RECONNAISANCE OF REEF BENTHOS
AS AN AID TO MANAGEMENT

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Name of Project Officer: Len Zell

RECONNAISSANCE OF REEF BENTHOS AS AN AID TO MANAGEMENT

by

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A Report to the Great Barrier Reef Marine Park Authority

Part I

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CONTENTS

FOREWORD

In the period 1976 to the present, the author and others have examined methodologies for the biological characterization of coral reefs at scales ranging from square meters to tens of square kilometers. This paper, which is part I of a two part report, describes an application of the 'manta-tow' method for characterizing reefs at a scale between these two extremes. This application has been developed under the auspices of the Great Barrier Reef Marine Park Authority, and is now a major tool in their reef reconnaissance programme.

In this paper, the status of the method as of March 1980 is reported. The aims and field methodology are presented and critically evaluated in the text; detailed instructions for map presentation and data tabulation are given in Appendix I, which may be used separately as an instruction manual. Those few results which are given are merely to exemplify the way in which the data should be used. The use of the data for management purposes would involve more extensive study of the maps and tables.

The author gratefully acknowledges the support in this work of several friends and institutions. Richard Kenchington first introduced me to the manta-board and has been closely associated with all stages of the study. Thanks are due to the Great Barrier Reef Marine Park Authority who supported the study, and to Professor Cyril Burdon-Jones who provided facilities and support at James Cook University of North Queensland. Thanks also to those friends who joined me in the field, especially Len Zell, Chris Smalley and Koko Wigness. Bob Pearson, Rod Garrett and Len Zell contributed in various ways to the methods development. Gordon Bull produced the maps of the Capricorn reefs.

INTRODUCTION

Management of a group of coral reefs for commercial, recreational, scientific and conservation uses should ideally be responsive both to the nature of these multiple uses, and to the individual characteristics of the reefs themselves. The Capricornia section of Australia's Great Barrier Reef Marine Park contains 21 of the two thousand or so reefs in the Great Barrier Reef region. A general description of the reefs is given in Mather and Bennett, 1978, pp7-14. Many more reefs will be included in the Park in the future, and recommendations relating to their management will be made by the Great Barrier Reef Marine Park Authority (G.B.R.M.P.A., a federally constituted body, whose full functions and responsibilities are specified by Anon., 1975 and summarised by Baker, 1977).

The Authority's management philosophy is responsive to traditional usage patterns and other socio-economic aspects of the reefs in the park. However it also recognises that the management of complex biological/geological systems should be based on a thorough knowledge of how such systems function. To this end, G.B.R.M.P.A. supports basic coral reef research and in addition has itself developed research programmes aimed at answering specific questions not addressed by other bodies.

Current scientific opinion holds that many of the coral communities which inhabit coral reefs are rather transient in their composition and structure (see reviews of Connell, 1978; Done and Pichon, in press). Coral communities are susceptible to damage by storms, predators and bio-eroders as well as the senescence and death of ageing colonies. Decisions regarding the management of such temporally variable entities should therefore be based on knowledge of their current status. Although information is accumulating which will allow reef ecologists to predict the general nature of the coral communities to be found on reefs in different Great Barrier Reef localities, the current status (*i.e.* 'health' or 'condition') of the communities at any time may only be ascertained by direct observation.

The G.B.R.M.P.A. has therefore developed a 'benthos reconnaissance programme', the function of which is to provide a broad picture of the range and condition of communities to be found on particular reefs, at the time management decisions are to be made. In addition, a 'benthos monitoring programme' is being explored so that a better understanding of the rates and nature of natural and man-induced change may be achieved. This report deals with the methods and results of the reconnaissance programme as used in the Capricornia section of the Marine Park. The monitoring methodology is the subject of a second report.

The reconnaissance programme aims to characterize 'entire' reefs on the basis of:

(a) the types of communities present, and
(b) the aereal cover of living and dead coral and other benthos in each community.

It also aims to locate areas of exceptionally high or low aesthetic appeal and diversity and areas where coral colony size is exceptionally large or small.

The approach in its broadest terms as adopted on the Capricornia reefs involved:

(a) the viewing of all the major coral colonized areas of the reefs by appropriately trained observers, and
(b) the utilization of appropriate information collection, storage, retrieval and presentation methods.

The viewing of reefs is itself of significant management value, since participants are able to make decisions based on informed comparisons between reefs, whereas decisions made before the reconnaissance would have lacked any biological basis except perhaps anecdotal accounts. The major intention for information presentation was that standing alone, it should be readily interpretable by individuals not involved in the surveys.

Reconnaissance was undertaken by snorkellers towed along reef margins behind a small boat and using a manta-board for manouverability (see Kenchington and Morton, 1976). Standard data presentation was by way of both tables and shaded maps of the tow path overlying an outline of the reef. The maps were produced on a computer plotter (see below).

The achievement of the programme's objectives was clearly a task of considerable magnitude. Some 270 km of reef margin were viewed by members of the observation team over a period of 160 man days. Observations made by snorkellers towed behind boats may only be described as cursory and impressionistic. As in any reconnaissance, interpretation must be tempered with a due regard to the imprecise nature of the data, and in addition, to unquantifiable intra- and inter-observer variability. Thus one function of this paper is to discuss the usefulness of the data, given its inherent shortcoming.

The Reconnaissance Area

Reconnaissance was made of 21 reefs in the Capricornia section of the Great Barrier Reef Marine Park, which lies at the southern end of the Great Barrier region (see Figure 1). The reconnaissance took place during 8 separate visits to the area during 1978 and 1979. The reefs include wall reefs, platform reefs with and without lagoons, and ring reefs (terminology of Maxwell, 1968) and twelve support vegetated coral cays. The reefs range in length from 1 km to 9 km (see Figure 1) and the total length of reef margin to be reconnoitred was about 270 km. Underwater visibility ranges between 10 and 30 meters and is not limiting to the methods described below.

METHODS

Field methods

The field team was accomodated for 7 - 12 days on a charter vessel which would anchor at the reef to be reconnoitred. The team consisted of a small-boat driver, a person to record data, and two observers. For each reef, the observers together aimed to record a standard set of observations for the entire seaward and (where present) the lagoonal margins of the reef. Observers were towed in turn along a section of the reef's margin using a manta board (Figure 2a) pulled by a 4.2 m Zodiac inflatable dingy powered by a 15 or 35 HP motor. The tow path was usually 100 - 400 m long and followed a sinuous path (Figure 2b), to enable the observer to examine both lower and upper slopes and adjacent reef tops. Observers planed on the surface and to a depth of about 10 m, which enabled satisfactory observations to about 15 m.

An observer completed his tow either

(a) when a marked change in the character of the reef was observed, or

(b) after a period of about ten minutes had passed without marked change.

Once the first observer had returned to the boat, the second would begin his tow. During the second observer's tow, the first would undergo a debriefing conducted by the recorder. The observer would recall his

FIGURE 1

Shape, size and orientation of reefs surveyed in Capricornia reconnaissance. Distance bar equals 500m; cays are stippled; lagoons are indicated.

1. North Reef
2. Sykes Reef
3. Polmaise Reef
4. Tryon Reef
5. Hoskyn Reef
6. Lamont Reef
7. One Tree Reef
8. Llewellyn Reef
9. Boult Reef
10. North West Reef
11. Fitzroy Reef
12. Erskine Reef
13. Heron Reef
14. Fairfax Reef
15. Wilson Reef
16. Masthead Reef
17. Lady Musgrave Reef
18. Broomfield Reef
19. Wreck Reef
20. Wistari Reef
21. Lady Elliot Reef

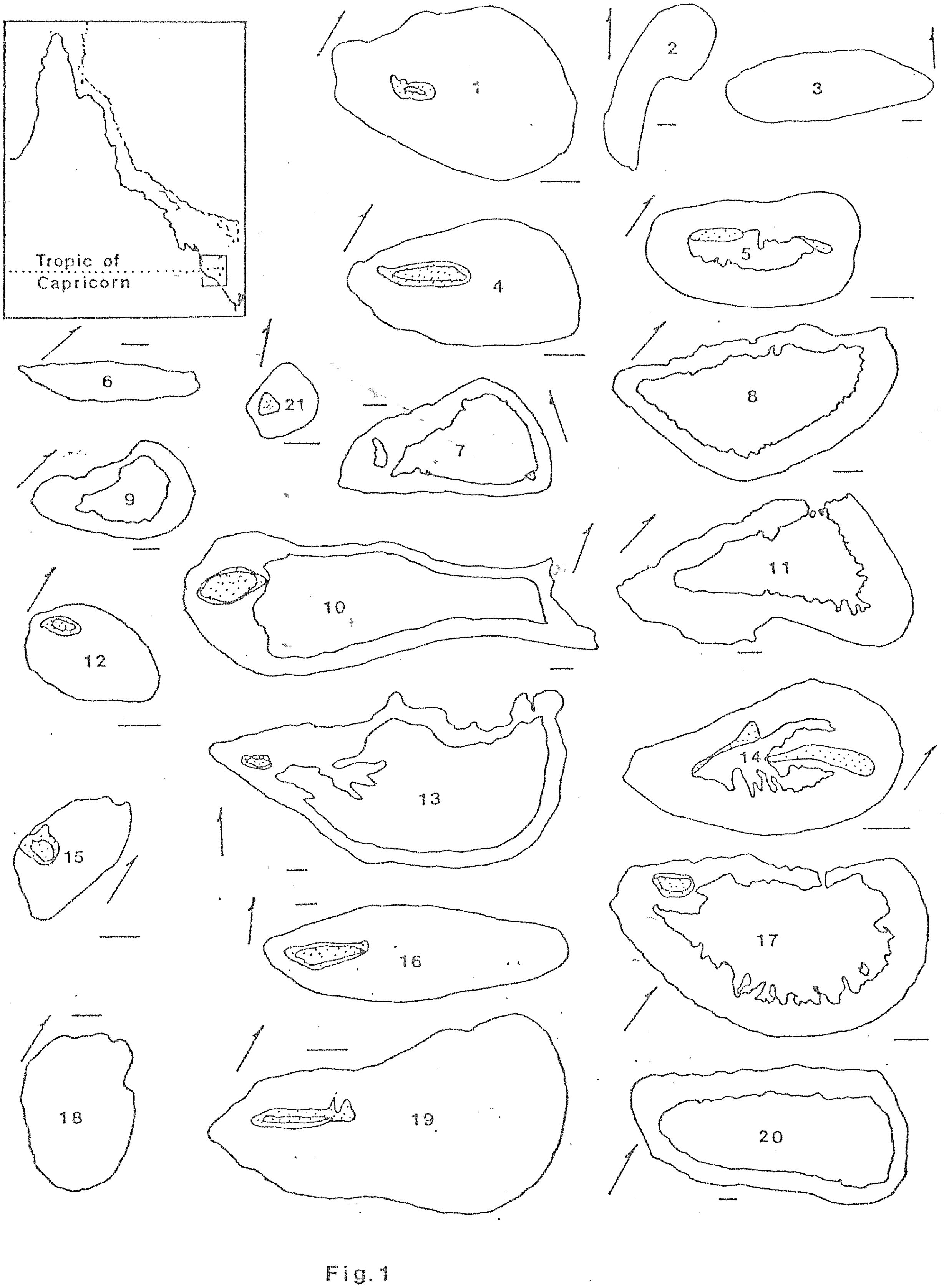
Tropic of
Capricorn
1
2
3
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Fig.1

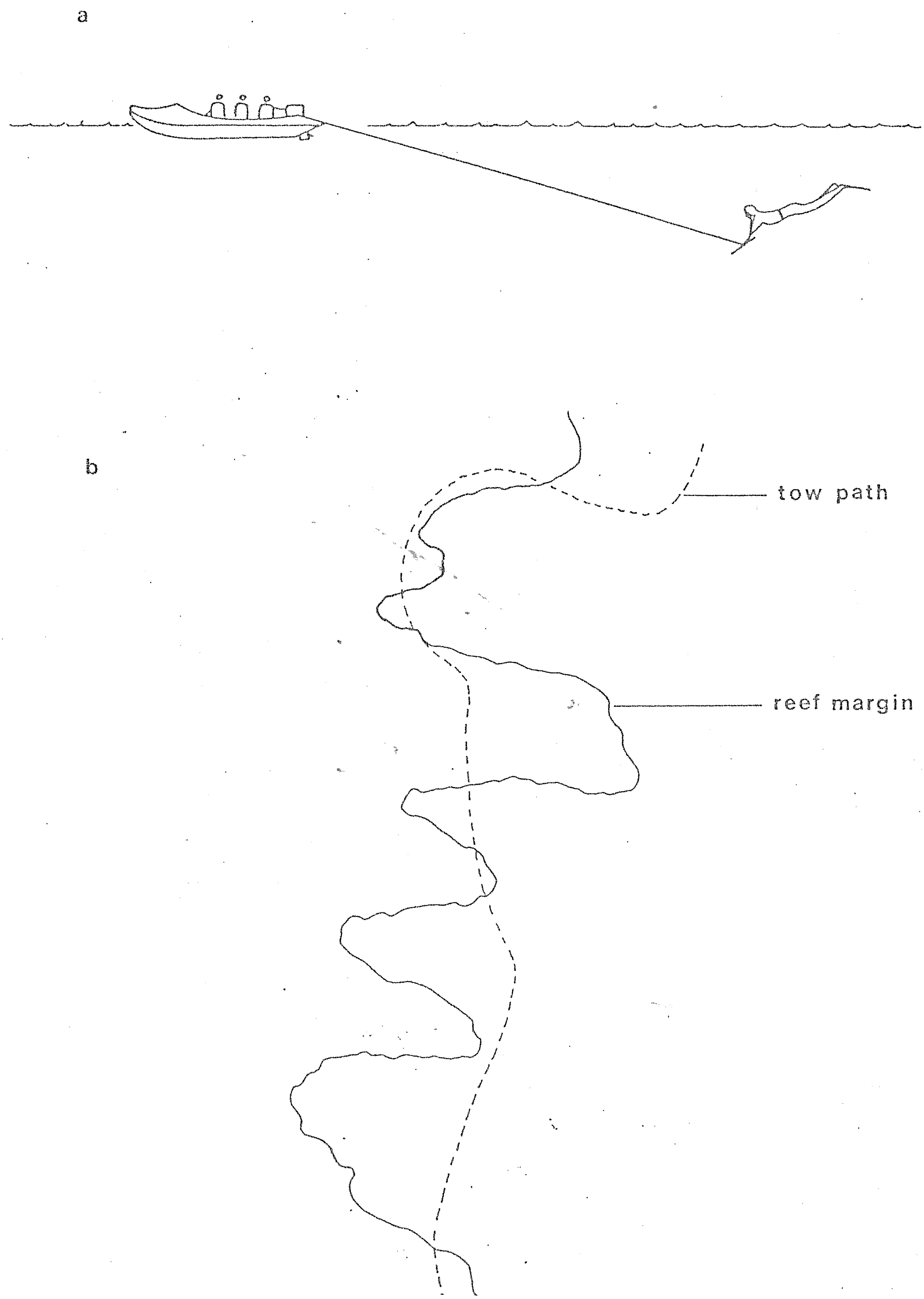


Fig. 2 a) A field team doing reconnaissance.
b) Representation of the sinuous tow path taken and its relation to the reef edge. Towed observer can manouver several meters laterally from the boat's path.

observations separately for as many coral zones as he could recognise (see below). The first observer would do another tow immediately on the return of the second observer. Working in this fashion, the boat moved continually and observers alternating thus could sustain concentration for up to about two hours. The smallest reef (*e.g.* Lady Elliot) could be completely circumnavigated in this time; larger reefs were surveyed over several days.

For the purpose of defining coral zones to be reported on, observers had been directed to mentally subdivide the reef into linear bands running parallel to the line of the reef margin. The vertical limits to these bands were dictated by the distinctness of the coral or structural zones as perceived by the observer, and were recorded as the estimated depths in feet.

The observers were required to estimate the parameters (see below) which collectively best described the 'condition' of each of the zones as integrated over the length of the tow (a distance usually between 100 and 400 meters). For spur and groove systems (which are oriented perpendicular to the reef margin and tow line) the assessment was made on the basis of the communities colonizing the spur tops. These are the most visible part of the spur and groove system, and were considered appropriate indicators of condition for that zone. Coral communities not growing on the reef structure (such as isolated thickets or knolls on the adjacent sea floor) were recorded separately.

The field data sheet

The recorder carried a number of field data sheets printed on water-proof paper or plastic drafting film. A separate sheet was completed after each tow by each observer, and the tow path marked on an aerial photograph (or tracing thereof).

The data sheet comprises three sections (see Figure 3). The top section consists of reef and tow identifiers, as well as observer's name and code number, the date, and time (at start and finish of tow). The remainder of the data sheet is divided into six columns, which allow observers to report on up to six zones per tow. The first two columns are

BENTHIC REEF SURVEY   DATA SHEET   MANTA TOWS

Reef Name ____ No. ____   Observer Name ____ No. ____   Date / /   Time :   Tow No. ____

Site Desc'n	reef top	reef crest				
Site No.	1	2				
Aesthetics, 1-6						
Slope, 0-6						
Substrate/Sediment: Mud						
Sand						
Gravel						
Stag Rubble						
Sm. Blocks <50cm						
Lg. Blocks >50cm						
Platform						
Depth, ft						
COVER: Hard Coral						
Soft Coral						
Dead Stand Hard Coral						
Macro Algae						
Colony Size, 1-3						
Diversity, 1-4						
V.D.O.'s						
Benthos Code with						
% hard coral, 1-6						
% soft coral, 1-6						
% other, 1-6						

Code	%
0	0
1	1-5
2	5-15
3	15-30
4	30-50
5	50-75
6	75-100

Fig. 3 A field data sheet. Attributes and units are described in the text.

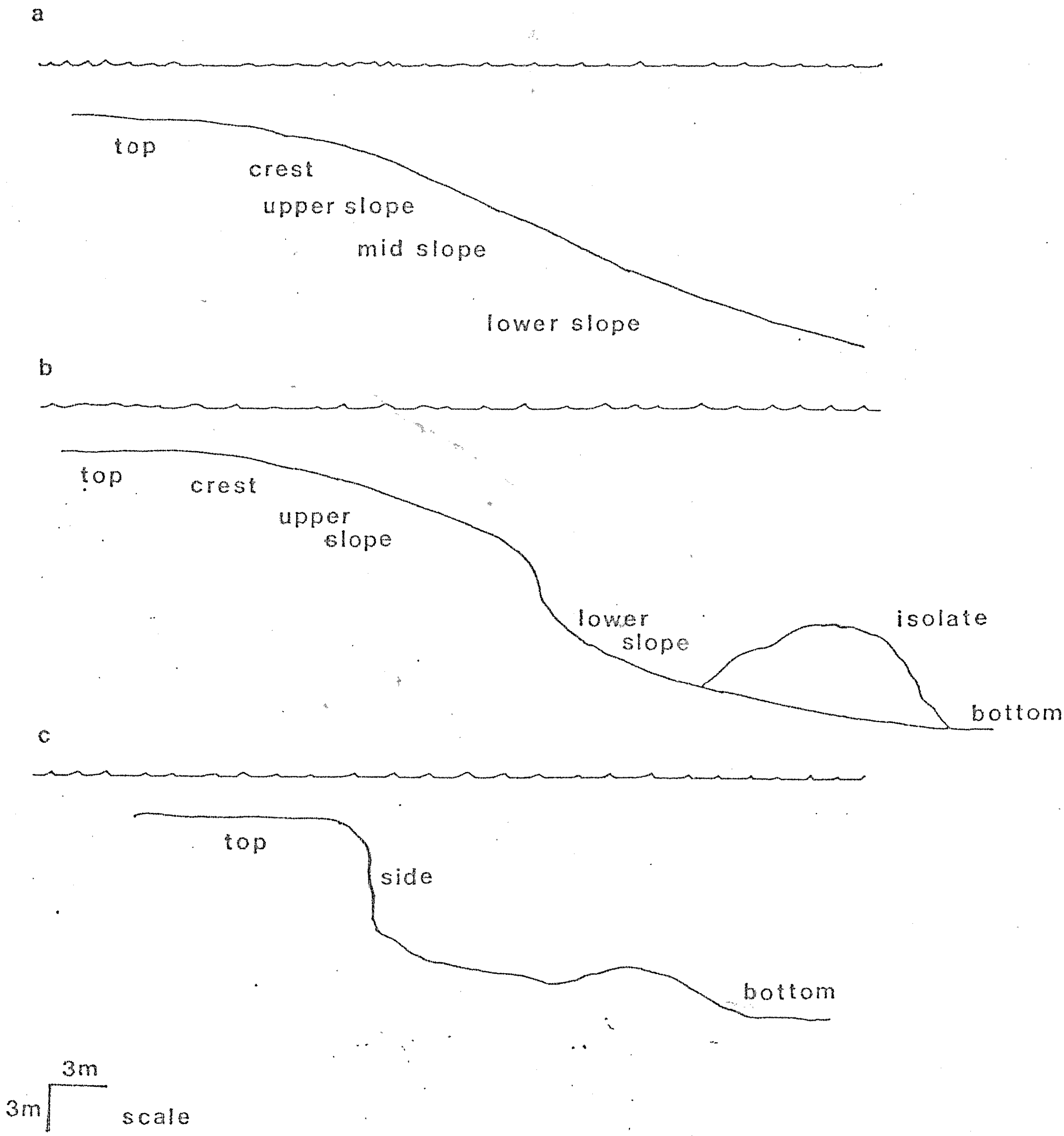


Fig. 4 Common types of reef profile, showing the terminology used to described reef zones.

a) seaward slope - weather side b) seaward slope - lee side
c) lagoon margin

		SPECIES		OBSERVER NO. 4			OBSERVER NO. 5			OBSERVER NO. 8			OBSERVER NO. 9		
				F	AVE	VAR	F	AVE	VAR	F	AVE	VAR	F	VAR	AVE
MASSIVE	211	LARGE HEADS		17.0	2.8	0.5	38.0	3.2	1.0	25.0	3.2	0.6	1.0	3.0	0.0
	212	SMALL HEADS		11.0	1.8	0.1	5.0	4.0	0.2	3.0	2.3	0.0	1.0	1.0	0.0
	220	SMALL CORALLITES		2.0	3.5	0.1	25.0	2.1	0.3	7.0	2.6	0.1	1.0	4.0	0.0
	230	CERIOID/PLOCOID CORALLITE		19.0	2.4	0.4	72.0	1.7	0.5	23.0	2.9	0.4	0.0	0.0	0.0
	240	MEANDROID CORALLITES, FIN		29.0	2.1	0.4	93.0	2.0	0.8	46.0	2.2	0.5	4.0	1.5	0.0
	250	MEANDROID CORALLITES, FLE		14.0	2.2	0.2	35.0	1.4	0.2	6.0	1.3	0.0	3.0	3.0	0.0
	260	MASSIVE WITH KNOBS OR DEN		12.0	1.8	0.1	20.0	1.8	0.2	6.0	2.2	0.1	0.0	0.0	0.0
	265	MILLEPORA		0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0
ACROPORA	310	TABULATE ACROPORA		54.0	3.4	2.1	99.0	3.8	3.1	61.0	4.2	2.3	3.0	4.3	0.1
	320	A. HUMILIS		12.0	2.8	0.3	58.0	3.3	1.4	19.0	2.5	0.3	3.0	3.7	0.1
	331	SHEETS	A. PALIFERA	7.0	2.3	0.1	37.0	3.2	0.8	12.0	2.7	0.2	4.0	4.5	0.1
	332	RIDGED	A. PALIFERA	1.0	2.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	333	CLAVIFORM	A. PALIFERA	35.0	2.6	0.8	22.0	2.3	0.3	6.0	2.5	0.1	1.0	5.0	0.0
	334	COLUMNAR	A. PALIFERA	2.0	3.5	0.1	4.0	3.8	0.1	10.0	2.1	0.1	1.0	5.0	0.0
	340	ACROPORA STAGHORN		40.0	2.7	1.0	117.0	3.2	2.7	49.0	2.6	0.8	2.0	2.5	0.0
	350	CAESPITOSE		31.0	2.0	0.5	3.0	2.0	0.0	2.0	1.5	0.0	0.0	0.0	0.0
	360	BUSHY/BOTTLEBRUSH		5.0	2.0	0.1	4.0	1.8	0.0	6.0	1.7	0.0	0.0	0.0	0.0
BRANCHING	410	NEEDLE CORAL - SERIATOPOR		9.0	1.9	0.1	13.0	1.5	0.1	10.0	2.2	0.1	0.0	0.0	0.0
	420	FINGER THICK BRANCHING		1.0	2.0	0.0	5.0	1.6	0.0	1.0	1.0	0.0	0.0	0.0	0.0
	421	MILLEPORA		3.0	2.0	0.0	9.0	2.4	0.1	2.0	3.0	0.0	1.0	3.0	0.0
	426	ACRHELIA		1.0	4.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	427	PORITES		28.0	3.5	1.1	17.0	3.5	0.5	6.0	3.5	0.2	0.0	0.0	0.0
	428	MONTIPORA		0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0
	450	STUBBY BRANCHES		0.0	0.0	0.0	4.0	1.0	0.0	8.0	2.0	0.1	0.0	0.0	0.0
	460	POCILLOPORA DAMICORNIS		5.0	1.6	0.0	43.0	1.6	0.2	16.0	1.9	0.1	0.0	0.0	0.0
LAMINAR	510	ENCRUSTING - NO FREE LIP		13.0	2.8	0.3	77.0	2.3	1.0	30.0	2.7	0.5	4.0	2.0	0.0
	520	ENCRUSTING WITH VERTICAL		0.0	0.0	0.0	2.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	530	EXPLANATE - WITH FREE LIP		16.0	2.3	0.2	46.0	2.4	0.6	37.0	2.6	0.6	0.0	0.0	0.0
	540	EXPLANATE WITH VERTICAL P		20.0	3.3	0.7	16.0	2.9	0.3	12.0	3.1	0.2	0.0	0.0	0.0
	560	LEAFY EXPLANATE		1.0	3.0	0.0	0.0	0.0	0.0	6.0	1.8	0.0	0.0	0.0	0.0
	570	YOSES/ROSES		8.0	2.8	0.2	14.0	2.2	0.2	2.0	1.5	0.0	0.0	0.0	0.0
EXPANDED POLYP	611	GONIOPORA/ALVEOPORA		7.0	2.1	0.1	21.0	1.5	0.1	5.0	2.8	0.1	0.0	0.0	0.0
	614	TUBIPORA MUSICA		2.0	1.5	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOLITARY	710	ROUND FUNGIIDS		0.0	0.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	711	FUNGIA ACTINIFORMIS		1.0	6.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SOFT OR HORNY	810	ERECT FLESHY CORALS		25.0	5.3	2.1	106.0	4.6	5.0	33.0	5.7	2.2	7.0	5.0	0.2
	820	PROSTRATE FLESHY CORALS		13.0	4.8	0.9	73.0	3.9	2.6	3.0	2.3	0.0	1.0	6.0	0.0
	823	ZOANTHIIDS		1.0	6.0	0.1	19.0	3.1	0.5	0.0	0.0	0.0	1.0	2.0	0.0
	830	SEA FANS AND SEA WHIPS		8.0	4.8	0.6	46.0	2.5	0.7	7.0	4.1	0.3	2.0	2.0	0.0
OTHER	910	SPONGE		4.0	5.0	0.3	8.0	6.0	0.6	2.0	6.0	0.1	1.0	1.0	0.0
	920	STINGING HYDROID		4.0	4.8	0.3	10.0	4.9	0.5	0.0	0.0	0.0	1.0	6.0	0.0

Table 5 A modified version of Table 4. OTU's were recoded to their appropriate 'minor category'.

reserved for 'reef top' and 'crest' (as depicted in Figure 4); the remaining four columns are for data pertaining to any other zones the observer deems appropriate. The morphological nature of each zone (*e.g.* upper slope, lower slope, knoll, floor) is written into the 'site description' box at the top of the appropriate column.

