Sea Level Fluctuations and Mass Mortalities of Reef Animals in Guam, Mariana Islands[1]

MASASHI YAMAGUCHI[2]

The Marine Laboratory, University of Guam, P.O. Box EK, Agana, Guam 96910

Abstract—Monthly mean sea level dropped as much as 44.2 cm below MSL on Guam in October 1972, where the tidal range is about 1 m during the spring tides. This was the most extensive sea level drop ever recorded on Guam since 1948. The 1972 sea level drop caused an intensive mass mortality in the reef flat communities along the windward reefs of Guam, killing virtually all macroscopic organisms within the inner reef flat of Pago Bay. Many macro-benthic animal populations killed there consisted predominantly of adult individuals.

Recovery of the benthic communities to pre-mortality conditions was incomplete on the inner reef flat of Pago Bay within a three year period. Corals, echinoderms, and some gastropod populations showed little recovery. The mass-mortality in 1972 appeared to be more intensive than the one in 1968.

The abnormal sea level drops at Guam and other tropical Pacific Islands within the Equatorial Current System are probably related to episodic anomalities in large scale oceanographic conditions. Local conditions such as wind stress may modify the magnitude of such fluctuations. The extensive sea level drops at Guam occurred mostly in winter months and they were well correlated with the lower than average sea levels in preceding summer months. The latter may be monitored as forerunners for predicting abnormal sea level drops on Guam.

Introduction

Abnormal sea level fluctuations, episodic or cyclic, have a profound influence on the population dynamics of organisms inhabiting shallow reef flats, particularly by causing mass mortalities during extreme low sea level. Glynn (1968) reported frequent mass mortalities of echinoids and other reef flat animals during midday, low water exposures in Puerto Rico. Fishelson (1973) observed that an extremely low tide killed or damaged numerous coral colonies on shallow table reefs in the Red Sea in September 1970. Exposure to the air and/or high temperature during the low tides are direct causes for these mass mortalities of tropical sedentary animals, since sea level drops are rather sudden and unpredicted phenomena for animals which have established themselves during normal or higher sea level years.

An extensive mass mortality occurred on Guam during late October 1972, due to abnormally low sea level which persisted for more than two weeks, exposing the

[1] Contribution No. 70, University of Guam Marine Laboratory.

[2] Present Address; School of Biological Sciences, James Cook University of North Queensland, P. O. James Cook University, Qld. 4811, Australia.

Micronesica 11(2): 227-243. 1975 (December).

reef flat along the windward coast (Yamaguchi, 1974). The present report is a summary of investigations on sea level records of Guam and some of the western Pacific islands such as Eniwetok (or Enewetak) in relation to the mass mortality.

Mass Mortality of Reef Flat Organisms on Guam in 1972

The mass mortality was most extensive on the reef flats along the windward coast of Guam. This was probably because the wind direction was abnormal during the period, i.e., the NE trade winds ceased or weakened and westerlies or southerlies persisted from the 8th to 13th October (local climatological data, National Weather Service). The personnel at the local weather station maintained that the low sea level was caused by the abnormal wind condition (personal communication). However, the sea level data indicate that the local climatological condition was not the principal factor in this case, although it certainly is conceivable that the abnormal wind condition contributed to some extent.

