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EFFECTS OF TURBIDITY ON SHALLOW-WATER REEF FISH ASSEMBLAGES IN TRUK, EASTERN CAROLINE ISLANDS

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ABSTRACT

Reef fish assemblages were monitored annually from 1978 to 1981 at a series of stations adjacent to an airport runway construction site on Moen, Truk. Monitoring began prior to construction activities and continued through three years during which dredging and filling of adjacent reef areas took place. As a result of construction activities, large amounts of sediments were released into the water. Turbidity was measured monthly throughout the period of the fish monitoring and showed considerable variation from station to station. Fish abundance and diversity were significantly reduced at stations which were inundated with fine sediments. However, at stations at which sediment did not accumulate, fish assemblages remained reasonably stable, even under conditions of high water turbidity. The value of using reef fish as indicators of early stages of environmental degradation is discussed.

INTRODUCTION

Sedimentation is an important type of marine pollution affecting coral reef communities. Although sediments are added to reef communities by natural processes, man's activities in coastal areas can accelerate these processes. Johannes (1977), in assessing the significance of man-caused sediment stress on reefs, has stated, "Accelerated sedimentation due to bad land management and dredging is probably responsible for more damage to reef communities than all other forms of human insult combined."

Wilber (1971a,b) has reviewed the nature and significance of turbidity in marine environments, and Johannes (1975) has reviewed the effects of sedimentation on coral reefs.

Developing island areas in the tropics often find themselves faced with the difficult problem of developing their coastal areas while attempting to preserve the productivity of nearby coral reef environments. Shoreside construction activities almost inevitably result in the release of suspended sediments into coastal waters. This potential impact poses two questions: How much siltation stress and water turbidity can reef organisms withstand? Are there indicator organisms which can provide advance warning of environmental deterioration so that silt-producing activities can be modified before irreversible damage is done to reef environments?

Reese (1977) has suggested that the colorful and conspicuous butterflyfishes might serve as indicators of the condition of the coral communities upon which they depend for food and shelter. Russell et al. (1978) point out, "Because of their mobility, fishes are able to respond rapidly to changes in their physical environment ..." The combination of rapid response to environmental changes and conspicuous appearance would make reef fishes valuable pollution indicators if, indeed, they do respond rapidly to environmental deterioration.

The research reported here provides information on the effects of turbidity and siltation stress on reef fish assemblages near Moen, Truk, and the usefulness of reef fish as early indicators of siltation stress is evaluated.

MATERIALS AND METHODS

Moen Island is one of nineteen high islands within Truk Lagoon (7°27'N, 151°51'E) in the Federated States of Micronesia. The commercial airport runway extends along the northwest coast of Moen. In order to improve the runway, fill material was dredged from a shallow reef flat area around the mouth of Pou Bay (on the north coast of Moen) and transported through a pipeline to the runway site where it was deposited to increase the length and width of the runway. Eleven biological monitoring stations were established at 8 locations (there were 2 monitoring stations at 3 of the locations) along the length of the dredging and construction zone (approximately 4.5 km). Stations 1, 2, 3A, 3B, 4A, and 4B were located adjacent to the dredge site; stations 5, 6, 7, 8A and 8B were located adjacent to the runway expansion site. Each monitoring station consisted of an isolated or semi-isolated coral mound on the lagoon floor just beyond the fringing reef margin (100-600 m from the emergent shoreline) at depths (at the base of the mound) ranging from 5.5 to 12.5 m. The lagoon floor surrounding the monitoring stations consisted predominantly of coarse *Halimeda* sand. A twelfth monitoring station (station 9), approximately 1 km off-shore, was also established to serve as a control. This station was on a lagoon patch reef at a depth of 5.2-12.3 m on a sloping bottom of *Halimeda* sand. The distance of this station from the dredging and filling sites was felt to be sufficient (in light of preliminary observations on water circulation patterns) to place it outside the expected area of influence by silt released during dredging and construction activities.

