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Title: Distribution of Butterflyfishes (Pisces: Chaetodontidae) on Three Contrasting Guam Reefs

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Abundance and diversity of chaetodontids on three contrasting coral reefs seem to be linked directly to the abundance of live coral. A total of sixty, 20-minute chaetodontid counts was made on the reef fronts and submarine terraces of the three reefs. Live coral cover was estimated at each of the six sites studied. Values ranged from 426 individuals in 16 species of Chaetodontidae seen at a site of approximately 14 percent coral cover, to 909 individuals in 21 species counted at a site of approximately 54 percent coral cover. Previous work, substantiated by further stomach analysis, established six species of the genus *Chaetodon* as strict coral polyp feeders. These are submitted as potential indicator species: *Chaetodon ornatissimus*, *C. punctato-fasciatus*, *C. quadrimaculatus*, *C. reticulatus*, *C. strigangulus*, and *C. trifasciatus*.

DISTRIBUTION OF BUTTERFLYFISHES (PISCES: CHAETODONTIDAE) ON THREE CONTRASTING GUAM REEFS

by

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I deeply appreciate Mr. Roy Chung's guidance in the application of multivariate techniques to this problem.

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INTRODUCTION

Butterflyfishes (Chaetodontidae) are well known inhabitants of the coral reef community. These conspicuously colored fishes are commonly seen flitting among the ramose coral structures much as their name implies. Many species of the genus Chaetodon have been observed to feed predominantly on living coral polyps (E. S. Reese, personal communication). This has prompted Reese to suggest that distribution and abundance of chaetodontids are related to the occurrence and diversity of corals. For example, should an environmental stress occur that resulted in a reduction of coral diversity and abundance, it would be reasonable to expect perturbations in the species composition and abundance of the extant chaetodontid population. This is the hypothesis that I wished to test.

Large-scale destruction of coral by the polyp-eating "crown-of-thorns" starfish, Acanthaster planci (L.), was first reported from Guam in 1969 (Chesher, 1969). Considerable damage was done to the island's northwestern reefs, leaving these "acanthasterized" areas nearly devoid of live coral (Randall, 1973). This study compares the chaetodontid assemblage of one such reef with those of two healthy, actively growing reefs. Stomach contents of species of the genus Chaetodon were also inspected for the purpose of confirming Reese's findings on which species were coral feeders, i.e., most dependent on living coral. It was especially hoped to show a direct correlation between abundance of these particular fish species and the percentage of live coral at a given site.

MATERIALS AND METHODS

Three contrasting reef areas (Fig. 1) were compared. Tanguisson is a northwestern, leeward, fringing reef which was very heavily "acanthasterized" in past years. At the southern tip of Guam, outside the leeward barrier reef of Cocos Lagoon, Acanthaster did little damage, but the luxuriant reef here greatly resembles the reef at Tanguisson prior to Acanthaster invasion (R. H. Randall, personal communication). Randall suggests that at one time the two reefs were quite similar in coral diversity and percent of live coral cover. The physiographic similarities still exist. The ideal experiment would have been to monitor the chaetodontids in an area such as Tanguisson prior to, during, and after Acanthaster invasion; since this was not done, the combined data from Cocos and Tanguisson serve to simulate a "before" and "after" sequence.

The third reef is in Pago Bay, a windward, fringing reef on the central eastern coast of the island. It is a diverse, thriving reef, showing almost none of the effects of Acanthaster damage.

The reef areas were each divided into physiographic zones--the reef front including the reef margin, the submarine terrace, and the seaward slope -- following the guidelines of Tracey *et al*. (1955). Study of the seaward slopes was later deleted because of depth-time considerations, and accumulated evidence that these data would not change the overall view. The reef fronts and submarine terraces of each area were treated as separate sites, since they are truly quite distinct habitats and usually display characteristic chaetodontid