Unfortunately, there were no systematic surveys of animal mortalities along

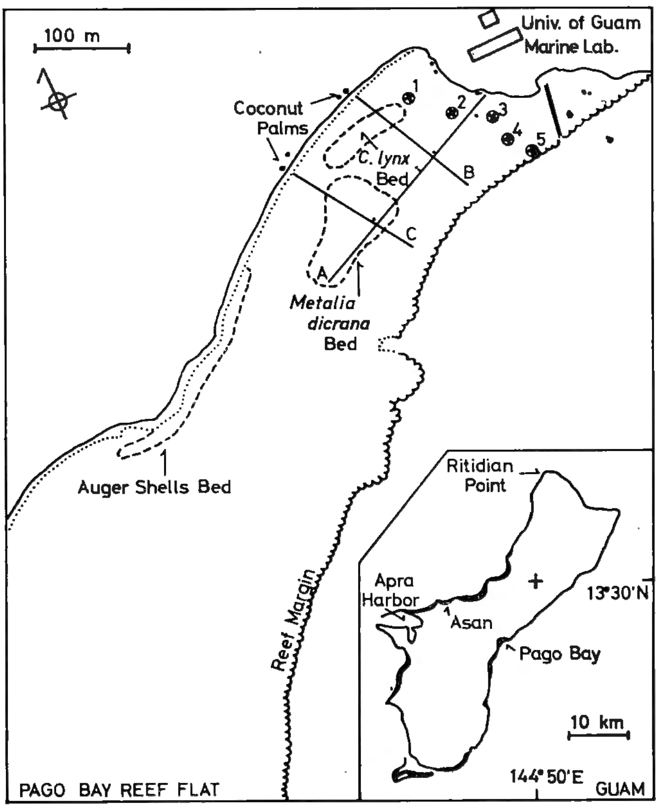

Fig. 1. North-east section of Pago Bay reef flat and habitat distributions of animals killed in October 1972.

Table 1. Hydrological conditions of reef flat pools during the mass mortality at Pago Bay on 17th October, 1972.

Pool[1]	Water Temperature °C	Salinity[2] ‰	Dissolved[3] Oxygen cc/l	%	Remarks
1	37.7	29.4	0.34	(8.5)	All Animals Dead
2	36.9	22.0	0.00	(0.0)	Anaerobic
3	37.1	30.7	0.37	(9.4)	All Animals Dead
4	36.6	30.5	1.46	(36.5)	Most Animals Dying, except Xanthid Crabs
5	33.6	34.4	5.97	(142)	No Mortality[4]

(1) The five pools were located from the near shore to the reef margin approximately in a line (see Fig. 1).

(2) Determined by silver nitrate titrations.

(3) Determined by Winkler's method, mean of two samples, with saturation level in parentheses.

(4) Fresh sea water was flushing occasionally over the reef margin.

the entire coastline of Guam. Fish mortalities were noted on the west coast (leeward), but there was no sign of mass mortality around Ritidian Point on the northwest tip of Guam, which was surveyed by a team of marine biologists from University of Guam Marine Laboratory.

I have made determinations of water temperature, salinity, and dissolved oxygen at five pools on the reef flat at Pago Bay (east, windward coast) on 17th October, when the mass mortality was at its height. The five pools were situated approximately in a line from the shore to the reef margin near the northern end of the bay where the reef flat is approximately 200 m wide (Fig. 1). The subsurface water in those pools with depth of less than 30 cm had temperatures ranging up to 37.7°C (from 1400 to 1430), with salinity from 22.0 to 34.4‰, and with very low oxygen level except for water in the pool near the reef margin (Table 1). The lowered salinity was caused by fresh water which diffused into the inner reef flat pools through the limestone substrate (cf. Emery, 1962). All animals in the three pools within the middle to inner reef flat were dead at the time of observation and Pool 2 was anaerobic, with sulfides making the water and substratum appear all black.

Most dead animals and plants disintegrated rapidly so I collected only those with calcareous skeletons, i.e., mollusc shells and spatangoid sea urchins. It was difficult to make any quantitative survey of dead animals because a large number of people took advantage of the mass mortality for collecting freshly killed edible animals and also for shelling. Table 2 is a summary of major macro-benthic animal groups killed during the period. Virtually all animals were killed within the inner reef flat, from midway to the shore. A notable exception was small hermit crabs which survived by aggregating outside the anaerobic pools but under moist boulders. Larger hermit crabs such as *Dardanus*, as well as brachyuran crabs, came out of pools and died on exposed limestone benches.

Table 2. Summary of macro-benthic animals killed at Pago Bay reef flat in October 1972.

