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# ANALYSIS OF CORAL COMMUNITY DATA USING MULTIVARIATE TECHNIQUES, AND THEIR APPLICATION TO OTHER COMMUNITY DATA

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# ANALYSIS OF CORAL COMMUNITY DATA USING MULTIVARIATE TECHNIQUES, AND THEIR APPLICATION TO OTHER COMMUNITY DATA

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DAMPIER ARCHIPELAGO MARINE STUDY

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# ABSTRACT

Coral data from the Dampier Archipelago, Western Australia are used as an example to illustrate the procedures necessary to convert raw field data, in the form of species lists, into a form that can be analysed by the Cornell Ecology Program Series. Classification of the data was carried out using composite clustering and two way indicator species analysis. Ordination was performed by detrended correspondence analysis. A brief description of each program is given. Data coding and input, program execution and output interpretation are also discussed.

Sites were classified into three main groups that correlated with the distribution of offshore, exposed and protected habitats within the Archipelago. Coral species diversity tended to be lower at protected and offshore sites than at exposed sites. There was a notable trend of species classification into their preferred habitats. Information derived from these analyses agreed well with data from the literature.

The successful application of these multivariate techniques in analysing coral data indicates that they may have a more widespread use; suggestions are made for their use in other studies.

## GENERAL INTRODUCTION

Multivariate techniques (ordination and classification) are used extensively in terrestrial ecology (Kershaw, 1973; Sneath and Sokal, 1973; Whittaker, 1978a, 1978b), and have also been applied to data from marine environments (Veron and Done, 1979; Wiegleb, 1980; Moran, 1981; Done, 1983).

The availability of computers, and the large range of programs for use in community studies has resulted in the use of these techniques on data not originally collected for ordination and classification analyses. While there is generally a wide choice of programs for data analyses (Gauch and Whittaker, 1981), the final decision usually rests on what information is being sought and which programs are available at respective research institutes. As a result a number of methods have been used and quoted in the literature (eg. Sneath and Sokal, 1973; Green and Vascotto, 1978; Veron and Done, 1979).

This report is divided into two sections. Section A briefly describes four Cornell Ecology Programs; this includes the methods of data coding and input as well as program execution and interpretation of output. Section B applies these techniques to data, not originally collected for this type of analysis, on corals from the Dampier Archipelago, Western Australia (Marsh, 1978, Fig. 1). The value of these techniques in analysing other descriptive community data is also discussed.

## A MULTIVARIATE TECHNIQUES

### 1. INTRODUCTION

The mechanics of computer program execution are often a deterrant to researchers. To assist in understanding the Cornell Ecology Programs applied in this study, a brief description is given below. In addition, data coding and input, program execution and output interpretation are discussed, using the coral data described in Section B.

These are brief descriptions only and the Cornell Programs' capabilities surpass the overview discussed here. The reader is directed to the appropriate program manuals (Gauch, 1982) for further information on their full capabilities and use.

### 2. PROGRAM DESCRIPTION

All programs described here (CONDENSE, COMPCLUS, TWINSPAN, DECORANA) were from the Cornell Ecology Program Series (Gauch, 1982) maintained at Murdoch University, Western Australia. These programs at the time of writing were also available for use at the University of Western Australia.

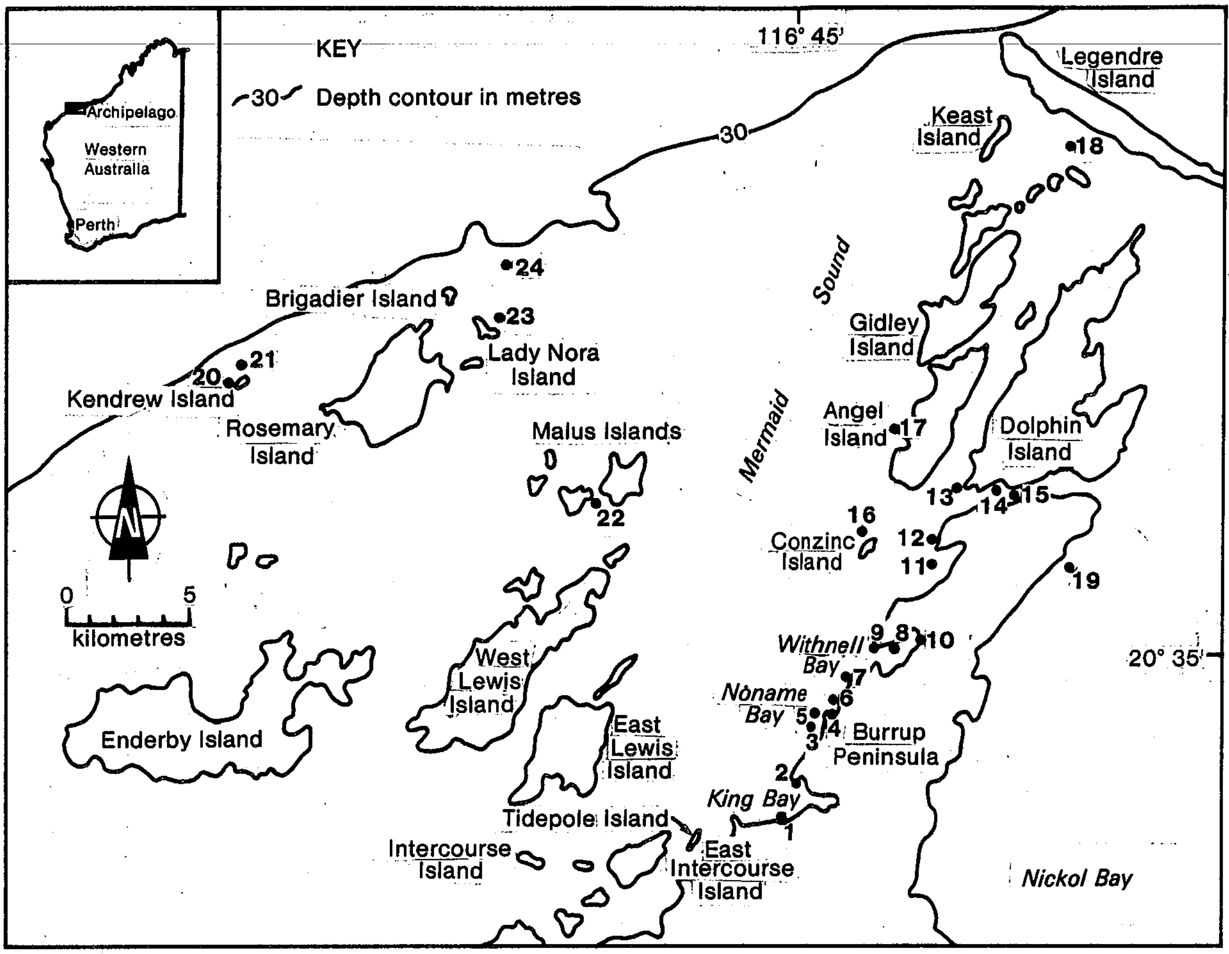


**Figure 1; Sample sites in the Dampier Archipelago where coral species were listed by Marsh (1978).**

To use the programs, COMPCLUS, TWINSPAN and DECORANA , input data had to be in a 'restricted condensed format' (Gauch, 1982) in samples (or sites) order. To achieve this restricted format, data was read into the computer in a matrix of samples by species and copied into a form acceptable to the above programs using a program called CONDENSE (Singer and Gauch, 1979). Once data had been condensed it could be used in the COMPCLUS, TWINSPAN and DECORANA programs.

### *COMPCLUS (Composite Clustering)*

Written by Gauch (1979), this is a FORTRAN program designed to enable large data sets (species and sites) to be clustered initially. This is useful where there are large numbers of species and samples. It is used to identify outlying samples and major groupings of samples (clusters). Each cluster produces a composite sample, which is an average of the samples contained, and these can be used for subsequent analysis by ordination or classification.

Clustering involves two operations; a sample is selected at random and samples clustered within a user-specified radius (several distance measures are available (Gauch, 1982)). This is repeated until all samples are allocated to a cluster, ignoring any sample that has been assigned to a cluster already. The second operation reassigns samples from small clusters (having fewer than a specified number of members) into the nearest large cluster, provided that the sample is within a user-specified radius (which is larger than the radius specified for the first operation).

The value of COMPCLUS is largely dependent on the initial size of the data set. A large array of figures can be reduced by grouping similar samples into classes. Relationships can then be studied among a smaller, comprehensible number of groups.

COMPCLUS was used in this study, but the relatively small number of sites (24) and species (99) did not require further reduction before analysis.

*TWINSPAN (Two Way Indicator Species Analysis)*
This is a package designed for use on data collected on the occurrence of a set of species in a set of samples (Hill, 1979a). This program uses a polythetic, divisive technique (ie. whereby the initial data set is divided sequentially into smaller groups ('divisive'), using a number of different characters ('polythetic')) to first construct a classification of the samples. The program then uses this to obtain a classification of the species according to their ecological preferences. The two classifications are then used together to obtain an ordered two-way table that expresses the species' relations as closely as possible.

TWINSPAN and other classification programs are compared by Gauch and Whittaker (1981) and the general theory of indicator species analysis (of which TWINSPAN is a further development) is discussed by Hill *et al.* (1975).

TWINSPAN was used in this study to classify coral communities based on site and species data.

*DECORANA (Detrended Correspondence Analysis)*
This is a FORTRAN program for detrended correspondence analysis (DCA) and reciprocal averaging (Hill, 1979b). Its main purpose is to make ordinations using DCA (Gauch, 1982).

Ecological ordination refers to the arrangement of samples (or species) either in relation to environmental gradients, or in relation to axes that may correspond to environmental gradients (Kessel, 1979). A major purpose of such an arrangement is to enable recognition of joint variation in community composition and environmental factors (Gauch *et al.*, 1977).

If ordination produces axes that are ecologically meaningless or species and site patterns that cannot be interpreted, the process is not useful.