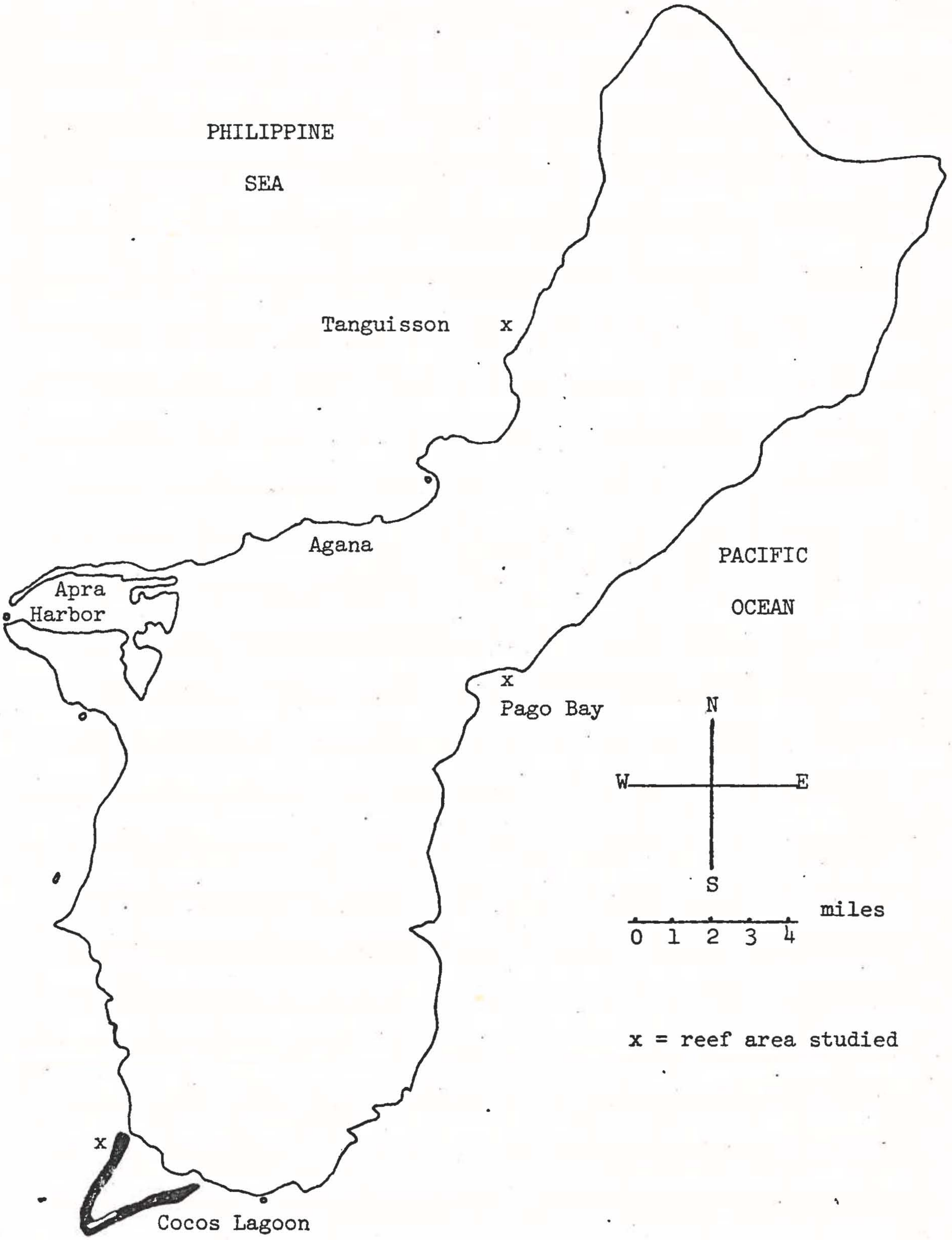

Fig. 1. General location map of Guam showing reef areas studied.

populations. Splitting the zones increased the sample size to six sites and revealed some very interesting patterns; however, the option to lump the data from a reef area was also open.

An estimate of live coral cover was made at each of the six sites using a very simple technique. A quarter meter square grid with 16 points of intersection, 5 cm apart, was thrown randomly 30 times and points on the grid overlying live coral, dead coral (usually covered with algae), soft coral, and sand were counted. Percentages of cover were calculated in the following manner -- the total number of points tabulated was 480 (16 x 30); the total number of points for each particular substrate was then divided by this value and multiplied by 100 to yield a percent.

