lower limit of the photic zone is located at a depth of 100-150 meters. Another term for photic zone is the zone epipelagic (Nontji, 2007; Nybakken, 1992).

According to Behrenfeld & Falkowski (1997a) euphotic depth can be directly derived from Diffused attenuation coefficient (Kd 490) product with the given expression:

$$Z_{eu} = 4{,}65/Kd$$

3.4.2.4. Image processing for primary productivity model

Subsequent processing steps performed to estimate the value of primary productivity in the study area per unit area per unit time by applying the Vertical Generalized Production Model or VGPM, which is developed by Behrenfeld & Falkowski, (1997b), by the use value of chlorophyll concentration on the sea surface to determine the monthly primary production. This model requires five input variables which are optimum carbon fixation rate within a water column (P^B_{opt}), monthly average solar irradiance (E_o), chlorophyll concentration (Chl_a), euphotic depth (Z_{eu}) and photoperiod/day length (D_{irr}), with expression as follows:

$$PP = 0.66125 x P^B_{opt} x \frac{E_0}{E_0 + 4.1} x Chl_a x Z_{eu} x D_{irr}$$

PP: Primary production (gr C/m^2/day)
P^B_{opt}: Optimal carbon fixation rate (mgC/(mg Chl)/h)
E_o: Sea surface daily PAR (enstein/m^2/day)
Z_{eu}: Euphotic depth (meter)
Chl_a: Chlorophyll concentration (mg/m^3)
D_{irr}: Photoperiod/day length (decimal hours)

3.4.3. Image based data validation

After the result of sea surface temperature and chlorophyll concentration image based available, this data need to test its validation with the in situ measurement of both same parameters (see figure 4.1). The goal of this test is to measure the validity level of image based data giving the both parameter information. Validation test using Root-Mean-Square Error tools (RMS Error), basically RMSE represents the standard deviation difference between sampling values and controlled values.

The standard RMSE equation as follow:

$$RMSE = \sqrt{\frac{\sum (z_i - z_j)^2}{n}}$$

Where z_i is image based data, z_j is in situ measurement data, and n represents number of data.

Second validation using r^2 (r squared) based on simple Pearson Correlation Analysis (Walford, 2011) given by:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{\{n\sum x^2 - (\sum x)^2\}\{n\sum y^2 - (\sum y)^2\}}}$$

R-squared indicates how close the data is attached to the regression line, also known as the coefficient of determination. R2 value is always between 0 and 1, where a value of 0 indicates no relationship variables were tested and the value of 1 means that there is a relationship between variables (Frost, 2013).

The use of statistical tests RMSE and correlation coefficient in the validation test on the data of sea surface temperature (Kim et al., 2010; Lee et al., 2005) and chlorophyll concentrations (Santamaria-del-Angel, et. al, 2011; Sebastia, et. al, 2012) with in situ data has been applied, so theoretically it is possible.

3.4.4. Mapping spatial distribution of sea surface temperature and chlorophyll concentration

ArcGIS application will be used to map Aqua MODIS imagery that has been applied preprocessing and processing steps. Spatial distribution map will be applied to all image related such sea surface temperature, chlorophyll concentration, primary production product image as much as need it to explain and support result analysis and discussion part.

In general, the result map and image will be analyzed using descriptive quantitative analysis to explain variation in distribution, how the differences and similarities of variable (Walford, 2011) during the study period frame.

3.4.5. Determination of reef fishes exploitation rate

To determine the level of reef fishes exploitation based on volume catch number referred to Ministry of Fisheries and Marine Affairs Bill Number KEP.45/MEN/2011 about Estimated Fish Resources In The Management Fisheries Of The Republic Of Indonesia (MKP, 2011) and The Potential Spread of Marine Fish Resources in Indonesian waters (Komnaskajiskan, 1998). The

3.4.6. Correlation analysis between sea surface temperature and chlorophyll concentration

Correlation analysis aimed to measure how strong the relation between two variables and also can express the quantitative relation of both variables. Sea surface temperature and chlorophyll concentration image based data analysis will cover correlation of monthly basis of both variables from 2005 to 2012.

Even though, many researchers and scientist has been stated that there is no significant direct effect of sea surface temperature of organic production on the marine environment (Eppley, 1972) but still need to perform in order to get the general information of both variable in the study area.

3.4.7. Correlation analysis between primary productivity and chlorophyll concentration

Correlation analysis between primary productivity and chlorophyll concentration is aimed to calculate the functional relationship between primary productivity and chlorophyll concentration. The coefficient correlation will show how strong the relation between two variables and also as a quantitative measurement indicator between both variables. If the coefficient (r^2) equal to 0, there is no relation at all, if closed in 1 the relation is strong.

3.4.8. Correlation Analysis Between Primary Productivity and Fisheries Statistics

Correlation analysis between primary productivity and fisheries statistics is aiming to measure the functional relationship between primary productivity and fisheries statistics of reef fish catch record. The coefficient correlation will show how strong the relation between two variables and also as a quantitative measurement indicator between both variables. If r^2 equal to 0, there is no relation at all, if closed in 1 the relation is exist.

Fisheries statistic data were quarterly basis, which informs the total production of landing fish for three consecutive months from 2010 to 2012. In order to make a feasible correlation with primary production this quarterly data can only use as mean of those months.

3.4.9. Laboratory Analysis

Sample of sea water was collected from ten stations surrounding Bintan Island that has been chosen purposively based on common fishing ground by the local fishers. About one to five liter of water sample was filtered using plankton net size 47 μm and kept in a dark tube and place inside cooler box during the sampling periods. As soon as sample arrived in the laboratory it will be applied treatment to filter the chlorophyll concentration from the sample (Strickland & Parsons, 1972), for detail steps as stated in Appendix 4.

3.5. Data Collections and Preparations

The sample of sea water and sea surface temperature were collected from ten purposively selected stations which is based on common fishing ground. The sea surface temperature recorded directly in the station with three time measurement for validation. Figure 4.4 shown sampling stations within the study area.

Sample of sea water was collected using plankton net (size 47 μm) then kept in a dark tube and place inside cooler box during travel back to laboratory for filtering treatment. The box was equipped with dried ice to stabilize the sample temperature.

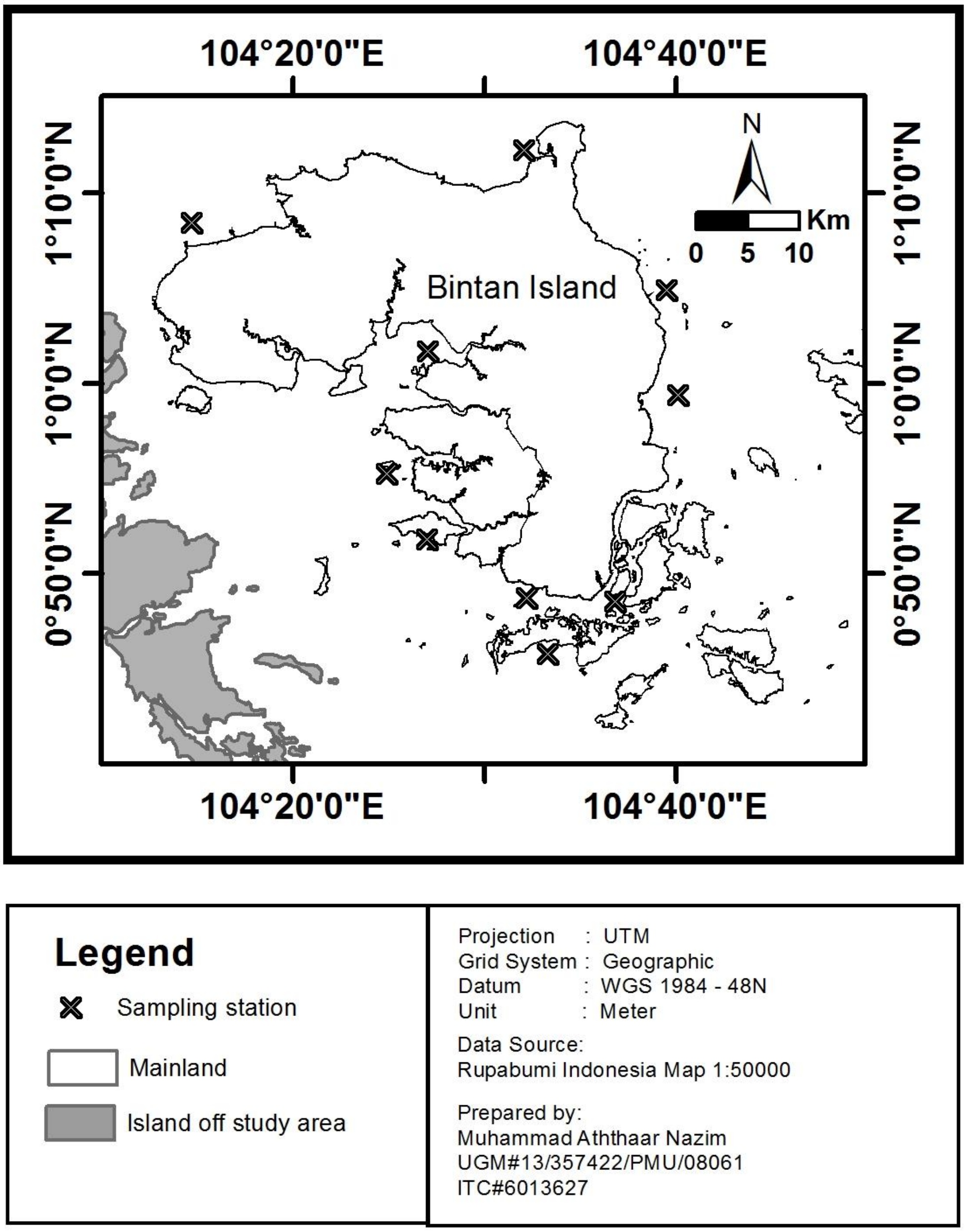


Figure 3.5. Distribution of sampling station in the study area.

Chapter 4. Results

4.1. Input parameters

All parameters for ocean primary productivity calculation derived from the NASA's Ocean Color Website (http://oceancolor.gsfc.nasa.gov/) as monthly basis as Aqua MODIS level 3 image with 4 km resolution, except for photoperiod. A primary productivity model based on Behrenfeld & Falkowski (1997a) expressed as:

$$PP = 0.66125 x P^B_{opt} x \frac{E_0}{E_0 + 4.1} x Chl_a x Z_{eu} x D_{irr}$$

Table 4.1. Input parameters and source of data for VGPM model

Parameters	Symbol	Units	Source
Optimal carbon fixation rate	$P^B{}_{opt}$	mg C/mg Chl/h	Estimated from MODIS sea surface temperature
Sea surface daily PAR	E_o *PAR*	Enstein/m^2/day	Derived directly from MODIS
Chlorophyll-a concentration	Chl_a	mg/m^3	Derived directly from MODIS
Euphotic depth	Z_{eu}	meter	Derived directly from MODIS
Day length	D_{irr}	decimal hours	Calculated from JGiesen web http://www.jgiesen.de

In general there are two kinds of pre-processing steps that will be applied to MODIS image level 3 to extract the values of each parameters. The MODIS image divided into two types based on its value; (i) image with a NaN value like SST and estimation of PP, and (ii) image with minus range value like (-27636), these includes chl-a, Kd, Z_{eu} and PAR.

The first image with NaN value will be masked to be given a value that will be needed to get the monthly and annual mean of SST and PP. The second one to mask abnormal value (-32767) with zero (0). This step will help to quantify image statistic data (central tendency) and also in image processing step.

4.1.1. Chlorophyll concentration

These satellite images according to Comiso (2010) provide information and distribution of chlorophyll concentration in water. The Aqua MODIS image of chlorophyll concentration level 3 SMI needs to be extracted before further processing. The georeferenced Aqua MODIS image will be performed masking, for the pixels outside the normal range as -32767, with zero (0). In order to obtained the value of central tendency zero (0) is converted to NaN that will avoid the effect of zero on image statistic calculation.

Image that covers the entire surface of the earth was cropped to focus on research areas with coordinate $0^{0}40'$ - $1^{0}50'$ N and $104^{0}10'$ - $104^{0}50'$ E. For further processed image is stored in a standard ENVI format and it was applied to all 96 images. Central tendency values are then transferred into a spreadsheet format so that the variation of concentration changes that occurred in eight years easily recognized and displayed in the form of a time series graph.

Figure 4.1 informs concentration of chlorophyll-a (chl-a), as mean calculated, from 2005 to 2012 varies from 0,4 to 3,4 mg/m^3. The highest chl-a concentration 3,4 and 2,6 mg/m^3 recorded on June 2012 and July 2012 respectively during dry season. In general lowest chl-a concentration exist between September-October (wet season) and February-March (dry season). Chl-a recorded in February 2009 and March 2012 at 0,4 mg/m^3. Of the entire image is processed, there are three monthly images that do not contain chlorophyll values at all that is in September 2006, December 2010 and December 2012.

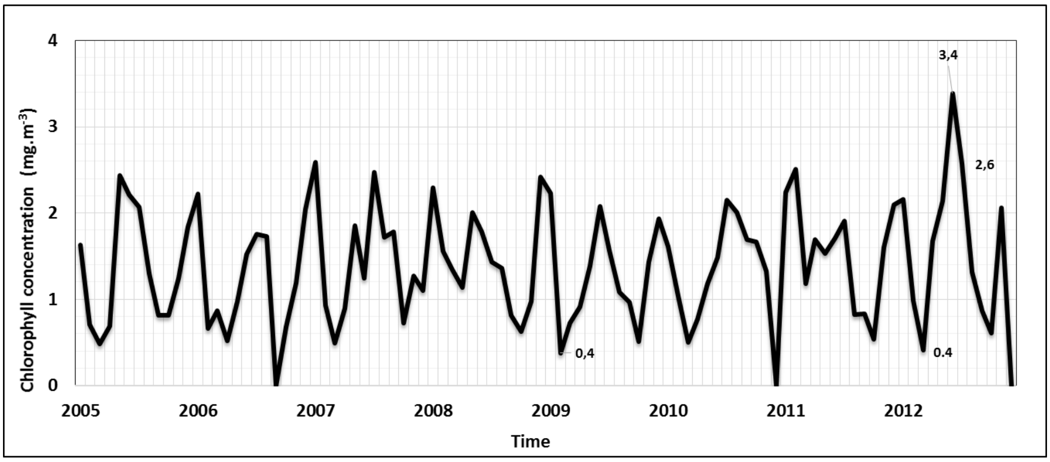


Figure 4.1. MODIS time series chlorophyll concentration variation from 2005 to 2012 (Source: Data analysis, 2015)

In general within eight years concentration of chlorophyll risen up at the beginning of the dry season and slowing down when entering rainy season. Compare to the average level (1,4 mg/m^3) in January, May, June, July and December recorded the highest number every years where as 8, 5, 7, 8 and 5 times respectively, where the culmination point recorded in December to January. These indicates that in general highest productivity in Bintan waters appears two periodes from December to January and May to July during the study periods (figure 4.4).

The lowest and the highest chlorophyll concentration found in March dan June 2012 respectively. The highest concentration in June 2012 between 0,9 to 9,8 mg/m^3. In June 2012 recorded chlorophyll distributed around the island. Generally, the neritic zone shows higher concentration from the oceanic zone as the nutrient that flows from inland and used by phytoplankton in photosynthesis. February 2009 was the lowest concentration of chlorophyll in study area within the range 0,3 to 0,5 mg/m^3. Apparently in the study area only a small part of north east recorded the concentration. Figure 4.2 and 4.3 illustrates these spatial distribution respectively.

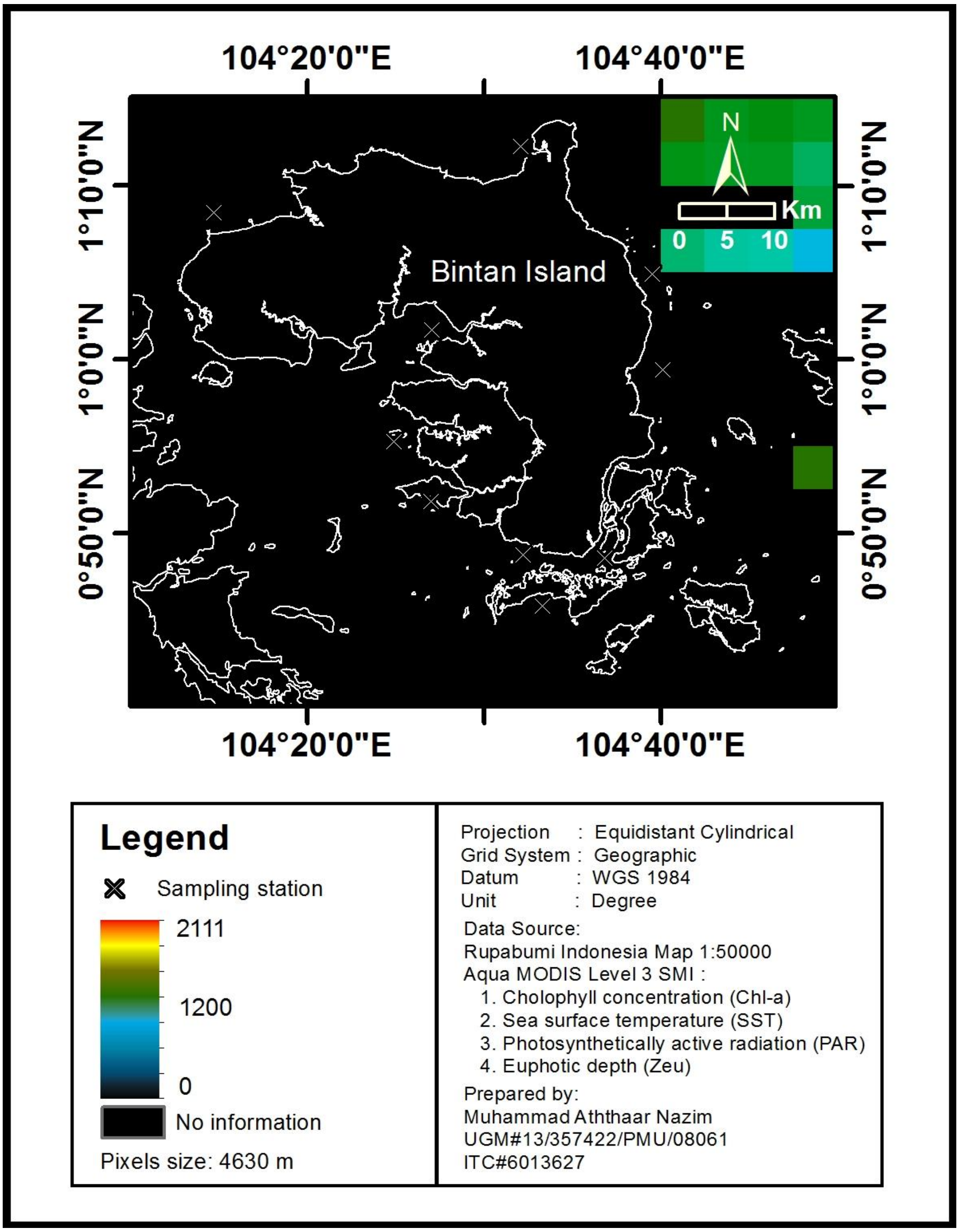


Figure 4.2. Spatial distribution of the highest chlorophyll concentration in June 2012 (Source: Image processing, 2015).