At each monitoring station, a transect line was placed across the long axis of the coral mound. Transect lengths ranged from 6.6 to 35.0 m depending upon the size of the mound. Fish were censused by a scuba diver swimming along the transect line, listing and enumerating all the species seen within 1 m of either side of the line. After the enumeration, the observer searched the mound for an additional 10-15 min, recording other fish species which occurred on the mound but which were not encountered on the transect. Most censuses were replicated. At each censusing, including replicates, the transect line was laid out anew; thus, the transect line did not invariably cross the mound at exactly the same location for each census.

The monitoring stations were visited during 4 successive years: 21 May-27 May, 1978, 5 April-11 April, 1979, 30 May-4 June, 1980, and 10 April-15 April, 1981. Over this same period, water turbidity (in nephelometric turbidity units [NTU]) was measured on a monthly basis at each of the station locations by the University of Guam Water Resources Research Center (now UOG Water and Energy Research Institute).

Analyses of the changes in the fish assemblages over the course of the study are based on all the fish species seen at the monitoring stations and also on a subset of species. This subset consisted of those species which, when observed on one member of a replicate census pair, were also seen on the other member at least 50% of the time. This procedure eliminated those species that visit the monitoring station occasionally but are not consistently found there as well as those cryptic species which are seen from time to time but which are easily overlooked even when they are present. The 40 species which met the criterion for membership in this subset are principally the more conspicuous species which are more or less permanent residents of the monitoring stations. They are termed "conspicuous residents." The full census data upon which these analyses are based are presented in Amesbury et al. (in prep.).

RESULTS

The airport runway construction commenced in early October 1978. Prior to construction, mean turbidity levels (measured near the bottom) at the monitoring stations ranged from 0.25 to 0.58 NTU (Table 1). Mean turbidity increased at all monitoring stations after construction began, but major increases occurred only at the stations located adjacent to the runway, stations 5, 6, 7, 8A and 8B. At the latter two stations, water circulation apparently was such that suspended silt settled from the water column and accumulated on the bottom in a layer exceeding a meter in thickness in some areas. This resulted in the complete covering station 8B and the partial submergence of station 8A in fine sediments.

A noticeable decline in species richness occurred at station 8A where the number of species dropped to about half the number originally seen (Table 2). The number of fish species seen at station 8B dropped abruptly to 0 on the 1980 census as a result of the coral mound being completely covered with sediments. Station 5 was inadvertently covered with large rocks during construction activities prior to the 1981 survey. Station 1 also exhibited a decline in species richness over the study period. None of the other stations exhibited noteworthy reductions in species richness.

Fish density, based on enumeration of fishes along the transect lines, proved to be quite variable, not only from year to year but also between replicate transects run during the same census period (Table 3). The most consistent decline in density occurred at station 1. Fish density declined to 0 at stations 5 and 8B which were completely covered with rocks and fine sediments, respectively. Although the total number of fish counted at station 8A declined during the course of the study, density was less noticeably affected as the size of the coral mound also diminished.

DISCUSSION

Fish could potentially serve as useful early indicators of environmental stress because their mobility permits them to escape areas where environmental quality is declining. Sessile organisms, on the other hand, are constrained to remain in their original habitats until environmental degradation becomes severe enough to result in their death (or until they are overgrown or outcompeted by species more tolerant to the changed conditions). Thus, if sessile organisms are used as indicators of environmental stress, the need for ameliorative action may not become apparent until environmental degradation becomes irreversible.

The results of this study suggest that reef fish species, particularly those species which hold territories or confine their activities to limited home ranges, continue to occupy habitats subject to high levels of water turbidity. Only at sites where signifi-

Table 1. Turbidity levels (NTU) at the monitoring stations, averaged over various time periods.

