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MONITORING CORAL REEFS FOR URBAN IMPACT

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ABSTRACT

Urban impact is becoming an increasing threat to coral reefs in many developing areas. A review of data on Mayor's transect in Pago Pago Harbor, with a baseline established in 1917, and of 10 years of reef monitoring transects elsewhere in American Samoa, has demonstrated major changes in coral and algal communities on the reef flats. However, too little is known about natural variation in reef populations to identify human impacts with certainty.

A monitoring program is being established to measure changes in the coral reefs in the urban area around Noumea, New Caledonia. The monitoring sites will provide information on the principal components of the coral reef community and on basic water quality and pollution indicators. The data from the monitoring program will assist in designing pollution control facilities for the urban area.

Despite some problems of definition and experimental design, simple coral reef monitoring techniques are capable of providing useful scientific information on variability in reef communities.

As coral reef studies advance, the amazing complexity of the coral reef ecosystem becomes increasingly apparent. First, it was the complexity of structure and species diversity that were elucidated, then the behavioral complexity of organism relationships and the physiological complexity of the cycling of energy and materials. More recent studies have shown the evolutionary complexity of the structural and community changes as a reef develops at a particular site, and the temporal complexity as the system responds to extreme situations such as epidemics and storms.

Since coral reefs are a significant resource, particularly in many poor tropical developing countries, this complexity creates problems for resource management. Reef areas are the basis for many subsistence fisheries and increasingly for commercial fisheries as well. They are important tourism and recreation sites. They provide protection for coastlines and harbors, and produce sand for beaches and construction. Even their role as a source of materials for handicrafts, jewelry and curios can be significant in a small economy.

These resource uses are threatened by many man-made influences, including increased turbidity and siltation, abnormal inputs of nutrients and organic matter, pollution by toxic chemicals and oil, thermal loading, alterations to freshwater runoff, changes in water circulation and wave exposure, direct physical damage and breakage, and the selective removal of organisms or system components producing population imbalances and possibly interfering with nutrient cycling. Indeed, any human use of a system beyond certain levels will alter it unless compensating actions are taken. There are also natural influences that can make undesirable changes in a resource of human importance. These can include damage from waves, heavy rainfall during storms, unusual tidal exposure, natural population imbalances or epidemics, and even the natural development, succession or change in the system.

The goal of resource management is generally to maintain or improve desirable characteristics of the system, such as its stability or diversity, the productivity of useful species or materials, the structure of the reef, or its aesthetic, scientific, or conservation value. Given the difficulties of managing a simple system such as a pasture or wheat field, it may seem unrealistic to contemplate the management of a system as complex as a coral reef. Yet only by trying can we learn what management approaches may be practical.

Management can only be done on the basis of knowledge. We must know the present state of the system and how it is changing. We must be able to measure the effect of any management actions we may take. The collection of information about the system is thus essential to management.

Monitoring is the collection of information about the state of a system or resource and its changes over time. Monitoring techniques must be reliable and repeatable, providing adequate significance within the economic limitations of time, expertise and resources. Developing a monitoring strategy requires compromises and tradeoffs between the scientifically-desirable and the practical. It is necessary to ask what is the minimum amount of information and minimum level of accuracy necessary to achieve a useful result (Dahl, 1977). This paper discusses three monitoring techniques being used to measure terrestrial and particularly urban impacts on coral reefs. Its emphasis is more on the methodologies than the results, which are beyond the scope of this paper and which will therefore be treated in detail elsewhere. However, significant results are discussed where they illustrate monitoring requirements or problems.

The Mayor Transect—American Samoa

In 1917, Alfred G. Mayor made a detailed quantitative survey of the fringing reef at Aua in Pago Pago Harbor, American Samoa (Mayor, 1924). Mayor laid a transect across the reef, and counted all the corals and certain other animals within a series of 7.32 m quadrats along the line from the shore to the outer edge of the reef. The transect was repeated using identical methods in 1973 (Dahl and Lamberts, 1977), and again in 1980 by the author. Two markers placed on the line in 1973 were still present in 1980, assuring the accurate repositioning of the line.

