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Effects of oceanographic factors on spatial distribution of Whale Shark in Cendrawasih Bay National Park, West Papua

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Abstract. Whale sharks are a leading species in Cendrawasih Bay due to its benign nature and its regular appearance. Recently, whale sharks are vulnerable to scarcity and even extinction. One of the efforts to maintain the existence of the whale shark population is by knowing its spatial distribution. This study aims to analyze how the oceanographic factors affect the spatial distribution of whale sharks in Cendrawasih Bay National Park. The method used in this research is descriptive with the quantitative approach using *the Generalized Additive Model* (GAM) analysis. The data consisted of the whale shark monitoring data in TNTC taken by WWF-Indonesia, and image data of sea surface temperature (SST) and chlorophyll-a concentration of Aqua-MODIS, and also sea surface current from Aviso. Analyses were conducted for the period of January 2012 until March 2015. The GAM result indicated that sea surface current was better than the other environment (SST and chlorophyll-a concentration) as an oceanographic predictor of whale shark appearance. High probabilities of the whale shark's to appear on the surface were observed in sea surface current velocities between 0.30-0.60 m/s, for SST ranged from 30.50-31.80 ºC, and for chlorophyll-a concentration ranged from 0.20-0.40 mg/m³.

1. Introduction

Whale sharks are one of the most common marine species found in TNTC waters [1]. The whale shark (*Rhincodon typus*) is the largest fish in the world, it has slowly grown and slow process of genital maturity, the number of tillers that it produces relatively little and live longer. These characteristics make the whale shark range scarcity and even extinction if exploitation uncontrollably [2].

Currently the whale shark population has declined globally, and has made the whale shark into the vulnerable status of IUCN Red List. In addition, whale sharks also enter into Appendix II of CITES and Annex I issued by UNCLOS. In Indonesia, the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia has established the status of the protection of whale sharks through the Decree of the Minister of Marine Affairs and Fisheries no. 18 of 2013.

Knowledge of whale sharks is very important, it is intended for the sustainability of living whale sharks. However, in Indonesia, research about whale sharks is relatively rare, especially whale sharks in TNTC. So still needed a study of whale sharks to add information and efforts in preserving the populations about this largest fish in their natural habitat. The purpose of this study was to analyze the effect of whale shark habitat seen from oceanographic factors in its spatial distribution.

Habitat whale sharks do not escape from the dynamic nature of oceanography. The occurrence of changes in a habitat will definitely affect the lives of biota living in the habitat. So we need a calculation that can calculate and analyze the relationship between variables in a non-linear manner. Analysis techniques that will be used in this research is using a statistic model of GAM (Generalized Addictive Model). GAM statistical modeling is a new modeling method that has strong strengths for non-linear approaches, so GAM can be conducted to support ecological-related research. Valavanis et al. (2008), the Generalized Additive Model (GAM) is one of the most common nonlinear statistical models used in the analysis of fisheries data [3].

2. Study area, material, and method

2.1. Study area

This study was conducted in August-December 2016 with study area is the waters of Teluk Cendrawasih that enter into the Cendrawasih Bay National Park area (figure 1). Geographically, Cendrawasih Bay National Park is located at coordinates 1^{o}43'-3^{o}22' S and 134^{o}06'-135^{o}10' E. Data processing is carried out in the Computer Laboratory of Fisheries and Marine Sciences Faculty, Padjadjaran University.

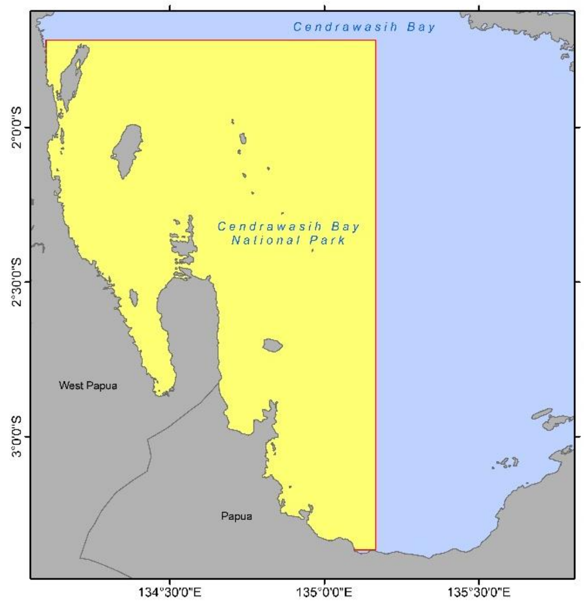

Figure 1. Study Area.

