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AN ACOUSTIC APPROACH TO RESOURCE MAPPING OF PULAU PAYAR'S CORAL REEF

Jabatan Perikanan Malaysia

BOBP For Fisheries Management
BAY OF BENGAL PROGRAMME

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Survey Report

AN ACOUSTIC APPROACH TO RESOURCE MAPPING OF PULAU PAYAR'S CORAL REEF

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PREFACE

This document discusses the rationale, the conduct and the results of a new approach – the hydro-acoustic method – tried out to map the reef substrate of four islands at Pulau Payar Marine Park, Kedah state, Malaysia.

The decision to adopt the method was taken after an October 1997 workshop held under the Special Area Management Plan of the Pulau Payar project, with support from the Bay of Bengal Programme (BOBP).

A private company carried out the reef mapping exercise, whose objective was to document the diversity of coral growth forms at Pulau Payar, map and quantify coral resources, and prepare an update on the coral reef status at Pulau Payar, assessing any damage to the reef.

The exercise was carried out in view of the plans by the Department of Fisheries, Malaysia, to inventory all the reefs in the country's islands.

Over the years, coral survey techniques have depended heavily on the SCUBA method which is considered risky, time-consuming and costly. Further, it is impossible to produce a broad-scale map with the SCUBA diving method. The author believes that the "new, repeatable and non-destructive hydro-acoustic survey approach" heralds a new era in corat studies.

The BOBP is a multi-agency regional fisheries programme which covers seven countries around the Bay of Bengal – Bangladesh, India, Indonesia, Malaysia, Maldives, Sri Lanka, Thailand. The Programme plays a catalytic and consultative role in developing coastal fisheries management in the Bay of Bengal to improve the conditions of small-scale fisherfolk in member-countries.

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Thanks also to Lee Yew Jin for his participation in the field work and his comments on the manuscript.

ABSTRACT

A new approach was applied to mapping out the reef substrate of the four islets of Pulau Payar Marine Park, in Kedah State, Malaysia. A seabed classification system which harnessed the RoxAnn hydroacoustic signal processor, Differential GPS and a 200 kHz echosounder was able to translate the echo return into hardness and roughness indices, which then exhibited unique characteristics for each bottom type recorded. The system was able to discriminate six major reef substrates i.e. live coral, dead coral, soft coral, coral rubble, rock and sand. Live hard coral represents a total coverage of 19.30% from the *157.68* km total length of transect recorded from the Payar group of islands. The four main growth forms found were the massive (10.11%), the branching (7.11%), the encrusting *(1.51%)* and the foliose (0.57%). Table corals and columnar corals were also present but in a very small quantity (surface area) – the RoxAnn seabed classification system was not able to classify them as a separate group. As for the Pulau Segantang group of islands, soft coral was the dominant coral type, accounting for 34.65% of the total 4.12 km of track run. Live coral coverage at P. Segantang in this survey was negligible. It was also common to find small coral colonies growing on the boulderssurface in shallower waters for both Payar and Segantang waters. They were grouped as a stand-alone coral substrate due to their unusual existence pattern. The real time trace data were also interpolated using Surfer®6.2 for thematic maps showing the depth contour, the 3D depth profile and the bottom surface area. The results were satisfactory, despite data distortion. The use of the hydroacoustic method for the mapping of coral reef substrate is independent of water depth, visibility, light penetration and time. Hence, the hydroacoustic method shows itselfto be a better alternative to the conventional transect line method and satellite images in terms of time and cost spent and the results gained especially for large-scale surveys.

Foreword

One of the most interesting pilot projects in Bay of Bengal Programme's Third Phase, which has drawn much attention throughout the region, is the one at Pulau Payar Marine Park in Kedah State, Malaysia. Set up in 1985 to conserve marine resources in surrounding waters, such as coral reefs, and protect bio-diversity, Pulau Payar is considered a treasure house of marine fauna and flora.

The Pulau Payar project was implemented by the Department of Fisheries, Malaysia, with BOBP support. It developed and tested a number of methods and innovative approaches to improve the conservation and management of marine parks. Today, Pulau Payar stands out as a success story in resource conservation.

One of the technical experiments carried out under the project is described in this report. It discusses the rationale and the conduct of a new coral survey technique, the hydro-acoustic method, to map the reef substrate of the Park's four islands.

The project used the Rox Ann Hydroacoustic Signal Processing System, which is a state-of-the-art hydroacoustic remote sensing tool. The authors point out that the technology uses a powerful underwater sonic searchlight to detect and enumerate physical and biological features of coral reefs. This enables faster and more accurate ground-truthing and mapping than the traditional SCUBA surveys, which carry an element of subjective interpretation and observation, and therefore the possibility of human error.

The report documents through maps and brief text, facts and features concerning the reef substrate made possible by the hydro-acoustic method. It says "This project can be considered a milestone in coal research history as it combines the use of remote sensing tools and ground truthing."

The BOBP made a special effort to obtain the best possible maps from the authors, and ensure good-quality printing. We hope that dissemination of this report improves better understanding of coral resources and their dynamics, creates awareness of the hydro-acoustic method for coral reef surveys and furthers the cause of marine resource conservation.

V S Yadava

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I. INTRODUCTION

Over the years, coral survey techniques have depended heavily on direct measurement and censusing with the SCUBA diving method. Given skilled and knowledgeable field workers, SCUBA diving is still the most reliable survey te~hnique to date, as it allows first-hand data collection. However, it is almost impossible to produce a broad-scale map with the SCUBA diving method,. Further, it poses high risks to the operator/diver, it is also time-consuming and costly. This method is also restricted by water depth, tidal currents, bad weather and poor visibility.

During the early 90s, the remote sensing technique was introduced as a new survey tool. Through GIS interpretation of various types of satellite images, thematic maps on physical characteristics of the water body can be obtained. As time passed, the resolution of satellite images increased, enabling more information to be gained, including the mapping of coral reef. However, remote sensing on coral reef is confined to the identification of general reef features in shallow water. The report on "Marine Park Island Management: Conceptual Plan For Peninsular Malaysia, 1994" clearly outlined the shortcomings of the use of satellite images. At present, more "ground truthing" works are needed to complement the remote sensing results from satellite images.

Scientists have been very innovative in exploring new survey tools for coral studies. Recent findings indicate that the hydroacoustic method is a promising approach, especially for large area surveys. Hydroacoustic techniques have been used over the past six decades, initially for undersea warfare. It is also a popular method utilised for years in fisheries resource surveys. The acoustic technology harnesses a powerful underwater sonic searchlight to detect, observe and enumerate physical and biological parameters of interest. Based on hydroacoustic theories and formulae, this technique is now being adopted to conduct reef surveys. It is a faster means of ground truthing and mapping compared to SCUBA diving. The other significant advantage of machinery surveys is that it minimises the possibility of human error due to subjective individual interpretation and observation during a SCUBA survey.

2. JUSTIFICATION

One of the many tasks of the Department of Fisheries, Malaysia (DOFM) is a reef inventory list of the islands in Malaysia. The Pulau Payar Marine Park, which consists of four islets, is well known for the great diversity of reefs over small areas. It thus highlights the need for an objective record of the inventory in the form of a thematic/GIS map. Under the Special Area Management Plan (SAMI- of the Pulau Payar Project, a workshop held in October 1997 suggested that the method used for reef surveys should allow for temporal comparison. An attempt to map out Payar's reef resources using the hydroacoustic method was therefore initiated as a continuation of the SAMP Pulau Payar Project.

A DOFM proposal to obtain the expert services of Elcee Instrumentation Sdn. Bhd (EISB) was accepted by BOBP as a potential contribution to coral reef management in the region. EISB was to work in collaboration with the DOFMs senior research officer.

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3. OBJECTIVES

To document the diversity of coral growth forms at Pulau Payar

2. To map and quantify the coral resources of Pulau Payar for resource management

3. To assess the damage and update the current coral reef status of Pulau Payar.

4. MATERIALS & METHODS

4.1 Survey site

Located at 6°2- 6°05N and 99°54'- 100°04E(Figure 1), the P.Payar group of islands are situated between Pulau Pinang and Langkawi islands on the Straits of Malacca, which is one of the busiest straits with marine traffic. The reefs here are therefore seriously exposed to the possibility of oil spills and discharges from tankers passing by. A thematic map on the coral resources is a niatter of high priority. Furthermore, Pulau Payar Marine Park has the distinction of being the most well-documented coral reef. Hence it enables proof of the feasibility of this technology development. P.Payar Marine Park is one of the most frequently visited marine parks (Aikanaithan & Wong, 1994). By enabling comparison of the past coral cover with the current status of the reefs, it makes possible an assessment of the impact of ecotourism activity on the reef. This can lead to better management and regulation of such activities.

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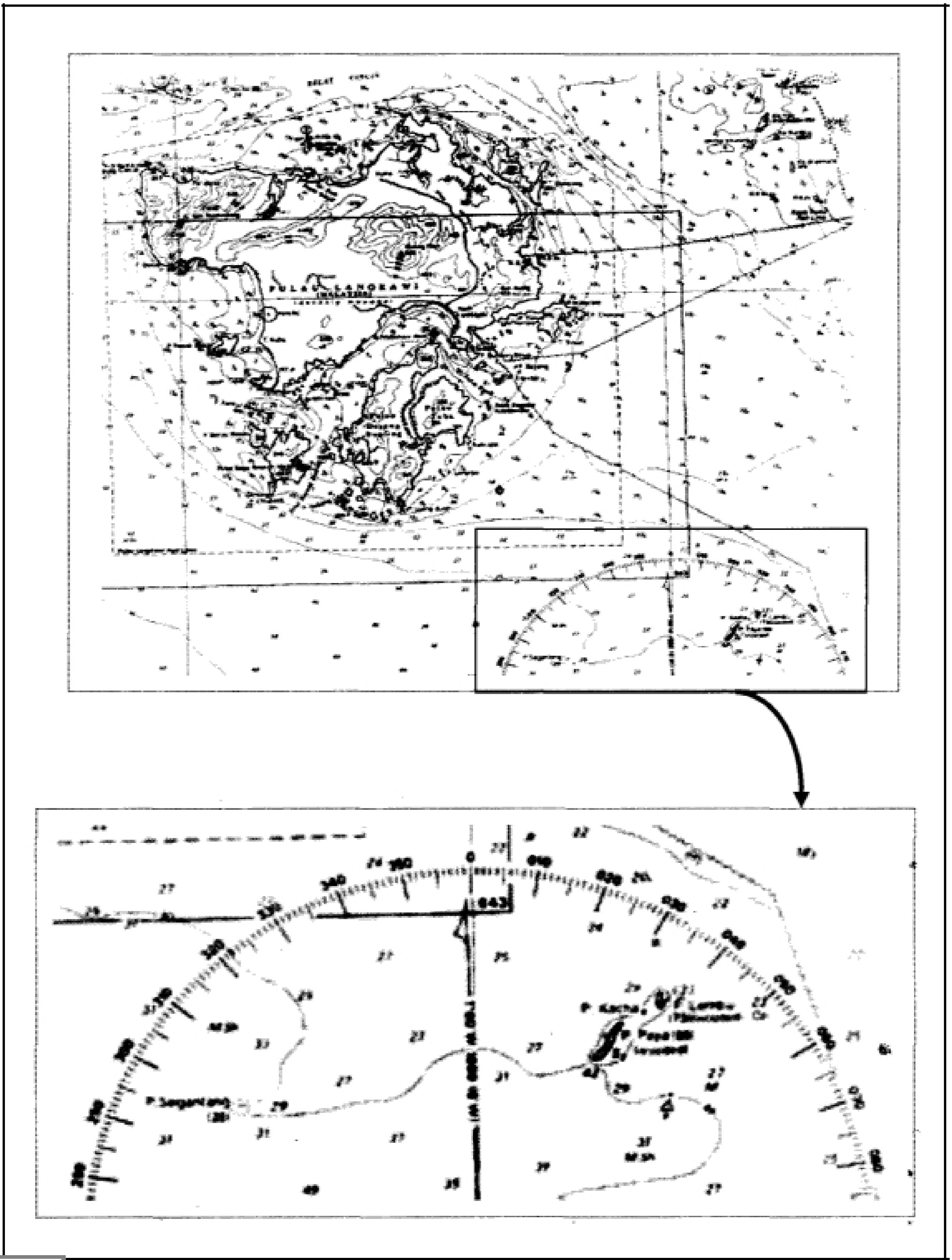
Figure 1: Location map showing the survey site



4.2. Materials

The survey equipment used is listed below:

Equipment	*Make*	*Brand*	*Specification*
Vessel	Boston Whaler	Challenger	- 24 footer, Twin 150HP outboard engine
Echosounder	Furuno	FCV522	- 500 Watts, Colour display
Transducer			- bronze, thru-hull 100 - width, single beam 200kHz.
Differential GPS	Fugro Omni Star	3000LR	- Virtual Base Station
GPS Receiver	Magellan	5000DXL	- 5 Channels
Hydroacoustic Signal Processing System	Marine Micro System	RoxAnnTM	- Single frequency 200 kHz
Laptop	Twinhead	Climnote3	- with 2 serial ports, 1 local port
Grab samplers	Wildco	Ekman	- Tall 6" x 6" x 9" with extra weights
Diving Gears			
Por%able Generator andfuel			
Back-up Battery and charger	Delco Voyager		- Marine grade 12VDC, deep cycle

4.3 Component Discussion

Vessel. A Boston Whaler with a 150HP twin outboard engine and shallow draft, provided by the Marine Park authority, was sufficient for an effective survey.

Echosounder and Transducer System. A bronze thru-hull transducer with 10°beam angle, 200kHz with a 500 watts output power colour echosounder, for resolution enhancement.

Differential Global Positioning System **(DGPS).** The normal GPS receives satellite signals to informusers about locations on earth. Depending on the prevailing SA (Selective Availability), such a receiver may generate errors up to 100m. The magnitude of this error is unacceptable for

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coral mapping work as the reefs found are mostly smaller than 50 meters. A much improved version of location readings is essential. DGPS works by placing a high-performance GPS receiver (reference station) at a known location. Since the receiver knows its exact location, it can determine errors in satellite signals. It does this by measuring the rangers of each satellite using the signals received, and comparing these measured ranges with the actual ranges calculated from its known position. The difference between the measured and calculated range is the total error. The error data for each tracked satellite is formatted into a correction message and transmitted to GPS users via a mobile (rover) unit. The correction message format follows the standard established by the Radio Technical Commission for Maritime Services (RTCM-SC 104). These differential corrections are then applied to the GPS calculations, thus removing most of the satellite signal errors and improving accuracy to !3m. More sophisticated receivers can achieve accuracy on the order of sub-meter.

RoxAnn Hydroacoustic Signal Processing Ssytem. The RoxAnn Hydroacoustic Sigital Processing System (RHSPS) is a state-of-the-art hydro-acoustic remote sensing tool. When connected to any single beam echosounder, it listens to and processes the signals returned from the transducer. These returned signals are simplified to the first echo (E, second echo E_2) and depth. The first echo received is a measure of the acoustic backscatter of the substrate, which is referred to as roughness. Rougher materials scatter more acoustic energy back towards the transducer, whereas a smooth substrate will act like a mirror and reflect away most of the acoustic energy from the transducer. The second echo return is a measure of the acoustic impedence of the substrate. The softer a substrate, the greater the acoustic impedence of the substrate. The timing diagram for E1 and E2 is shown in Figure 2. A complete RHSPS incorporates the input of real time, geo-referenced survey data i.e the longitude and latitude. For each valid E1 and E2 signal collected, RHSPS sends a RS232 string containing depth, E1 and E2 information to the PC/laptop for processing using the RoxMap Scientific Software. With the information gathered from E1 and E2, a RoxAnn Square is configured (Figure 3). It is a Cartesian graph, where E1 (index of roughness) is plotted along the Y-axis and E2 (index of hardness) is plotted along the Y-axis. Since every substrate will have a different range of E1 and E2 values, these areas can be 'boxed off' or classified with an assigned colour. With the addition of longitude, latitude, time and data information, tracks coloured according to substrate type are generated on built-in electronic charts.

Grab Sampler: A grab sampler is needed on board to classify non-coral substrate, whereas diving gears are required for ground-truthing corals found in deeper water.

Alternate and Back-up Power Supply. To power up the survey system for consistent and reliable acoustic data.

A schematic survey system setup is illustrated in Figure 4.

4.4 Methodology

The survey was carried out in three main stages: system mobilisation (including calibration and classification), data collection and post-processing.

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Figure 2: Echo signal processing technique