The differences in the coral communities recorded between the three surveys is quite striking, and illustrates the variability in what should be the most stable element in the coral reef ecosystem (Table 1). The total number of coral colonies in the 10 resurveyed quadrats decreased from 3,670 in 1917 to 2,657 in 1973 and to 1,880 in 1980, perhaps related to the steadily increasing urban impact in the harbor area. The zone containing the innermost quadrat, which has been dominated by small Porites in the earlier surveys, was a thicket of *Acropora formosa* in 1980, with some individual colonies reaching 2 m in diameter. This species nearly disappeared from the rest of the reef where it had previously been more abundant. All the other *Acropora* series were greatly diminished or entirely absent in 1980, as were most other genera except *Psammocora* and *Millepora*, and *Porites andrewsi* which had replaced *Pocillopora* and regained its 1917 abundance to become the dominant coral (in numbers) on the inner reef. While coral development on the in-shore reef flat was much improved in both numbers and size in 1980 over 1973, except for the decline in *Pocillopora*, the outer half of the reef was practically denuded of coral cover. There seems no obvious explanation for these opposite trends on two parts of the same reef. Among the other animals counted (Table 2), the black holothurian *Stichopus chloronotus* Brandt remained at the high level of 1973, the blue starfish *Linckia laevigata* Linnaeus greatly increased in abundance, and the alcyonarians nearly disappeared.

The data are insufficient and the surveys of the Mayor transect too widely spaced in time to draw any conclusions, other than a general decline in the area,

Table 1. Number of living coral heads upon each 7.32 m² on the Aua Line, Pago Pago Harbor, Tutuila, American Samoa (*1917*, 1973, **1980**)

Coral	Distance From Low Tide Mark of Shore										Total	Percent of Total
Meters	61–68	91–99	122–129	140–147	160–168	183–190	213–221	233–241	247–255	259–267		
Feet	200–224	300–324	400–424	460–484	526–550	600–624	700–724	766–790	812–836	850–874		
Psammocora contigua (Esper)	*2*	*46*	*49*	*259*	*17*	*9*	*1*	*5*			*388*	*10.6*
		10	14	6	12	2	7	33	21	15	120	4.5
		7	**26**	**4**	**1**		**6**	**7**	**54**	**45**	**150**	**7.9**
Pocillopora damicornis (L),	*3*	*24*	*23*	*3*	*6*	*35*	*5*	*19*		*31*	*149*	*4.1*
P. brevicornis Lamarck,	11	349	75	60	63	32	15	23	46	45	719	27.1
P. eydouxi Milne-Edwards & Haime	**18**	**22**	**57**	**62**	**8**	**2**	**19**	**7**	**6**	**16**	**217**	**11.5**
Acropora formosa (Dana)		*3*	*13*	*38*	*59*	*151*	*265*	*407*			*936*	*25.5*
(some to 2 m dia)	7	23	3	14	11	30	6	26	15	9	144	5.4
	189	**1**	**1**	**2**					**4**	**10**	**207**	**11.0**
Acropora hebes (Dana)							*1*	*4*	*144*	*8*	*157*	*4.3*
		1			1	16	1	9	15	56	99	3.7
		1	**1**				**4**		**15**		**21**	**1.1**
Acropora nana (Studer)			*2*	*2*			*16*	*15*		*15*	*50*	*1.2*
and *A. quelchi* Brook		8	2		3	4	2	19	6	3	47	1.8
									1		**1**	**0.05**
Acropora humilis (Dana) or									*13*	*161*	*174*	*4.7*
A. rotumana Gardiner		1	1	4	3	8	2	12	36	68	135	5.1
Acropora hyacinthus (Dana)		1		1		6	3		15	36	62	2.3
					3		**1**				**4**	**0.2**
Acropora sp. "Juveniles"							2	55	265	214	536	20.2
								3		**60**	**63**	**3.3**
Montipora sp.						*2*	*6*	*13*		*21*	*42*	*1.1*
							4	17	11	13	45	1.7
	1	**1**									**2**	**0.1**
Pavona frondifera Lamarck		*2*	*1*	*22*	*35*	*10*	*7*	*4*			*81*	*2.2*
		6	5		4	2	1	7	8	10	43	1.6
		3	**4**	**3**			**3**		**2**		**15**	**0.8**