2.2. Material

Software used in this research shown in table 1.

Table 1. Software.

No.	Software	Utility
1.	ArcGis	Create a study area map Create merging of distribution of whale shark with oceanographic factors
2.	R	GAM analysis
3.	SeaDas	Data extracting from. TIFF format
4.	Ms. Excel	Data control process

A material used in this research shown in table 2.

Table 2. Material.

No.	Dataset (2012-2015)	Resolution		Source
		Temporal	Spatial	
1.	Sea Surface Temperature (SST)	2012-2015	4 Km	www.oceancolor.gsfc.nasa.gov
2.	Chlorophyll-a	2012-2015	4 Km	www.oceancolor.gsfc.nasa.gov
3.	Sea Surface Current	2012-2015	Wind Direction	www.aviso.altimetry.fr
4.	Point of whale shark's appearance	2012-2015	Point of occurrence	WWF Indonesia TNTC

2.3. Generalized Additive Model (GAM)

In general, the nature of oceanography and whale sharks that are dynamic, difficult to control and unpredictable, make the necessary calculations that can know the correlation between the two. Statistical calculations that have a non-linear approach can be the solution. This research data will be processed using statistical models of GAM (Generalized Additive Model). GAM static modeling calculations use the mgcv package contained in software R, using the following formula:

$$g(u_i) = \alpha_0 + S_1(X_{1i}) + S_2(X_{2i}) + S_3(X_{3i})$$

Where:
G: The link of function
A: The expected value of the dependent variable (Whale Sharks's Appearance)
α_0: The model constant
$\chi_{1,2,3}$: Parameter values (Sea surface current-SST-Chlorophyll-a)
Sn: A smoothing function for each of the model covariates

We used the GAM model to determine the relation between parameters of oceanography to the distribution of whale sharks in TNTC. GAM modelling is done by using Gaussian distribution and identity link function [3]. GAM model formation starts with every single explanatory variable, followed by a combination of two and three explanatory variables.

2.4. Comparative analysis

The results of the calculations using statistical modelling were analysed descriptively to get a descriptive comparison between oceanographic factors to the spatial distribution of whale sharks. Comparative descriptive analysis was also conducted to determine which oceanographic factors have a greater influence by comparing the oceanographic factors to the spatial whale shark distribution.

3. Results and discussion

3.1. Whale sharks distribution

The data used to determine the spatial and temporal distribution of whale sharks in TNTC were collected by fisherman and TPHP WWF Indonesia TNTC from 2012 to 2015. On the table 3, the number of observations made each month was not the same means observation was not done every day. This causes the number of occurrences of whale sharks recorded each month to differ so that the number of whale sharks from 2012 to 2014 was much different. The difference in the number of whale sharks can also be caused by the behavior of whale sharks.

Table 3. Whale Shark's Occurrence in TNTC.

Month	2012			2013			2014			2015		
	D	A	D/A	D	A	D/A	D	A	D/A	D	A	D/A
Jan	31	610	20	18	115	6	9	24	3	14	39	3
Feb	29	580	20	28	396	14	16	54	3	11	23	2
Mar	31	853	28	31	248	8	16	27	2	5	17	3
Apr	30	544	18	30	156	5	17	7	0	-	-	
May	23	258	11	30	156	5	19	48	3	-	-	
June	27	91	3	17	99	6	19	0	0	-	-	
July	18	35	2	19	81	4	21	0	0	-	-	
Aug	8	14	2	17	55	3	21	0	0	-	-	
Sept	21	44	2	26	100	4	16	0	0	-	-	
Oct	19	104	5	10	30	3	10	167	17	-	-	
Nov	8	15	2	4	27	7	18	57	3	-	-	
Dec	11	15	1	5	21	4	9	33	4	-	-	
Total	**256**	**3163**		**235**	**1484**		**191**	**417**		**30**	**79**	