Animal Groups	Conspicuous Species	Remarks
Corals	*Porites lutea* *Porites compressa* *Psammocora contigua* *Pocillopora damicornis* *Pavona divaricata*	All coral colonies died (at least superficially) on the flat.
Echinoderms	*Holothuria atra* *Holothuria leucospilota* *Echinothrix diadema* *Brissus latecarinatus* *Metalia dicrana* *Ophiocoma* sp. *Macrophiothrix longipeda*	Most echinoderms were killed but holothurians in the outer reef flat zone survived.
Crustaceans	*Calappa hepatica* *Carpilius maculatus* *Atergatis floridus* *Dardanus* spp. *Alpheus* sp.	Numerous species of small crustaceans died except small hermit crabs and small xanthid crabs.
Molluscs	*Cypraea lynx* *Conus pulicarius* *Conus flavidus* *Terebra crenulata* *Terebra dimidata* *Strombus gibberulus* *Scutarcopagia scobinata*	Octopus, nudibranchs, and numerous other molluscs were killed. *Cerithium nodulosum* survived well on the outer flat.
Other Macro-benthic Invertebrates	*Dysidea herbacea* *Palythoa* sp. *Eurythoe* sp. *Ptychodera* sp.	Various worms, actinians, and sponges were killed throughout the middle and inner flat. *Palythoa* lived at near the reef margin.

A total of 40 species of fishes were also found dead at Pago Bay. Among them, 6 species of eels, the stone fish *Synanceia verrucosa*, and a trigger fish *Rhinecanthus aculeatus* were the most conspicuous (identifications by H. Larson).

I picked up about 1000 dead individuals of the cowry *Cypraea lynx* within an area of ca. 20×100 m in the inner reef flat (Fig. 1). This snail is very cryptic in habit and I had not previously noticed its presence in this area where I had frequently visited to collect the coral *Pocillopora damicornis*, (which was also completely killed along with other coral species). There were aggregations of the sponge *Dysidea herbacea* with which *C. lynx* was probably associated. At least several hundred more *C. lynx* were collected by other shell collectors from the same area. Therefore, the mean population density of the cowries was nearly 1 per square meter within the area at the moment of the mass mortality, although they actually occurred in denser aggregations localized under shelters such as the basements of dead and live coral colonies which were surrounded with the sponge.

Spatangoids (*Metalia spatagus, M. dicrana,* and *Brissus latecarinatus*) emerged from sand-shingle sediments, which veneered the reef flat limestone bench, and died on the open surface. I collected about 100 individuals of mostly *M. dicrana* from an area of distinct sand-shingle zone (Fig. 1) in a middle portion of the northern reef flat. *Brissus* appeared to be more wide-spread in distribution. Numerous small acorn worms (*Ptychodera* sp.) were killed in the same area.

Except for small numbers of individuals which inhabited the outer reef flat, most holothurians, which were the most conspicuous and abundant macrobenthos on the reef flat, died and eviscerated their intestines and gonads. Many *Holothuria leucospilota* revealed very well developed gonads. Also impressive was that about half of the crab *Calappa hepatica* population were carrying eggs.

Mass mortalities such as occurred on Guam in 1972 might be a significant factor in limiting distributions of shallow water organisms both within local habitats and in geographical ranges. For example, there are a number of organisms which are absent in the marine biota of Guam, although there are presumably suitable habitats around the island. Tsuda (1968) pointed out an absence of a green alga genus *Ulva* at most islands in Micronesia including Guam, although it is distributed in the surrounding areas.

Asteroids such as *Archaster typicus* and *Protoreaster nodosus* normally occur abundantly within very shallow reef flats in certain areas such as Palau but they are absent from these habitats on Guam (Yamaguchi, 1975). The same is true for the giant clams *Hipoppus hipoppus* and *Tridacna crocea*, which are gregarious and occur mostly on reef flats. Corals such as *Favites aspera* and *Oulastrea crispata* normally live close to shore but are absent from Guam. Of course, the chances of immigration to Guam from source areas may be limited for the species mentioned above but they would easily be eliminated from appropriate habitats on Guam by occasional mass mortalities which act most selectively on those species that colonize reef flats.