Data collection was accomplished by means of timed fish counts made parallel to and within the contours of one reef zone. Chaetodontid species and numbers were tallied on a prepared slate. The reef front descends to about 6 meters and the submarine terrace slopes gently from 6 meters to about 15 meters, where the slope begins (Randall and Holloman, 1974). Swimming was confined within a 4- or 5-meter corridor, but grooves, coral heads, etc. were also investigated. The major restriction was to move in a relatively straight line and fast enough to avoid counting the same fish twice. Adequate sample time was determined by modification of the species/area curve (Oosting, 1956) into a species/time curve. Four, 30-minute counts were conducted at two of the sites (Fig. 2). It was found that, in all cases, at least 90 percent of the total species observed after 30 minutes had been observed within 20 minutes. Twenty minutes was, therefore, considered an adequate sample time. Ten counts per

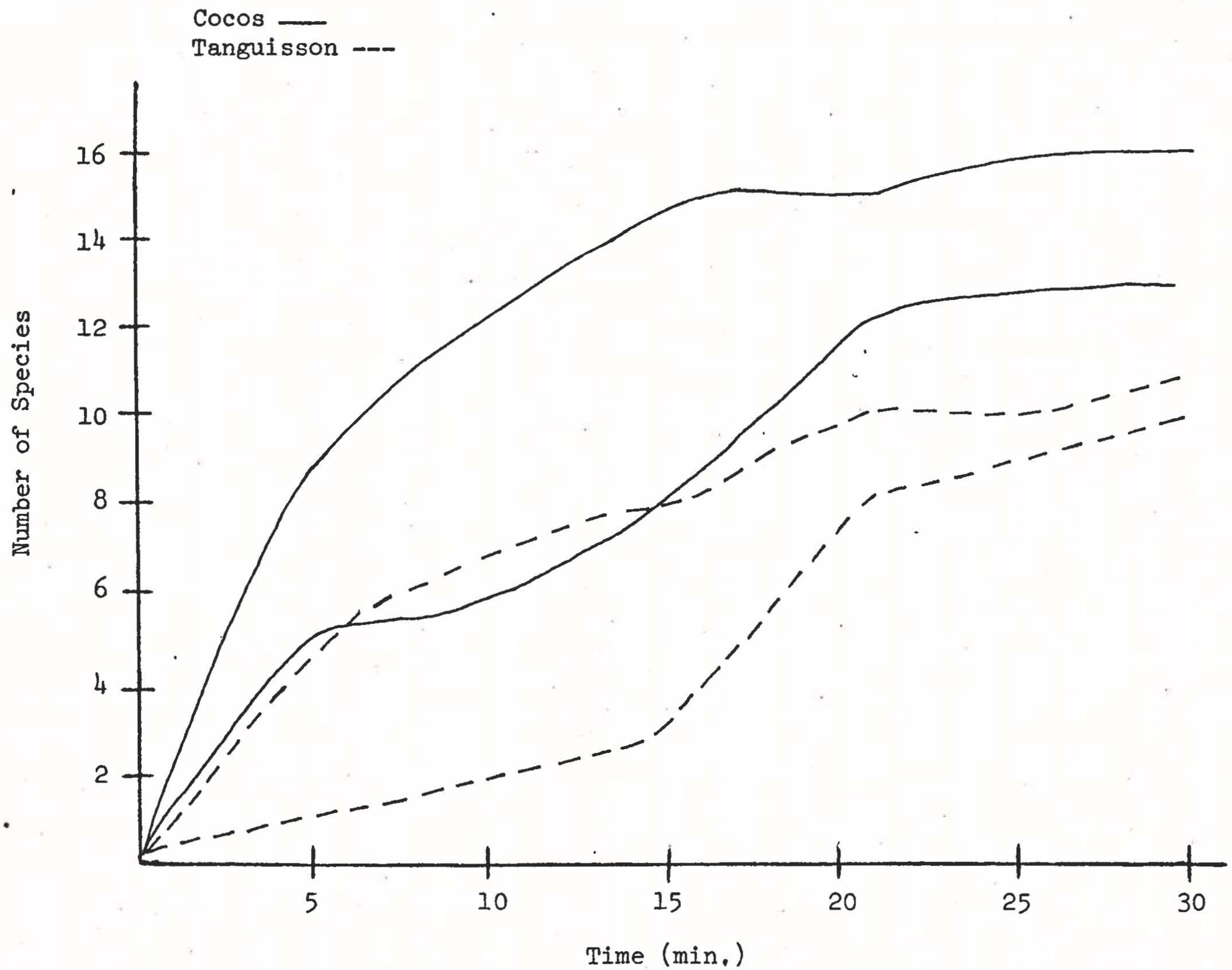

Fig. 2. Species/time curves from Cocos Terrace and Tanguisson Terrace.

reef area or a total of sixty, 20-minute counts was carried out in this study.