Table 1. Continued

Coral	Distance From Low Tide Mark of Shore										Total	Percent of Total
Meters	61–68	91–99	122–129	140–147	160–168	183–190	213–221	233–241	247–255	259–267		
Feet	200–224	300–324	400–424	460–484	526–550	600–624	700–724	766–790	812–836	850–874		
Porites "massive"	*82*	*94*	*190*	*205*	*90*	*32*	*18*	*23*			*734*	*20.0*
mostly ***P. lutea***	68	119	33	22	16	44		1			303	11.4
Milne-Edwards & Haime	**66**	**82**	**17**	**17**	**7**	**2**					**191**	**10.1**
Porites "branched" mostly	*79*	*157*	*317*	*319*	*49*	*2*					*923*	*25.1*
P. andrewsi Vaughan	61	145	31	40	37	8					322	12.1
	57	**560**	**178**	**176**	**16**	**1**	**2**				**990**	**52.4**
Favites sp.	*1*					*2*			*1*		*4*	*0.1*
						2		1	1	5	9	0.3
Leptastrea purpurea (Dana)	*1*	*7*	*4*	*10*							*22*	*0.6*
	1	3	2		4	3					13	0.5
							1				**1**	**0.05**
Galaxea fascicularis (L.)									*1*		*1*	*0.03*
							1	4	7	29	41	1.5
					1		**1**				**2**	**0.1**
Millipora sp.		*1*	*2*	*4*			*2*				*9*	*0.2*
										19	19	0.7
				4				**3**	**3**	**14**	**24**	**1.3**
Total coral heads	*168*	*334*	*601*	*862*	*256*	*243*	*321*	*490*	*159*	*236*	*3,670*	
	148	666	166	147	154	157	44	207	446	522	2,657	
	331	**677**	**284**	**268**	**36**	**5**	**37**	**20**	**85**	**145**	**1,888**	

Table 2. Numbers of blue-black holothurians (*Stichopus chloronotus*), Blue Starfish (*Linckia laevigata*), and Alcyonarians on the Aua Line, Pago Pago Harbor, Tutuila, American Samoa (1917, 1973, 1980)

	Distance From Low Tide Mark of Shore										
Meters	61–68	91–99	122–129	140–148	160–168	183–190	213–221	233–241	247–255	259–267	
Name Feet	200–224	300–324	400–424	460–484	526–550	600–624	700–724	766–790	812–836	850–874	Total
Holothurians	*183*	*115*	*170*	*135*	*34*	*12*	*4*	*3*			*656*
	229	173	289	300	410	500	249	38	20		2,208
	247	196	330	390	470	210	158	159	115	13	2,288
Blue starfish	*1*		*1*								*2*
		6	1	2							9
		7	4	1			11	26	11	2	62
Alcyonarians	*3*	*2*		*5*					*3*		*13*
					1	8			18	3	30
							1				1

or to suggest any causative factors. Much of the 1980 coral cover is of fragile species which could be broken up in a severe storm, making the community more vulnerable to such damage (relative to the total cover) than it was earlier. It is plain, however, that the corals which are the basic structural element of most reefs can change greatly over time.

While Mayor's technique gives a clear picture of the coral community on a reef, it has some disadvantages for monitoring purposes. Counts of coral colonies with no indication of size are difficult to compare. A few large corals can be statistically drowned by many small regenerating fragments, and the number of colonies in a dense aggregation may be impossible to determine accurately. The observers must be able to identify the corals to genus and often to species, and to relate their own identifications to the often different taxonomic definitions of the past. The survey requires about 12 man/h to complete, even in an area where working conditions on the reef are good and survey markers already in place.

The relationship between the observed changes on the Mayor transect and the increasing urbanization in the Pago Pago Harbor area is not easy to determine in the absence of control areas without urban impact. Mayor studied a number of sites in different parts of Pago Pago Harbor, but did not extend his work to the reefs on the open coast. Perhaps the best measure of urban impact on local reefs is the fact that, of all the sites Mayor studied, only the transect of Aua has survived reasonably intact, and even there the four innermost quadrats were lost to dredging. The others have all been dredged or filled in beyond recognition.