The body of the data sheet is for recording observations on a variety of each zone's physiographic features (from 'Aesthetics, 1 - 6' to 'Diversity, 1 - 4', inclusive) and on its visually dominant benthic organisms, (VDO's) respectively.

(a) Physiographic features

The seemingly illogical order of attributes in this section of the data sheet (see Figure 3) is in fact a result of the field experience of observers who found the order illustrated easier than that on earlier versions of the data sheet. Physiographic attributes consist of three types. The primary attributes (discussed below) are those which the reconnaissance is primarily after - aesthetics; cover of hard, soft and dead coral and macroscopic algae; colony size; and diversity. These are the attributes to be mapped.

The secondary physiographic attributes are collectively labelled 'substrate / sediment' on the data sheet. These were included as an aid to interpretation of the maps, but were not intended to be routinely mapped themselves.

The tertiary attributes are 'slope' and 'depth'. These were included simply to better define the area observed and to aid in interpretation.

(b) Visually dominant organisms (VDO's)

The bottom part of each column is for recording those few corals (or other benthos) which are the most visually predominant to the towed observer. The categories of VDO's and their code numbers are presented in Table 1. 'VDO' is an umbrella term which encompasses three levels of taxonomic/morphologic resolution. As can be seen from Table 1 the highest level of rèsolution contains a mixture of genera, species and ecomorphs (*i.e.* environmentally induced growth forms of individual species). These are the operational taxonomic units (OTU's), and they have been grouped

200 MASSIVE COLONIES

210 PORITES
211 LARGE HEADS
212 SMALL HEADS

220 SMALL CORALLITES

230 CERIOID/PLOCOID CORALLITES
231 DIPLOASTREA

240 MEANDROID CORALLITES, FINE
241 LEPTORIA
242 PLATYGYRA

250 MEANDROID CORALLITES, FLESHY
251 LOBOPHYLLIA
252 SYMPHYLLIA

260 MASSIVE WITH KNOBS OR DENTS
261 FAVIA STELLIGERA
262 PAVONA CLAVUS
263 HELIOPORA
264 SYNAREA
265 MILLEPORA
266 PSAMMOCORA

300 ACROPORA

310 TABULATE ACROPORA
311 A. HYACINTHUS TYPE

320 A. HUMILIS

330 A. PALIFERA
331 SHEETS
332 RIDGED
333 CLAVIFORM
334 COLUMNAR

340 STAGHORN ACROPORA
341 THICKETS HIGH
342 THICKETS LOW
343 CLUMPS HIGH
344 CLUMPS LOW
345 ACROPORA FLORIDA
346 ACROPORA 'ROBUSTA' GROUP

350 CAESPITOSE
351 A. EXILIS TYPE

360 BUSHY/BOTTLEBRUSH
361 A. ECHINATA TYPE
362 A. ROSARIA TYPE
363 XMAS TREE TYPE

400 BRANCHING CORALS (NON-ACROPORA)

410 NEEDLE CORAL - SERIATOPORA

420 FINGER THICK BRANCHING
421 MILLEPORA
422 ANACROPORA
423 HYDONOPHORA RIGIDA
424 CLAVARINA
425 ECHINOPORA
426 ACRHELIA
427 PORITES
428 MONTIPORA
429 PALAUASTREA
431 STYLOPHORA PISTILLATA
432 TUBASTREA
433 CAULASTREA

440 CLUB-LIKE BRANCHES
441 POCILLIPORA EYDOUXI

450 STUBBY BRANCHES
451 POCILLOPORA VERRUCOSA
452 STYLOPHORA MORDAX

460 POCILLOPORA DAMICORNIS

470 DENDROPHYLLIA NIGRANS

500 LAMINAR

510 ENCRUSTING - NO FREE LIP
511 MILLEPORA
512 MONTIPORA
513 PORITES
514 FAVIIDS
515 TURBINARIA STEVENSONI
516 ECHINOPORA HORRIDA

520 ENCRUSTING WITH VERTICAL PROJECTIONS
521 HYDONOPHORA EXESA
522 MONTIPORA
523 GALAXEA

530 EXPLANATE - WITH FREE LIP
531 MYC/ECH/OXY
532 MONTIPORA
533 TURBINARIA
534 PODOBACIA/LITHOPHYLLON
535 PACHYSERIS
536 LEPTOSERIS
537 ECHINOPORA
538 MERULINA

540 EXPLANATE WITH VERTICAL PROJECTIONS
541 SCAPOPHYLLIA
542 MERULINA
543 ECHINOPORA MAMMIFORMIS
544 PORITES LICHEN TYPE
545 SYNAREA
546 MONTIPORA
547 PAVONA DECUSSATA
548 PAVONA YABEI
549 PECTINIA
551 PACHYSERIS RUGOSA

560 LEAFY EXPLANATE
561 PAVONA CACTUS
562 LEPTOSERIS GARDINERI
563 PECTINIA LACTUCA

570 VASES/ROSES (FOLIOSE ERECT)
571 MONTIPORA
572 TURBINARIA
573 ECHINOPORA LAMELLOSA

610 HARD CORALS WITH POLYPS EXTENDED
611 GONIOPORA/ALVEOPORA
612 EUPHYLLIA
613 PHYSOGYRA
614 TURIPORA MUSICA

700 SOLITARY CORALS

710 ROUND FUNGIIDS
711 FUNGIA ACTINIFORMIS
712 CYCLOSERIS
713 DIASERIS

720 ELONGATE FUNGIIDS
721 F. ECHINATA/H. SIMPLEX
722 H. LIMAX/H. WEBERI
723 HALOMITRA/PARAHALOMITRA
724 POLYPHYLLIA

730 OTHER ELONGATE
731 PARASCOLOMYIA
732 TRACHYPHYLLIA

800 ALCYONARIA AND ANTIPATHARIA

810 ERECT FLESHY CORALS
811 TUFTY LOW
812 MASSIVE BRANCHING
813 SARCOPHYTON
814 NEPHTHIIDAE
815 ZENIIDAE

820 PROSTRATE FLESHY CORALS
821 MASSIVE PROSTRATE
822 THIN ENCRUSTING
823 ZOANTHIIDS

830 SEA FANS AND SEA WHIPS
831 FAN
832 WHIP
833 COMB
834 RUMPHELLA
835 BLACK CORAL BUSH

900 OTHER

910 SPONGE
911 CUP SPONGE
912 VERTICAL LEAF SPONGE
913 VASE SPONGE
914 ENCRUSTING SPONGE

920 STINGING HYDROID
921 BROWN FEATHER
922 WHITE FINE

930 ASCIDIANS
931 SMALL WHITE COLONIAL

Table 1.

List of visually dominant organisms (VDO's). Major category headings (in boxes) are never used in field scoring of VDO's. Field observers score a mixture of minor categories (underlined) and OTU's (the remainder). A photographic guide to the VDO's has been produced by Zell, 1980.

TABLE 2

Units used to score the following physiographic features:

a) Total cover of hard coral, soft coral, dead standing coral and macroscopic algae. Relative cover of VDO's.

b) Slope of the tow zone (refers to the predominant slope over the length of the zone).

c) Aesthetic appeal.

d) OTU diversity; since only a small number of VDO's are recorded, a separate observation of diversity is required. The gradation is based on the number of types of OTU registered by the moving observer as he assessed the VDO's.

e) Colony size; areas with a predominance of exceptionally small or large colonies are identified by the three point scale.

a. Area Coverage

Grade	Range - percent
0	0
1	1 - 5
2	1 - 15
3	15 - 30
4	30 - 50
5	50 - 75
6	75 -100

b. Slope

Grade	Range - degrees
0	0
1	+ - 15
2	15 - 30
3	30 - 45
4	40 - 60
5	60 - 75
6	75 - 90

c. Aesthetic Appeal

Grade	Description
1	very poor
2	poor
3	average
4	good
5	very good
6	outstanding

d. OTU Diversity

Grade	Description
0	coral absent
1	monospecific area
2	low diversity
3	moderate diversity
4	high diversity

e. Colony Size

Grade	Description
1	Exceptionally small colonies predominant
2	Unexceptional - can't decide
3	Exceptionally large colonies predominant

successively into minor and major categories.

Observers had been familiarized with the OTU's and the three levels of resolution using a photographic guide compiled by Zell, (unpublished m/s, 1980). Observers were required to score VDO's at a resolution of minor category or better, and in practice, a mixture of minor categories and OTU's was used. The logical numbering system shown in Table 1 facilitated the simple conversion from OTU to higher categories at the data analysis stage (see below).

(c) Units

With the exception of 'depth' (which was expressed in feet), all the physiographic attributes were recorded as graded scores with a range of either 7, 6, 4 or 3 points. A seven point area coverage score (see Table 2a) was used to record the amount of hard coral, soft coral, dead standing hard coral and macroscopic algae present. The same scale was used to record the two or three most predominant types of 'substrate/sediment' (the non-living material beneath and around the coral benthic communities). Slope was scored on the seven point scale shown in Table 2b. The entirely subjective 'aesthetics' was scored on a six point scale, the verbal equivalent of which is expressed in Table 2c. 'Diversity' was scored on a four point scale (Table 2d); the purpose of this attribute was simply to highlight areas of exceptionally low and high OTU diversity (scores 1 and 4). Likewise 'colony size' (3 point scale, Table 2e) was intended to highlight areas of very small colony size (which in some cases indicate pioneer communities recolonizing a damaged area) or very large colony size (which are frequently of great aesthetic value).

VDO's were scored on the seven point scale (Table 2a) used as an indicator of relative area coverage (whereas for the physiographic features it referred to absolute area coverage). Thus if total hard coral had a cover of only 10% (grade 2), hard coral VDO's were expressed as a graded proportion of that 10%, not of the total area surveyed. Similarly, soft coral VDO's were expressed as a graded proportion of the total soft coral cover. Neither algae nor dead standing hard coral were subdivided into VDO's.

Data Handling

(a) Shaded maps

For each reef surveyed, the completed field data sheets and the tracing of the tow paths were used to produce separate shaded maps of the seven primary attributes. (See details of procedures in Appendix I which includes instructions for preparation of a detailed outline of the reef on which is drawn a stylized representation of the tow path, and for the use of this so called 'source map' to produce up to four maps on a single run of the computer). The procedures are based on the use of the CALFORM computer plotting program at James Cook University of North Queensland, with which we superceded SYMAP, a line printer mapping program used for producing maps of reef surveyed early in the Capricornia reconnaissance programme.

(b) Tabulation and statistics

Tabulation and statistics of the data were obtained using *ad hoc* programs (see Appendix Ib).

(c) Definition of benthic assemblages

VDO data were examined for the occurrence of groups of VDO's which frequently occurred together (assemblages) and which thus characterized the benthic communities present. Pattern analysis procedures were used in defining the assemblages, in particular, program 'Clustan 1c' at James Cook University (see Wishart, 1978). Site group classifications were made separately on the data of observers 4, 5 and 8 for ten reefs. These reefs consisted of all eight reefs in the Bunker Group, plus Tryon and Broomfield reefs in the Capricorn Group; they were chosen because of the participation of the author in this section of the reconnaissance programme. The recommended methodologies for analysis of the remaining data are established here.

An agglomerative hierarctical procedure in Clustan was used to define site groups on the basis of their hard coral VDO compositions; (other benthos were excluded for this stage because it was felt they were less effectively surveyed; however, they were included in later sections of the analysis). The Canberra Metric dissimilarity index (with joint absences excluded) and the Group Average strategy were selected after trials with squared euclidian distance and incremental sum of squares has proven unsatisfactory. (This latter combination produced a classification so strongly determined by the most dominant VDO's that more subtle but nonetheless readily observable differences, were not brought out).

Clustan procedure 'Result' was used to list the membership of all groups, with number of groups ranging from 10 to 18 (see Wishart, 1978 for details). Spatial pattern in the distribution of members of site groups was examined by plotting their positions on outline maps of the reefs.

The VDO composition of the site groups was determined using program 'Subset' which lists those VDO's which are most constantly present in members of the specified site group, along with the mean and variance of their cover grades. A VDO is referred to as 'constant' if it occurs in two thirds or more of the sites in a site group. The site descriptive attributes of depth, slope and predominant substrate are also listed by Subset. By using the Subset output, and the distribution map together, 'diagnostic constant' VDO's were defined for the major reef habitats surveyed (*i.e.* outer slopes and lagoon margins, sub-divided into zones). In cases where a site group contained sites from both outer slope and lagoon, the site was further subdivided into slope and lagoon subgroups and 'diagnostic constants' defined for each sub groups. It is these lists of 'diagnostic constants' which are loosely referred to as 'assemblages', although of course many more than the listed organisms would be required to precisely define the assemblages.

RESULTS

Summaries of the data are presented in Appendix III and Table 3. In Appendix III the full data as recorded are summarised; in Table 3 all attributes scored on seven point scales are condensed to a four point scale in which points 1 and 2, 3 and 4, and 5 and 6, respectively, are combined. This four point scale should (at least partially) compensate for intra- and inter-observer variability, and the following presentation of results is therefore based on Table 3, in which reefs are listed in descending order of average score for each attribute.

a) Physiographic features

1. Aesthetics (Table 3a)

Wilson Is. reef ranked highest in terms of average aesthetics score, although this top ranking was due not to high scores but an absence of scores below three. North West Is. reef had the greatest proportion of 5-6 scores, these being located mainly on north and south facing reef fronts adjacent to the island (see Figure 5). The eastern end of the reef was considered drab.

Erskine Is. reef ranked last, due to the allocation of a score of 1 to almost half the towed areas. Neither Heron Is. reef nor Wistari Reef (the two most accessible to the tourist resort on Heron Island) were ranked highly.

2. Hard coral cover (Table 3b)

Six reefs had a mean score of 4 or more (*i.e.* hard coral cover > 50%) and of those, Fairfax, Wistari and Llewellyn had the greatest proportion of 5-6 scores. The two lowest ranked reefs (Erskine and Polmaise) are amongst the closest inshore. However, the highest ranked reef, Masthead, is also one of the closest to shore.

3. Soft coral cover (Table 3c)

Soft coral cover was generally lower than hard coral cover (range of mean scores 0.59 to 3.08, c.f. 2.67 to 4.25 for hard coral). Masthead Is. reef had a large area with scores of 3-4; (Figure 6). No reef had more than 10% of 5-6 scores. Seven of the lowest eight average scores were recorded for reefs from the Bunker group.

4. Dead coral (Table 3d)

On no reef did average dead coral score exceed 1.0 (*i.e.* 5%) or did more than 15% of scores exceed 2. On Llewellyn Reef, 6 of the 71 sites scored 4; observers noted that many of the dead colonies had been recently killed by a localized population of the crown of thorns starfish, *Acanthaster planci*.

5. Macroscopic algae (Table 3e)

Polmaise Reef had a higher average score for macroscopic algae than it did for hard or soft coral. (Half of its sites scored 5 or...

TABLE 3

Reefs ranked in order of decreasing average score for each of the seven physiographic features recorded.

a) Aesthetics
b) Hard coral cover
c) Soft coral cover
d) Dead coral cover
e) Macroscopic Algae
f) Colony size
g) Diversity

The number of records (i.e. tow zones) and the proportion of scores of 0, 1-2, 3-4 and 5-6 are indicated. (For aesthetics and colony size, zero scores are missing data)

TABLE 3 a-c

AESTHETICS

a)

REEF	NO.RECS.	AVE.SCR.	6-5	4-3	2-1	0
WILSON ISLAND REEF	10	3.70	0.20	0.80		
TRYON ISLAND REEF	15	3.40	0.13	0.73	0.13	
NORTH WEST ISLAND REEF	33	3.39	0.27	0.42	0.27	0.03
ONE TREE ISLAND REEF	46	3.13	0.11	0.59	0.30	
FAIRFAX ISLANDS REEF	40	3.13	0.15	0.50	0.35	
SYKES REEF	21	3.10	0.10	0.67	0.24	
MASTHEAD ISLAND REEF	24	3.00	0.13	0.50	0.38	
LLEWELLYN REEF	71	2.99	0.13	0.46	0.39	
FITZROY REEF	96	2.98	0.10	0.53	0.36	
LADY ELLIOTT ISLAND REEF	19	2.84	0.11	0.47	0.42	
WISTARI REEF	29	2.79	0.07	0.52	0.45	
POLMAISE REEF	16	2.75	0.13	0.31	0.56	
HERON ISLAND REEF	88	2.74	0.08	0.41	0.49	0.01
BROOMFIELD REEF	25	2.68	0.12	0.28	0.60	
BOULT REEF	81	2.63	0.11	0.37	0.53	
LADY MUSGRAVE ISLAND REEF	85	2.58	0.11	0.40	0.49	
LAMONT REEF	27	2.56	0.07	0.44	0.48	
NORTH REEF ISLAND REEF	21	2.52		0.48	0.52	
HOSKYN ISLANDS REEF	27	2.30		0.41	0.59	
WRECK ISLAND REEF	18	2.17		0.22	0.78	
ERSKINE ISLAND REEF	24	2.13		0.38	0.63	

HARD CORAL

b)

REEF	NO.RECS.	AVE.SCR.	6-5	4-3	2-1	0
MASTHEAD ISLAND REEF	24	4.25	0.38	0.63		
FAIRFAX ISLANDS REEF	40	4.13	0.63	0.13	0.20	0.05
NORTH WEST ISLAND REEF	33	4.06	0.48	0.36	0.09	0.06
SYKES REEF	21	4.05	0.43	0.43	0.10	0.05
WISTARI REEF	29	4.00	0.55	0.17	0.28	
LLEWELLYN REEF	71	4.00	0.52	0.25	0.15	0.07
WILSON ISLAND REEF	10	3.80	0.40	0.40	0.20	
TRYON ISLAND REEF	15	3.80	0.47	0.27	0.27	
HOSKYN ISLANDS REEF	27	3.63	0.33	0.37	0.26	0.04
BROOMFIELD REEF	25	3.60	0.40	0.32	0.24	0.04
ONE TREE ISLAND REEF	46	3.54	0.28	0.48	0.24	
LADY ELLIOTT ISLAND REEF	19	3.42	0.37	0.32	0.26	0.05
BOULT REEF	81	3.40	0.33	0.32	0.25	0.10
HERON ISLAND REEF	88	3.38	0.26	0.45	0.23	0.06
FITZROY REEF	96	3.38	0.34	0.33	0.23	0.10
LAMONT REEF	27	3.33	0.30	0.41	0.15	0.11
LADY MUSGRAVE ISLAND REEF	85	3.33	0.36	0.28	0.26	0.09
WRECK ISLAND REEF	18	3.17	0.28	0.44	0.17	0.11
NORTH REEF ISLAND REEF	21	2.90	0.14	0.57	0.29	
POLMAISE REEF	16	2.69	0.31	0.19	0.30	0.13
ERSKINE ISLAND REEF	24	2.67	0.21	0.25	0.38	0.17

SOFT CORAL

c)

REEF	NO.RECS.	AVE.SCR.	6-5	4-3	2-1	0
MASTHEAD ISLAND REEF	24	3.08	0.08	0.63	0.29	
WILSON ISLAND REEF	10	2.90	0.10	0.60	0.30	
ERSKINE ISLAND REEF	24	2.25	0.08	0.38	0.42	0.13
NORTH WEST ISLAND REEF	33	2.15	0.09	0.30	0.52	0.09
TRYON ISLAND REEF	15	2.07	0.07	0.27	0.67	
WRECK ISLAND REEF	18	1.94	0.06	0.33	0.44	0.17
SYKES REEF	21	1.90		0.19	0.71	0.10
BROOMFIELD REEF	25	1.80	0.04	0.20	0.52	0.24
WISTARI REEF	29	1.79		0.31	0.45	0.24
NORTH REEF ISLAND REEF	21	1.71		0.29	0.67	0.05
LLEWELLYN REEF	71	1.41	0.03	0.18	0.41	0.38
ONE TREE ISLAND REEF	46	1.37	0.02	0.15	0.57	0.26
POLMAISE REEF	16	1.31	0.06	0.06	0.63	0.25
FAIRFAX ISLANDS REEF	40	1.05		0.15	0.43	0.43
FITZROY REEF	96	0.97	0.03	0.07	0.42	0.48
LAMONT REEF	27	0.96		0.04	0.67	0.30
HERON ISLAND REEF	88	0.94		0.08	0.52	0.40
LADY MUSGRAVE ISLAND REEF	85	0.86		0.08	0.47	0.45
LADY ELLIOTT ISLAND REEF	19	0.68		0.05	0.42	0.53
BOULT REEF	81	0.62	0.01	0.06	0.30	0.63
HOSKYN ISLANDS REEF	27	0.59		0.04	0.37	0.59

TABLE 3 d-f

DEAD CORAL

d)

REEF	NO. RECS.	AVE. SCR.	6-5	4-3	2-1	0
LADY MUSGRAVE ISLAND REEF	85	0.91		0.14	0.33	0.53
FITZROY REEF	96	0.84		0.15	0.31	0.54
LLEWELLYN REEF	71	0.72		0.08	0.28	0.63
BOULT REEF	81	0.60		0.06	0.28	0.65
HOSKYN ISLANDS REEF	27	0.52		0.07	0.22	0.70
FAIRFAX ISLANDS REEF	40	0.52			0.45	0.55
POLMAISE REEF	16	0.50			0.31	0.69
MASTHEAD ISLAND REEF	24	0.50		0.08	0.21	0.71
ERSKINE ISLAND REEF	24	0.50		0.04	0.33	0.63
HERON ISLAND REEF	88	0.47		0.06	0.19	0.75
WRECK ISLAND REEF	18	0.39		0.11	0.06	0.83
WISTARI REEF	29	0.34			0.31	0.69
LADY ELLIOTT ISLAND REEF	19	0.32			0.21	0.79
WILSON ISLAND REEF	10	0.30			0.20	0.80
ONE TREE ISLAND REEF	46	0.26		0.02	0.13	0.85
NORTH WEST ISLAND REEF	33	0.21			0.18	0.82
SYKES REEF	21	0.14			0.14	0.86
NORTH REEF ISLAND REEF	21	0.05			0.05	0.95
LAMONT REEF	27	0.04			0.04	0.96
TRYON ISLAND REEF	15	0.00				1.00
BROOMFIELD REEF	25	0.00				1.00

MACRO ALGAE

e)

REEF	NO. RECS.	AVE. SCR.	6-5	4-3	2-1	0
POLMAISE REEF	16	3.25	0.50		0.25	0.25
ERSKINE ISLAND REEF	24	1.38	0.04	0.13	0.54	0.29
NORTH REEF ISLAND REEF	21	1.38	0.05	0.10	0.52	0.33
MASTHEAD ISLAND REEF	24	1.17		0.17	0.38	0.46
NORTH WEST ISLAND REEF	33	1.15	0.03	0.06	0.58	0.33
BROOMFIELD REEF	25	1.08		0.08	0.56	0.36
TRYON ISLAND REEF	15	0.87		0.13	0.33	0.53
LLEWELLYN REEF	71	0.87	0.03		0.62	0.35
HOSKYN ISLANDS REEF	27	0.78		0.11	0.30	0.59
WILSON ISLAND REEF	10	0.70			0.70	0.30
ONE TREE ISLAND REEF	46	0.67		0.02	0.52	0.46
WRECK ISLAND REEF	18	0.67			0.61	0.39
FAIRFAX ISLANDS REEF	40	0.65	0.02	0.08	0.25	0.65
HERON ISLAND REEF	88	0.63		0.03	0.42	0.55
WISTARI REEF	29	0.59			0.55	0.45
LAMONT REEF	27	0.56	0.04	0.04	0.19	0.74
BOULT REEF	81	0.53		0.01	0.37	0.62
LADY MUSGRAVE ISLAND REEF	85	0.48	0.01	0.01	0.33	0.65
LADY ELLIOTT ISLAND REEF	19	0.47		0.11	0.16	0.74
SYKES REEF	21	0.38			0.33	0.67
FITZROY REEF	96	0.15			0.14	0.86

COLONY SIZE

f)

REEF	NO. RECS.	AVE. SCR.	3	2	1	0
WILSON ISLAND REEF	10	2.10	0.10	0.90		
TRYON ISLAND REEF	15	2.07	0.33	0.40	0.27	
MASTHEAD ISLAND REEF	24	2.00	0.13	0.75	0.13	
FAIRFAX ISLANDS REEF	40	1.95	0.27	0.45	0.22	0.05
WISTARI REEF	29	1.90	0.07	0.76	0.17	
HOSKYN ISLANDS REEF	27	1.89	0.22	0.48	0.26	0.04
NORTH WEST ISLAND REEF	33	1.88	0.18	0.58	0.18	0.06
SYKES REEF	21	1.86	0.10	0.71	0.14	0.05
HERON ISLAND REEF	88	1.80	0.06	0.74	0.15	0.06
ONE TREE ISLAND REEF	46	1.80	0.09	0.63	0.28	
FITZROY REEF	96	1.79	0.27	0.34	0.29	0.09
LLEWELLYN REEF	71	1.77	0.23	0.41	0.28	0.08
BOULT REEF	81	1.77	0.23	0.40	0.27	0.10
LAMONT REEF	27	1.74	0.19	0.48	0.22	0.11
LADY MUSGRAVE ISLAND REEF	85	1.72	0.18	0.46	0.27	0.09
LADY ELLIOTT ISLAND REEF	19	1.68	0.21	0.32	0.42	0.05
BROOMFIELD REEF	25	1.56	0.16	0.28	0.52	0.04
NORTH REEF ISLAND REEF	21	1.52		0.52	0.48	
POLMAISE REEF	16	1.38	0.06	0.44	0.31	0.19
ERSKINE ISLAND REEF	24	1.38	0.04	0.46	0.33	0.17
WRECK ISLAND REEF	18	1.33		0.44	0.44	0.11