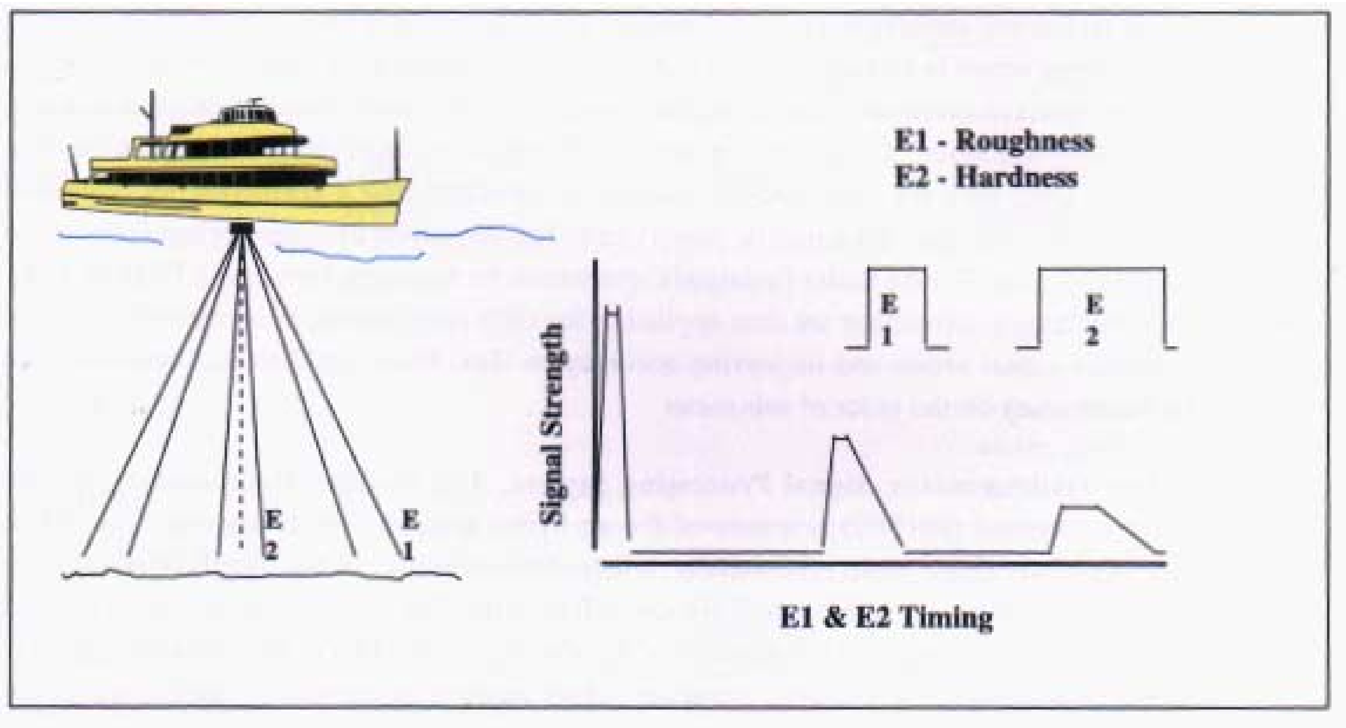

Figure 3: Typical Rox Square showing locations of some bottom types

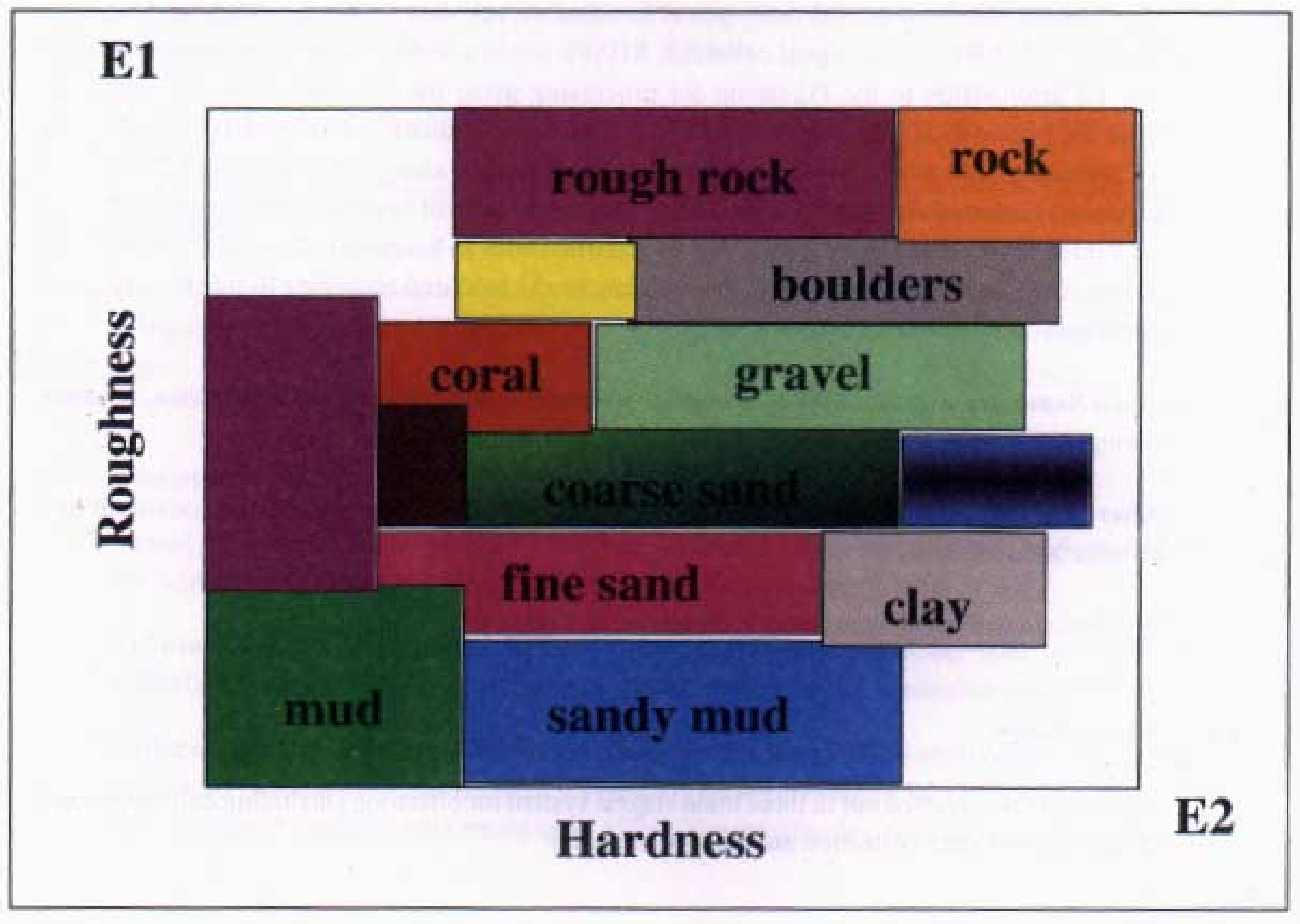

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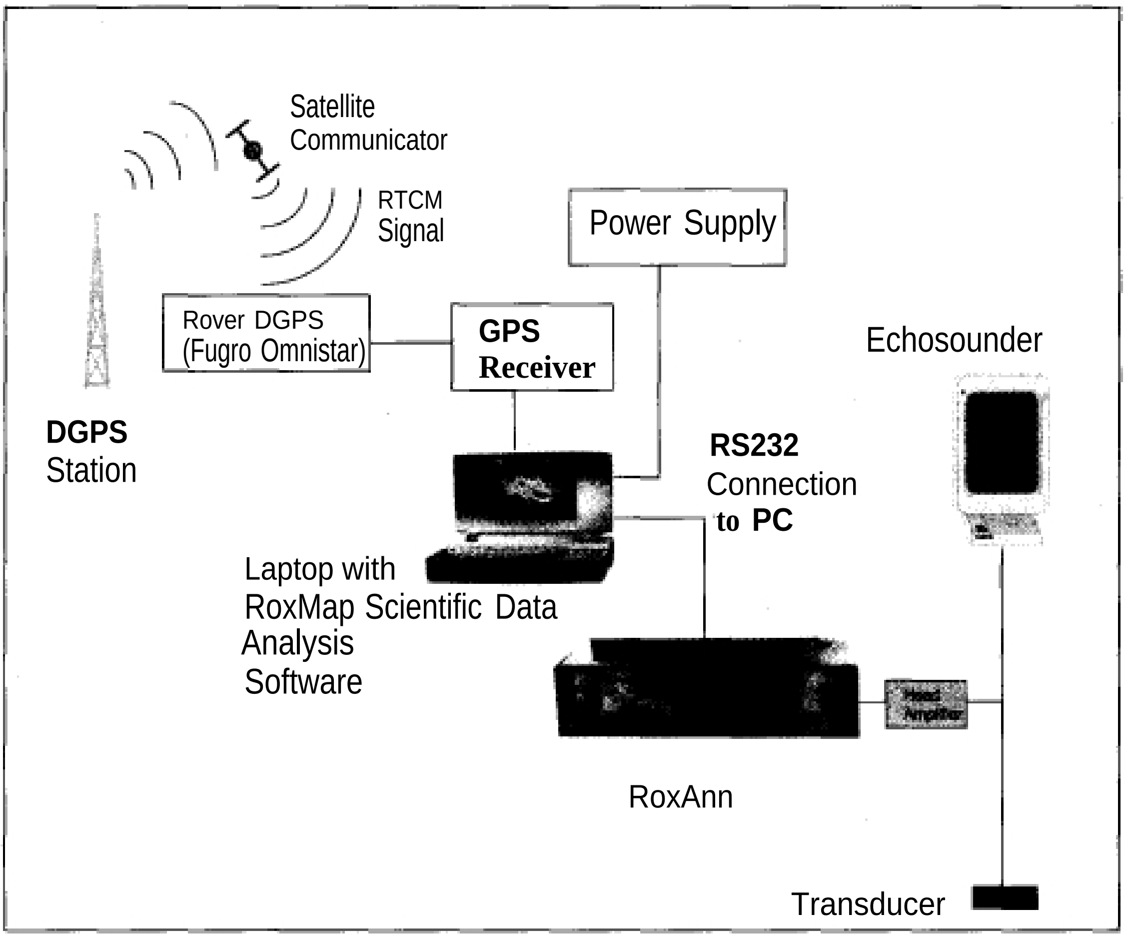
Figure 4: Set-up of the survey system



4.4.1 *Calibration of Survey System*

Calibration is crucial to synchronise the system component for communication; in the same times, set up an optimum E1 and E2 range. It was achieved by deploying the system on the survey vessel and initiating it at the Kuala Kedah cockle-mud ground in shallow waters (2.5m). A grab was used to verify the bottom type during calibration.

4.4.2 Classification of Reef Substrate Types

For the purpose of this survey, classification refers to a series of processes of assigning a specific colour to each bottom type or growth form to be determined, based on the range of E1 and E2 values consistently received and displayed on the RoxSquare. A laptop was used as data logger, navigational and display unit. During classification, the survey vessel was stationed on the desired bottom type with substantial surface area in order to "imprint" the system with the respective signal memory. Upon receipt of the echoes generated by the transducer, data were extracted by the RoxAnn Hydroacoustic Signal Processor (RHSP) and converted to classifiable readings. Then an optimum signal range for that particular bottom type was determined by drawing a box over the RoxSquare. Targeted for the survey were six common coral reef substate i.e. live hard coral, dead coral, coral rubble, soft coral sand and rock. Live hard coral will be classified further based on their growth forms. The six major growth forms to be identifled: plate/table, branching, foliose, massive, columnar and encrusting.

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Upon completion ofthis 'imprinting' process, the system was connected to a Magellan 5000DLX GPS receiver and a Fugro OmniStar 3000LR. Differential Global Positioning (DGPS) modulator for accurate positioning data input. The use of DGPS will bring down the positioning error to 1-3 m instead ofthe normal 15-100 meters found in all GPS units. The system, complete with the DGPS, is now ready for transect run.

4.4.3 *Data Collection*

During the survey run, RoxMap Scientific was used to reveal the real-time position of the survey vessel and the previous track runs, besides recording the bottom type. The skipper could always refer to the laptop screen to double-check if the tracks formed were well - spaced between each other. The vessel ran at an average speed of 3.4 knots forming a continuous 'U' transect at 5-10 meter surface interval, perpendicular to each island. It enabled the seabed type at 3m-25m (±2m tidal variation), where most live coral and other important habitat are found to be recorded. Some transects parallel to each island were also run so as to plot an outline for the respective island besides serving the purpose of'cross-checking' the 'U' transects.

4.4.4 *Post Processing and Generation of Thematic Map.*

Data collected in ASCII form were processed using Surfer62 TIN modelling software for thematic maps. All depth models were generated by interpolation using Kriging method, and substrate maps were interpolated using the Nearest Neighbour method with a Hewlett Packard Pentium 73 Vectra PC.

4.5 Project Activities

A summary for the survey activities in chronological order was as follows:

Day	*Date*		*Activity*
	20/4/98 (Mon)	am pm Night	- Mobilisation (Travel from KUL to AOR) - K Kedah to P. Payar - Calibration at K. Kedah - Group meeting
2	21/4/98	am pm	- Classification - Classification
3	22/4/98 (Wed)	 am pm	 - Trouble shooting on DGPS and PCMCIA card slot - YJ/CS: Lat/Lon for Segantang, Kaca, Lembu
4	23/4/98 (Thur)	 am pm	 - Trial run at Coral Garden and Japanese Garden - Glass bottom boat

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5	24/4/98 (Fri)	am	-	Transect I : Parallel Payar 1
			-	Transect 2: Parallel Payar 2
			-	Transect 3: Perpendicular Payar North, 1st quarter
6	25/4/98 (Sat)	am	-	Transect 4: Parallel Kaca
			-	Transect 5: Parallel Lembu
			-	Transect 6: Eastern Payar
			-	Transect 7: Marine Park Jetty-Banana Reef
				(Boat went to K.Kedah for fuel)
7	26/4/98 (Sun)	am	-	Transect 8: to patch up transect I
			-	Transect 9: South-West of Payar, lower quarter
		pm	-	Transect (10): Parallel Payar 3 (missing)
			-	Diving I :WS/Sharil, pauzi/Zakaria - From Marine
			-	Park Jetty to Langkai Coral
		am	-	Transect 10: Marine Park Jetty to Grouper Farm
8	27/4/98 (Mon)		-	Transect 11: Southern tip Payar
		pm	-	Transect 12: Northern tip Payar
			-	Transect 14: Parallel Kaca & Lembu
			-	Dive I: Pauzi/Zakaria - Boat Reef
9	28/4/98 (Tue)	am	-	Travel from Payar to Segantang
			-	Dive 3: Pauzi/Zakaria - Southeast of Segantang
		Noon	-	Transect 14: Parallel Segantang & Cupak
		pm	-	Transect 14: Parallel Payar
10	29/4/98 (Wed)	pm	-	EMP2000 water quality data collection
		Site I	:	Langkawi Coral
		Site 2	:	Northern tip, Payar
		Site 3	:	West Kaca
		Site 4	:	Kaca-Lembu channel
		Site 5	:	Eastern Lembu
		Site 6	:	Monroe rock
		Site 7	:	Coral Garden
		Site 8	:	Marine Park Jetty
			-	100 in Comparison transect
			-	Dive 5: Pauzi/Zabawi followed by Transect 15
11	30/4/98 (Thu)	am	-	Demobilisation

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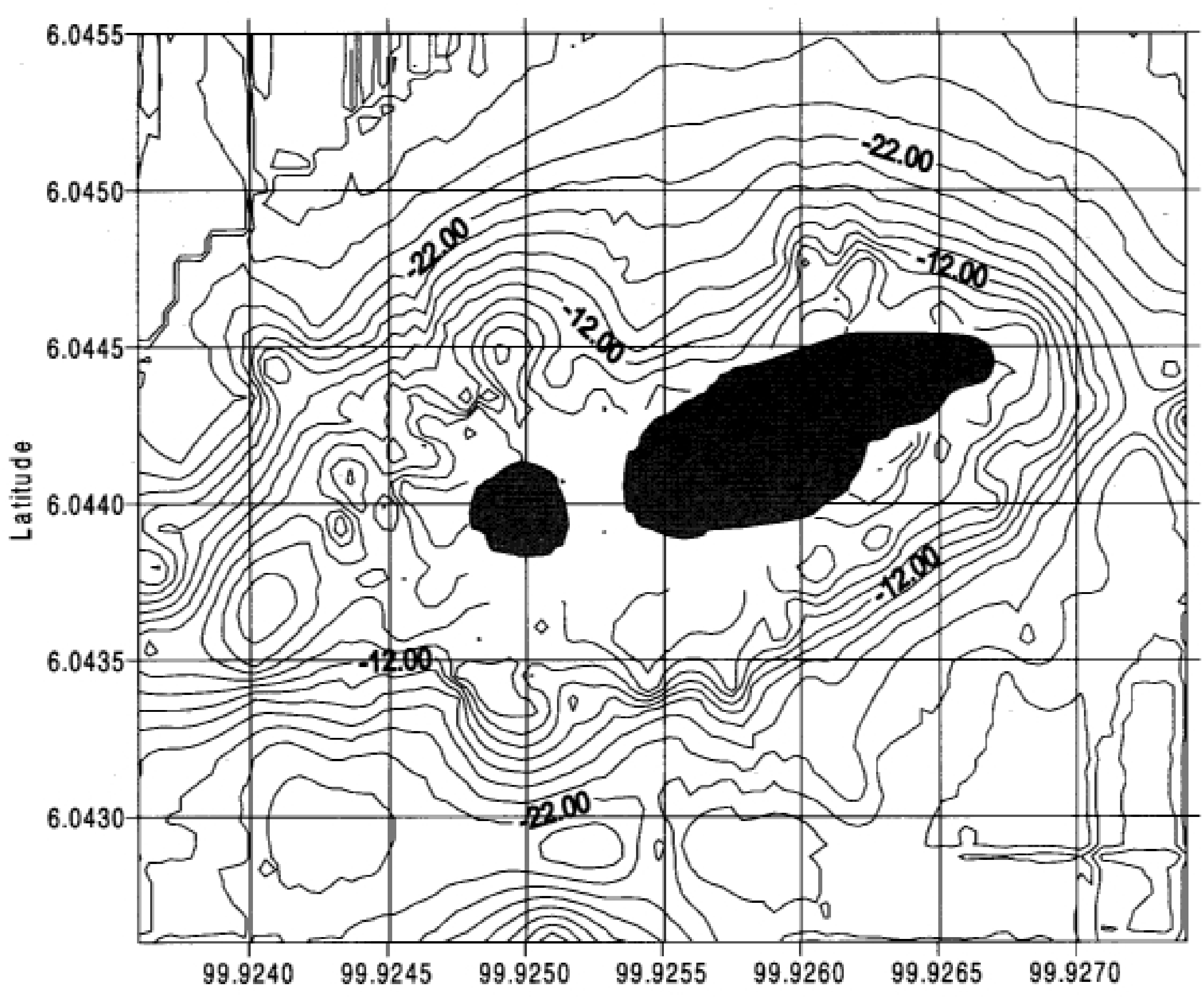
Figure 5: Simple depth contour line, P. Segantang



Longitude

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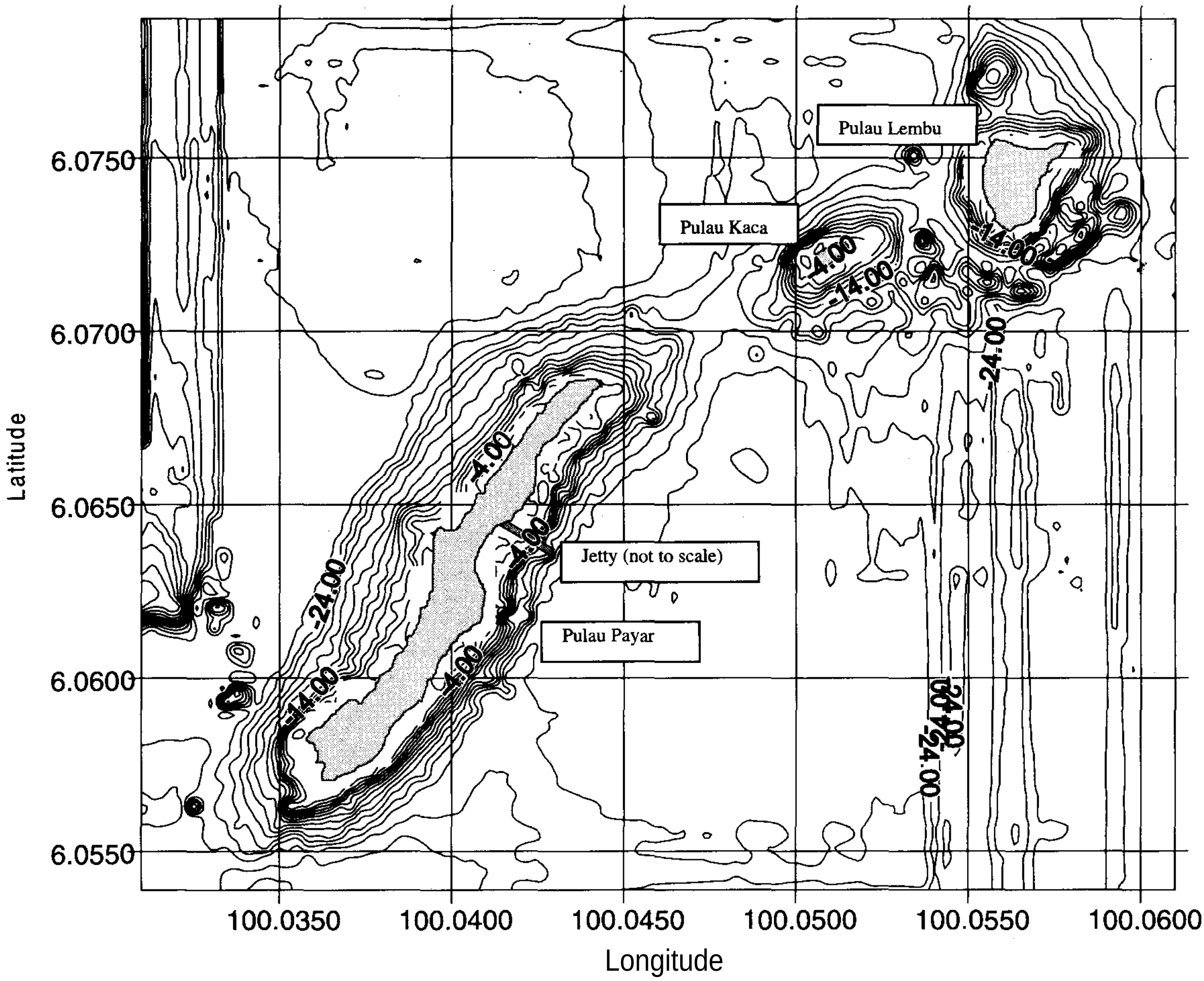
Figure 6: Simple depth contour line, Pulau Payar (Group of Islands)



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5. RESULTS

5.1 General

A total track run of 161.80 km was recorded with the RoxAnn system over the Pulau Payar Marine Park waters from 24th to 28th April 1998. All tracks started with parallel runs to the shoreline followed by perpendicular runs for better coverage. The individual track lenghts recorded for the P.Segantang and P. Payar Group of Islands were 4.12 kin and 157.68 kin respectively (Table 1: Substrate Composition for Pulau Payar Group of Islands).

Pulau Segantang actually consists of two rock outcrops referred to as P.Segantang and P. Cupak by the locals. They are separated by a narrow channel which is approximately 7 m wide and has less than 7 m of water during high tide (personal diving observation). For discussion purposes, these two rock outcrops will be referred to as P. Segantang only. The island has in general an evenly spaced depth contour line over a short distance (Figure 5). A very steep slope exists on the southern side of the islands and a short and medium slope of 45° at the northern part. The island is surrounded by rocky shore. There are some submerged rock-outcrops situated from the west to the north side of P. Cupak in about 4-6 meters underwater during high tide. Depth contours beyond 26 meters are interpolated images.