DECORANA, by default, produces four axes of variation, each with a calculated eigenvalue (see Sneath and Sokal, 1973 for further definition). An eigenvalue is equal to the variance along its corresponding axis. Thus the principal axis corresponding to the largest eigenvalue is the dimension that accounts for the greastest amount of variance from the sample (Sneath and Sokal, 1973). Likewise the next highest eigenvalue is that of the second most important axis and accounts for the second largest variance, and so on.

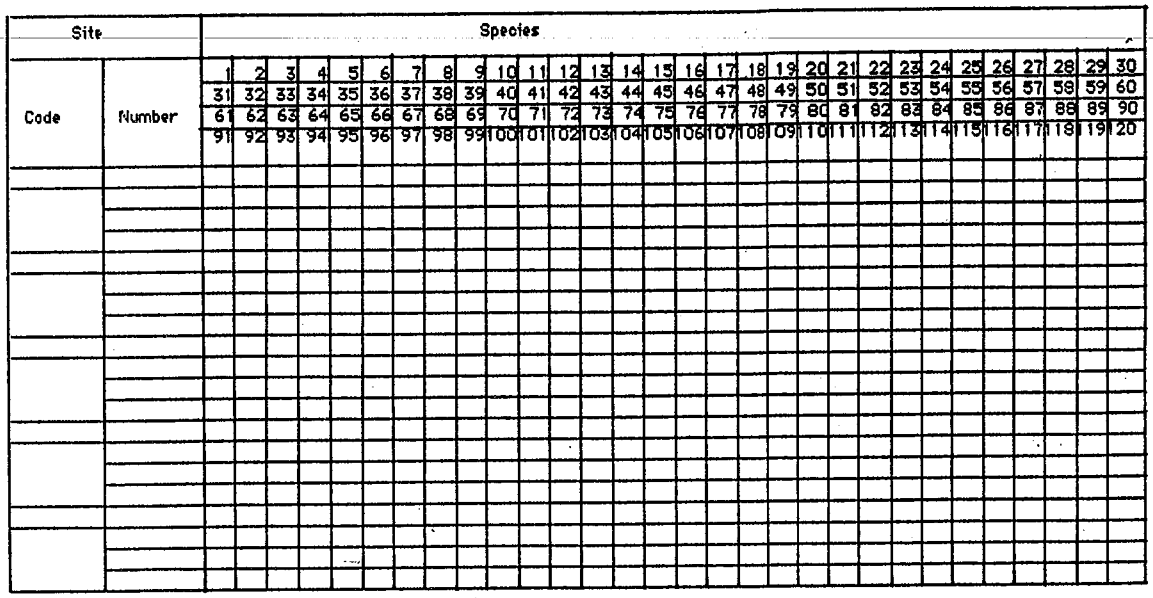
DECORANA also produces scatter diagrams of samples and species. These usually need to be replotted, using the values given for each axis, and then examined.

The present study applied DECORANA to determine whether the distribution of coral communities could be related to some combination of environmental factors.

## 3. DATA CODING AND INPUT

The allocation of a unique number to each coral species recorded in the Dampier Archipelago generated, for each coral site, a species presence/absence list. This enabled data to be coded into a site by species matrix (a proforma of which is shown in Fig. 2) for input into the Cornell Ecology Programs. Relative abundance figures given by Marsh (1978) were modified to allow them to be used in the programs as follows; 0: absent, 1: rare, 2: common, 3: abundant.

The data file was then placed on computer disk with the appropriate FORTRAN statements necessary to read the data into the CONDENSE program (Fig. 3). The generated output (Fig. 4) was then in the restricted format required for COMPCLUS, TWINSPAN and DECORANA.



| Site | | Species | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code | Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| | | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| | | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
| | | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 |

**Figure 2;** **A proforma for presence/absence data on species lists at various sites.** '0' is filled in if species are absent, and '1' if present. In this study '1' signified rare species, '2' common and '3' abundant.

## 4. PROGRAM EXECUTION

The execution of the Cornell Programs consists mainly of a set of statements to assign input and output to various devices such as the lineprinter and the console. These statements and assignations are likely to vary from one computer to another. The descriptions given here are those used for running the programs housed at Murdoch University on a Perkin/Elmer 8/32. Explanations of commands are given in brackets after each command:

*CONDENSE*

| | |
|---|---|
| L CORNCOND | [Loads the CONDENSE program] |
| AS 1.DAMP.DAT | [Assigns the input file, which is 'DAMP.DAT', shown in Fig. 3] |
| AS 3.CON:* | [Input and output directed to the console] |
| XAL DAMPCOND.DAT.IN.80 | [Creates an output file called 'DAMPCOND.DAT'] |
| AS 7.DAMPCOND.DAT | [Assigns the output to the file called 'DAMPCOND.DAT', shown in Fig. 4] |
| ST | [Starts the program] |

*The console is attached because these are user-interactive programs.

```
CONVERT 10(I3), 10(I3, F2.0))
   99   24DAMPIER CORAL COMMUNITY DATA 1978 - 99 SPECIES 24 SAMPLES   T*DAMP**
(3(2X, 30F2.0/), 2X, 9F2.0)                                  30
 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 0 0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
 1 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 0 0 0 0 1 1 0 1 0
 2 0 0 0 0 0 0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1
 2 0 1 1 0 1 0 0 1 0 1 0 0 1 0 0 1 0 1 1 0 0 1 1 1 0 0 1 1 1 1
 2 0 0 0 0 0 0 0 1 1 0 0 1 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 0
 2 0 0 0 0 2 2 1 0 1
 3 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0
 3 0 0 0 0 2 0 0 1 0 0 0 0 0 0 0 0 0 1 2 1 0 0 1 0 0 1 2 0 0 1
 3 0 0 0 1 0 1 0 1 0 0 0 1 0 0 0 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0
 3 0 0 0 0 0 1 0 0 1
 4 0 0 0 3 0 0 2 0 0 1 0 2 1 0 2 0 0 0 0 0 0 0 1 0 0 0 2 0 1 0
 4 1 0 1 0 1 0 0 2 0 0 0 1 0 0 0 0 0 2 0 0 0 2 0 0 0 0 0 0 1 1
 4 1 0 1 0 1 0 0 2 0 0 0 1 0 0 0 0 0 2 0 0 0 2 0 0 0 0 0 0 1 1
 4 0 0 0 0 1 1 1 1 0
 - Additional data here -
20 0 1 2 0 1 0 0 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
20 0 0 1 0 2 0 0 0 0 0 0 0 0 1 0 0 2 1 0 0 1 1 0 0 0 0 2 0 1 1
20 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0
20 0 0 0 0 0 0 0 0 0
21 0 2 1 1 1 0 0 0 2 0 1 1 0 0 0 0 0 0 0 0 0 0 2 0 0 0 0 0 0 0
21 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 2 1 2 0 0 1 0 0 0 0 2 2 1 0
21 0 0 1 0 0 1 0 0 0 1 0 1 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0
21 0 1 0 2 0 1 0 0 0
22 0 0 0 0 0 0 0 0 1 0 2 2 0 0 1 0 0 0 0 1 0 0 3 0 0 0 2 2 0 0
22 0 0 0 0 3 0 0 0 0 1 0 0 0 0 0 0 0 2 2 0 0 2 2 1 1 0 2 0 1 0
22 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 2 0 0 1 0 0 0 0 0 2 0 0 0 0
22 0 0 0 0 0 1 0 0 0
23 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0
23 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0
23 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
23 0 0 0 0 1 1 0 0 0
24 0 0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0
24 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 1 0 0 0 0 0 0
24 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
24 0 0 0 0 0 0 0 0 0
MILI    MILP    PSAD    PSAC    PSAS    STYG    POCD    POCE    POCV    STPP
ACRH    ACRH    ACR2    ACR3    ACR4    ACR5    ACR6    ACR7    ASTM    MON1
MONR    MONE    PACD    PAVM    PACR    CUSS    FUNF    HERL    POLT    PODC
ALVS    GON1    GON2    GONT    POR1    POR2    POR3    CAUT    CYPM    CYP1
CYPS    FAVA    FAVF    FAVT    FAVX    FAVP    FAVS    FAV1    FATA    FATC
FATP    FAT1    GOSA    GOSU    GOSE    GOSP    GOSR    ECHL    HYDE    HYDM
HYDR    LEPP    LETP    MOTC    MOTC    PLAD    PLAS    PLEV    MOSL    DIPH
TRAG    GALF    GALC    MERA    SCA1    ACAE    LOBC    LOBH    SYMR    ECNA
OXYL    MYCE    MYCT    MYC1    PECP    PEC1    CATJ    EUPG    EUPF    PLR1
DEN1    DEN2    DUNA    TUBA    TURB    TURF    TURM    TURP    TURR
          1       2       3       4       5       6       7       8       9      10
         11      12      13      14      15      16      17      18      19      20
         21      22      23      24
```

**Figure 3; The input file to CONDENSE which consists of FORTRAN statements, the data, species codes and site numbers.**

*COMPCLUS*

| | |
|---|---|
| L CORNCLUS | [Loads the COMPCLUS program] |
| AS 3.CON: | [Input and output directed to the console] |
| AS 5.DAMPCOND.DAT | [Assigns the input file to be 'DAMPCOND.DAT' - the product of the CONDENSE program] |
| AS 6.PR: | [Assigns output to the lineprinter] |
| AS 7.NULL: | [Indicates no assignation] |
| ST | [Starts the program] |

*TWINSPAN*

| | |
|---|---|
| L CORNTWIN | [Loads the TWINSPAN program] |
| AS 1.CON: | [Input from the console] |
| AS 3.PR: | [Assigns output to the lineprinter] |
| AS 4.CON: | [Output to the console] |
| AS 5.DAMPCOND.DAT | [Assigns the input file to be 'DAMPCOND.DAT'] |
| AS 7.NULL: | [Indicates no assignation] |
| ST | [Starts the program] |

*DECORANA*

| | |
|---|---|
| L CORNDECO | [Loads the DECORANA program] |
| AS 1.DAMPDECO.CMD | [Assigns a command file which specifies program parameters] |
| AS 3.PR: | [Assigns output to the lineprinter] |
| XAL DAMPDECO.OUT.IN132 | [Creates an ouput file called 'DAMPDECO.OUT'] |
| AS 4.DAMPDECO.OUT | [Assigns output to the file 'DAMPDECO.OUT'] |
| AS 5.DAMPCOND.DAT | [Assigns the input file 'DAMPCOND.DAT'] |
| AS 7.NULL: | [Indicates no assignation] |
| ST | [Starts the program] |

Within each program there exists the capability of changing certain parameters; for example, sites and species may be omitted or data transformed. These manipulations are detailed in the appropriate program manuals and the reader is directed to these for further information.