After all counts were made in an area, Chaetodon species were speared in order to investigate stomach contents. Ninety-six fish in 15 species were examined. Stomach contents were described on a presence-absence basis. A percentage of times that a food item was present was calculated for all specimens in each species. Since filamentous algae is often incidentally ingested, and because the concern was to generally discriminate between coral eaters and algae eaters, algal presence was acknowledged only in cases where it equalled or exceeded 10 percent of the stomach contents. If coral tissue was present, it was always in quantities greater than this value, so that no such restriction was necessary. Other items were noted strictly by presence or absence.

Much of the data were punched on computer cards for the purpose of performing multivariate analyses. Cluster analysis (McQuitty, 1961) and orthogonal power-vectored factor analysis (Overall and Klett, 1972) were performed on the data matrix, but only the results of the power-vectored factor analysis were included in this report. Factor analysis on presence-absence data of 55 taxa from 209 sampling stations in Kaneohe Bay was used very successfully by Smith (1973).

RESULTS AND DISCUSSION

Observational Analysis

It is evident from the overall abundance figures (Table 1) that Tanguisson's chaetodontid population is impoverished compared to those of Cocos barrier reef and Pago Bay. Little more than half as many chaetodontids were sighted at Tanguisson as compared to the other two reef areas. Concurrently, live coral cover at Tanguisson is less than 15 percent (Table 2). Tanguisson reef front and terrace lack several species, e.g., _Chaetodon bennetti_, _C. punctato-fasciatus_, and _C. unimaculatus_, which are at least partial coral feeders. The similarly low diversity on Pago reef front is probably more accountable to the frequently harsh surf conditions of the windward front since there is about 30 percent live coral at this site. In Eniwetok, Reese observed that on rough days there was less feeding and interaction among chaetodontids. It may also be that many species re-locate to the quieter depths of the terrace.

Under calmer conditions, the chaetodontid data basically reflect coral cover as expected. The Pago terrace supports the greatest abundance of chaetodontids, and, at the same time, is the most luxuriant reef (54 percent coral cover) of the three.

Stomach samples (Table 3) were minimal and restricted to the genus _Chaetodon_ because confirmation of Reese's previous findings was the chief intention rather than establishing self-supporting evidence of food habits. Replication was especially good with regards to the obligatory coral feeders. Reese (personal communication) presents

Table 1. Numbers of chaetodontids seen during ten, 20-minute counts at each of six sites. T=Tanguisson; C=Cocos; P=Pago. Subscript f=front; subscript t=terrace. $\bar{x}$=mean; S.D.=standard deviation; C.V.=coefficient of variation.

Species	Sites								
	T_f	T_t	C_f	C_t	P_f	P_t	$\bar{x}$	S.D.	C.V.(%)
Centropyge bispinosus (Gunther)	-	-	-	79	-	-	13.17	32.35	245
C. flavissimus (Cuvier)	15	88	9	99	5	3	36.50	44.48	122
C. heraldi Aoyagi	-	-	-	-	-	25	4.17	10.21	245
Chaetodon auriga Forskal	87	33	12	7	83	89	51.83	38.84	75
C. bennetti Cuvier	-	1	6	2	-	11	3.33	4.37	131
C. citrinellus Cuvier	89	115	102	108	314	242	161.67	93.34	151
C. ephippium Cuvier	24	18	37	23	35	34	28.50	7.82	27
C. falcula Bloch	23	7	92	8	13	20	27.17	32.39	119
C. kleinii Bloch	-	1	-	1	-	-	0.33	0.52	158
C. lunula (Lacepede)	54	50	11	16	22	47	33.33	19.08	57
C. melannotus Schneider	-	-	-	-	2	1	0.50	0.84	168
C. mertensii Cuvier	-	-	-	31	-	-	5.17	12.66	245
C. ornatissimus Solander	26	1	89	27	9	8	26.67	32.27	121
C. punctato-fasciatus Cuvier and Valenciennes	-	4	4	188	-	97	48.83	78.07	160