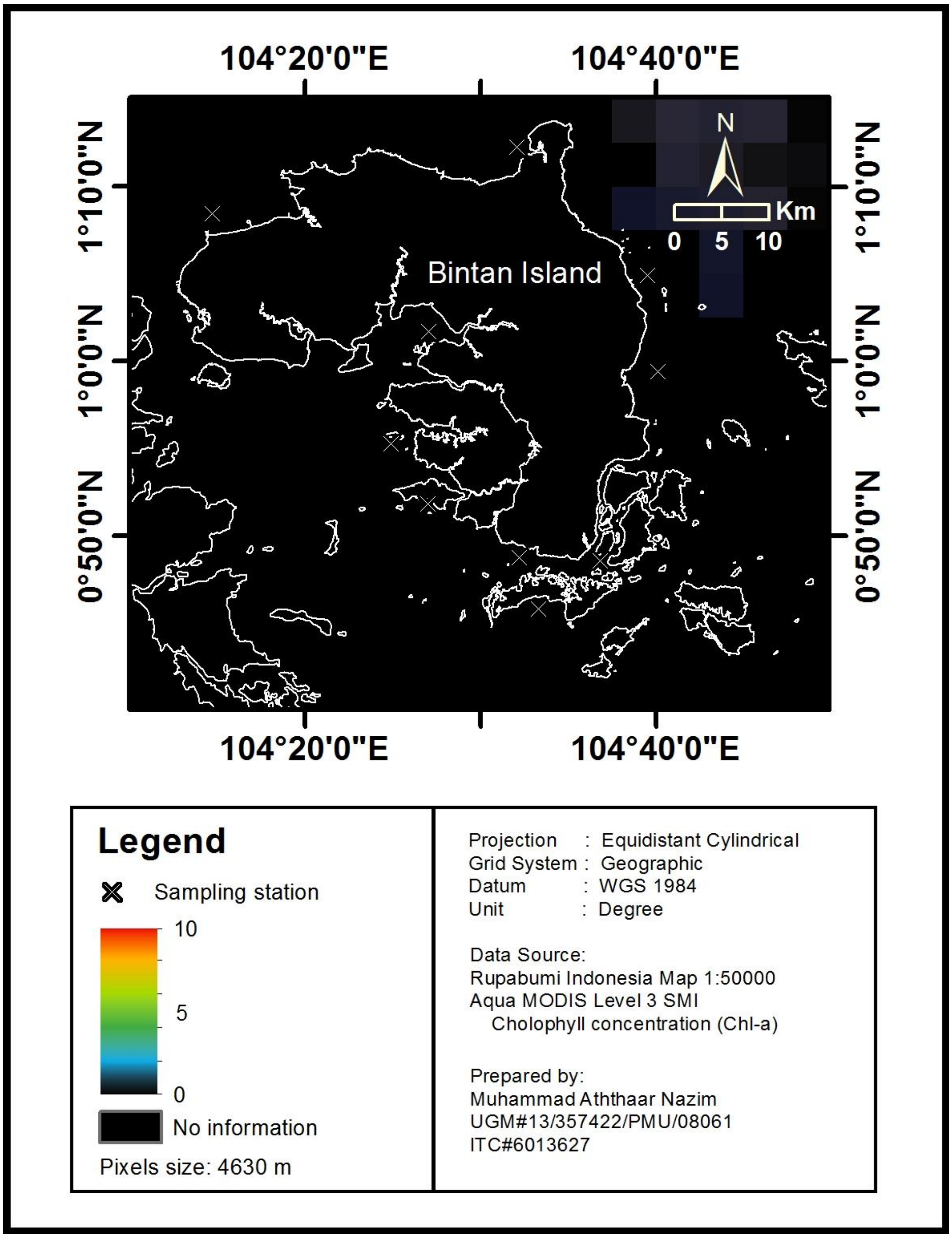


Figure 4.3. Spatial distribution of the lowest chlorophyll concentration in February 2009 (Source: Image processing, 2015).

Over eight years highest chlorophyll growth occurs twice a year, first in January (wet season) and the second in July (dry season) with values of 2.12 mg/m^3 and 1.99 mg/m^3 respectively. During the rainy season, rainfall will affect the decrease in temperature at the sea surface and as the optimum temperature is reached the concentration of chlorophyll produced slightly higher than during the summer. The growth rate of chlorophyll concentration in one year as in Figure 4.4.

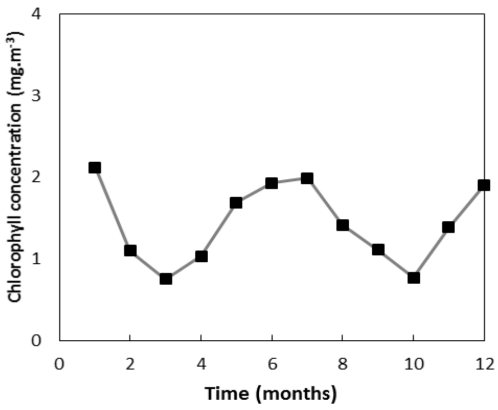


Figure 4.4. Monthly average of MODIS chlorophyll concentration in study area (Source: Data analysis, 2015).

The variation of mean monthly chlorophyll concentration in the study area from 2005 to 2012 shows in Figure 5.4. The lowest concentration recorded in March to April within the range 0,7 to 1,0 mg/m^3 then rose to 1,7 to 1,9 mg/m^3 from May to July. From August it was decreased to 0,8 mg/m^3 in October. Started from November rise to 2,1 mg/m^3 in January.

Eastern and Northern part of the study area are surrounded by small islands which can provide nutrient from run off and river that flown to neritic zone and enrich the waters properties. As shown most of chlorophyll concentration spatially disributed in those part.

Figure 4.5 and 4.6 illustrates spatial variation of chlorophyll concentration in the study area. Chl-a concentration decreased at the end of wet season (February-March) and start to grow as entering dry season until its peak in June/July (Figure 4.5). In August the chl-a concentration decreased until the lowest point in October (Figure 4.6). Its start to grow from November to December until reached the peak in January.

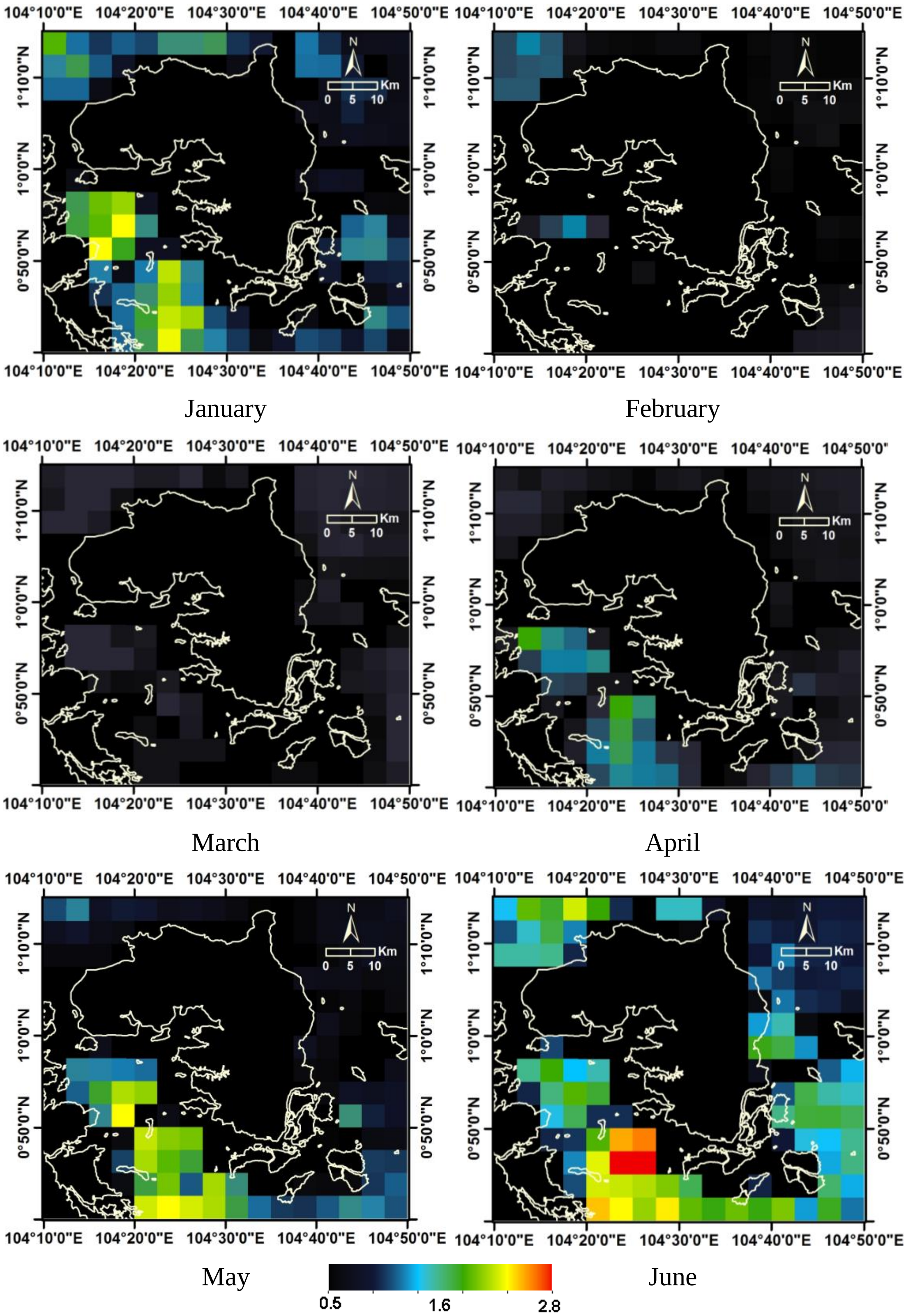


Figure 4.5. Monthly chlorophyll concentration maps of study area in a year (January-June) (Source: Image processing, 2015)

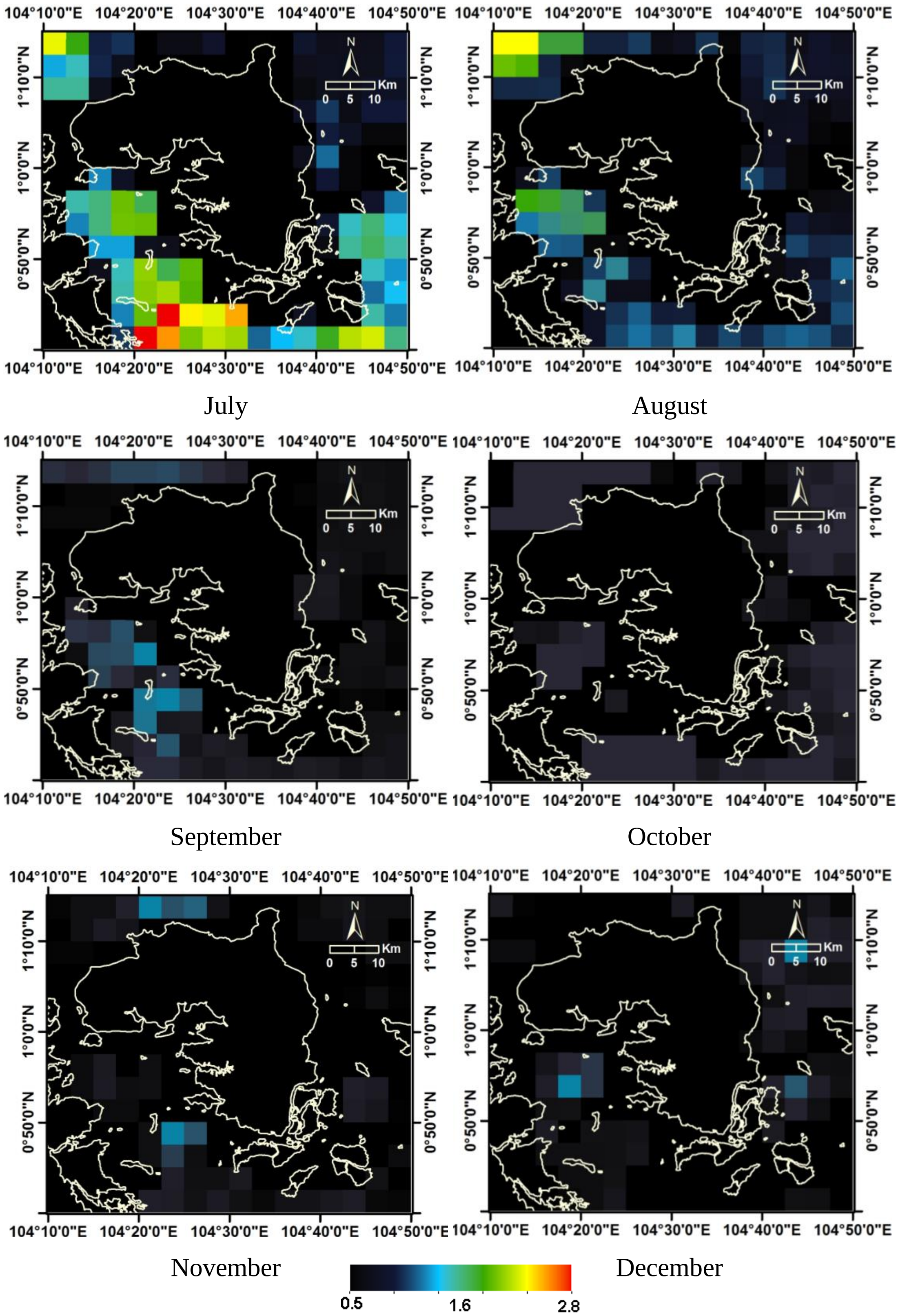


Figure 4.6. Monthly chlorophyll concentration map of study area in a year (July-December) (Source: Image processing, 2015)

4.1.2. Sea surface temperature

Unlike chlorophyll image, Aqua MODIS Sea surface temperature has been designed to have the actual temperature of the entire surface of the world ocean. So masking treatment is not performed and value of sea surface temperature can be directly obtained after image cropping to the location of research. Sea surface temperature values of all 96 images are then transferred into a spreadsheet format for further processing. Time series MODIS sea surface temperature (SST) from 2005 to 2012 as mean calculated varies from 27,0^{0}C to 31,9^{0}C (as illustrates in figure 4.7). SST start to rise at the beginning of the dry season (from March to July) and decreased when rainy season come (at the end of October to February).

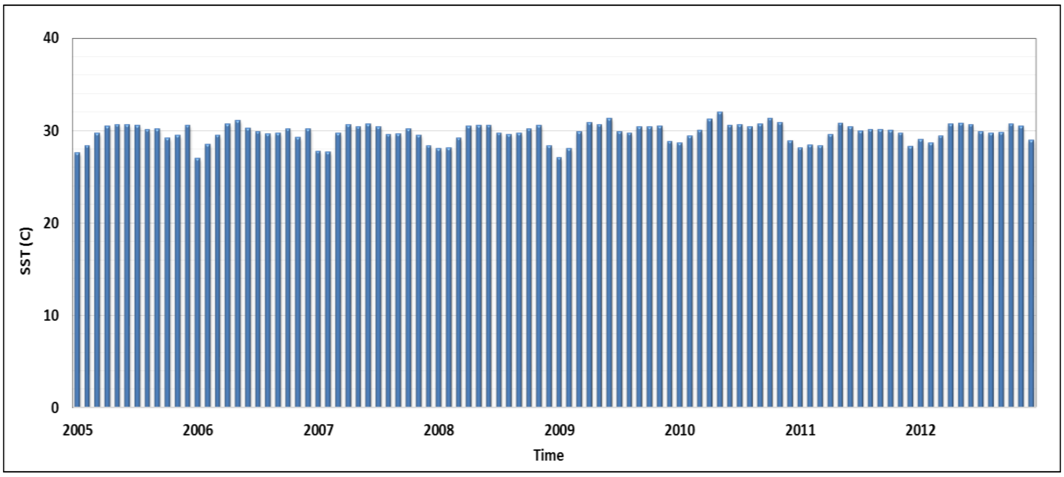


Figure 4.7. Time series MODIS SST variation from 2005 to 2012
(Source: Data analysis, 2015)

The highest monthly temperature recorded in May and June 2010 at 31,9 and 31,5^{0}C respectively. Annually the temperature had risen at the end of February until June/July and decreased when leaving October through January. Between July and October it's fluctuated less or more with the closest month. Generally, over eight years the lowest temperature was recorded in January (wet season) and reach the high temperature in dry season (May).