## 5. OUTPUT INTERPRETATION

The output derived from the Cornell Programs, is described by the appropriate manuals. The main features of output for the present study are discussed briefly below.

### *COMPCLUS*

The output of COMPCLUS consisted of a description of the clusters and which sites were included in each. Also detailed were the most abundant species present in each cluster.

```
 99   24DAMPIER CORAL COMMUNITY DATA 1978 - 99 SPECIES 24 SAMPLES   TCDAMP**S
(I3, 10(I3, F2.0))                                         10
  1 151. 331. 351. 401. 481. 672. 771. 951. 961. 981.
  2 101. 131. 151. 231. 281. 301. 321. 331. 351. 381.
  2 401. 431. 461. 481. 491. 521. 531. 541. 571. 581.
  2 591. 601. 681. 691. 721. 761. 771. 891. 952. 962.
  2 971. 991.
  3 131. 231. 271. 352. 381. 481. 492. 501. 531. 561.
  4  43.  72. 101. 122. 131. 152. 231. 272. 291. 311.
  4 331. 351. 382. 421. 482. 522. 591. 601. 661. 691.
  4 712. 721. 741. 772. 791. 891. 951. 961. 971. 981.
  - Additional data here -
 20  21.  32.  51.  81.  91. 111. 241. 331. 352. 441.
 20 472. 481. 511. 521. 572. 591. 601. 631. 771. 781.
 20 791.
 21  22.  31.  41.  51.  92. 111. 121. 232. 341. 351.
 21 472. 481. 492. 521. 572. 582. 591. 631. 661. 701.
 21 721. 771. 781. 791. 921. 942. 961.
 22  91. 112. 122. 151. 201. 233. 272. 282. 353. 401.
 22 482. 492. 522. 532. 541. 551. 572. 591. 661. 741.
 22 761. 772. 801. 862. 961.
 23 111. 131. 191. 201. 311. 401. 481. 521. 951. 961.
 24  91. 111. 121. 211. 341. 361. 491. 531. 541. 671.
  0
MILI     MILP     PSAD     PSAC     PSAS     STYG     POCD     POCE     POCV     STPP
ACRH     ACRH     ACR2     ACR3     ACR4     ACR5     ACR6     ACR7     ASTM     MON1
MONR     MONE     PACD     PAVM     PACR     CUSS     FUNF     HERL     POLT     PODC
ALVS     GON1     GON2     GONT     POR1     POR2     POR3     CAUT     CYPM     CYP1
CYPS     FAVA     FAVF     FAVT     FAVX     FAVP     FAVS     FAV1     FATA     FATC
FATP     FAT1     GOSA     GOSU     GOSE     GOSP     GOSR     ECHL     HYDE     HYDM
HYDR     LEPP     LETP     MOTC     MOTC     PLAD     PLAS     PLEV     MOSL     DIPH
TRAG     GALF     GALC     MERA     SCA1     ACAE     LOBC     LOBH     SYMR     ECNA
OXYL     MYCE     MYCT     MYC1     PECP     PEC1     CATJ     EUPG     EUPF     PLR1
DEN1     DEN2     DUNA     TUBA     TURB     TURF     TURM     TURP     TURR
            1        2        3        4        5        6        7        8        9       10
           11       12       13       14       15       16       17       18       19       20
           21       22       23       24
```

**Figure 4; The output file generated by CONDENSE from the file shown in Fig. 3.** This file is now ready for use as input to other Cornell Ecology Programs.

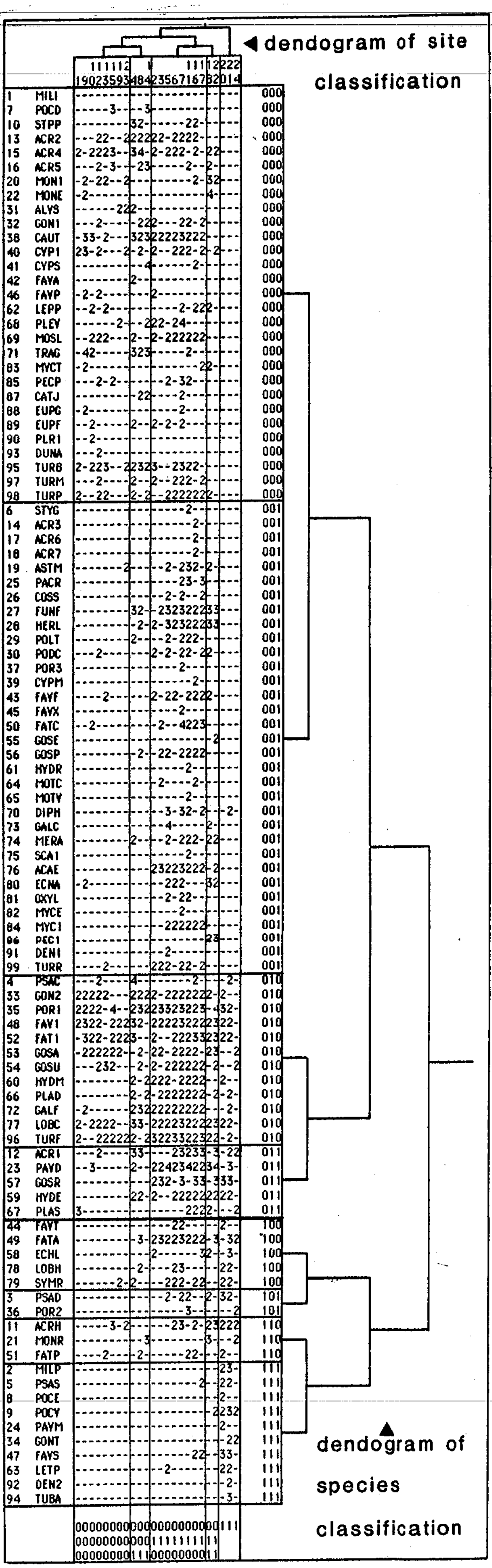


Figure 5; An example of a site by species table produced by TWINSPAN.

### *TWINSPAN*

Output gained from TWINSPAN allowed dendograms to be drawn of sites and species (as in Fig. 8). Indicator species for each division were also produced. The tabular arrangement of species and sites (Fig. 5) indicated the arrangement of species with regard to their site preferences. For example, those species shown at the bottom of Fig. 5 tended to occur in the sites numbered 20, 21 and 24.

