Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

The Application of Geographic Information System to the Coral Reef of Southern Okinawa

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Abstract

Geographic Information Systems (GIS) was used as a tool to study the spatial characteristics of the coral reefs of Southern Okinawa. The study involved the intensive use two main spatial analysis modules of the GIS namely the image processing module and the decision support system module. Image processing was undertaken on a Landsat satellite image to produce a marine benthic habitat map. This process utilized a depth compensation algorithm, and the unconventionally used Bayesian “soft and hard” supervised classification to produce not only a single thematic map, but a set of multiple maps showing the probability values for each of the categories selected. Each of these produced images was assessed for their accuracy with the results showing only moderate accuracy, which is typical in contemporary literature. These maps are intended to serve as baseline information that can be used for future spatial analysis processes. The next step involved the use of the images produced from the image processing together with other derived images, to undertake a spatial decision support analysis. The analysis utilized five spatial images as evidences (i.e., carbonate probability cover, sand probability cover, land areas, deep water areas and distance from Chibishi reefs image) to produce a suitability map showing the areas where coral larvae from Chibishi will most likely settle in the intertidal areas of Southern Okinawa. Another spatial evidence was added (i.e., chl. *a* image) to produce another map to showing the chances of surviving of these larvae. Results show that the bay areas in the eastern side of Okinawa as having very low probabilities of settlement and survivorship of larvae from Chibishi. It is argued that this might be one of the reasons why these areas with very good coral cover 30 years ago is now mostly just dead reefs.

Key Words; *Decision Support System, GIS and Environmental Modelling, Bayesian Probability, Okinawa, Marine Benthic Habitat Classification, Idrisi*

Introduction

Man has constantly altered the earth different ecosystem. The coastal areas, which support 60% of the world’s population, are arguably one of the areas where anthropogenically-driven change is most intense (Pernetta & Milliman 1995). Nowadays, more concerted efforts are being undertaken towards understanding how anthropogenic changes affect the environment. For it is only in understanding ecosystems that humans can make better decisions and judgements on their actions that will ultimately affect their own survival. Using Geographic Information Systems (GIS) as a tool in the study of our environment offers the advantage of gathering data for large areas with limited physical intervention and very low cost, to produce outputs that makes helps us understand and thus manage our environment. In this study, GIS was used as a tool to understand the spatial characteristics of the coral reefs systems of Southern Okinawa. Most particularly, this study involved the intensive use of image processing and Decision Support Analysis (DSA) modules of the GIS to;

(1) Produce a geo-referenced vector base map of the coastline of southern Okinawa and Chibishi from a Landsat Image.
(2) Create a shallow water marine benthic habitat map of Southern Okinawa by applying depth compensating algorithms, using unconventional “soft and hard” supervised classification to a Landsat TM Image, and assessing it’s accuracy from ground truthing field surveys.
(3) Produce a “model” image showing the probable areas of larval settlement and eventually survivorship of these larvae based on different “spatial evidences” from different data sources using the spatial decision analysis module of a GIS.

The first and second objectives involve the classification or clustering of the different objects based on their spectral response which has been the basis for many of the published work in marine environment related remote sensing/GIS applications (Holden & LeDrew, 1998). What is probably unique is this study is the third objective in which GIS is being used not only for producing baseline marine resource assessment data but also in actual analysis and modelling of the marine environment.

The GIS’s capability to analyze and thus model different spatial processes have had limited emphasis in most of the published studies. Modeling of spatial processes through GIS, which is not really new in terrestrial

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applications, could help predict different probable scenarios, which in turn could provide useful information in the eventual management of coastal environments.