Stations	20 May-1 Sept 78 (prior to construction)			4 Oct 78-3 Apr 79 (beginning construction to 2nd fish survey)			7 May 79-28 May 80 (2nd fish survey to 3rd fish survey)			27 June 80-9 Apr 81 (3rd fish survey to 4th fish survey)		
	$\overline{X}$	S.D.	N	$\overline{X}$	S.D.	N	$\overline{X}$	S.D.	N	$\overline{X}$	S.D.	N
1	.47	.125	6	.81	.393	6	.79	.341	14	.65	.251	10
2	.45	.122	6	.57	.201	6	.70	.457	14	.54	.146	10
3A/3B	.45	.096	6	.64	.212	6	.97	.573	14	.51	.159	10
4A/4B	.41	.095	5	.48	.223	6	.80	.407	14	.51	.185	10
5	.33	.031	6	1.05	.721	6	1.17	.544	14	.94	.558	10
6	.32	.055	6	1.01	.658	6	1.43	.667	14	1.33	1.201	10
7	.39	.114	6	.73	.295	6	1.17	.466	14	1.04	.320	10
8A/8B	.58	.243	6	.86	.368	7	1.51	1.410	12	3.74	3.506	10
9	.25	.047	6	.47	.233	5	.46	.189	14	.39	.104	10

Table 2. Mean number of fish species observed at monitoring stations, with range of replicates in parentheses. "Conspicuous residents" is defined in text.

Station	1978		1979		1980		1981	
	All Species	Conspicuous Residents	All Species	Conspicuous Residents	All Species	Conspicuous Residents	All Species	Conspicuous Residents
1	34	16	37(35-39)	18.5(17-20)	33(31-35)	14(13-15)	22.5(22-23)	12.5(12-13)
2	10	8	14(13-15)	8.5(8- 9)	16.5(16-17)	11.5(11-12)	16.5(15-18)	12(12-12)
3A	14	7	13.5(12-15)	9.5(8-11)	15.5(13-18)	11(10-12)	16(15-17)	12(11-13)
3B	19	11	21.5(19-24)	11(11-11)	22.5(21-24)	11.5(11-12)	21.5(19-24)	11.5(10-13)
4A	22	15	29.5(29-30)	17(16-18)	31(22-40)	15.5(12-19)	36.5(32-41)	17.5(15-20)
4B	17	10	32	18	32(29-35)	17.5(17-18)	37(37-37)	18(18-18)
5	16	8	14.5(14-15)	9(8-10)	20(19-21)	7.5 (7-8)	0	0
6	20.5(20-21)	10.5(10-11)	13.5(9-18)	8.5(8- 9)	22(16-28)	10.5(9 -12)	21(20-22)	11(10-12)
7	33	14	27.5(24-31)	14.5(14-15)	39(36-42)	15.5(15-16)	33(33-33)	16(15-17)
8A	27	10	17.5(14-21)	5(5- 5)	7(5- 9)	3.5(3- 4)	10.5(8.13)	5(5- 5)
8B	22	8	12.5(11-14)	7.5(7- 8)	0	0	0	0
9	48	19	38.5(38-39)	20.5(19-22)	39(35-43)	20.5(20-21)	42(41-43)	19(19-19)

Table 3. Mean fish density (no./m^2) on the monitoring station transects, with range of replicates in parentheses. "Conspicuous residents" is defined in text.

