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REMOTE SENSING OF CORAL REEFS: SOUTH PACIFIC EXAMPLES.

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Ground verification method for bathymetric satellite image maps of unsurveyed coral reefs

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ABSTRACT

A method is presented for the ground verification of 20 m resolution bathymetric image maps of relatively unknown and unsurveyed coral reefs. The method is based on the availability of a reef geomorphologic map and/or aerial photographs, radar and echo-sounder. The test site was located in the South Pacific on Tetembia Reef, northwest of Noumea, New Caledonia.

In the past five years, remote sensing techniques have gradually been adopted as reliable tools for mapping and monitoring coral reef resources. This confidence has arisen from positive ground verifications of remotely sensed reef image maps [6, 2]. For the ground verification process, a survey and sampling method is devised which is compatible with both the image map and the accessibility of the particular reef environment. It is therefore usually tailored to the particular mapping task. This article reports on a method devised to verify bathymetric image maps of relatively unknown and unsurveyed coral reefs, typical of those in the South Pacific. The correlation between the image mapped bathymetry and actual depths is reported alsewhere [10].

EXISTING VERIFICATION METHODS

Most of the reported work on ground verification methods for remotely sensed coral reef image maps has been conducted on the Great Barrier Reef. A method devised by Kuchler [7] and Mayo *et al* [12] was tailored to the specific needs of an experiment to test the utility of Landsat MSS for mapping coral reef surface covers. It was an application of the primary and secondary sampling units reported in Colwell [4]. Ground control was achieved by using a 1:5000 orthophoto map from which photo information for selected points was located on the ground. Later methods by Jupp *et al* [6] and Kuchler *et al* [8, 9] were aimed at a more general level of map verification with the goal of possibly developing a standardized method for routine work. Jupp's method was laboratory-based and relied on scientists with detailed reef cover knowledge, while Kuchler's relied on a hydrographic survey control team. Both methods depended on information (orthophoto maps) or expertise (scientists with reef knowledge; a survey control team) which are generally not available for isolated coral reefs such as those in the South Pacific.

Bina *et al* [1] also recognized the vast distribution and inaccessible locales of coral reef areas, and used four methods simultaneously to obtain ground truth data on surface cover and bathymetry for verifying satellite image maps. The four methods—transects, "bounce" dives, underwater sled transects and shallow surface reconnaissance—are not detailed in terms of sample size or frequency. Depth measurements were recorded with a submersible depth gauge, the type of accuracy of which was not indicated. Analogue depth gauges, however (*eg*, Tekna brand, 75 m scale), have an accuracy of approximately 0.4 m in 0.4 to 9.0 m of water and ± 0.8 m in 9.0 to 24 m of water (digital gauges record depth with much greater accuracies). The image-to-reef surface registration was achieved using a surveyor's compass, the accuracy of which was also unreported.

SPOT HRV BATHYMETRIC IMAGE MAP

SPOT, a second- generation Earth observation satellite, was launched by France in February 1986. Its payload includes two high resolution visible (HRV) sensors [3]. Simulated SPOT image data were used in this study, and were recorded before the launching of the satellite using an airborne "Daedalus" radiometer [11]. The data were re-structured to give a radiometry equivalent to the operational SPOT HRV channels. On 17 December 1983, a transect was scanned at 0936 hours during a low tide (coefficient 0.6 m) over Tetembia Reef [2]. The data in channels XS1, XS2 and XS3 were preprocessed and analyzed, and bathymetric image maps were created using a microBRIAN system (*ie*, a microcomputer-based image processing system). The bathymetric or depth-of-(light)penetration map is created with the premise that for constant water colour, turbidity and substrate type, Landsat MSS band radiances vary inversely with depth down to the depth threshold of each band [6]. (The production method and accuracy of these maps are reported in Kuchler *et al* [10].)

STUDY SITE

The ground verification method was tested on Tetembia Reef (22°10'E, 166°5'S), northwest of Noumea (New Caledonia) in the Coral Sea (Figure 1). Tetembia is a relatively shallow, unsurveyed elongate barrier reef with an open back lagoon.