Table 1. Continued

Species	Sites T_f	T_t	C_f	C_t	P_f	P_t	$\overline{x}$	S.D.	C.V.(%)
Chaetodon quadrimaculatus Gray	6	-	20	3	22	1	8.67	9.79	113
C. reticulatus Cuvier	60	17	172	31	23	12	52.50	60.94	116
C. strigangulus (Gmelin)	3	-	31	-	61	33	21.33	24.70	116
C. trifasciatus Mungo Park	78	16	198	8	36	68	67.33	69.75	154
C. unimaculatus Bloch	-	-	48	56	28	99	38.50	37.77	98
Forcipiger spp. (cf. _F. flavissimus_ Jordan and McGregor or _F. longirostris_ (Broussonet))	11	64	33	42	16	97	43.83	32.27	74
Heniochus monoceros Cuvier	-	-	1	1	-	8	1.67	3.14	188
H. permutatus Cuvier	1	-	2	15	-	-	3.00	5.93	198
Holocanthus trimaculatus Cuvier	1	6	-	3	-	2	2.00	2.28	114
Pomacanthus imperator (Bloch)	2	4	-	6	2	8	3.67	2.94	80
Total individuals	481	426	868	754	673	909			
Total species	16	16	19	21	16	21			

Table 2. Estimate of cover of basic substrate components at the six sites. T=Tanguisson; C=Cocos; P=Pago. Subscript f=front; subscript t=terrace.

Substrate (%)	Sites T_f	T_t	C_f	C_t	P_f	P_t
Live Coral (stony)	12	14	28	21	31	54
Dead Coral (usually covered with algae)	84	84	72	68	66	45
Soft Coral	-	-	-	5	-	-
Sand	4	2	-	6	3	1

Table 3. Results of stomach analyses. Values represent percent of occurrence of food items. Numbers in parenthesis after species names indicate sample number.

Species	Food Items Coral (stony)	Soft coral	Sponge	Annelids	Eggs	Crustacea	Algae	Detritus
Chaetodon auriga (4)	-	-	-	100	25	-	100	-
C. bennetti (2)	100	-	-	-	-	-	-	50
C. citrinellus (12)	67	-	8	67	33	33	67	-
C. ephippium (9)	-	-	22	22	-	-	100	11
C. falcula (6)	67	-	-	-	17	-	100	17
C. lunula (8)	25	-	-	100	25	-	100	13
C. melannotus (2)	-	-	-	-	-	-	100	-
C. mertensii (1)	-	-	-	100	-	-	-	-
C. ornatissimus (10)	100	1	-	-	-	-	-	10
C. punctato-fasciatus (6)	100	-	33	17	-	100	33	-
C. quadrimaculatus (5)	80	-	-	20	20	-	40	-
C. reticulatus (13)	100	-	-	-	-	7	-	-
C. strigangulus (3)	67	-	-	-	-	-	33	33
C. trifasciatus (9)	100	-	-	-	-	-	11	11
C. unimaculatus (5)	80	40	-	-	-	20	40	20

the following as obligate polyp feeders: *Chaetodon ornatissimus*, *C. punctato-fasciatus*, *C. quadrimaculatus*, *C. reticulatus*, *C. strigangulus*, and *C. trifasciatus*. My results corroborate this. Hiatt and Strasburg (1960) analyzed 13 specimens of *Chaetodon strigangulus* and found 100 percent coral tissue in all of them. They pointed out that the dentition of this species is especially adapted to feeding on polyps since the teeth are massed toward the front of the jaw and protrude. The opportunistic omnivores most commonly include *Chaetodon auriga*, *C. lunula*, *C. citrinellus*, and *C. falcula*.

The species distributions seem to reflect their food habit roles. For example, the coral feeders were more abundant at sites where there were more live corals. In addition, analysis of the coefficients of variation (Table 1) for the species provides empirical verification of the above observations. The coefficient of variation (Sokal and Rohlf, 1969) is a weighted measure of variation $(\frac{S.D.}{\bar{X}} \times 100)$ and is a particularly useful measure of variation between distributions whose means differ significantly. The omnivores have less restriction in site distribution and display a lower coefficient of variation than the coral feeders, since the opportunistic omnivores are more uniformly distributed. Such is the case with the omnivores *Chaetodon auriga* and *C. lunula* which have coefficients of variation of 75 percent and 57 percent, respectively. *Chaetodon auriga* is especially adaptive in food habits. From 30 specimens, Hiatt and Strasburg (1960) found that 28 percent of the *C. auriga* examined contained coral, 28 percent contained algae, 46 percent contained polychaetes, and 19 percent contained crustacea.