Population Structures of Some Reef Animals Killed in 1972

The mass mortality provided a unique opportunity to investigate the population structure of common animals, particularly those cryptic in habit and otherwise very difficult to census. It also provided an opportunity to see whether past mass mortalities have had any effect on the population dynamics of reef flat animals. The sea level drop in 1968 (see later section) caused mass mortalities of fishes (R. S. Jones, personal communication) on the reef flats around Guam, although no information about invertebrates was collected at the time.

I collected 51 species of gastropods and 15 species of bivalves from the inner reef flat soon after the 1972 reef kill but most species were not abundant enough to establish size-frequency histograms. Only two auger shells (Fig. 2), three cone shells (Fig. 3), and one cowry (Fig. 4) are shown here along with one of the three spatangoid species (Fig. 5). For each of these species, all individuals seen within certain areas (see Fig. 1) were collected.

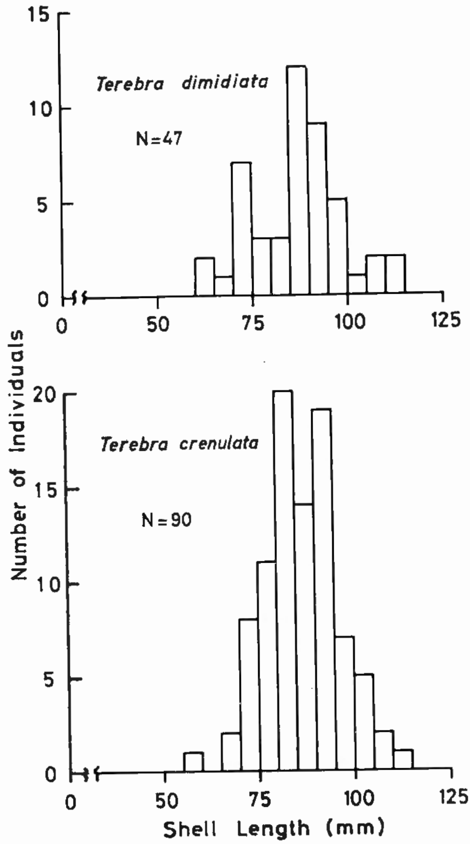

Fig. 2. Size-frequency distributions of two auger shells, *Terebra dimidiata* and *Terebra crenulata*, killed in the inner reef flat of Pago Bay in October 1972.

The most characteristic trend in the size-frequency distributions was that larger or adult individuals predominated within each population sample except in the case of *Strombus gibberulus* in which samples contained 40% juveniles. Only four pre-transformation stage juvenile *Cypraea lynx* were found among ca. 1000 adult individuals (in this species adults do not grow). Transforming (to adult) or newly-transformed *C. lynx* have thin shells and the apex remains unburied under adult shell layers. Such young adults were only about 3% of the specimens collected. Frank (1969) likewise found that juveniles constituted only small fraction (up to 2%) of the population in *Cypraea annulus* at Heron Island, Australia.

Populations consisting predominantly of adults are common among macrobenthic animals inhabiting coral reefs. Kohn (1959) and Kohn and Nybakken (1975) have shown such size-frequency distributions for most common species of *Conus* in Hawaii and other Indo-Pacific islands. Frank (1969) remarked that most gastropods studied at Heron Islands, Australia had negatively skewed size-