TABLE 3g

DIVERSITY

g)

REEF	NO. RECS.	AVE. SCR.	4	3	2	1	0
NORTH WEST ISLAND REEF	33	2.79	0.24	0.42	0.27		0.06
TRYON ISLAND REEF	15	2.67	0.13	0.40	0.47		
WISTARI REEF	29	2.55	0.10	0.34	0.55		
WILSON ISLAND REEF	10	2.50	0.10	0.30	0.60		
NORTH REEF ISLAND REEF	21	2.48		0.48	0.52		
MASTHEAD ISLAND REEF	24	2.46	0.04	0.38	0.58		
SYKES REEF	21	2.43		0.52	0.43		0.05
BROOMFIELD REEF	25	2.36	0.08	0.28	0.60		0.04
LLEWELLYN REEF	71	2.35	0.07	0.39	0.44	0.01	0.08
ONE TREE ISLAND REEF	46	2.28	0.02	0.28	0.65	0.04	
HOSKYN ISLANDS REEF	27	2.22	0.04	0.26	0.63	0.04	0.04
LAMONT REEF	27	2.19	0.07	0.30	0.48	0.04	0.11
FITZROY REEF	96	2.19	0.06	0.26	0.57	0.01	0.09
FAIRFAX ISLANDS REEF	40	2.18		0.35	0.52	0.08	0.05
HERON ISLAND REEF	88	2.17	0.02	0.26	0.64	0.02	0.06
LADY MUSGRAVE ISLAND REEF	85	2.14	0.02	0.32	0.53	0.04	0.09
LADY ELLIOTT ISLAND REEF	19	2.05		0.21	0.68	0.05	0.05
BOULT REEF	81	2.00	0.02	0.21	0.60	0.06	0.10
WRECK ISLAND REEF	18	1.89		0.11	0.78		0.11
POLMAISE REEF	16	1.88	0.06	0.06	0.69	0.06	0.13
ERSKINE ISLAND REEF	24	1.88	0.04	0.17	0.58	0.04	0.17

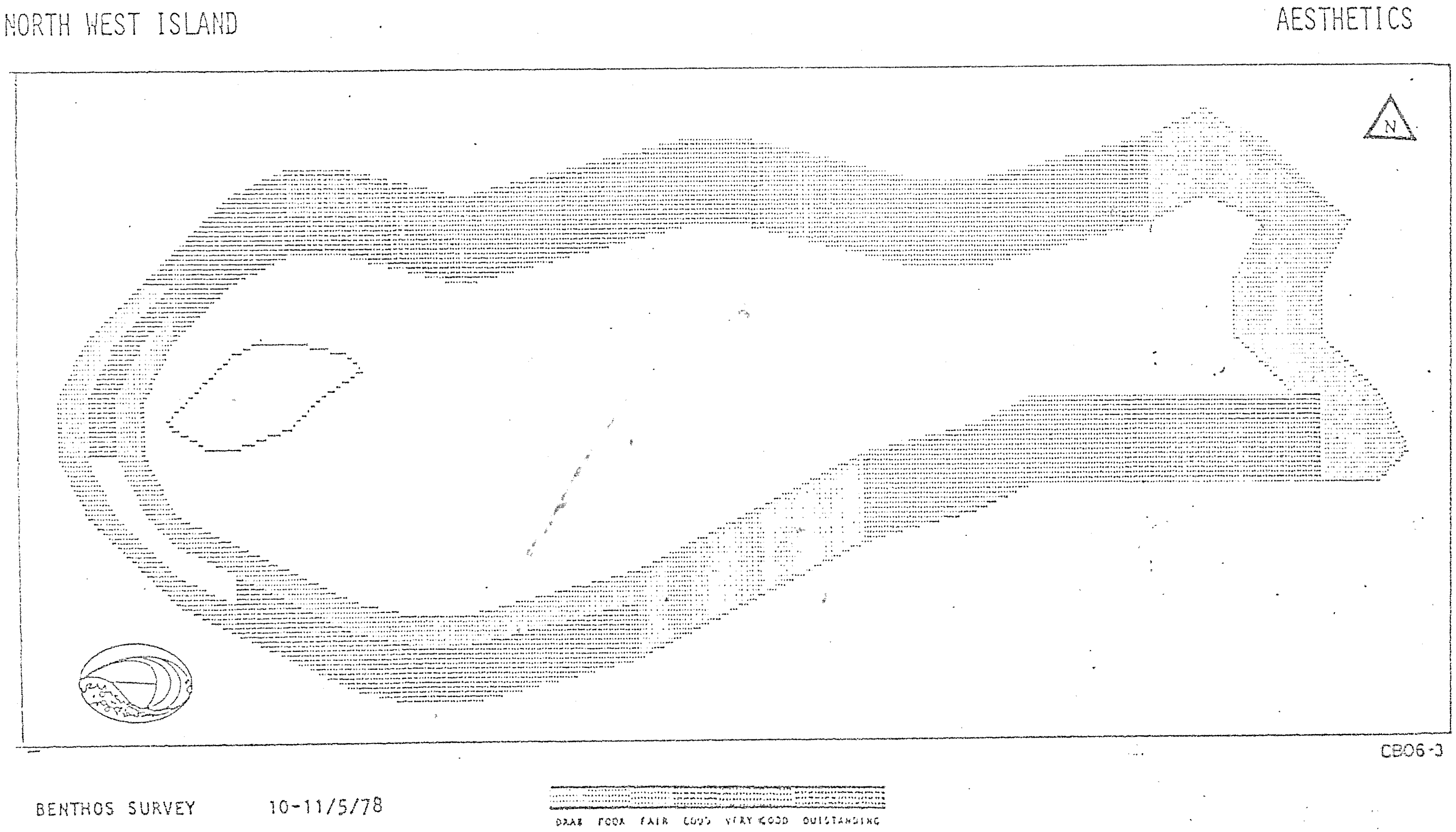
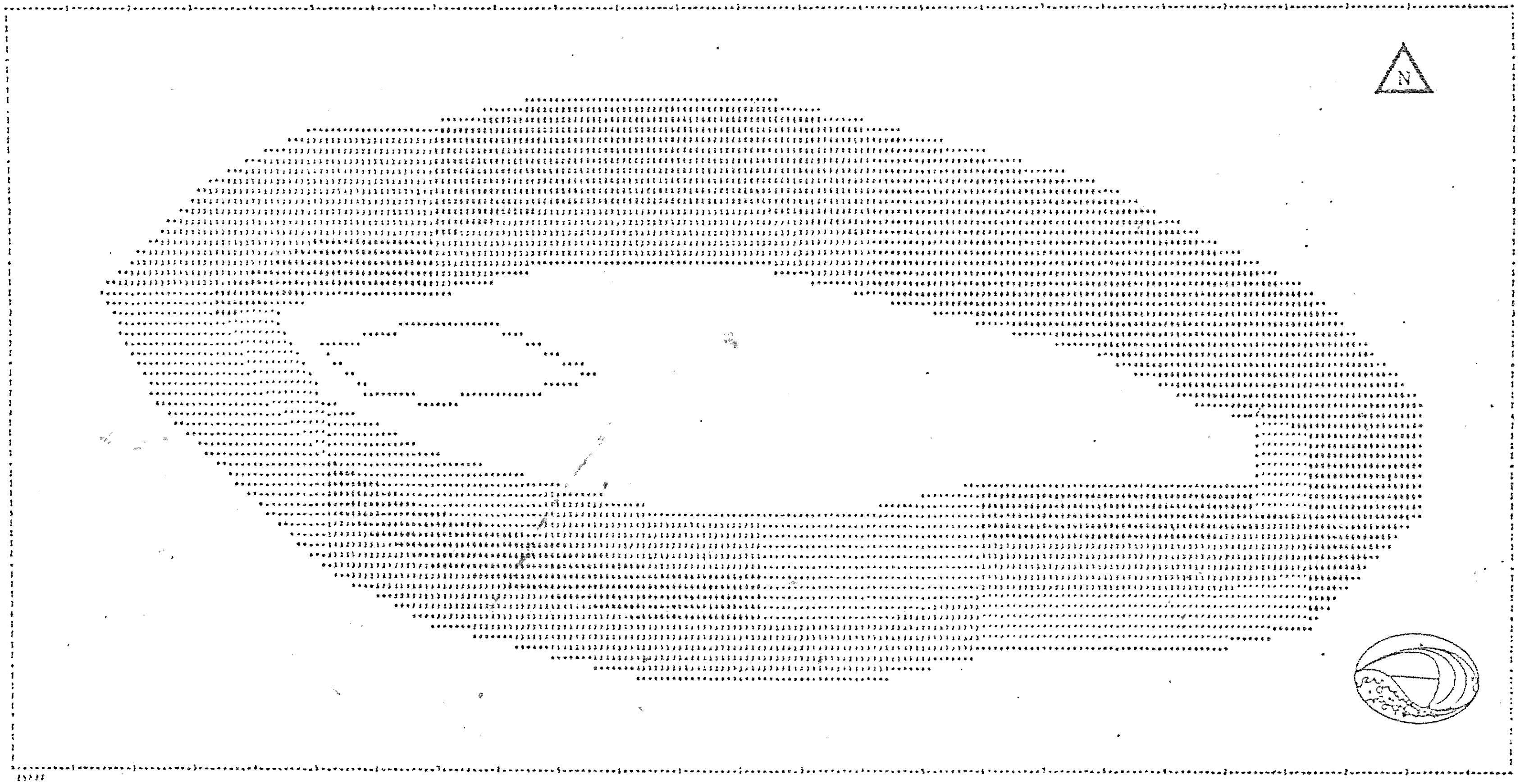


Fig.5 Shaded map of aesthetic appeal at North West Island. Dark shading indicates high scores, light shading low scores.

MASTHEAD ISLAND

SOFT CORAL COVER



CB08-6

BENTHOS SURVEY 17-18/5/78

NIL 1-5% 5-15% 15-30% 30-50% 50-75% 75-100%

Fig. 6 Shaded map of soft coral cover at Masthead Island.

	SPECIES	OBSERVER NO. 4			OBSERVER NO. 5			OBSERVER NO. 8			OBSERVER NO. 9		
		F	AVE	VAR	F	AVE	VAR	F	AVE	VAR	F	AVE	VAR
Massive	211 LARGE HEADS	17.0	2.8	0.5	38.0	3.2	1.0	25.0	3.2	1.4	1.0	3.0	0.0
	212 SMALL HEADS	11.0	1.8	0.1	5.0	4.0	0.2	3.0	2.3	0.1	1.0	1.0	0.0
	220 SMALL CORALLITES	2.0	3.5	0.1	25.0	2.1	0.3	7.0	2.6	0.3	1.0	4.0	0.0
	230 CERIOID/PLOCOID CORALLITE	19.0	2.4	0.4	72.0	1.7	0.5	23.0	2.9	1.0	0.0	0.0	0.0
	240 MEANDROID CORALLITES, FIN	26.0	2.0	0.3	54.0	1.9	0.5	43.0	2.1	1.0	0.0	0.0	0.0
	241 LEPTORIA	1.0	3.0	0.0	2.0	3.0	0.0	3.0	2.7	0.1	2.0	1.5	0.0
	* 242 PLATYGYRA	2.0	3.0	0.1	38.0	1.9	0.3	2.0	2.5	0.1	2.0	1.5	0.0
	250 MEANDROID CORALLITES, FLE	5.0	1.6	0.0	13.0	1.3	0.0	2.0	1.0	0.0	0.0	0.0	0.0
	251 LOBOPHYLLIA	9.0	2.6	0.2	17.0	1.5	0.1	4.0	1.5	0.0	2.0	3.5	0.0
	* 252 SYMPHYLLIA	0.0	0.0	0.0	6.0	1.3	0.0	0.0	0.0	0.0	1.0	2.0	0.0
	260 MASSIVE WITH KNOBS OR DEN	10.0	1.6	0.1	16.0	1.8	0.1	6.0	2.2	0.1	0.0	0.0	0.0
	261 FAVIA STELLIGERA	2.0	2.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	262 PAVONA CLAVUS	1.0	2.0	0.0	4.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	265 MILLEPORA	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0
Acropora	310 TABULATE ACROPORA	38.0	2.6	0.9	92.0	3.6	2.6	51.0	3.2	2.7	2.0	5.0	0.1
	311 A. HYACINTHUS TYPE	25.0	3.8	1.2	10.0	4.8	0.5	38.0	3.2	2.0	1.0	3.0	0.0
	320 A. HUMILIS	12.0	2.8	0.3	60.0	3.3	1.4	19.0	2.5	0.7	3.0	3.7	0.1
	331 SHEETS (A. PALIFERA)	7.0	2.3	0.1	38.0	3.2	0.8	12.0	2.7	0.4	4.0	4.5	0.1
	332 RIDGED (A. PALIFERA)	1.0	2.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 333 CLAVIFORM (A. PALIFERA)	35.0	2.6	0.8	22.0	2.3	0.3	6.0	2.5	0.2	1.0	5.0	0.0
	* 334 COLUMNAR (A. PALIFERA)	2.0	3.5	0.1	4.0	3.8	0.1	10.0	2.1	0.2	1.0	5.0	0.0
	340 ACROPORA STAGHORN	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0
	341 THICKETS HIGH	9.0	3.1	0.3	8.0	3.6	0.2	4.0	3.0	0.2	0.0	0.0	0.0
	342 THICKETS LOW	8.0	3.1	0.3	17.0	2.9	0.3	6.0	3.5	0.4	0.0	0.0	0.0
	343 CLUMPS HIGH	4.0	3.3	0.1	9.0	3.6	0.3	1.0	4.0	0.1	2.0	2.5	0.0
	344 CLUMPS LOW	18.0	2.1	0.3	77.0	2.4	1.1	25.0	2.2	0.6	0.0	0.0	0.0
	* 346 ACROPORA 'ROBUSTA' GROUP	5.0	1.2	0.0	35.0	2.9	0.7	20.0	2.0	0.4	0.0	0.0	0.0
	* 350 CAESPITOSE	29.0	2.0	0.4	3.0	2.0	0.0	2.0	2.5	0.0	0.0	0.0	0.0
	351 A. EXILIS TYPE	3.0	2.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	360 BUSHY/BOTTLEBRUSH	4.0	1.8	0.0	4.0	1.8	0.0	6.0	1.7	0.1	0.0	0.0	0.0
	363 XMAS TREE TYPE	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Branching	410 NEEDLE CORAL - SERIATOPOR	9.0	1.9	0.1	13.0	1.5	0.1	10.0	2.2	0.2	0.0	0.0	0.0
	420 FINGER THICK BRANCHING	0.0	0.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
	421 MILLEPORA	3.0	2.0	0.0	9.0	2.4	0.1	2.0	3.0	0.1	1.0	3.0	0.0
	423 HYDNOPHORA RIGIDA	1.0	2.0	0.0	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	425 ECHINOPORA	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	426 ACRHELIA	1.0	4.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 427 PORITES	28.0	3.5	1.1	17.0	3.5	0.5	6.0	3.5	0.4	0.0	0.0	0.0
	428 MONTIPORA	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0
	431 STYLOPHORA PISTILLATA	15.0	1.6	0.1	20.0	1.8	0.2	13.0	2.2	0.3	0.0	0.0	0.0
	433 CAULASTREA	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	451 POCILLOPORA VERRUCOSA	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0	0.1	0.0	0.0	0.0
	452 STYLOPHORA MORDAX	0.0	0.0	0.0	3.0	1.0	0.0	7.0	1.7	0.1	0.0	0.0	0.0
	* 460 POCILLOPORA DAMICORNIS	5.0	1.6	0.0	43.0	1.6	0.2	16.0	1.9	0.3	0.0	0.0	0.0
Laminar	* 510 ENCRUSTING - NO FREE LIP	3.0	3.0	0.1	2.0	2.0	0.0	20.0	2.5	0.6	0.0	0.0	0.0
	511 MILLEPORA	4.0	2.0	0.1	41.0	2.1	0.4	10.0	2.4	0.3	3.0	2.0	0.0
	* 512 MONTIPORA	6.0	3.2	0.2	42.0	1.7	0.3	0.0	0.0	0.0	1.0	2.0	0.0
	513 PORITES	0.0	0.0	0.0	4.0	3.8	0.1	4.0	2.0	0.1	0.0	0.0	0.0
	514 FAVIIDS	0.0	0.0	0.0	5.0	2.4	0.1	1.0	2.0	0.0	0.0	0.0	0.0
	522 MONTIPORA	0.0	0.0	0.0	1.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	523 GALAXEA	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 530 EXPLANATE - WITH FREE LIP	0.0	0.0	0.0	4.0	3.0	0.1	35.0	2.6	1.3	0.0	0.0	0.0
	532 MONTIPORA	16.0	2.3	0.2	40.0	2.3	0.5	2.0	2.5	0.1	0.0	0.0	0.0
	537 ECHINOPORA	0.0	0.0	0.0	2.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 540 EXPLANATE WITH VERTICAL P	0.0	0.0	0.0	0.0	0.0	0.0	9.0	2.8	0.3	0.0	0.0	0.0
	542 MERULINA	1.0	1.0	0.0	4.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	543 ECHINOPORA MAMMIFORMIS	0.0	0.0	0.0	2.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	544 PORITES LICHEN TYPE	17.0	3.2	0.6	8.0	3.0	0.2	3.0	4.0	0.2	0.0	0.0	0.0
	546 MONTIPORA	4.0	3.3	0.1	6.0	2.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	560 LEAFY EXPLANATE	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.8	0.1	0.0	0.0	0.0
	561 PAVONA CACTUS	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	570 VASES/ROSES	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.5	0.0	0.0	0.0	0.0
	571 MONTIPORA	8.0	2.6	0.2	11.0	2.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	572 TURBINARIA	0.0	0.0	0.0	5.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	573 ECHINOPORA LAMELLOSA	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 611 CONIOPORA/ALVEOPORA	7.0	2.1	0.1	21.0	1.5	0.1	5.0	2.8	0.2	0.0	0.0	0.0
	614 TUBIPORA MUSICA	2.0	1.5	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	710 ROUND FUNGIIDS	0.0	0.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	711 FUNGIA ACTINIFORMIS	1.0	6.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soft or horny	810 ERECT FLESHY CORALS	0.0	0.0	0.0	7.0	5.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	* 811 TUFTY LOW	15.0	4.5	0.9	76.0	3.8	2.5	13.0	4.4	1.4	2.0	4.5	0.1
	812 MASSIVE BRANCHING	16.0	4.1	0.9	14.0	4.3	0.5	7.0	5.1	0.9	4.0	4.5	0.1
	* 813 SARCOPHYTON	5.0	1.6	0.0	55.0	3.3	1.4	15.0	3.9	1.3	3.0	2.3	0.0
	814 NEPHTHIIDAE	0.0	0.0	0.0	0.0	0.0	0.0	9.0	4.0	0.7	0.0	0.0	0.0
	815 XENIIDAE	4.0	4.5	0.3	7.0	2.9	0.1	10.0	4.6	1.1	2.0	3.5	0.0
	820 PROSTRATE FLESHY CORALS	0.0	0.0	0.0	2.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 821 MASSIVE PROSTATE	8.0	4.5	0.5	64.0	3.9	2.3	3.0	2.0	0.1	1.0	6.0	0.0
	822 THIN ENCRUSTING	6.0	4.5	0.4	9.0	3.3	0.2	1.0	2.0	0.0	0.0	0.0	0.0
	823 ZOANTHIIDS	1.0	6.0	0.1	19.0	3.1	0.5	0.0	0.0	0.0	1.0	2.0	0.0
	831 FAN	0.0	0.0	0.0	2.0	2.5	0.0	3.0	2.0	0.1	0.0	0.0	0.0
	832 WHIP	0.0	0.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	* 834 RUMPHELLA	10.0	5.0	0.8	47.0	2.3	0.7	4.0	5.8	0.6	2.0	2.0	0.0
Other	910 SPONGE	0.0	0.0	0.0	2.0	6.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	912 VERTICAL LEAF SPONGE	5.0	5.2	0.4	6.0	6.0	0.4	3.0	5.0	0.4	1.0	1.0	0.0
	914 ENCRUSTING SPONGE	0.0	0.0	0.0	1.0	6.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	921 BROWN FEATHER	4.0	4.8	0.3	9.0	5.2	0.5	0.0	0.0	0.0	1.0	6.0	0.0
	922 WHITE FINE	0.0	0.0	0.0	2.0	4.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Table 4 A comparison of the use of VDO by four observers. VDO's marked with a '*' were particularly inconsistently used. 'F' is the frequency (i.e. total number of times the attribute was scored). Average ('AVE') and variance ('VAR') were calculated using non-zero scores only.

6). On all other reefs, macro-algae were inconspicuous, particularly on the more offshore reefs (lower entries of Table 3e).

6. Colony size (Table 3f)

Most reefs had a majority of sites in which colony size was unexceptional (score 2). The highest proportion of sites with exceptionally large colonies occurred at Tryon Is. reef, followed by Wistari and Fitzroy reefs. The greatest proportion of low scores were recorded at Broomfield and North reefs. (Note all zero scores for aesthetics, and colony size are missing data).

7. Diversity (Table 3g)

Average diversity (on a 0-4 scale) ranged from 1.9 to 2.8. North West Island reef had both the highest average and the greatest proportion of 4's scored. Most reefs had a majority of 2's (low diversity) indicating the depauperate appearance of many of the communities. Very few 1's were scored, indicating the relative scarcity of monospecific stands.

b) Visually dominant organisms - composition and distribution

The records of observers 4, 5, 8 and 9 on the reefs in the Bunker group were used in the assessment and their use of the VDO's is summarised in Table 4. Observers 4, 5 and 8 reported on 99, 197 and 92 sites respectively and as the tows of each covered the full range of habitats, it may be assumed that the same range of benthic organisms was observed. Observer 9 was a short-term volunteer who reported on only 11 sites. For each observer, Table 4 indicates the frequency, average and variance of each VDO where

a) frequency is the number of times it was recorded (regardless of score), and

b) the calculation of average and variance excludes zero scores.

Those VDO's not recorded by any observer are excluded from the table.

Collectively, the four observers scored 89 of the 140 VDO's on the data sheet. Observer 5 used 75, observer 4 used 58, observer 8 used 54 and observer 9 used 27. Marked discrepancies in the use of individual VDO's may be seen by inspections of the table (see particularly VDO's marked thus '*'). In general, observer 5 tended to score individual OTU's more than the others, and observer 8 used higher categories more.

The differences between observers may be reduced by considering the data set at a level of some lower common denominator. Table 5 is based on a modified matrix, in which most OTU's were recoded to their higher category; (those which were not recoded were generally those which were scored consistently or were considered important at the OTU level). The modified matrix contained 41 VDO's and observers 4, 5, 8 and 9 used 36, 38, 32 and 20 of these respectively. This far more consistent usage of the VDO's greatly enhanced the ability to reconcile the observers' different perceptions of the same communities (see discussion) although at a cost of some information loss.

The data of observer 9 is not considered further. The considerable work involved in analysing VDO data is not justifiable for a data set of only 11 sites; the use of observers for such short times is to be discouraged.

Site group classification of the unmodified matrix was unsatisfactory. Although the dendrograms produced had a suggestive structure, Subset analysis of the VDO composition of groups at several levels indicated that few VDO's (in several cases, no VDO's) were consistently present in members of the site groups.

The term 'assemblage' loosely refers to the list of diagnostic constants defined for Clustan site groups (see methods for detail). The distributions of members of all site groups containing more than three sites are plotted in Figures 7 to 9. Examination of these distributions indicates the existence of a number of ubiquitous assemblages, and others which are more restricted in their occurrence. Generalized profiles showing the distributions of the ubiquitous assemblages are presented in Figure 10, and the diagnostic constant VDO's are presented in Tables 6 - 9.

1. <u>Ubiquitous assemblages</u>

<u>Weather and lee slopes</u>

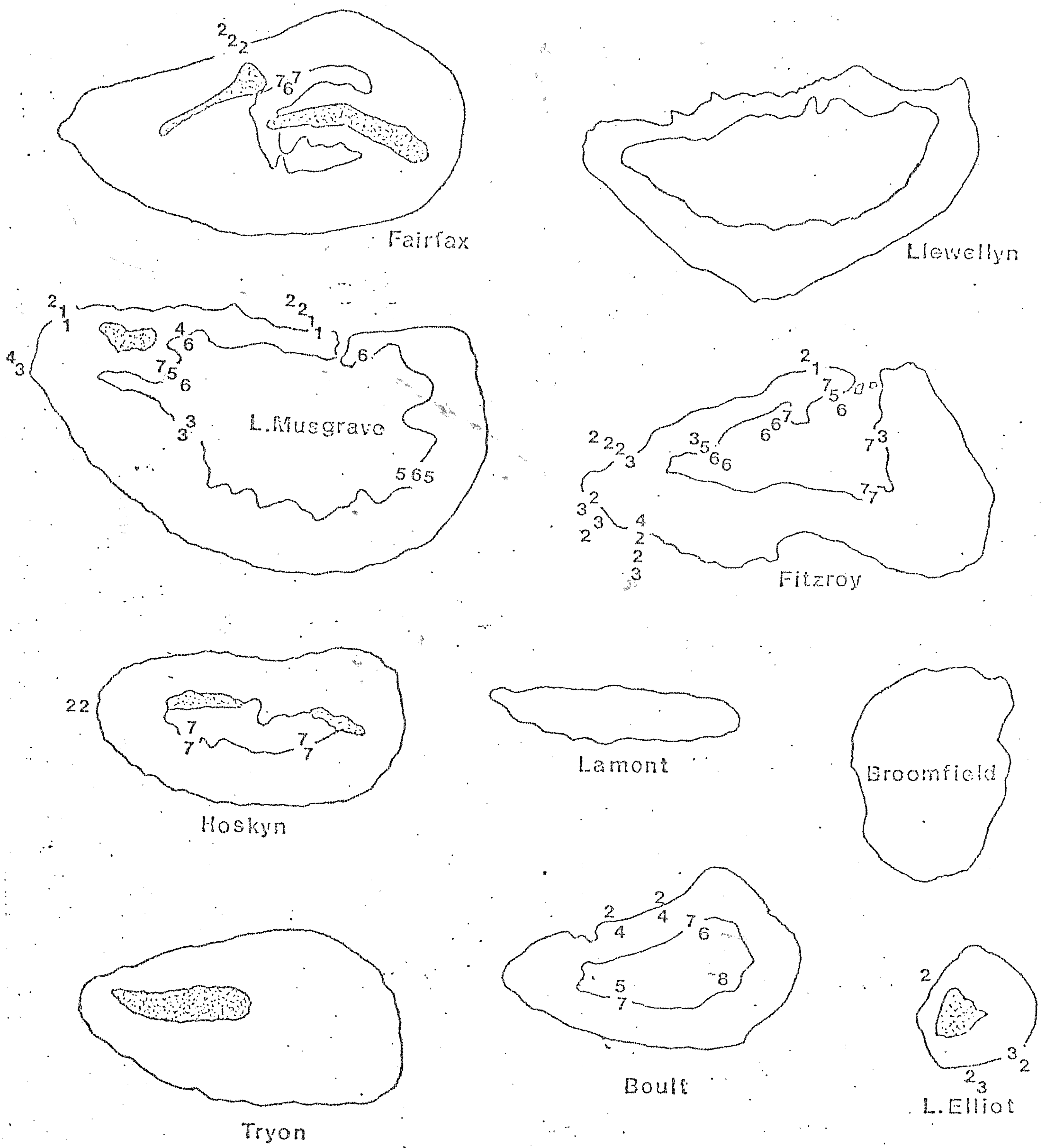


Fig. 7 Distribution of site groups - observer 4. Numbers are site group numbers as defined in Table 6.