D: number of observations (days); A: number of occurrences (whale sharks); D/A: average daily

The appearance of whale sharks to sea level was related to the behaviour of whale sharks. Whale sharks will swim and occurrence on the sea surface to search for food, but the whale shark will also dive into the water column to follow where the food goes. Generally, whale sharks spend time in shallow waters less than 50 m or near the surface because whale sharks are plankton-eating sharks and are animal filter feeders. According to Brunnschweiler *et al*. (2009), the tendency of whale shark to dive in the deep waters allegedly to follow the movement of food or to detect the condition of a water [2].

The number of occurrences of zero (0) in a given month could be said that whale sharks at the same time are swimming in the water column, so monitors did not see whale sharks appearing on the surface. The absence of whale shark's recording may be due to non-monitoring at any given time. Many factors that cause monitoring could not be done. In addition to knowing the number of whale sharks occurring over a period of time, the observations made in the TNTC region also showed the point of whale sharks. At one point the emergence of whale sharks, not only shows an individual that appears, but can represent more than one individual that appears (figure 2). This showed that whale sharks aggregate or stay in the same place within a few days.

The presence of differences in the point of occurrence could be due to the whale shark was an active swimmer. This was evidenced by the telemetry study by Stewart (2014), that there are six individual whale sharks attached to satellite markers showing movement in and out of TNTC [4].

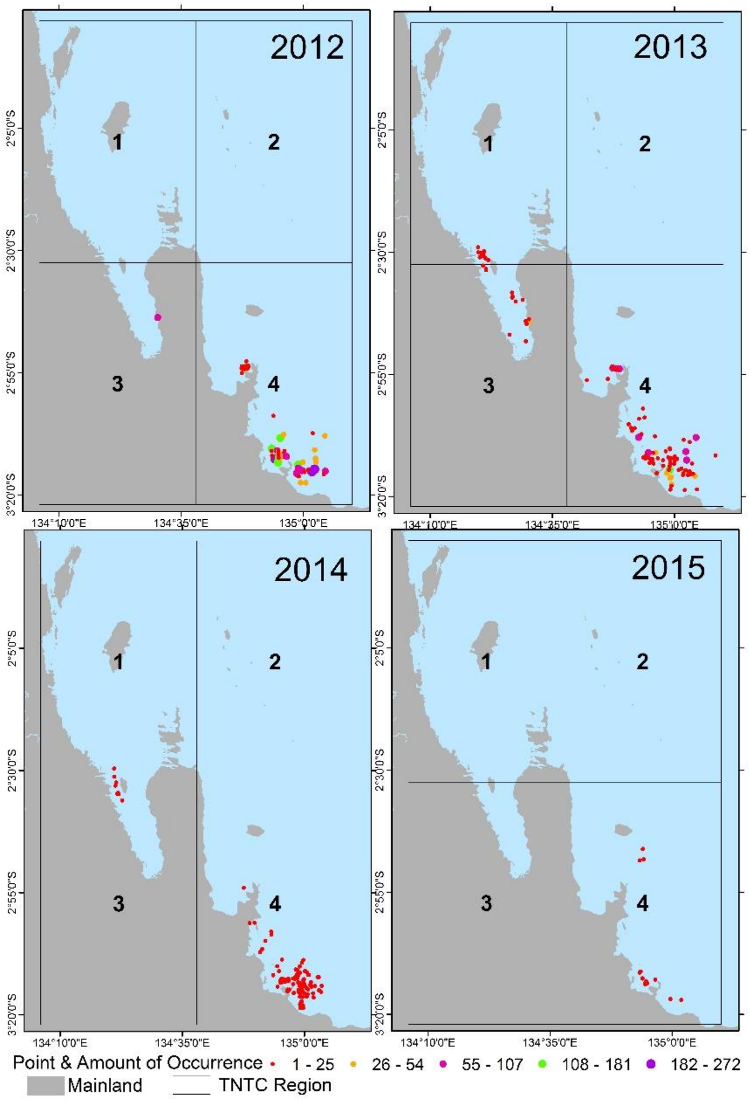

Figure 2. Point of Whale Shark's Occurrence.