Pulau Payar group of Islands has a much steeper slope at most of its edges, compared to that of P. Segantang. Figure 6 shows a closer distance between contour lines in irregular shapes, except the Northwest side of P. Payar. From its 3D depth model, P. Payar has a near 90° slope at the eastern side and more than 45° at the western side, whereas P. Kaca and Lembu have steep slopes surrounded by irregular bottom at the southern side.

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Table 1

Class	Pu. Segatang		Pu. Payar Group		Total	
	%	**Km**	%	**Km**	%	**Km**
Other Substrates	0.99	0.04	1.89	2.99	1.87	*3.03*
Rock	18.48	0.76	5.16	8.14	5.50	8.90
New/Stunted Coral on Rock	1.98	0.08	1.62	2.56	1.63	2.64
Softcoral	*34.65*	1.43	3.01	*4.75*	3.82	6.18
Mixture of Hard & Soft Coral	0.66	0.03	0.95	1.50	0.94	1.53
Coral, Massive	0.66	0.03	10.11	15.94	9.87	15.97
Coral, Branching	0.00	0.00	7.11	11.21	6.93	11.21
Coral, Montipora	0.00	0.00	1.51	2.38	1.47	2.38
Coral, Foliose	0.00	0.00	0.57	0.90	0.56	0.90
Sand & Rock	0.66	0.03	3.66	5.78	3.59	5.81
Sand	9.57	0.39	46.59	73.46	45.64	73.85
Dead Coral	0.99	0.04	1.17	1.85	1.17	1.89
Rubble	30.69	1.26	8.17	12.89	8.75	14.15
Unclassified Substrates	0.66	0.03	8.46	13.34	8.26	13.37
Total	100.00	4.12	100.00	157.68	100.00	161.80

5.2 **RoxSquare**

The constructed RoxSquare accumulated a total of 28 classes **(Figure** 7) throughout the survey. Similar classeswere merged later during post processing. The merged classes include different grain sizes and composition of sands into one simple class, namely Sand. Different classes of rocks, including Algae on **Rock,** were integrated to the class, Rock. The **Sand & Rock** class remains unmerged due to its special characteristic, where it solely belongs neither to **Rock** nor Sand. New **Coral** on **Rock** (later referred to as New Stunted Coral on Rock) was also a stand-alone due to its unique growth feature.

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Figure 7: Rox Square with legend

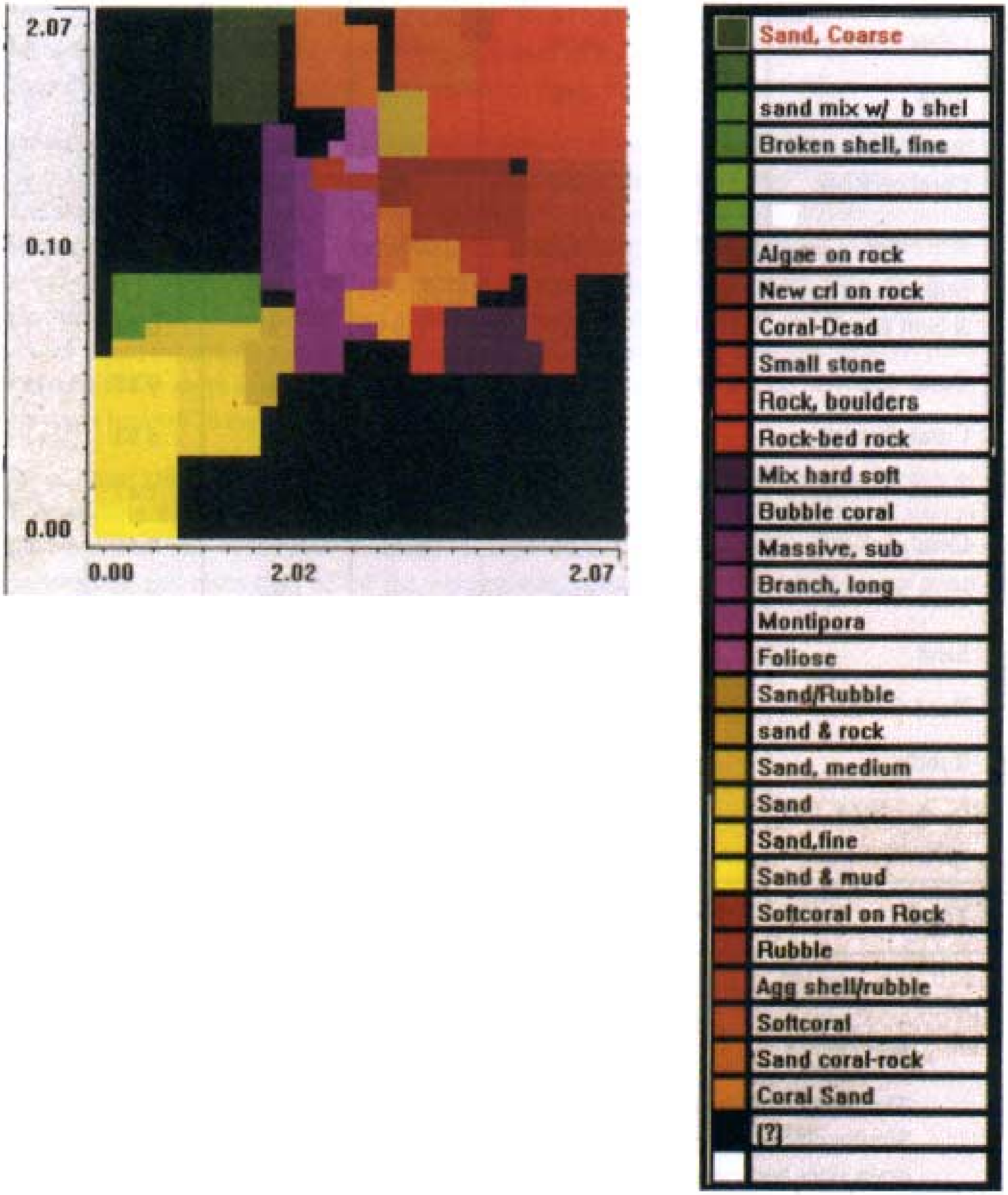

Figure 8: Pulau Segantang – 2D survey track

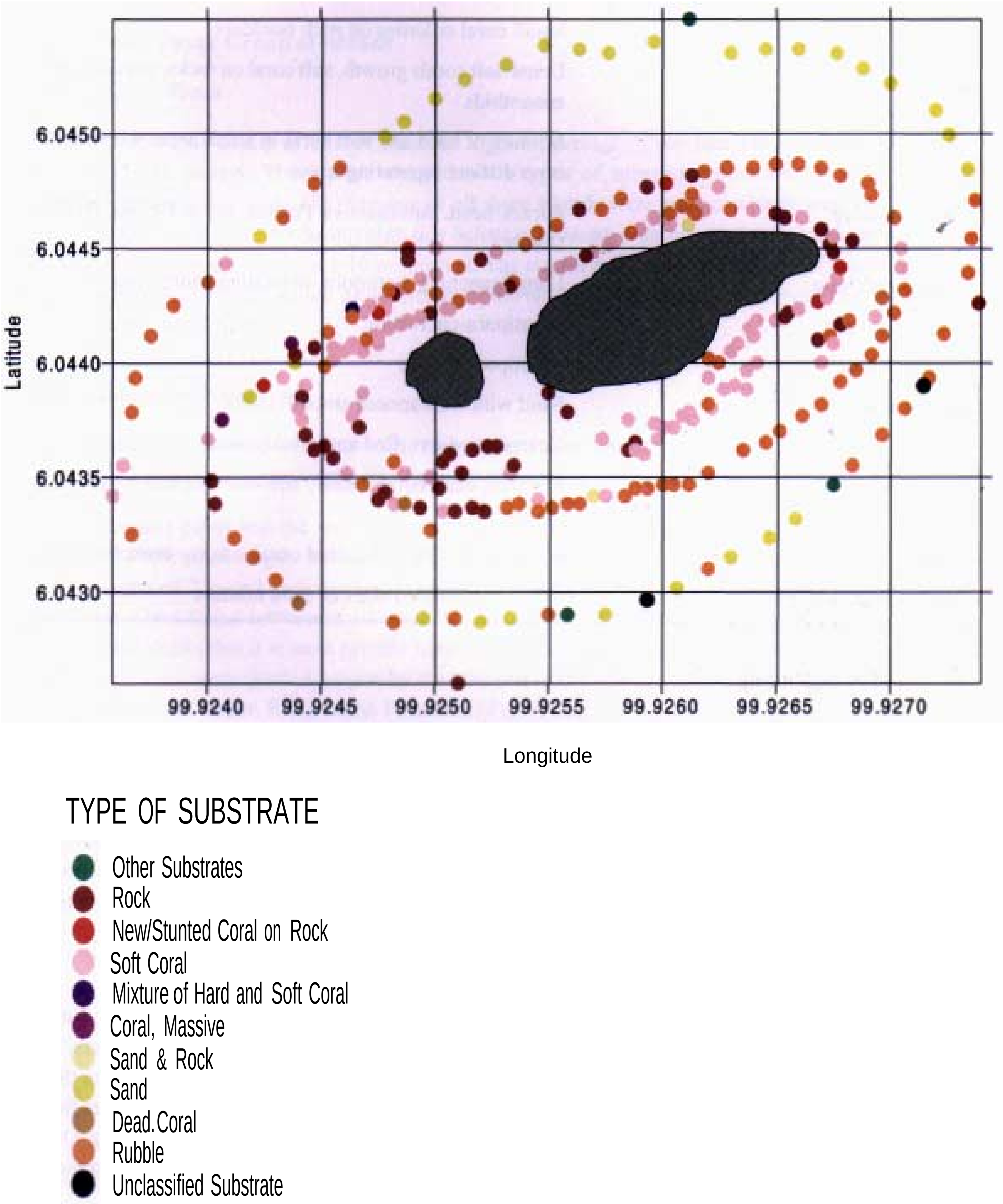

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Table 2 listed below shows the class and the ground-truthed substrate types included.

Classes	*Substrate Type Included*
Other substrates	Fine broken shells
Rock	Boulders, Rock-bed Algae on Rock, Small stones
New/Stunted Coral Rock	Small coral colonies on rock boulders
Soft Coral	Dense soft corals growth, soft coral on rocks, sea anemone, zooanthids
Mixture of Hard & Soft Coral	Mixture of hard and soft coral in small areas where there is no distinct separating space
Coral, Massive	Porites head, sub-massive Porites, Brain Corals, Bubble Corals
Coral, Branching	Long branching Acropora, branching Montipora
Coral, Montipor	Montipora-encrusting
Coral, Foliose	Montipora-foliose
Sand & Rock	Sand with well-spaced smooth rocks
Sand	Coarse, medium, find and muddy sand
Dead Coral	Standing dead coral, mostly sub-massive and long branching
Rubble	Coral debris and loose dead coral, mostly branching type
Unclassified Substrates	Other unclassified sizes of sand mixture

5.3 **Pulau Segantang**

5.3.1 ***Survey Track***

Figure 8 shows the original 2D track run for P. Segantang, which represents a total track length of 4.12 km, comprising 11 substrate classes. Data on substrate type was obtained solely from the parallel track run to both rock outcrop at P. Segantang during high tide. The first two parallel runs were at intervals about 5-10 meters and subsequent runs were further apart. No perpendicular run was conducted in view of the absence of substrates of interest at depth more than 23 meters.

5.3.2 ***Substrate Composition***

Soft coral was the most dominant substrate (34.65%) at this area, covering the upper slope, particularly at the Southeast and Northwest of P.Segantang. Beyond 12m - 16m of waters, the substrate type changes from soft coral dominant to rubble dominant (30.69%). Being the third most common substrate at 18.48%, rocks were well distributed among the substrate types from shallow waters till about 22 m depth. Hard corals were extremely scarce at P. Segantang. Only a massive type of coral at 0.66% was found in the island water at the submerged rock outcrop at the western side. A mixture of hard soft coral with a total pcrcentage of 0.66% were found at 6-8 m depth and only at the northwest and east of P. Segantang. Percentage of dead coral is less than 1% of the total surveyed track. This substrate was found only at the western side. The individual substrate distribution patterns are illustrated in Figures 9-13. Despite.low hard coral occupancy, there was quite a number of small coral colonies on the rock. A total of 1.98% of this growth form was found occupying the shallow water at locations shown in Figure 14.

5.4 Pulau Payar Group of Islands

5.4.1 *Survey Track*

Pulau Payar Group of Islands received a good coverage of survey track which totalled up to 157,680 meters. There were altogether 14 types of substrate encountered, including the Unclassified (Figure 15). Surveys of all three islands were started with at least two 'round-island' parallel tracks during high tide before continuing with perpendicular tracks which were generally separated by a 5-10 m interval. The cut off point for the deep end of each track was determined by the isoline of 30 meters or the absence of substrate of interest, whichever was encountered first.

5.4.2 *Substrate Composition*

Sand was the most prevalent substrate type for Payar's waters, contributing 46.50% of the total track surveyed. Corals were also found in abundance within the transects.

Massive coral was the second largest substrate type which sums up to 10.11%, equivalent to 15.49km total length. Massive coral at the east side of P. Payar generally starts at shallow waters of 2 ni and ends at about 20 m depth. On the western side of the island, such a growth form was fouiid between the 8 and 24 meter depth range. The distribution pattern for massive coral shows that it is most prolific between Monroe Rock and the Southwest tip of Payar. This area has a more gentle topography than the rest of the island. Massive coral is also prevalent in between P. Payar, P. Kaca and P. Lembu (Figure 16).

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Figure 9: Pualau Segantang – Distribution pattern for soft coral

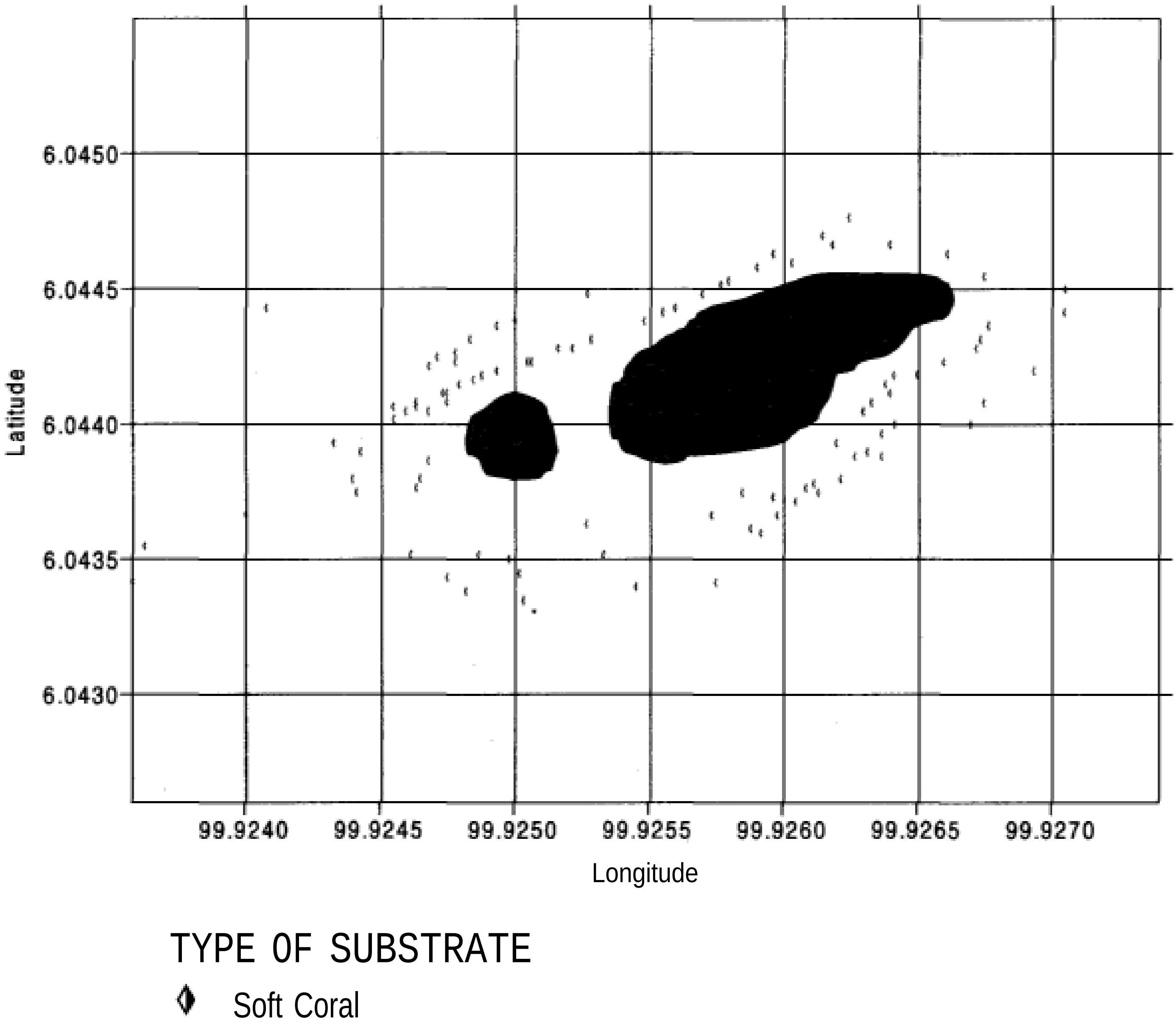
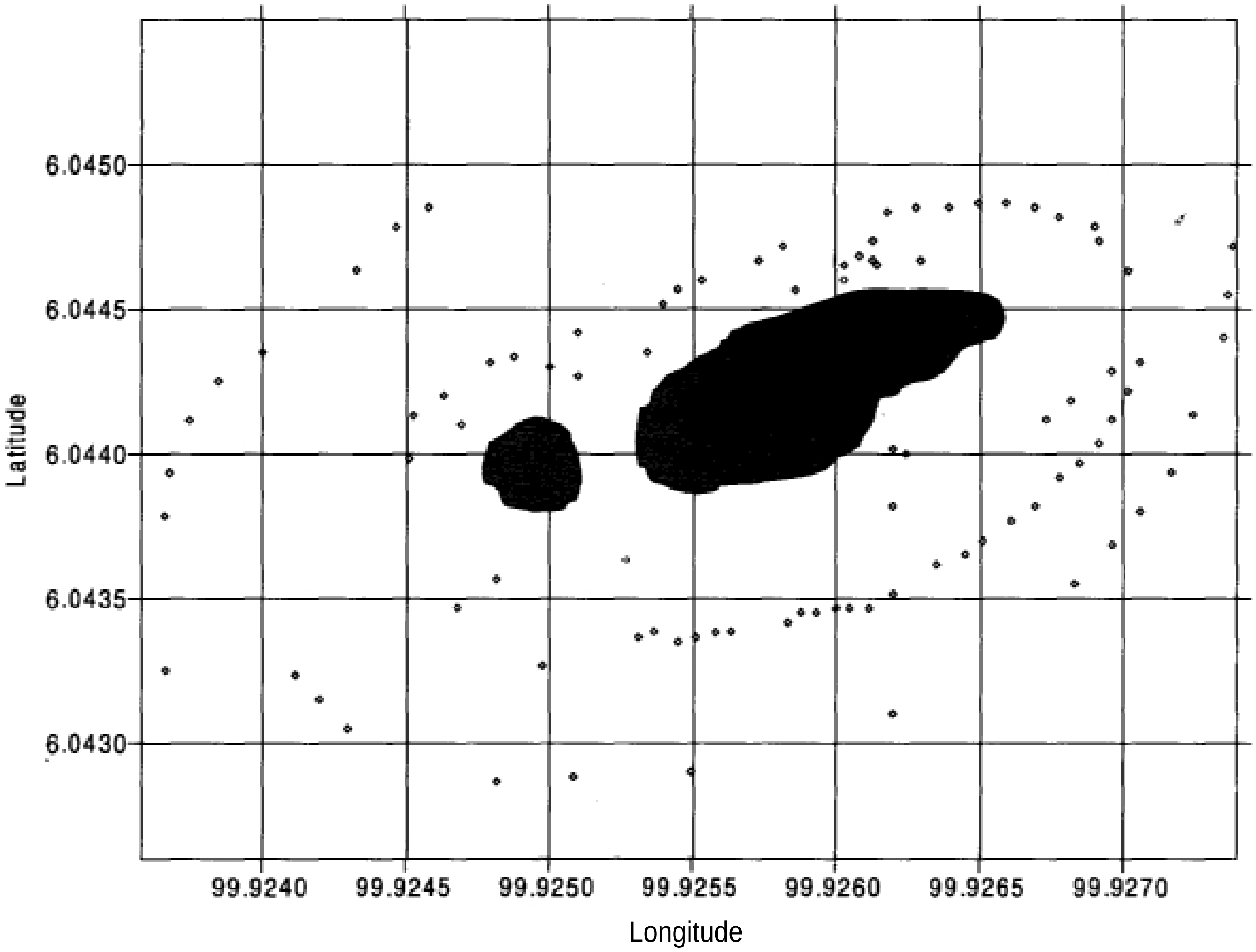