American Samoa Monitoring Transects

The author began a series of monitoring transects on coral reef flats in American Samoa in 1970 (Dahl, 1972). These transects were intended to measure major changes in the reef flat structure or populations that might be related to terrestrial development. Six sites around Tutuila Island at locations with different types of terrestrial impact were surveyed up to six times over 10 years. Transects from the shore across the fringing reef to the reef crest were so located with respect to major coastal features that it was possible to reposition the transect line within a few meters on each occasion. A profile of the transect was drawn, and for each 5 m long by 1 m wide section along the transect, the area coverage of the substrate types and the readily distinguishable corals and algae or algal communities was subjectively estimated in one of six classes (absent, present in small quantity, approximately 25%, 50%, 75%, and 100% coverage). Categories distinguished on most transects included turf, crustose coralline algae, crustose fleshy algae, *Halimeda, Dictyosphaeria, Pavona, Psammocora, Porites, Pocillopora, Acropora,* and living coral cover. Major transitions, and other significant features or organisms were also noted. A standard data form permitted rapid compilation of the information.

While this technique is not much more than general observations related to specific locations and distances out across the reef, it is sufficient to detect gross changes in the reef flat community structure. It has the advantage that a single observer can complete a transect of at least 100 m (the width of most fringing reefs on Tutuila) during one low tide.

The transects were first surveyed 6 months apart in 1970 as a check for seasonal variation, and were resurveyed in 1973 and 1980. Some transects were also resurveyed in 1975 and 1976. Tide and wave conditions sometimes prevented complete surveys out to the reef crest, but the major part of the line was checked on each occasion. Since some observed variations could be related to inaccuracies in repositioning the transect line, fixed markers were installed in 1980 as an aid to future surveys. The detailed survey data is being prepared for publication elsewhere. However, some general notes on the results are pertinent here.

The reef flat algal communities showed considerable change on those transects more subject to man-made influences. This suggests that more attention should be paid to algae as possible environmental indicators on tropical reefs. On two transects, including one in Pago Pago Harbor, living coral cover increased in the mid-1970's to approximately 50%, then decreased again, while on others the corals remained constant or declined gradually. There was a marked reduction in 1980 in living coral on reef crests, perhaps associated with the recent *Acanthaster* infestations in Samoa. Species of the genus *Acropora* seemed to show the greatest variability, with some evidence of occasional die-off affecting certain populations. Extensive dead standing *Acropora* was noted even before the *Acanthaster* epidemic, and dying colonies observed in 1980 were mixed randomly with healthy stands with no apparent physical or biological correlation.

Since the observed variability in reef flat community structure is not always related to obvious human influences, it is apparent that much more will need to be known about natural changes in reef communities before human impacts can be distinguished. The results demonstrate, however, that even a simple, largely subjective survey technique, if used systematically, can give useful results.

Noumea Urban Impact Study

A coral reef monitoring survey is presently being established in the lagoon around Noumea, New Caledonia, at the request of the government. This survey is part of a major study of pollution and sanitation problems in the Noumea urban area, which will permit a much better correlation of observed conditions on the reefs with clearly defined urban impacts and known pollution levels.

The method used was developed at an Expert Meeting on Coral Reef Monitoring in 1978 and will be published by the South Pacific Commission in a Coral Reef Monitoring Handbook (Dahl, in preparation). It is designed to be usable by a non-scientist after short training and to minimize subjective judgements and problems of definition.

The major elements of the survey are fish counts of major predators (snappers, groupers and emperors) and chaetodonts (butterfly fish) along a 100 m line, and several measures within a 50 m^2 (4 m radius) circle.