3.2. GAM analysis

GAM model forming techniques began with one explanatory variable with a combination of two, and three explanatory variables or vice versa. In the model calculation results, there was a value of deviance and value of Akaike's Information Criterion (AIC). These two values indicate the level of accuracy of the explanatory variables in explaining the variation of response variables in each GAM model equation. The greater the value of deviance and the smaller the AIC value means the higher the accuracy of the GAM model in explaining the variation of response variables [3,5].

The GAM model equation by combining the three explanatory variables has the highest deviance value and the lowest AIC value. This shows that the combination of GAM models with the three explanatory variables has a high degree of accuracy. The significance level of each explanatory variable is grouped by Verzani (2005). The results of significance obtained in each explanatory variable are extremely significant and highly significant (table 3).

Table 4. GAM Results.

Model	Var.	Dev.	*P-Value*	AIC
s(SST) +s(Chl-a) +s(Current)	Current	3.14	0.000096***	0.0000000862
	SST	2.69	0.000354***	0.000000356
	Chl-a	1.85	0.001563**	0.00025
***Deviance* (%)**			6.16	
*** *Extremely Significant*			** *Highly Significant*	

At the time of formation of GAM model equations, there was a smoothing curve function used to model the relationship between response variables and their explanatory variables. The calculation result of smoothing curve estimation on each explanatory variable can be shown in graphical form using *the plot command* in program Rb (table 4).

The estimation graph of the smoothing curve consists of the x and y axis. The x-axis shows the values of the explanatory variables of the oceanographic parameter, and the y-axis shows the result of smoothing against the corresponding response variable value. The black lines on the graph show the results of GAM calculations visualized in graphical form, while the dashed black lines represent the 95% confidence interval. The red horizontal line represents the zero limit of data, where the data below the zero limit can be interpreted as the absence of correlation between the response variable and the explanatory variable or it can be said that the range of values is not the optimum value of the whale shark to surface (figure 3).

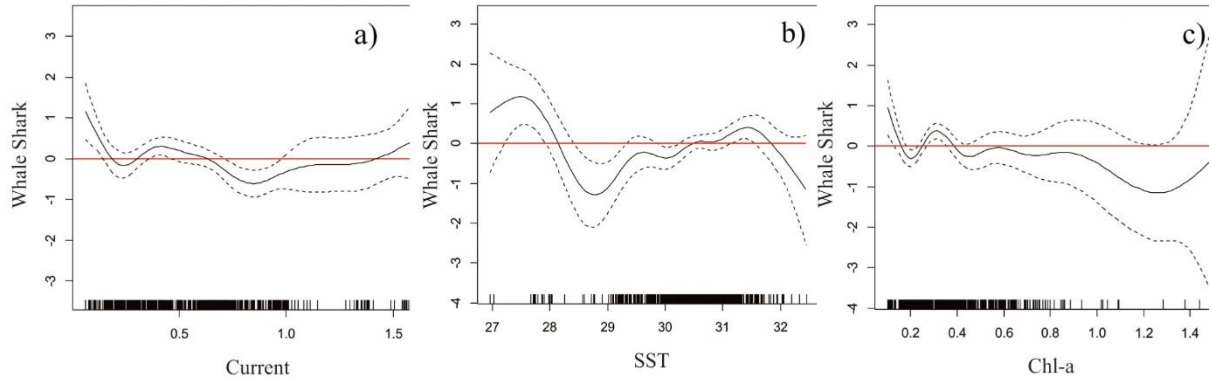

Figure 3. Effect of the Three Oceanographic Variables.

Whale sharks are plankton-eating animals. They may follow prey, such as various plankton, which are associated with high chlorophyll-a concentration [6]. Besides phytoplankton, there are many categories of zooplankton and small fishes and squids, which are also prey of the whale shark, and quantifying the prey in several areas where sharks pass through is needed [6].

The variable of chlorophyll-a concentration showed the lowest significance value when compared with other explanatory variables. Although whale sharks target many plankton as food, but whale sharks are more targeted zooplankton as its prey, so the analysis results showed smaller numbers of significance. In addition, the chlorophyll-a pigment is only owned by phytoplankton as the primary producer, so there was no direct contact between phytoplankton and the whale shark.