Figure 4.8 and 4.9 illustrates the spatial distribution of sea surface temperature at higher level 31,9^{0}C (May 2010) and minimum level 27,0^{0}C (January 2009) respectively in the study area. Sea surface temperature was distributed evenly only some spot shows the red color that indicates a higher temperature than the green color. Spot closest with neritic zone commonly has a higher temperature than oceanic zone, where wind and wave help to distribute the heat within the water column and keep the temperature lower than neritic zone.

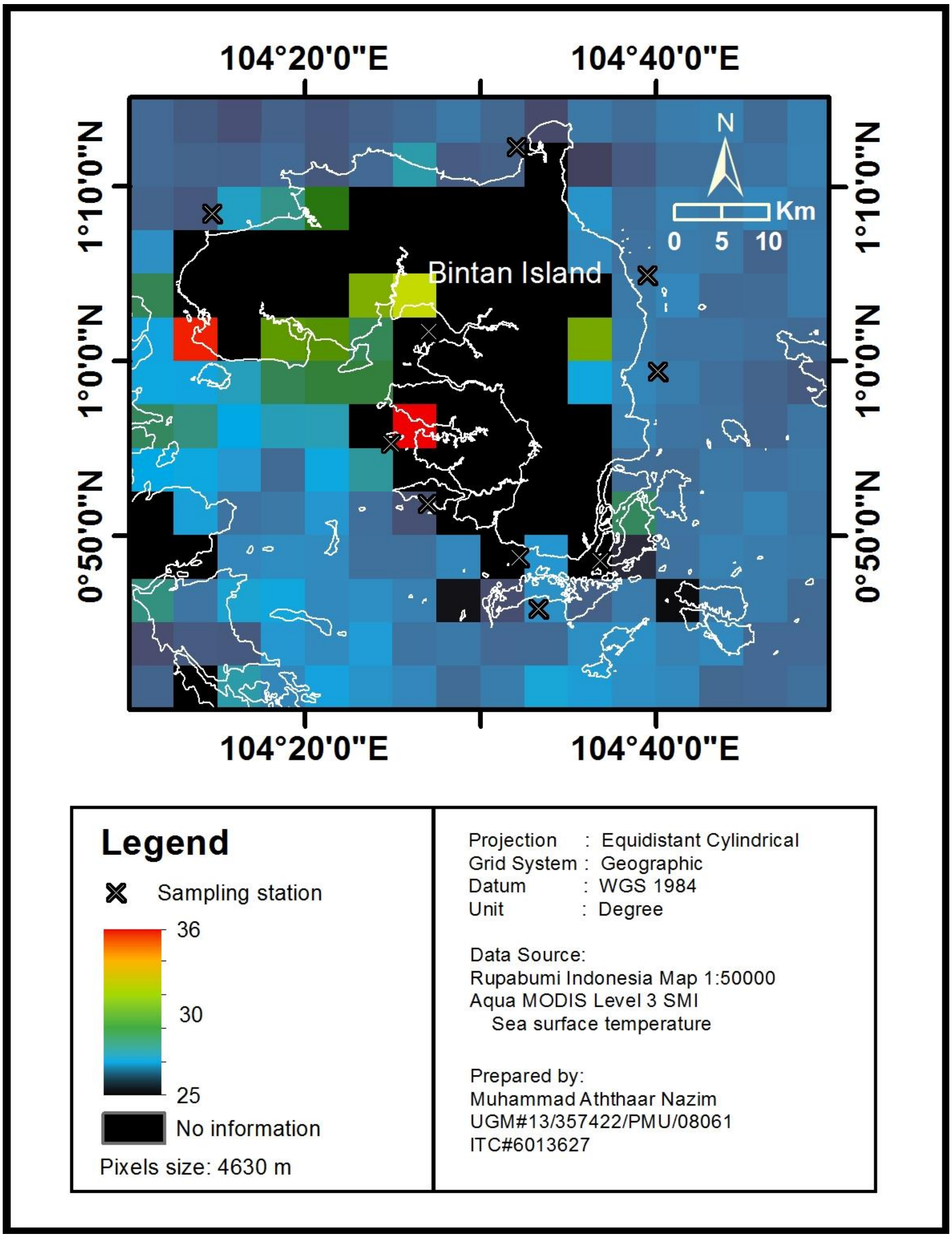


Figure 4.8. Spatial distribution of the highest sea surface temperature in May 2010 (Source: Image processing, 2015).

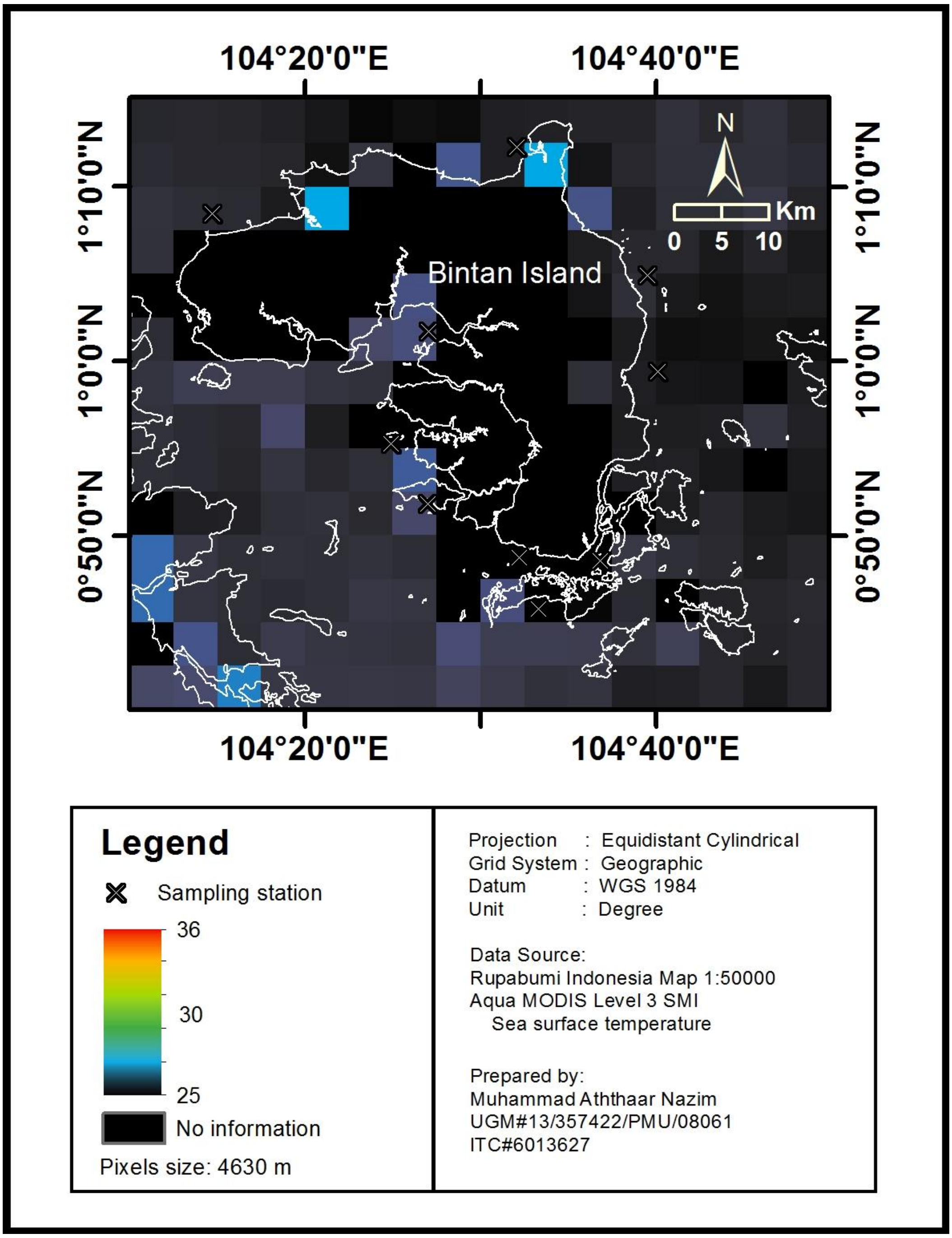


Figure 4.9. Spatial distribution of the lowest sea surface temperature in January 2009 (Source: Image processing, 2015).

Between 2005 and 2012, monthly average of sea surface temperature in the study area varies from 27,9 to 30,8^{0}C. The highest temperature recorded in May and the lowest appeared in February. The temperature raised down to minimum in rainy season (October-February) and rose up to maximum in dry season. Annual sea surface temperature in Bintan waters within the study periods around 30,3^{0}C (figure 4.10).

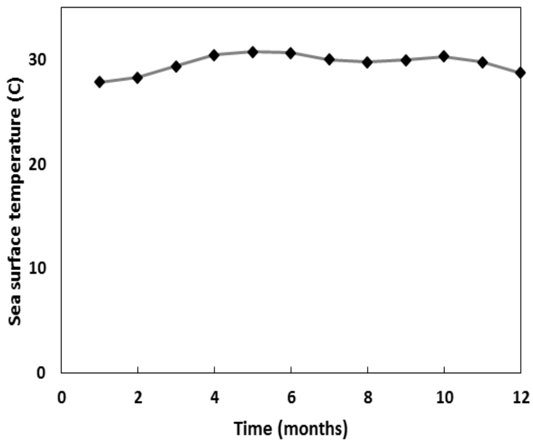


Figure 4.10. Monthly average of sea surface temperature in the study area (Source: Data analysis, 2015).

Figure 4.11 and 4.12 illustrates spatial variation of sea surface temperature in the study area. In general, sea surface temperature start to grow at the beginning of the dry season March/April as precipitation decreased significantly. Winds and waves helps to distribute the heat from sunlight in the Bintan waters. It's growing until reach the peak in May/June as the image cover with reddish color surrounding the study area, as displayed in Figure 4.11. After July sea surface temperature decreasing gradually until December. It is caused by changes in wind season in Indonesia. In Transition season I (around April to May), winds relatively weak and high intensity of illumination and calm water conditions causing heat absorption into the sea water becomes higher and sea surface temperature become maximum. In the Transition Season II (around November), highest precipitation and a very strong wind speeds, and relatively low radiation intensity and more wavy sea surface, thereby reducing heat and resulted in the minimum sea surface temperature (Illuhade & Nontji, 1999; Rasyid, 2010).

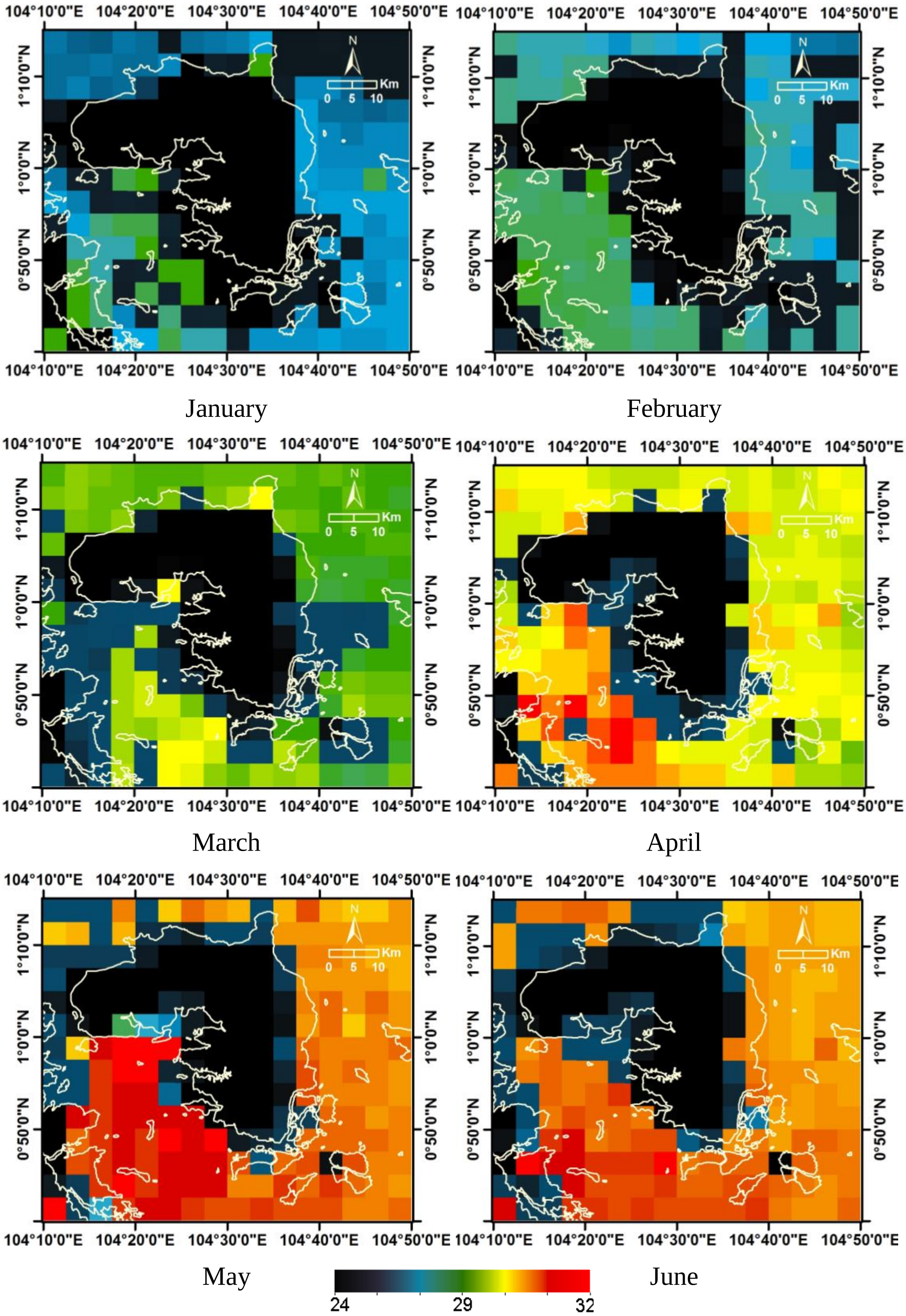


Figure 4.11. Spatial variation maps of sea surface temperature in a year (Jan-June) (Source: Image processing, 2015)

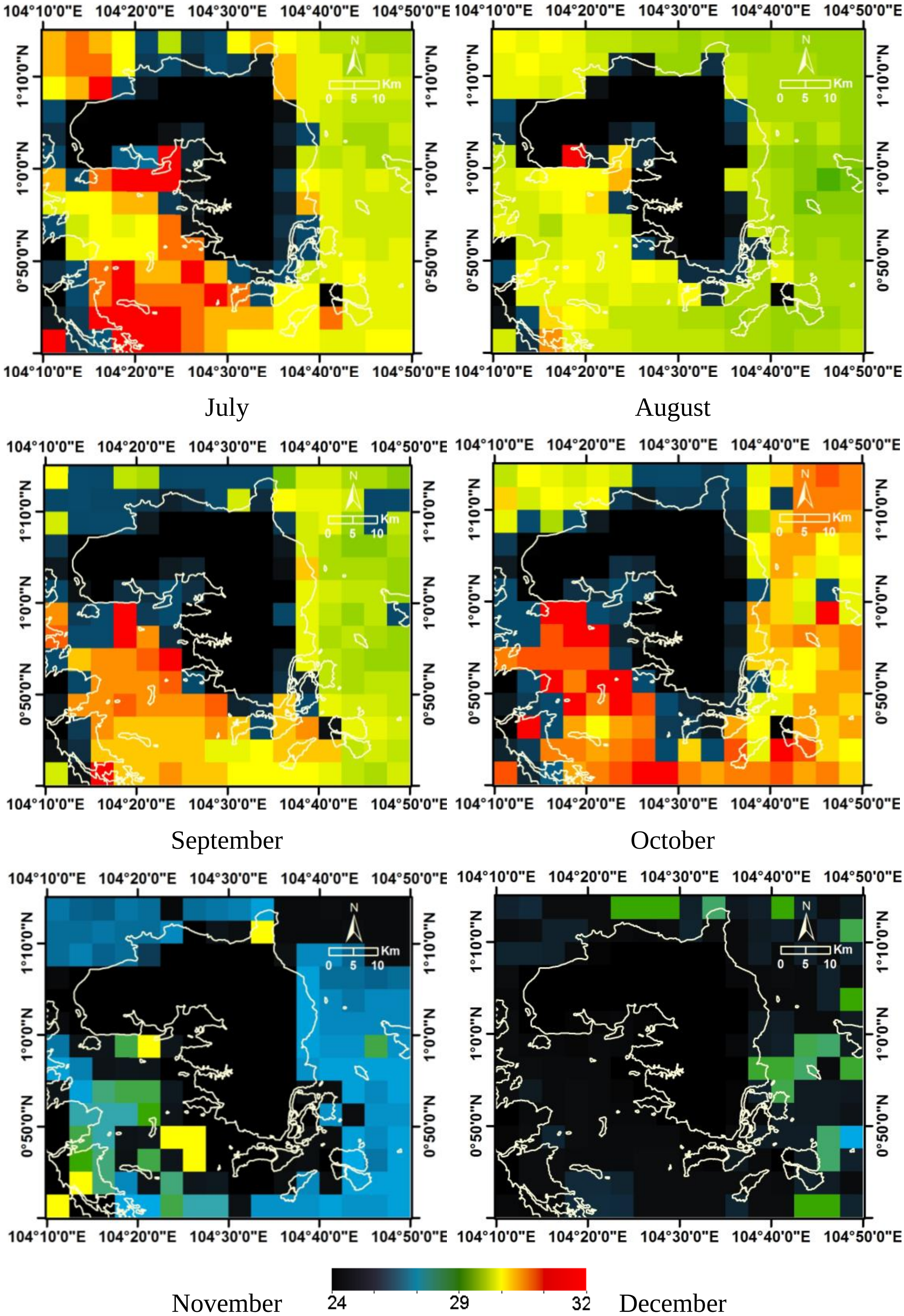


Figure 4.12. Spatial variation maps of sea surface temperature in a year (July-December) (Source: Image processing, 2015)

