An Integrated Approach in the Determination of Optimum Condition and Controlling Factors for Coral Reef Distribution in the Case of Ibaruma Coast, Ishigaki Island, Okinawa, Japan.

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1. Introduction

The declining status of coral reefs has long been a worldwide issue as it brought significant loss to global biological diversity and socio-economic and ecological realms. Several efforts have been made in order to conserve, sustain, and restore degraded reefs to prevent their extinction (Hoegh-Guldberg, 2006). It is therefore critical to have a better understanding of specific environmental drivers of coral reef distribution, as well as enhanced scientific concept of what comprises a healthy reef so it will be possible to predict coral community's responses to multiple ecosystems' stressors (Bauman, et. al., 2013).

For both local and geographical scales, the distribution and development of coral reefs are governed by various and frequently interacting environmental factors such as temperature, light, salinity, solar radiation, sedimentation, water quality and hydrodynamic variables (Bauman, et. al., 2013). A number of studies have been conducted to investigate how these individual factors independently influence the coral reef distribution (i. e., Hongo and Yamano, 2003); however, most of these are species-specific and the variables were considered in relative isolation.

Currently, studies integrating all environmental factors that affect the coral reefs distribution are still limited, and to some extent, mostly covered regional scales only (Bauman, et. al., 2013). However, these various environmental factors that collectively affect the reef distribution patterns may be different from a regional scale to a local scale, and is driven by area-specific conditions.

In this study, the correlation between the range of environmental factors and coral reef distributions on a local scale will be investigated using a methodological approach which integrates field observation, GIS mapping, numerical-wave simulation and SST remote sensing.

1.1 Background and Purpose of the Study

In the near shore areas of Ibaruma, Ishigaki Island, Okinawa Prefecture, Japan, the information about specific environmental parameters which significantly control the distribution of the reef, as well as the optimum condition for corals, are particularly important in its current restoration and conservation activities. Investigating the environmental conditions where the corals are most abundant will provide a management and monitoring tool to estimate and locate the most suitable area for transplantation.

It is hypothesized in this study, that the reef distribution is not always primarily controlled by a single environmental factor, but that it is dependent on the combination of different interacting environmental variables. Ultimately, the goal of this study is to determine where the corals are most abundant and what are the optimum conditions and the controlling factors of such distribution in the area. To achieve this, the following specific objectives must be satisfied:
(1) to determine coral distribution along Ibaruma

Coast; (2) to identify, quantify, and plot various interacting environmental variables that affects the coral reef distribution: (wave energy, light attenuation, temperature data), and; (3) to determine the optimum condition for corals based on the identified controlling factors, as well as the presence of environmental stressors in the area (e.g., heat stress).

2. Materials and Methods

2.1 Study Site

Ibaruma is located on the northeast coast of Ishigaki Island (24° 30' 0" North, 124° 17' 0"), which is situated in the southern Ryukyu Islands, Japan (Fig. 1). Since Ishigaki Island is situated in an Asian monsoonal climate region, wind directions change seasonally: approaches from north during winter and from east to south during summer. The average sea-surface temperature (SST) is 24°C in winter and 28°C in summer (Japan Meteorological Agency website).

The reefs found in Ibaruma are characterized by fringing type which approximately span 1320m wide. Since Ibaruma coast faces the open ocean, it is greatly affected by monsoonal change of wind direction. It comprises of coral species that are typically windward-high- energy-forming reef.

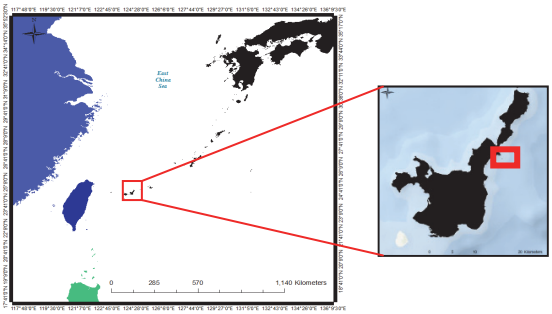

Figure 1. Location Map of Ishigaki Island situated at the southern part of Ryukyu Islands, Okinawa, and location of Ibaruma Coast in Ishigaki Island