The occurrence of whale sharks in coastal waters is believed to coincide with productivity events that provide an ample supply of zooplantonic/larval food [7]. Our results strongly suggest that whale sharks target zooplankton as their primary food source in Bahia de Los Angeles and forage using several strategies that appear to be linked to prey abundance and composition [8].

In contrast to chlorophyll-a, the SST variable yields a very strong significance value, but is not as strong as a sea surface current variable. SST is believed to affect marine life, as well as the distribution of whale sharks. The cause of SST is not the most influential variable first, perhaps because whale sharks can tolerate a wide range of temperatures.

Whale shark dive to over 979.5 m, and can tolerate a temperature range 26.4 ^{0}C [9]. According to Colman (1997), a fairly large distribution of whale sharks can also show that whale sharks are tolerant of temperature, although whale sharks still favour warm temperatures [4]. The distribution of whale sharks is found in warm tropical and subtropical waters (18-30 ^{o}C) between 30^{o} N and 30^{o} S, except in the Mediterranean Sea [4].

Compared with SST and chlorophyll-a, surface current variables have the greatest effect on the distribution of whale sharks in TNTC. Tracking data show that the direction of travel in three sharks was influenced by prevailing geo-strophic currents [10]. The dominant whale shark's behaviour was near the surface of the sea, allegedly used by whale sharks to reach high-productivity areas. However, in the previous discussion, it appears that the movement of whale sharks was not affected by the speed and direction of surface currents. It was important to note that the whale sharks' data used were not data from whale shark tagging, so the movement of individual whale sharks was unknown.

Overall, the results of GAM analysis used to determine the magnitude of the influence of the three explanatory variables on response variables can only explain 6.16%. This value shows a small value. The low deviance value of the resulting GAM equation is thought to be due to the small number of datasets used. Although the data set used amounted to 1887, but the amount of time used was inconsistent in each year. In addition, the coordinates used in the dataset are coordinates that are almost always the same at each time, not the coordinates that cover the entire TNTC region.

Based on GAM plots, it could be seen the range of values of the explanatory variables that had a positive influence on the response variable. This positive influence showed the range of explanatory variable values favored by whale sharks to rise to the surface of the ocean. Positive effects for surface current variables ranged from 0.30 to 0.60 m / s. Positive effects of SST variables ranged from 30.50 to 31.80 ^{o}C, whereas for the variable chlorophyll-a concentration ranged from 0.20-0.40 mg / m^3.

3.3. Prediction of whale sharks in TNTC

Prediction of whale shark distribution in TNTC was spatially conducted to determine the number of individual whale sharks likely to surface or visit one of the areas in TNTC. This prediction calculation used the *predict. gam* function in the mgcv package that is inputted and calculated using the software R. The result of *predict. gam* function calculation is the number of individuals who have the opportunity to appear at the same point with the inputted data. The predictions map presented only consists of two months, where the month is the highest average and the lowest average appearance of whale sharks for four years.

In March, predictions show that about 2-4 individuals of whale sharks appear in all areas of TNTC. In March 2012, almost all areas of TNTC are predicted to be visited by 3-4 individuals of whale sharks. Didn’t much different from March 2012, March 2013-2015 is predicted to be visited by 2-3 individuals whale sharks. In each year, whale sharks are predicted to often visit area 4 or in areas close to the mainland.