4.1.3. Optimal carbon fixation rate

Carbon fixation is part of the photosynthesis processes that occurs when there is no light and serves to reduce carbon dioxide into organic compounds. The level of carbon fixation lasted several hours in the water column. In this equation Behrenfeld & Falkowski (1997b) estimating these variables of temperature-dependent relationship as given:

$$P^{B}_{opt} = 1{,}2956 + 2{,}749xT + 6{,}17x10^{-2}T^{2} – 2{,}0462x10^{-2}T^{3} + 2{,}462x10^{-3}T^{4} – 1.348x10^{-2}T^{5} + 3{,}4132x10^{-6}T^{6} – 3{,}27x10^{-8}T^{7}$$

The following expression was applied in band math feature to estimate the optimal carbon fixation rate for each month of sea surface temperature, where b1 is Aqua MODIS sea surface temperature.

```
(b1 ge -1 AND b1 le 28.5)*((-0.0000000327*(b1^7)) +
(0.0000034132*(b1^6)) - (0.0001348*(b1^5)) +
(0.002462*(b1^4)) - (0.0205*(b1^3)) + (0.0617*(b1^2)) +
(0.2749*b1) + 1.2956) + (b1 gt 28.5)*4
```

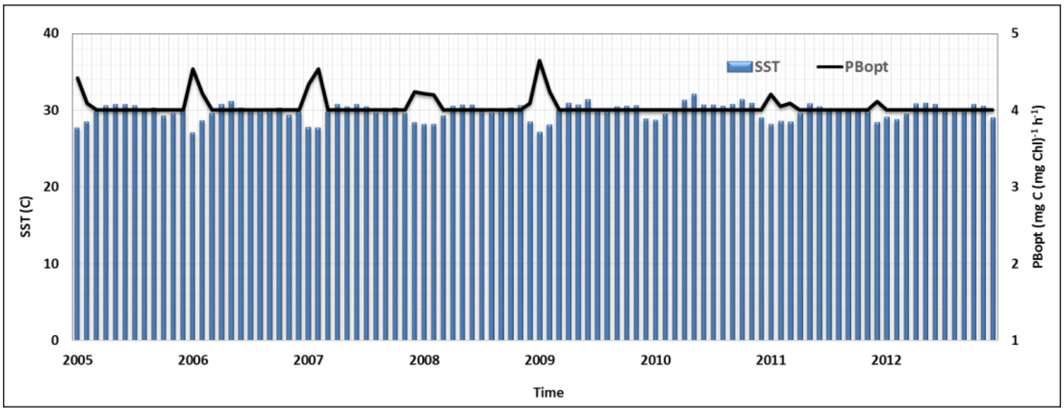


Figure 4.13. Time series MODIS SST and P^{B}_{opt} variation from 2005 to 2012
(Source: Data analysis, 2015)

In general, over the study periods, value of P^{B}_{opt} is equal to 4 (for SST>28,5^{0}C). The seventh order polynomial equation that applied to SST range between -1^{0}C and 28,5^{0}C. Only in December and January the equation returned with P^{B}_{opt} value more than 4 as the temperature reached its lowest position within a year (figure 4.14).

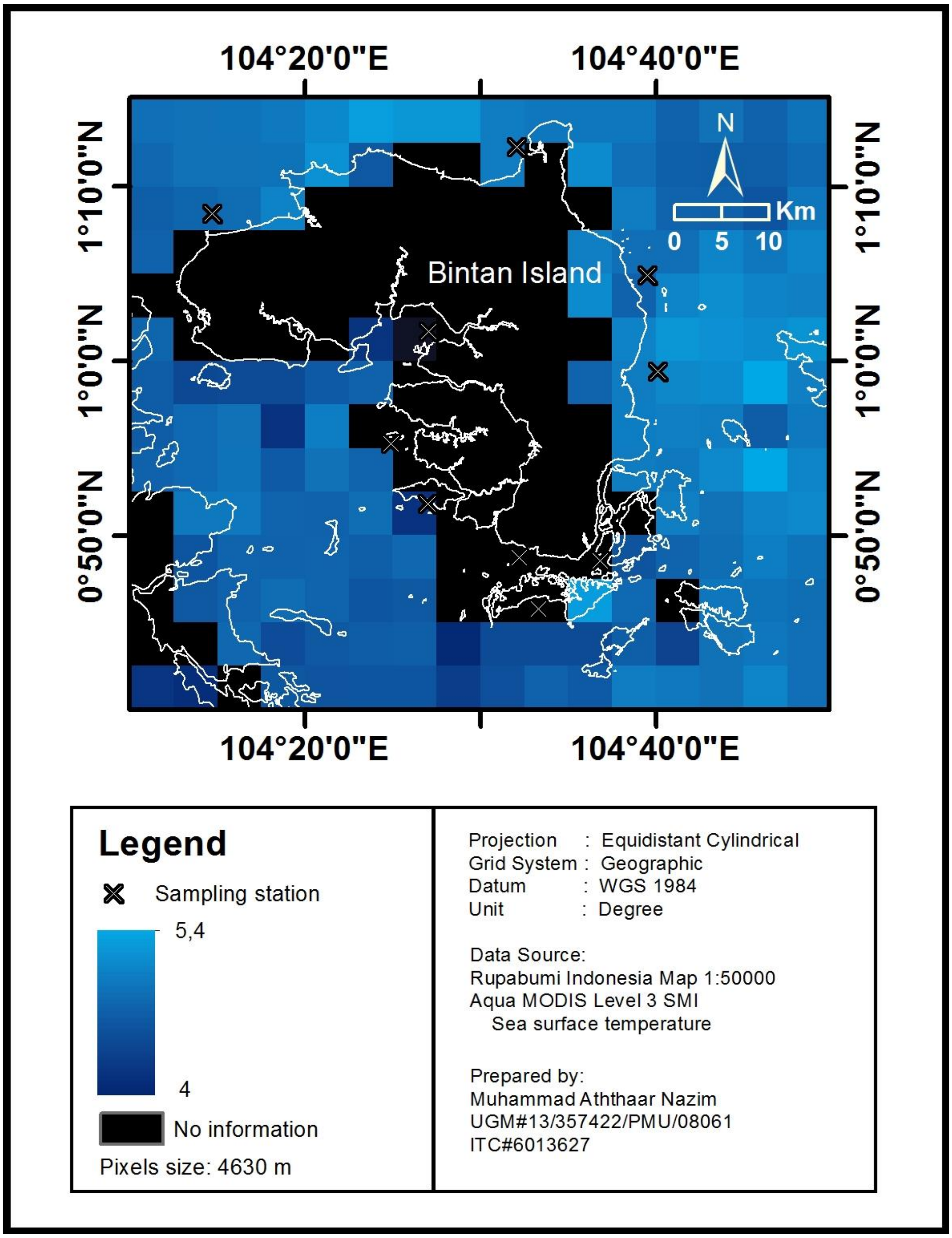
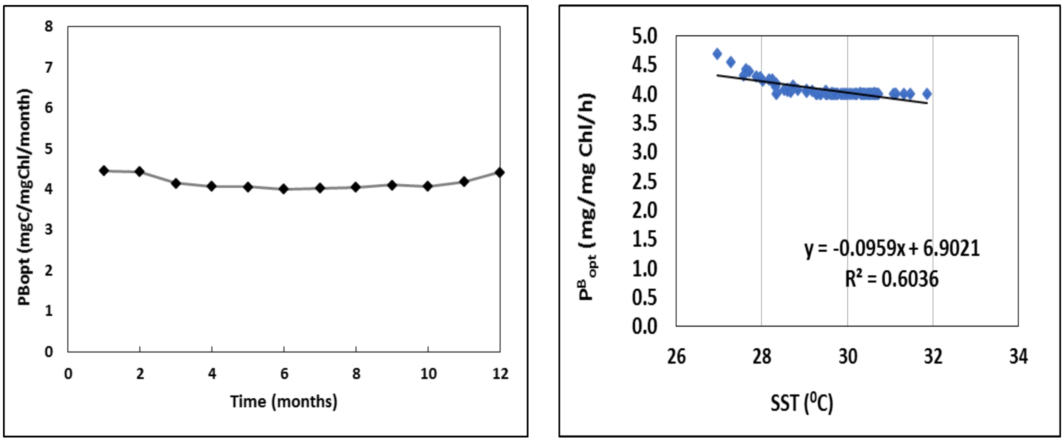


Figure 4.14. Spatial distribution of the highest P^{B}_{opt} in January 2009 (Source: Image processing, 2015)

Calculated monthly mean of sea surface temperature during the study period is 29,7^{0}C and will return as 4 values for the optimal carbon fixation rate. As the temperature decline in November to January, the optimum fixation carbon rate ($P^B{}_{opt}$) rose to 4,5 and then falling to a stagnant level (figure 4.15a). The highest optimal fixation carbon rate recorded in January 2009 correspond to low temperature in the same month (figure 4.13).



(a) (b)

Figure 4.15. Monthly average of Optimal carbon fixation rate and relationship between SST and $P^B{}_{opt}$ (Source: Data processing, 2015).

In figure 5.13 the time series MODIS SST and $P^B{}_{opt}$ from 2005 to 2012, shows a reverse pattern of temperature and optimum carbon fixation rate whereas SST valley return as peak in $P^B{}_{opt}$. It mean that low temperature will creates higher value for optimal carbon fixation rate and both have an intermediate correlation (r^2 = 0,60) as illustrates in Figure 4.15b.

4.1.4. Photosynthetically active radiation

Photosyntetically active radiation (PAR) is an optimum amount of light intensity for photosynthesis (Morel & Prieur, 1977).

Aqua MODIS Photosynthetically Active Radiation image has to performed masking, for the pixels outside the normal range as -32767, with zero

(0). In order to obtained the value of central tendency zero (0) is converted to NaN that will avoid the effect of zero on image statistic calculation.

Photosynthetically Active Radiation (PAR) informs the spectral radiation range that often used by microorganism for photosynthesis process which is between 400 to 700 nm (Behrenfeld & Falkowski, 1997b). PAR indicates the availability of light that required in the photosynthesis process. Variability of PAR in the ocean influenced by water attenuation and alga pigment absorbing availability, colored dissolved organic matter and total suspended material (Robinson, 2010).

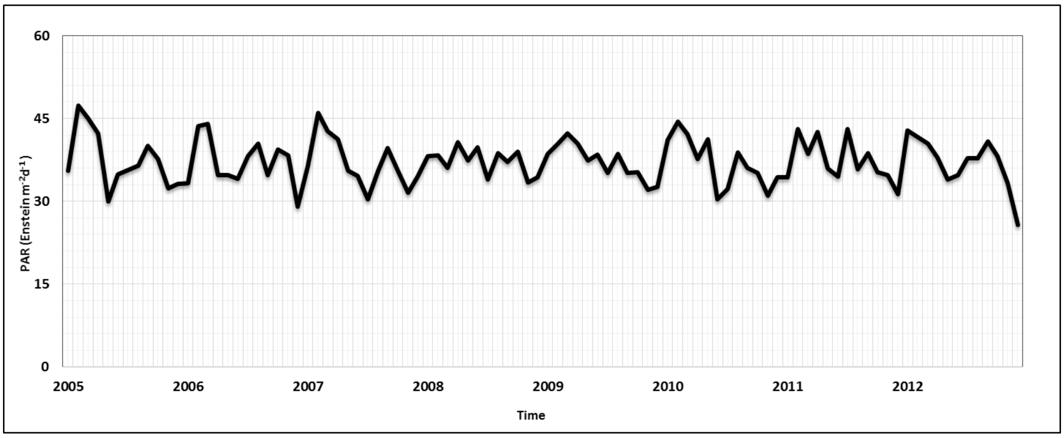


Figure 4.16. Time series diagram of PAR from 2005 to 2012 in study area (Source: Data analysis, 2015).

From 2005 to 2012 variation of PAR, calculated as mean, between 25,8 and 47, 4 Enstein m^{-2} day^{-1} (Figure 4.16) February has the highest PAR is 47,4 and 46,0 in 2005 and 2007 respectively. The value of PAR will be used to determine daily surface PAR that required in the primary productivity calculation. The highest variety of PAR recorded in February 2005 as shown in Figure 4.17.

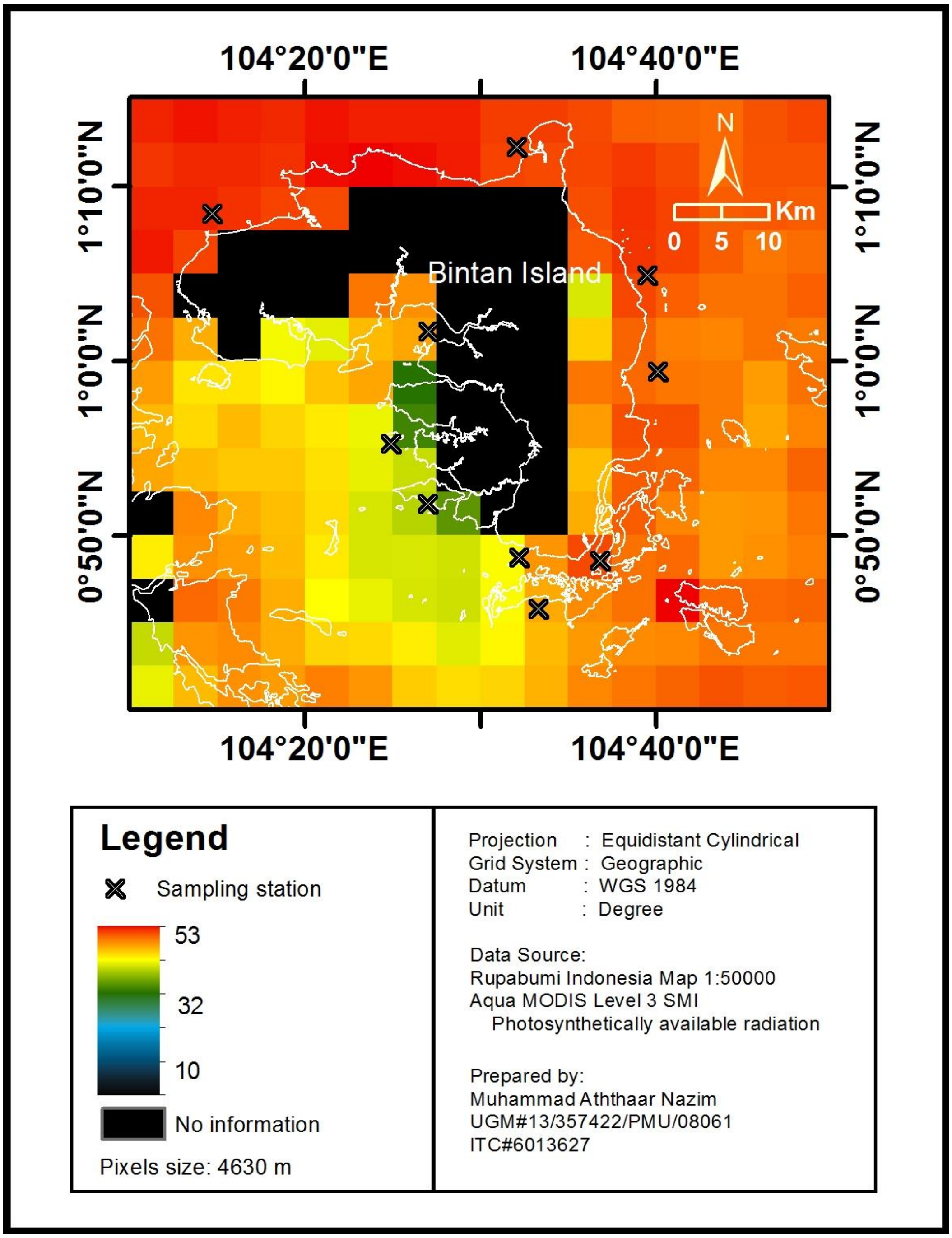


Figure 4.17. Spatial distribution of the highest *PAR* in February 2005 (Source: Image processing, 2015).

During the study period, from 2005 to 2012, monthly average of PAR generally decreased from the end of the rainy season until the end of the year, from February to December, while in January there is an increased until its peak at

February. The variety of PAR within a year in the study area as illustrated in Figure 4.18.

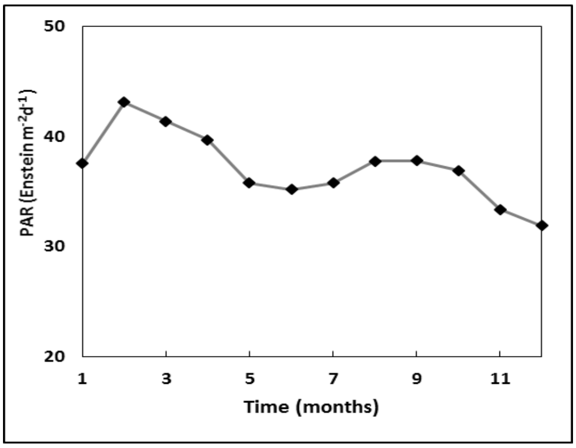


Figure 4.18. Monthly average of Photosynthetically active radiation during study period (Source: Data analysis, 2015).

4.1.5. Euphotic depth

Aqua MODIS Photosynthetically Active Radiation image has to performed masking, for the pixels outside the normal range as -32767, with zero (0). In order to obtained the value of central tendency zero (0) is converted to NaN that will avoid the effect of zero on image statistic calculation.