Figure 10: Pulau Segantang – Distribution pattern for coral rubble



TYPE OF SUBSTRATE

◇ Rubble

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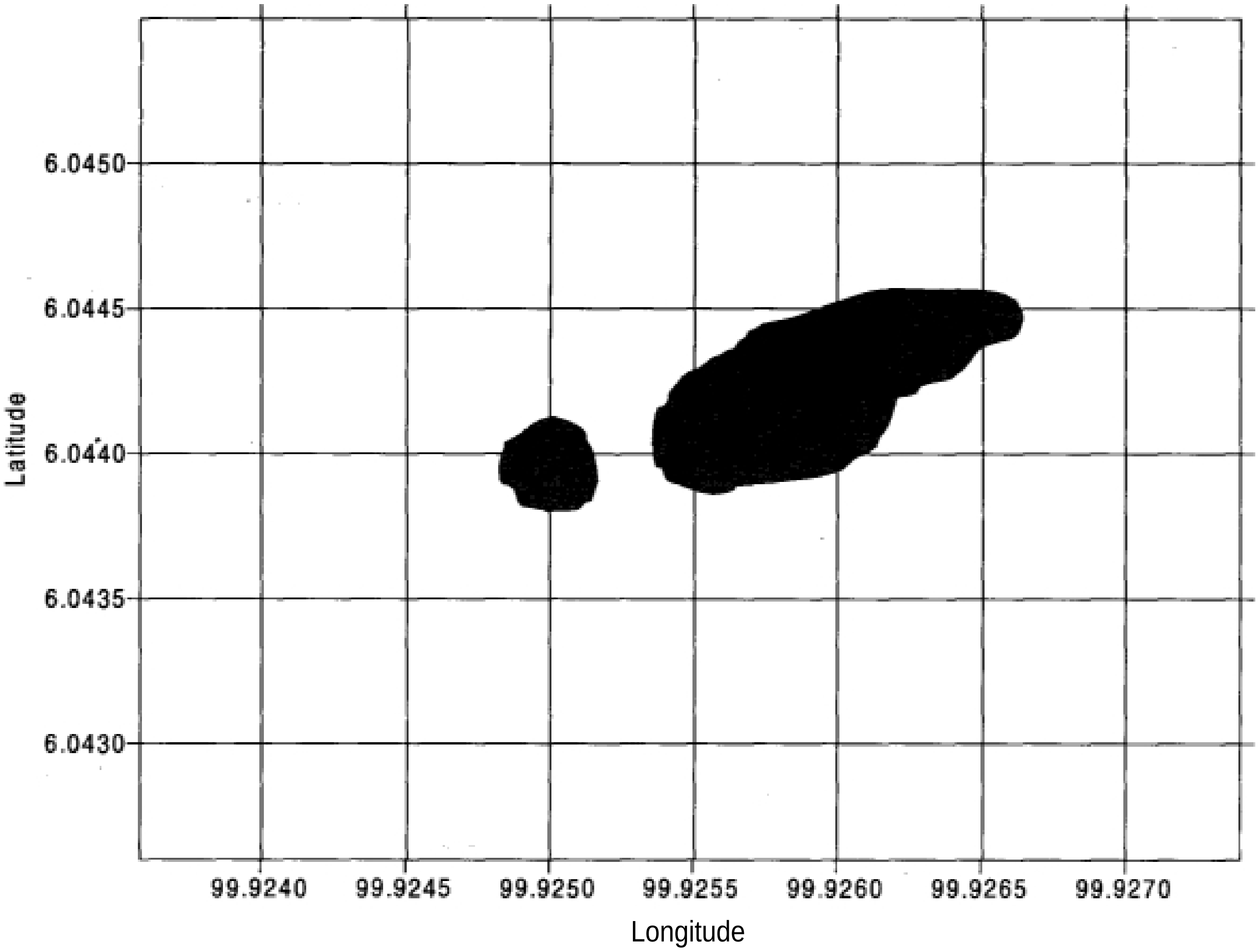
Figure 11: Pulau Segantang – Distribution pattern for massive coral

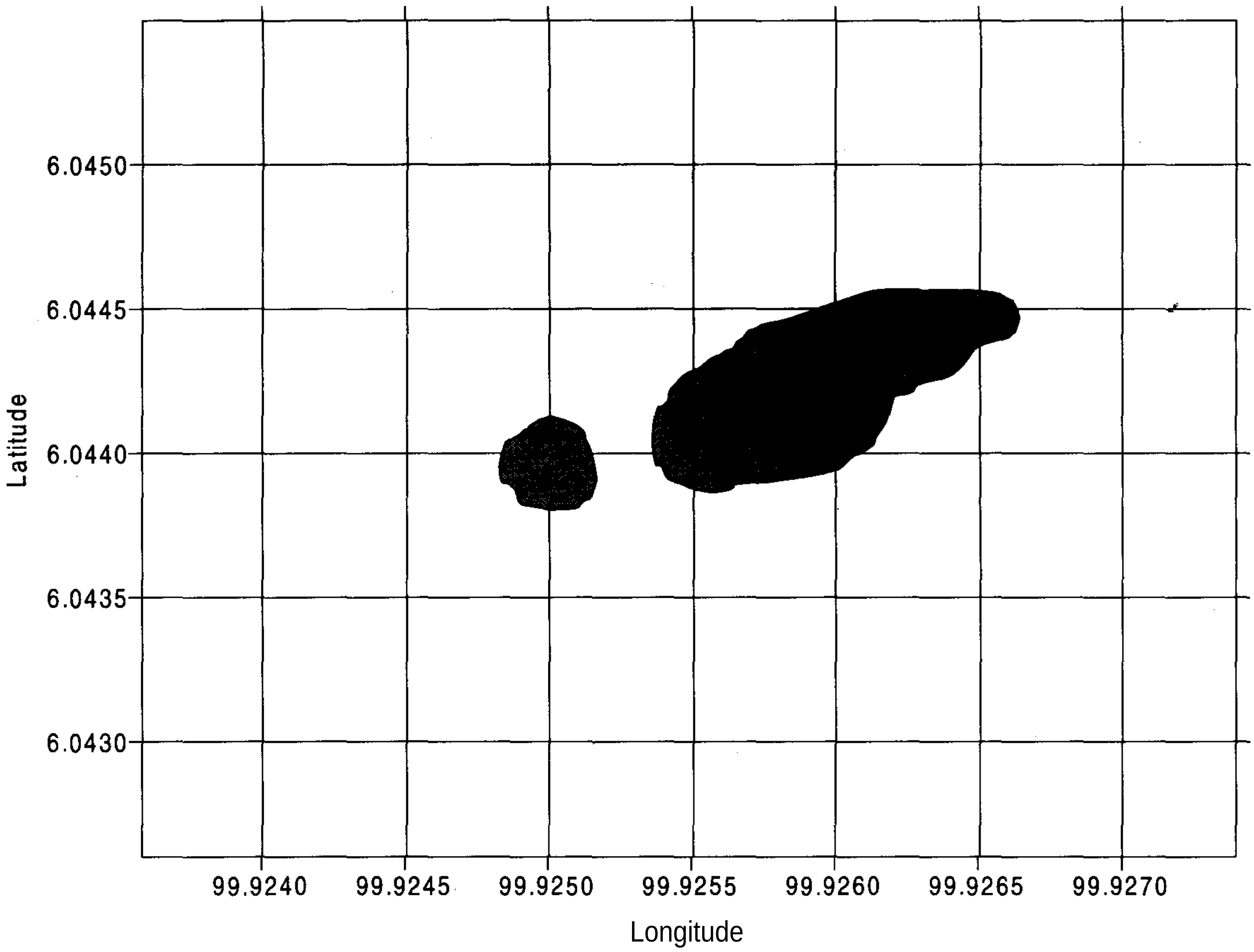


TYPE OF SUBSTRATE

Coral, Massive

<<

Figure 12: Pulau Segantang – Distribution pattern for mixture of hard and soft coral



TYPE OF SUBSTRATE

+ Mixture of Hard and Soft Coral

k FIG 12

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Figure 13: Pulau Segantang – Distribution pattern for dead coral

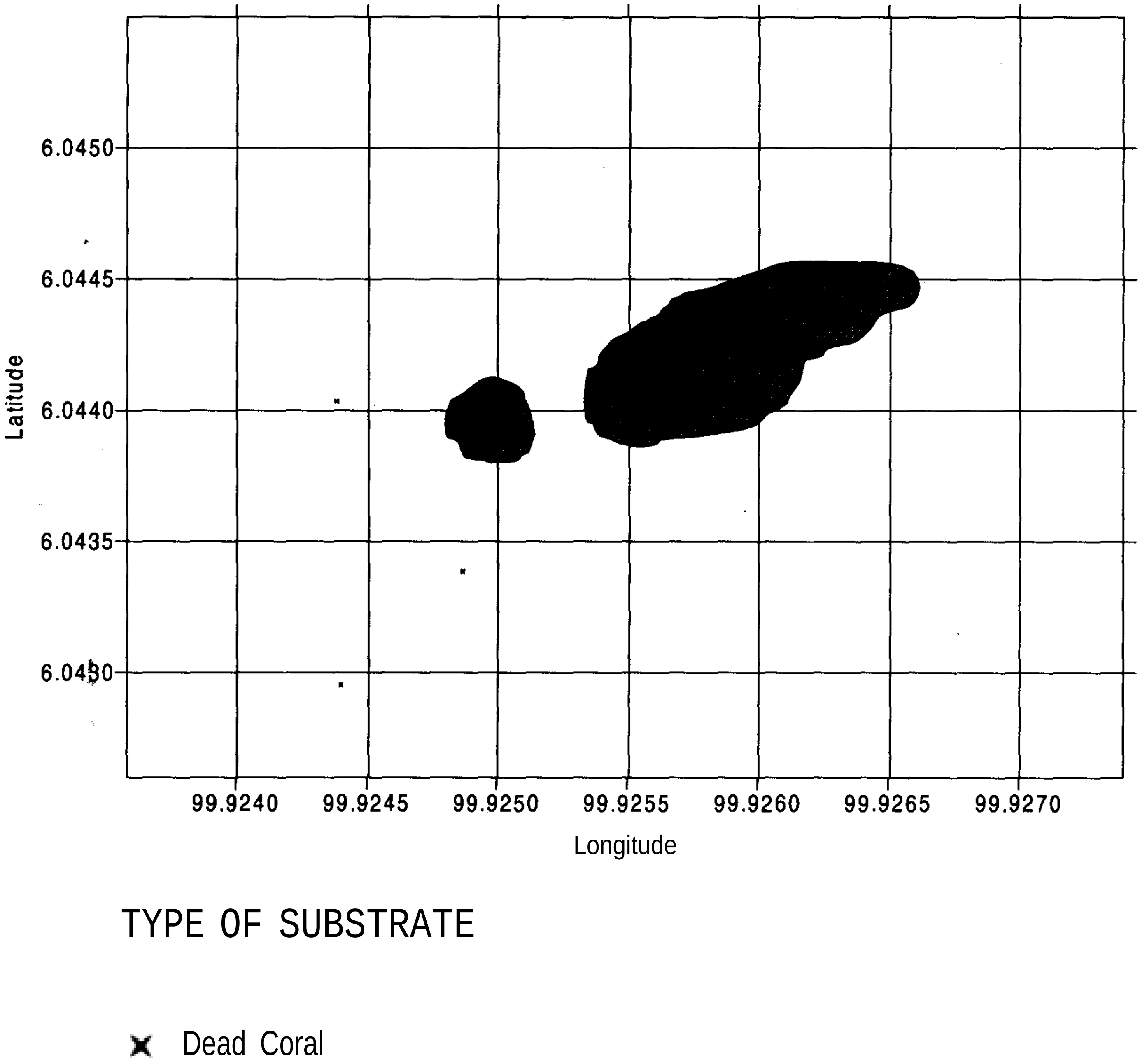

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Figure 14: Pulau Segantang – Distribution pattern for New/Stunted Coral on Rock

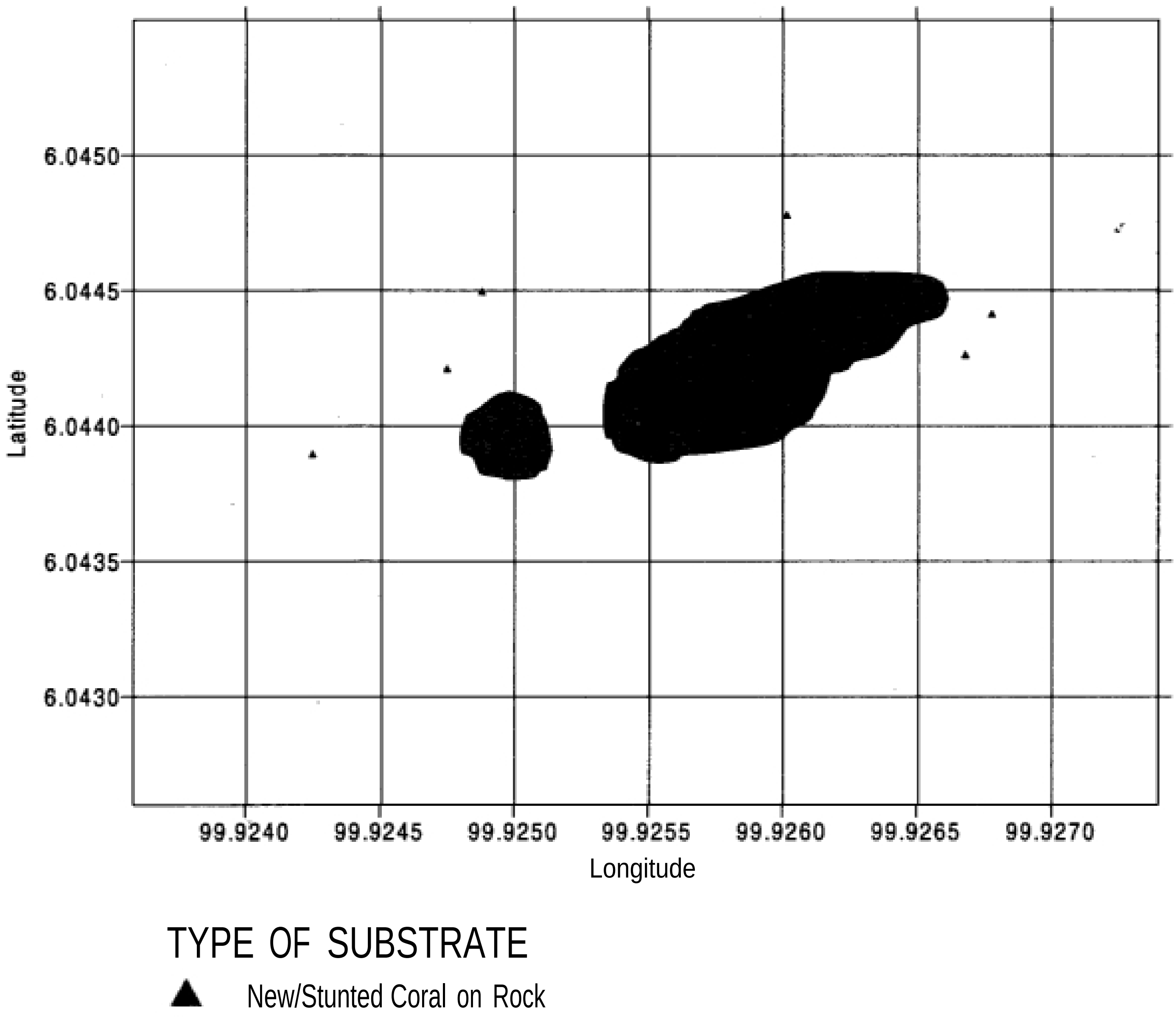

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Figure 15: Pulau Payar – 2D survey track (24th - 28th April, 1998).