2.2 Field Observation

Field survey to measure water depths and coral cover distribution in Ibaruma, as well as in situ measurement of photosynthetically active radiation (PAR) values were conducted on February, and June 2013 respectively. Water depths were measured using HydroSurveyorTM M9 (YSI), while live coral cover was assessed by employing video-transect method over a 1100 m along the coast by 800 m across the shore towards the reef crest. PAR values were measured using light sensor, assuming that the amount of chlorophyll (ChL) approaches to 0 mg/L Chl, and exhibits low turbidity.

2.3. Environmental Variables

Additional environmental parameters which have been examined in this study were the following:

Environmental Parameters	Source
1. Significant Wave height (m) - normal and stormy weather condition	SWAN Numerical simulation
2. Total Energy Dissipation (W/m^2) -normal and stormy weather condition	SWAN Numerical simulation
3. Orbital Velocity near the bottom -normal and stormy weather condition	SWAN Numerical simulation
4. Sea surface temperature (°C)	Extraction from Landsat Satellite Images

2.4 ArcGIS-Mapping, Spatial Analyst Tools and Data Analysis

After obtaining all the environmental variables that affect the distribution of corals, the data were plotted in a map using ArcGIS 10.1 software. Various spatial analysis tools such as interpolation, resampling, and data conversion and management tools were employed to achieve the appropriate resolution of the

spatial distribution of the different environmental factors. The final resolution for each variable maps was 30m, and all vector data are converted to raster format. The converted raster data were overlaid in the map (Figure 2) and the relationship of each variable in relation to each other and to the coral reef distribution were calculated and analyzed using partial least square regression. In addition, the optimal condition for corals were also determined based on the area where 100% coral cover is observed.

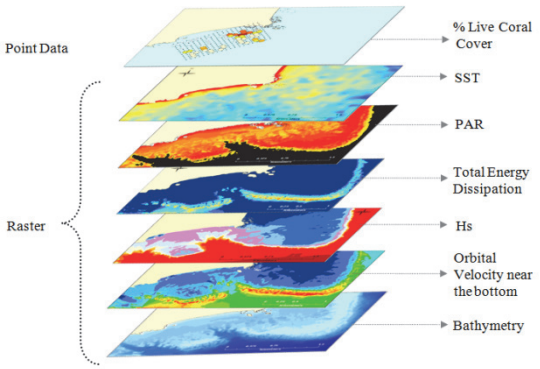

Figure 2. A graphic representation of the core GIS data types for the coral cover distribution and environmental factors.

3. Results and Discussion

3.1 % Live Coral Cover Survey

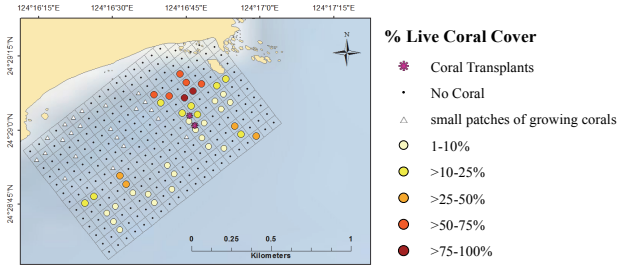

Figure 3. Percent Live Coral Cover present in the area.

Figure 3 shows the result of the coral cover field survey. It shows that the coral colony distribution is not evenly dispersed. Coral colonies, with high percent live cover, tend to occur in clumps at the eastern side of the observation area (124°16'45"E, 24°29'05"N) which is near some small islets.