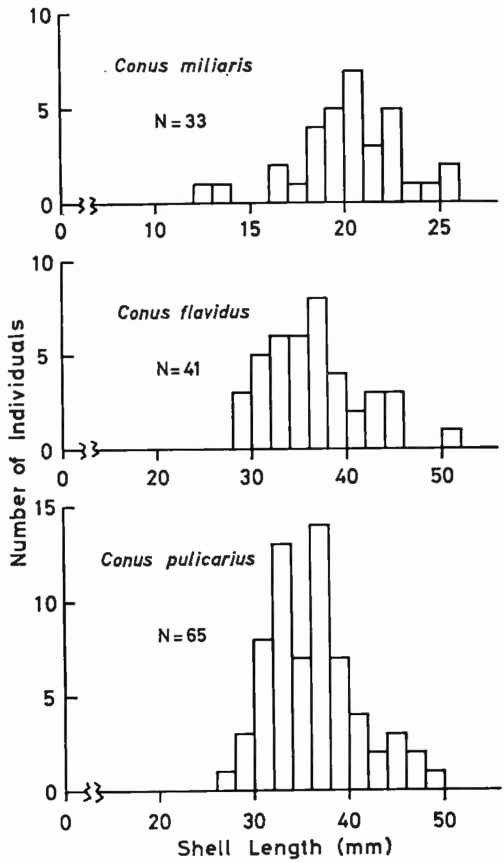

Fig. 3. Size-frequency distributions of three cone shells, *Conus miliaris*, *Conus flavidus*, and *Conus pulicarius*, killed in the inner reef flat of Pago Bay in October 1972.

frequency distribution (i.e., smaller frequencies for smaller individuals) and attributed this to faster juvenile growth and long adult life.

If there were mass mortalities of these animals at Pago Bay in 1968, their populations have had to re-establish themselves within less than four years. However, the 1968 mass mortalities were probably less severe than those of 1972 because the actual sea level drop was less extensive and because the 1972 mass mortalities wiped out coral populations which seem to have been older than four years and so must have survived the 1968 mass mortalities. For example, all *Pocillopora damicornis* in the inner reef flat were killed in 1972. If this coral grew at a rate of ca. 6 cm in diameter per year as was reported for the species at Low Isles, the Great Barrier Reef (Stephenson and Stephenson, 1933), those larger than 25 cm in diameter (which were not uncommon) must have been older than four years at the time. *Porites lutea* probably grows at a much slower rate but there

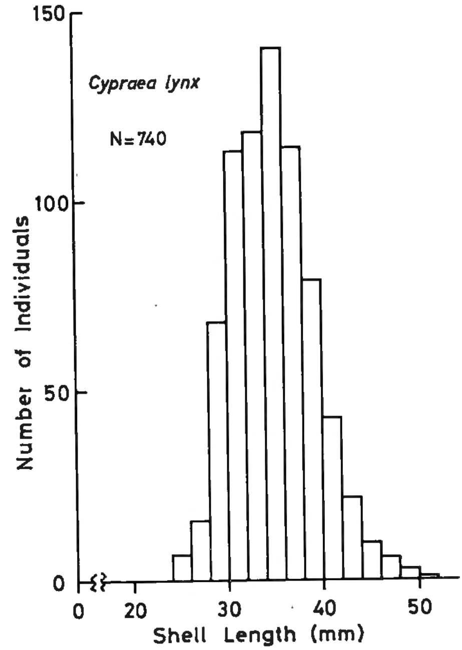

Fig. 4. Size-frequency distribution of *Cypraea lynx* killed in the inner reef flat of Pago Bay in October 1972. A composite of two (N: 420 and 320, total 740) out of three sub-samples is shown, excluding four pre-transformation stage juveniles. Attempts to distinguish age classes by measuring relative thickness of shell have failed to demonstrate any polymodal age-structure from the sample.

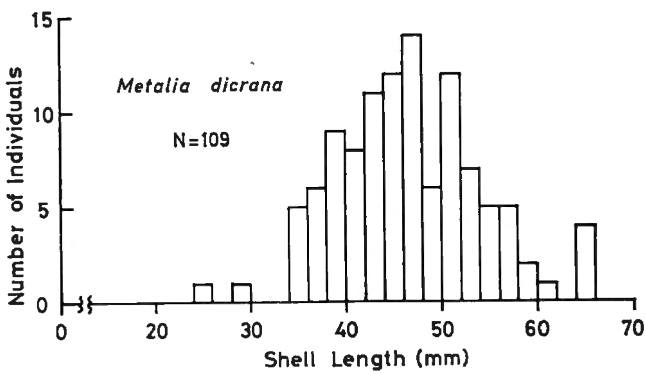

Fig. 5. Size-frequency distribution of the spatangoid *Metalia dicrana* killed in the middle section of the northern reef flat of Pago Bay in October 1972.

were large (up to a few meters in diameter) live micro-atolls of this coral among many long-dead ones before the mass mortalities.