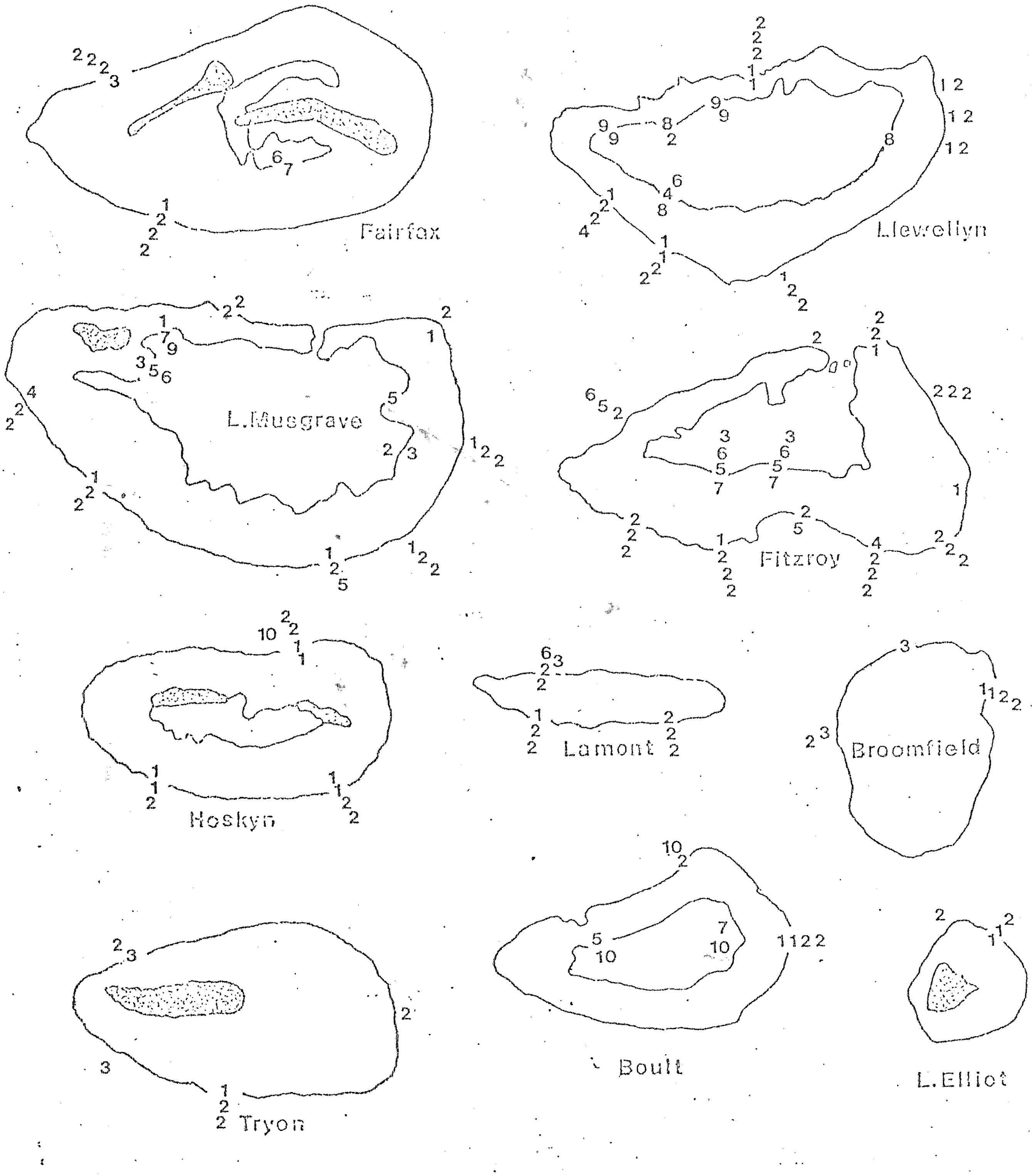


Fig. 8 Distribution of site groups - observer 5. Numbers are site group numbers as defined in Table 7.

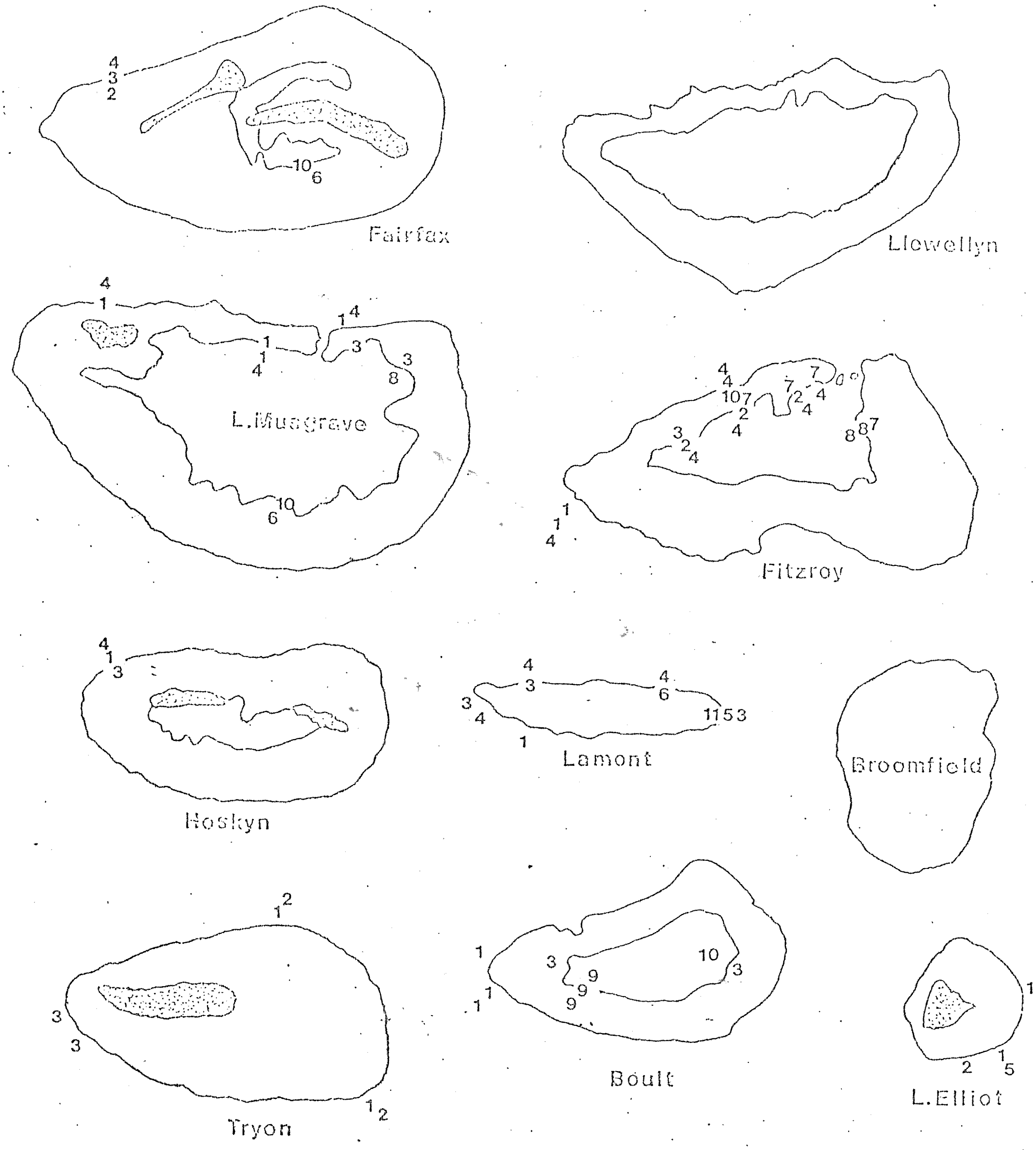


Fig. 9 Distribution of site groups - observer 8. Numbers are site group numbers as defined in Table 8.

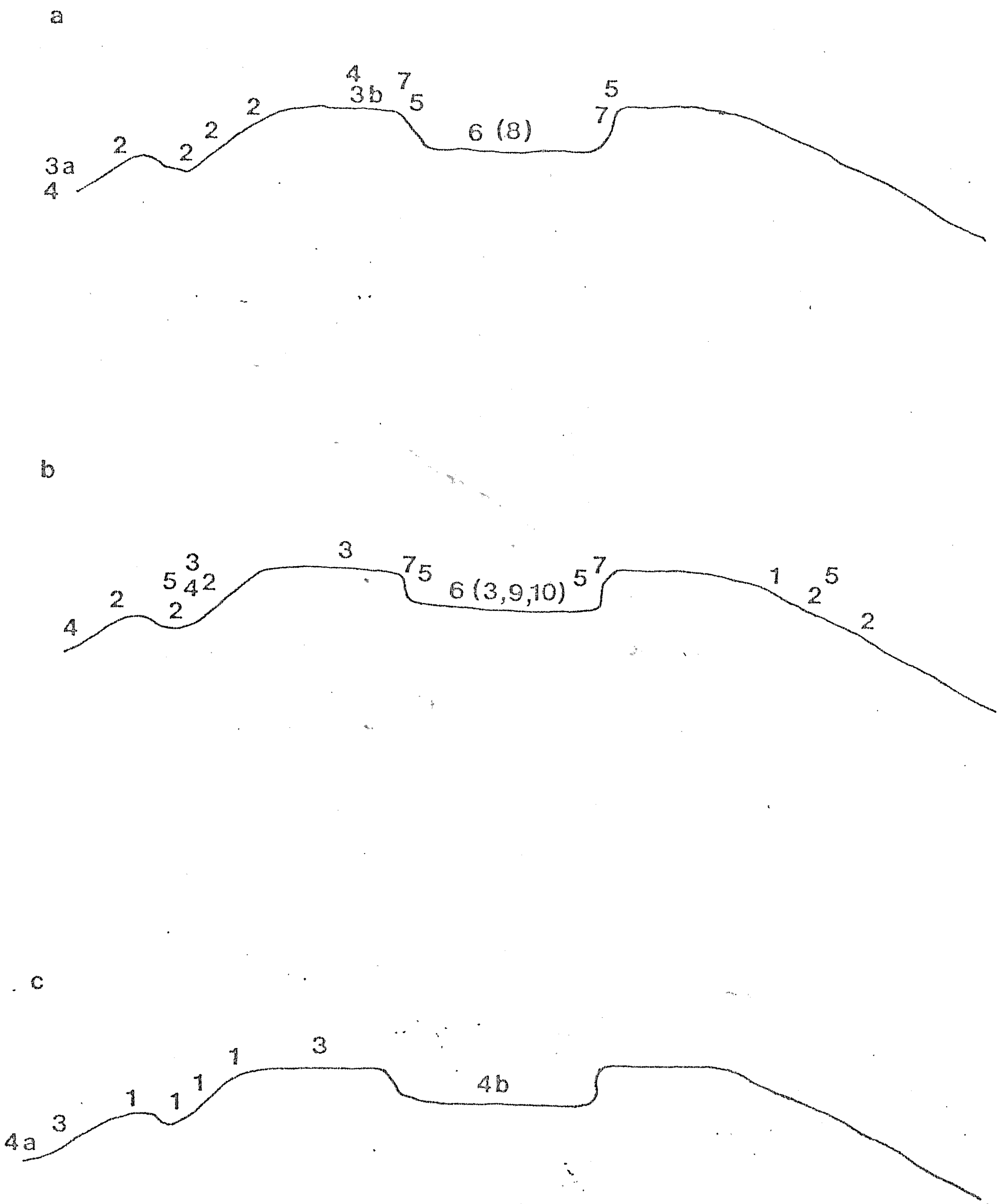


Fig. 10 The distribution of the most ubiquitous coral assemblages on generalised Bunker reef profiles.

a) observer 4 b) observer 5 c) observer 8

CONSTANT VDO's

Observer 4

GROUP 2 (26 sites)	GROUP 3 (12 sites)	GROUP 4 (5 sites)
Tabulate *Acropora*		
Massive - meandroid (fine)		
Staghorn *Acropora*	*Acropora palifera* (claviform)	Ceaspitose *Acropora*

GROUP 1 (5 sites)
Acropora palifera (sheets) *Acropora humilis*

GROUP 5 (5 sites)	GROUP 7 (15 sites)
Acropora palifera (claviform)	
Staghorn *Acropora* Explanate *Porites* (branching)	Explanate with v.p.

GROUP 6 (12 sites)	GROUP 8 (4 sites)
Porites (branching)	
Staghorn *Acropora* Massive *Porites* (large)	Vases / roses

Table 6 A tabulation of the 'diagnostic constants' in Clustan generated site groups of Observer 4. Site groups are themselves grouped to highlight similarities between them. 'Diagnostic constant' VDO's occur in two thirds or more of the sites in a site group.

CONSTANT VDO's

Observer 5

GROUP 2 (90 sites)

- Tabulate *Acropora*
- Massive – meandroid (fine)
- Staghorn *Acropora*

GROUP 1 (37 sites)

- *Acropora humilis*
- *Acropora palifera* (sheets)
- Encrusting

GROUP 4 (5 sites)

- Tabulate *Acropora*
- *Acropora palifera* (sheets)
- Massive-cerioid/plocoid

GROUP 3 (10 sites)	GROUP 5 (11 sites)	GROUP 9 (5 sites)
Acropora staghorn	*Acropora* staghorn	*Acropora* staghorn
Pocillopora damicornis	*Pocillopora damicornis*	*Porites* – branching
Massive-cerioid/plocoid	Explanate	*Porites* – massive (large)
	Massive-meandroid (fleshy)	Vases/Roses

GROUP 7 (5 sites)

- Explanate with v_xp.
- *Acropora palifera* (claviform)
- Massive – cerioid/plocoid

Table 7 A tabulation of the 'diagnostic constants' in Clustan generated site groups of Observer 5. Site groups are themselves grouped to highlight similarities between them. 'Diagnostic constant' VDO's occur in two thirds or more of the sites in a site group.

CONSTANT VDO's

Observer 8

<table>
<tr><th>GROUP 1 (23 sites)</th><th>GROUP 4 (17 sites)</th><th>GROUP 3 (13 sites)</th></tr>
<tr><td colspan="3">Tabulate Acropora</td></tr>
<tr><td colspan="2">Staghorn Acropora
Massive - meandroid (fine)</td><td rowspan="2">Massive - cerioid/ plocoid</td></tr>
<tr><td>Encrusting</td><td>Massive-Porites (large)
Explanate</td></tr>
</table>

GROUP 2 (6 sites)	GROUP 7 (4 sites)	GROUP 9 (4 sites)
Explanate Explanate with v.p. Explanate - leafy Tabulate *Acropora* Staghorn *Acropora*	*Acropora humilis* Massive-cerioid/plocoid *Pocillopora damicornis*	*Acropora palifera* (sheets) *Pocillopora damicornis*

Table 8 A tabulation of the 'diagnostic constants' in Clustan generated site groups of Observer 8. Site groups are themselves grouped to highlight similarities between them. 'Diagnostic constant' VDO's occur in two thirds or more of the sites in a site group.

HABITAT/ZONE		OBSERVER 4	OBSERVER 5	OBSERVER 8
OUTER SLOPES:	UPPER:	1. *A. humilis* *A. palifera* (sheets)	1. *A. humilis* *A. palifera* (sheets) Encrusting	
	MIDDLE:	2. Tabulate *Acropora* Staghorn *Acropora* Massive-meandroid (fine)	2. Tabulate *Acropora* Staghorn *Acropora* Massive-meandroid (fine)	1. Tabulate *Acropora* Staghorn *Acropora* Massive-meandroid (fine)
	LOWER	As for mid-slope [3a. Tabulate *Acropora* Massive-meandroid (fine)][3]	2. (as for middle slopes)	As for mid-slope [4a. Massive - *Porites* Tabulate *Acropora* Staghorn *Acropora*][3]
REEF FLAT:	SHELTERED	3b. Tabulate *Acropora* *A. palifera* (claviform) Massive-meandroid (fine) *Pocillopora damicornis*	3. Staghorn *Acropora* Massive-cerioid/plocoid *Pocillopora damicornis*	3. Tabulate *Acropora* Massive (cerioid/plocoid)
LAGOON MARGIN:	TOP/UPPER:	7. *A. palifera* (claviform)[1] Explanate with v.p.[2]	7. *A. palifera* (claviform)[1] Explanate with v.p.[2]	
	LOWER:	5. Staghorn *Acropora* *A. palifera* (claviform) Branching *Porites*	5. Explanate *Acropora* Staghorn *Acropora* *Pocillopora damicornia* *Goniopora/Alveopora* Massive-meandroid (fleshy)	
LAGOON FLOOR:		6. Branching *Porites* Massive - *Porites* Staghorn *Acropora* [8. Vases/Roses Branching *Porites*][3]	6. Staghorn *Acropora* [9. Branching *Porites* Massive *Porites* Staghorn *Acropora* Vases/Roses][3]	4b. Massive *Porites* Staghorn *Acropora* Explanate

NOTES:

1. May be *A. bruggemani*
2. Mainly *Porites lichen*.
3. Not the most ubiquitous, but common

Table 9 A comparison of the 'ubiquitous assemblages' found in various reef habitats and zones thereof.

In general, the upper 15 meters of the weather slopes of the Bunker reefs are gently sloping (10-30^{o}) and relatively featureless, while the lee slopes are steeper (40-90^{o}) and frequently have spur and groove structures. Only observer 5 had data for both weather and lee slopes. In general, the sequence of assemblages was similar, regardless of aspect, and consisted of assemblage 1 on the upper reef slopes, and assemblage 2 on mid and lower slopes. As may be seen in Table 9, the diagnostic constants of observer 5's upper slope assemblage 1 are *Acropora humilis* and the 'sheet' growth form of *Acropora palifera*. On the mid and lower slope, tabulate *Acropora* is very important, and staghorn *Acropora* and 'massive-meandroid (fine)' colonies also dominant.

Table 9 also indicates that observers 4 and 8 scored the same or similar VDO's in describing these zones. Differences occurres in the lower slopes, where, in addition to the mid-slope assemblage, they recorded deeper slope variants.

Reef flat sites

A small number of reef flat sites adjacent to lagoon margins and outer slopes were surveyed. These sites tended to group together in the classification. Table 9 indicates only partial overlap in the VDO composition of these sites, indicating perhaps the variability of these sites as much as differences in observer perceptions.

Lagoon margins

Bunker reef lagoon margins characteristically consist of a vertical or near vertical face adjoining a very flat reef top. The adjacent sandy lagoon floor is from 2-5 meters below the reef top.

Observers 4 and 5 each defined a characteristic lagoon margin assemblage, and in each case, the constants were the 'claviform' growth form of *Acropora palifera* and the 'explanate with vertical projections' growth form, which was invariably a reference to the encrusting *Porites lichen*.

The coral assemblages occupying the lagoon margin face consisted of elements of the adjacent reef top and lagoon floor assemblages. Massive and branching *Porites* colonies, staghorn *Acropora* and foliose species (*i.e.* 'vases/roses' growth form) were characteristic of the habitat. When the lagoon face and floor are considered together (see Table 9), there is considerable agreement between observers in the composition of the diagnostic constant VDO's. However, considered separately, there are differences, perhaps an indication of the patchiness of coral distributions in this habitat, and/or differences in observer perception of visual dominance (see Discussion).

2. Assemblages of restricted distribution

Each observer scored a number of sites which did not fit well into his classification. The failure of sites to join large site groups, or to form small groups, may simply be due to deficiencies in the data or the classification, or may truly indicate sites of unusual composition; the latter may be of particular interest to reef managers.

3. Interpretation of equivalent assemblages recorded by three observers

Figure 11 is a composite compiled from the data of the three observers. It is based on an interpretation by the author of equivalences between the assemblages of the different observers, the key for which is included with the figure. Assemblages which do not fit into the scheme of equivalences are marked using a two point number thus; observer no./site group no.

DISCUSSION

GBRMPA's formulation of a zoning plan for the Capricornia reefs benefited greatly from the fact that pairs of informed eyes had viewed many of the reefs concerned. Zoning of reefs without any knowledge of their current biological status was an unacceptable option and so the reconnaissance satisfied a need.

Proper interpretation of reconnaissance data

This report attempts to present results in a form which is compatible with the data. For reasons which are discussed below, the data is subject to the largely uncontrollable variation which is inherent in any biological reconnaissance. In this programme, problems are exaggerated by the strenuous mental and physical nature of the tow and the complex and alien environment in which observers must work. Data presentation and analysis were done bearing in mind the limitations of the data.

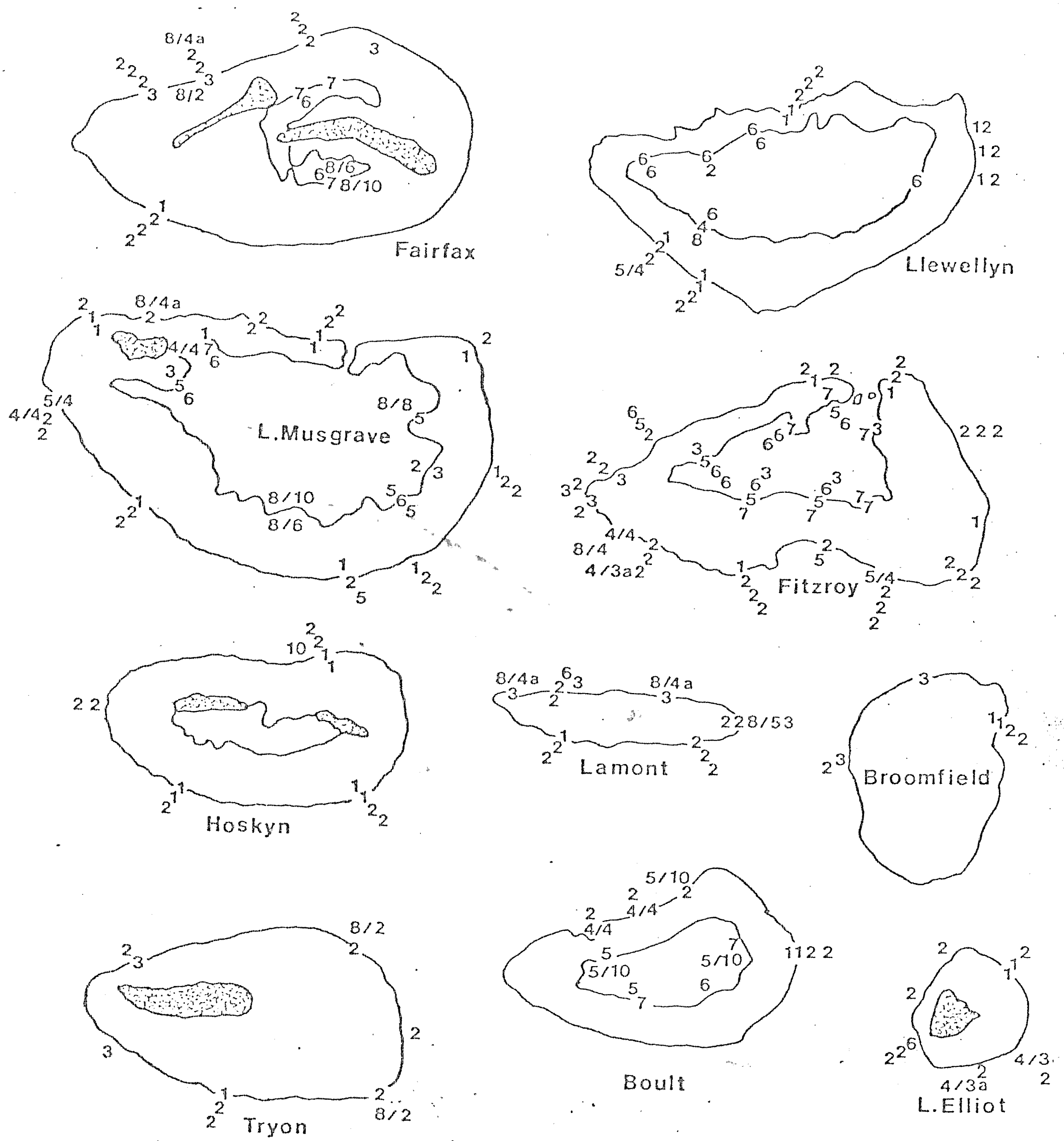


Fig. 11 Composite of assemblage distribution maps for observers 4, 5 and 8. The 'general' assemblage numbers are equivalent to specific observer's assemblages as shown.