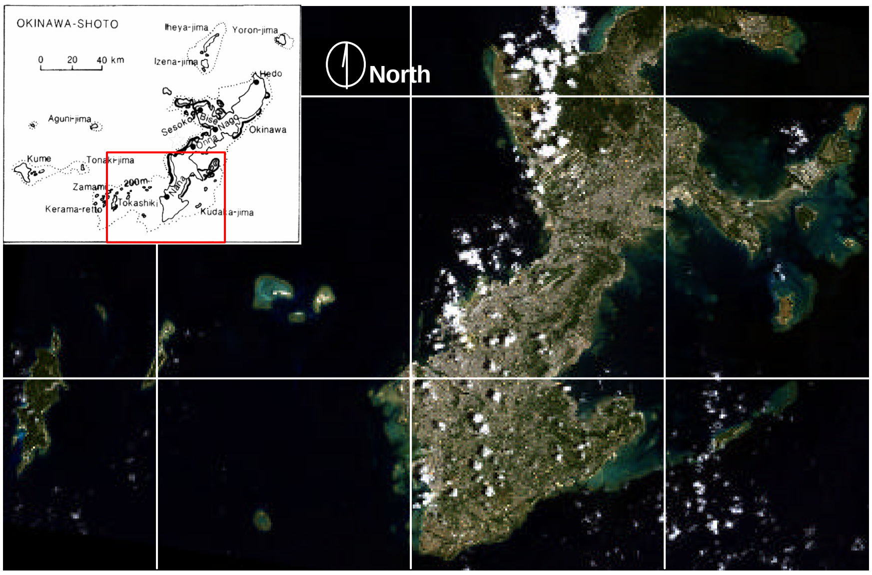

Figure 1. A composite image of Southern Okinawa and its outlying islands

The study area encloses the southern part of the Island of Okinawa in the Ryukyu archipelago, Japan which also includes the small offshore islands of Chibishi and parts of the Kerama Islands ~5 km and ~20 km southwest of Okinawa respectively (See Fig. 1). Coral Reef areas on the main island of Okinawa are under constant pressure because its proximity to populated areas unlike that of its offshore islands. And it has been theorized that because of this, disturbances such as the El Niño phenomenon in 1998 cause massive mortalities on the corals in Main Island while those at the offshore islands manage to survive. Thus it is the consequent objective of this study to try to foresee where in Southern Okinawa will the settlements and eventual survival of coral larvae from these offshore reefs is most suitable.

Methods

Two data sources were used in this study namely: Landsat Satellite Data and SeaWiFS chlorophyl *a* data. The data was obtained from the Earth Observation Research Center (EORC) of the National Space Agency of Japan. The GIS software program Idrisi, version 32.04 from Clark Labs, was the software utilized in the study. From the raw satellite image to the final output, showing the areas on the intertidal areas of southern Okinawa where probability of settlement is most likely, different modules of the GIS system were utilized. These involved the following major phases (see Fig. 2) which are further comprised of many sub-phases.

The pre-processing of the raw images involved all the basic methods such as extraction, cropping and masking to prepare it for next phase, which is the classification. The classification phase, involved a water correction phase (Lyzenga, 1981 & UNESCO, 1999) to take away the effects of water attenuation and a supervised image classification involving based on Bayesian Probability to produce different probability maps representing a certain theme for each benthic category (see Fig. 3).

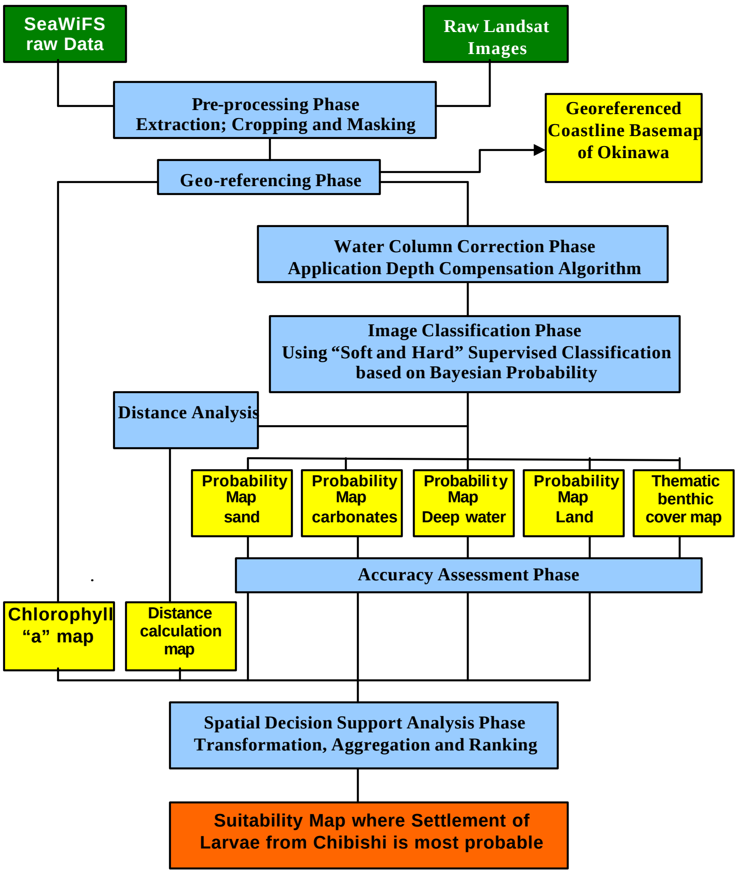

Figure 2. Schematic Diagram of the process involved in the study. Green boxes represent raw data used, yellow boxes represent outputs and orange represents the final result of the analysis