### *DECORANA*

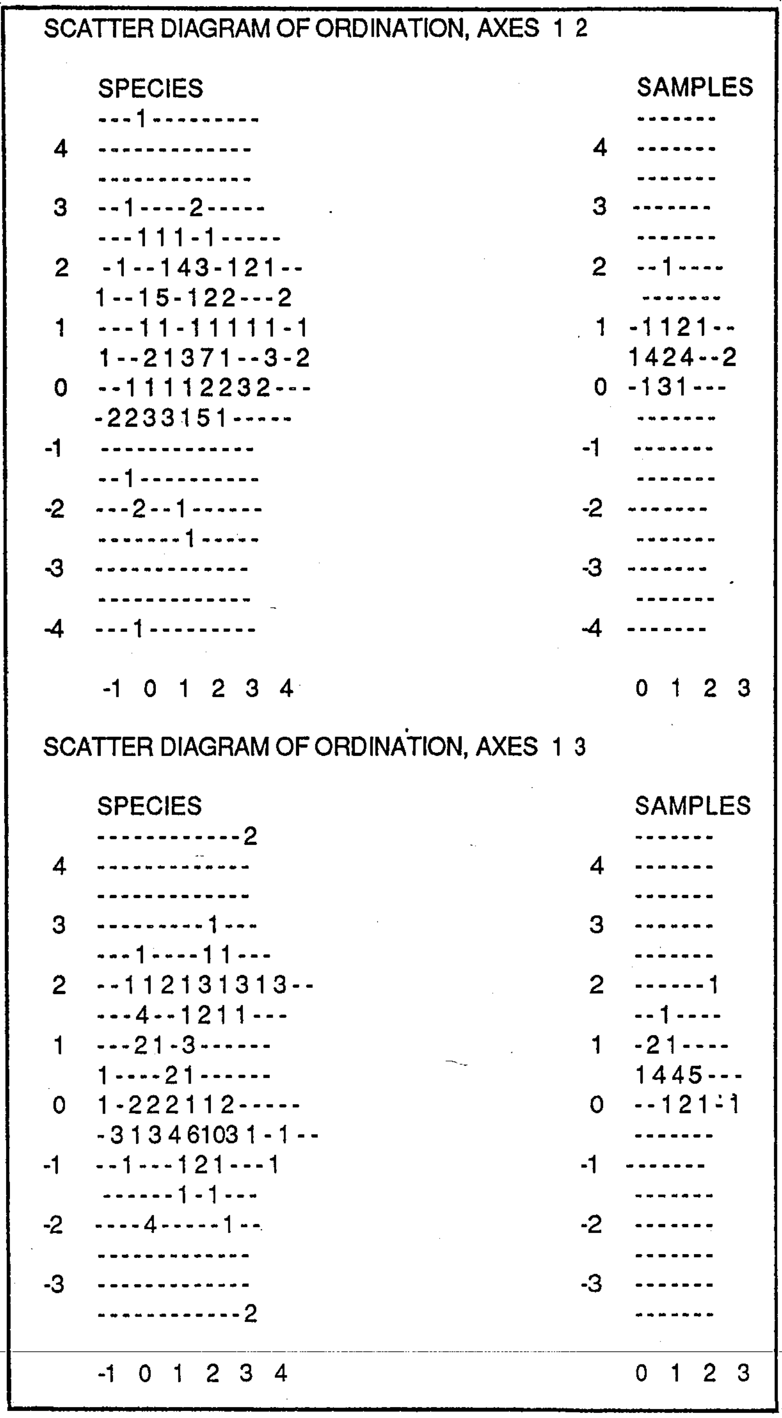
Ordinations produced by DECORANA appeared as four axes for both sites and species, in which sites were ranked from highest to lowest. Values for each axis (Fig. 6) have been multiplied by 100. Hence a value of 310 (Fig. 6, * ) can be interpreted as 3.1 sd (standard deviations), and so on. These axes were also plotted in scatter diagrams (Fig. 7), although for clarification it was necessary to replot the axes using the printed values, as the scatter diagrams did not show species and site numbers. The main function of the scatter diagram output by DECORANA (Fig. 7) was to illustrate the presence of obvious gradients. The replotting of data from Fig. 6 can be seen in Fig. 11.

```
 99 24DAMPIER CORAL COMMUNITY DATA 1978 - 99 SPECIES 24 SAMPLES TCDAMP
DECORANA OPTIONS - DOWNWEIGHTING 0 RESCALING 4 ANALYSIS 0 SEGMENTS 26 THRESHOLD 0.00
TRANSFORMATION   0.00  0.00

SAMPLE SCORES - WHICH ARE WEIGHTED MEAN SPECIES SCORES
   N  NAME   AX1 AX2 AX3 AX4  !  RANKED 1    !  RANKED 2   !  RANKED 3    ! RANKED 4  !
                              !  EIG=0.362   !  EIG=0.194  !  EIG=0.135   ! EIG=0.088 !
   1   1     112 102 108   3  ! 21   21 *310 !  18   18 225 !  20  20  206 !10 10 168  !
   2   2     121  59  71 114  ! 20   20  305 !   5    5 139 !  19  19  168 ! 9  9 124  !
   3   3     177  34  60  92  ! 24   24  218 !  24   24 129 !  23  23  138 !19 19 121  !
   4   4     119   0  54  59  ! 22   22  194 !  22   22 120 !  15  15  116 ! 2  2 114  !
   5   5     177 139  48  98  ! 17   17  183 !  15   15 119 !   1   1  108 ! 7  7 112  !
   6   6     152  78  98  86  !  3    3  177 !   1    1 102 !   6   6   98 ! 5  5  98  !
   7   7     158  81  83 112  !  5    5  177 !  20   20  99 !   9   9   95 !11 11  93  !
   8   8     120  41  91  42  !  7    7  158 !  11   11  96 !  22  22   95 ! 3  3  92  !
   9   9      58  95  95 124  ! 16   16  154 !   9    9  95 !   8   8   91 ! 6  6  86  !
  10  10      98  49  52 168  !  6    6  152 !  17   17  88 !  13  13   90 !22 22  85  !
  11  11     137  96  12  93  ! 11   11  137 !  21   21  85 !   7   7   83 !17 17  83  !
  12  12      82  64  68  68  ! 19   19  135 !  13   13  84 !  18  18   79 !20 20  71  !
  13  13      86  84  90  39  ! 18   18  124 !   7    7  81 !   2   2   71 !12 12  68  !
  14  14       0  67  55  51  !  2    2  121 !   6    6  78 !  12  12   68 !21 21  66  !
  15  15      99 119 116  45  !  8    8  120 !  23   23  76 !   3   3   60 !18 18  62  !
  16  16     154  56  59   0  !  4    4  119 !  14   14  67 !  16  16   59 ! 4  4  59  !
  17  17     183  88  45  83  !  1    1  112 !  12   12  64 !  14  14   55 !14 14  51  !
  18  18     124 225  79  62  ! 15   15   99 !   2    2  59 !   4   4   54 !23 23  50  !
  19  19     135  11 168 121  ! 10   10   98 !  16   16  56 !  10  10   52 !15 15  45  !
  20  20     305  99 206  71  ! 23   23   93 !  10   10  49 !   5   5   48 ! 8  8  42  !
  21  21     310  85  25  66  ! 13   13   86 !   8    8  41 !  17  17   45 !13 13  39  !
  22  22     194 120  95  85  ! 12   12   82 !   3    3  34 !  21  21   25 !24 24  25  !
  23  23      93  76 138  50  !  9    9   58 !  19   19  11 !  11  11   12 ! 1  1   3  !
  24  24     218 129   0  25  ! 14   14    0 !   4    4   0 !  24  24    0 !16 16   0  !
```

**Figure 6; Axes produced by DECORANA for all species and all sites.** *Values are multiplied by 100 and must be reduced when replotting for scatter diagrams.

the printed values, as the scatter diagrams did not show species and site numbers. The main function of the scatter diagram output by DECORANA (Fig. 7) was to illustrate the presence of obvious gradients. The replotting of data from Fig. 6 can be seen in Fig. 11.



```
SCATTER DIAGRAM OF ORDINATION, AXES 1 2

      SPECIES                              SAMPLES
      ---1---------                        -------
 4    -------------                   4    -------
      -------------                        -------
 3    --1----2-----                   3    -------
      ---111-1-----                        -------
 2    -1--143-121--                   2    --1----
      1--15-122---2                        -------
 1    ---11-11111-1                   1    -1121--
      1--21371--3-2                        1424--2
 0    --11112232---                   0    -131---
      -2233151-----                        -------
-1    -------------                  -1    -------
      --1----------                        -------
-2    ---2--1------                  -2    -------
      -------1-----                        -------
-3    -------------                  -3    -------
      -------------                        -------
-4    ---1---------                  -4    -------

      -1  0  1  2  3  4                    0  1  2  3

SCATTER DIAGRAM OF ORDINATION, AXES 1 3

      SPECIES                              SAMPLES
      ------------2                        -------
 4    -------------                   4    -------
      -------------                        -------
 3    ---------1---                   3    -------
      ---1----11---                        -------
 2    --112131313--                   2    ------1
      ---4--1211---                        --1----
 1    ---21-3------                   1    -21----
      1----21------                        1445---
 0    1-222112-----                   0    --121-1
      -313461031-1--                       -------
-1    --1---121---1                  -1    -------
      ------1-1---                         -------
-2    ----4-----1--                  -2    -------
      -------------                        -------
-3    -------------                  -3    -------
      ------------2                        -------

      -1  0  1  2  3  4                    0  1  2  3
```

**Figure 7;** **Examples of scatter diagrams produced by DECORANA for all species and all sites.** Numbers within each diagram refer to the frequency of occurrence of species or sites. For example in the scatter diagram of samples from axes 1 and 2, the number '4' signifies that four sites are included in that 'area' (ie. within the resolution of the diagram).

The eigenvalue is given at the head of each axis (Fig. 6). According to Hill (1979b) axes which have eigenvalues much lower than the highest value are probably not significant. For example, in Fig. 6, where values are 0.362, 0.194, 0.135 and 0.088 for axes 1 to 4 respectively, only the first three axes are likely to be significant.

## B. ANALYSIS OF DAMPIER ARCHIPELAGO CORAL COMMUNITIES

### 1. INTRODUCTION

In the past the structure and zonation of coral communities have been explained on the basis of prevailing environmental conditions (Braithwaite, 1971; Dana, 1976; Glynn, 1976; Done, 1977; Veron and Done, 1979). Recent information, however, has suggested that aperiodic, episodic events may also determine coral zonation and community structure (Connel, 1978; Done, 1983). Stated simply, the question is to what degree the species present in a community are there as a result of the surrounding physical and biotic environment.

The interpretation of community composition is complicated by the presence of widespread species that may overlap communities so much that their presence is not an indication of the long term physical conditions. This observation has led to the suggestion that the growth forms of ubiquitous coral species may be more distinctly zoned in their distribution. Thus alternatively, the form of a species may be a better indicator of the environment than the presence or absence of species (Done, 1983).

Light, and water movement (waves, currents and tides), are environmental factors recognised as major determinants of coral distribution (Done, 1983). Water movement also determines sediment dynamics (sediment depth, grain size, suspended load and deposition), which is another factor determining coral distribution patterns (Loya, 1976).

The aim of this study was to use the multivariate techniques described in Section A to determine broad patterns in coral community composition and to find their physical determinants in different areas of the Dampier Archipelago. The approach taken was to group sites on the basis of species composition and to determine if physical factors could be used to explain the grouping of these communities.

### 2. STUDY AREA

The Dampier Archipelago is a marine area characterised by groups of islands, rocky reefs, coral reefs and shoals that rise from a general deep water plain (Semenuik *et al.*, 1982). Numerous geomorphic units are recognised within the Archipelago based mainly on substrate type, substrate heterogeneity and tidal level. These units have been developed by a combination of factors which include: erosion versus sedimentation, underlying stratigraphic sequence, tidal level, wave action and ancestral (pre-Holocene) physiography (Semenuik *et al.*, 1982).

Virtually every shoreline in this region has exposed and protected settings. In addition there is a wide range of habitats throughout the Archipelago that vary from those exposed to wave action on outer islands with clear waters (eg. Sites 20, 21, 22 and 24, Table 1, Fig. 1), to sheltered areas within bays that can become extremely turbid (eg. Sites 8, 9 and 10, Table 1, Fig. 1). Intermediate conditions exist for shores of a different aspect, topography, slope and varying current regimes (Marsh, 1978).

## 3. METHODS

### Coral data

Data used for clustering (classification) and ordination were obtained from coral species lists reported in Marsh (1978). These data were collected from a number of sites in the Dampier Archipelago in 1978 (Fig. 1). At each site transects were made from the intertidal zone to a depth of 7 to 9 m where coral reefs gave way to a sandy bottom (Semenuik *et al.*, 1982). Sites were surveyed by divers using a boat-mounted hookah apparatus, SCUBA and snorkelling. The depth, substrate type, an indication of species abundance at each site (in terms of absent, rare common and abundant), and the percent cover of living coral were also noted (Marsh, 1978).