Assemblage Numbers

General	Obs. 4	Obs. 5	Obs. 8
1	1	1	
2	2	2	1
3	3b	3	3
5	5	5	
6	6,8	6,9	4b
7	7	7	

In the G.B.R.M.P.A. context, management requires that decisions be made regarding uses to be made of entire reefs or groups of reefs. It thus seems that a ranking of reefs on the basis of their individual biological attributes is appropriate, and Tables 3a to 3g are intended to fulfill this need. They give the reef manager his first 'in' to the data, since he knows that reefs towards the top have high mean scores for the particular attribute, and reefs towards the bottom have low mean scores. The frequency distribution of the scores shows how a particular average came about. He may then refer to the appropriate shaded map to ascertain the spatial distribution of high, intermediate and low scores. The spatial distribution of scores relative to access points, anchorages, facilities, etc. may influence management decisions. More detailed and intensive confirmatory surveys may be necessary in areas the reconnaissance indicates as influential to the final decision.

The main value of the VDO reconnaissance is that it provides a broad scale biological characterization of the reefs considered collectively. In this respect, a significant degree of concordance among different observers allowed a composite map of uniquitous assemblages to be compiled. There is a degree of uncertainty regarding the remaining sites not inhabited by 'uniquitous assemblages'; some will truly be inhabited by unusual assemblages (a finding which might be of interest to a reef manager); others will only appear different due to data inconsistencies (see below). This uncertainty is inherent in the manta tow method as currently practiced, and it is unlikely to be removed by manipulation of the data. A reappraisal of that part of the data and/or a further localised field survey may be called for in critical cases.

It will probably never be logistically or financially possible to validate the reconnaissance on an appropriate scale. It must be taken for what it is - the first impressions of often tired and soggy snorkellers. However, used in a conservative and cautious manner, the data are useful in the characterization of reefs over a scale of hundreds of meters. The data will generally not coincide with critical literal interpretation, or with objective measurement within a small section of a tow site. Anyone interpreting the data of this programme must bear these limitations in mind, and the following section is included to ensure they are not underestimated.

Methodological short-comings and limitations

The programme's originators and participants were aware of the outset of its potential short-comings and limitations and this awareness was reinforced during field observations.

Limits to the interpretation which may be made of the data are dictated by the following factors:

(a) the complexity of coral reefs;

(b) the physical aspects of the reconnaissance;

(c) intra-observer variability;

(d) inter-observer variability.

(a) The complexity of coral reefs

The structural complexity of coral reefs and the nature of their benthic communities result in a vast amount of information being received by the towed observer. Observers were required to integrate over small scale (10's of square meters) patchiness but to halt the tow after qualitative or major quantitative changes of a large scale. Differences between the observers in both the way they integrate and the way they subdivide the tows are a source of unquantified variability.

(b) The physical aspects of the reconnaissance

The sinuous nature of the tow path, the lateral limits of vision, and the observer's tendency to concentrate upon a single zone at a time results in the observation of only a sample of each zone. Furthermore, the relatively fast speed of the tow (about 1.5 knots) allows only a cursory look at each sample. These attributes of the methodology force the observer to overlook detail and attempt to assimilate and integrate within-zone units of tens of square meters, to arrive at his final scores. However, he is also required to recall the VDO's, which requires a certain amount of notice be taken of those individual colonies which collectively make the greatest visual impression.

(c) Intra-observer variability

An individual observer's results may be inconsistent over time. Observers almost always found data recall and integration extremely difficult on their initial training attempt at reconnaissance. However, the skills were generally learnt after a small number of tows.

Individuals tended to improve in their recognition of VDO's with increased experience. For example, they became aware of OTU's not previously recorded, or recorded at a lower level of resolution. Such inconsistencies were counteracted by using a data matrix reduced to a common lower level of resolution (see Results).

A further inconsistency exhibited by individual observers results from fatigue. It was found that two hours was the maximum time a team of two observers could sustain concentration, and so tow periods were generally limited to this time. Three tow periods of up to two hours each and separated by at least one hour could be completed daily. After a period of seven consecutive days, observers felt their accumulated fatigue and information overload was beginning to affect their performance. During winter tows, the physical stress caused by low sea temperatures tended to shorten effective working times.

(d) <u>Inter-observer variability</u>

The observation teams included people of varying background and coral reef experience; (those with little or no prior experience were given several familiarization tows before their data were used). Observers also differed in their interpretation of what constituted particular VDO's; this indicated deficiencies in training, and was counteracted in the present reconnaissance by use of the matrix reduced to a lower level of resolution.

Even given equal experience and understanding of the VDO's, and an identical tow path, individual estimates of area cover do vary. Kenchington (1978) found that individuals could be calibrated according to their tendency to under- or overestimate cover, but this calibration has not been done in the current study reconnaissance. Rather, a very conservative use of the data was made (viz. the reduction of graded cover data from a 7 to 4 point scale - see Results).

In assemblages where no clear dominants exist, individual perceptions of the most dominant benthos may also vary, *i.e.* two individuals viewing the same mixed assemblage may record different dominants. It is not possible at this stage to differentiate in all cases between real differences in the coral assemblages and simple observer inconsistencies. However, the good correlation between the identify of the diagnostic constants, for most of the site groups (Table 9) gives encouragement that this aspect of the reconnaissance is also of value.

SUMMARY AND CONCLUSION

The aims, methods and some results of the Capricornia reconnaissance programme are presented. The extent of interpretation and method of data presentation are dictated by the needs of reef managers and the impressionistic nature of reconnaissance data. An approach to the use of the reconnaissance data, and the sources of its variability, are discussed. Now it is necessary that the data be evaluated in a real reef management context, so decisions concerning the method's future use (as is, or in a modified form) may be made.

At the time of writing, two important aspects of the study remain to be completed. Firstly, although the computer mapping procedure described in detail in Appendix I was fully developed, the unavailability of the James Cook University plotter during late 1979 and early 1980 meant that the maps were not produced in time for inclusion with this report. With the plotter now functional, and the prepared data on the computer's archive, it will be a simple matter to produce a full set of maps.

Secondly, the treatment of VDO assemblage data was incomplete. It should be possible using the interpretation illustrated in Figure 11 to compile assemblage distribution maps for each reef. This may readily be done by selecting special symbolism in the plotting program, and assigning an appropriate 'assemblage type' code to each tow zone in the data file. This task was not attempted due to time limitations, but should be done for the sake of completeness.

I, like all participants, am enthusiastic about the overview which the method provides. I hope that the form of data presentation developed here appropriately represents the impression gained.

REFERENCES

Anon. 1975. Great Barrier Reef Marine Park Act 1975. Australian Government Act No. 85 of 1975, 28pp.

BAKER, J.T., 1977. Management of the Great Barrier Reef Marine Park. Proc. Third Int. Coral Reef Symp. (2), 598-603.

CONNELL, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science, 199: 1302-1310.

DONE, T.J. and PICHON, M. (in press). Zonation of coral assemblages. In: Barnes, D.J. (ed.) 'Growth, Maintenance and Control of Coral Reefs' (tentative title). Australian National University Press.

KENCHINGTON, R.A. and MORTON, B., 1976. Two Surveys of the Crown of Thorns Starfish over a Section of the Great Barrier Reef. Australian Government Publishing Service, Canberra, Australia. v and 187pp., illustr.

KENCHINGTON, R.A., 1978. Visual surveys of large areas of coral reefs. In, Stoddart, D.R. and Johannes, R.E. (eds.) 'Coral Reefs: Research Methods'. UNESCO, pp149-161.

MATHER, P. and BENNETT, I. (eds.) 1978. 'A Coral Reef Handbook.' Great Barrier Reef Committee, Handbook Series No. 1

MAXWELL, W.G.H., 1968. 'Atlas of the Great Barrier Reef'. Elsevier, Amsterdam, London and New York.

WISHART, D., 1978. Clustan user manual. Program Library Unit, Edinburgh University.

ZELL, L.D., 1980. A photographic guide to visually predominant benthos on the Great Barrier Reef. Great Barrier Reef Marine Park Authority - internal document.

APPENDIX I

INSTRUCTIONS FOR

MAPPING OF REEF BENTHOS RECONNAISSANCE DATA

AND

TABULATION OF DATA

by

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Appendix to a Report to the Great Barrier Reef Marine Park Authority, Part I

31st March 1980

CONTENTS

APPENDIX 1a

Instructions for the use of computer mapping programs with data collected by the Great Barrier Reef Marine Park Authority Staff and Associates.

INTRODUCTION

The CALFORM computer plotting program at James Cook University of North Queensland has been used to produce shaded conformant maps of the GBRMPA coral reef reconnaissance data for Bunker reefs. (The method supersedes the SYMAP procedures used to produce the Capricorn maps; see the consultancy to James Cook University, June to December, 1978).

The CALFORM manual (appended) describes a wide range of options and gives full details for running the program. The GBRMPA data require a standard set of options to represent the graded data relating to coral cover, aesthetics, diversity, etc. This paper describes a new program called CALSET, which

a. simplifies data preparation, and
b. selects standard options.

for multiple production of maps using CALFORM.

The following assumptions have been made

i. The field data are recorded on standard GBRMPA field data sheets (Figure A1);
ii. A reef outline with labelled paths (labels corresponding to the tow numbers in the data sheet) accompanies the field data;
iii. The reader is familiar with the CALFORM manual, part I;
iv. The reader is familiar with rudimentary file handling and editing on the James Cook University Computer.

Step by Step Instructions

1. Preparation of the field data

(a) Check that data sheets are filled in completely and placed in numerical order by tow number. Data for all reefs surveyed on the one trip are to be kept together.

(b) Data sheets are forwarded to James Cook University Administration Computer Service section for punching onto cards. Instructions for card punching are as follows:

i. each column on the data sheet requires two cards; the first includes site identifiers and all data down to and including 'Diversity' (*i.e.* cover data); the second includes site identifiers and all the VDO data.

ii. Instruct punch card operator that cover data and VDO data may be punched separately.

iii. Site identifiers are punched in the first positions of each card of both cover and VDO data. The format is shown in Figure A2.

iv. The formats of the actual data in the cover and VDO files are also shown in Figure A2.

v. Once cards have been punched and verified, they are submitted to the computer centre to be read. The two files are given the extensions .COV and .SPP for the cover and VDO data respectively. For example, the Bunker data are called BUNK.COV and BUNK.SPP.

vi. Once on the users area these files should be archived

. ARCH BUNK.COV, BUNK.SPP

(this command will delete the files from the users' area). The files can be retrieved using the command

.RETR BUNK.COV, BUNK.SPP

Retrieval may take several hours, so should be anticipated.

2. Preparation of source map

(a) The source map is to consist of an outline of the reef and any other important features such as islands, banks or knolls. (A tracing of the 5000' ASL colour series was used for the Bunker Reefs, but a smaller scale will be necessary for larger reefs). Superimposed over the outline is a stylized representation of the tow path, subdivided into the sections for which field data were recorded. On each section (or POLYGON in the CALFORM terminology, is noted the tow.site number (*i.e.* a decimal number consisting of tow number and site number as recorded on the field data sheet.

The computer maps can only be as good as the source map, so care is required in its compilation.

Two copies of the source map are required; dyeline copies of large maps can be made by JCU Buildings and Grounds section.

Figure A1

The field data sheet whose entries are punched according to the format indicated in Figure A2.

BENTHIC REEF SURVEY DATA SHEET MANTA TOWS

Reef Name ____________ No. [ ]

Observer Name ____________ No. [ ]

Date / /

Times :

Tow No. [ ]

Site Desc'n	reef top	reef crest				
Site No.	1	2				
Aesthetics, 1-6						
Slope, 0-6						
Substrate/Sediment: Mud						
Sand						
Gravel						
Stag Rubble						
Sm. Blocks <50cm						
Lg. Blocks >50cm						
Platform						
Depth, ft						
COVER: Hard Coral						
Soft Coral						
Dead Stand Hard Coral						
Macro Algae						
Colony Size, 1-3						
Diversity, 1-4						
V.D.O.'s						
Benthos Code with						
% hard coral, 1-6						
% soft coral, 1-6						
% other, 1-6						

Code	%
0	0
1	1-5
2	5-15
3	15-30
4	30-50
5	50-75
6	75-100

Figure A2

Required punching format for data recorded on field data sheet (see Figure A1). A copy of Figure 2 should be forwarded to the punchcard operators along with the completed field data sheets.

VDO DATA FORMAT

Reef No.
Tow No.
Zone No.
Observer No.
Year
Month
Day
Start time
VDO Code
Score
VDO Code
Score
VDO Code
Score
VDO Code
Score
VDO Code
Score
VDO Code
Score
VDO Code
Score
VDO Code
Score
VDO Code
Score

GRADED SCORE DATA FORMAT

Reef No.
Tow No.
Zone No.
Observer No.
Year
Month
Day
Start time
Aesthetics
Slope
Mud
Sand
Gravel
Stag rubble
Small blocks
Large blocks
Platform
Depth - min.
Depth - max.
Hard coral
Soft coral
Dead standing coral
Macro algae
Colony size
Diversity

(b) The co-ordinates of the reef outlines and polygons are recorded at points chosen by the user. The more points there are the smoother the map will be. Points defining the POLYGONS are marked on copy 1 of the source map; points defining reef, island and knoll outlines are marked on copy 2.

Up to 4,000 points are allowed by CALFORM: and each is to be individually numbered (although not all numbers need to be written on the map; see below).

Copy 1. Points 1 and 2 are reserved for reef name and attribute type, respectively, and numbered crosses should be marked on copy 1 at the position at which these legends are required to commence.

The remaining points are marked on the outline of the tow sites. The following convention must be followed:

THE NUMBERED POINTS MUST BE ARRANGED, AS FAR AS POSSIBLE, SEQUENTIALLY ALONG THE CONTOUR LINES WHICH DEFINE THE UPPER AND LOWER MARGINS OF EACH TOW SITE.

An example of the correct procedure is given in Figure A3a. Failure to follow this convention will make coding of the data unnecessarily laborious.

Copy 2. The first point entered on copy 2 is assigned the number immediately following the highest number on copy 1. Points are marked on the reef outline, island outline, etc.; include as many points as necessary to achieve the required detail. It has been found to be satisfactory to label only every fifth point on long sequences on readily visible lines. See Figure A3b.

3. Digitizing the source map

The co-ordinates of all the number points are digitized on the large digitizing table at AIMS using the following procedures:

(a) Tape copy 1 of the source map to the digitizing table;

(b) Run program TERRY and follow the instructions displayed;

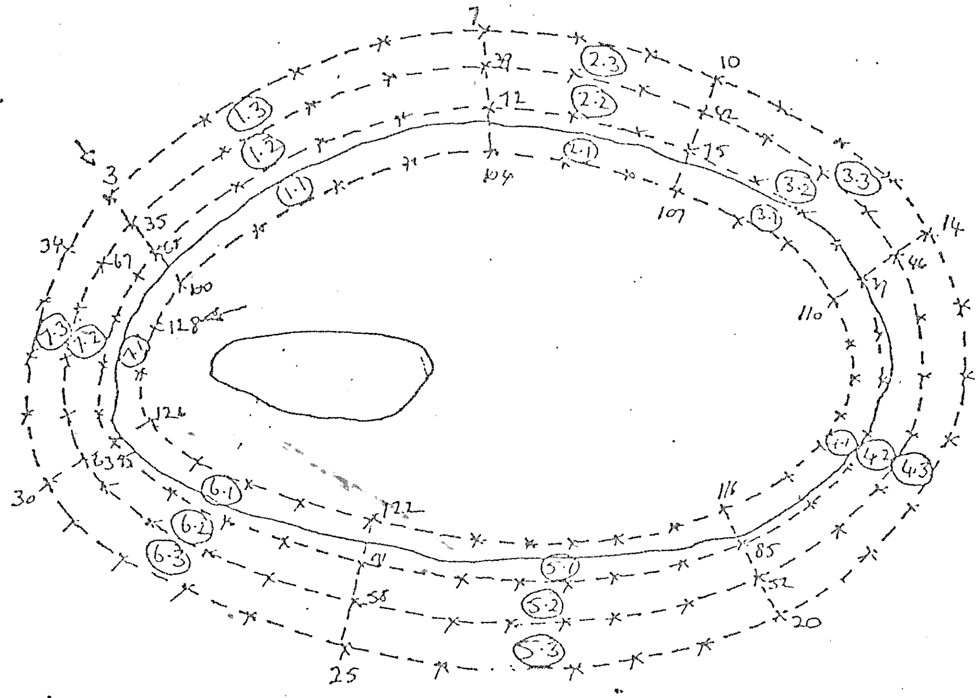
(c) Give the output file the name (reef no. 1.DIG) *e.g.* CB341.DIG;

Figure 3

a) Copy 1 of a hypothetical source map showing points used to define legend and title starting positions (points 1 and 2) and tow zones (points 3 - 128). The sequence of numbering should always follow along the 'contours' as shown. Numbers in each tow zone correspond with tow site number on data sheet.

b) Copy 2 of the hypothetical source map, showing how numbering sequence continues uninterrupted from copy 1.

a

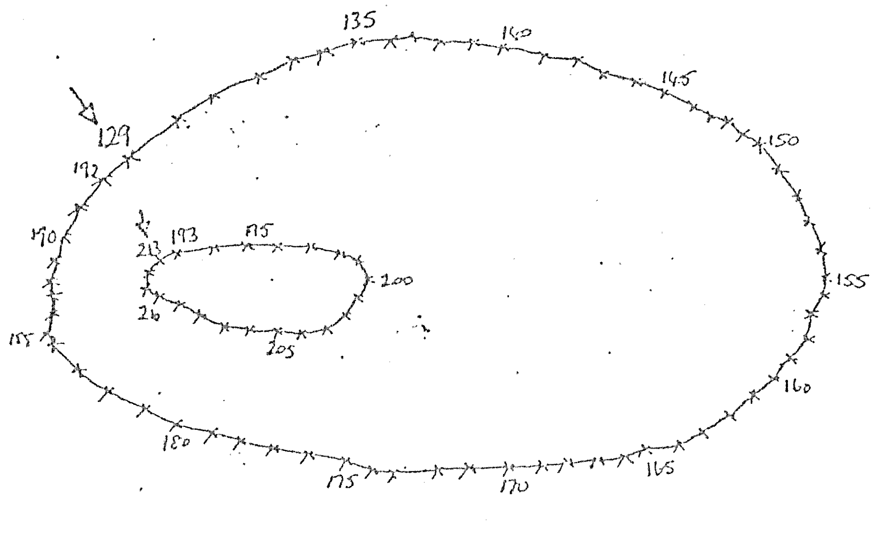


7
29
12
104
10
15
107
3
35
34
67
128
110
14
46
126
30
116
122
85
52
20
58
25
1.3
1.2
1.1
2.3
2.2
2.1
3.3
3.2
3.1
7.3
7.2
7.1
4.3
4.2
4.1
6.1
6.2
6.3
5.1
5.2
5.3

×1

×2

b



135
140
145
150
155
160
165
170
175
180
190
192
129
193
200
205

(d) Starting at point No. 1, touch each of the points in turn with electronic pen;

(e) Exit from the program as instructed;

(f) Tape copy 2 of the source map in exactly the same position as copy 1 (as near an exact overlay as possible);

(g) Give the output the name (reef no. 2.DIG) *e.g.* CB342.DIG;

(h) Starting at the lowest number, touch each of the points in turn;

(i) Exit from the program as instructed.

4. <u>Transfer of digitized map co-ordinates to James Cook System</u>

Data are transported on Floppy discs which can be read at J.C.U. Floppy discs can be obtained from the James Cook University Computer Centre.

(a) <u>At AIMS</u>
Run program FLOPPY to load data onto the floppy disc.

(b) <u>At JCU</u>
Hand over floppy disc to Mr Duce, Administration Computer Services, to have it read onto JCU system.

5. <u>Coding of the source map</u>

It is necessary to define the outlines of the POLYGONS, reefs, islands etc. in terms of the numbered points. Special CALSET coding forms (Figure A4) have been printed with a resumé of the following instructions included.

(a) Have a listing of the cover data file (*e.g.* BUNK.COV) at hand. Locate the data set for the required reef.

(b) Fill in the CALSET coding form for POLYGONS as follows:
   i. Enter the reef identifying code (*e.g.* CB34) and name (*e.g.* Hoskyn) in the spaces indicated at top of form;
   ii. Locate on copy 1 of the Source Map the POLYGON with the first tow.site number listed in the cover data file. Enter the tow.site number right justified in column 1 - 4 on coding sheet;

Figure A4

A coding form completed by the user to define tow zone outlines, legends, titles and outlines of reefs, islands, etc. The detailed rules for using the form are included in the text.

CALSET CODING FORM

TJD-11/79

TO BE USED FOR CODING 'POLYGONS' AND 'LINES'

PAGE OF

REEF ID: USE (=FILE NAME) REEF NAME: SURVEY DATE

Instructions

a) POLYGONS: Enter decimal tow-site no. in cols 1-4; enter pairwise 'POINTS' to define sequence; if no sequence leave 2nd position blank; close polygon by '9999' in first posn. of pair after last POINT entered. Enter 'END' in cols 1-3 after last POLYGON defined.

b) LINES: Enter pairwise points to define sequence: after last LINE defined, enter 'END' in cols 1-3.

c) Enter POLYGONS data first and immediately follow by LINES data.

iii. Define its shape in terms of the points on its outline.

- consecutive sequences such as 34 35 36 37 38 should be abbreviated 34 - 38.
- If no consequentive sequence exists, the number should be entered to the left of a dash on the coding sheet, NEVER the right.
- It is not necessary to close the POLYGON by repeating the first number.
- When coding of the POLYGON is complete, write 9999 to left of next dash, (never to the right).
- Locate the next numbered tow site from the cover file and repeat from (b) iii.
- When last POLYGON has been defined, write END in columns 1 - 3 of the next line.

(c) Continue filling in CALSET coding form for reef outline and other features as follows:
(remember to enter reef number and name and page number at top of each coding form used).

- Leave columns 1 - 4 blank.
- Define outlines; the conventions are the same as for POLYGONS, except;
  it is necessary to repeat the first number to obtain a closed outline, and;
  it is not required that the four 9's be inserted at the end of an outline.
- More than one line of the coding form may be used if necessary.
- A maximum of 100 points are allowed for any one line or outline, so it will sometimes be necessary to break long reef outlines into sections of 100 or fewer points.
- Write END in columns 1 - 3 when all outlines have been defined.

6. Punching POLYGON and Outline Data

The CALSET coding forms are to be handed to punchcard operators for punching and verifying.

(a) Each reef's data is to be punched as a separate file, the name of which is indicated on the top of each coding form as (reef no.USE) *e.g.* CB34.USE. The names of all the files should be listed on the job form submitted with the work.

(b) The cards are submitted to the computer centre for reading as separate files.

7. Checking of data before map production

It is vital that the following check of data be made before map production:

(a) Obtain a listing of the cover data file (*e.g.* BUNK.COV);

(b) Obtain a listing of the user file for the reef involved (*e.g.* CB34.USE);

(c) Check that the order of the tow.site numbers on .COV file is identical to the order on the .USE file.

(d) If there is a disparity, it will be necessary either to define extra POLYGONS or delete lines of .COV data, using an editing program.

(e) Once disparities are removed, a trial run of the data is advised.

8. Trial run

It is recommended that a trial run be made to produce a single map with outlines only and no shading.

(a) Run the sequence of programs as indicated in the anotated example below, but:
   i. request only 1 map (see 8(c) iii) in anotated example;
   ii. edit the output from CALSET (*i.e.* FOR21.DAT) as follows:
      . delete all lines between, but excluding 'VALUES' and the next 'END';
      .. delete the 'X' from the MAP line.

(b) Run CALFORM on this edited file and plot the map (steps 10 - 14 in anotated example).

9. Production of shaded maps

The trial run will indicate if errors in coding of polygons and outlines have occurred. Once these have been eliminated, a production run can be made. The procedure for producing maps of aesthetics, hard coral cover, soft coral cover and dead coral cover in a single run is shown in the anotated example. The choice of other attributes is shown in 8(c) iii).

10. Conclusion

The quality of map output by this method depends on the quality of the source map and the distance between POINTS used to define POLYGONS and outlines. Variations in the standard shading options may be made by simple adjustments to the CALSET program and users are referred to the author (T. Done) if changes of this type are desired.

Example Run for Production of Maps Using CALFORM

```
1.)  .COP FOR22.DAT=CB341.DIG,CB342.DIG
     .EX DIVAD
2.a) LINK:   Loading
     [LNKXCT DIVAD Execution]

  b) %FRSDAT Illegal character in data [   ]
     Unit=22 DSK:FOR22.DAT<057>/ACCESS=SEQINOU/MODE=ASCII
     (I6,2F7.0)

  c)       160     1528     1632
           161     1215     1392
           162      888     1164
           163      662     1073
           164      524     1048
           165      343     1073
           166      159     1164
           167       60     1305
           168       17     1452
           169      115     1671
           170      250     1838
           171      375     2041
           172      602     2262
           173      819     2474
           174      944     2704
           175
     ^

     Name       (Loc)      <<----   Caller    (Loc)      <#Args> [Arg Types]
     IOLST.     (404132) <<----   MAIN.+6(157)      <#0>      []

     ? Job aborted

     END OF EXECUTION
     CPU TIME: 2.05   ELAPSED TIME: 27.82
     EXIT

3.)  .ED FOR22.DAT
           1      499      160
  a) *L / 160 /
         160     1528     1632
  b) *U

  c) *DEL
         160     1528     1632
  d) *B
  e)
  f) *DEL
     ***END
  g) *FI
     [EDIFIL Filed : DSKA:FOR22.DAT]

4.)  .EX DIVAD
     LINK:   Loading
     [LNKXCT DIVAD Execution]

     STOP

     END OF EXECUTION
     CPU TIME: 1.88   ELAPSED TIME: 11.74
     EXIT
```

Instructions for Production of Maps using CALFORM

(To be read in conjunction with 'Example Run')

1. Copy the two .DIG files onto FOR22.DAT, which is the input file for DIVAD

2. a) Execute program DIVAD

   This first run of program DIVAD will discover end of file characters which are inserted by the AIMS system, but which are 'blank errors' to the JCU system

   b) The error is signalled - it appears as a blank inside the square brackets

   c) The blank error is on the line preceding the line containing, in this example, 160 1528 1632 in file FOR22.DAT.

   We also know a similar 'blank error' has been inserted by the AIMS system as the last line of FOR22.DAT.