Euphotic depth, symbolized as Z_{eu} and meter as a unit, informs the depth in the ocean where is 1% of light can penetrate and sufficient for photosynthesis (Robinson, 2010). Euphotic depth derived from diffused attenuation coefficient (*Kd*) which also provided from Aqua MODIS sites. Firstly image masking, pixel with value (-32767) will be masked with zero (0). In order to obtained the value of central tendency, zero (0) is converted to NaN that will avoid the effect of zero on image statistic calculation. The deepest level recorded in March 2012 and February 2009 at level 79,3 and 74,6 m respectively. Figure 4.19 shows the time series diagram of *Kd* and Z_{eu}. Euphotic depth will be estimated from diffused attenuation coefficient as given expression:

$$Z_{eu} = \frac{4,65}{Kd}$$

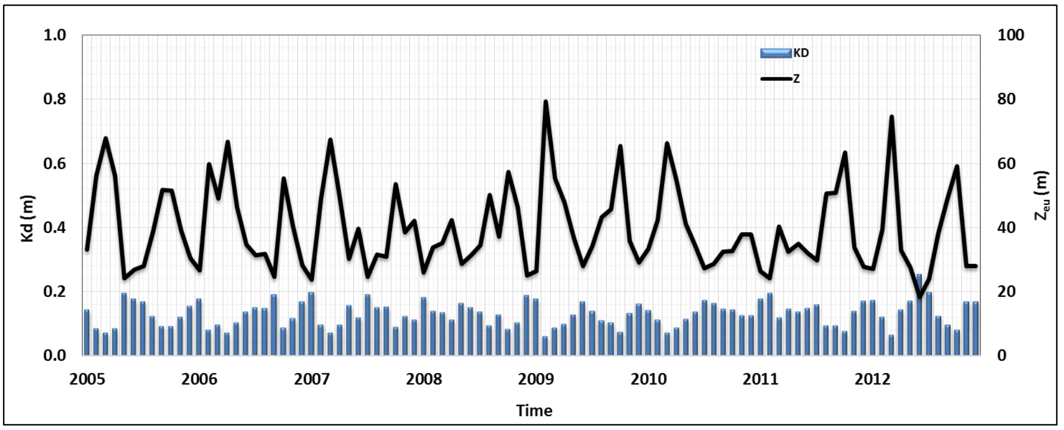


Figure 4.19. Time series distribution of Kd and euphotic depth (Z_{eu}) from 2005 to 2012 in the study area (Source: Data analysis, 2015).

Within eight years, the deepest euphotic depth in the study area was recorded on February 2009 and March 2012 as calculated mean 79,2 and 74,6 m respectively. The lowest level at 18,5 m and 23,8 m recorded on June 2012 and January 2007 respectively. The deepest point where 1% of light can penetrate and sufficient for photosynthesis retrieved on February 2007 instead of February 2009 as illustrates in Figure 4.20.

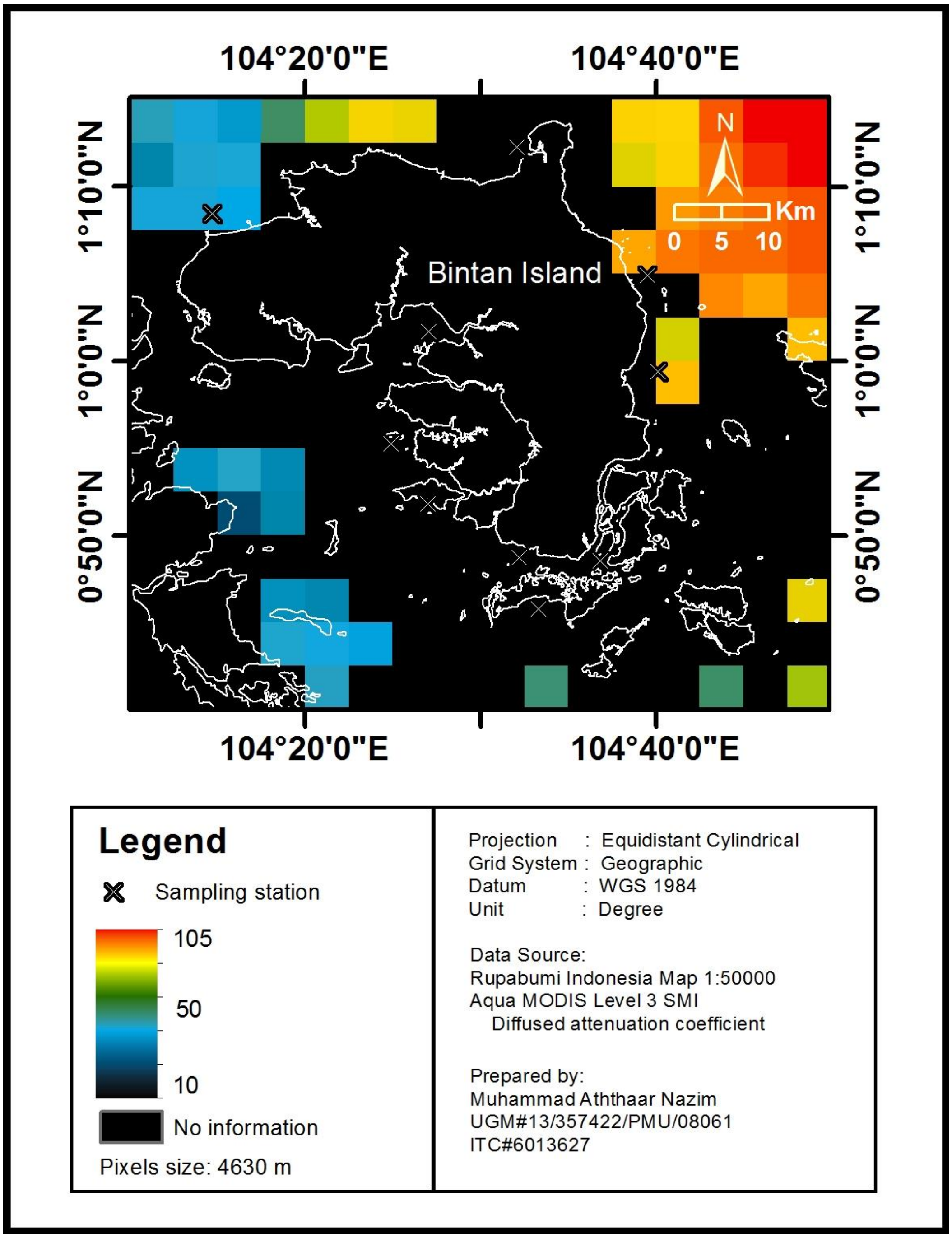


Figure 4.20. Spatial distribution of euphotic depth in February 2007 (Source: Image processing, 2015).

Kd is an indicator of the value of sediment or turbidity in the water column. The existence of particles suspended in water depth affects the penetration of sunlight into the water. In this study, Kd value derived directly from Aqua MODIS image Diffused attenuation coefficient 490. In general the annually deepest point of euphotic depth recorded in March and October while shallow point happens in January and July (figure 4.21).

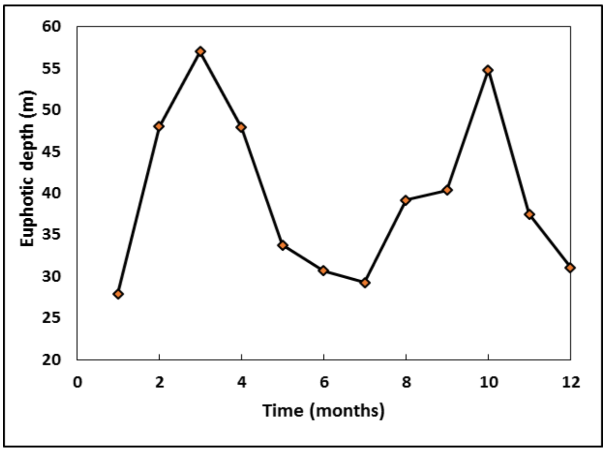


Figure 4.21. Monthly average of euphotic depth during the study period (Source: Data analysis, 2015)

4.1.6. Photoperiod

Photoperiod describe as a certain length of time in a day during which an organism receives illumination and get sufficient light for photosynthesis. This sunshine duration informs a period where the direct solar irradiance exceeds 120 wm^{-2} (WMO, 2003), also known as day length. Day length calculated based on the latitude of study area that front for the length of time of phytoplankton exposed by daily light and measured as the sunshine through sunset each day.

Sunshine duration over the study area retrieved from geo-astronomy website (Giesen, 2007) where the average photoperiod varies from 11,94 to 11,98 from 2005 to 2012, with annual mean 11,96. Photoperiod will influence performance of microorganism (algae) to catch and produce sufficient light energy (Reynolds, 2006).

4.2. Primary Productivity

Primary production measured based on Vertical Generalized Production Model (VGPM) which is developed by Michael J. Behrenfeld and Paul G. Falkowski (Behrenfeld & Falkowski, 1997b). This model determines daily phytoplankton carbon fixation rates based on daily measured chlorophyll concentration on the sea surface as given by expression:

$$PP = 0.66125 x P^{B}_{opt} x \frac{E_0}{E_0 + 4.1} x Chl_a x Z_{eu} x D_{irr}$$

Primary production equation transforms into the ENVI band math expression as follow:

0.66125*b1*(b2/(b2+4.1))*b3*(4.65/b4)*11.96

Where b1 represents the optimal fixation carbon rate (P^{B}_{opt}), b2 is sea surface daily PAR, chlorophyll concentration as b3 and b4 represents diffused attenuation coefficient for estimates Z value, and average photoperiods is 11.96 hr.

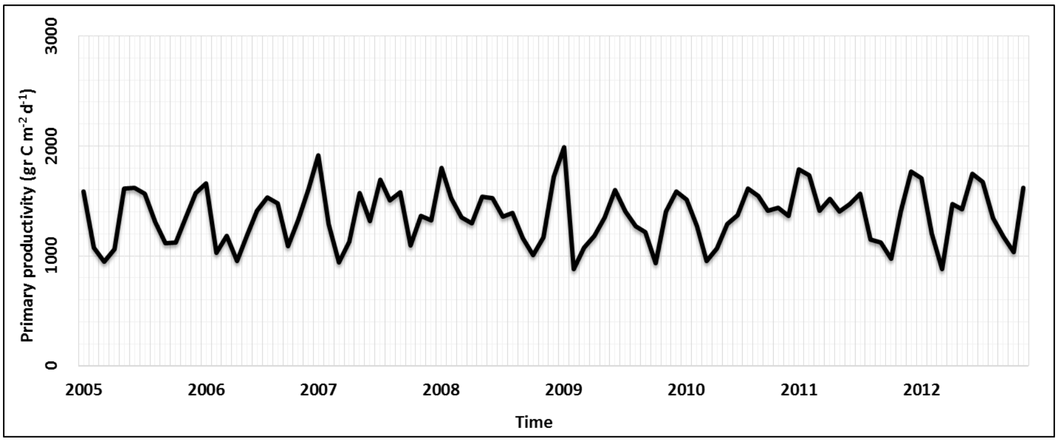


Figure 4.22. Time series primary productivity in the study area from 2005 to 2012 (Source: Data analysis, 2015).

VGPM considered sea surface temperature, optimal carbon fixation rate, sea surface daily photosynthetically available radiation, euphotic depth and photoperiod. From 2005 to 2012, calculated mean primary productivity (PP) varies between 877,9 to 1990,4 gr C/m^2/d (figure 4.22).

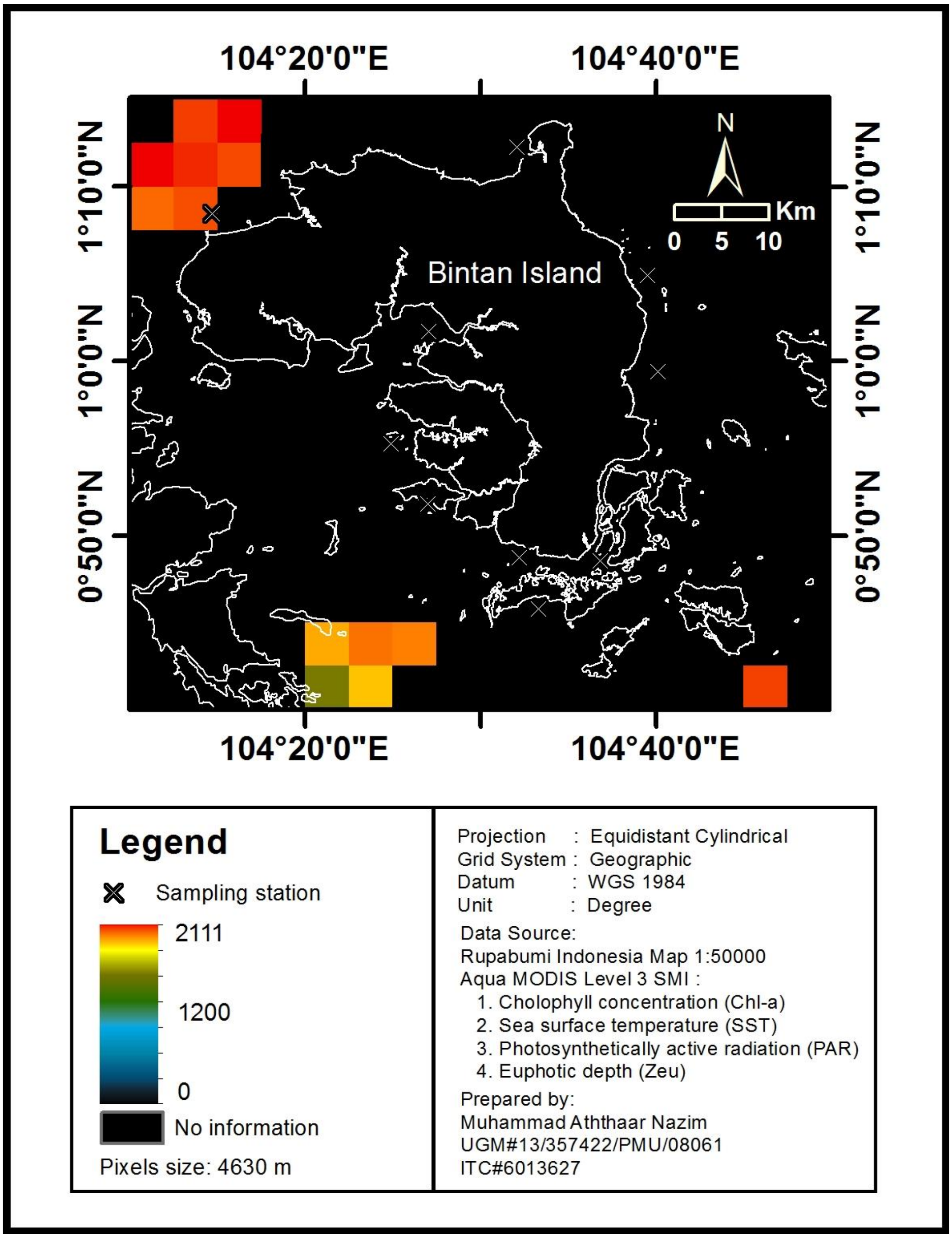


Figure 4.23. Spatial distribution of the highest primary production in January 2009 (Source: Image processing, 2015).

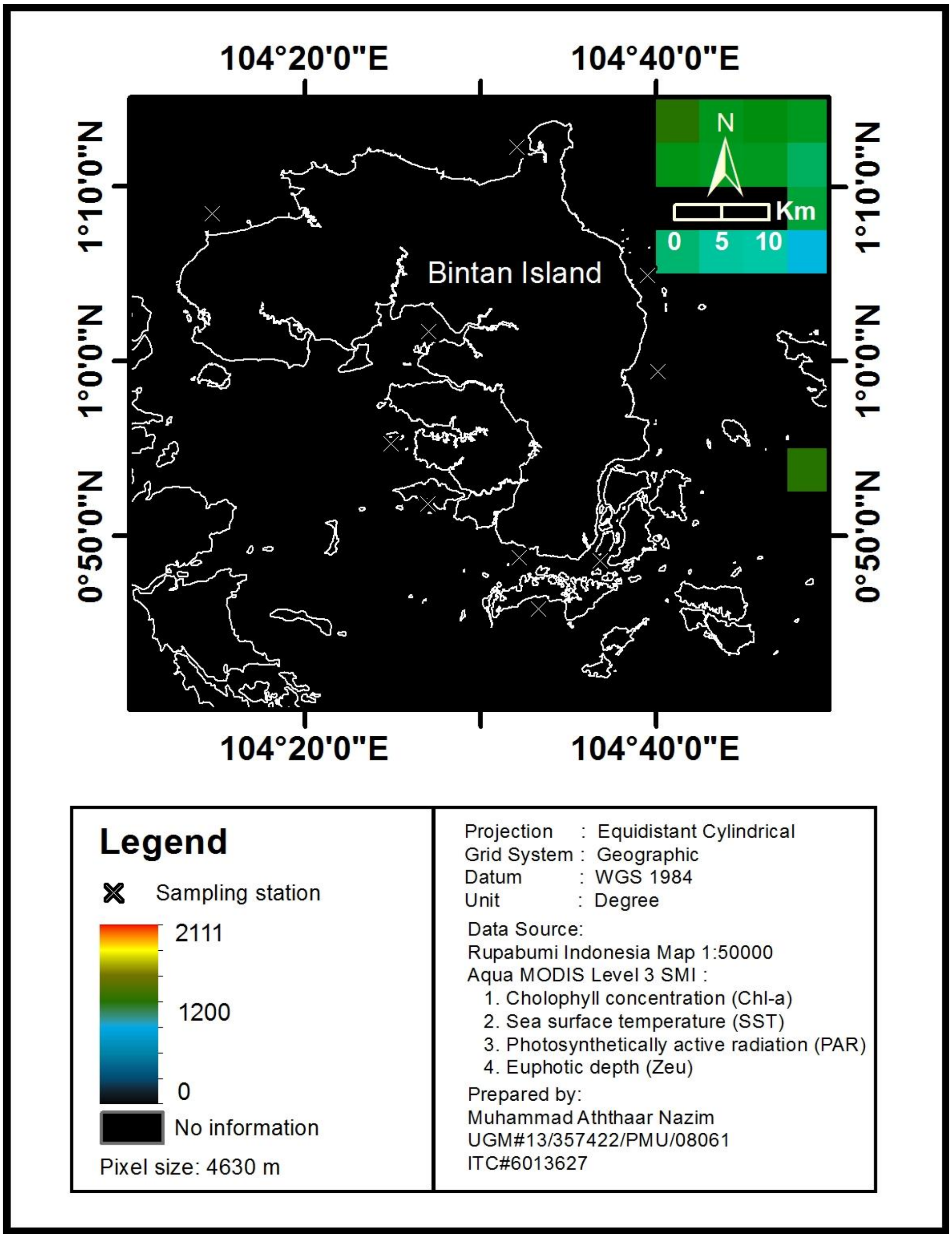
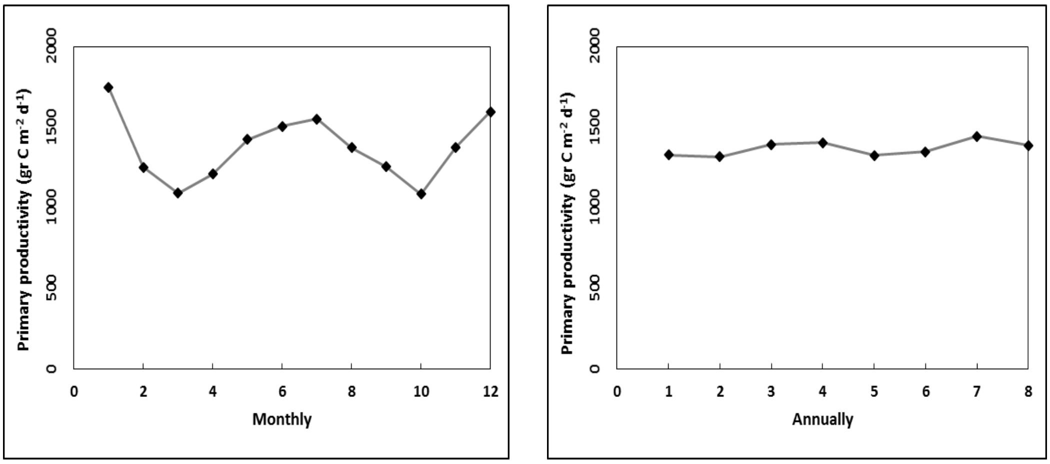


Figure 4.24. Spatial distribution of the lowest primary production in March 2012 (Source: Image processing, 2015).