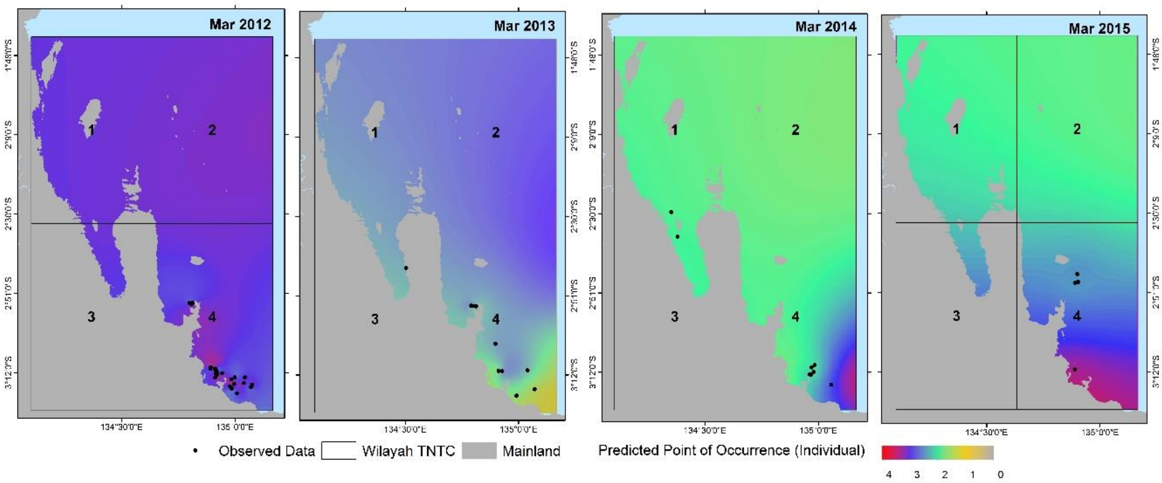

Figure 4. Prediction of Whale Shark's Occurrence on March.

Did not much different from March, August prediction shows 2-3 individuals whale sharks will appear in region 4. In August 2012, it's predicted that about 3 individual whale sharks will visit region 4, whereas in other regions only predicted about 2 individuals. In contrast to August 2012, August 2013 predicted whale sharks will visit the entire region of TNTC with the same number of individuals, which are about 2-3 individuals (figure 4).

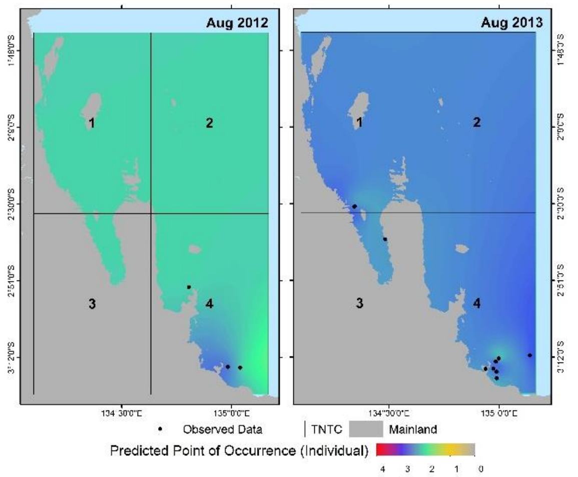

Figure 5. Prediction of Whale Shark's Occurrence on August.

This prediction results are similar to the results of monitoring conducted by TPHP WWF Indonesia TNTC. Whale sharks would still always visit region 4 as its favourite territory when compared to other regions. However, there was a little difference in March 2013, whereby whale sharks predicted dominant visiting in areas close to the high seas compared to areas close to the mainland (figure 5).

The differences could be attributed to the location of the monitoring and behaviour of the whale shark itself. Monitoring locations didn't cover the entire territory of TNTC made the lack of data in certain locations. The behaviour of whale sharks that are active but dominant swimmers make use of ocean surface currents, making the reason strong enough if whale sharks are constantly migrating and migrating for food or for finding new habitat locations.

Predicted results for both months showed similar results with monitoring results. The predominant individual is predicted to appear or visit on region 4 or in areas close to the mainland. This is related to the depth of the waters adjacent to the different land with deep water depths with the land. Whale sharks are known to favour shallow waters, which in the shallow waters of whale sharks can find their prey with ease, as well as warmer temperatures in the waters near land than those farther offshore.

4. Conclusion

Based on the results of the study and discussion, it can be concluded that the sea surface current has the high significant value on the emergence of whale shark Rhincodon typus in TNTC region, compared to sea surface temperature (SPL) and chlorophyll-a concentration. The range of oceanographic factors favoured by the whale shark to appear on the sea surface, respectively, is the velocity of sea surface current between 0.30-0.60 m/s; SPL between 30.50-31.80ºC, and chlorophyll-a concentration between 0.20-0.40 mg/m^3.

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