3. Edit FOR22.DAT to eliminate these 'blank errors'

   a) Locate the line containing, in this example, 160 1528 1632

   b) go up to the line above

   c) delete

   d) go to the bottom line of the file

   e) bottom line appears blank, but contains a 'blank error'

   f) delete this bottom blank line

   g) exit from the editor by typing FI

4. Execute program DIVAD

   This time, the program will convert the digitized map data into centimeters recorded in an appropriate format for the following steps. The output from DIVAD is in FORØ1.DAT

```
5.  .ED FOR01.DAT
              1       10.99        7.60
b)  *L /_/
)   ***END
)   *^C

6.  .COP FOR20.DAT=CB34.USE


7.  .COP FOR02.DAT=BUNKR.COV

8.  .ED FOR20.DAT
     1.3          122- 121  123-        150-        152- 151 9999-
a)  *T
    ***TOP
)   *I
    Input:
       34                   HOSKYN ISLAND REEF
c)     15

e)  *FI
    [EDIFIL Filed : DSKA:FOR20.DAT]

9.  .EX CALSET
    LINK:   Loading
    [LNKXCT CALSET Execution]

         1
         2
    STOP

    END OF EXECUTION
    CPU TIME: 9.68  ELAPSED TIME: 44.92
    EXIT


10. .COP CALFOR.DAT=FOR21.DAT
```

5. It is necessary to examine FORØ1.DAT to ensure there are no negative co-ordinates, as these are unacceptable to the programs to follow: EDIT is used to check the file for negative signs.

a) Load FORØ1.DAT onto the editing program.

b) Locate the character '-' (i.e. negative sign)

c) This reply indicates the editor has reached the end of the file without finding any negative data, so

d) exit from EDIT using 'control C'

NOTE a) Should negative data occur in FORØ1.DAT, it will be necessary to find the greatest absolute negative value for both x and y co-ordinates, and then adjust program DIVAD so that all x and y values have a number added such that the smallest is positive. Once this has been done, repeat steps 4. and 5. which will remove all negative data, and confirm their absence, respectively..

b) Once FORØ1.DAT is free of negative data, it becomes input for the next program - CALSET

6. Copy the .USE file into FOR2Ø.DAT

7. Copy the field cover data into FORØ2.DAT. The program will select only data for the specified reef, so the entire data file can be copied into FORØ2.DAT

8. Use EDIT to insert records 1 and 2 onto top of FOR2Ø.DAT

a) go to top of file

b) input command

c) Record 1

i) type 'reef number', right justified in columns 1-5

ii) either - leave 15 blank spaces to obtain 'default option', maps (as in example)

i.e. aesthetics (attribute No. 1)
hard coral cover (attribute No. 2)
soft coral cover (attribute No. 3)
dead coral cover (attribute No. 4)

or insert the number of any required attribute in columns 8, 11, 14 and 17.

The remaining attributes are:

macroscopic algae (attribute No. 5)
colony size (attribute No. 6)
diversity (attribute No. 7)

If less than four maps are required, type '99' to end in column 11, 14 or 17, which ever immediately follows the last map specified.

iii) Starting column 21, type in any text which identifies the series of maps produced.

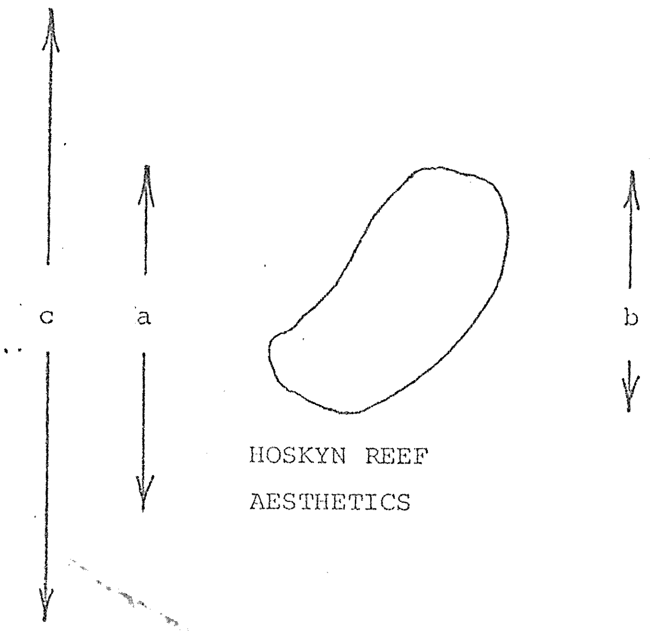
Example of a run to obtain algae, size and diversity maps.

```
...34..5..6..7.99...HOSKYN IS REEF
```

d) Record 2

Type in free format, the height of the source map, in inches (to nearest inch). This figure is used to calculate the scale of factor to produce a map and legends of total height 10 inches. The following should be noted.

i) This height should include the legends as well as the map itself i.e. distance a, not b.



If the legends are not accounted for an error will usually result.

ii) A small map may be output by exaggerating this figure as required (e.g. distance c). Thus, for a map plus legends height of 5 inches, distance c should be double distance a.

e) Close the file using command FI

9. Execute program CALSET, which, providing there are no errors in the input data so far, will set up the input deck for CALFORM using standard shading options.

10. The output from CALSET is called FOR21.DAT. It is copied to a file called CALFOR.DAT, which is the required name for the CALFORM input file. This command will overwrite any data already in CALFORM.DAT

```
11. .RU CALFOR

a)  POI
    POL
    FAC
    VAL
   *MAP
    LIN
    LEG
    TIT
    ADV
    FAC
    VAL
   *MAP
    LIN
    LEG
    TIT
    ADV
    FAC
    VAL
   *MAP
    LIN
    LEG
    TIT
    ADV
    FAC
    VAL
   *MAP
    LIN
    LEG
    TIT
    ADV
  **FIN

    PLOTS PRODUCED THIS RUN

b {      CAL40.PLT
         CAL41.PLT
         CAL42.PLT
         CAL43.PLT
    CALFORM PACKAGE - END OF RUN

    END OF EXECUTION
    CPU TIME: 42.05 ELAPSED TIME: 3:19.74
    EXIT


12  .REN CB34*.PLT=CAL*.PLT
    Files renamed:
    CAL40.PLT
    CAL41.PLT
    CAL42.PLT
    CAL43.PLT

13  .DIR CB34*.PLT

    CB340   PLT    19  <057>   17-Dec-79    DSKA:   [6365,6365]
    CB341   PLT    21  <057>   17-Dec-79
    CB342   PLT    16  <057>   17-Dec-79
    CB343   PLT    19  <057>   17-Dec-79
      Total of 75 blocks in 4 files on DSKA: [6365,6365]
```

11. This is the command to run the CALFORM program

a) In the example, the program responds by printing out the first three letters of each procedure reached. Note that four maps (marked by *) were produced, since the default option (of four maps) had been requested (see 8. c) ii) above) Note also that the FINISH command (marked by **) was reached.

If the specified number of maps were not produced, or FINISH not reached, there has been an error in running. The nature of this error can be ascertained by typing TY CALOUT.DAT which is the output file for CALFORM. Adjustments to the data can be made on the basis of the error message therein (see also the CALFORM manual if necessary).

b) In a successful run, the plots will always have these names. These should be renamed immediately as shown in 12.

12. This command renames the plot. Note that the first four characters 'CB34' are the reef code for Hoskyn Reef; choose the appropriate reef code in each case.

13. This command confirms that the plot files have been renamed, and shows their new names.

14. .PLOT CR340.PLT
Total of 19 blocks in 1 file in PLT request

15. .ARCH CR34*.PLT
ARCHIV CR34*.PLT=CR34*.PLT
Total of 3 files, 56 blocks processed by ARCHIV.

16. .PRINT CALOUT.DAT
Total of 112 blocks in 1 file in LPT request

14. The first of these plot files is plotted using this command (and is automatically deleted from the user's area).

15. All remaining plot files of the form CB34*.PLT are archived and removed from the user's area.

Once the plot requested in 14 has been examined and found satisfactory, the plot files from the archives may be retrieved as follows:

.RETR CB34*.PLT

This may take several hours, so should be anticipated. Once on the users area these files may be plotted using the command

.PLOT CB34*.PLT

Note that this command will delete the files from the user's area.

16. This command prints the output file, which should be checked for warning or error messages which are explained in the CALFORM Manual, but which should, by this stage, be non-existant.

Repeat Runs

a) For extra attributes on the same reef

Edit the first line of FOR20.DAT to indicate the required attributes (see step 8, above) and continue from step 9 to 11. Rename the plot files to names which are different to earlier renamed files for this reef.

b) For new reefs

Start from step 1, and follow to 16. However, if field-data are on same file as the previous run, there is no need to do step 7.

APPENDIX Ib

Instructions for Production of Tables Summarizing the Attribute Scores on Groups of Reefs

EXAMPLE RUN OF ATTAB1

```
1  COP FOR01.DAT=CBALL.RAW

2  .EX REF
   LINK:   Loading
   [LNKXCT REF Execution]

   STOP

   END OF EXECUTION
   CPU TIME: 0.93  ELAPSED TIME: 1.42
   EXIT

3  .COP FOR01.DAT=FOR02.DAT,BUNKR.COV

4  .COP FOR02.DAT=RENOS.CAP

5  .EX ATTAB1
   LINK:   Loading
   [LNKXCT ATTAB1 Execution]

6  ENTER REEF NO. OF FIRST REEF.
   1

   [SRTXPN Expanding to 55P+15P]

   [SRTXPN Expanding to 55P+15P]

   [SRTXPN Expanding to 55P+15P]

7  [SRTXPN Expanding to 55P+15P]

   [SRTXPN Expanding to 55P+15P]

   [SRTXPN Expanding to 55P+15P]

   [SRTXPN Expanding to 55P+15P]
   STOP

   END OF EXECUTION
   CPU TIME: 4.23  ELAPSED TIME: 17.06
   EXIT

8  .REN ATT7.DAT=FOR07.DAT
   Files renamed:
   FOR07.DAT

9  .PRI ATT7.DAT/FORMS:PLAIN/DI:R
   Total of 27 blocks in 1 file in LPT request
```

Instructions for Production of Tables Summarizing the Attribute Scores on Groups of Reefs

PROGRAMS ATTAB1 AND ATTAB2

(to be read in conjunction with 'Example Run ')

1. Copy the CBALL.RAW data into FORØ1.DAT

2. Execute REF, which puts CBALL.RAW into the same format as BUNKR.COV

3. Copy the two files FORØ2.DAT (which is the reformated output of CBALL.RAW) and BUNKR.COV into FORØ1.DAT

4. Copy the file of reef numbers and names into FORØ2.DAT

5. Execute ATTAB1 (or ATTAB2)
   ATTAB1 tabulates all attributes in a 7 column table
   ATTAB2 tabulates the 7 grade attributes on a 4 point scale

6. Input the reef number of the first reef in file FORØ1.DAT

7. This output shows program is running correctly

8. Rename FORØ7.DAT (the output file) to a more logical name (optional)

9. Print the output tables on plain paper and delete it from the area.

APPENDIX II

Summary of raw data. Reefs are ranked in order of decreasing average attribute score. The number of records (*i.e.* tow zones) and the proportion of scores of 0, 1, 2, 3, 4, 5 and 6 are indicated. Attributes summarised are aesthetics, and cover of hard, soft and dead standing coral, and macroscopic algae. Raw data for colony size and OTU diversity are as in Tables 3f and 3g.

AESTHETICS

REEF	NO. RECS.	AVE. SCR.	6	5	4	3	2	1	0
WILSON ISLAND REEF	10	3.7	0.10	0.10	0.20	0.60			
NORTH WEST ISLAND REEF	33	3.4	0.03	0.24	0.27	0.15	0.18	0.09	0.03
TRYON ISLAND REEF	15	3.4		0.13	0.33	0.40	0.27	0.07	
SYKES REEF	21	3.1		0.10	0.24	0.43	0.14	0.10	
ONE TREE ISLAND REEF	46	3.1		0.11	0.28	0.30	0.24	0.07	
FAIRFAX ISLANDS REEF	40	3.1	0.02	0.13	0.35	0.15	0.15	0.20	
MASTHEAD ISLAND REEF	24	3.0	0.04	0.08	0.21	0.29	0.25	0.13	
FITZROY REEF	96	3.0	0.02	0.08	0.25	0.28	0.23	0.14	
LLEWELLYN REEF	71	3.0		0.13	0.23	0.24	0.15	0.24	
WISTARI REEF	29	2.8	0.03	0.03	0.31	0.21	0.21	0.24	
POLMAISE REEF	16	2.8		0.13	0.25	0.06	0.38	0.19	
LADY ELLIOTT ISLAND REEF	19	2.8	0.05	0.05	0.32	0.16	0.11	0.32	
HERON ISLAND REEF	88	2.7	0.01	0.07	0.19	0.22	0.31	0.18	0.01
BROOMFIELD REEF	25	2.7		0.12	0.20	0.08	0.44	0.16	
LAMONT REEF	27	2.6		0.07	0.19	0.26	0.19	0.30	
BOULT REEF	81	2.6	0.02	0.09	0.17	0.20	0.31	0.22	
LADY MUSGRAVE ISLAND REEF	85	2.6		0.11	0.18	0.22	0.18	0.32	
NORTH REEF ISLAND REEF	21	2.5			0.14	0.33	0.43	0.10	
HOSKYN ISLANDS REEF	27	2.3			0.22	0.19	0.26	0.33	
WRECK ISLAND REEF	18	2.2			0.11	0.11	0.61	0.17	
ERSKINE ISLAND REEF	24	2.1			0.17	0.21	0.21	0.42	

HARD CORAL

REEF	NO. RECS.	AVE. SCR.	6	5	4	3	2	1	0
MASTHEAD ISLAND REEF	24	4.3		0.38	0.50	0.13			
NORTH WEST ISLAND REEF	33	4.1	0.12	0.36	0.24	0.12	0.09		0.06
FAIRFAX ISLANDS REEF	40	4.1	0.30	0.32	0.05	0.08	0.08	0.13	0.05
WISTARI REEF	29	4.0	0.17	0.38	0.07	0.10	0.21	0.07	
SYKES REEF	21	4.0	0.19	0.24	0.29	0.14	0.05	0.05	0.05
LLEWELLYN REEF	71	4.0	0.24	0.28	0.13	0.13	0.11	0.04	0.07
WILSON ISLAND REEF	10	3.8		0.40	0.20	0.20	0.20		
TRYON ISLAND REEF	15	3.8	0.07	0.40	0.13	0.13	0.20	0.07	
BROOMFIELD REEF	25	3.6	0.08	0.32	0.12	0.20	0.20	0.04	0.04
HOSKYN ISLANDS REEF	27	3.6	0.22	0.11	0.30	0.07	0.07	0.19	0.04
ONE TREE ISLAND REEF	46	3.5		0.28	0.35	0.13	0.11	0.13	
HERON ISLAND REEF	88	3.4	0.10	0.16	0.25	0.20	0.13	0.10	0.06
FITZROY REEF	96	3.4	0.10	0.24	0.18	0.16	0.16	0.07	0.10
BOULT REEF	81	3.4	0.22	0.11	0.15	0.17	0.15	0.10	0.10
LADY ELLIOTT ISLAND REEF	19	3.4	0.16	0.21	0.16	0.16	0.05	0.21	0.05
LAMONT REEF	27	3.3		0.30	0.11	0.30	0.07	0.07	0.11
LADY MUSGRAVE ISLAND REEF	85	3.3	0.13	0.24	0.13	0.15	0.14	0.12	0.09
WRECK ISLAND REEF	18	3.2		0.28	0.17	0.28	0.11	0.06	0.11
NORTH REEF ISLAND REEF	21	2.9		0.14	0.10	0.48	0.10	0.19	
POLMAISE REEF	16	2.7	0.13	0.19	0.06	0.13		0.38	0.13
ERSKINE ISLAND REEF	24	2.7		0.21	0.21	0.04	0.29	0.08	0.17

SOFT CORAL

REEF	NO. RECS.	AVE. SCR.	6	5	4	3	2	1	0
MASTHEAD ISLAND REEF	24	3.1		0.08	0.33	0.29	0.17	0.13	
WILSON ISLAND REEF	10	2.9		0.10		0.60	0.30		
ERSKINE ISLAND REEF	24	2.3		0.08	0.21	0.17	0.28	0.33	0.13
NORTH WEST ISLAND REEF	33	2.2		0.09	0.12	0.18	0.15	0.36	0.09
TRYON ISLAND REEF	15	2.1		0.07	0.13	0.13	0.13	0.53	
SYKES REEF	21	1.9				0.19	0.62	0.10	0.10
WRECK ISLAND REEF	18	1.9		0.06		0.33	0.22	0.22	0.17
WISTARI REEF	29	1.8			0.07	0.24	0.34	0.10	0.24
BROOMFIELD REEF	25	1.8		0.04	0.16	0.04	0.32	0.20	0.24
NORTH REEF ISLAND REEF	21	1.7			0.14	0.14	0.05	0.62	0.05
ONE TREE ISLAND REEF	46	1.4		0.02		0.15	0.24	0.33	0.26
LLEWELLYN REEF	71	1.4		0.03	0.13	0.06	0.18	0.23	0.38
POLMAISE REEF	16	1.3		0.06		0.06	0.19	0.44	0.25
LAMONT REEF	27	1.0				0.04	0.19	0.48	0.30
FITZROY REEF	96	1.0	0.01	0.02	0.02	0.05	0.15	0.27	0.48
FAIRFAX ISLANDS REEF	40	1.0			0.02	0.13	0.15	0.27	0.43
HERON ISLAND REEF	88	.9				0.08	0.18	0.34	0.40
LADY MUSGRAVE ISLAND REEF	85	.9			0.01	0.07	0.13	0.34	0.45
LADY ELLIOTT ISLAND REEF	19	.7				0.05	0.11	0.32	0.53
BOULT REEF	81	.6		0.01	0.02	0.04	0.05	0.25	0.63
HOSKYN ISLANDS REEF	27	.6			0.04		0.27	0.30	0.59

DEAD CORAL

REEF	NO. RECS.	AVE. SCR.	6	5	4	3	2	1	0
LADY MUSGRAVE ISLAND REEF	85	.9			0.04	0.11	0.12	0.21	0.53
FITZROY REEF	96	.8			0.01	0.14	0.08	0.23	0.54
LLEWELLYN REEF	71	.7			0.06	0.03	0.13	0.15	0.63
BOULT REEF	81	.6			0.02	0.04	0.11	0.17	0.65
HERON ISLAND REEF	88	.5			0.03	0.02	0.07	0.13	0.75
POLMAISE REEF	16	.5					0.19	0.13	0.69
MASTHEAD ISLAND REEF	24	.5			0.04	0.04		0.21	0.71
ERSKINE ISLAND REEF	24	.5				0.04	0.04	0.29	0.63
HOSKYN ISLANDS REEF	27	.5				0.07	0.07	0.15	0.70
FAIRFAX ISLANDS REEF	40	.5					0.08	0.38	0.55
WRECK ISLAND REEF	18	.4				0.11		0.06	0.83
WISTARI REEF	29	.3					0.03	0.28	0.69
ONE TREE ISLAND REEF	46	.3				0.02	0.07	0.07	0.85
WILSON ISLAND REEF	10	.3					0.10	0.10	0.80
LADY ELLIOTT ISLAND REEF	19	.3					0.11	0.11	0.79
NORTH WEST ISLAND REEF	33	.2					0.03	0.15	0.82
SYKES REEF	21	.1						0.14	0.86
NORTH REEF ISLAND REEF	21	0.0						0.05	0.95
TRYON ISLAND REEF	15	0.0							1.00
BROOMFIELD REEF	25	0.0							1.00
LAMONT REEF	27	0.0						0.04	0.96

MACRO ALGAE

REEF	NO. RECS.	AVE. SCR.	6	5	4	3	2	1	0
POLMAISE REEF	16	3.3	0.38	0.13			0.13	0.13	0.25
ERSKINE ISLAND REEF	24	1.4	0.04		0.04	0.08	0.17	0.38	0.29
NORTH REEF ISLAND REEF	21	1.4		0.05	0.10		0.24	0.29	0.33
NORTH WEST ISLAND REEF	33	1.2		0.03	0.06		0.18	0.39	0.33
MASTHEAD ISLAND REEF	24	1.2			0.08	0.08	0.21	0.17	0.46
BROOMFIELD REEF	25	1.1			0.04	0.04	0.24	0.32	0.36
TRYON ISLAND REEF	15	.9				0.13	0.13	0.20	0.53
LLEWELLYN REEF	71	.9		0.03			0.11	0.51	0.35
HOSKYN ISLANDS REEF	27	.8			0.04	0.07	0.11	0.19	0.59
ONE TREE ISLAND REEF	46	.7			0.02		0.27	0.46	0.46
WRECK ISLAND REEF	18	.7					0.06	0.56	0.39
WILSON ISLAND REEF	10	.7						0.70	0.30
HERON ISLAND REEF	88	.6				0.03	0.10	0.32	0.55
WISTARI REEF	29	.6					0.23	0.52	0.45
LAMONT REEF	27	.6		0.04		0.04	0.07	0.11	0.74
FAIRFAX ISLANDS REEF	40	.6		0.02	0.02	0.05	0.02	0.22	0.65
BOULT REEF	81	.5			0.01		0.11	0.26	0.62
LADY MUSGRAVE ISLAND REEF	85	.5		0.01	0.01		0.05	0.28	0.65
LADY ELLIOTT ISLAND REEF	19	.5				0.11		0.16	0.74
SYKES REEF	21	.4					0.05	0.29	0.67
FITZROY REEF	96	.1					0.21	0.13	0.86

CLOSE RANGE PHOTOGRAMMETRY FOR TIME SERIES STUDIES OF REEF CORAL COMMUNITIES

by

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A Report to the Great Barrier Reef Marine Park Authority

Part II

31st March, 1980

CONTENTS

FOREWORD

This paper is Part II of a report to the Great Barrier Reef Marine Park Authority. It relates the status of a photogrammetric monitoring programme partly developed during the course of the project "Study for Development and Refinement of Coral Baseline and Monitoring Methodology".

The author gratefully acknowledges the support of the Great Barrier Reef Marine Park Authority for funding the project from March 1979 to March 1980. Thanks also to Professor Cyril Burdon-Jones who provided facilities and support at James Cook University of North Queensland, and Richard Kenchington, who assisted the study in numerous ways.

INTRODUCTION

The Great Barrier Reef Marine Park Authority has a need for two types of basic biological data. The first is baseline data relating to the condition of coral communities on particular reefs at a point in time. The second is time series data to indicate the types and rates of change which might occur in these communities. The Authority's 'benthos reconnaissance programme' is considered in an accompanying report. This report deals with a photogrammetric benthos monitoring technique developed by the author with the support, in the latter stages, of the Authority.

Ecological systems composed of mixed populations of organisms have an inherent propensity for change. The concepts of ecological equilibrium and non-equilibrium evolved from the observation that some living communities maintain a more or less constant species composition through time, and others undergo a succession in which species composition and/or numerical relationships change through time.

Coral reef ecologists have proposed various equilibrium and non-equilibrium hypotheses to account for observations of change in reef coral communities (see Connell, 1978, for a review). Coral reef managers, in particular the Great Barrier Reef Marine Park Authority, have a practical interest in the phenomenon of change in reef coral communities; they are likely, for example, to be called upon to make decisions regarding the useage of reefs in the light of change which may take place in the communities due to disturbance by man (through over use, pollution, etc.) or natural sources (*e.g.* cyclones, sedimentation). Decisions of this type will require an understanding of baseline conditions, including natural rates of change in coral community structure.

Traditional methods for documenting coral community structure usually involve the use of line transects (*e.g.* Loya, 1972; Porter, 1972) or quadrats (see Scheer, 1978). They provide useful ecological data, but are extremely demanding of labour and expertise. Time series photography of permanently marked sites provides a less demanding method for documenting change in reef coral communities. Connell (1973) and Pearson (1974) used this approach, the former as a primary data source, the latter as an adjunct to detailed field measurements of colonies. Porter (pers.comm.) has used time series photography of coral plots to illustrate changes associated with storm damage. Laxton (1976) has developed a close range rig for monitoring change in sewerage polluted benthos. Other workers have used photography in primary survey of coral communities (*e.g.* Laxton and Stablum, 1974; Drew, 1977).

All the above workers have used single camera systems in which an index of coral cover is derived from the area of the image on the photograph. Scale objects are generally placed in the field of view, and the photography position standardized as far as possible on each occasion. Even given identical relocation of the camera, the single camera method suffers from two major shortcomings. The first is a scaling problem; the photographic image of an object will vary in size depending upon the object's distance from the camera. This can be a major source of error in close range photogrammetry of this type. The second shortcoming is due to the limits of photographic resolution; there are frequently insurrmountable difficultues in precisely identifying species from their photographic image. These problems may be circumvented in studies (*e.g.* Connell, 1973) where distances of colonies from the camera are rather constant and corals are identified in the field.

The object of the current study was to develop a methodology capable of documenting and quantifying change in a great diversity of reef habitats, including weather and lee slopes at various depths, and reef top habitats. The photographic method provides a means by which a large number of permanently marked sites can be periodically monitored. A stereoscopic camera system is used which, by its geometry, provides a means of estimating the distance of each colony from the camera (and hence, its scale). Its superior image resolution, allows an acceptable level of taxonomic resolution to be achieved by stereoscopic viewing of the photographs. Other shallow water diver-operated systems have been reported by Lundälv, 1976 and Fryer *et al.* 1979).