The highest mean calculated primary production recorded in 1990,4 and 1913,8 grC/m^2/d on January of 2009 and 2007 respectively. The lowest value is 877,9 and 882,8 grC/m^2/d in March 2012 and February 2009 respectively. The highest and the lowest primary productivity in the study area as illustrates in Figure 4.23 and 4.24.

In average monthly calculated mean primary production in January was the highest and October the lowest at 1744,2 and 1085,2 grC/m^2/d respectively. Annually 2011 was the highest primary production while 2006 was the lowest productivity record at at 1442,8 and 1315,5 gr C/m^2/d respectively. This trend illustrated in Figure 4.25a.

The annual growth of primary production starts at the beginning of wet season around November until January. Second growth begin at April until July and gradually reduced until the end of dry season (figure 4.25.a). Generally, during the study period there is no extreme different of estimated primary productivity which is calculated from MODIS Aqua imagery (figure 4.25.b).



(a) (b)

Figure 4.25. Monthly (a) and annually (b) calculated mean primary productivity from 2005 to 2012 in the study area (Source: Data analysis, 2015).

Figure 4.26 and 4.27 illustrates spatial variation of estimated primary productivity in the study area.

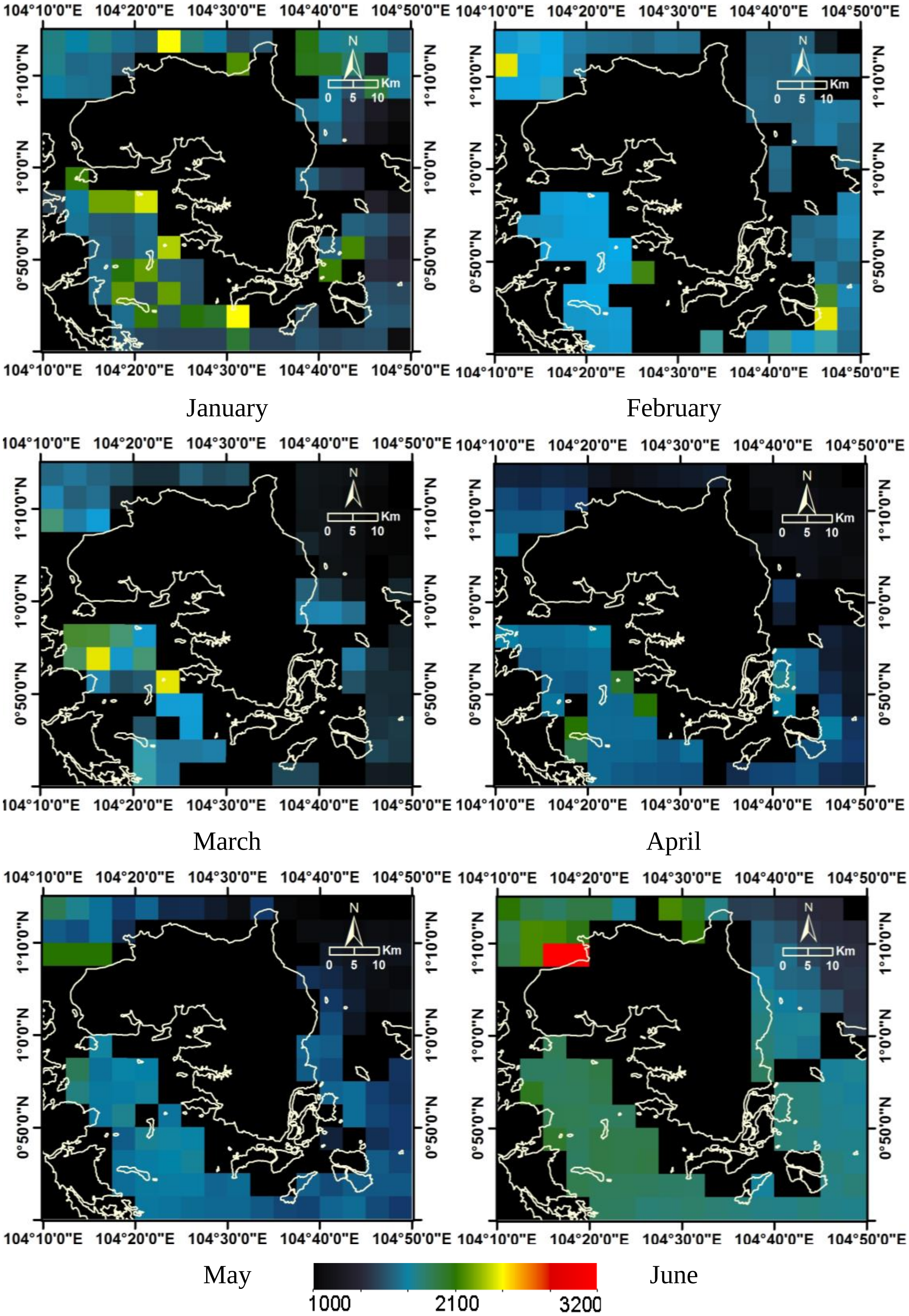


Figure 4.26. Spatial variation maps of primary production in a year (Jan-June)
(Source: Image processing, 2015)

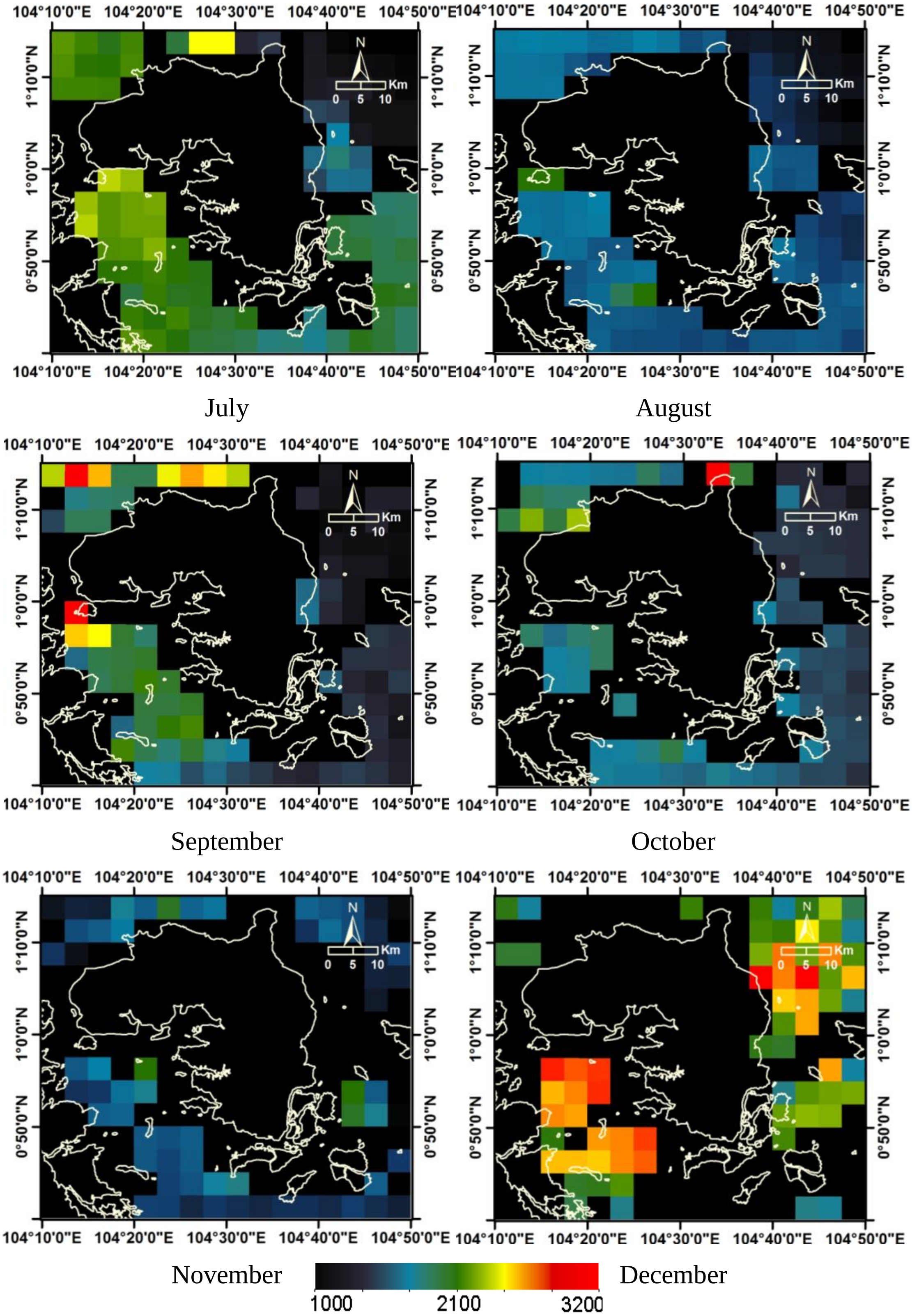
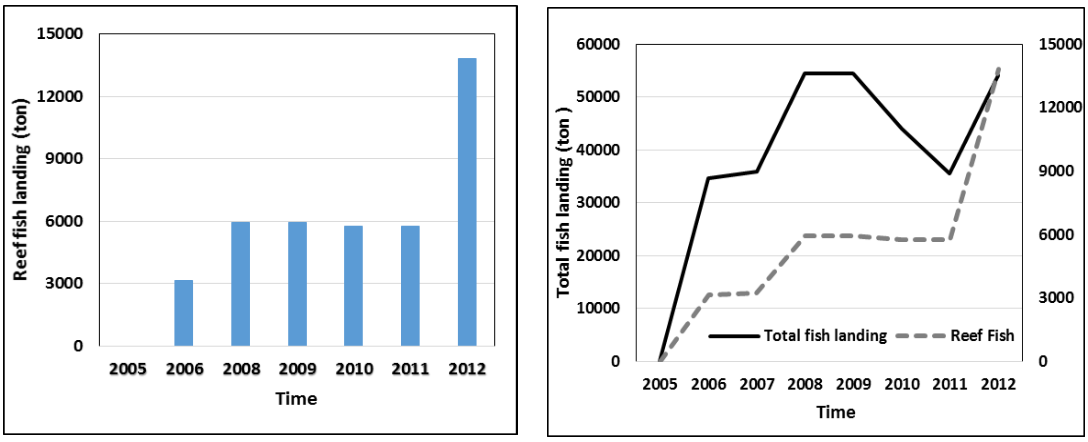


Figure 4.27. Spatial variation maps of primary production in a year (July-Dec) (Source: Image processing, 2015).

In February value of primary production decreased from January until the lowest in March as the end of the wet season. The primary production start to grow in April until peaks in June/July (Figure 4.26) before decreasing in August. Although the primary production generally decreased, some pixel shown higher value in September and October (reddish color), this happens coincide with the anomaly of sea surface temperature in the same month. As November comes grows again until its peak in December (Figure 4.27).

4.3. Fisheries statistics

Bintan Island is geographically occupied by two administrative regions, namely Tanjungpinang and Bintan regency. Tanjungpinang is located in the west of the island least than a quarter area of this island. Bintan regency occupied more than three quarters of the island. Bintan Island has a number of potential opportunities in the natural field such as tourism, industry, fisheries, mining and livestock. As an archipelago region fishery is a common economic activity of local people, as reef fish is also the common commercial fish in a local fish market and restaurant.



(a) (b)

Figure 4.28. Reef fisheries production between 2006 and 2012 (a), and production of marine fish landing and reef fish in the study area (b) (Source: Data analysis, 2015).

Reef fisheries yield increased from 2006 to a stagnant point around 6000 ton year^{-1} until 2011, and in 2012 rose up more that 100% reaching more than 13.000 ton (figure 4.28.a). Unlike the reef fish record, total of fish production has a fluctuation during the study period, reef fish record shows not similar pattern as total fish production. (Figure 4.28.b).

In 2008, as stated in Appendix 1, this level has passed and reached the peak in 2012. In 2008 the utilization of reef fisheries exceeded 175% of its optimum level, compare to last production in 2012 that exceeded more than 400%, whereas National Commission on Fishing Resources Study determines the optimum production of reef fisheries based on maximum sustainable yield is 3390 ton/year in Bintan Island waters (Komnaskajiskan, 1998) as stated in Appendix 2.

Between 2008 and 2012, there is a decline of reef fish production in this region; the number of catches of *caesio cunning* (yellow tail), mangrove red snapper, and spangled emperor has reduced (DKP, 2014), but the golden-line spine foot and crimson snapper increased gradually. Multiple disturbance might influence this decline; over catch exceeds, IUU fishing, destructive fishing practices, and pressure from human activities (Lau, 2014; Supriharyono, 2007).

National fisheries statistics, collected by Ministry of Marine Affairs and Fisheries, was produced four times a year (quarterly). Production of reef fisheries as shown below based on monthly average from 2010 to 2012 (figure 4.29). In general, production increased during Q2 to Q3 and falling down to Q1. Unfortunately, only data from 2010 to 2012 still has completed record quarterly, others did not available in digital or print out.

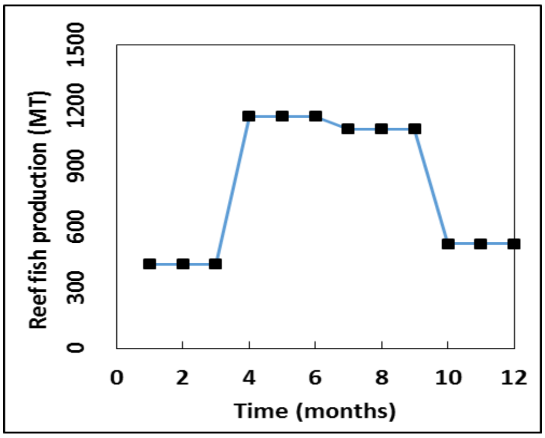


Figure 4.29. Average number of reef fish production from 2010 to 2012 in the study area (Source: Data analysis, 2015).

Until 2012 the island only has two units of landing fishing point and also has a function as a fish market (DKP, 2011). The exploitation of reef fisheries has exceeded the optimum level and these happen in the lack facility of fishing port. The lack of fishing port facility could be the driven factor of uncertainty in collection of total fish landing for the whole region. Table 4.2 illustrates the distribution of fishing vessels related to the tonnage and the number which distributed into four regions of the study area.

Table 4.2. Summary of fishing vessels in terms of number and tonnage in the study area in 2012.

No.	Vessel Type	Vessels				Total Unit	Tonnage				Total Tonnage
		North	South	West	East		North	South	West	East	
1	Boat	291	235	1441	135	2102	29	24	144	14	4123
2	Engine Boat	41	71	307	66	485	21	36	154	33	1172
3	< 5 GT	374	921	1263	294	2852	935	2303	3158	735	12460
4	5-10 GT	11	343	18	2	374	83	2573	135	15	3542
5	10-30 GT	0	122	34	20	176	0	2440	680	400	3872
6	> 30 GT	0	21	77	5	103	0	630	2310	150	3296
	Total	717	1713	3140	522	6092	1067	8004	6580	1347	28465

Source: Data analysis, 2015.

Both of the fish landing port are located in the Western part of the island. In fact, table 4.2 shows that western part is the highest area with a number of vessels (3140 unit), follow by southern area (1713 unit), northern part (717 unit) and the Eastern part (522) respectively. In terms of amount of tonnage only has slightly, where eastern area has more tonnage (1347 ton) than northern part (1067 ton). Related with reef fishes only small fishing boat operated below five miles from sea shore.

By comparing the number of vessel from 2010 to 2012 there is an increase in the last three years (table 4.3). In average there is an increased 2% of small vessel unit from 2010 to 2012.

Table 4.3. Summary of fishing vessels from 2010 to 2012.