To facilitate analysis, sample sites were renumbered (Table 1), and a complete species list of all corals was recorded. All species were given an individual number to generate presence and absence data for each site, this information was then stored on computer file and subsequently transformed to a 'restricted condensed format' using the CONDENSE program (Section A).

### Site and species classification

The program TWINSPAN (Hill, 1979a) was used to classifiy sites and species using four divisive levels. Initially all species (99) and sites (24) were used in the classification. A second classification, however, was used after removing rare species (leaving a total of 79) and one site (Site 9; Withnell Bay barge). This was performed because the distribution of rare species (those occurring at one site only) was not considered a good indicator of environmental conditions. Furthermore the barge in Withnell Bay was an artificial and unique substrate. General patterns were being sought, which could be obscured by rare species and outlying samples (Gauch, 1977).

Groups of sites and species derived from TWINSPAN were then examined on the basis of predominant substrate type and other physical characteristics at each site. Species preferences for water conditions (for example; exposed, protected, turbid or clear) were determined for the majority of species present using taxonomic information described by Braithwaite (1971), Marsh (1978), Mather and Bennet (1978), Veron and Pichon (1976, 1979, 1982) and Veron *et al.* (1977).

**Table 1;** **Code numbers allocated for this study to sample sites, coral genera and species.** Data and original site codes from Marsh (1978), (see Fig. 1).

| Sample site | Site code (Marsh, 1978) | Site code (This study) | Number of genera | Number of species | Range of % living cover |
|---|---|---|---|---|---|
| King Bay/Dampier | ML16 | 1 | 8 | 10 | <1% |
| North King Bay | ML15 | 2 | 21 | 32 | 5-50% |
| South Noname Bay | ML14 | 3 | 16 | 20 | 5% |
| Noname Bay | ML2 | 4 | 23 | 30 | 1-50% |
| Noname Rocks | ML3 | 5 | 32 | 38 | <1-30% |
| Near Noname Bay | ML1 | 6 | 22 | 33 | 0-50% |
| Withnell/Noname Bay | ML5 | 7 | 35 | 55 | <1-60% |
| Withnell Bay | ML7 | 8 | 17 | 25 | 10-20% |
| Withnell Bay barge | ML27 | 9 | 13 | 15 | - |
| Withnell east | ML28 | 10 | 15 | 16 | 1-5% |
| Conzinc Bay | ML9a | 11 | 34 | 51 | <1-80% |
| North Conzinc Bay | ML10b | 12 | 16 | 25 | <1-20% |
| Southwest Dolphin Is. | ML11a | 13 | 11 | 16 | 5-10% |
| West end of Boat Passage | ML11b | 14 | 16 | 20 | 5-20% |
| Central Boat Passage | ML11c | 15 | 9 | 12 | - |
| North Conzinc Is. | ML12 | 16 | 29 | 48 | 5-10% |
| West Angel Is. | ML13 | 17 | 27 | 40 | 5-50% |
| North Gidley/Legendre Is. | - | 18 | 23 | 29 | 50-100% |
| Nickol Bay | - | 19 | 7 | 7 | <1% |
| Kendrew Is. | WAM1 | 20 | 14 | 21 | 1-20% |
| Kendrew Is. | WAM2 | 21 | 21 | 27 | 5-50% |
| Malus Is. (Whalers Bay) | ML30 | 22 | 19 | 25 | 60-80% |
| North Lady Nora Is. | ML17a | 23 | 8 | 10 | <1% |
| Miller Rocks | ML17b | 24 | 9 | 10 | 1-5% |

### Site ordination

Ordination of sites was performed using the technique of detrended correspondence analysis incorporated into the computer package DECORANA (Hill, 1979b). The axes of variation derived from this process were then examined using known site characteristics. A second ordination process was carried out after removing rare species and Site 9, for the reasons given above.

## 4. RESULTS

### Site classification

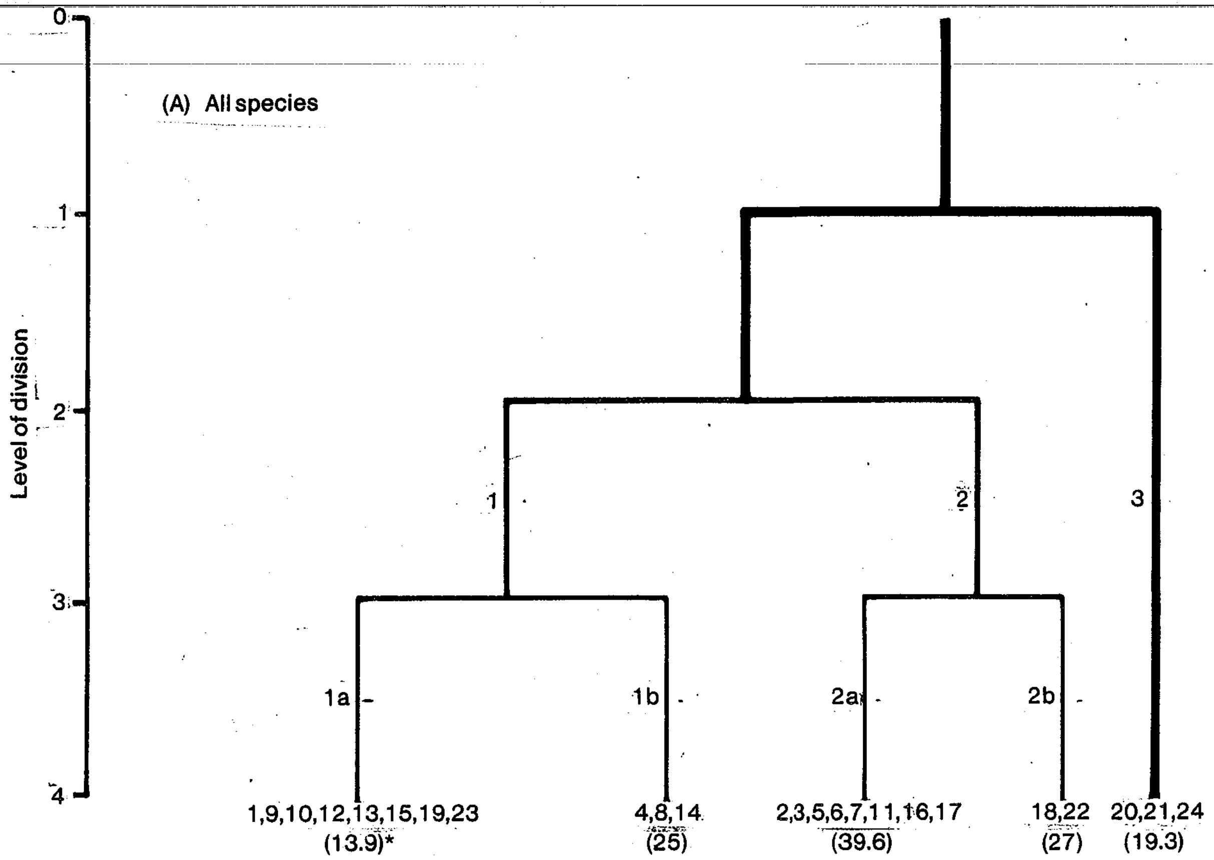
TWINSPAN, for both classifications, separated the offshore from the nearshore sites (20, 21 and 24) at the first division (Fig. 8). An additional outer site (Lady Nora Island - Site 23), in both classifications, was grouped with sites occurring on or near the Burrup Peninsula (Fig. 9). This occurred because there were species present both at Site 23 and on the Burrup Peninsula that did not occur at the other offshore sites. These species were *Alveopora sp.* (Poritidae); *Acropora sp.*, *Astreopora myriopthalma* (Acroporidae); *Favites sp.* (Faviidae) and *Turbinaria bifrons* (Dendrophylliidae).

The main subgroups occurring on the Burrup Peninsula were the relativley sheltered sites (Group 1b: Sites 1, 8, 10, 12-15) which tended to have a lower number of species present (Fig. 8(b)); and the more exposed sites (Group 2a: Sites 2-7, 11, 16, 17) which had more species.

In general there was less living coral (<1% - 20% cover, Marsh, 1978) and a low species diversity in protected sites on the Burrup Peninsula (Group 1b, Fig. 8(b), Table 2) compared with more

**Table 2; The number of genera and species present in coral families occurring in protected and exposed sites on the Burrup Peninsula and at offshore sites, (see Fig. 8).**