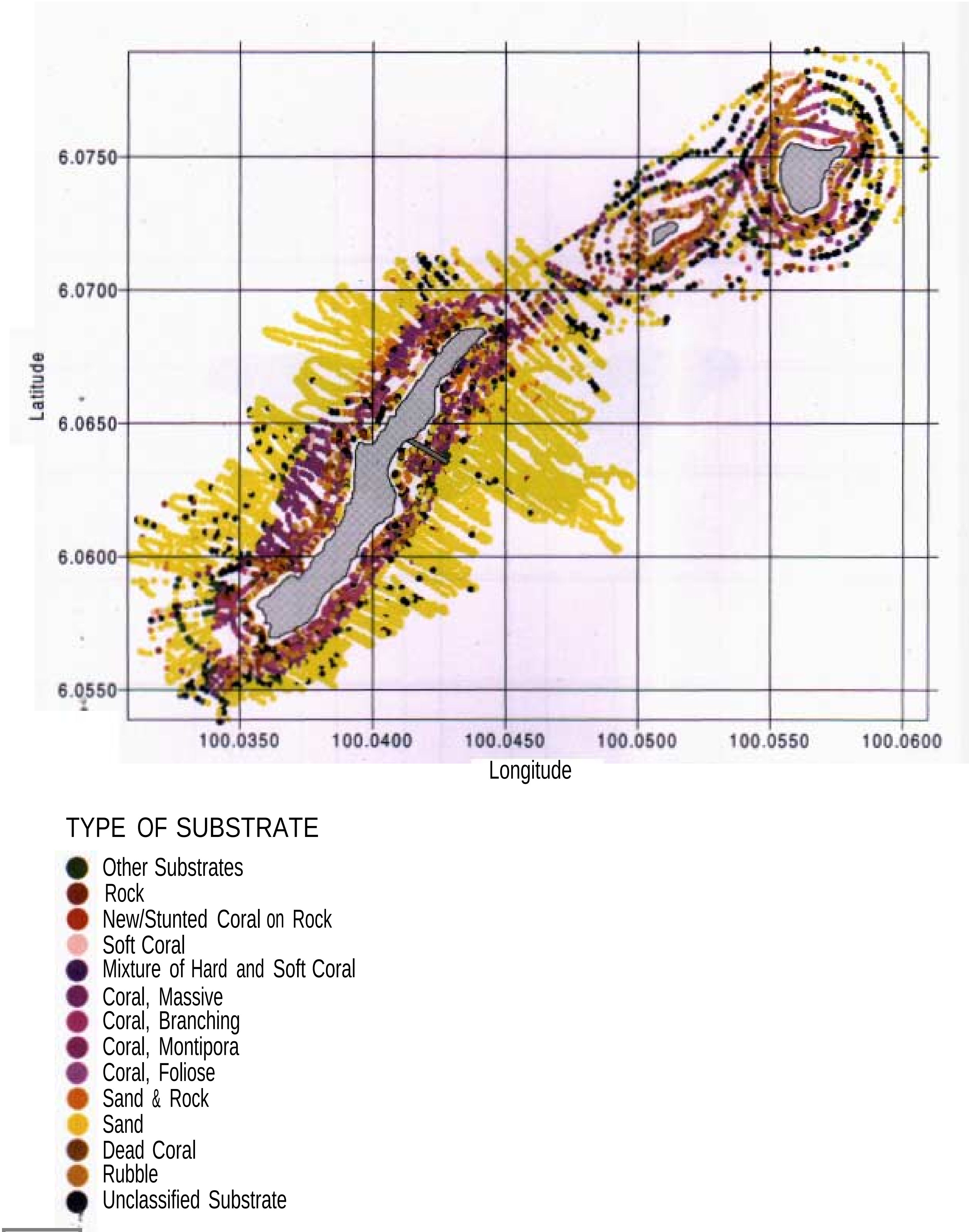

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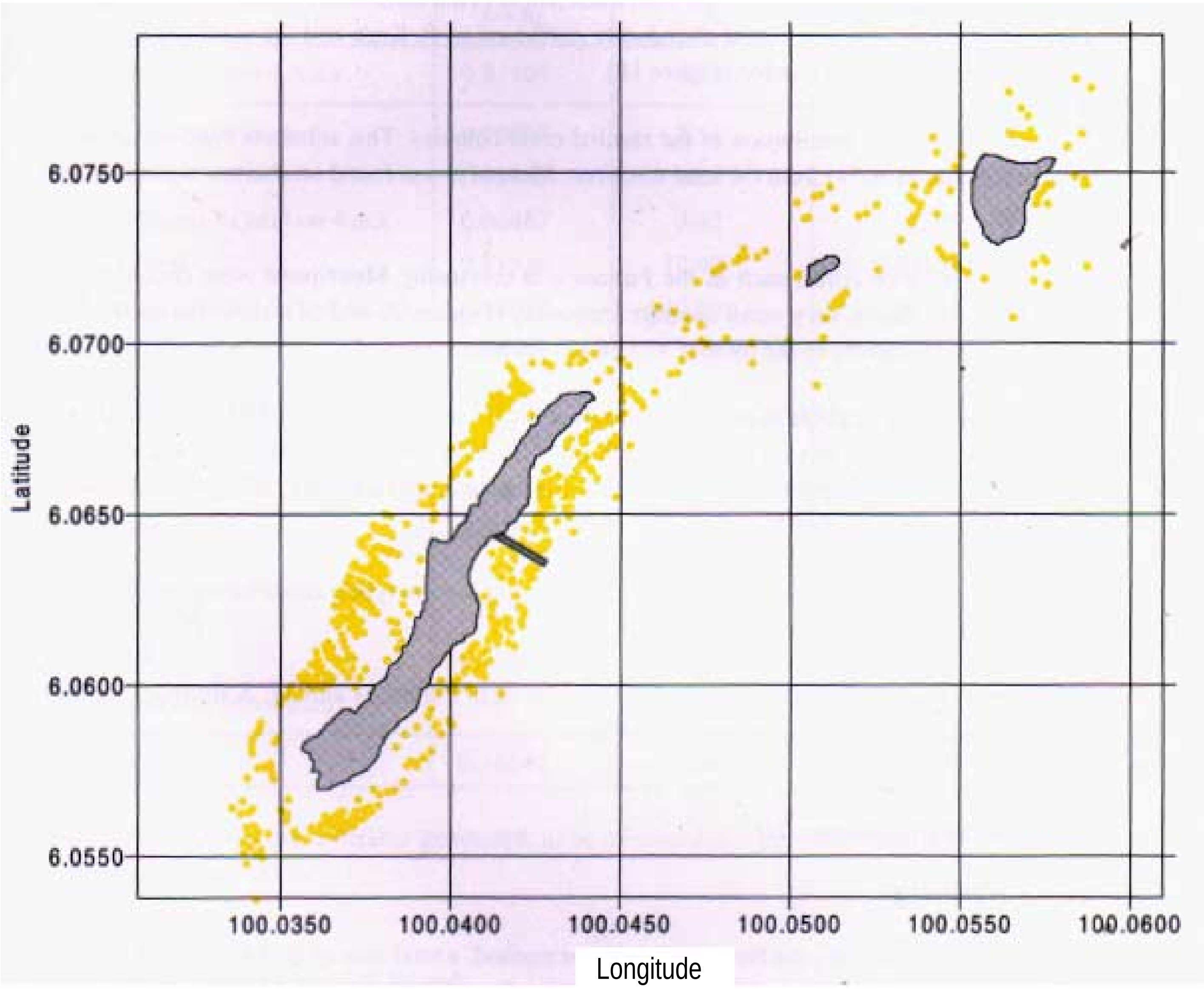
Figure 16: Pulau Payar— Distribution pattern for massive coral.



TYPE OF SUBSTRATE

Coral, Massive

<<

Branching Coral (7.11%) is the second most abundant coral type found in P.Payar with a total length of 11.12 km recorded. It was distributed all around the three islands from 2-20 meter waters (Figure 17). This coral type can be seen frequently also along Banana Reef to Japanese Garden.

Soft Coral is quite a common resident in Payar waters. With the substrate type ranking at number 8, it contributes 3.01% of the total track length. This community is distributed sparsely around P. Lembu, but was found abundantly northwest of P. Kaca and the southern tip of P. Payar, namely the Coral Garden (Figure 18).

Figure 19 shows the distribution of the stunted coral colonies. This substrate type occupied a total of 2.56km (1.62%) from the total track run. Most of it was found on shallow waters about 6 m deep.

Other types of hard corals such as the Foliose and encrusting Montipora were encountered around the isle, but in very small quantity/frequency (Figures 20 and 21), contributing *0.57%* and 1.51% respectively to the total of 157.68 km transect surveyed.

The percentage for Rubble is moderately high at 8.17%, equivalent to 12.89 km, while Dead Coral has about 1.85 km total track length only Rubble was mostly found at water depth beyond 6 meters. Distribution of this substrate was concentrated around P. Lembu and P. Kaca as well as the lower half of P. Payar (Figure 22).

Abiotic substrate such as Sand **and Rock** are the major bottom types, constituting 46.59% and 6.16% respectively of the total substrate type.

Distribution patterns for other substrates are as shown in Figure 23 and 24. A summary of the important coral substrates is illustrated in Figure 25.

5.5 **Substrate Interpolation** - 2D

5.5.1 ***Pulau Segantang***

Upon interpolation using the Nearest Neighbour method, a total area of 0.14 km sq (0.432km x 0.33 km) was derived from the Longitude ranging from 99.9236° - 99.9270°N and Latitude range of 6.0426°-6.455°E. The total island area was estimated at 0.012 km sq. This reading was derived through Surger 62 software analysis by digitising and later blanking the inner part of the track run (Figure 26).

Rubble has become the major substrate after interpolation, covering an area of *0.51* km sq. ***(35.56%)*** followed by Sand which has an area of 0.036 km sq representing 24.98% of the total area. Total interpolated area of Soft **Coral** is now 0.016 km sq (10.92%), ranking the third most common substrate. Massive **Coral** has the least surface area which constitutes only 0.002 km sq. Mixture **of Hard and** Soft **Coral** after interpolation has an area of 0.001 km sq, whereas Dead **Coral and** New Coral on Rock covered 0.003 km sq and 0.005 km sq respectively.

A summary of the interpolated substrate area for P. Segantang is as shown in Table 3.

<<

Table 3: A summary of the interpolated substrate area for Pulau Segantang and Pulau Payar.

islands	*P. Segantang & P. Cupak*		*P. Pavar Group of ls.*	
Longitudnal Range	*99.9236 - 99. 9274N*		*/00.03/ - 100.06/N*	
Latitude Range	*6.0526 - 6.0455E*		*6.05388 - 6.07893E*	
Total Interpolated Area	*0. 14246 km sq.*		*: 9.7885 km sq.*	
Class	*km sq.*		*km sq.*	
Blank@Est.Island Area	0.01166	8.18	0.37168	3.80
Other Substrates	0.00300	2.11	0.28948	2.96
Rock	0.00888	6.24	0.10464	1.07
New/Stunted Coral on Rock	0.00487	3.42	0.20287	2.07
Soft coral	0.0155.6	10.92	0.12509	1.28'
Mixture of Hard & Soft Coral	0.00088	0.62	0.09 199	0.94
Coral, Massive	0.00196	1.38	0.14341	1.47
Coral, Branching	0.00000	0.00	0.22850	2.33
Coral, Montipora	0.00000	0.00	0. 10777	l .10
Coral, Foliose	0.00000	0.00	0.09777	1.00
Sand & Rock	0.00403	2.83	0.10355	1.06
Sand	0.03559	24.98	6.30659	64.43
DeadCoral	0.00344	2.42	0.14752	1.51
Rubble	0.05066	*35.56*	0.93158	9.52
Unclassifies Substrates	0.00193	1.35	0.53641	5.48
Total	**0.14246**	**100.00**	**9.78885**	**100.00**

(Note: All statistics are computer generated, to be remained at 5 decimal point in this table for reference purposes).

5.5.2 *Pulau Payar Group of Islands*

An area of 3.411km x 2.870 covering the Longitude and Latitude range of 100.03 10°-100.061 0°N and 6.0538°-6.0790°E was interpolated. Total island area derived was approximately 0.372 km sq (Figure 27).

Sand is still the most prevalent substrate type with a total estimated cover of 6.306 km sq. The ranking for Rubble has improved from number 4 (original track data) to number 2 after interpolation with a total area of 0.932 km sq *(9.52%).*

Branching Coral has become the most abundant hard coral, covering an area of approximately 0.228 km sq after interpolation, followed by New Coral on Rock with a total coverage of 0.203 km sq (2. 19%).

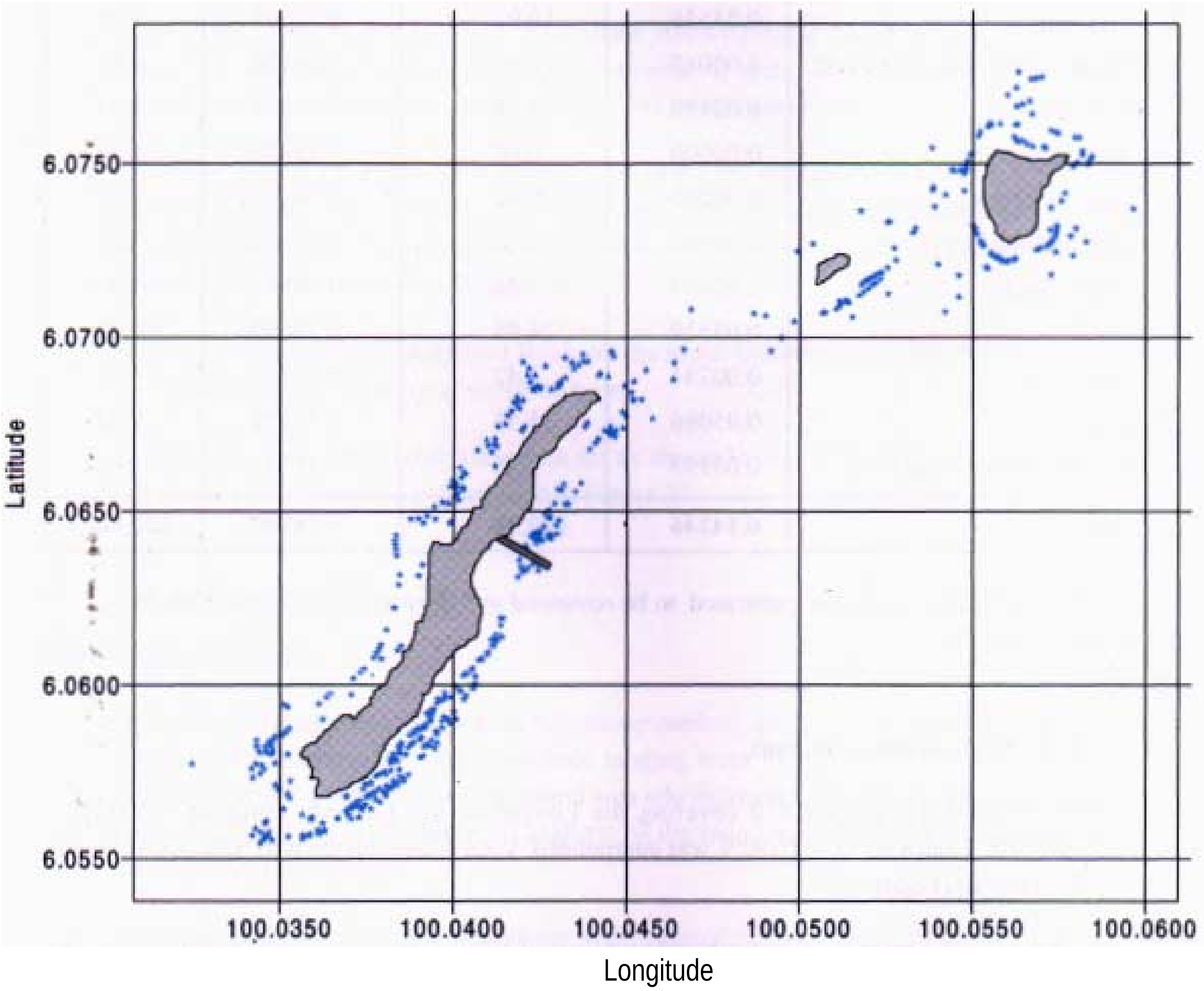
<<

The interpolated ranking for Dead Coral has also leaped to number 7, occupying a total surface **area of approximately 0.148 km sq.**

Massive Coral showed up as the third most abundant live coral type after the Branching Coral and New/Stunted Coral on Rock. It took up a total of 1.47% of the 9.789 km **sq Soft coral and** Montipora cover, an area of *0.125* km sq and 0.107 km sq rspectively. Other substrate compositions are as shown in Table 3.

For reference purposes, data collected from the track run were further interpolated in 3D by overlaying the 2D substrate data to 3 D depth model (Figures 28-31).

Figure 17 Pulau Payar – Distribution pattern for branching coral



TYPE OF SUBSTRATE

Coral, Branching

<<

Figure 18 Pulau Payar – Distribution pattern for soft coral

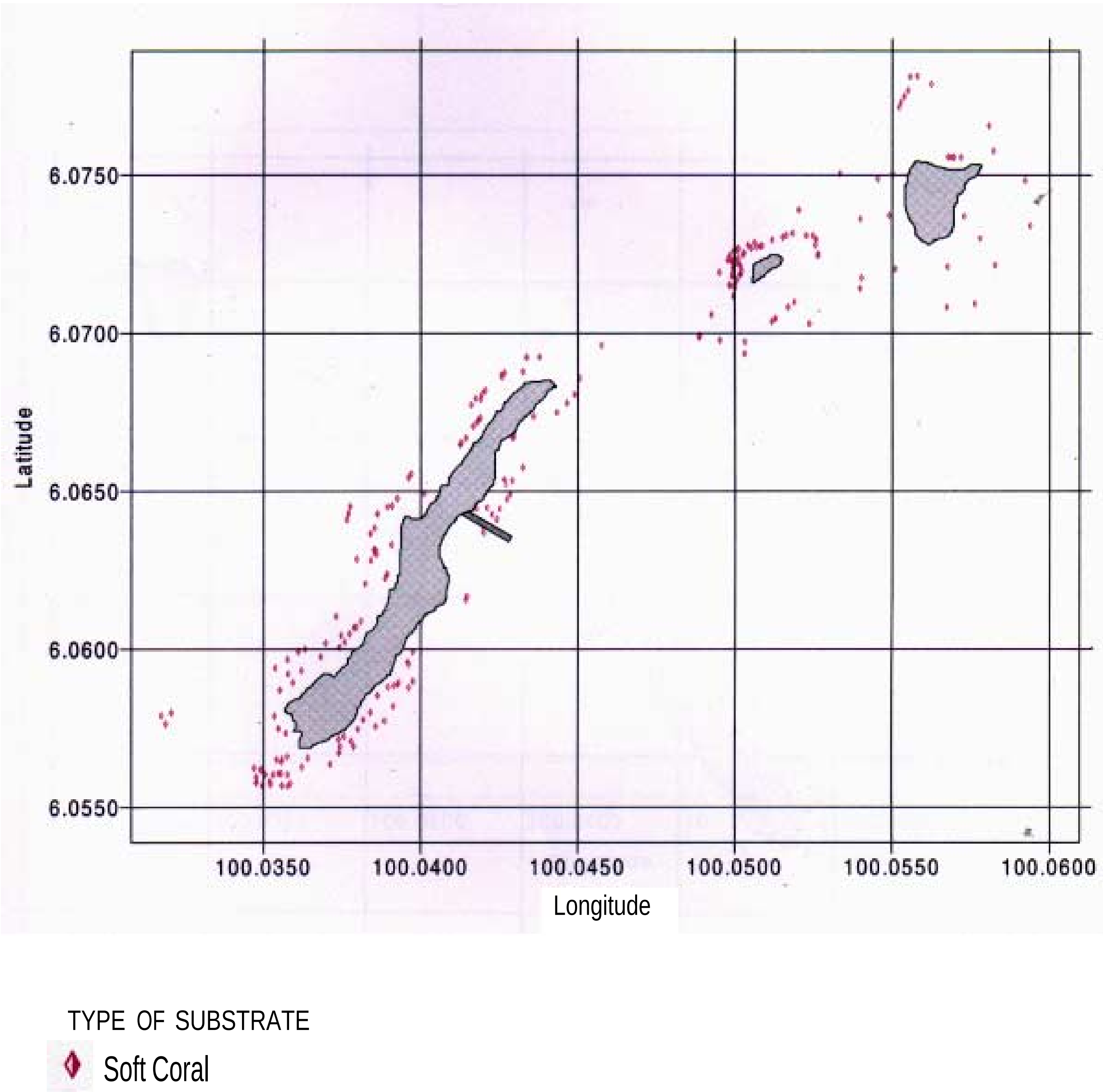


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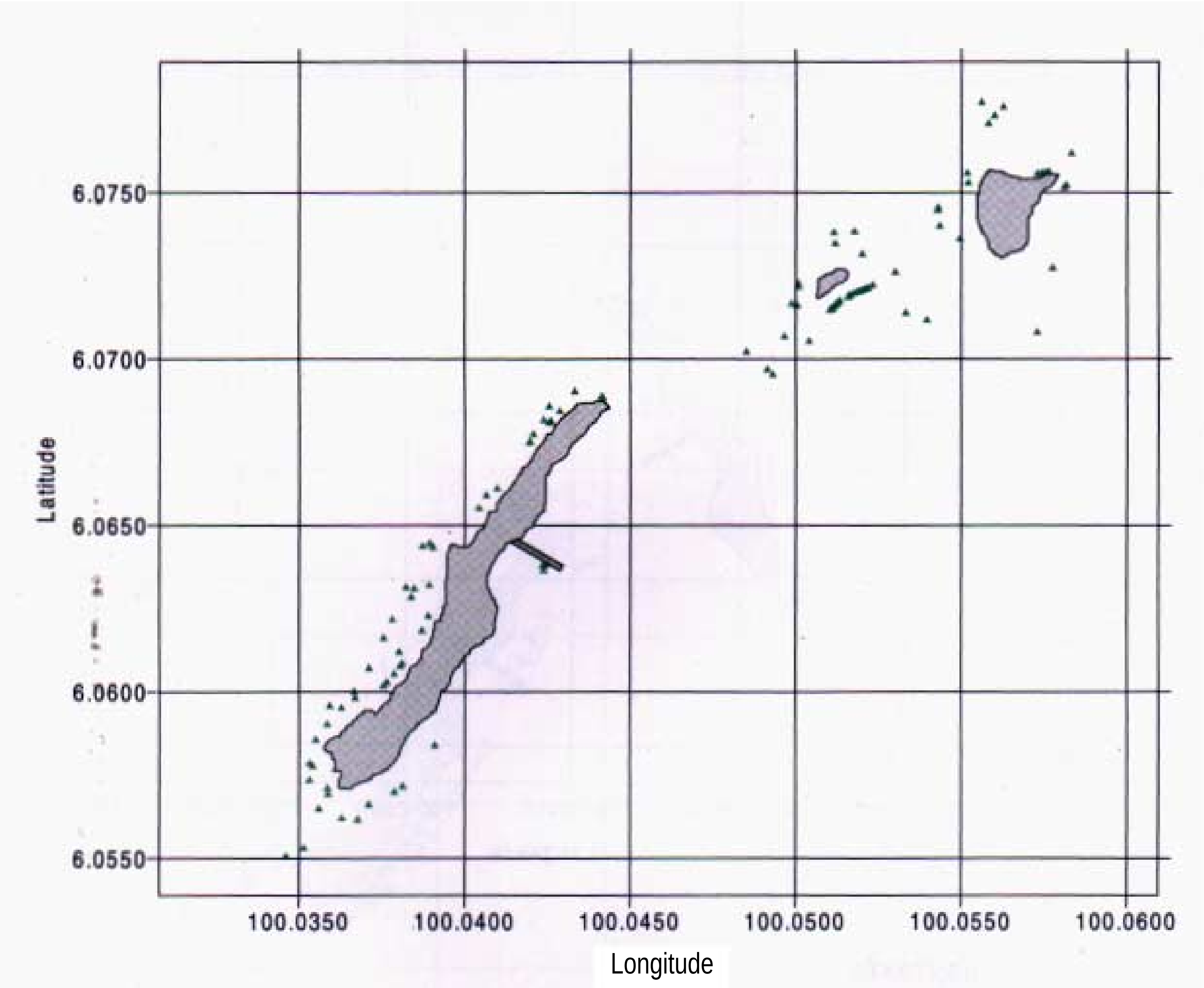
Figure 19: Pulau Payar – Distribution pattern for new/stunted coral on rock