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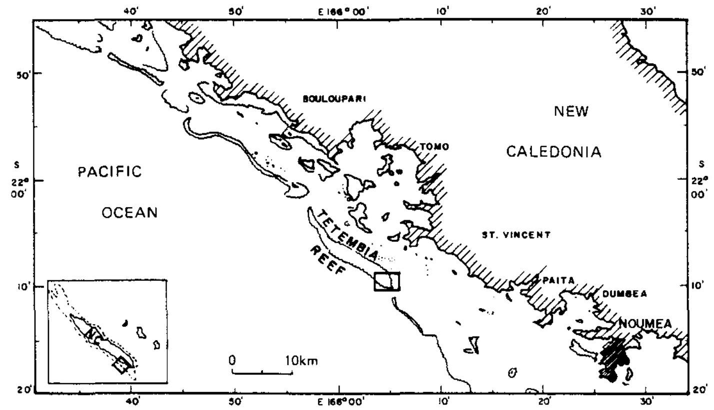

FIGURE 1 Tetembia Reef location map

VERIFICATION METHOD

The method requires the availability of laminated bathymetric image maps, a reef geomorphologic map at 1:20000 scale [13] and/or aerial photographs, a radar, radar beacons and an echo-sounder. In our work, the echo-sounder was housed on the research vessel, but a portable echo-sounder aboard a zodiac would have offered considerable advantages for reef access. The minimum requirements are aerial photographs and an echo-sounder.

The first step is to select sampling frequency, site location, sampling technique and location of ground control points (GCPs). The decision making process (being task specific) is influenced by image map variability, site accessibility, the size of the survey team, radar capability and verification field time. Sampling frequency and site locations are decided largely by a trade-off between field time, reef accessibility and water depth variability as mapped by the remote sensor (in this example from SPOT simulation data). Since the bathymetry is mapped as homogeneous zones, the verification process could easily adopt a random sampling technique. The Tetembia Reef study showed, however, that reef accessibility and field time were governing factors. The number and distribution of sample sites used in the Tetembia Reef study are shown in Figure 2.

Two depth sampling techniques were employed: one using depth profile soundings from an echo- sounder and the other using a graduated and weighted tape. Our echo- sounder was aboard the research vessel "Dawa". Its use was therefore limited to areas accessible by the vessel, *ie*, waters more than 3 m deep. The Furuno echo-sounder [5] had a medium transmission frequency of 50 kHz (50B - 5NR) and a beamwidth of 50 degrees. This gives a detecting circle of 9.3 m diameter at a depth of 10 fathoms (18.3 m). For the purpose of this study, the depth accuracy of the echo-sounder was governed by the amount of boat pitching and rolling and transmission frequency. The most accurate readings are taken on calm seas and by an echo-sounder with a high transmission frequency of 200 kHz (200B - 5NR), since this gives a narrower beamwidth detecting area. It is advisable to take depth measurements only in relatively calm seas. Sounded depth measurements were recorded for sites located along transect lines (Figure 2). An example of a trace depth recording is shown in Figure 3.

A weighted tape was used from a zodiac to measure water depths of less than 3 m, *ie*, waters inaccessible by the research vessel. The tape method, however, is limited to distances within visibility range of the radar. The tape-measure was used to take 10 point readings within a 20 m diameter circle centered on the sampling site. The sample size may be varied so that it is compatible with the extent of the depth zone and sampling frequency.

The relative accuracies of the echo-sounder and weighted tape methods for depth measurements were tested by taking simultaneous measurements at 12 sites along the transect path. The measurements were comparable within a range of $\pm$ 0.10 m to $\pm$ 0.50 m. This accuracy seems reasonable given the depth range of the bathymetric zones on the image map (15 to 5 m for band 4 (XS1) bathymetric zones, 5 m to 50 cm for band 5 (XS2) and less than 50 cm for band 6 (XS3) [8]).

Ground control is a particular problem for coral reefs because of the general lack of surveyed points and above sea level topography. This problem is addressed in all image map verification work, since control between the image map and the Earth's surface is required for the accurate positioning of sample sites. In this verification method, control is achieved through triangulation. The process involves three steps. First, prominent reef features are highlighted on an aerial photograph, then radar beacons are positioned on three of these features. These features are selected so that their distribution forms the apexes of a