| Family | Protected sites on the Burrup Peninsula (1b) (Fig. 8b) | | | | | | | | | | | | | | Exposed sites on the Burrup Peninsula (2a) (Fig. 8b) | | | | | | | | | | | | | | | | | | Offshore sites (3) (Fig. 8b) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 8 | | 10 | | 12 | | 13 | | 14 | | 15 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 11 | | 16 | | 17 | | 20 | | 21 | | 22 | | 24 | |
| | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S | G | S |
| Milleporidae | | | | | | | 1 | 1 | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | | | | |
| Thamnasteriidae | | | | | | | 1 | 1 | | | | | | | | | | | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | | | | |
| Astrocoeniidae | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | |
| Pocilloporidae | | | 1 | 1 | | | | | | | 2 | 2 | | | 1 | 1 | | | 2 | 2 | | | | | | | 2 | 2 | 2 | 2 | | | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 |
| Acroporidae | 1 | 1 | 1 | 4 | 1 | 1 | 2 | 5 | 2 | 3 | 2 | 3 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 2 | 1 | 4 | 2 | 5 | 2 | 4 | 3 | 9 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 2 | 2 |
| Agariciidae | | | | | 1 | 1 | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| Siderastreidae | | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | 1 | 1 | | | | | 1 | 1 | | | | | | | | |
| Fungiidae | | | | 2 | 2 | | | 1 | 1 | | | | | | | 2 | 2 | 1 | 1 | 2 | 2 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | | | | | 2 | 2 | |
| Poritidae | 2 | 2 | 2 | 3 | 2 | 2 | 7 | 10 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 1 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 |
| Faviidae | 3 | 3 | 8 | 11 | 7 | 8 | | | 6 | 7 | 7 | 7 | 3 | 4 | 10 | 16 | 9 | 12 | 8 | 10 | 10 | 14 | 10 | 14 | 12 | 20 | 12 | 21 | 11 | 22 | 12 | 20 | 5 | 9 | 9 | 11 | 6 | 10 | 4 | 4 |
| Merulinidae | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | | | 1 | 1 | 2 | 2 | 1 | 1 | | | | | | | 1 | 1 | | |
| Mussidae | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 4 | 3 | 4 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | | |
| Pectiniidae | | | | | | | 1 | 1 | | | | | 1 | 1 | | | | | | | 4 | 4 | 2 | 2 | 4 | 5 | 3 | 3 | 1 | 1 | 1 | 2 | | | | | 2 | 2 | | |
| Caryophylliidae | | | 1 | 1 | 2 | 2 | | | | | 1 | 1 | | | 1 | 1 | | | 1 | 1 | 1 | 1 | | | 2 | 3 | | | | | | | | | | | | | | |
| Dendrophylliidae | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 5 | 1 | 4 | 1 | 3 | 1 | 1 | 1 | 4 | 1 | 2 | 1 | 4 | 2 | 4 | 1 | 4 | 1 | 5 | 1 | 5 | 1 | 3 | 1 | 4 | | | 3 | 3 | 1 | 1 | | |
| Total: Genera (G) | 8 | | 17 | | 15 | | 16 | | 11 | | 16 | | 9 | | 21 | | 16 | | 23 | | 32 | | 22 | | 35 | | 34 | | 29 | | 27 | | 14 | | 21 | | 19 | | 9 | |
| Species (S) | | 10 | | 25 | | 16 | | 25 | | 16 | | 20 | | 12 | | 32 | | 20 | | 30 | | 38 | | 33 | | 55 | | 51 | | 48 | | 40 | | 21 | | 27 | | 25 | | 10 |



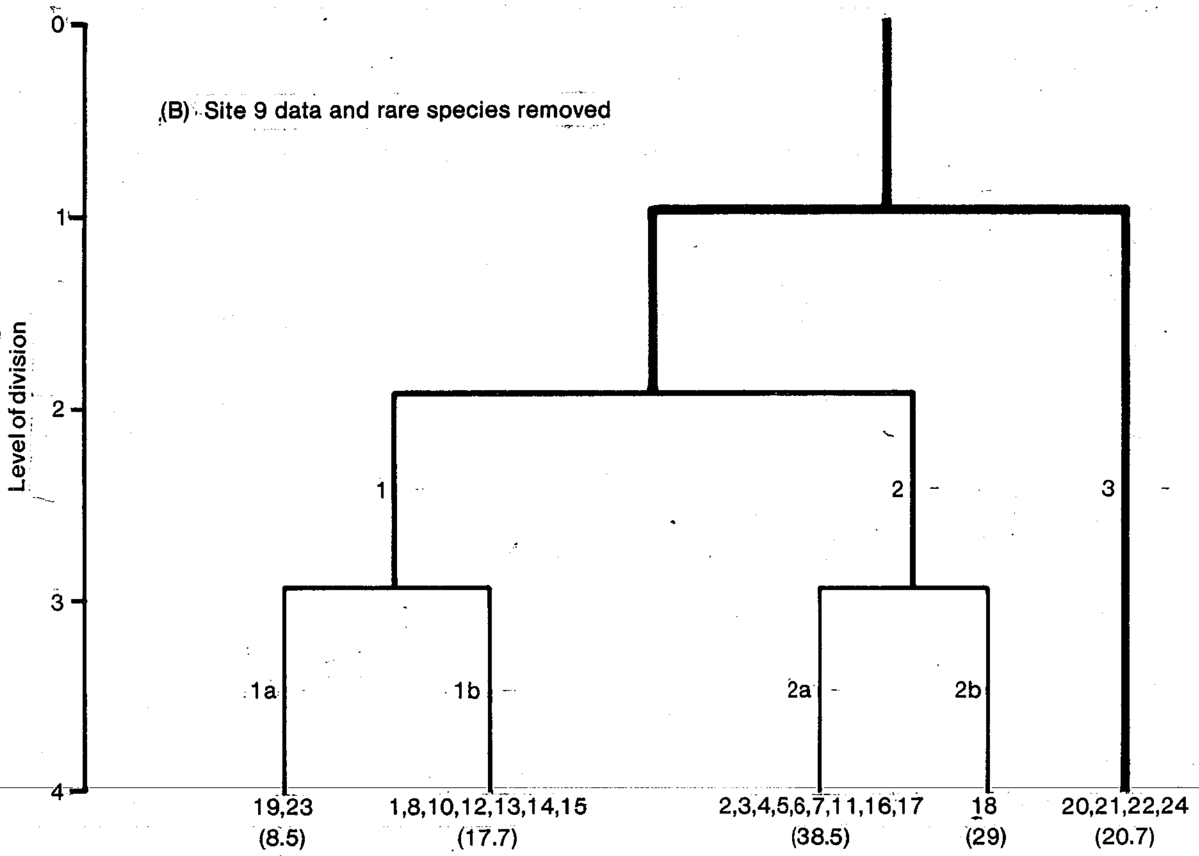


**Figure 8;** **Two dendograms of sample sites produced by TWINSPAN.** *Refers to the average number of species per site.

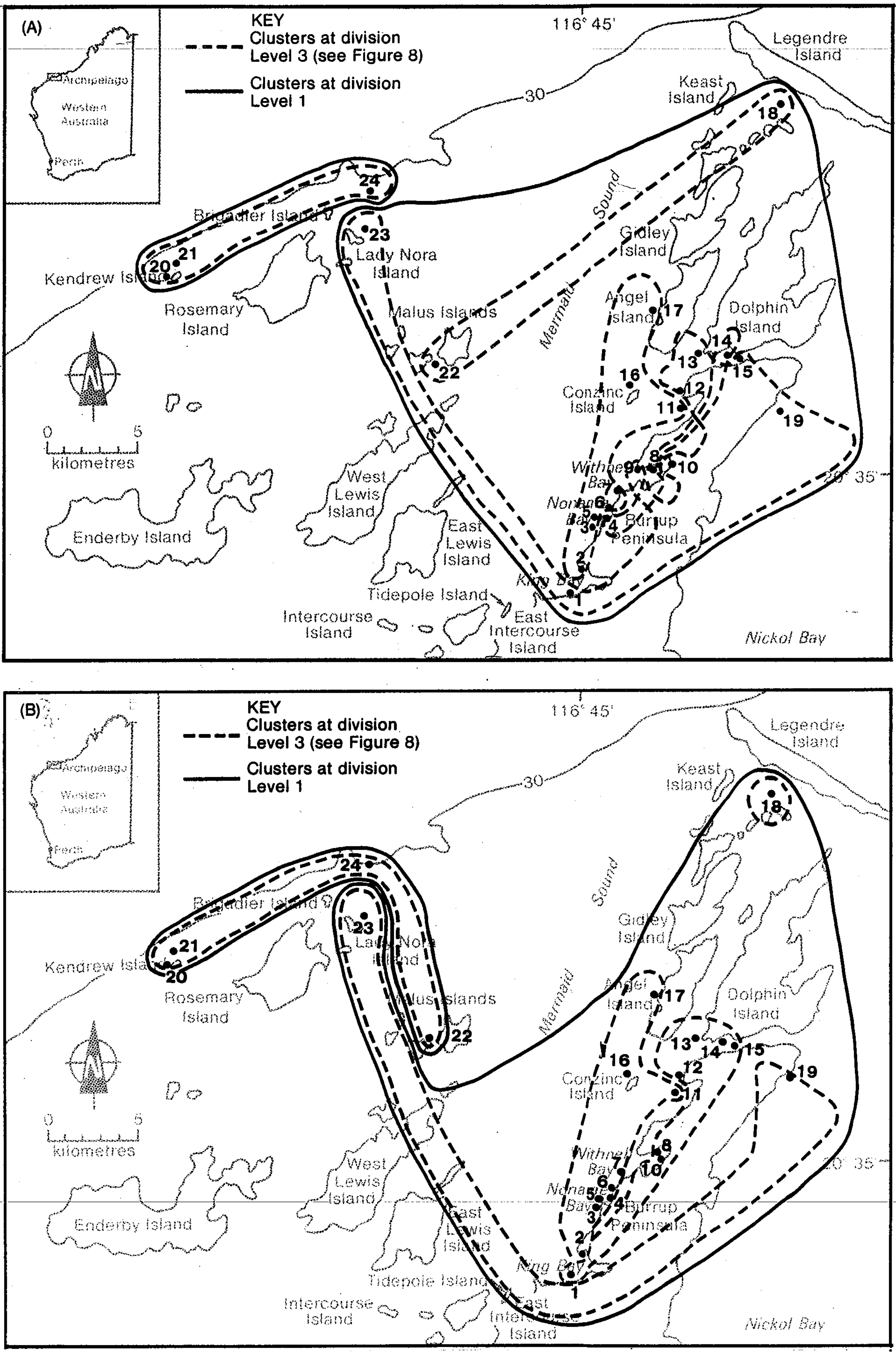


**Figure 9; Site groupings produced by TWINSPAN.** Map A for all species; Map B has Site 9 and rare species removed.

exposed sites (Group 2a, Fig 8(b) that had more living coral (up to 80% cover) and a greater diversity (Table 2). At offshore sites (20, 21, 22 and 24) on average there was less living coral, though cover up to 80% was noted (Marsh, 1978), and species numbers were also low when compared with the exposed sites on the Burrup Peninsula.