The herbivorous *Chaetodon ephippium* was most uniformly distributed of all the species; its coefficient of variation was 27 percent. The more strict food habits of this species, as compared to the omnivores, seem not to be limiting, probably due to the fact that at least a third of the substrate of all six sites is covered by algae. Ten specimens of *Chaetodon ephippium* were examined by Hiatt and Strasburg (1960); six stomachs contained coral polyps, five contained algae, one contained polychaetes, and one contained crustacea.

On Cocos barrier reef, *Chaetodon auriga* and *C. lunula* seemed somewhat supplanted by *C. falcula* and *C. unimaculatus*, species which Reese labels omnivores, but which frequently eat coral polyps. In addition, *Chaetodon unimaculatus* exhibits a preference for soft corals which, as Table 2 shows, were only found on Cocos terrace.

Chaetodon citrinellus is another omnivore that prefers coral polyps, so it is predictable that this species' numbers increase as one goes from Tanguisson to Cocos barrier reef to Pago Bay. Hiatt and Strasburg (1960) found that 94 percent of their specimens of *Chaetodon citrinellus* contained coral tissue; only 16 percent contained algae, and 5 percent contained polychaetes.

Factor Analysis

Tables 4 and 5 involve a power-vectored factor analysis of the data matrix (Overall and Klett, 1972). Factor analysis discerns underlying patterns among the variables being investigated. These patterns are determined by factors which are inherent to the variables or the environment. The reduction of a large number of variables to a few functional groupings greatly facilitates the search for order and logical synthesis in complex data sets.

Factor I of Table 4 strongly asserts the importance of live coral cover as logically opposed to dead coral cover. This importance value rests not merely on coral as a food item, but also as a source of shelter. Heniochus monoceros, Pomacanthus imperator, and Forcipiger sp. rarely feed on coral tissue, however, they are quite cryptic and rely on ramose coral structures to hide in. Pygoplites diacanthus, which displays very similar behavior to the above species, also loads quite high (.571) on this factor, although its highest loading (.577) is on factor II. Chaetodon unimaculatus, C. bennetti, and C. ephippium often feed on coral polyps, and apparently load high on factor I because of this trait. Chaetodon citrinellus and C. strigangulus are not in the bracketted grouping of factor I, however, they load high (.593 and .506, respectively) on factor I. These species are established coral feeders.

From the seven species of chaetodontids and the set of site characteristics loading highest on it, factor II appears to be a terrace-related depth factor. Percent sand and percent soft coral were highest on the submarine terrace (Table 2). The species of chaetodontids loading high on this factor were almost exclusively

Table 4. Orthogonal power-vectored factor analysis of chaetodontid data and coral cover.*

Variables	Factors I	II	III	IV	V
Percent live hard coral	.987	.015	.055	.130	.048
Percent dead hard coral	-.950	-.238	-.013	-.196	-.005
Heniochus monoceros	.949	.110	-.076	-.283	-.006
Centropyge heraldi	.940	.017	-.200	-.269	-.085
Pomacanthus imperator	.889	-.351	-.262	.021	-.042
Chaetodon unimaculatus	.879	.396	.255	-.005	.015
C. bennetti	.878	.033	.289	-.355	.076
Forcipiger sp.	.689	.187	-.256	-.518	.390
Chaetodon ephippium	.613	-.310	.559	.470	-.049
C. mertensii	-.198	.974	.075	.074	-.036
Centropyge bispinosus	-.198	.974	.075	.074	-.036
Percent sand	-.198	.974	.075	.074	-.036
Chaetodon punctatofasciatus	.274	.957	-.017	-.073	-.061
Heniochus permutatus	-.233	.949	.197	.047	-.064
Centropyge flavissimus	-.502	.664	-.267	-.275	.417
Percent soft coral	-.515	.644	-.362	.306	-.275
Chaetodon kleinii	-.445	.624	-.312	-.272	.587
Pygoplites diacanthus	.571	.577	-.518	-.269	.024
Chaetodon ornatissimus	.119	-.090	.977	-.083	-.035
C. reticulatus	-.177	-.277	.944	-.114	-.012
C. falcula	.059	-.345	.934	-.123	.052
C. trifasciatus	.142	-.456	.872	-.165	-.081
C. lunula	.050	-.359	-.701	-.543	-.259
Holacanthus trimaculatus	-.230	.279	-.551	-.537	.480
Chaetodon auriga	.402	-.490	-.525	.207	-.511
C. melannotus	.482	-.238	-.298	.779	.033
C. strigangulus	.506	-.396	.155	.750	.105
C. quadrimaculatus	-.074	-.400	.555	.731	.041
C. citrinellus	.593	-.192	-.330	.708	.108