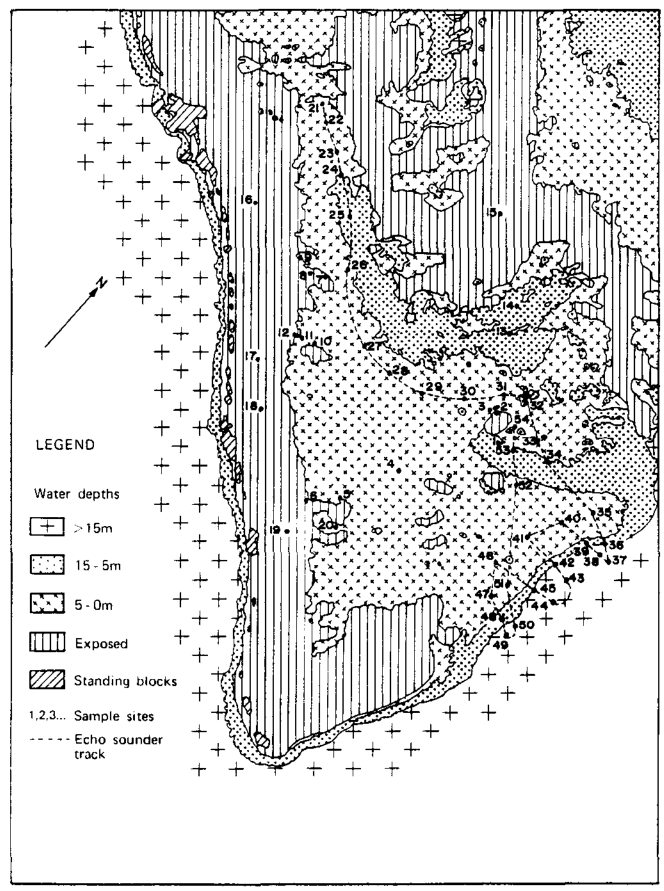

FIGURE 2 Study sites

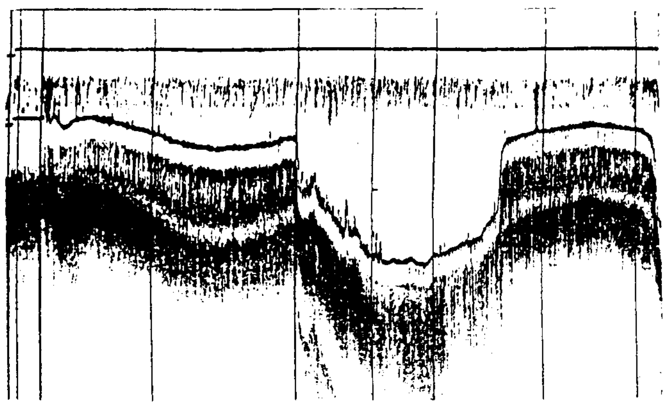

FIGURE 3 Echo-sounder trace recording

triangle encompassing the sample sites. Finally, the radar is used to locate sample sites in relation to the beacons. A walkie-talkie allows ship personnel to direct the survey team to sample site locations.

DISCUSSION AND CONCLUSION

Existing coral reef image verification methods are tailored to the resolution of a particular sensor and the availability of either detailed knowledge or surveyed information. Reliance on this second condition governs the general applicability of the methods, since the operational scale of the verification process can be adjusted to comply with the image (sensor) resolution. The need to verify bathymetric image maps of an unsurveyed coral reef and the unavailability of a hydrographic survey team led to the method presented here. This method, however, is also tailored to these specific conditions and is probably similar to the unreported method used by Pirazzoli [14].

In comparison with other reported verification methods, the one described here is the least rigid and accuracy would be substantially lower than that reported elsewhere [9]. This is caused by a combination of the quality of the resources available to the verification process and the isolated nature of the reef environment being mapped. The ground control and depth measuring techniques were the weakest components, but, given the study conditions, were the best available. In some isolated coral reef environments in the South Pacific where a radar and echo-sounder are unavailable, verification accuracy would be even lower.

Earlier attempts to develop an operational and standardized method for verifying coral reef image maps aimed at a general, universally applicable method of map verification. The progress of satellite and digital image technology in providing images with different combinations of spectral and spatial resoltions, together with the many different types of coral reefs being mapped from satellites, has led to the development of a number of verification methods. Other methods will also be devised since the verification of reef front slopes, for example, still needs to be addressed. Eventually, standardization will probably be achieved by a group of verification techniques from which a selection is incorporated into a method tailored to a specific verification task.

Given the remote marine environments of coral reefs, the mapping of their resources is logistically difficult, expensive and time-consuming. The ability to extract water depths from remotely sensed data is a primary requirement to a fuller exploitation of this technology for cost-effective mapping. The method presented here allows verification of a technology which is capable of providing important depth-related resource information on coral reefs.

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RESUME

Une méthode est présentée pour la vérification de sol à l'aide de cartes images avec une résolution bathymétrique de 20 m de barrières de corail relativement inconnues et non levées. La méthode est basée sur la disponibilité de cartes géomorphologiques de barrières et/ou de photographies aériennes, de radar et d'écho-sondeur. Le site test était localisé dans le Pacifique sud, sur la barrière Tetembia au Nord-ouest de Nouméa en Nouvelle-Calédonie.

RESUMEN

Se presenta un método para la verificacion en el terreno de mapas de imagenes batimetricas de arrecifes de coral relativamente desconocida y no levantadas. El metodo esta basado sobre la disponibilidad de un mapa geomorfologico de un arrecife y/o fotografias aereas, radar y eco-sonda. El lugar de la prueba fue ubicado en el Oceano Pacifico en el Arrecife Texembia, al noroeste de Noumea, Nueva Caledonia.