No.	Vessel Type	Year		
		2010	2011	2012
1	Boat	1,992	2,102	2,115
2	Engine Boat	505	485	502
3	< 5 GT	2,845	2,852	2,875
4	5-10 GT	371	374	379
5	10-30 GT	163	176	316
6	> 30 GT	103	103	103
	Subtotal	5,979	6,092	6,290

Source: Data analysis, 2015

The lack availability of fishery statistical data, particularly related to the development of the amount of the fishing unit causing difficulty in taking a relationship between the increased catches of reef fish and fishing facilities growth during the study period.

4.4. Relation between primary productivity and SST

In general, the relation between primary productivity and sea surface temperature is mostly of highest PP applied at the lowest temperature in a year. The peak of PP in January 2009 is 1990 at 27^0C temperature (figure 4.30). Each month, of the highest primary production were happening in the lowest temperature record of the year.

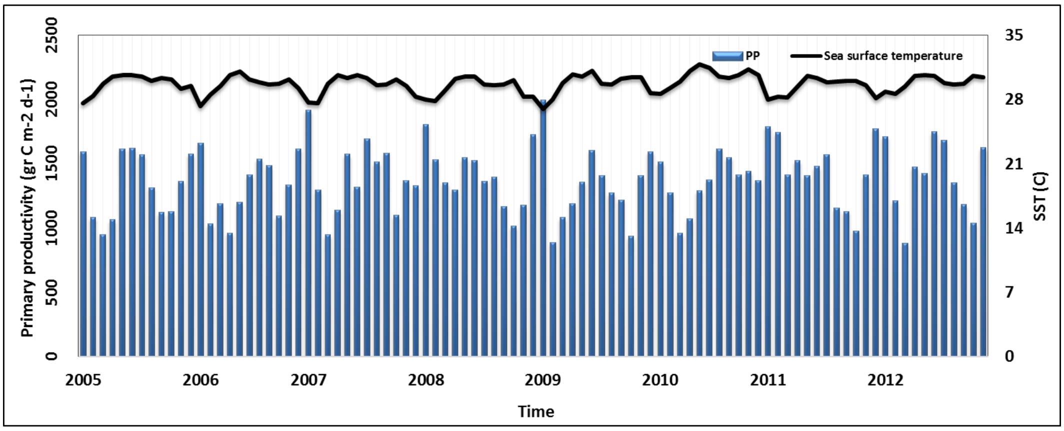


Figure 4.30. Times series between primary productivity and sea surface temperature (Source: Data analysis, 2015).

Unfortunately, statistic did not proved this pattern and revealed coefficient relation r^2=0,03 as shown in Figure 4.31, its mean that there is no correlation between these variables level during the study period.

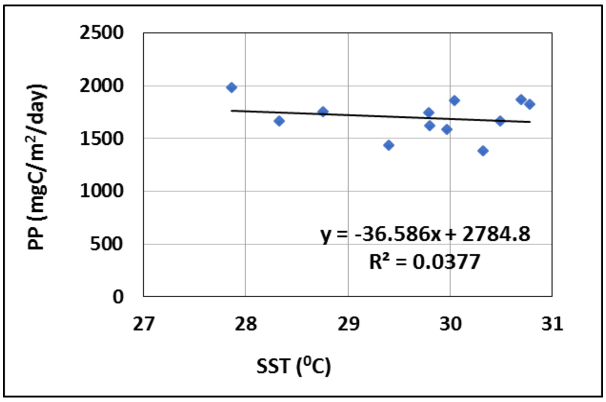


Figure 4.31. Correlation of MODIS PP and SST (Source: Data analysis, 2015).

4.5. Relation between primary productivity and chl-a concentration

Primary productivity and chlorophyll concentration from 2005 to 2012 shows good relationship. Generally trend of chlorophyll concentration followed by the similar primary production record. Peaks of primary production conjunction with highest growth of chlorophyll in the study area. As illustrates in Figure 4.32, both data shows similar pattern across the year. Mostly both peaks recorded from December to February in a year.

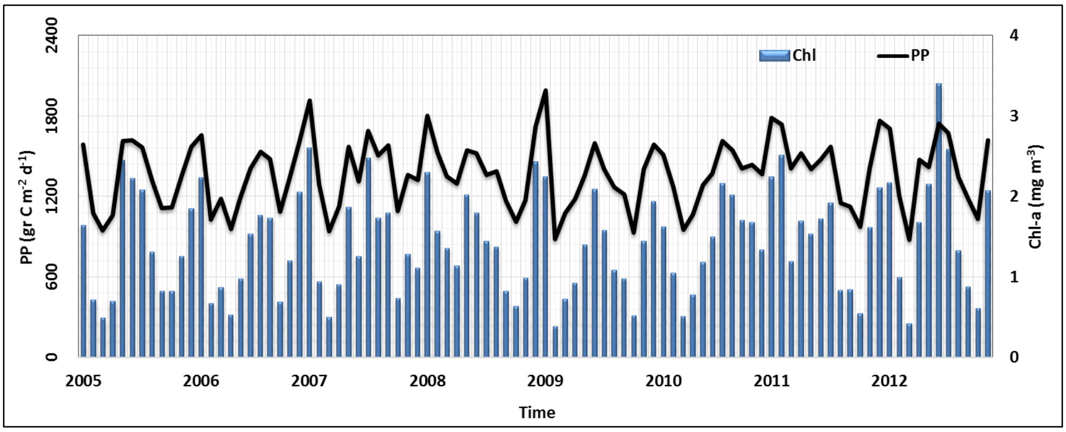


Figure 4.32. Times series relation between primary productivity and variety of chlorophyll concentration (Source: Data analysis, 2015).

Relationship between primary production and chlorophyll concentration was found to be linear. Statistic revealed correlation between both variables were very strong with r^2=0,86 (as shown in Figure 4.33). In general, the chlorophyll concentration is one of important parameter that will influenced the variety of primary productivity in the ocean environment.

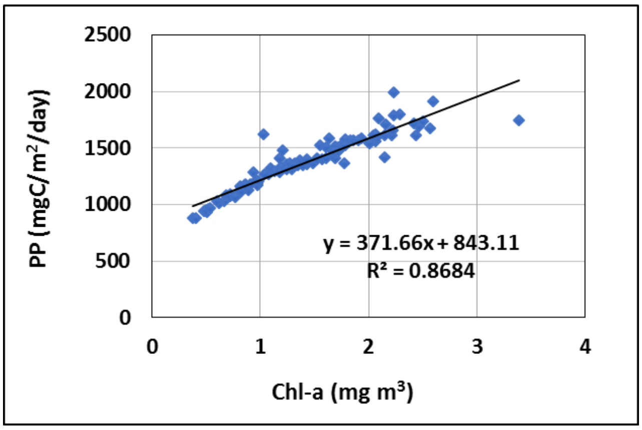
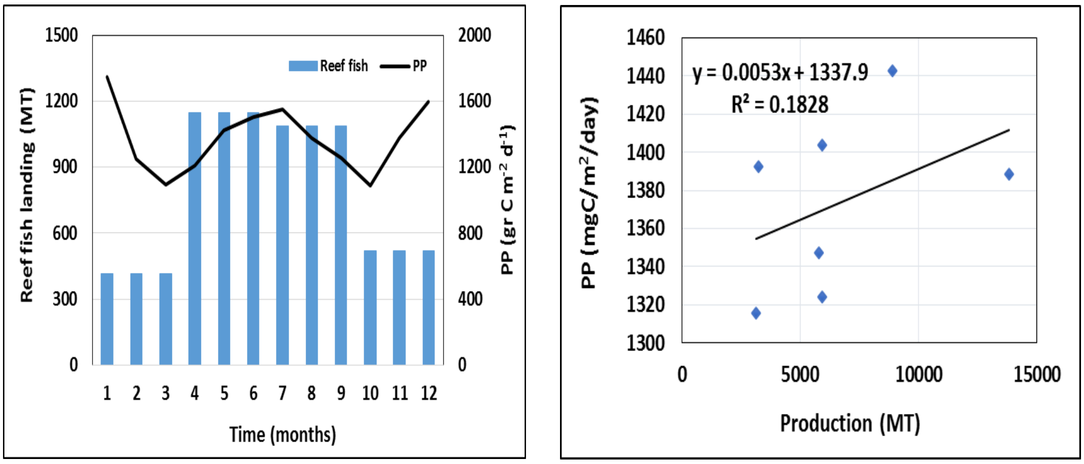


Figure 4.33. Correlation of MODIS PP and Chl-a (Source: Data analysis, 2015).

4.6. Relation between primary productivity and fish statistics

In general, there is no relation between primary productivity and reef fish production from 2005 to 2012 as illustrated in Figure 4.34b, but there is interesting point that the production of reef fishes reach maximum during Q2 and Q3 whereas primary productivity also shown second highest growth in a year (figure 4.34.a).



a b

Figure 4.34. Monthly comparison of primary productivity and reef fish production (a), and correlation of both variables (b) (Source: Data analysis, 2015).

Although the relationship was found linear, statistic returned as r^2=0,18 which mean no significant correlation between primary productivity and reef fish production (figure 4.34b). It can be concluded from this value, that in eight years there is no relationship of mutual influence between the level of primary productivity in the waters of the Bintan Island to the increased catches of reef fish itself.

4.7. Relation between sea surface temperature and chl-a concentration

Data shows that generally high abundant of chlorophyll concentration related to minimum temperature lies on sea surface during the wet season from December to February. Unfortunately, chlorophyll concentration is not always performing as the general fact, the second growth of chlorophyll arises in the dry season, from May until August, whereas temperature higher than rainy days (figure 4.35).

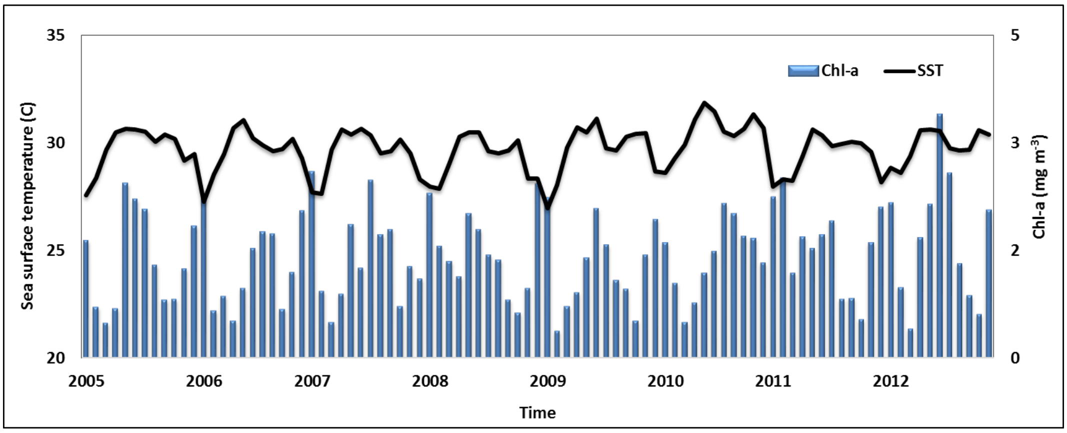


Figure 4.35. Times series relation between sea surface temperature and chl-a (Source: Data analysis, 2015).

Its relation close to linear with negative direction where growth of chlorophyll concentration happened in lower temperature. Unfortunately, there is no significant correlation between these variables as statistic revealed r^2=0,01 (figure 4.36).

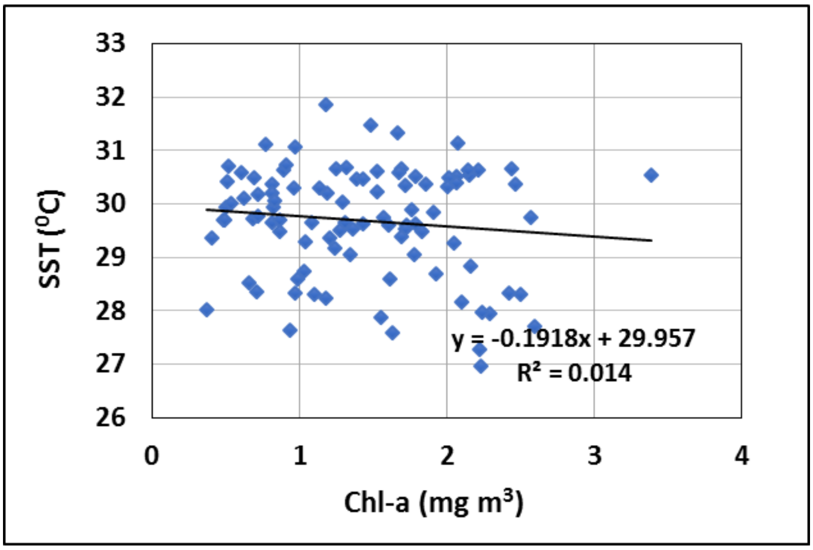


Figure 4.36. Correlation of SST and Chl-a (Source: Data analysis, 2015).

Chapter 5. Discussion

5.1. Chlorophyll Concentration

The distribution of chlorophyll concentration variance within one year as found in this study. The chlorophyll production peak occurred in May to July (dry season) except in January that shows the same value as in May. Ke, et. al, (2012) found that the distribution of chlorophyll (and environmental factors) are influenced by the pattern of sea surface currents and an abundance of food, and this effect is greater in the summer. While the low chlorophyll concentrations recorded in September to December (wet season). Average concentration of chlorophyll in the summer (0,7 mg/m^3) nearly doubled the rainy season (0.4 mg/m^3). The results of validation using the RMSE was 0.11 (n = 10) it shows that the values obtained satellite images have good accuracy. So is the value of the correlation coefficient (r2 = 0,32) also shows considerable correlation.

The high content of chlorophyll in the summer is likely to be influenced by the abundance of food and sunlight penetration in waters that support the process of photosynthesis that eventually led to the abundance of fish in the waters. Landed reef fish production data show good value between April to September (see figure 4.29).

Distribution of chlorophyll content pretty well in the area around the beach (between 5-10 km) allows to be used as a location for the development of fish farming, given the high availability of chlorophyll and sheltered area between the small islands. Especially from Western to Southwestern part of the study sites.

5.2. Sea Surface Temperature

In tropical regions, such as Indonesia, within one year only distinguished in two seasons, dry and wet season, where temperatures are generally higher in the dry season than during the rainy season. As aforementioned, the SST 31,9^{0}C highest recorded in May 2010 (dry season) and 27^{0}C as the and lowest in January

2009 (wet season). The distribution of sea surface temperatures start to vary the time of entering the summer (April) and relatively constant until the end of the season. Temperatures fell as he entered the rainy season (October) until it reaches the lowest temperature month of January. Validity test of MODIS data and in situ shows the value RMSE = 0.007 significance level of data accuracy is very good. The average temperature in the summer of 30^0C and 29^0C during the rainy season.

SST from MODIS imagery tends to be higher than the temperature in situ. This is probably due to the value of sea surface temperature obtained by Aqua MODIS satellite sensor for one month to the average value of one month's image.

Sea surface temperature affects the rate of photosynthesis and distribution of phytoplankton in the water column. The optimal temperature range for the breeding of phytoplankton in the tropics, range 25-32^0C (Kemili & Mutiara, 2012; Nontji, 2007). According to Nybakken, (1992) temperature of sea water is very high in the surface layer will be resulted in mixing of water masses with the underlying layer (down welling) so that phytoplankton also carried over into the water column and the waters become less productive.

In general, the surface temperature of the water near the shore is slightly higher than the temperature in the offshore. The average sea surface temperature in Indonesian waters range between 28-31^0C (Nontji, 2007). In Indonesian waters maximum temperature occurs in the Transition Season I (around April- May) and a minimum in the Transition Season II (around November). In Transition season I, winds relatively weak and sea surface warming is becoming stronger, due to the high intensity of illumination and calm water conditions causing heat absorption into the sea water becomes higher and sea surface temperature become maximum. In the Transition Season II, highest precipitation, very strong wind speeds, and relatively low radiation intensity and more wavy sea surface, thereby reducing heat penetration into the sea, it has resulted in the minimum sea surface temperature (Illuhade & Nontji, 1999; Rasyid, 2010).

MODIS sea surface temperature imagery is also used to determine the amount of the daily value of optimal carbon fixation rate (P^B_{opt}) on VGPM models, using seventh polynomial equation. At the optimum temperature between 18 and 22^{0}C will provide value P^B_{opt} maximum 6,6. In the study the maximum value obtained in December and January, are 4,43 and 4,45 mgC/mgChl/h respectively (see figure 4.15a).

5.3. Primary Productivity

Primary productivity in study locations varied enough in a year. The average monthly value of primary productivity showed the highest values in December of 2270 grC/m^2/d and low of 1264.6 grC/m^2/d in March. Mean value variations of primary production as illustrates in Table 5.1.

Although the average scores were highest in December, the highest actual value recorded in June of 3219.6 grC/m^2/d. In contrast to the distribution of chlorophyll concentration average value of primary productivity in the rainy season is higher than in the summer, which 1593.6 gr.C/m^2/d and 1481.0 grC/m^2/d respectively (see Table 5.1.)

In the eight years of data of this study, we can see that entering the peak of the rainy season between December/January primary productivity values reached a peak and then decreases to the smallest value in February. Entering the summer, which is quite a lot of sunlight to support photosynthesis, PP grew back to its peak in June/July and then declined until October before going up to the November-December.

The average value of the concentration of chlorophyll in December and January is smaller than the months in the summer. However, the value of primary productivity showed the highest value for the month. Nor et al., (2013) and Woldegiorgis (2012) reported that the factor which likely plays an important role in this regard is the daily rate of carbon fixation (P^B_{opt}) where the optimum temperature will also be a crucial factor for the model used in this study.