Regardless of the effect of the 1968 mass mortalities the foregoing size-frequency distributions of killed animals of Pago Bay indicate that juveniles have not recruited heavily to the adult populations within the last few years. If these animals had recruited periodically each year their juvenile cohorts might have been recognized within each population. However, such case is rarely seen among the macro-benthic animals on the coral reef. Perhaps, there would be fairly heterogeneous and resurgent recruitment of those animals in space and time. For example, I have seen a large recruitment of *Cypraea moneta* juveniles at Pago Bay in January 1971 (but this population diminished rapidly) and also strong recruitment of echinoid *Diadema savignyi* juveniles (5 to 10 mm test diameter) along the lee coast of Guam in June 1973.

Recovery of the Benthic Animal Populations at Pago Bay after the Mass Mortalities in 1972

By January 1974 (ca. 15 months after the mass mortalities), the snails *Strombus gibberulus, Cerithium asperum*, and *Cypraea moneta*, and the acorn-worm *Ptychodera* sp. were the re-established members of the macrobenthic community. Predatory animals, such as the crab *Calappa* and the snails *Cymatium, Vasum*, and *Conus*, were either absent or very rare.

There were no living corals within the inner reef flat at Pago Bay after the 1972 mass mortality. All colonies of *Pocillopora damicornis, Psammocora contigua, Pavona decussata, P. varians, P. divaricata, Porites compressa*, and a few other species of scleractinian genera (*Goniastrea* and *Favia*) were completely killed. Most *Porites lutea* colonies appeared to be killed completely but some of the "dead" colonies renewed growth began, primarily from the bottom where they were partially buried in sandy sediment, in late 1974. The majority of *Porites lutea* heads remained dead, however, and the few revived ones recovered to various degrees in the three years (Table 3). One small, cryptic coral *Stylocoeniella armata* re-

Table 3. Recovery of 3 colonies of *Porites lutea* on the inner reef flat of Pago Bay in September 1975, ca. 3 years after the mass mortality.

Colony	Size		Estimated Recovery in Circumference (%)	Maximum Recovery Height from Bottom (cm)
	Diameter (cm)	Height (cm)		
1	100×100	50	25	10
2	110× 90	30	35	20
3	35× 30	25	75	25

The three samples represent well-recovered, regularly-shaped coral heads. They superficially appeared dead soon after the mass-mortality in October 1972.

established itself in the inner reef flat by May 1975. Live fragments of *Porites lutea, P. compressa*, and *Psammocora contigua* up to about 10 cm in diameter are occasionally being carried into the inner flat by current and wave action (and also by crabs) and they were becoming established by September 1975. However, colony tips of *Acropora* (mostly *A. nasuta* and *A. humilis*), likewise fragmented and being carried from seaward reef front to the reef flat, appears not to survive there. I have found a few very young spat (less than 1 cm in diameter) of *Pocillopora damicornis* under rock boulders in the inner flat in May 1975. This coral wlil eventually re-establish itself in the habitat where it was abundant prior to the mass mortalities.

Large sea anemones with clown fishes (unidentified) were common under edges of larger rocks but they totally disappeared at the time of the mass mortality and no recovery has been seen by October 1975.

The hemispherical sponge *Cinachyra australiensis* became abundant in the inner reef flat in early 1975. Another conspicuous green sponge *Dysidea herbacea* came back, gradually forming encrusted patches of up to 1 m in diameter in May 1975.