### Species classification

Species assemblages in general reflected the site classifications (Fig. 10). The most notable trend was the classification of some species into their preferred habitats. Species known to be rarely found in turbid waters, such as *Pocillopora eydouxi*, *P. verrucosa*, *Millepora platyphylla* and *Favia stelligera* were exclusively found in the offshore habitats (20, 21, 24). On the other hand, species preferring or tolerating silty conditions or turbid waters, *Moseleya latistellata*, *Trachyphyllia geoffroyi*, *Euphyllia glabrescens* and *E. (Fimbriaphyllia) sp.* (Fig. 10), were confined to inshore sites (Groups 1 & 2: Sites 1-17 Fig. 8). Species ubiquitous at most sites included *Acropora hyacinthus*, *Favites* species, *Porites* species and *Turbinaria frondens*.

### Site ordination

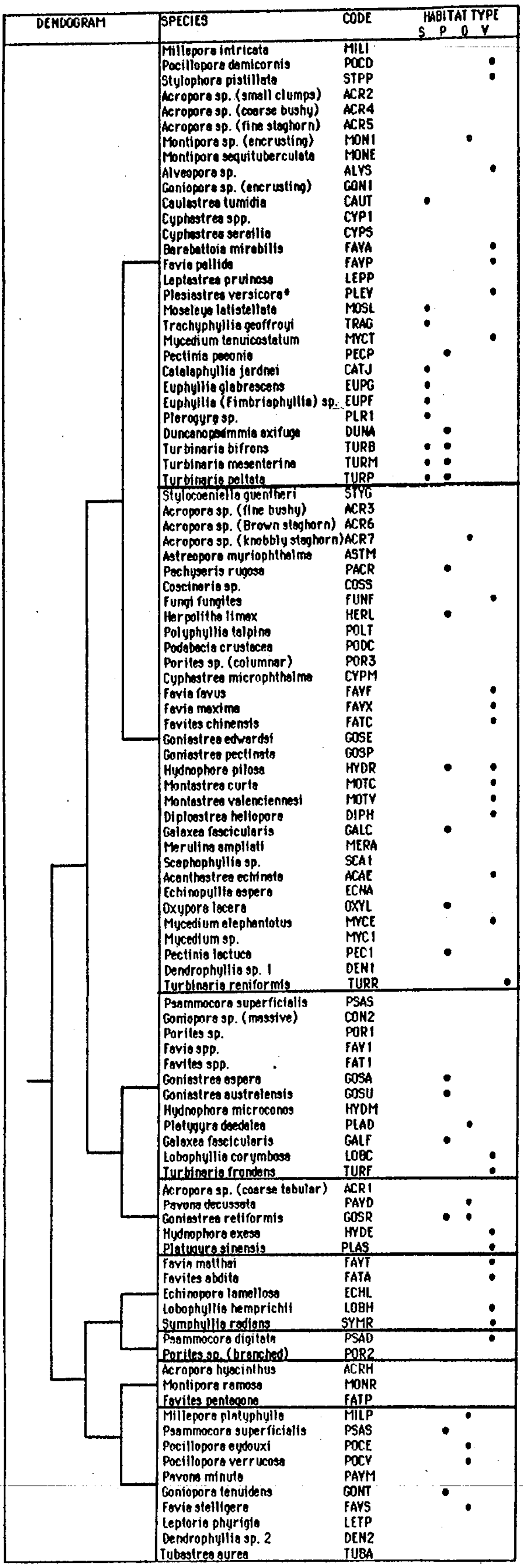
The greatest separation (variance) of sites occurred on the higher axes of ordination (axis 1: eigenvalue = 0.362, and axis 2: eigenvalue = 0.194). Axes 3 and 4 had eigenvalues of 0.135 and 0.088 respectively.

Substrate characteristics (the proportion of live coral found on rock, sand or coral rubble) appeared most able to explain the distribution of sites on the axes (Fig. 11). Ordination in general confirmed those groups classified by TWINSPAN. The grouping of Site 23 with sites on the Burrup Peninsula, just as TWINSPAN grouped them, was also evident using the DECORANA ordination program. Both Site 19 and Site 23, which were grouped together by TWINSPAN, were exposed to waves only from an easterly direction (Fig. 11).

## GENERAL DISCUSSION

The groups of sites identified here by computer analysis are similar to those described by Marsh (1978). The Dampier Archipelago has a rich coral fauna compared with other areas in Western Australia (Wilson and Marsh, 1979), chiefly because there is a wide range of coastal habitats varying from exposed to very sheltered (Marsh, 1978; Semenuik *et al.*, 1982).

While there were no distinctly different coral assemblages in each habitat, 'indicator species' were present which, by their tolerance of (or preference for) certain environmental conditions, gave an indication of some site characteristics. The distribution of families in the sites classified by



| SPECIES | CODE | HABITAT TYPE | | | |
|---|---|---|---|---|---|
| | | S | P | O | V |
| Millepora intricata | MILI | | | | |
| Pocillopora damicornis | POCD | | | | ● |
| Stylophora pistillata | STPP | | | | ● |
| Acropora sp. (small clumps) | ACR2 | | | | |
| Acropora sp. (coarse bushy) | ACR4 | | | | |
| Acropora sp. (fine staghorn) | ACR5 | | | | |
| Montipora sp. (encrusting) | MON1 | | | ● | |
| Montipora sequituberculata | MONE | | | | |
| Alveopora sp. | ALYS | | | | ● |
| Goniopora sp. (encrusting) | GON1 | | | | |
| Caulastrea tumidia | CAUT | ● | | | |
| Cyphastrea spp. | CYP1 | | | | |
| Cyphastrea serailia | CYPS | | | | |
| Barabattoia mirabilis | FAVA | | | | ● |
| Favia pallida | FAVP | | | | ● |
| Leptastrea pruinosa | LEPP | | | | |
| Plesiastrea versicora* | PLEV | | | | ● |
| Moseleya latistellata | MOSL | ● | | | |
| Trachyphyllia geoffroyi | TRAG | ● | | | |
| Mycedium tenuicostatum | MYCT | | | | ● |
| Pectinia paeonia | PECP | | ● | | |
| Catalaphyllia jardnei | CATJ | ● | | | |
| Euphyllia glabrescens | EUPG | ● | | | |
| Euphyllia (Fimbriaphyllia) sp. | EUPF | ● | | | |
| Plerogyra sp. | PLR1 | ● | | | |
| Duncanopsammia axifuga | DUNA | | ● | | |
| Turbinaria bifrons | TURB | ● | ● | | |
| Turbinaria mesenterina | TURM | ● | ● | | |
| Turbinaria peltata | TURP | ● | ● | | |
| Stylocoeniella guentheri | STYG | | | | |
| Acropora sp. (fine bushy) | ACR3 | | | | |
| Acropora sp. (Brown staghorn) | ACR6 | | | | |
| Acropora sp. (knobbly staghorn) | ACR7 | | | ● | |
| Astreopora myriophthalma | ASTM | | | | |
| Pachyseris rugosa | PACR | | ● | | |
| Coscinaria sp. | COSS | | | | |
| Fungi fungites | FUNF | | | | ● |
| Herpolitha limax | HERL | | ● | | |
| Polyphyllia talpina | POLT | | | | |
| Podabacia crustacea | PODC | | | | |
| Porites sp. (columnar) | POR3 | | | | |
| Cyphastrea microphthalma | CYPM | | | | |
| Favia favus | FAVF | | | | ● |
| Favia maxima | FAVX | | | | ● |
| Favites chinensis | FATC | | | | ● |
| Goniastrea edwardsi | GOSE | | | | |
| Goniastrea pectinata | GOSP | | | | |
| Hydnophora pilosa | HYDR | | ● | | ● |
| Montastrea curta | MOTC | | | | ● |
| Montastrea valenciennesi | MOTV | | | | ● |
| Diploastrea heliopora | DIPH | | | | ● |
| Galaxea fascicularis | GALC | | ● | | |
| Merulina ampliata | MERA | | | | |
| Scaphophyllia sp. | SCA1 | | | | |
| Acanthastrea echinata | ACAE | | | | ● |
| Echinopyllia aspera | ECNA | | | | |
| Oxypora lacera | OXYL | | ● | | |
| Mycedium elephantotus | MYCE | | | | ● |
| Mycedium sp. | MYC1 | | | | |
| Pectinia lactuca | PEC1 | | ● | | |
| Dendrophyllia sp. 1 | DEN1 | | | | |
| Turbinaria reniformis | TURR | | | | ● |
| Psammocora superficialis | PSAS | | | | |
| Goniopora sp. (massive) | CON2 | | | | |
| Porites sp. | POR1 | | | | |
| Favia spp. | FAV1 | | | | |
| Favites spp. | FAT1 | | | | |
| Goniastrea aspera | GOSA | | ● | | |
| Goniastrea australensis | GOSU | | ● | | |
| Hydnophora microconos | HYDM | | | | |
| Platygyra daedalea | PLAD | | | ● | |
| Galaxea fascicularis | GALF | | ● | | |
| Lobophyllia corymbosa | LOBC | | | | ● |
| Turbinaria frondens | TURF | | | | ● |
| Acropora sp. (coarse tabular) | ACR1 | | | | |
| Pavona decussata | PAVD | | | ● | |
| Goniastrea retiformis | GOSR | | ● | ● | |
| Hydnophora exesa | HYDE | | | | ● |
| Platygyra sinensis | PLAS | | | | ● |
| Favia matthai | FAVT | | | | ● |
| Favites abdita | FATA | | | | ● |
| Echinopora lamellosa | ECHL | | | | |
| Lobophyllia hemprichii | LOBH | | | | ● |
| Symphyllia radians | SYMR | | | | ● |
| Psammocora digitata | PSAD | | | | ● |
| Porites sp. (branched) | POR2 | | | | |
| Acropora hyacinthus | ACRH | | | | |
| Montipora ramosa | MONR | | | | |
| Favites pentagona | FATP | | | | |
| Millepora platyphylla | MILP | | | ● | |
| Psammocora superficialis | PSAS | | ● | | |
| Pocillopora eydouxi | POCE | | | ● | |
| Pocillopora verrucosa | POCV | | | ● | |
| Pavona minuta | PAVM | | | | |
| Goniopora tenuidens | GONT | | ● | | |
| Favia stelligera | FAVS | | | ● | |
| Leptoria phyrigia | LETP | | | | |
| Dendrophyllia sp. 2 | DEN2 | | | | |
| Tubastrea aurea | TUBA | | | | |

**KEY**

Habitat type - known preferences of
species: S - silty or turbid
P - protected
O - clear waters
V - variable conditions

Figure 10; Species classification (for all sites and species) produced by TWINSPAN.