The distribution maps were prepared for the environmental variables. When overlaid at each together with the coral reef data point, the following optimal condition for the coral reef were determined (Table 1), and the correlation map (Figure 4) were obtained:

Environmental Variables	**Optimum Condition**	**Stormy Condition Coral Cover are**
Depth (m)	1.04 ~ 2.67	
Light attenuation (PAR) (W/m^2)	995 ~ 1863	
Significant wave height (Hs) during normal condition (m)	0.146 ~ 0.191	0.556 ~ 0.963
Orbital velocity near the bottom (U_{bot}) (m/s)	0.077 ~ 0.156	0.402 ~ 0.777
Total energy dissipation (E_{total}) (W/m^2)	2.20e -06 ~8.21e -06	6.58e -05 ~ 1.42 e -03
Sea surface temperature (SST) (°C)	27.1 ~ 27.4	

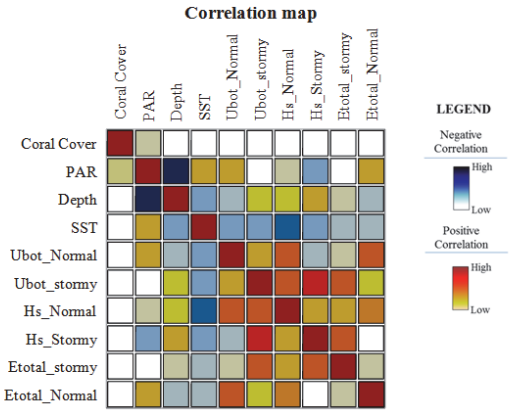

Figure 4. Correlation Map of % Coral cover and the different environmental variables employed in this study.

Quantifying the relationship of variables to each other provided an integrated overview of how one factor affects another. It must be noted that a low significant correlation result were obtained between coral cover and among all the environmental variables considered in this study. It must be accounted to the relatively

smaller ratio of the area of coral cover to the total observation area. Nonetheless, although low values for correlation were obtained, the factor which has the highest impact to the coral distribution was still obtained through the partial least square regression analysis: Figure 5 shows the variable of importance in the projection of corals. In the case of Ibaruma, depth gradation was identified as the most important factor explaining the distribution/condition of coral cover. Since most of the environmental variables is a function of depths, directly, or indirectly, the results obtained are just logical.

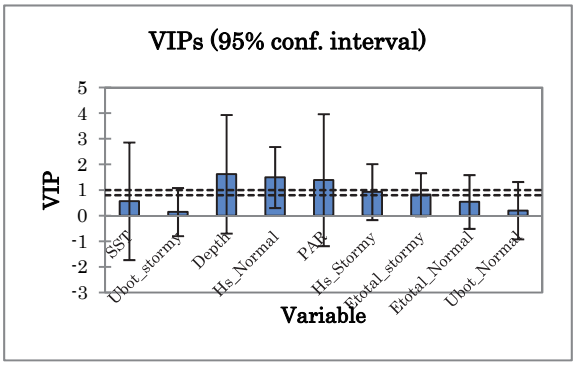

Figure 5. Variable of importance in the projection of coral cover.

4. Conclusion

The reef distribution is not always predominantly controlled by a single environmental factor, but it is dependent on the combination of different interacting environmental variables. Using a methodological approach which integrates field observation, GIS mapping, numerical-wave simulation and SST remote sensing, this study was able to determine the correlations between the range of environmental factors and coral reef distributions in Ibaruma Coast, Ishigaki Island Okinawa, Japan. The areas where the corals are most abundant, as well as the optimum conditions for corals were identified. Upon the course of identifying the optimum conditions for corals in the area, environmental stressors, such as possible heat stress occurrence and areas where corals will be most affected by extreme weather events such as typhoons, were identified. Ultimately, this study has identified the most controlling factor affecting the distribution of coral reefs in a local scale. Supported by the results of statistical analysis, series of simulations, and field observations, the most controlling factor among the environmental variables considered in this study, in the case of Ibaruma Coast, is the depth. Such information will be a useful management and monitoring tool in the current restoration and transplantation activities in the area.

While the findings of this study have underscored and confirmed the possibility of overlaying and mapping the various environmental factors in order to understand the complex interaction happening in a coral reef ecosystem on a local scale, there is still a need to improve the study design and include other environmental parameters such as other water quality parameters (salinity, nutrient loadings, turbidity), and tidal fluctuations. This will give a better understanding and holistic view of the synergistic and antagonistic effects of each environmental factor to the distribution of coral reefs.

5. References

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