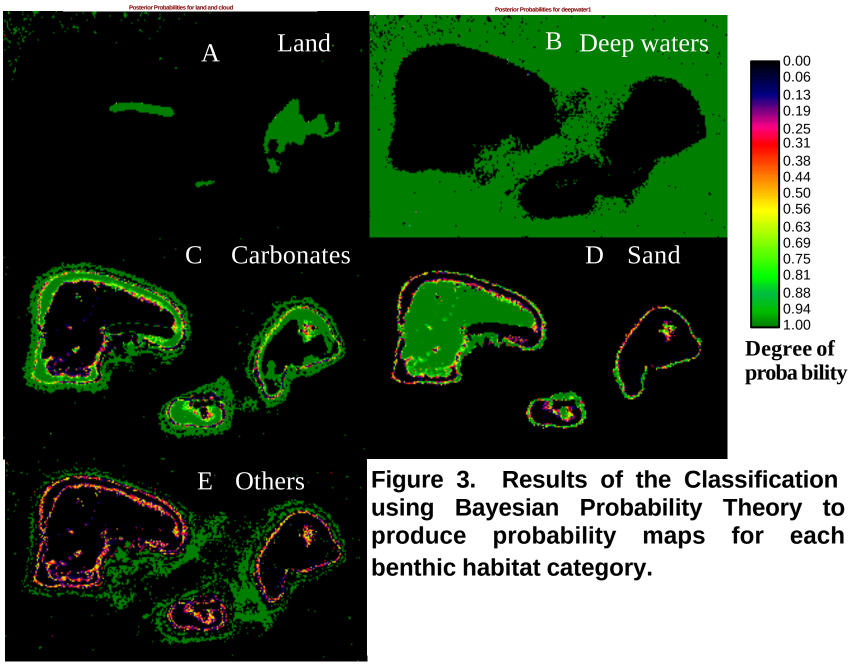

Figure 3. Results of the Classification using Bayesian Probability Theory to produce probability maps for each benthic habitat category.

Ground truthing surveys were undertaken to assess the accuracy of each of the produced maps. This involved going out in the littoral with a GPS and recording the percentage cover for each of the benthic classes identified.

The next phase, the Spatial Decision Support Analysis Phase, is the phase where the product from the previous phases together with other processed images were used as evidences (see Table 1) for a decision support analysis in order to arrive to a single index of evaluation – or a suitability map. Two new evidences were added for this analysis namely; 1) chlorophyll A thematic map derived from SeaWIFS data and, 2) distance-from-Source map derived using the cost-distance analysis (Eastman, 1999), which will serve as the evidences (decision criteria) from which decisions were evaluated and acted upon -- otherwise known as the decision rule.

Table 1. The different evidences and criterion type used in the multi-criteria evaluation and their respective transformation.

	Evidences	Criteria type	Transformation
1.	Areas of land cover	Constraint	- Boolean transform
2.	Areas of Deep water	Constraint	- Boolean transform
3.	Distance to Source	Factor	- fuzzy transform
4.	Areas of Carbonate Cover	Factor	- fuzzy transform
5.	Areas of Sand Cover	Factor	- fuzzy transform
6.	Chlorophyll *a* values	Factor	- fuzzy transform

These different images underwent transformation using either a Boolean transform or Fuzzy transforms to standardize each image for evaluation. The next step in the data analysis was the evaluation or aggregation stage. The aggregation stage involved the combination of the different evidences to form a single suitability map. This method was conducted in a stepwise manner. The first involved only the first five evidence of Table 1 in order to see only the larval settlement probabilities. While the second aggregation already involved all six evidences to produce a suitability map showing the larval settlement and survivorship probabilities.

At this stage, each of the factors were given their own factor weights and multiplied with its corresponding pixel value and then added with other factor results. Another second sets of weights, the order weights, was added to control the manner in which the weighted factors were aggregated. After which, they were then multiplied with the boolean constraints to "zero out" excluded areas.