Station	1978		1979		1980		1981	
	All Species	Conspicuous Residents	All Species	Conspicuous Residents	All Species	Conspicuous Residents	All Species	Conspicuous Residents
1	4.00	3.57	4.42(2.21-4.63)	4.09(4.02-2-4.16)	2.58(2.45-2.70)	1.77(1.25-2.28)	0.93(0.58-1.27)	0.70(0.32-1.08)
2	3.95	3.79	4.19(3.63-4.74)	3.56(2.74-4.37)	8.26(7.71-8.80)	4.95(2.60-7.29)	3.42(3.39-3.44)	3.31(3.28-3.33)
3A	3.26	2.80	2.27(1.89-2.65)	1.94(1.67-2.20)	4.29(4.29-4.29)	4.14(4.14-4.14)	3.04(2.72-3.36)	2.89(2.57-3.21)
3B	4.70	4.15	2.77(2.37-3.17)	2.61(2.20-3.01)	4.17(2.82-5.52)	3.71(2.32-5.10)	3.80(1.75-5.84)	3.39(1.45-5.32)
4A	11.08	3.16	15.57(12.75-18.38)	6.52(5.31-7.72)	4.93(4.91-4.94)	4.53(4.40-4.65)	10.21(8.94-11.47)	9.53(7.87-11.19)
4B	3.37	2.89	7.55	7.18	5.84(3.00-8.68)	5.57(2.88-8.26)	4.05(3.10-5.00)	3.50(2.38-4.62)
5	14.83	13.33	7.67(4.78-10.56)	7.53(4.67-10.39)	41.84(27.06-56.61)	9.39(3.88-14.89)	0	0
6	1.71(1.68-1.73)	1.18(1.04-1.32)	0.93(0.45-1.41)	0.73(0.45-1.00)	1.48(1.42-1.54)	1.01(1.00-1.02)	3.04(2.57-3.50)	1.81(1.33-2.29)
7	4.50	3.73	2.80(2.53-3.07)	1.84(1.67-2.00)	7.13(6-16-8.10)	2.93(2.28-3.57)	3.69(3.07-4.30)	3.30(2.70-3.90)
8A	1.97	1.33	5.84(3.04-8.64)	4.68(2.60-6.75)	1.10(1.00-1.19)	1.05(0.90-1.19)	1.22(1.13-1.30)	1.10(1.10-1.10)
8B	3.50	2.22	0.83(0.70-0.96)	0.69(0.56-0.82)	0	0	0	0
9	3.73	1.72	3.66(3.28-4.03)	2.92(2.88-2.95)	2.93(1.98-3.87)	2.24(1.88-2.59)	3.33(2.90-3.76)	2.45(2.37-2.52)

cant amounts of sediment accumulated and coral substrates were buried did reef fish assemblages suffer major impacts. The decline in species richness and fish density at station 1 cannot be related to either turbidity or sediment accumulation, however, as turbidity levels at this station were among the lowest of all the stations, and no noticeable sediment accumulation occurred.

Other investigators have reported reduction in abundance and species richness of reef fishes subject to siltation (e.g. Brock et al. 1966). The relative stability in fish abundance and diversity exhibited at those stations subject to high turbidity levels, but where silt did not accumulate, suggests that suspended sediment (at least at the level and duration observed during this study) may not, by itself, cause fish to abandon their places of residence.

Several studies have indicated that a fairly wide variety of reef fish species habitually remain within rather limited areas of the reef (Bardach 1958, Randall 1961, Springer and McErlean 1962, Low 1971, Sale 1971, Reese 1973, Amesbury et al. 1979). In some cases these species hold and defend specific territories and aggressively repel invading individuals of the same species (or of ecologically similar species). Other home ranging species also remain within circumscribed areas wherein are contained their necessary food resources and predator refuges. The persistence exhibited by several species of reef fishes in this study in remaining at their residence locations under conditions of substantial environmental deterioration suggests that selective pressures favor provincialism in residence patterns of these fish. The likelihood of a fish successfully establishing itself at a new location, when faced by possible predation or aggression from competing territory-holders, may be sufficiently small to select against adventuresome individuals.

Although reef fish species have the potential to emigrate from areas where environmental quality is deteriorating, the results of this work indicate that this option may not be exercised by territorial and home ranging species until stresses are such that other, less variable and more easily quantified, sessile species become impacted. Thus, reef fish assemblages may have no particular value as indicators of early stages of environmental degradation caused by turbidity and siltation.

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