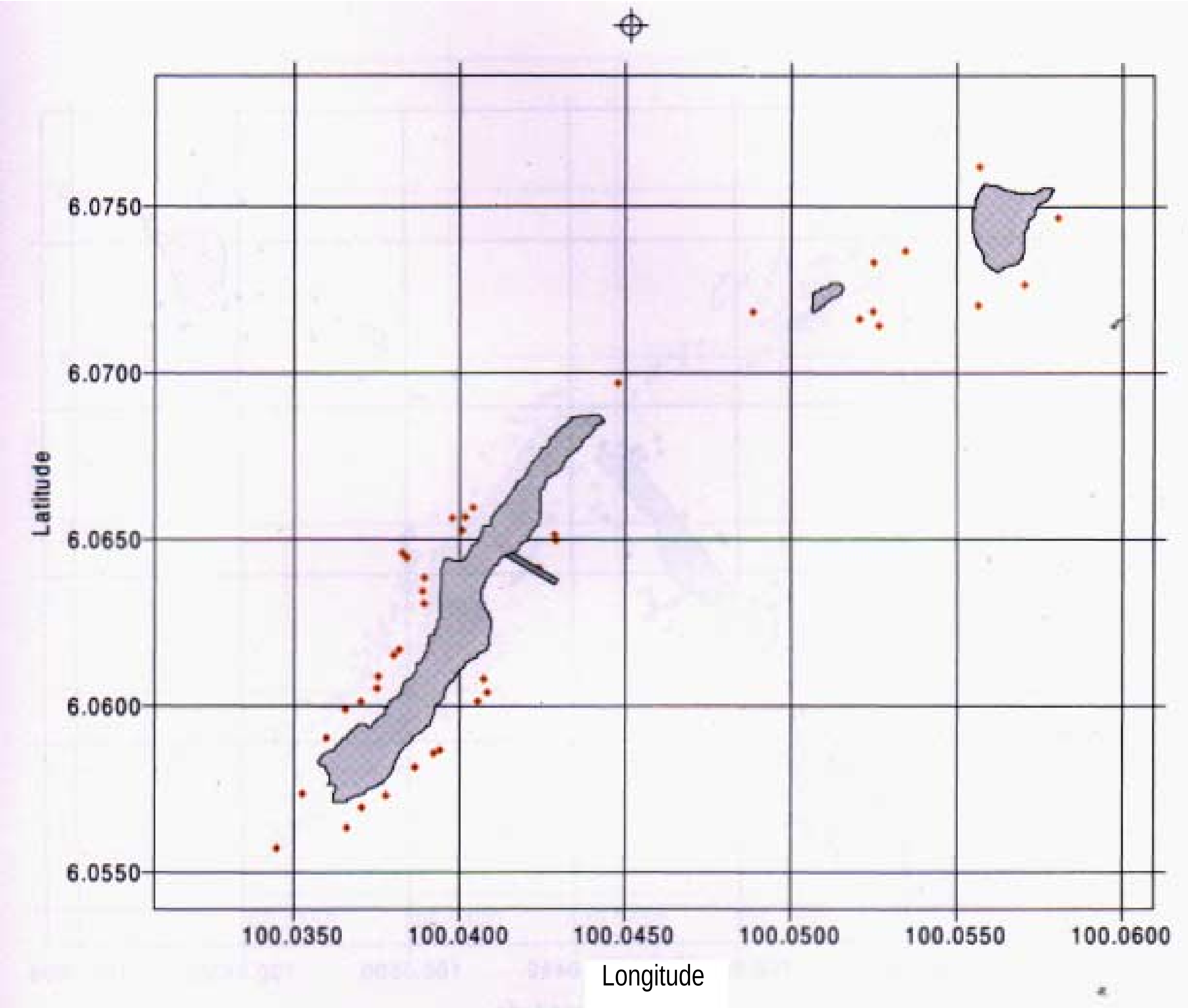


TYPE OF SUBSTRATE

▲ New/Stunted Coral on Rock

<<

Figure 20: Pulau Payar – Distribution pattern for foliose coral

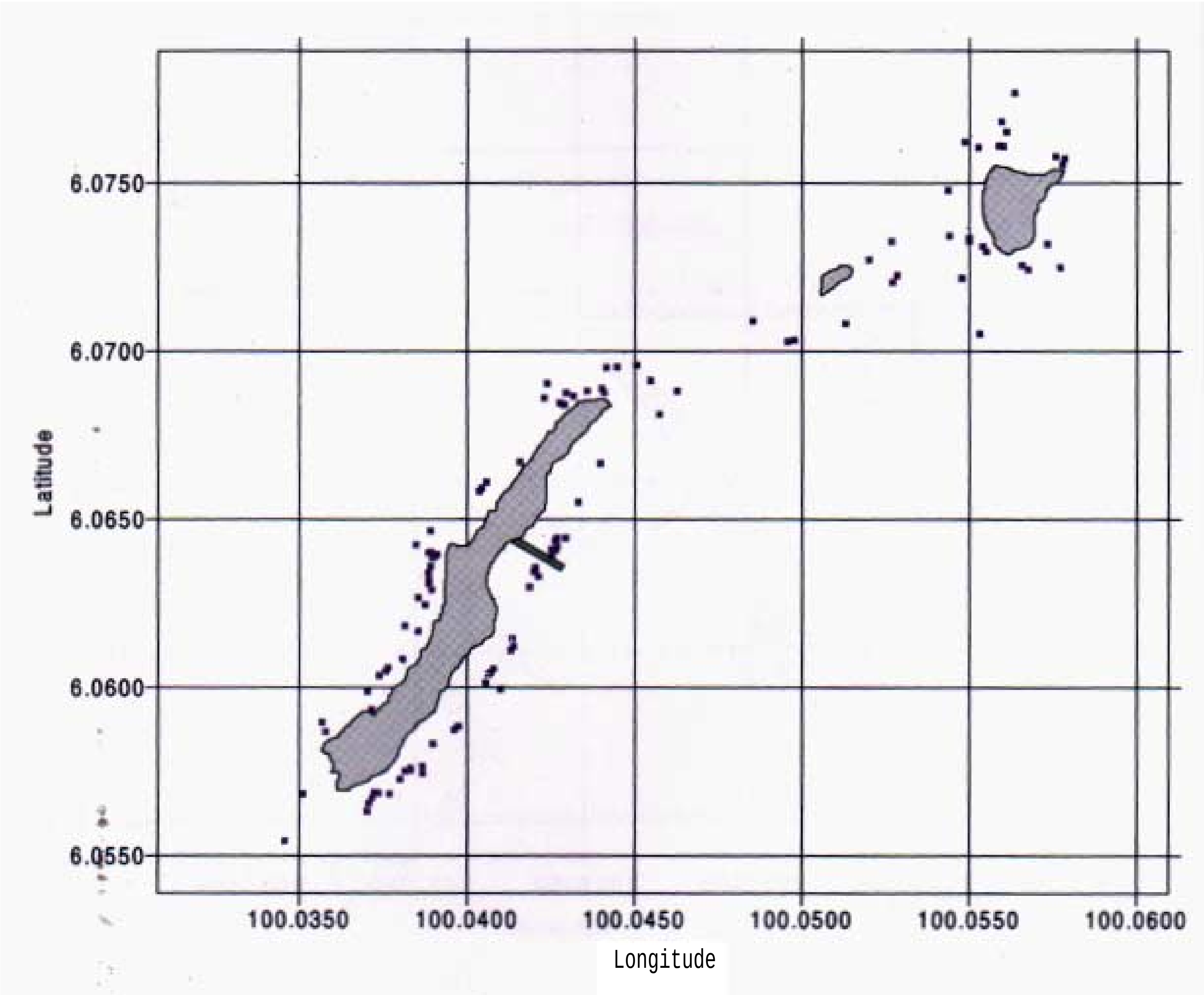


TYPE OF SUBSTRATE

Coral, Foliose

<<

Figure 21: Pulau Payar – Distribution pattern for Montipora

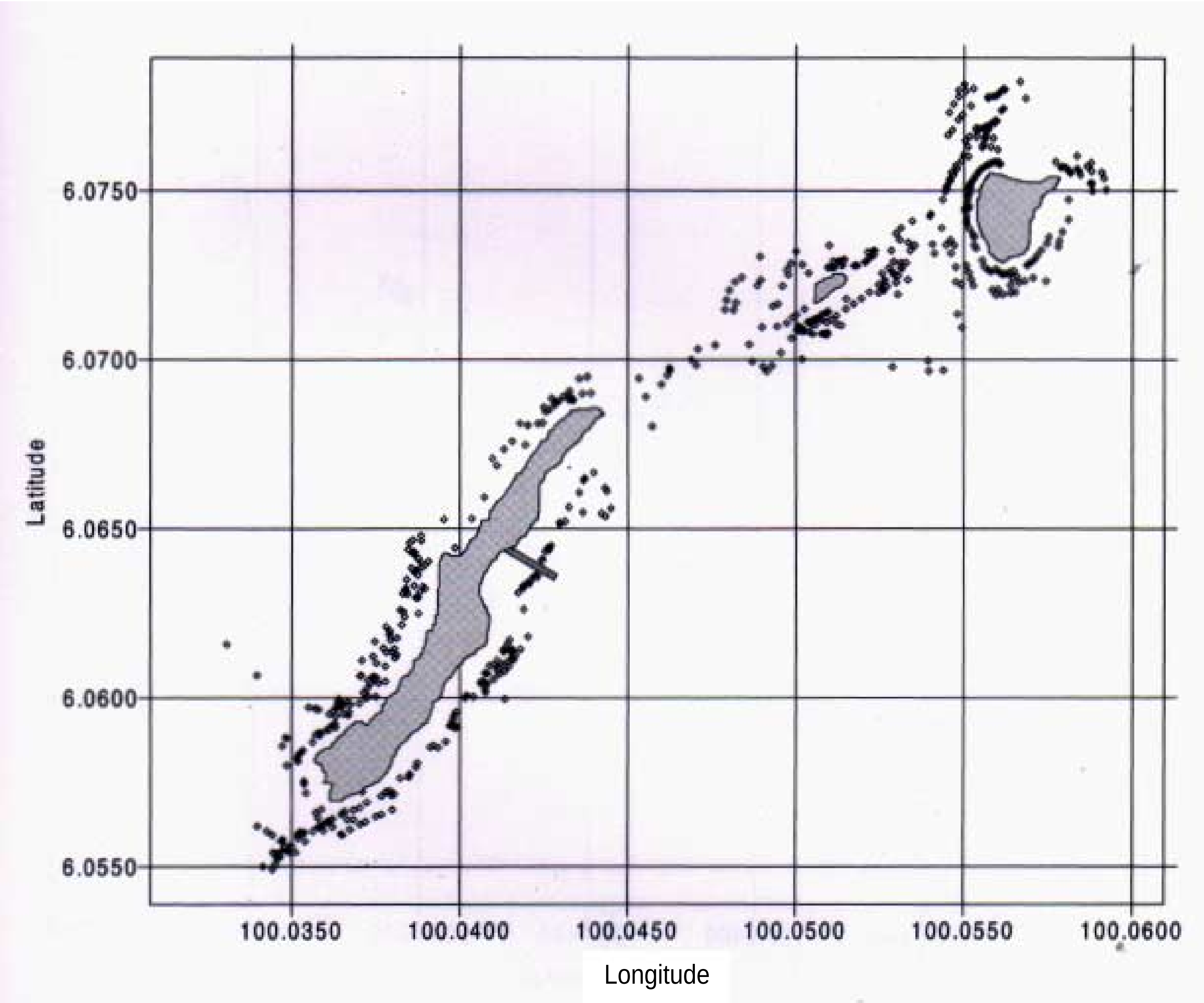


TYPE OF SUBSTRATE

Coral, Montipora

<<

Figure 22: Pulau Payar – Distribution pattern for coral rubble

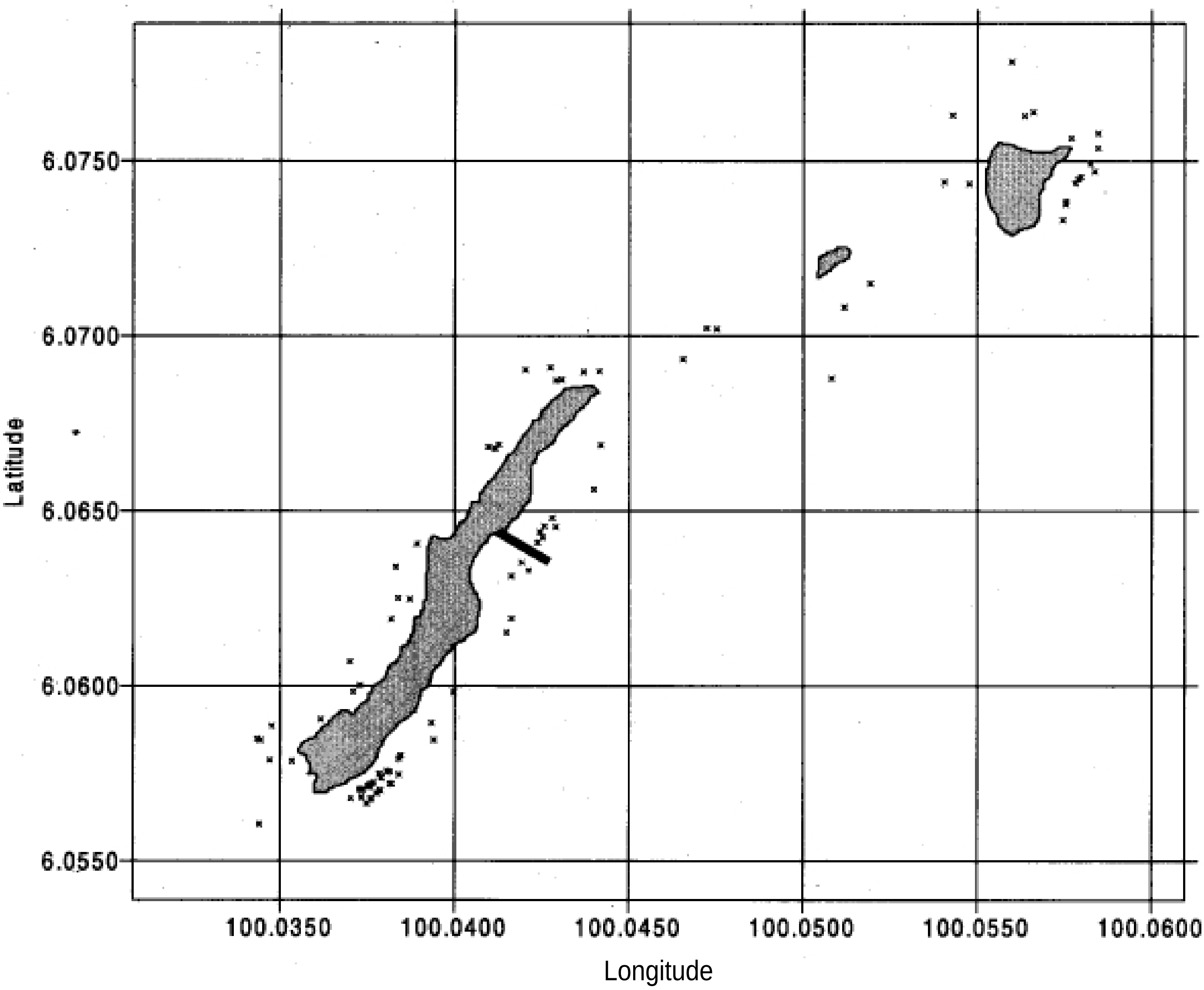


TYPE OF SUBSTRATE

◆ Rubble

<<

Figure 23: Pulau Payar – Distribution pattern for dead coral

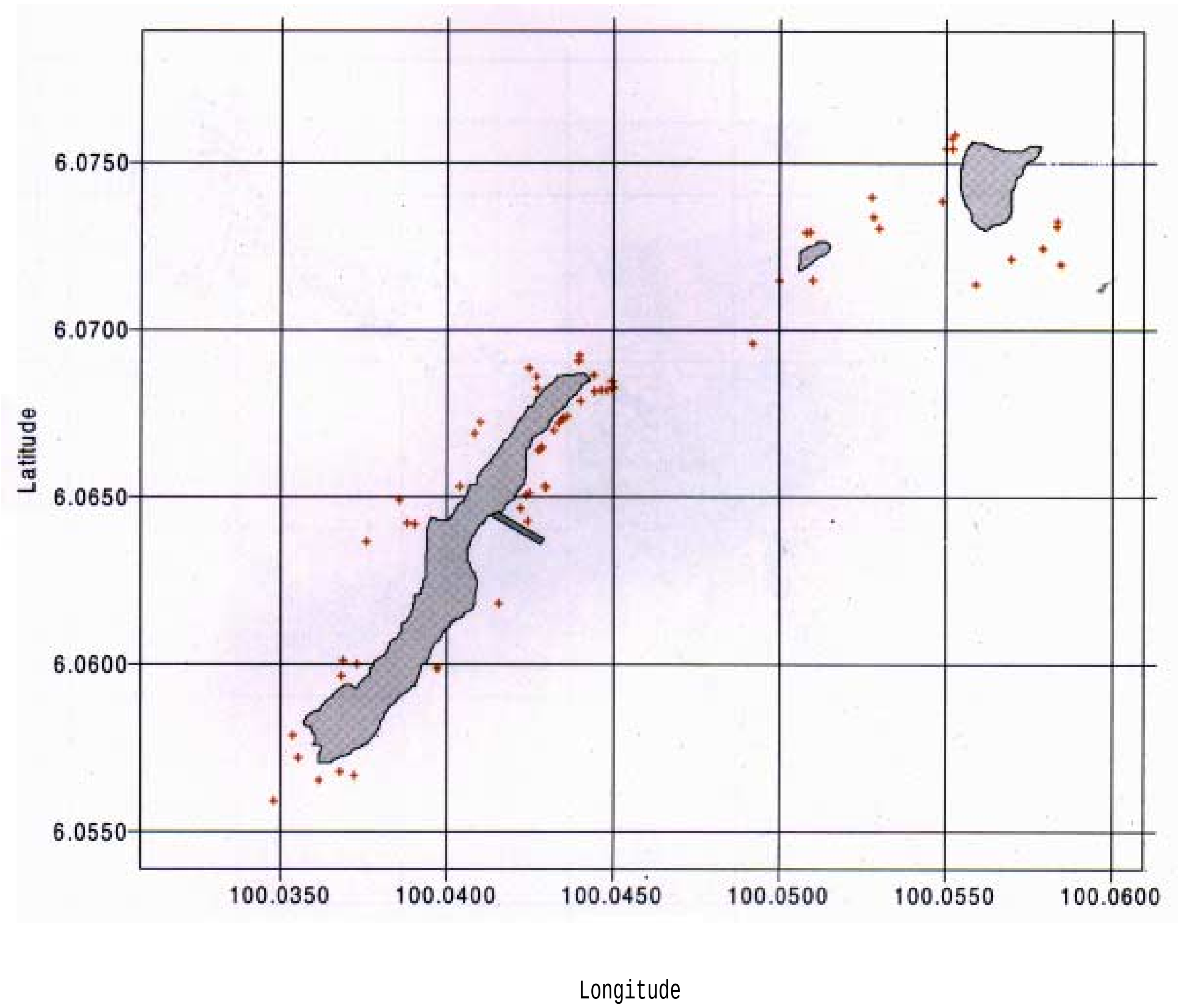


TYPE OF SUBSTRATE

✕ Dead Coral

<<

Figure 24: Pulau Payar – Distribution pattern for mixture of hard and soft coral

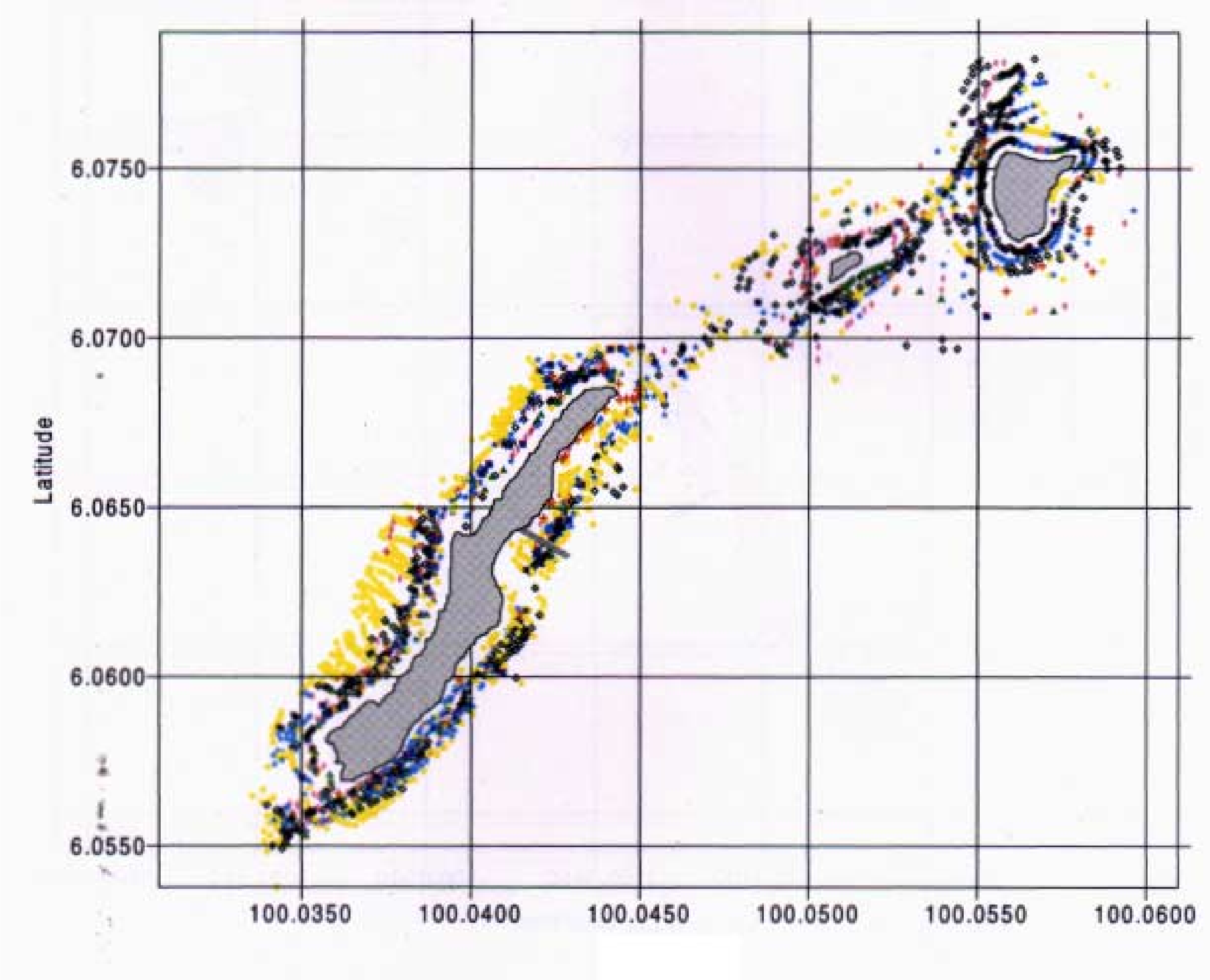


TYPE OF SUBSTRATE

Mixture of Hard and Soft Coral

<<

Figure 25: Distribution pattern for the important coral substrates



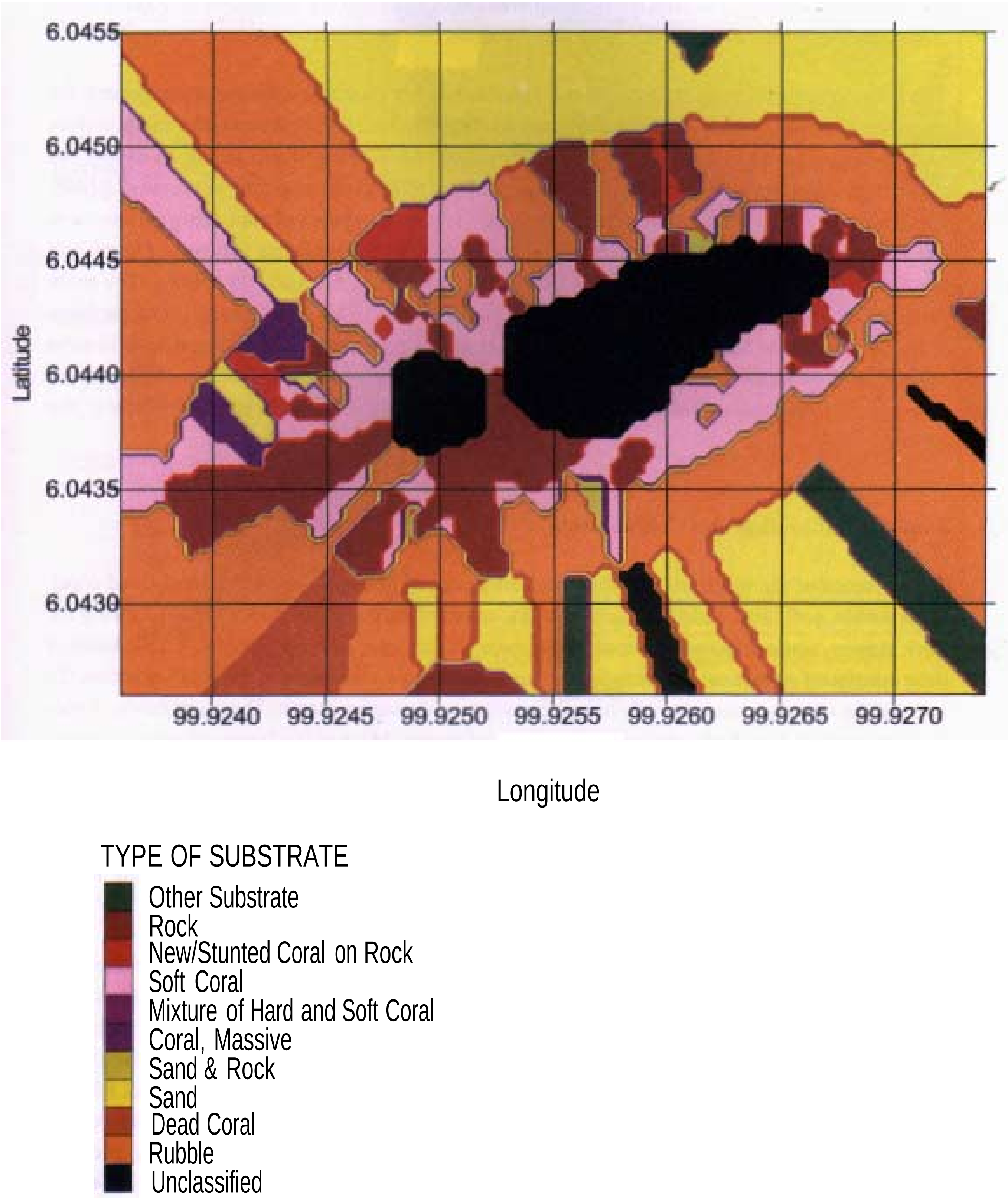
Longitude

TYPE OF SUBSTRATE
New/Stunted Coral on Rock
Soft Coral
Mixture of Hard and Soft Coral
Coral, Massive
Coral, Branching
Coral, Montipora
Coral, Foliose

Dead Coral
Rubble

<<

Figure 26: Pulau Segantang – Substrate Distribution Interpolated in 2D



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6. DISCUSSION

6.1 The Use of a New **Mapping Approach**

In view of the sensitivity and rapid degradation of coral reefs as a natural response to localised environmental changes, there is an urgent need to update and map out the coral reefs in detail for an overall picture. The RoxAnn system was chosen to map out the extent of Payars coral coverage due to the relatively low cost and the short survey time allowed.

The adoption of this new, repeatable and non-destructive hydroacoustic survey approach for resource mapping heralds a new millennium in coral studies. The hydroacoustic method does not depend on physical factors such as visibility, light penentration, depth and to an extent, the sea-surface roughness. RoxAnn can be run practically at all times for real time substrate mapping. It was also observed in this survey that the RoxAnn system is capable of measuring certain coral substrate density directly. The system was actually able to identify dense soft coral growth and less dense soft coral growth on rock as two different acoustic (El and E2) entities. The more dense soft coral growth has lower E2 (hardness) value than the less dense growth. The hardness index for less dense soft coral growth was higher as the system received stronger second echo returns from reflections on the interstitial bare rock surface. However, they share the similar value of El (roughness). The exact density was not quantified as it is beyond the scope of the survey.