Results and Discussions

Image processing was undertaken on a Landsat satellite image to produce a marine-benthic-habitat map. The process utilized a depth compensation algorithm and Bayesian "soft and hard" supervised classification to produce not only a single thematic map, but also a set of multiple maps for each benthic category (see Fig 2). Advantage of using such a method in classification is its subpixel classification. Sub-pixel classification is a characteristic of the classifier that allows it to determine the extent to which mixed pixels (mixels) exist in the image, and in the content of mixture analysis, there is a strong correlation between proportional representation and actual condition (Wang 1990).

Accuracy assessments were performed for each of the classified images. The overall accuracy of these thematic maps was 90% and 59%, respectively. The soft-classification-output maps had an overall accuracy of 59% and 61%, for carbonate and sand respectively (See Fig. 4). Although such results are only moderate by statistical standards, these are not unrealistic values, especially in remote sensing of marine environments as reported by Mumby et. al. in 1998. A lot of factors might have contributed to this such as the delay in the time of ground truthing and the time when the satellite image was taken, and the water column correction algorithm may not remove the effects of water attenuation completely.

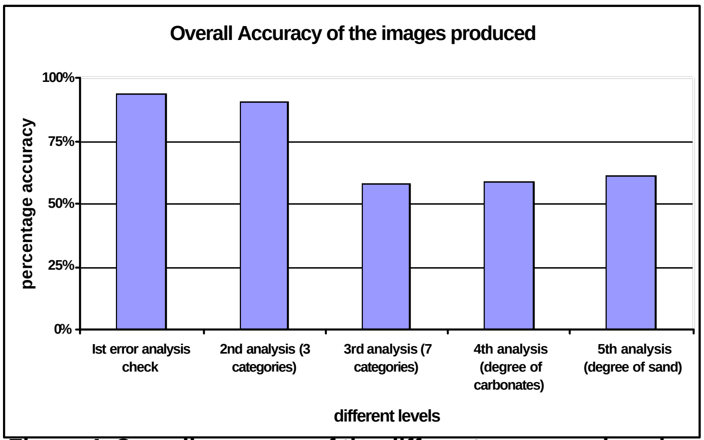

Figure 4. Overall accuracy of the different maps produced using Bayesian supervised classification.

The final analysis phase utilized results from previous phases, plus the other derived images. Decision Support Analysis was used to ask a hypothetical question: where do coral larvae, broadcast from a source reef, most likely settle? It is a general knowledge that coral larvae exhibits site preference when it comes to settlement. The probability image showing areas of carbonates can be considered as optimal areas for larvae settlement while others (i.e., sandy areas, deep water and land areas) are considered sub-optimal. Theses probability maps together with the distance image map based on 1-3 day optimal dispersal phase of larvae from the offshore islands were then transformed using a certain function based on fuzzy-logic analysis. Using Multi Criteria Evaluation (MCE), they were then aggregated to produce the suitability map showing the areas where larvae from the offshore islands will most likely settle.

From this map and based on similar analyses, chlorophyll *a* concentrations in the water column (i.e., SeaWiFS data), reflecting sub-optimal reef-growth conditions abundance (Van Woesik et al. 1999), were added as evidence to produce a probability map of coral survival (see Fig. 5). The eastern bays of Okinawa showed low probabilities of coral settlement and survival when the larval source stemmed from Chibishi (the proposed source).