The first measure is the percent coverage of major community and structural elements in six classes (0, 1–5%, 6–30%, 31–50%, 51–75%, and 76–100%). To describe the substrate, the coverage of four sizes of sediments is noted: mud, sand, rubble, and blocks. The remainder is understood to be solid or cemented. The percent coverage of five biotic categories, live hard corals, soft corals and sponges, dead standing coral, crustose corallines, and marine plants, is also recorded. A second measure in the circle is the presence of major forms of hard corals (branching, staghorn, tabulate/flat, massive, encrusting, erect foliose, cup-shaped, and mushroom), massive or fan and whip forms of soft corals and sponges, and important plant types (thick turf, long filaments, large browns, *Halimeda*, other fleshy algae, and seagrass). The dominant form in each category is indicated, together with its maximum size (fist-, forearm-, or armspan-sized). For the third measure, certain distinctive types of animals are counted (up to a maximum of 20), including mushroom coral, synaptids, other holothurians, *Acanthaster*, other starfish, urchins, giant clams, *Trochus*, and others which can be specified in particular cases. Finally, any visible pollution is noted.

A standard data sheet has been developed for rapid recording in the field. It can also be used to compile sequential surveys, and aligns with a matching analysis sheet which assists the non-scientist field worker with the interpretation of the results.

The survey sites have been chosen to represent the major coastal areas around the city, including sites with existing urban impact, sites with expected future impact, and sites up-current and down-current and offshore from the urban area. At least 10 sites will be needed in all. Each survey takes 1–2 h for a single person to complete. Where possible, two observers survey the site independently as a check on accuracy. Since the surveys have only begun in 1980, it is too early to report any results, although the technique has proven its practicability in the field.

Discussion

Urban impact on coral reefs is becoming an increasing problem in many parts of the world, particularly in developing countries. The three coral reef monitoring studies described above illustrate some of the simple techniques which can be used to measure urban impact, and some of the problems which are encountered. All attempt to overcome the enormous spatial heterogeneity of reef areas by repeating observations over time in the same localized area. Yet the choice of sites is a difficult one, particularly since local reefs are often totally destroyed with urban development. The number of sites and their location will probably be more a function of the resources and logistic support available than of experimental design. In any case, future impacts are usually difficult to anticipate. If a sufficiently large number of sites is established, some at least can be expected to give useful information.

It has proven difficult to define the entities being measured with adequate precision. Even where Mayor counted individual species, the equivalence of his species with modern taxonomic entities could not always be determined with complete certainty. Some imprecision here will always be encountered. It may be better to choose entities for the ease with which they can be distinguished in the field, rather than for their correspondence with scientific definitions. The above studies suggest that even genera, or community or morphological groupings, change sufficiently over time to be useful for monitoring purposes.

Another problem concerns appropriate techniques for data analysis. Computerization of the data with multivariate analysis would be ideal, but is still far from practical in many smaller developing countries without much scientific infrastructure. The techniques described here all lend themselves to simple numeric or graphic tabulations which permit a rapid visual comparison of results. If standardized survey techniques are adopted over a wide area, a national or regional data processing center could be considered.

The appropriate frequency of resurveys has yet to be determined. The studies in Samoa suggest that intervals of several years are too long even to monitor changes in the coral composition of a reef. Annual or bi-annual surveys would probably be the minimum necessary to document changes in variable and fast-growing corals such as *Acropora*. Monthly or quarterly surveys would be needed to relate changes to particular damaging incidents, whether natural or man-made. Much more research is obviously needed on stability and variability in coral reef communities at various scales in time and space.

This underlies the problem of effectively monitoring coral reefs for urban impact. Too little is known about natural fluctuations or changes in reef populations to distinguish many human impacts with certainty, other than those with major physical or catastrophic effects. The management of coral reef resources is thus correspondingly difficult, since an adequate foundation of scientific knowledge is lacking.

On the other hand, the existence of considerable natural variability suggests that many coral reefs are quite dynamic systems. There may be a considerable capacity for recovery from damage which could be utilized or even manipulated in the management and maintenance of reef resources. However, the requirements and limits of these recovery mechanisms are still far from being understood.

It is to be hoped that these attempts at monitoring coral reefs for urban impact will inspire both a much more extensive use of simple monitoring techniques, and more detailed, comprehensive and rigorous studies of the mechanisms underlying reef variability.

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