6.2. Acoustic Calibration and Classification

The presence of the initial six common reef substrates of interest – live hard coral, dead coral, coral rubble, soft coral, sand and rock - was documented during initial classification. During the track survey, some new and previously unknown classes were also constructed, on the basis of their consistent acoustical characteristics. Boxes were drawn real time in the RoxSquare on the basic of the signatory acoustic reflections appearing on the laptop screen. These unknown classes were then ground-truthed using grab samplers and diving. Most of the “new-unknown” classes turned out to be of different grain size and composition of sand. In shallower waters, there was simple sand with small grain size. As the depth increases to about 20 meters, the sand is mixed with fine pieces of broken shells and rubble. The ratio for broken shells and rubble to sand gradually increased further away from the islands.

The new coral on rock class (see Rox Square legend) was created to accommodate small coral colonies growing on rock surface and big boulder. Most of these small coral colonies found are less than 8 inches in total diameter – e.g the *Acropora* spp. *Seriatopora* spp. and *Pocillopora* spp. This substrate was common in Payar waters. The presence of these small colonies of corals is perhaps a sign of the re-colonisation process. However, DeSilvea & Ridzwan reported some “stunted” staghorn and small table forms – *Acropora* on the reef flat during a survey in 1982. It is possible that the two different descriptions refer actually to the same substrate. Therefore, for record purposes, this substrate type is referred to as New/Stunted **Coral on Rock.**

<<

Figure 27: **Pulau Payar – Substrate Distribution Interpolated in 2D**

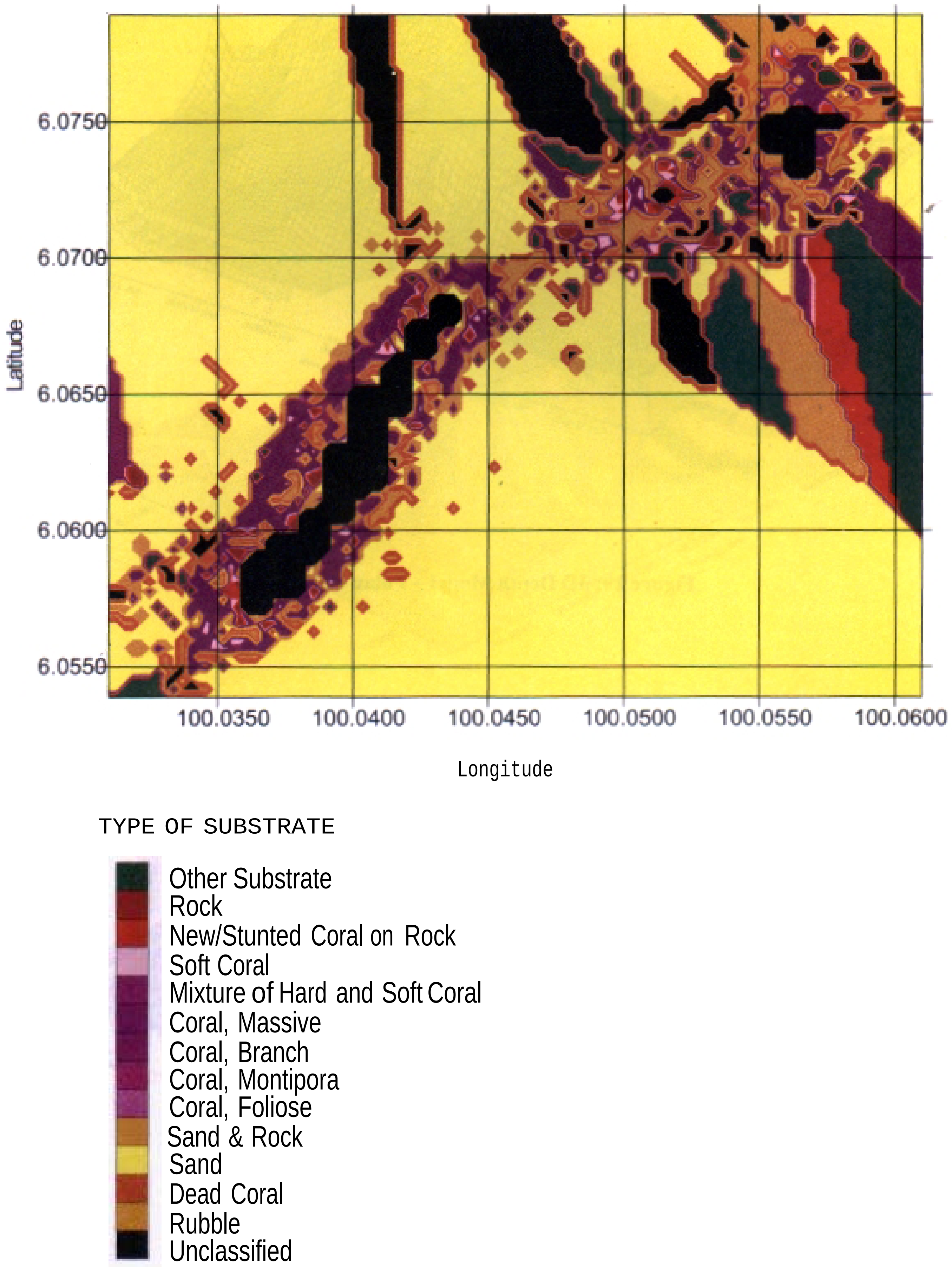

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Figure 28: 3D Depth Model – Segantang

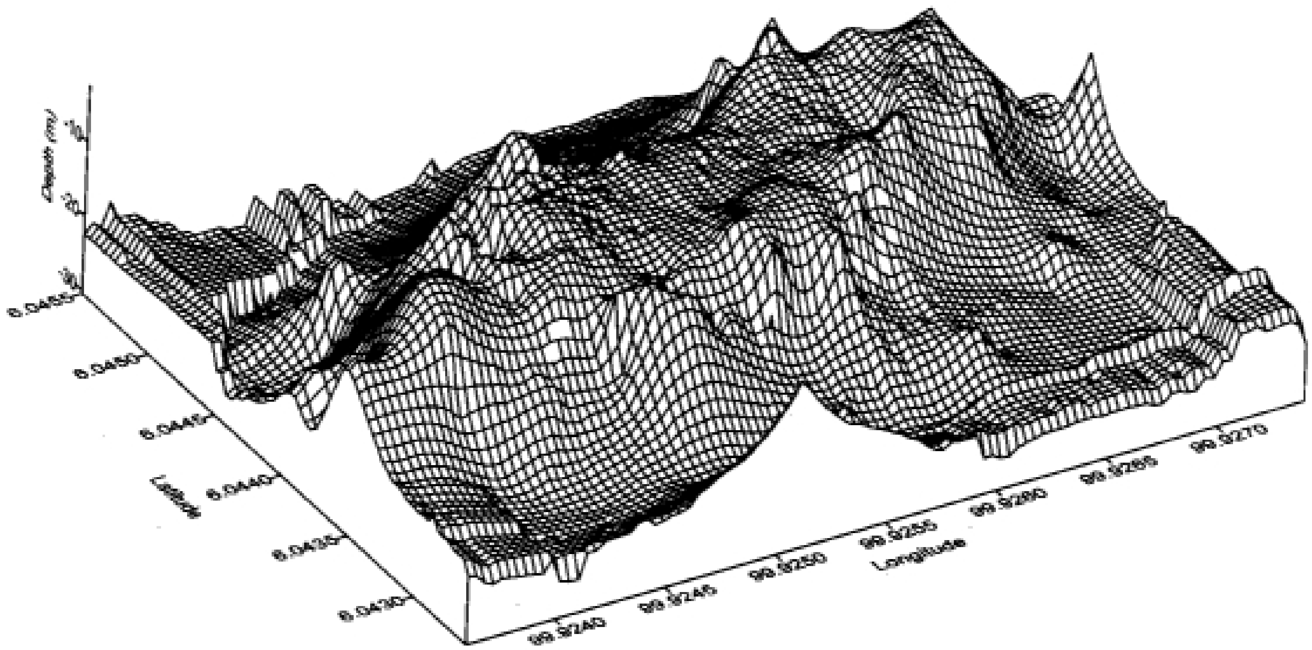


Figure 29: 3D Depth Model – Pulau Payar

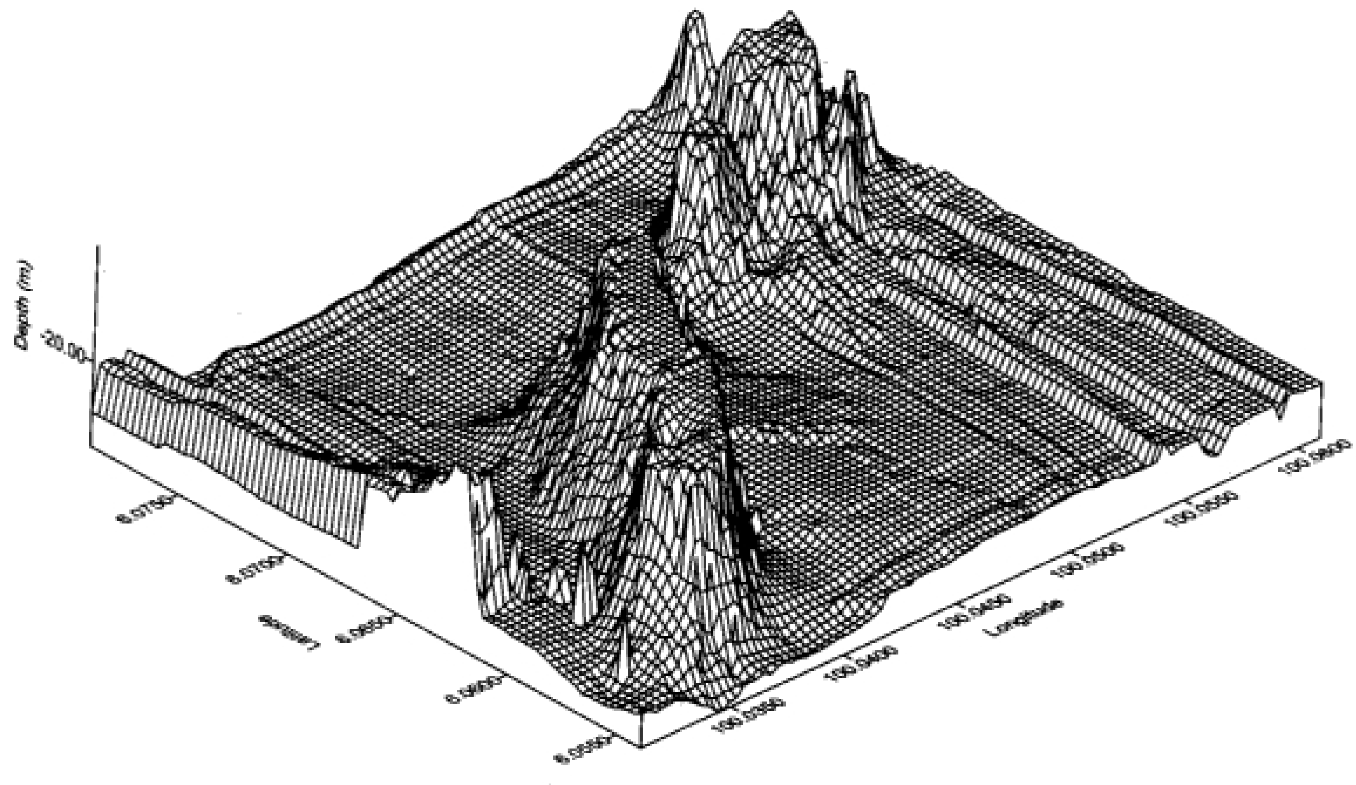
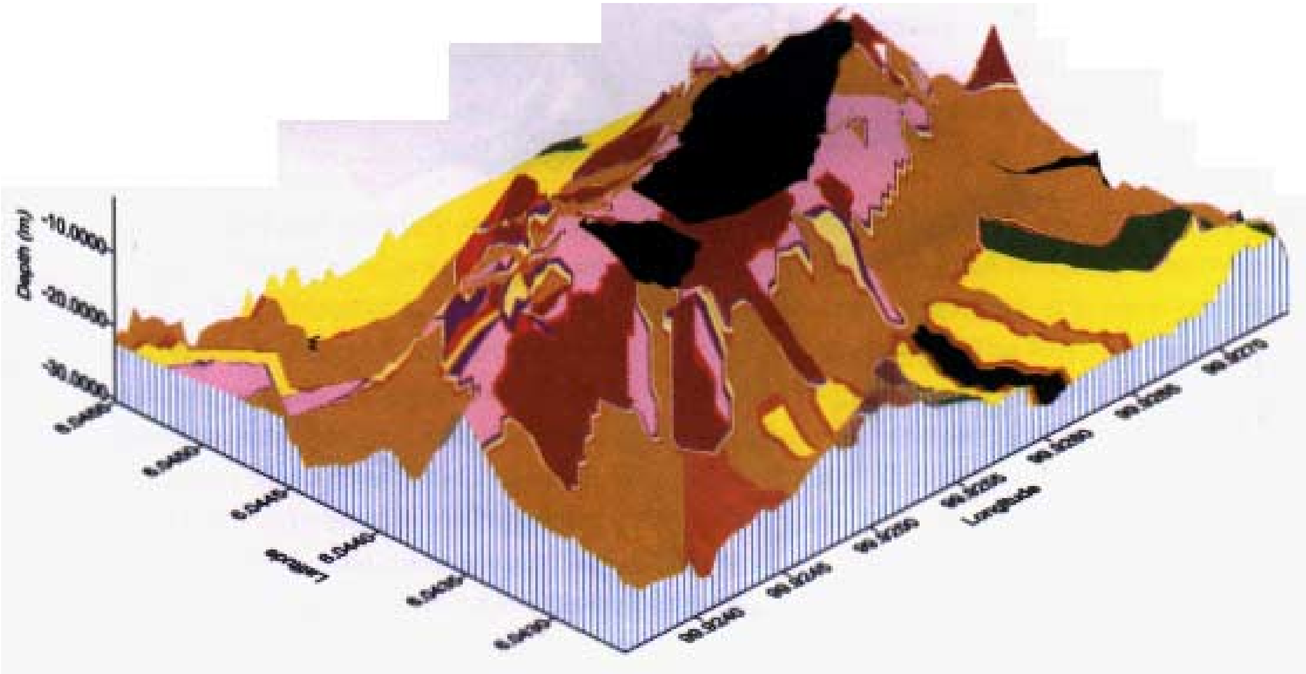