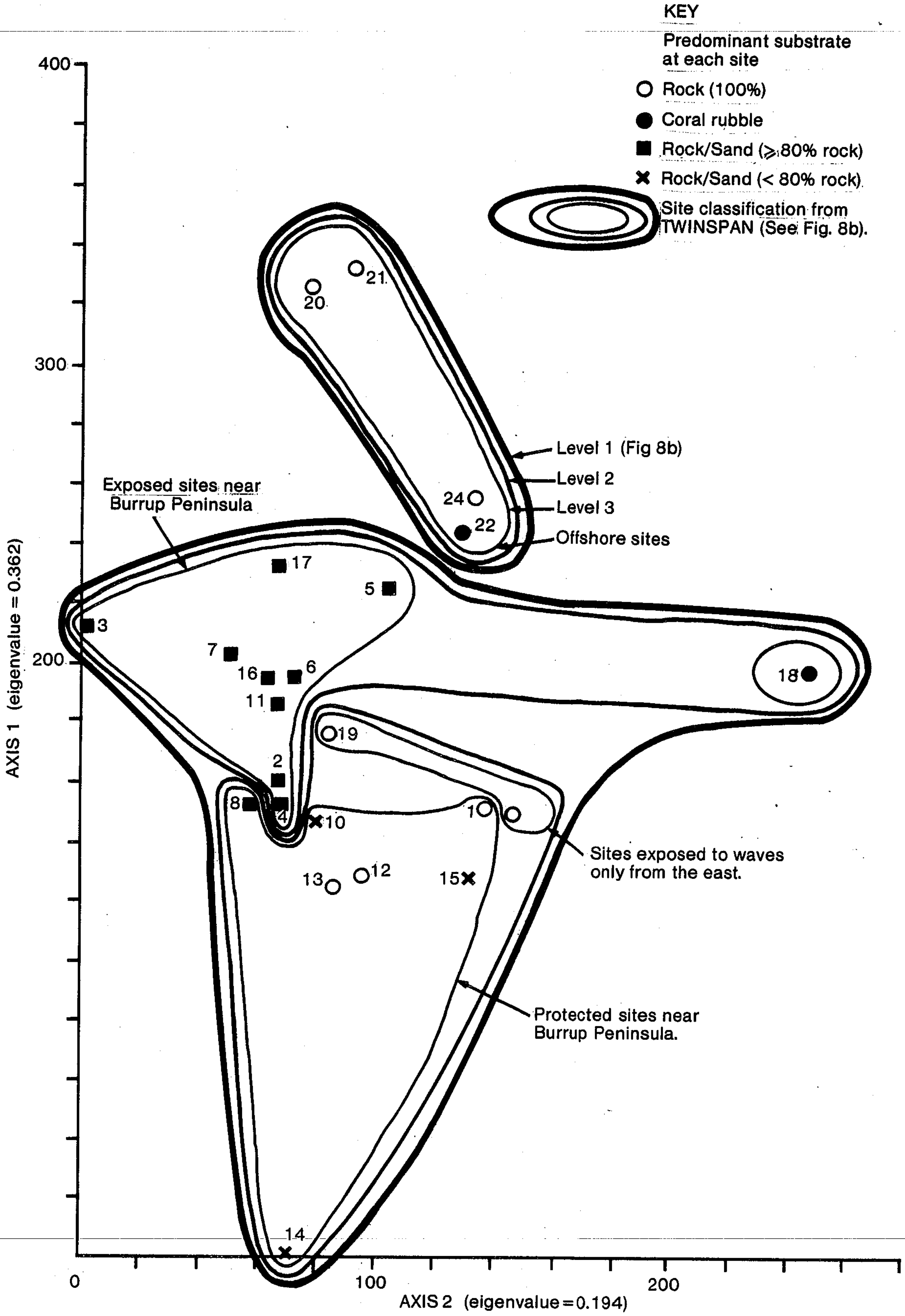


**Figure 11;** **Ordination produced by DECORANA. These axes, 1 and 2, were determined from data with rare species and Site 9 removed.** Axes are measured in units of standard deviation ÷ 100.

TWINSPAN conformed to what is known about the genera within them. Families tending to occur in exposed and offshore groups (Table 2) contained those species described as occurring in open water (Marsh, 1978; Veron and Pichon, 1976, 1979); for example, Thamnasteriidae (*Psammocora superficialis*), Pocilloporidae (*Pocillopora eydouxi, P. verrucosa*) and Agariciidae (*Pavona minuta*). Caryophylliidae, a family more common at sites on the Burrup Peninsula (Groups 1b, 2a, Figs. 8(b) and 9, Table 2), contained species tolerant of silty conditions; *Euphyllia glabrescens, E.* (*Fimbriaphyllia*) *sp.* and *Cataphyllia jardnei* (Fig. 10). Ubiquitous families were the Poritidae, Acroporidae, Faviidae, Mussidae and the Dendrophylliidae. These were indicated by Done (1983) to be tolerant of a wide range of physical and topographical conditions.

An offshore site, Lady Nora Island (Site 23, Fig. 1), was consistently classified with sites occurring on the Burrup Peninsula (Figs. 8 and 9). This was in contrast to its habitat; sheltered with relatively clear water. TWINSPAN, on the basis of commonality of species grouped Site 23 with the inner sites. Site ordination (Fig. 11), also failed to separate this site with the other outer sites. One explanation is that the site had a high proportion of algal cover with corals occurring only on exposed rock. It was also more sheltered from wave action than the other outer sites; in effect a semi-lagoonal environment. Thus, both the Burrup sites and Site 23 were sheltered, the former being turbid and the latter non-turbid (L. Marsh pers. comm.).

The site classification (Fig. 8) appears to relate highly to the predominant substrate on which species were found (Fig. 11). To determine which group of variables corresponded to each axis, however, was difficult without detailed physical data for each site. The positioning of Site 14 (Boat Passage) away from other points on the ordination axes may reflect that it was a rather specialised habitat. This site was shallow, partly exposed to air at low tide and subject to strong currents (Marsh, 1978).

The higher species numbers at the more exposed sites may have resulted from the greater availability of habitats. Diversity was low in the protected sites because conditions were extreme; high turbidity and a wide temperature range occurred at these sites. The low species numbers at the outer sites may have resulted from a number of factors. These sites were more exposed than the Burrup sites to wave action and environmental disturbances such as cyclones (Connell, 1978). Marsh (1978) attributed a reduction of the number of genera at Kendrew Island (Sites 20 and 21) between 1974 (36 genera) and 1978 (21 genera) to *Acanthaster planci*, the Crown of Thorns starfish, predation and cyclone damage in the intervening period.

Furthermore, the percentage living coral cover at Kendrew Island was much higher in 1974 (50-80% coral cover) before predation and cyclone damage than in 1978 (1-50% coral cover).

While the techniques described here are useful for data already collected, further information can be obtained by collecting data with these types of analyses in mind. On this basis, two recommendations are made for future data collection. Firstly the need for pilot studies and secondly the measurement of physical data.

Before the main data collection begins, a pilot study to allow for initial analysis of data is useful for the following reasons:

- A suitable, efficient sampling method can be designed, so that the number of samples needed and the sample area size can be determined to minimise time, equipment and costs.

- Major environmental gradients may be recognised and the sampling modified accordingly.

- Field data sheets may be constructed, along with the appropriate codes for species, abundance and environmental factors etc. A standardised field sheet is particularly valuable when a number of workers are collecting data.

The measurement of environmental parameters when species are noted will help the final interpretation of biological data. The amount and type of physical data could include (see also Scheer, 1978):

- Water temperatures
- Water depths (species groups and average site depth)
- Salinity
- Turbidity
- Light
- Wind
- Currents
- Tidal amplitude and period
- Wave action

- Site aspect (sheltered, exposed)
- Habitat type (slope, reef flat, bottom topography)
- Sediment (composition, type, influx, resuspension)
- Substrate composition (sand, silt, rubble, rock)
- Biotic factors (competition, predation)

## GENERAL CONCLUSION

TWINSPAN classified sites into groups that correlated with the distribution of offshore, exposed and protected habitats within the Archipelago. TWINSPAN could not determine distinct coral assemblages in terms of species groups, probably because of the variety of habitats available for colonisation. It is arguable therefore that this conclusion can be reached without using computer analysis. The treatment of data in this way however, is rapid, simple and would be a valuable aid to community classification for other environments where little physical data are known. DECORANA ordination produced similar results to TWINSPAN; offshore groups being separated from inner sites. The failure of ordination, however, to produce any distinct separation of sites into groups was likely, once again, to be caused by the wide range of habitats. Gradients, if they occur are usually the result of many environmental variables such as current, sediment and wave exposure. For this study there was little environmental data available.

The successful application of the Cornell Ecology Programs to these coral data (as described in Section A) indicate that they could have more widespread use. TWINSPAN, for example, may be used without accompanying physical site data and is a useful technique for site and species classification on the basis of presence/absence data alone. Hence, there is no reason why other data should not be used for analysis in this way. Examples of habitats or studies where TWINSPAN may be useful include: island fauna and flora; algal communities; taxonomic studies (presence/absence of characters); bottom faunal communities; bird and mammal populations; gut floras; fish communities; and plant species stands.

Ordination using DECORANA, confirmed the results derived from TWINSPAN, and its usefulness would increase with the availability of more environmental data. Though, if clearly defined environmental gradients are present, the use of ordination when little site data is available, may provide valuable information on the causes of site species composition.

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