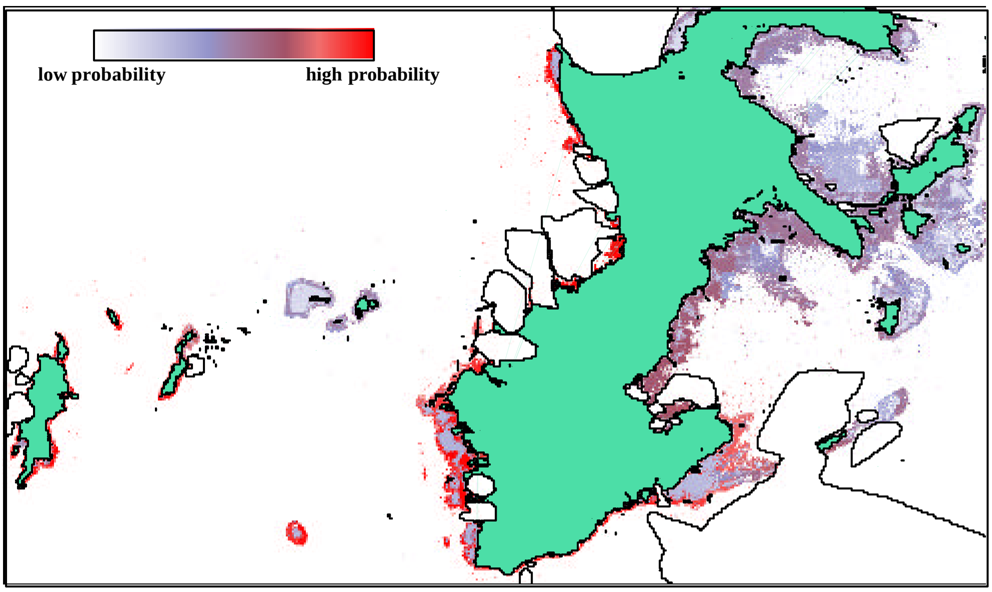

Figure 15. Suitability map showing the intertidal areas in southern Okinawa where settlement and survivorship of Chibishi coral larvae is most probable

The results of this study clearly show that the Bay areas in the eastern side of Okinawa have low levels of coral settlement and probably coral survivorship of potential larvae from the southwest islands. And adding the adverse conditions in the bays could slow down recovery of these reef areas, unlike the reef areas in the west Side of Okinawa. This effect is more pronounced especially after the occurrence of a major natural or man-made disturbances. This could probably explain why these areas, just 30 years ago were described as one of the best coral reef areas of the Ryukyuan Islands (Moyer pers. comm.), are now mostly just dead reefs.

As the name of this analysis (i.e., "decision support") implies, results from this study do not mean that it is the answer to the problem but rather that it should only be used as a support for the final answer to the problem. Although results from the decision support analysis showed concrete and easy to understand outputs, it would be wrong to conclude and say that the final results of this analysis are truly the correct answer to the problem presented. Thus, results from this study should be used with great caution. This nevertheless, does not diminish the importance of such modelling studies in science.

In the field of coastal resource management where in a lot of instances, management decisions have to be made regardless of whether or not comprehensive scientific studies are available (Stanbury & Starr 1999). This type of research is a better alternative than making decisions without any background or understanding of the processes involved. And in many third world countries where financial and intellectual capability for massive scientific undertakings are limited and data are absent, such studies could provide a better alternative in the management of the resources. And finally, as Okinawa continues its rapid development, the results of this study could be used as basis for other future studies/activities that will involved the rehabilitation, protection and use of the intertidal areas of Southern Okinawa.

Conclusions

As the results show, there are two main outputs of this study namely; 1) A benthic habitat map of the intertidal areas of southern Okinawa produced from a Landsat image and incorporating depth compensating algorithms and 2) a suitability map showing the areas of Chibishi coral larvae settlement and eventually survivorship probabilities in the intertidal areas of Okinawa. Such maps would prove useful not only as a source of baseline data (for the former) but also in the understanding of some of the process of the reefs of Okinawa (i.e., the latter).

This study produced not only the usual outputs of most the published remote sensing/GIS studies but also incorporated another of the GIS's spatial analysis tool which is the Decision Support analysis. The use of GIS in the analysis of the ecosystems spatial components has shown to be promising although not yet perfect. Admittedly, inaccuracies are present in the results of this study. However, most of this inaccuracy is due to the quality of data and the limited financial and manpower capability thus can be lessened. This study also showed that, contrary to what Green et al. (1996) reported and what many of today's scientist believe, the use of GIS technology is possible even with limited resources.

A lot of improvements for this study are still possible. Using most of the newer (but more expensive) satellite and airborne data could increase the accuracy of the benthic habitat maps (Hochberg and Atkinson 2000, Mumby et al 1998). More factors could be included as evidences for the study and the incorporation of the temporal component to the study would make the result more applicable for management purposes. It is my hope that this study will lead to other future studies of the coral reefs Okinawa using GIS as a tool.

Acknowledgements

The author would like to express his heartfelt thanks to Dr. Robert Van Woesik for his guidance throughout the conduct of this study, to Dr. Masashi Yamaguchi for his support, and to University of San Carlos for the experience.

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