Figure 30: Pulau Segantang – Substrate Distribution Interpolated in 3D

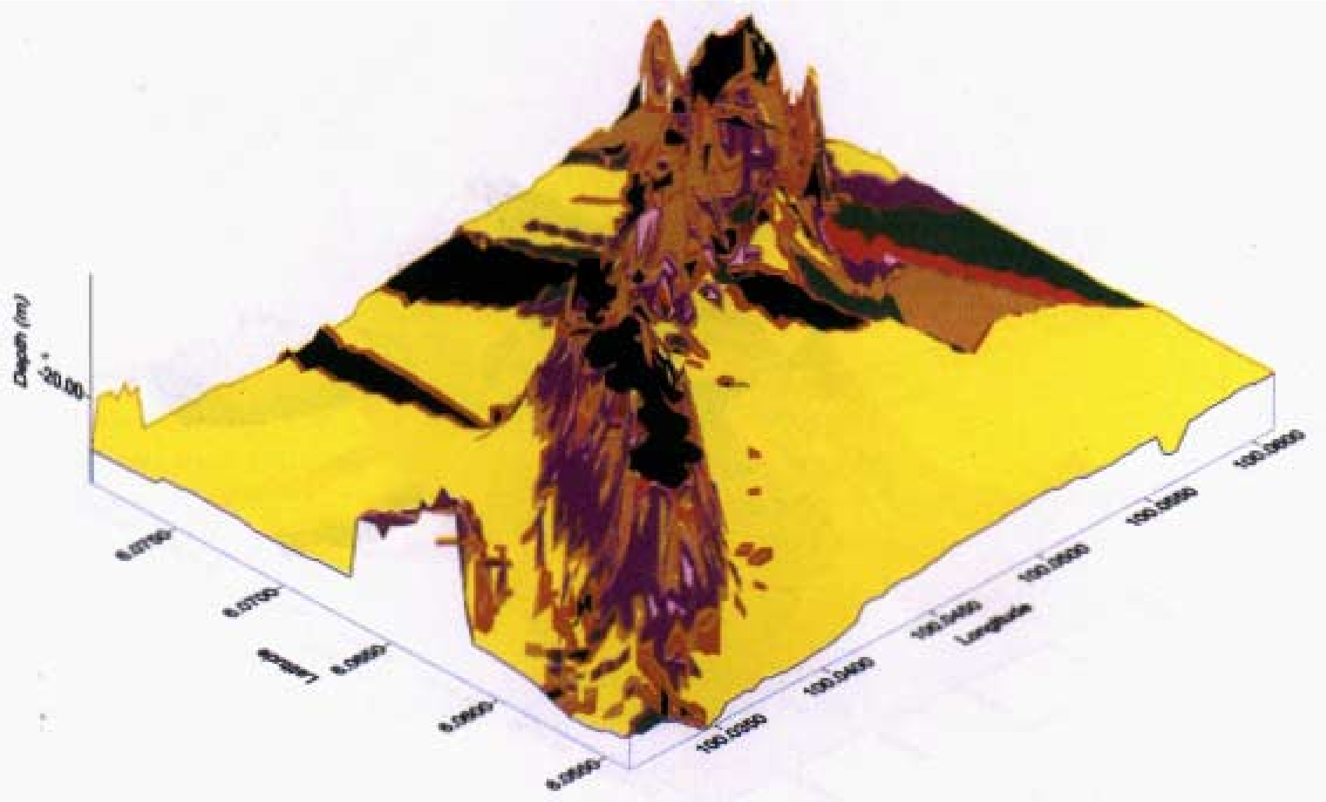


TYPE OF SUBSTRATE

Other Substrate
Rock
New/Stunted Coral on Rock
Soft Coral
Mixture of Hard and Soft Coral
Coral, Massive
Sand & Rock
Sand
Dead Coral
Rubble
Unclassified

<<

Figure 31: Pulau Payar – Substrate Distribution Interpolated in 3D



TYPE OF SUBSTRATE

- Other Substrate
- Rock
- New/Stunted Coral on Rock
- Soft Coral
- Mixture of Hard and Soft Coral
- Coral, Massive
- Coral, Branch
- Coral, Montipora
- Coral, Foliose
- Sand & Rock
- Sand
- Dead Coral
- Rubble
- Unclassified

<<

It was observed that Payar waters have a low variety ofmajor coral growth forms: It was common to find all the growth forms existing within a small area. When the different growth forms were too close together, the RoxAnn system collectively and consistently identified them as an individual substrate group. The mixture of hard and soft coral class was a group of small colonies of hard and soft corals which grew on the surface of a rock or boulders. They include the small branching *Acropora* spp, *Seiatopora* spp. *Pocillopora* spp and sub-massive *Porites* spp, that grow in between the soft corals.

The initial six major live coral growth forms to be identified were: place/table, branching foliose, massive, colunnar and encrusting. However, throughout the survey, only four growth forms were recorded. They are the massive, branchiüg, foliose and encrusting type. Foliose and encrusting form are totally absent at P.Cupak and P. Segantang. They are found only at the Payar group of islands and confined only to the genus *Montipora.* The remaining two growth forms encountered – i.e plate/table and columnar – were scant and not sufficient for classification purposes, thus not recorded as a substrate type during the transect run.

In a nutshell, all substrate types identified by RoxAnn are stored as El and E2 signal strength/ value. Allocation of substrate names e.g. ROCK. PORITES, BRANCHING, etc. was done assigning a colour to a certain box area on the RoxSquare. Therefore, it is very important to determine the correct box size and shape for each substrate type. The RoxAnn recorded large patches of branching coral at Teluk Kilis which were not reported by any institution or by previous publications. Upon ground truthing by diving, we found only Porites boulders occuping the gentle slope from 3 to 12 m depth. These are Porites with diameters ranging between 1 and 3 m. Each individual is well spaced with a sandy bottom. Most of them are massive with some sub-massive at shallower waters (7m). There were also occasional 'deformed' Porites where the growth forms resembled the tapered-columnar type. Branching coral was also found, but the occurrence was low. In RoxSquare, the MASSIVE box was adjacent to that of BRANCHING. Error tends to occur when the box for Branching is too large, it thereby encroaches on the massive coral box area in RoxSquare. During field data collection, these boxes were constructed according to the El and E2 intensity and their outer limits, while classifying a certain type of substrate. Because of the sensitivity of RoxAnn, these signals may vary as the transducer impinges on the same type of growth form but with a slightly different surface e.g. Porites with sediment on the polyps, and/or Porites without sediment on the polyps, or even Acropora with polyps protruded and without polyps protruded. Therefore the boxing process and the care taken in doing so are very crucial in determining the final visual output on the tracks.

6.3 Track Runs

The track run was originally intended at every 5 m interval, perpendicular to the shoreline at fixed bearings. However, it was later found impractical for the boatman to follow these pre-planned tracks displayed in a navigational form. We also realised that it was advisable to start with at least two initial parallel or round-island tracks during high tide for two reasons. The first is to obtain the individual island outline and location since there is no map of such scale available. The second is to make sure that the reef receives a good swath coverage. We had to take advantage of the high water to record as much as possible of the shallow water substrates in the shortest time possible, where the boat may not be able to reach if the tide went out.

In the first round-island track run for P. Payar, the boat managed to maintain a distance of about 6m ±3m from shoreline and 2 m isodepth during high tide. The second round -island transect was approximately 5 m away from the first track. At all other islands (Kaca, Lembu and Segantang), the boat was about 20 m ±10 m away from the shoreline so as to avoid the shallow submerged rock outcrop. At these islands, the minimal depth recorded was not less than 3 m during high tide. Subsequent tracks for the Payar group of islands were all perpendicular to the shoreline. Depending on the skipper's experience, as well as wind and current influence, the "U" shape transect was maintained at an interval of 5-10 meters.

Real-time data was collected via track run at an average boat speed of 3-4 knots. The upper limit for boat speed was set arbitarily at 5 knots.

The Fugro Omnistar DGPS used in the survey was found to have an error of 1-2 m about 10% of the time, and 3-5 m about 90% of the time on the fly.

6.4 The Preliminary Results - 2D Track Data

6.4.1 *Pulau Seguntang*

Pulau Segantang is situated less than 14 km from the P. Payar Marine Park jetty, as can be seen on the location plot on the electronic grid. The island's outline was plotted on the track shape. Pulau Segantang actually consists of two huge rock outcrops. The locals used to describe the bigger outcrop as P. Segantang and the smaller one as Pulau Cupak. For the purpose of discussion, these two rock outcrops will be referred to as Pulau Segantang, as termed in the Marine Park gazettment.

Hermatypic hard corals were rarely found in waters here. Soft coral is the most lavish substrate covering the reef slopes. Ground truthing via diving revealed that these are actually thick zones of zoonathids and aggregate sea anemone at the southern side of both islands. They occupy the submerged rocky slope extending from the island until about 20 m deep. The first 15m of the slope is extremely steep, but the slope gets gentle beyond that. At the northern side, a similar substrate type was found but with less density. The slopes here are more gentle, extending to about 30 m of horizontal distance from the shore, before giving way to sandy and rubble sea bottom. There were still substantial rock surfaces on the interstitial, providing growing space for the small colonies of new coral. There were also some isolated, small massive coral near the end of the reef slope, besides some barrel sponges. These massive corals were not picked up by the RoxAnn system as the echosounder footprint might have overlooked them due to their scantiness. Roxann managed to detect two patches of this massive coral near the submerged rock at the west side of P. Cupak. In this vicinity, Sun corals (Tubastea sp) and tree coral (Dentrophyllia) are commonly found on and hanging over from the rock crevices.

Coral cover here was once quite impressive as reported by DeSilva and Ridzwan (1982). It is believed that the quantity of coral cover has decreased drastically due to fishing activities. Some entangled fish net on the rock boulders confirms such evidence. Rubble, being the second-most important bottom type also suggests the same fate for the corals. They were found in loose forms in shallow water. Beyond 22m, larger rubble aggregate were compactly bound with seamoss along with a mixture of empty shell.

Pulau Segantang is still a popular stop-over for most fishing boats. At one point during this survey, it was observed that about 10 fishing boats were anchored around the island. Some of the fishermen were fishing with handlines and others were just sorting out their catch. Fish life was most abundant here, compared to that in the rest of the islands. The current was strong towards the south during the high tide.

6.4.2 *P. Payar Group of Islands*

The island outline has been plotted by estimating the empty inner part of the first round-island transect run (Figure 32). The actual island area should be slightly smaller, as RoxAnn only managed to cover till the shallowest depth of two meters along the shoreline.

Pulau Payar's reefs are of a fringing type, with a general growth pattern where most of the corals are found at the reef front and the reef slope is at a depth of 6-20 meters before hittiig the sandy bottom. There were very few corals found on the reef flat. In general, the reef profile has very short or no reef flat at all except the stretch in front of the Marine Park Centre. The existing reef slopes generally end at a depth of 20 m, with more than 45 degrees of slope. Such reef slopes are considered short, thus providing relatively little available space for coral growth.

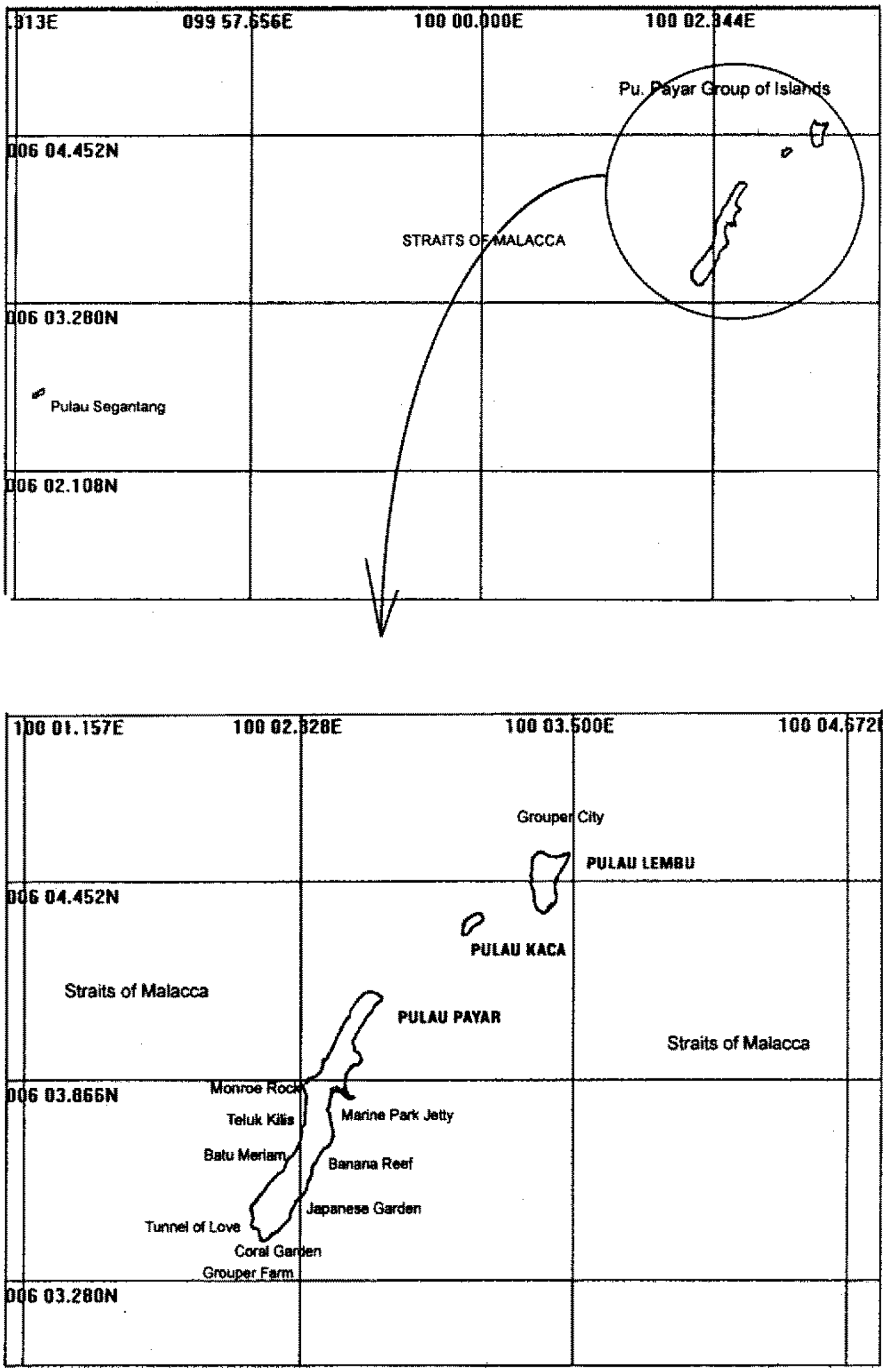
The occurrence of hard corals is evident around the Payar island. Visualized from the 2D real time track data, it is most diverse at the southeast side of the island. All the varieties of growth form can be found compactly here on this stretch of topography.

At the northern side of Payar, coral abundance and diversity is subjected to weather and wave action as exhibited by the steep rocky cliff and wave gullied walls. Only a narrow protective belt suited coral growth, and only hardy species survive the torture of wave and current. During rough weather, turbulence occurs and brings about turbidity and sedimentation. Both factors are detrimental to healthy coral growth.

In the south eastern side of Payar, the presence of beaches and gradual underwater slope with a wide fetch of 3-13 meter deep area is suitable for coral growth and expansion. Such favorable conditions allow for varieties of coral species to co-exist, according to J.C. Sy. et. al. (1981).At the edge of the reef crest, coral abundance becomes very high and then declines, while diversity continues to rise. Coral abundance, evenness, and diversity are all high in the upper portions of the reef wall. The latter two indices stay high, while coral abundance declines along the lower half of the reef wall.

Payar's reef may be regarded as one of the oldest reefs in Malaysia. It has a variety of dense coral growth in a relatively small area. According to Veron (1986), coral diversity can exist only after ecological balance is achieved. In another word, Payar's reef has existed long enough to reach its present ecologically stable/mature stage. The relatively low coverage of coral might possibly be due to the lack of suitable growing space. According to De Silva and Ridzwan (1982), 73 hard coral species were listed from Pulau Payar. They consisted of 19 species from family Favidae, 13 species from Family Acroporidae, and seven species from family Portidae. The remaining 34 species were from other minor families.

Figure 32: Island outline for Pulau Payar Group of Islands



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6.5 Data Interpolation

Attempts were made to further interpolate 2D real time track data to a thematic map showing different types of substrate coverage. The results are satisfactory where the software shows a very reasonable visual projection of substrate type.

The interpolated 2-dimension surface area for each substrate type was also calculated for reference purposes. The results for P. Segantang are satisfactory where the software shows a very reasonable visual projection of substrate type. However, as for the P. Payar group of islands, the **Massive** Coral did not turn out to be the most dominant coral substrate as expected. The **Branching coral** emerged as the most abundant growth form after interpolation instead. This suggests that the interpolated results may depend on the track pattern. All interpolated results have a certain degree of data distortion. The results derived from interpolation are strictly for reference. One should always refer to the original 2D real time track data.

7. CONCLUSIONS

The utility of the hydroacoustic method to map out reef substrate types and coral growth forms has been proven in this survey. Pulau Payar has one of the oldest reef formations in view of its high diversity in a relatively small area. Most of the live coral cover are encountered on the eastern side of the island. No statistical calculation was done to assess the coral damage. However, it was not visibly significant. The main factor contributing to coral damage was the wind and waves that occur during the monsoon season when the fragile branching Acropora is turned to rubble. In other words, the Pulau Payar Marine Park authority has done a good job in protecting the nation's valuable resources from anthropogenic threats.

The use of the hydroacoustic approach in reef research has not been documented so far. This project can be considered a milestone in coral research history as it combines the use of remote sensing tools and ground truthing. There is more to it than just mapping out desired substrate as there is also unknown potential to be discovered. Acquisition of updated primary data on the reef ecosystem with this new technology will allow continuous year-to-year comparison at minimum expense. Most important of all, the data and final results generated are fully traceable and reconstructible.

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