Table 5.1. Temporal variability of primary productivity from 2005 to 2012 in the study area (Source: Data analysis, 2015)

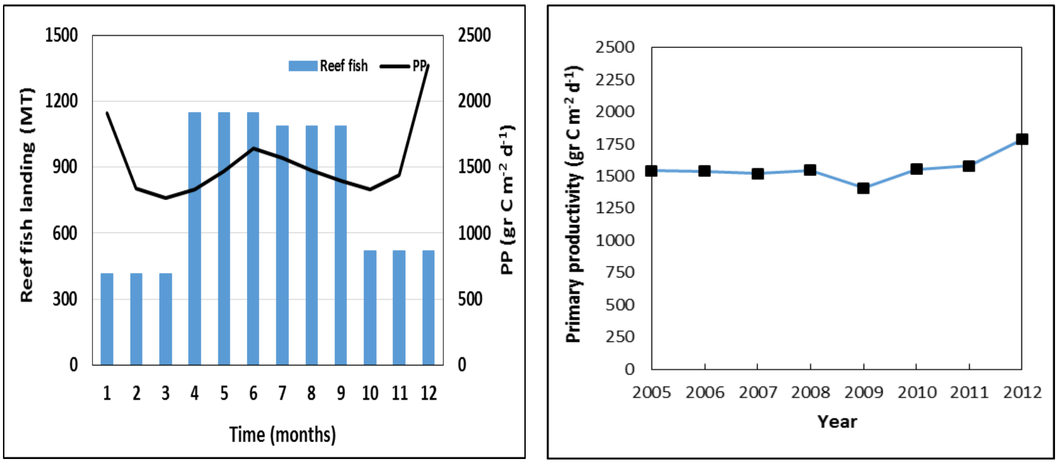
No	Months	PP (gr C $m^{-2}d^{-1}$)		
		Min	Max	Mean
1	January	1242.1	2666.0	1909.8
2	February	852.7	2320.6	1341.2
3	March	867.6	2523.3	1264.7
4	April	847.7	1962.0	1329.3
5	May	912.7	2217.1	1470.0
6	June	993.6	3219.6	1644.5
7	July	1040.3	2590.4	1569.7
8	August	943.4	1799.0	1476.6
9	September	868.0	2887.9	1395.9
10	October	851.3	2721.0	1334.1
11	November	955.5	2363.5	1441.6
12	December	1494.1	2850.1	2270.0

5.4. Exploitation of Reef Fisheries

In general, the production of reef fish in the waters of the island of Bintan has exceeded the amount recommended by the Ministry of Maritime Affairs and Fisheries, there has been excessive exploitation of the species of reef fish in these waters. This excessive exploitation has occurred since 2008 in which of the allowed volume of 3390 MT production reached 175% (Figure 4.28). Even in the last year of this study exploitation rate exceeds 400% of the allowed amount. The same is indicated by (Dahuri, 2003) that in the year he expected excess catch reef fish has reached 300%.

By comparing the pattern of distribution of PP and reef fish production in the study area (from 2010 to 2012) found a pattern that is quite interesting, that the peak catches occurred in the summer between April and September where the value of the PP also showed a similar pattern. But at the peak of PP production value slipped so far, this is due between October to April, when the wind blows the northeast monsoon. At its peak between November to February, the weather turned erratic as wind speed and sea waves, even the ocean wave height can reach

2 to 4 meters. So that fishermen prefer to moor the boat and perform maintenance on production facilities at their home.



(a) **(b)**

Figure 5.1. Temporal variation of primary production and reef fish statistic from 2010 to 2012 in the study area (Source: Data analysis, 2015).

Comparing the annual primary productivity and annual reef fish catches are something quite interesting, where annual data are compared there is a relationship that reef fish production is quite high at the time of the second growth of primary productivity in the ocean (figure 5.1a).

Comparing variety of the annual primary productivity and annual reef fishes catches In general, over exploitation of reef fisheries has not been triggered by environmental variables, as within eight years the primary production level are considerably have no extreme variation (figure 5.1.b).

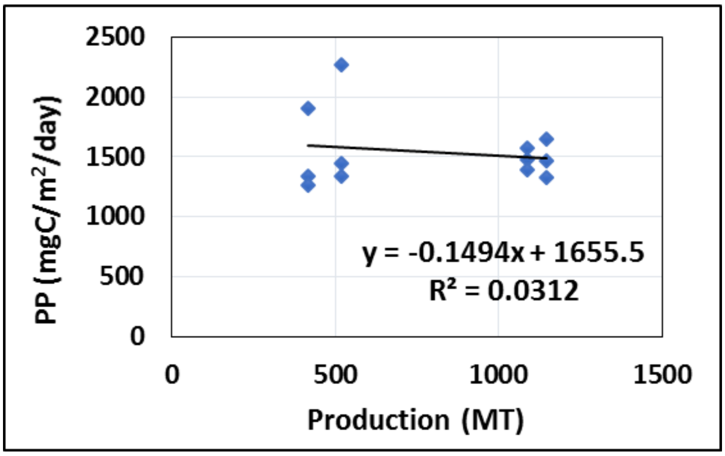


Figure 5.2. Correlation coefficient of primary production and reef fish statistic from 2010 to 2012 in the study area.

Across study period there is no significant correlation between the variation of primary productivity and reef fish landing data as revealed r^2=0,03 and the negative mark inform that even in the highest primary production, reef fish catch shows a reverse form (figure 5.2).

Chapter 6. Conclusions and Recommendations

6.1. Conclusions

Following are the answers of research question:

1. Are there any major differences in dynamic of sea surface temperature distribution during 2005-2012?

   In eight years the general pattern of sea surface temperature changes started in October to the lowest in January or February. SST recorded 31,9^{0}C month high of May 2010 and the lowest temperature in January 2009. 27,0^{0}C. within a year the highest sea surface temperatures average 31,5^{0}C in June and the lowest was in February 28,7^{0}C. The year 2010 was recorded as the warmest year with an annual average temperature of the highest and lowest 30,8^{0}C 29,8^{0}C in 2008. When compared between seasons, summer temperatures are on average higher than wet season, 31.0^{0}C and 29,6^{0}C respectively.

2. Are there any major differences in dynamic of chlorophyll concentration distribution during 2005-2012?

   The highest monthly chlorophyll concentration mostly recorded in January. However, actual highest chlorophyll concentration of 3.4 mg/m^3 actually occurred in June 2012 and the lowest was 0.4 mg/m^3 in February 2009. Average monthly chlorophyll-a concentration are 2.1 mg/m^3 and 0.7 mg/m^3 recorded in January and March respectively. Of the eight years of data studied in 2012 is the year with the highest chlorophyll concentration about 1.6 mg/m^3 and in reverse recorded in 2009 almost 1,3 mg/m^3. Comparison between seasons shows that in summer chlorophyll concentration a little bit higher than the wet season, which is 0,7 mg/m^3 and 0,4 mg/m^3 respectively.

3. What kind of relationship exists between SST and chlorophyll concentration distribution in Bintan island waters during 2005-2012?

   In general there is a reciprocal relationship between sea surface temperature and chlorophyll concentrations in surface waters, at high temperatures recorded low chlorophyll concentrations and vice versa. However, statistical tests pointed there is no relationship between those two variables (r^2 = 0,01).

4. What kind of the relationship between primary productivity and chlorophyll concentration?

   A very strong relationship between chlorophyll concentration and primary production value, in the waters around the Bintan Island, was indicated with high correlation coefficient value (r^2= 0,86). This means that when chlorophyll concentration increased in the water is always followed by the increasing primary productivity value per unit area per unit time.

5. Is there any relation between exploitation of reef fish with aquatic primary production?

   Although was had a linear relationship, between reef fish production and primary productivity estimation values have a weak correlation (r^2=0.18). But there is an interesting fact, a comparison of three years of data from 2010 to 2012, that production pattern of catches similar to the variation of primary productivity in one year.

6. What are the alternatives to maintain a sustainable reef fisheries?

   Fishery statistical data shows other variables that follows the reef fish production grew is fishing vessels units, especially smaller boats with deadweight less than 5 GT and cruising under five miles. Allegedly aquatic habitat reef fish already saturated by the increase in fishing fleet units operating in the region. To prevent the spread of this trend, we need a rule that regulates fisheries governance, particularly for the use of reef fish. Provision of equitable fishing port facilities may help to determine the actual production of reef fish species in the study area. So that preventive measures can be taken before it becomes too late.

6.2. Recommendations

The following recommendations were formulated based on the result of the study:

1. Indispensable availability of reliable and sustainable fisheries statistical data that can be used as a basis for fisheries development planning activities in the future and could also be an early indication to determine the level of utilization of various types of fishery resources.
2. Based on the utilization rate of reef fishes are already exceeded the allocation of the total allowable catch of the Ministry of Maritime Affairs and Fisheries, recommended further research to find out more detail the factors that lead to an excess of the catch. For that, once again the availability of reliable and sustainable fisheries statistical data to be important.

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APPENDIX

Appendix 1. Statistic of Reef Fish Catch Report from 2006 to 2012 in from Bintan Waters (MT)

No	Coral Fish		2005	2006	2007	2008	2009	2010	2011	2012
	Local Name	Market Name								
1	*Ekor kuning*	Yellow tail	0	1346	1356	2891	2891	1890	1890	1034
2	*Lencam*	Spangled emperor	0	184	194	215	215	1238	1238	21
3	*Bambangan*	Crimson snapper	0	332	342	1890	1890	1403	1403	5321
4	*Kakap merah*	Mangrove red snapper	0	61	71	97	97	102	102	320
5	*Kurisi*	Nemipterus sp.	0	187	207	46	46	343	343	218
6	*Kerapu karang*	Coral hind	0	607	627	256	253	244	244	2786
7	*Kerapu lumpur*	Leopard coralgrouper	0	0	0	0	0	0	0	808
8	*Kerapu sunu*	Orange-spotted grouper	0	0	0	0	0	0	0	111
9	*Dingkis*	White-spotted spinefoot	0	0	0	0	0	0	0	38
10	*Baronang*	Golden-lined spinefoot	0	428	438	543	543	552	552	3162
	Total		0	3145	3235	5938	5935	5772	5772	13821

Appendix 2. Estimation of the Potential of Fish Resources in Each Fishery Management Area (FMA) of the Republic of Indonesia

Appendix I of Decree of the Minister of Marine and Fisheries of the Republic of Indonesia. No. KEP.45/MEN/2011 on Potential Estimation of Fish Resources in Regional Fisheries Management of the Republic of Indonesia

Estimation of the potential of fish resources in each fishery management area (FMA) of the Republic of Indonesia

Fishery Resources	Malaka Strait	Indian Ocean		South China Seas	Java Seas	Makasar Strait-Flores Seas	Banda Seas	Tomini Bay - Seram Seas	Sulawesi Seas	Pacific Ocean	Arafura Seas-Timor Seas	Total
	WPP 571	WPP 572	WPP 573	WPP 711	WPP 712	WPP 713	WPP 714	WPP 715	WPP 716	WPP 717	WPP 718	
Big pelagic fish	27,7	164,8	201,4	66,1	55,0	193,6	104,1	106,5	70,1	105,2	50,9	1.145,4
Small pelagic fish	147,3	315,9	210,6	621,5	380,0	605,4	132,0	379,4	230,9	153,9	468,7	3.645,7
Demersal fish	82,4	68,9	66,2	334,8	375,2	87,2	9,3	88,8	24,7	30,2	284,7	1.452,5
Penaeid Shrimps	11,4	4,8	5,9	11,9	11,4	4,8	*	0,9	1,1	1,4	44,7	98,3
Reef fishes for consumption	5,0	8,4	4,5	21,6	9,5	34,1	32,1	12,5	6,5	8,0	3,1	145,3
Lobster	0,4	0,6	1,0	0,4	0,5	0,7	0,4	0,3	0,2	0,2	0,1	4,8
Squid	1,9	1,7	2,1	2,7	5,0	3,9	0,1	7,1	0,2	0,3	3,4	28,3
Total pontential (1000 MT/year)	276,0	565,2	491,7	1.059,0	836,6	929,7	278,0	596,6	333,6	299,1	855,5	6.520,1

Appendix 3. Reef fishes total allowable catch in Kepulauan Riau waters.

No	Region	Potential (MT/year)
1	Bintan	3.386,49
2	Tanjungpinang	4,31
3	Batam	107,85
4	Karimun	258,84
5	Lingga	10.288,89
6	Natuna	1.811,88
7	Anambas	1.704,03
Total		17.562,29

Source: Komnasjiskan 2010 (adjusted data)
Dinas Kelautan dan Perikanan Provinsi Kepulauan Riau, 2011.

Appendix 4.

WATER COLUMN CHLOROPHYLL *A* EXTRACTION

Adapted from: A Practical Handbook Of Seawater Analysis, Determination of chlorophyll, Spectrophotometric determination of chlorophylls and total carotenoids. By Strickland, J. D. H., & Parsons, T. R. (1972).

A. Introduction.

An extraction with 90% acetone under the conditions described in the method which follows has been considered satisfactory by most workers for many years. We believe this still to be the case for most seawater samples, having regard to the accuracy considered adequate for most investigations of marine ecology. Chlorophyll a, a characteristic algal pigment, constitutes approximately 1% to 2% (dry weight) of planktonic algal biomass. This feature makes chlorophyll a convenient indicator of algal biomass. This method is applicable to most surface waters.

B. Outline Of Method

The larger zooplankters are removed by straining a sample of sea water through a nylon net of about 300-p, mesh size and then the phytoplankters are filtered onto a Millipore AA filter or a glass filter. Pigments are extracted from the algae cells for estimation spectrophotometrically.

C. Special Apparatus And Equipment

Millipore filtration equipment designed to hold 47-mm diam membrane filters. One 300-ml polyethylene wash bottle. Stoppered graduated centrifuge tubes of 15-ml capacity having both glass and polyethylene stoppers. "Small volume" spectrophotometer cells having a path length of 10 cm but holding 10 ml or less of solution.

D. Sampling Procedure And Sample Storage

Adequate sampling of the euphotic zone or detrital layers for phytoplankton is a subject which is outside the scope of the present method. Once obtained, the final sample (generally 500 m1-5 liters in volume) is filtered through a small piece of clean 0.3-mm mesh nylon netting to remove the larger zooplankton.

For open sea samples filtration of small volumes through a 0.15-mm mesh net will still not retain significant amounts of phytoplankton. The required volume of this filtrate should be measured by a polyethylene measuring cylinder into a polyethylene bottle.

Two or three drops (Ca. 0.1-0.2 ml) of magnesium carbonate suspension are added. The sample may then be stored in a cool dark place for a maximum of about 8 hr. It is desirable, however, that samples be filtered through a membrane filter at the time of collection.

Membrane filters can be stored by folding them in half (with the plankton innermost) and storing them in the dark in a desiccator frozen to -20^{0}C but only for a few weeks. This procedure almost always leads to low results and makes the extraction of chlorophyll more difficult; filters should be extracted without delay if at all possible.

E. Special Reagents

1. Special Reagents

Distill reagent grade acetone over about 1% of its weight of both anhydrous sodium carbonate and anhydrous sodium sulphite. Collect the fraction boiling at a constant temperature near 56.5 C (uncorrected). 100 ml of water is pipetted into a liter volumetric flask and acetone added to make the volume to exactly 1000 ml. The redistilled acetone should be stored in a tightly stoppered dark glass bottle and the 90% reagent prepared in moderately small amounts (say 1 liter at a time) for use. This reagent is conveniently dispensed from a polyethylene wash bottle which should be kept nearly full. If good quality reagent acetone is available, it should be shaken with a little granular anhydrous sodium carbonate and decanted directly for use.

2. Magnesium Carbonate Suspension

Add approximately 1 g of finely powdered magnesium carbonate (light weight or "Levis" grade) of analytical reagent quality to 100 ml of distilled water in a stoppered Erlenmeyer flask. Shake vigorously to suspend the powder immediately before use.

F. Experimental

1. Invert the polyethylene bottle containing the sample into the funnel of the Millipore filter equipment fitted with either a 47-mm diameter Millipore AA filter or a 4.5-cm Whatman GF/C glass filter paper. The bottle need not be rinsed but the contents should be shaken vigorously, before filtration is commenced. If not added previously, add about 1 ml of magnesium carbonate suspension to the last few hundred milliliters of sample being filtered.
2. Drain the filter thoroughly under suction before removing it from the filtration equipment and if a Millipore filter is used trim away the peripheral excess of unstained membrane with clean scissors. Store the filter if necessary but if possible extract the pigment without delay.
3. Place the filter in a 15-ml stoppered graduated centrifuge tube. If a Millipore filter was used add approximately 8 ml of 90% acetone, stopper the tube, and dissolve the filter by shaking the tube vigorously. If a glass paper was used add approximately 10 ml of 90% acetone, stopper the tube, and disperse and disintegrate the paper by shaking the tube vigorously. Allow the pigments to be extracted by placing the tube in a refrigerator in complete darkness for about 20 hr. It is good practice to shake the tubes vigorously once more after they have been 1 or 2 hr in the refrigerator.
4. Remove tubes from the refrigerator and let them warm up in the dark nearly to room temperature. Add 90% acetone to make the extracts from Millipore filters up to exactly 10.0 ml and those from glass filters to exactly 12.0 ml Centrifuge the content of the tubes for 5-10 min having replaced the glass stoppers on the centrifuge tubes with plastic stoppers to prevent breakage during centrifugation.

5. Decant the clear supernatant liquid into a 10-cm-path-length spectrophotometer cell designed to hold 10 ml or less of liquid. In the event of extinction values exceeding about 1.3 the measurements described below should be made with 2.5-cm or 1-cm cells and the extinction values multiplied by 4 or 10, respectively, to normalize them to the values expected with a 10-cm cell. If 12 ml of acetone is used with glass papers multiply the extinction values by 1.2 to normalize them to the values expected from 10 ml of extract.
6. Without delay measure the extinction of the solution against a cell containing 90% acetone at 7500, 6650, 6450, 6300, and 4800 A. Record the extinction values to the nearest 0.001 unit in the range 0-0.4 and the nearest 0.005 for extinctions exceeding about 0.4.
7. Calculate the concentration of pigments in sea water from the equation

$$C = 11{,}6 * E665 - 1{,}31 * E645 - 0{,}14 * E640\left(\frac{extract\_volume\_(ml}{cuvette\_width\_(cm)})\right)$$

Where C is a value obtained from the following equations and V is the volume of sea water filtered in liters. When the Parsons-Strickland equations are used values for chlorophylls a, b, or c will be in mg/m^3.