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*Computed by POWFAC, a program adapted for the IBM Systems/3 Model 10, University of Guam, by Roy Chung, after the program for orthogonal power-vectored analysis in Overall and Klett, 1972.

sighted on the terrace (Table 1). The high coefficients of variation of these species support a selectivity for site. Species such as *Centropyge bispinosus*, *C. heraldi*, and *Chaetodon mertensii* are, for the most part, inhabitants of the seaward slope, but it can be seen that some occasionally move up onto the fringes of the terrace.

Factor III may be interpreted as a food habits factor -- coral polyp feeders versus omnivores. All the positive variables -- *Chaetodon ornatissimus*, *C. reticulatus*, *C. falcula*, and *C. trifasciatus* -- are essentially coral feeders, while *Chaetodon lunula*, *Holacanthus trimaculatus*, and *Chaetodon auriga*, which loaded negatively, are omnivorous. There is the added factor, although not so strong as the former, that all the positively related species reside chiefly on the reef front, whereas, the inversely related species seem to prefer the submarine terrace. It is interesting to note that *Holacanthus trimaculatus* was seen most often on the Tanguisson terrace mingling with the large schools of grazing scarids.

No underlying pattern could be extracted from factor IV, however, with further study the loadings may acquire a meaning which is now obscure.

The groupings of Table 4 fit the expected "reality" quite closely. Factor I is especially strong in supporting my hypothesis, i.e., a direct relationship between live coral cover and the presence of chaetodontids.

Table 5 is based on a small sample size and very general parameters, so that it is difficult to make anything but general statements about the determining factors. Factor I is the most useful in that, by showing an inverse relationship between coral and algae, it

Table 5. Orthogonal power-vectored factor analysis of food habits.

	Factors			
Variables	I	II	III	IV
Algae	-0.780	0.009	0.061	-0.177
Hard Coral	0.743	0.226	0.298	0.079
Chaetodontid Species	-0.737	-0.017	-0.229	-0.054
Annelids	-0.612	0.266	-0.064	0.344
Date Collected	-0.352	-0.028	0.093	-0.241
Crustacea	-0.027	0.684	-0.002	-0.058
Chaetodontid Length	-0.076	-0.634	0.347	0.115
Eggs	-0.315	0.440	-0.033	0.208
Soft Coral	0.133	-0.104	-0.385	0.006
Detritus	0.019	-0.126	0.380	-0.108
Sponge	-0.130	0.185	0.013	-0.499
Sex	-0.380	0.331	-0.202	0.400
Site	-0.172	-0.189	-0.001	-0.363

can be suggested that a fish that eats coral usually will not eat algae and vice versa. With minor adjustments, this statement assumes the observed "reality." Algae, chaetodontid species, and annelids all have strong negative loadings on factor I. This might be explained in the following manner -- algae and annelids are common food items for omnivorous species of chaetodontids as opposed to the coral-feeding chaetodontid species.

Factor II, which has crustacea and eggs loading positively, seems to imply that the eggs noted in the stomach contents may have been crustacean eggs since they were often found in the same samples. The loadings on factors III and IV are low and difficult to interpret at this preliminary stage.

Multivariate analysis was not only instrumental in illuminating the positive relationship between live coral and chaetodontids, as was the chief intent of this research, but, also, since a review of the literature disclosed no previous applications of multivariate techniques to this particular problem, the procedure is a new analytical approach.

CONCLUSION

In a reverse light, it may be possible to evaluate the general health of the coral reef community based on the chaetodontid population, more specifically, those members of the genus Chaetodon which are essentially obligatory coral feeders. These may be potential indicators of stress within the community.

Analyzing the health, diversity, and abundance of the corals themselves requires much time and expertise, whereas, butterflyfishes can be identified and enumerated simply and with little experience. Should this secondary approach be viable, the value of such a tool is obvious in the study of natural or man-induced stresses on coral reefs.

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