METHODS

The camera system

The camera system consists of two Nikonos III cameras mounted side by side on a frame with their optical axes parellel to each other (see Figure 1). Each camera has a National PE326 electronic flash in a housing mounted beneath it. The cameras are triggered within about .1

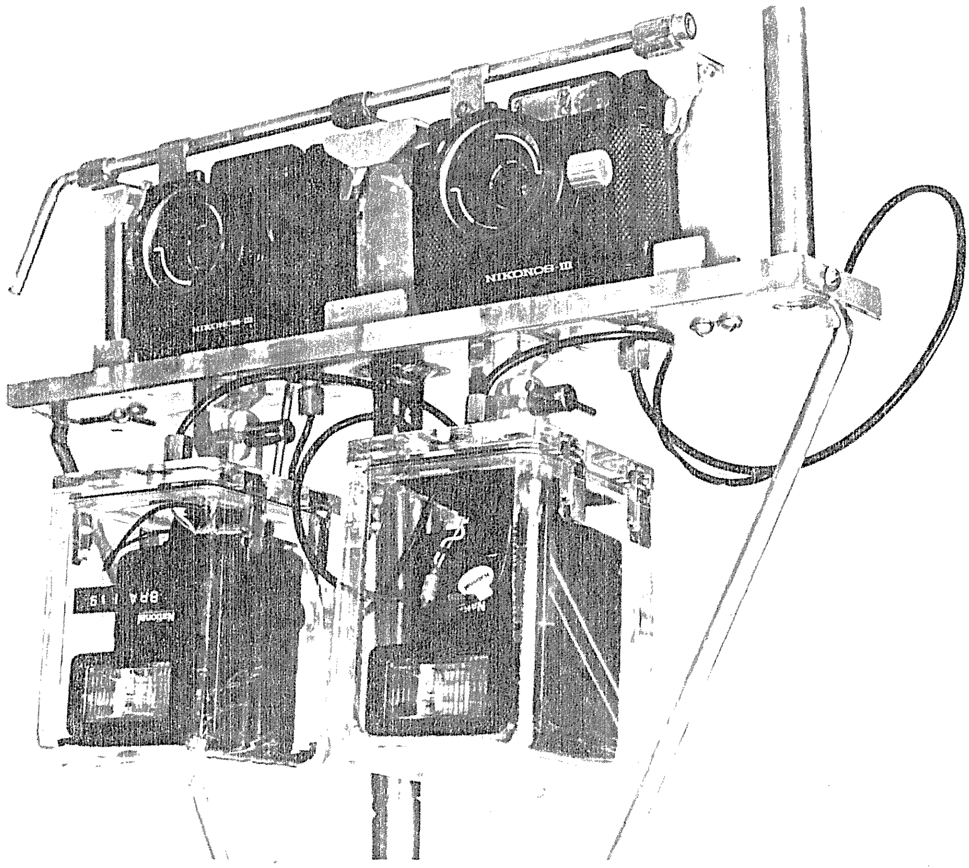
FIGURE 1

a) Upper part of stereophotography apparatus. Cameras are bolted to base plate and aligned parallel with each other. They are triggered by a synchronizing bar; each fires its own flash.

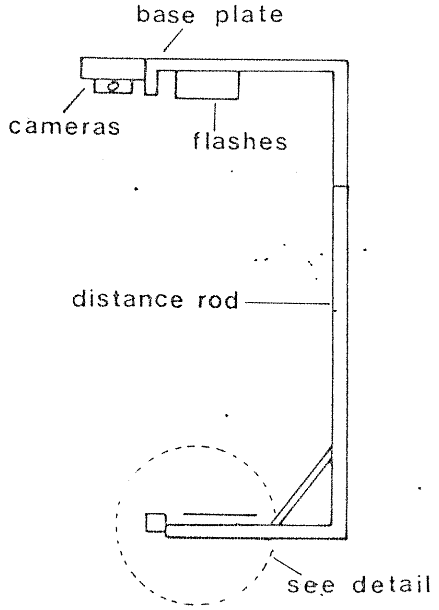
b) Diagram of side view of apparatus showing distance rod and extension in place.

c) Detail of spirit levels and name plate (plan view).

a



b


base plate
cameras
flashes
distance rod
see detail

c

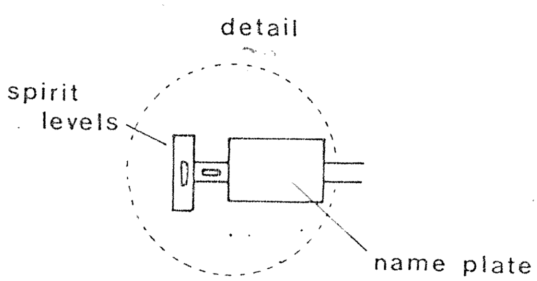
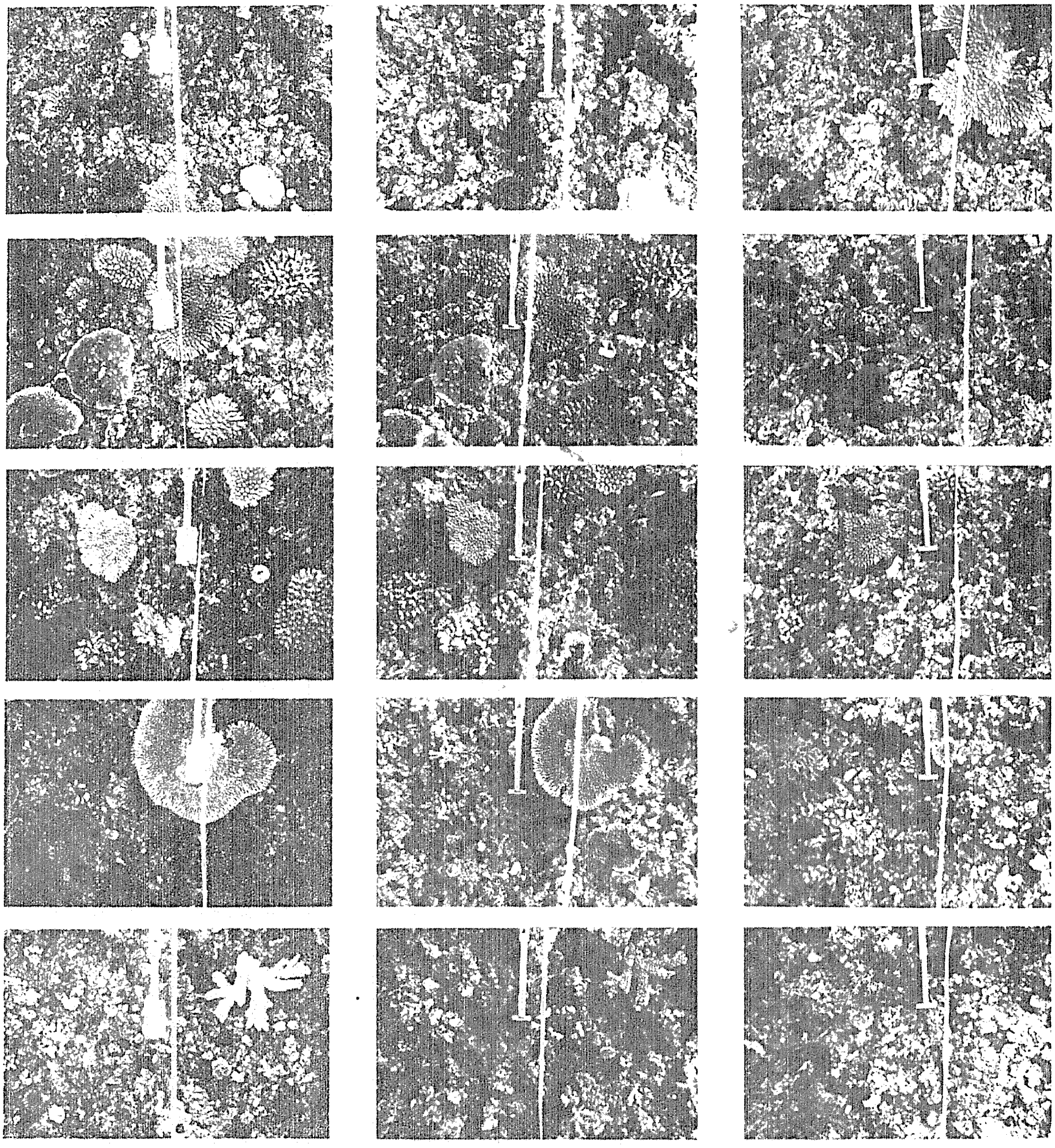

detail
spirit levels
name plate

FIGURE 2

Part of line transect A1T1 at John Brewer Reef. Photographs are centered on 3, 4, 5, 6 and 7 meter marks of line transects.

left	-	October, 1976
middle	-	April, 1979
right	-	January, 1980



second of each other using a mechanical synchronizing bar.

A distance rod holder is a permanent part of the frame. Three interchangeable distance rods may be used, giving a camera to subject range of from 0.5 to 2 meters (plus depth of field).

A projection from the distance rod extends into the field of view. It carries two small spirit levels and a name plate; all appear in the photograph. The system is designed to take near vertical photographs, and at 1.9 meters (the standard distance used in the current study) there is approximately 80% overlap of the stereopairs. The field of view at 1.9 m is approximately 1.2 x 1.8 m (28 mm lens) and 0.8 x 1.2 m (35 mm lens). Black and white (125 ASA) and colour print film (100 ASA and 400 ASA) have been used successfully.

Field procedures

Photographs are taken at 1 meter intervals along a 10 meter tape laid between two steel pegs driven permanently into the reef (see Figure 2). The distal projection is oriented along the tape, and the optical axis made near vertical by centering the bubble in each spirit level. A photographic sample set consists of the eleven stereopairs required to photograph the line from 0-10 meters inclusive. However, in this report the characteristics of the method are demonstrated by examining one section of one line taken on three different occasions. This is the 4 meter mark of Pearson and Garrett's transect A1T1 (unpublished data) at John Brewer Reef, near Townsville. Dates of photography were October 1976, April 1979 and January 1980.

An invaluable characteristic of the method is that it is not essential to place the distance rod in an identical position on each occasion, since differences in position may be accounted for in the interpretation stage. However, it is desirable to place it as close as possible to the same position on each occasion, and to this end, a waterproof copy of the previous series of photographs is used as a guide.

Interpretation and measurement

Photographs are developed to the edge of the negative margin so that the principal point of each may be established by joining diagonals. Photographs are set up, viewed and parallax measurements taken in accordance with routine procedures (Tewinkle, 1965). Sokkisha Mirror Stereoscope M27 and Parallax Bar P1 were used in the current study.

The aims of the interpretation are twofold:-

i) recording of qualitative change from prior states, such as loss of colonies, establishment of new colonies, coral damage, etc.

ii) Determination of the scale of each colony on the photograph, which, as mentioned above, depends on the distance from the camera focal plane. Once a scaling factor has been established, linear and area measurements from the print may be converted to estimates of *in situ* measurements.

The mean of four measurements of parallax is determined for each colony plus the top of the spirit level. If a number of assumptions are made (see below), the height of a colony relative to the spirit level may be calculated using the simple parallax equation:

$$\Delta h = H \times \frac{\Delta p}{b + \Delta p} \qquad \text{(Tewinkle, 1965, p.23)}$$

H_i, the estimated distance from the focal plane to colony i is:

$$H_i = H - \left(\frac{H \times \Delta p}{b + \Delta p}\right)$$

where

Δh is the height difference between the spirit level and the coral,

Δp is the mean parallax difference between the spirit level and the coral,

b is the photographic base (*i.e.* the average distance between each principal point and its conjugate) and

H is the distance from the focal plane to the top of the spirit level.

The scaling factor by which print measurements are multiplied to estimate *in situ* measurements is:-

$$SF = Hi/(f \times r \times Sp)$$

where

SF is the scaling factor,

f is the focal length of the lens used,

r is the refractive index of water,

Sp is the photographic enlargement factor, determined by microscopic measurement of the print and negative images of the name plate, and dividing the former length by the latter.

The above computations are based on the following assumptions:

i) lenses are identical and optically flat,
ii) lens focal length equals nominal focal length,
iii) optical axes of photos are vertical and parallel,
iv) measurement of parallax is precise,
v) photoenlargement is precisely calculated,
vi) the distance H is accurately known.

All of these assumptions are violated to a greater or lesser degree in the present study (as they are in most field studies using photogrammetry). They may be counteracted by introducing extra control points into the field of view, using optically more suitable equipment, and adding a series of correction terms to the basic equations. (However, these correction terms require a more sophisticated and time-consuming interpretation than used here).

All of these options may be considered for future studies requiring precise data. For the present purposes a simple, empirical validation of the method using photographs of objects of known size was considered adequate. Ecological data is notoriously imprecise, and an estimate of known errors of the system is sufficient to allow a reasonable use of the cover estimates obtained.

RESULTS

Theoretical considerations of known errors

A number of computations were made so that the effect of some of the known error sources could be quantified.

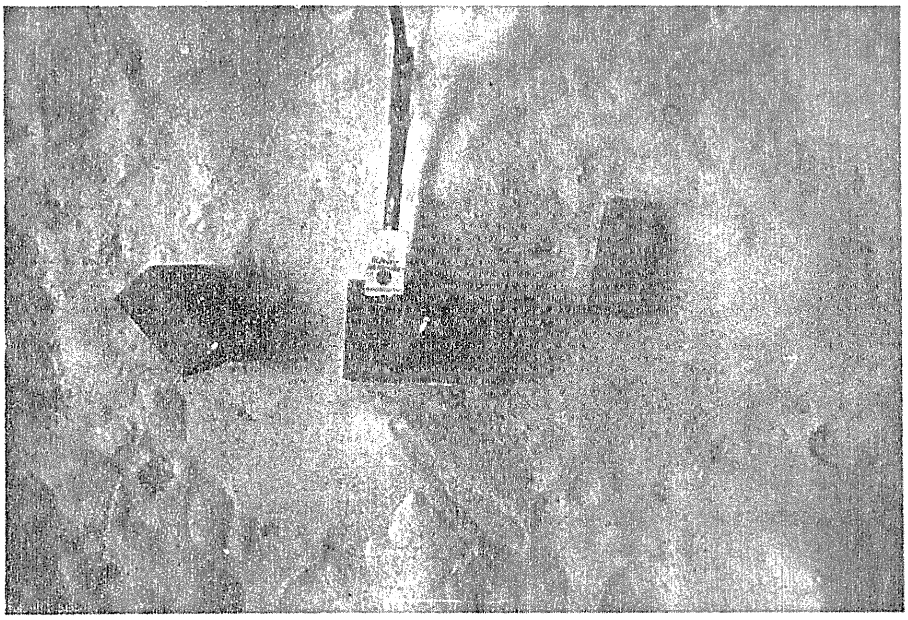
a) Nominal focal length not equal to actual focal length

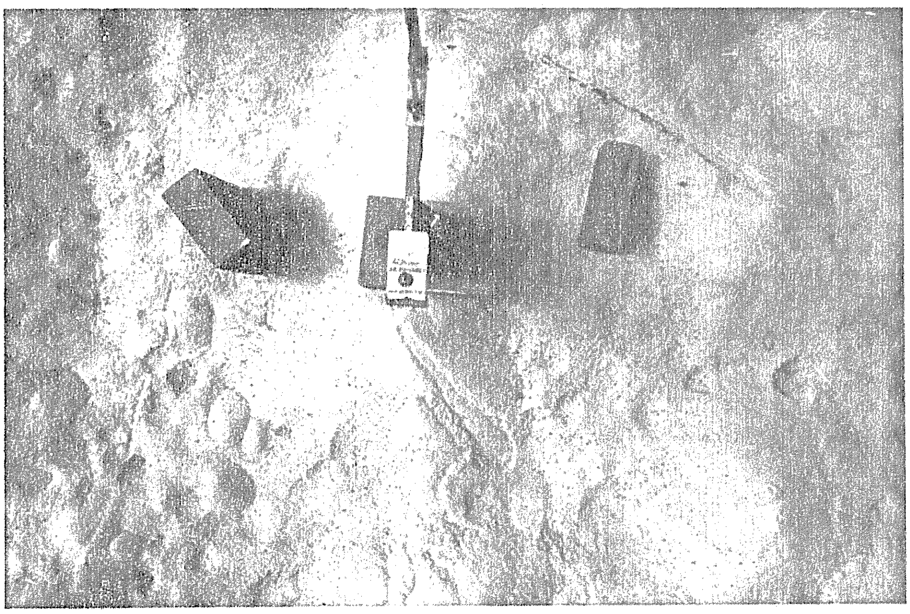
If a lens nominally stated to have a focal length of 35 mm is in fact 2 mm smaller or larger than this figure, errors of -5.4% and +6.8% in length estimates occur. Actual deviations from the nominal focal length would presumably be much less than 2 mm.

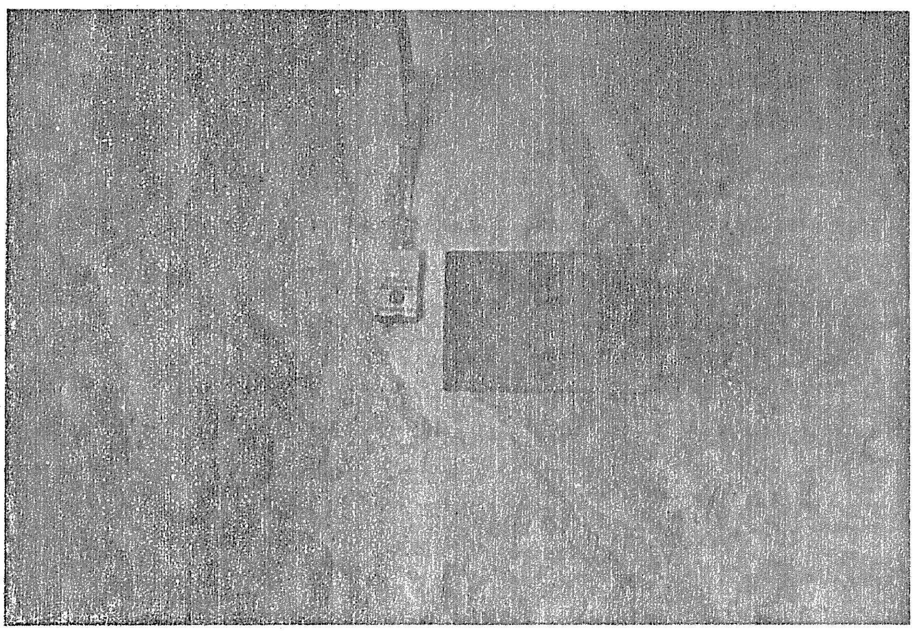
FIGURE 3

Housebrick validation experimental setups.

top	-	Bricks 1.1 to 1.3 m from cameras
middle	-	Bricks 1.9 to 2.2 m from cameras
bottom	-	Bricks 1.6 to 1.8 m from cameras







Estimated Distance from focal point (mm)	Estimated Length (mm)	Actual Length (mm)	Estimated/Actual x 100% (%)
1134	84.5	77	109.7
1146	118.7	112	105.9
1320	192.0	191	100.5
1327	306.6	291	105.4
1577	108.8	112	97.1
1582	72.8	77	94.6
1705	186.4	191	97.6
1721	88.1	89	99.0
1762	281.3	291	96.7
1758	186.1	191	97.4
1805	71.7	77	93.1
1842	224.5	232	96.8
1940	89.1	89	100.1
1949	184.7	191	96.7
1964	274.0	291	94.2
2034	185.6	191	97.2
2193	223.0	232	96.1
2209	75.3	77	97.8

Table 1 Estimates of housebrick dimensions at distances shown. Maximum error of estimate was 17 mm at 1964 mm.

b) Optical axes not perfectly vertical

In a tilted photograph, the scale of any point is a function of tilt and distance from isocenter (see Tewinkle, 1965, p.27). Points on the print margin have the greatest error. A tilt of 5^{o} was calculated to cause an error in the linear scaling factor of -4% to +2%; a tilt of 10^{o} causes an error of -7 to +4%. The actual tilt occurring in the field has not been quantified, but the use of the spirit levels is intended to minimise tilt.

c) Imprecise measurement of parallax

Trials by the author with the parallax bar indicated that an inconsistancy of up to 0.1 mm was present. The consequences of this amount of error vary according to the distance of the object from the camera. Objects 1 m from the camera have an error in linear scale of about 4% caused by a 0.1 mm error in parallax measurement. This figure declines to 0.6% at 2 m and becomes negligible by 3 m. However, at distances closer than 1 m from the camera, the error increases exponentially such that at 0.5 m it is 10% and at 0.25 m it is 20%. Fortunately, objects this close to the cameras are out of focus using the present system.

Empirical validation of the system

The photogrammetric accuracy of the system was tested using photographs of objects of known dimensions. Building bricks of two sizes were photographed in various configurations on the lagoon floor of John Brewer Reef. In order to simplify the test situation, the upper surfaces of the bricks were kept horizontal. Three test configurations are indicated in Figures 3a to 3c. A range of camera to subject distance of 1.1 m to 2.2 m was encompassed by the three configurations.

A photogrammetric estimate of the length and width of each brick's upper surface was made. The print dimensions were measured to 0.1 mm using a "Peak Scale Lupe 10X"; parallax measurements were made using a mirror stereoscope and parallax bar. The distance from the focal plane to each upper corner of each brick was calculated using the simple parallax equation (see Methods) and the scale of each side then computed. The estimated edge length is then simply the product of print length and scaling factor.

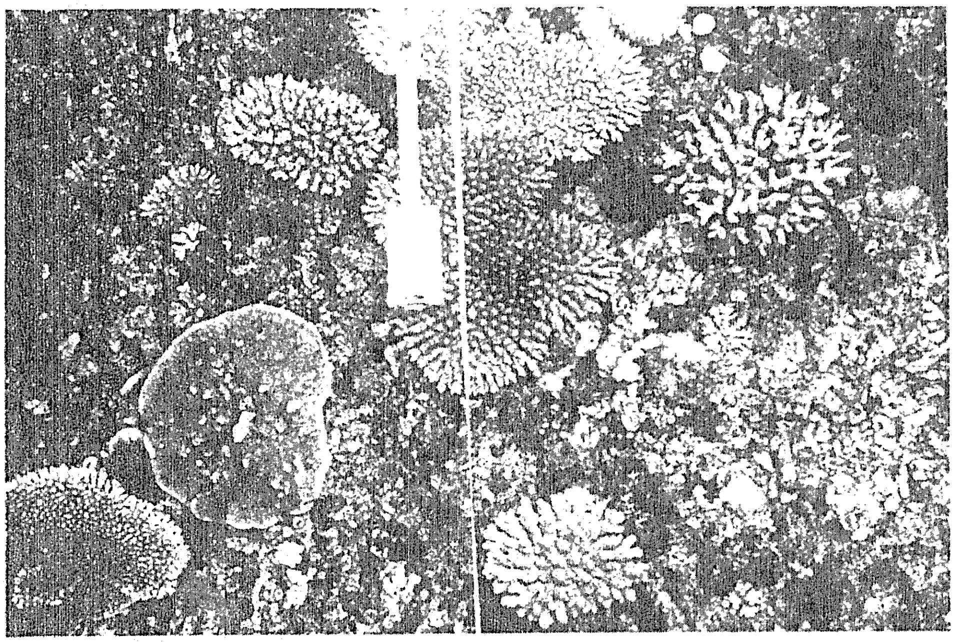
Estimated and actual lengths are compared in Table 1. The greatest

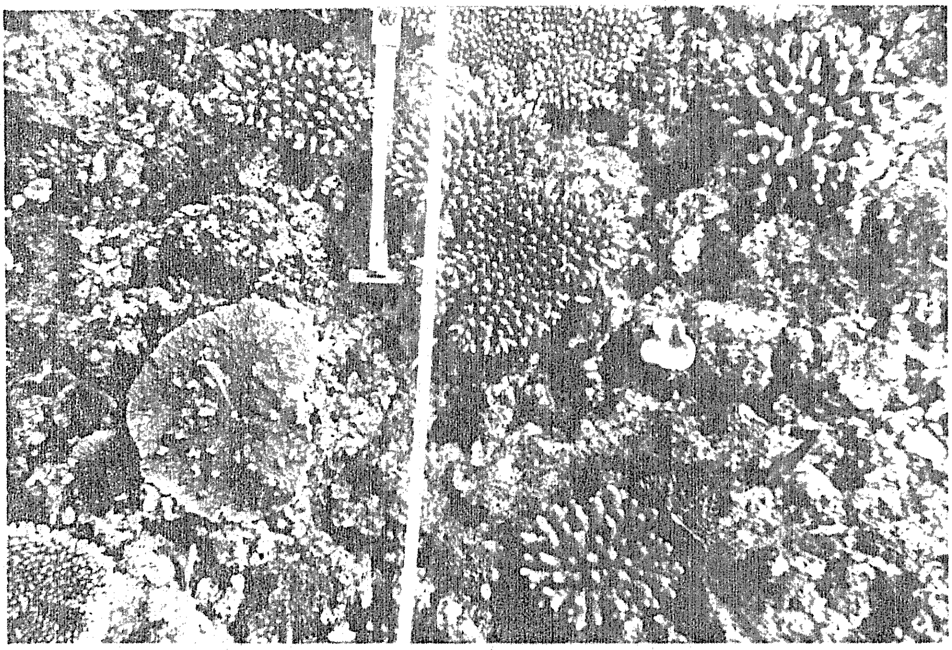
FIGURE 4

Four meter mark of transect A1T1 at John Brewer Reef. Growth of individual colonies may readily be observed (see Figure 5 for identification of colonies). Resolution is markedly improved in stereopairs.

top - October 1976
middle - April 1979
bottom - January

N.B. These photographs have been cropped. SP1 was in fact fully included in stereoprints.





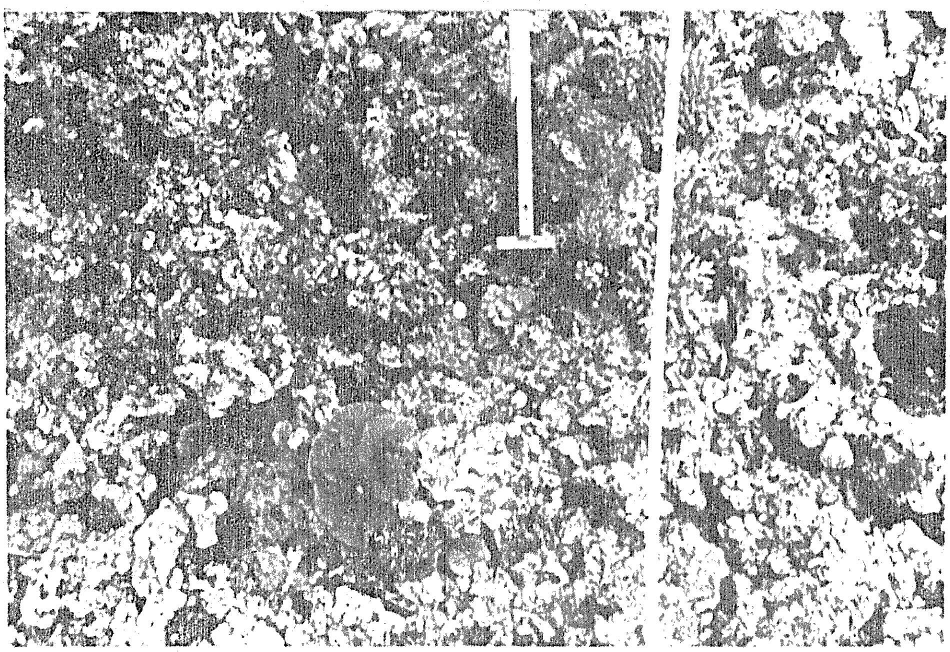


FIGURE 5

Tracing of Figure 4 showing identity of individual colonies.

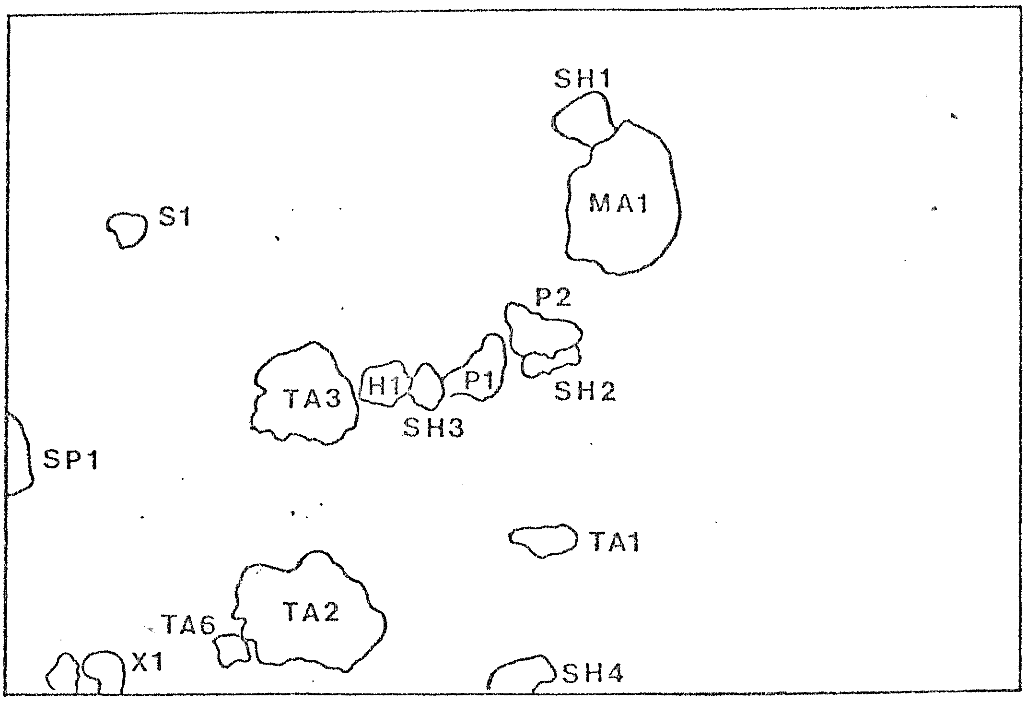
top - October, 1976

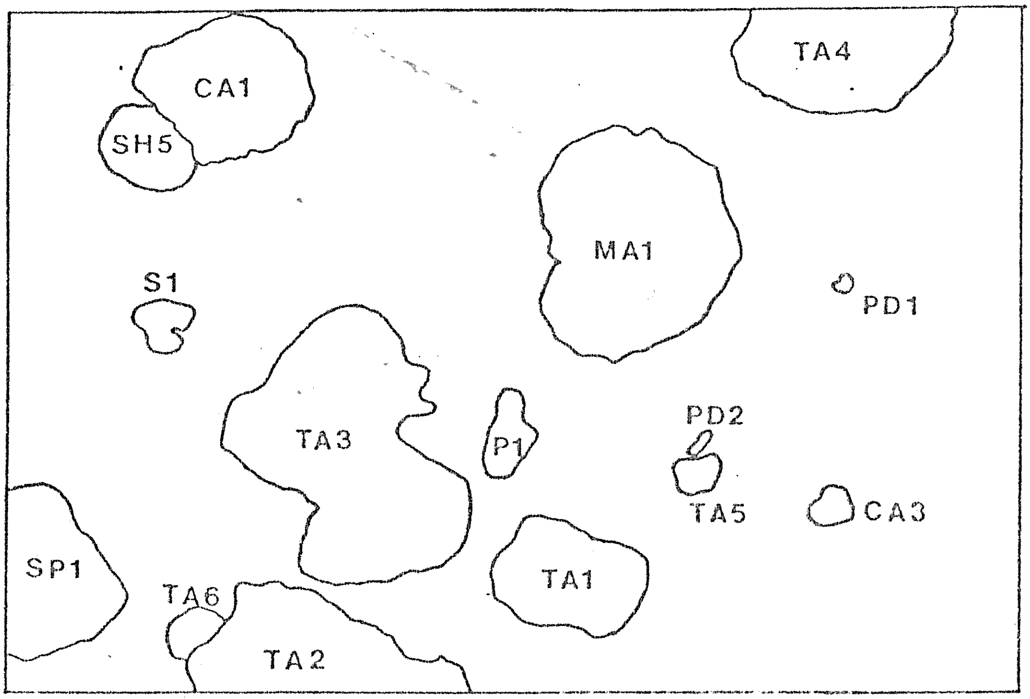
middle - April, 1979

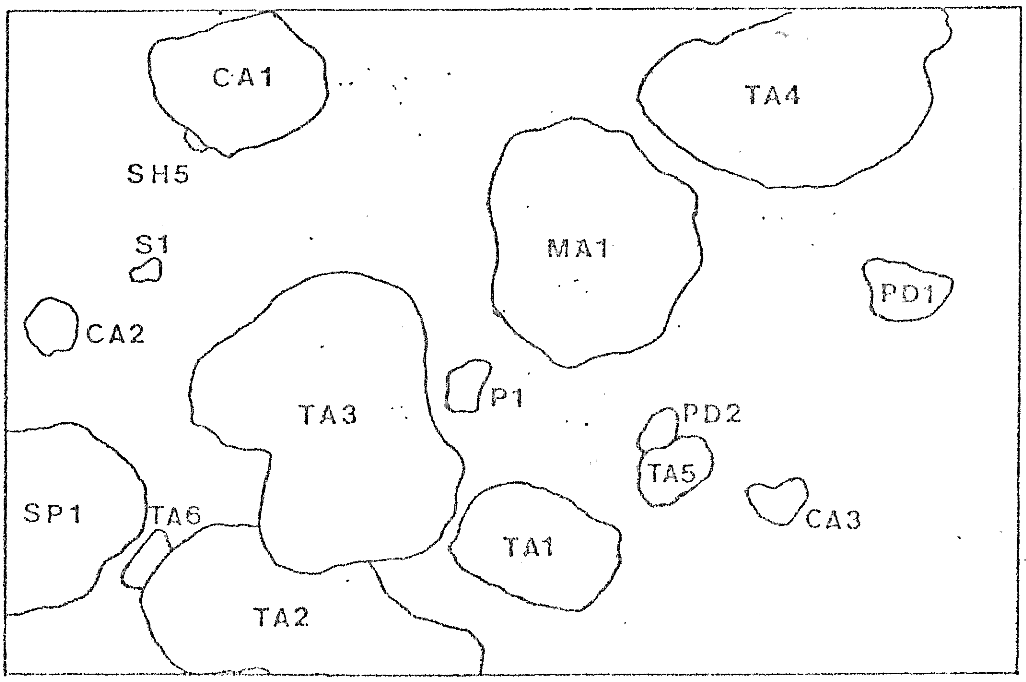
bottom - January, 1980

Abbreviations

TA	-	tabulate *Acropora*
CA	-	caespitose *Acropora*
SP	-	*Stylophora pistillata*
PD	-	*Pocillopora damicornis*
SH	-	*Seriatopora hystrix*
P	-	*Porites*
H	-	*Hynophore exesa*
MA	-	*Merulina ampliata*
S	-	*Sarcophyton*
X	-	Xeniidae


SH1
MA1
S1
P2
TA3
H1
P1
SH2
SH3
SP1
TA1
TA2
TA6
X1
SH4


TA4
CA1
SH5
MA1
S1
PD1
PD2
TA3
P1
TA5
CA3
SP1
TA1
TA6
TA2


CA1
TA4
SH5
MA1
S1
PD1
CA2
P1
PD2
TA3
TA5
SP1
TA6
CA3
TA1
TA2

DATE		IND NAME	DISTANCE	LENGTH 1	LENGTH 2	LENGTH 1*2
761021	310	1 TABULATE ACROPORA	1916.	59.	30.	1755.
761021	310	2 TABULATE ACROPORA	2297.	178.	133.	23643.
761021	310	3 TABULATE ACROPORA	1936.	105.	97.	10186.
761021	431	1 STYLOPHORA PISTILLATA	2248.	139.	113.	15691.
761021	542	1 MERULINA	1586.	141.	104.	14691.
761021	521	1 HYDONOPHORA EXESA	1941.	38.	26.	985.
761021	513	1 PORITES	1913.	89.	48.	4264.
761021	513	2 PORITES	1908.	74.	29.	2175.
761021	813	1 SARCOPHYTON	1940.	37.	37.	1405.
761021	410	1 NEEDLE CORAL - SERIATOPOR	1530.	47.	41.	1959.
761021	410	2 NEEDLE CORAL - SERIATOPOR	1793.	69.	21.	1440.
761021	410	3 NEEDLE CORAL - SERIATOPOR	1926.	30.	22.	664.
761021	410	4 NEEDLE CORAL - SERIATOPOR	2320.	99.	90.	8844.
761021	815	1 XENIIDAE	2681.	104.	41.	4293.
					TOTAL:	82825

DATE		IND NAME	DISTANCE	LENGTH 1	LENGTH 2	LENGTH 1*2
790421	310	1 TABULATE ACROPORA	2014.	225.	143.	32169.
790421	310	2 TABULATE ACROPORA	1993.	354.	202.	71594.
790421	310	3 TABULATE ACROPORA	1804.	348.	275.	95537.
790421	310	4 TABULATE ACROPORA	1516.	269.	162.	43508.
790421	542	1 MERULINA	1713.	287.	252.	72328.
790421	350	1 CAESPITOSE	1600.	187.	162.	30311.
790421	431	1 STYLOPHORA PISTILLATA	1767.	233.	197.	45974.
790421	310	5 TABULATE ACROPORA	2026.	72.	46.	3330.
790421	350	2 CAESPITOSE	1720.	35.	35.	1219.
790421	460	1 POCILLOPORA DAMICORNIS	1787.	23.	18.	411.
790421	460	2 POCILLOPORA DAMICORNIS	1920.	19.	10.	190.
790421	813	1 SARCOPHYTON	1755.	71.	71.	5078.
790421	513	1 PORITES	1920.	117.	78.	9108.
790421	815	1 XENIIDAE	1958.	99.	99.	9874.
790421	310	6 TABULATE ACROPORA	1941.	79.	39.	3106.
790421	350	3 CAESPITOSE	2047.	62.	42.	2588.
					TOTAL:	426325

DATE		IND NAME	DISTANCE	LENGTH 1	LENGTH 2	LENGTH 1*2
800126	310	1 TABULATE ACROPORA	1975.	237.	158.	37465.
800126	310	2 TABULATE ACROPORA	2076.	471.	221.	104249.
800126	310	3 TABULATE ACROPORA	2020.	377.	364.	137105.
800126	310	4 TABULATE ACROPORA	1977.	395.	369.	145908.
800126	542	1 MERULINA	2154.	359.	330.	118635.
800126	431	1 STYLOPHORA PISTILLATA	2045.	300.	232.	69519.
800126	350	1 CAESPITOSE	2092.	237.	237.	56257.
800126	310	5 TABULATE ACROPORA	2246.	150.	105.	15707.
800126	460	1 POCILLOPORA DAMICORNIS	2285.	152.	107.	16246.
800126	460	2 POCILLOPORA DAMICORNIS	2176.	58.	44.	2526.
800126	813	1 SARCOPHYTON	2130.	43.	43.	1815.
800126	350	2 CAESPITOSE	2085.	70.	70.	4833.
800126	513	1 PORITES	2177.	102.	102.	10324.
800126	815	1 XENIIDAE	2472.	198.	132.	26080.
800126	310	6 TABULATE ACROPORA	2400.	160.	48.	7683.
800126	350	3 CAESPITOSE	2306.	92.	62.	5674.
					TOTAL:	760026

Table 2 Estimates of colony dimensions
a) October, 1976 b) April, 1979 c) January, 1980
Total growth index for each series is indicated.

DATE	IND	NAME	DISTANCE	LENGTH 1	LENGTH 2	LENGTH 1*2	PERCENT INCREASE	
							'76-'80	'79-'80
761021	310	1 TABULATE ACROPORA	1916.	59.	30.	1755.		
790421	310	1 TABULATE ACROPORA	2014.	225.	143.	32169.	116	
800126	310	1 TABULATE ACROPORA	1975.	237.	158.	37465.		2135
761021	310	2 TABULATE ACROPORA	2297.	178.	133.	23643.		
790421	310	2 TABULATE ACROPORA	1993.	354.	202.	71594.	146	
800126	310	2 TABULATE ACROPORA	2076.	471.	221.	104249.		449
761021	310	3 TABULATE ACROPORA	1936.	105.	97.	10186.		
790421	310	3 TABULATE ACROPORA	1804.	348.	275.	95537.		
800126	310	3 TABULATE ACROPORA	2020.	377.	364.	137105.	144	1346
790421	310	4 TABULATE ACROPORA	1516.	269.	162.	43508.		
800127	310	4 TABULATE ACROPORA	1977.	395.	369.	145908.	355	
790421	310	5 TABULATE ACROPORA	2026.	72.	46.	3330.		
800126	310	5 TABULATE ACROPORA	2246.	150.	105.	15707.	472	
790421	310	6 TABULATE ACROPORA	1941.	79.	39.	3106.		
800126	310	6 TABULATE ACROPORA	2400.	160.	48.	7683.	247	
790421	350	1 CAESPITOSE	1600.	187.	162.	30311.		
800126	350	1 CAESPITOSE	2092.	237.	237.	56257.	186	
790421	350	2 CAESPITOSE	1720.	35.	35.	1219.		
800126	350	2 CAESPITOSE	2085.	70.	70.	4833.	396	
790421	350	3 CAESPITOSE	2047.	62.	42.	2588.		
800126	350	3 CAESPITOSE	2306.	92.	62.	5674.	219	
761021	410	1 NEEDLE CORAL - SERIATOPOR	1530.	47.	41.	1959.		
761021	410	2 NEEDLE CORAL - SERIATOPOR	1793.	69.	21.	1440.		
761021	410	3 NEEDLE CORAL - SERIATOPOR	1926.	30.	22.	664.		
761021	410	4 NEEDLE CORAL - SERIATOPOR	2320.	99.	90.	8844.		
761021	431	1 STYLOPHORA PISTILLATA	2248.	139.	113.	15691.		
790421	431	1 STYLOPHORA PISTILLATA	1767.	233.	197.	45974.	151	
800126	431	1 STYLOPHORA PISTILLATA	2045.	300.	232.	69519.		443
790421	460	1 POCILLOPORA DAMICORNIS	1787.	23.	18.	411.		
800126	460	1 POCILLOPORA DAMICORNIS	2285.	152.	107.	16246.	3953	
790421	460	2 POCILLOPORA DAMICORNIS	1920.	19.	10.	190.		
800126	460	2 POCILLOPORA DAMICORNIS	2176.	58.	44.	2526.	1329	
761021	513	1 PORITES	1913.	89.	48.	4264.		
790421	513	1 PORITES	1920.	117.	78.	9108.	113	
800126	513	1 PORITES	2177.	102.	102.	10324.		242
761021	513	2 PORITES	1908.	74.	29.	2175.		
761021	521	1 HYDONOPHORA EXESA	1941.	38.	26.	985.		
761021	542	1 MERULINA	1586.	141.	104.	14691.		
790421	542	1 MERULINA	1713.	287.	252.	72328.	164	
800126	542	1 MERULINA	2154.	359.	330.	118635.		808
761021	813	1 SARCOPHYTON	1940.	37.	37.	1405.		
790421	813	1 SARCOPHYTON	1755.	71.	71.	5078.		
800126	813	1 SARCOPHYTON	2130.	43.	43.	1815.	36	129
761021	815	1 XENIIDAE	2681.	104.	41.	4293.		
790421	815	1 XENIIDAE	1958.	99.	99.	9874.	264	
800126	815	1 XENIIDAE	2472.	198.	132.	26080.		608

Table 3 — Table 2 resorted to show growth of individual colonies. Last two columns show increase in growth index (length 1 x length 2) for October, 1976 to January, 1980, and April, 1979 to January, 1980.

errors in length estimate were 17 mm (at a distance of 1964 mm and 15 mm at 1327. The remaining errors were all less than 10 mm. As a result, estimated lengths ranged between 93% and 110% of the actual lengths and the great majority were within the range 96-106%. Area estimates using these linear estimates lie between 86 and 121% of their true values (the sources of error were discussed above). It may be assumed that the following photogrammetric estimates are subject to errors of the order of those quoted here.

Field Testing

Figure 4 shows the 4 meter plot on John Brewer Reef transect A1T1 in October 1976, April 1979 and January 1980. The diameters of each colony (as shown in Figure 5) were measured from the prints and an estimate of their *in situ* dimensions calculated using the procedures outlined above. Comparisons of qualitative and quantitative changes were made between the 1976 and 1980 series (38 month interval) and the 1979 and 1980 series (8 month interval). Thirty-five millimeter lenses were used in 1976 and 1979, and 28 mm lenses in 1980.

a) Thirty-eight month time interval

In the reef area in common to both photographs, fourteen colonies were present in 1976 and thirteen in 1980. Six colonies which were visible in the 1976 photograph were not visible in the 1980 photograph, and three new colonies had established (see Table 2, Figure 4a, c).

Space previously occupied by the six disappearing colonies was either bare or otherwise occupied, indicating that death and/or dislodgment of the colonies had taken place. Two *Seriatopora* colonies had been dislodged and two had been overgrown; the central tabulate *Acropora* and *Merulina* in the 1980 photograph had overgrown places previously occupied by encrusting *Porites* and *Hydnophora*. (Details such as these are readily observed by stereoscopic viewing, but cannot be so readily observed monoscopically - *e.g.* Figure 4. This black and white reproduction of colour negatives gives a more grainy picture than can be obtained on colour prints).

Of the seven colonies recognisable in both photographs, six exhibited considerable growth (Table 3). The three tabulate *Acropora*, *Stylopora pistillata* and *Merulina ampliata* at least doubled their diameters. The growth suggested for *Porites* specimen 1 is less certain, however, as its outline was less clear. The apparent decrease in size of *Sarcophyton* was due to the contracted state of the soft coral in the 1980 photograph.

b) Eight month time interval

A comparison of the data from 1979 and 1980 is also made in Table 3. The prints were qualitatively similar, but significant size changes were detected. An increase in the dimensions of all hard coral colonies was detected. The 'growth index' (*i.e.* the product of the two dimensions) increased by between 113 and 3,953% and only two (*Porites* 1 and tabulate *Acropora* 1) increased by less than 120% (which is the suggested limit of areal resolution of the system, as determined by the housebrick validation study reported above). The figure of 3,953% (which refers to a *Pocillopora* colony) over-estimates growth in this colony, since the original size was underestimated (the colony being partly hidden in 1979).

c) Total coral cover

Visual inspection of Figure 4 indicates that considerable increase in total coral cover took place during the study. The growth index (length 1 x length 2) was computed *in lieu* of an area estimate (Tables 2, 3) since a sufficiently sensitive planimeter was not available. The total growth index increased from .082 m^2 in 1976 to 0.43 m^2 in 1979. (Since the 1976 and 1979 prints cover about 0.8 x 1.2 or .96 m^2 of reef, the figures represent an increase of from 8% to 40% total coral cover in 30 months. This order of change could readily be detected by the Authority's crude reconnaissance method, if it occurred over a sufficiently large area - see accompanying report).

DISCUSSION

The results presented above suggested that the system as currently constructed, operated and interpreted can record qualitative and quantitative change in the macrobenthos of permanently marked plots over time periods at least as short as eight months.

The results may by critically examined in two frames of reference - the photogrammetric and the ecological. As an excercise in photogrammetry *per se*, the results can not be considered precise; the errors of up to 17 mm in the house brick validation study are far greater than would be acceptable in many applications. For example, volumetric studies of individual coral colony growth (which could readily be approached photogrammetrically) would require a more controlled system of photography and interpretation (*e.g.* that of Fryer *et al.* 1979 or a modification to the system presented here).

However, as a tool for the study of net change in reef coral communities, the system appears to have many advantages. Comparisons with line transect methods (*e.g.* Loya 1972, Porter 1972) and quadrat methods (*e.g.* Pearson 1974) are appropriate.

In line transect studies, a tape measure (Loya 1972) or a chain (Porter 1972) usually 10 m or more in length, is laid in a straight line over the corals to be monitored. An index of cover for individual species is the sum of the intercepts of the individual colonies on the tape (in centimeters) or chain (in number of links); the total cover index is the sum of the population indices. The method has the advantage that a competent taxonomist may identify to species level some specimens which could not be so precisely identified from a stereopair. In time series studies, a degree of unquantifiable error is present, since it is rarely possible to lie the line in exactly the same place on each sampling occasion. An assumption must be made that, given a sufficiently large sample size, these errors will tend to cancel each other out. Those species which are rare are not satisfactorily monitored by this method.

Pearson (1974) used 1 m^2 quadrats along 10 m line transects. Within his quadrats, he measured directly the greatest diameter only. He is better able to locate cryptic specimens and obtain an estimate of establishment and extinction of very small colonies not resolved by the photographic method. Whereas the smallest colony resolved in the current stereo field trial was 19 mm in diameter, Pearson (1974) recorded colonies less than 10 mm diameter.

Line and quadrat methods are most suited to quantification of coverage of coral in which growth is predominantly horizontal. Pichon (1978) has reviewed some of the problems involved in estimating cover in corals with a significant vertical dimensionality. Photogrammetry has the great advantage that it may be used to estimate vertical growth in colonies; (this aspect has not been explored here).

In terms of field time efficiency, stereophotography compares very favourably with line and quadrat methods. In an area of high coral cover and diversity, a single operator in shallow water may lay and census one or two ten meter line transects per dive (personal estimates - Done 1977). Pearson (1974) can census only 3 1 m^2 quadrats per day. With the current system, a single operator can, during one dive, lay and photograph two 10 meter lines at 1 meter intervals.

In terms of data processing, the photogrammetric method is the most time consuming because it requires an interpretation stage before analysis may begin. The interpretation and measurement of stereo photos in the current field trial took approximately forty minutes per pair, including setting up time. At this rate, a photo series at 1 meter intervals along a 10 m line transect requires 7-8 hours of interpretation before the data analysis stage. However, the data matrix obtained is considerably greater than for a normal 10 m line transect, because it refers to a belt transect approximately 1 meter wide (c.f. the line transect's effective width of 1 - 2 cm). The photographs themselves contain a great deal of information unavailable to the practitioners of line transect and quadrat methods. In line transects, there is usually uncertainty about the identify of individual (especially smaller) colonies from one monitoring period to the next. (For this reason the line transect practitioner cannot interest himself with individual colonies - the photogrammetrist can confidently do so).

The line practitioner cannot always be sure that the absence of a previously present rare species from his data is truly due to its local extinction or merely due to a chance deviation of the line. Such deviations are inevitable in areas of water movement, even with line anchoring pegs as close as 5 meters apart (personal observations). This characteristic limits the use of line transects to estimating cover of abundant species and total cover, and its use for these purposes has been very profitable to ecologists.

The quadrat method, especially if supplemented by a near vertical photograph (as practised by Connell, 1973 and Pearson, 1974) does not have the same uncertainty associated with individual colonies.

CONCLUSION

Reef ecologists and reef managers have a common need for information regarding qualitative change and rates of change. The high field efficiency of the current application of stereophotogrammetry allows a great diversity of habitats to be monitored in a limited field time. This is an extremely important consideration on the Great Barrier Reef, where the majority of reefs are at least tens of miles from a shore facility. The ready use of the equipment by competent divers without any biological knowledge is also important in this regard. The photogrammetric approach requires an interpretation stage not involved in traditional methods, but rewards the investigation by providing greater area coverage, a variety of additional qualitative data, and a permanent record. The photogrammetrist must accept some loss in taxonomic resolution as a trade off for these rewards.

The high information and permanent record of the photogrammetric approach facilitates retrospective analysis and impressive pictorial demonstration of change (or absence of change) in reefs. The latter attribute can be of value in communicating with influential parties such as politicians and can be used as evidence in court (Porter, pers. comm.).

Close range stereophotogrammetry is clearly a tool which could find an important place in the documentation of change in coral reef (and other) benthic systems.

REFERENCES

CONNELL, J.H., 1973. Population ecology of reef-building corals. *In*: Jones, A.O. and Endean, R. (Eds.) Biology and Geology of Coral Reefs, 2. Biology 1. Academic Press, N.Y. 205-245.

CONNELL, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science, 199 : 1302-1310.

DONE, T.J., 1977. A comparison of units of cover in ecological classifications of coral communities. Proc. 3rd Int. Coral Reef Symp. 9 - 14.

DREW, E.A., 1977. A photographic survey down the seaward reef front of Aldabra Atoll. Atoll Res. Bull. 193 : 1-7, + figs.

FRYER, J.G., ELFICK, M.H. and PEARSON, G.A., 1979. Underwater 35 mm photogrammetry? Aust. Surveyor, 29 : 461 - 464.

LAXTON, J.H., 1976. Sewerage disposal from coastal cities. Hunter District Waterboard Journal, Newcastle, 461 - 464.

LAXTON, J.H. and STABLUM, W.J., 1974. Sample design for quantitative estimation of sedentary organisms of coral reefs. Biol. J. Linn. Soc., 6 : 1 - 18.

LOYA, Y., 1972. Community structure and species diversity of hermatypic corals at Eilat, Red Sea. Mar. Biol. 13 : 100 - 123.

LUNDÄLV, T.L., 1976. A stereophotographic method for quantitative studies on rocky bottom biocoenoses. *In*: Drew, E.A., Lythgoe, J.N., Woods, J.D. (Eds.) Underwater Research. Academic Press, London, 299 - 302.

PEARSON, R.G., 1974. Recolonisation by hermatypic corals of reefs damaged by *Acanthaster*. Proc. 2nd Int. Symp. on Coral Reefs, 2 : 207 - 215.

PICHON, M., 1978. Problems of measuring and mapping coral colonies. *In*: Stoddart, D.R. and Johannes, R.E. (Eds.) Coral Reefs: Research Methods. UNESCO, 219 - 230.

PORTER, J.W., 1972. Patterns of species diversity in Carribean reef corals. Ecology, 36 : 315 - 320.

SCHEER, G., 1978. Application of phytosociologic methods. *In*: Stoddart, D.R. and Johannes, R.E. (Eds.). Coral Reefs: Research Methods. UNESCO, 175 - 196.

TEWINKLE, G.C., 1965. Basic mathematics of photogrammetry. *In:* Thompson, M.M. (Ed.). Manual of Photogrammetry. Third Edition, American Society of Photogrammetry, 17 - 65.