Among crustaceans, a box crab *Calappa hepatica*, hermit crabs of the genera *Dardanus* and *Carcinus*, and an unidentified alpheid shrimp became common in the inner reef flat by September 1975. A mantis shrimp, although uncommon, appeared and there were large number of advanced alima larvae of a stomatopod (supposed to be the mantis shrimp) appeared on the reef flat in July 1975 (found by G. Vermeij).

Cryptic spatangoids are difficult to find in their habitat but probably had not recovered well within the three years after the mass mortalities, because I had not seen any dead tests appearing on the reef flat during the period. On the other hand, a small fraction of the populations of the two most common holothurians *Holothuria atra* and *H. leucospilota* survived at the outer flat and eventually migrated into the inner flat. They were relatively common except near the shore

Table 4. Population densities of three holothurian species and the asteroid *Linckia laevigata* at Pago Bay reef flat in October 1975.

		Holothuria(1) *atra*	*Holothuria*(1) *leucospilota*	*Actinopyga*(1) *echinites*	*Linckia*(1,3) *laevigata*
Transect A (250 m)		38	10	2	5
Transect B (150 m)		10	2	3	1
Transect C (150 m)		14	0	1	0
Density(2) (per 100 m²)	A	7.6	2.0	0.4	1.0
	B, C	4.0	0.3	0.7	0.2

(1) Number of individuals within 1 m both sides of transect lines, see locations of each transect line in Fig. 1.

(2) There were no individuals within 50 m from the shore along the Transect B and C. This is reflected by the lower density of animals for the two lines, except for *Actinopyga echinites*.

(3) About 1000 individuals *Linckia laevigata* were transplanted from Asan Reef in March and May 1975.

(Table 4) in October 1975. *Holothuria atra* reproduces asexually by transverse fission (Bonham and Held, 1963). Other species common before the mass mortalities, such as *Holothuria argus, Stichopus chloronotus,* and *Synapta maculata* became rare in Pago Bay. Sea urchins were not abundant before the mass mortality but the common species *Echinometra matheai* and *Echinothrix diadema* disappeared from the inner flat and were not seen (but *E. matheai* was common at the southern section of Pago Bay) in September 1975. There were no sizable populations of asteroids either before or after the kill. I tried to see whether or not the common reef flat starfish *Linckia laevigata* (which was absent prior to transplanting) could survive after being transplanted from other reefs to Pago Bay. An estimated 250 individuals survived in October out of ca. 1000 transplanted from Asan Reef during March and May 1975. Many individuals probably had been taken out by people or washed on the shore by wave actions. In short, echinoderm populations dwindled in Pago Bay by the 1972 mass mortality and there was little apparent recruitment towards recovery to the previous conditions during the three year period.

In addition to those species already recovered in January 1974, various gastropod molluscs appeared to have re-established themselves in the inner flat by February 1975. They were *Strombus mutabilis, Cerithium columna, Cymatium nicobarium, C. muricinum,* and *Vasum turbinellum*. Although there was not a single

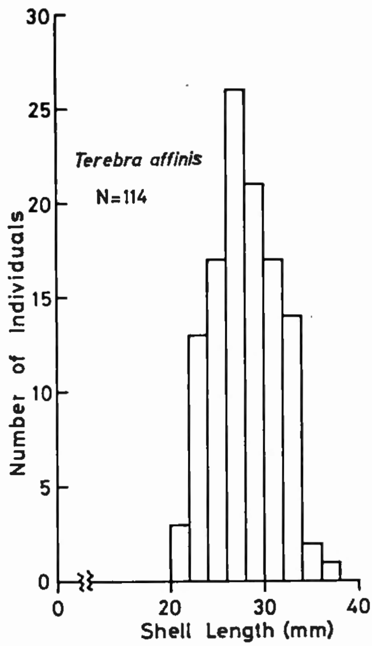

Fig. 6. Size-frequency distribution of *Terebra affinis* collected by two one-hour searches in the auger shell bed (Fig. 1) at Pago Bay in October 1975. No larger species of auger shells was found.

killed specimen collected from the inner flat in 1972, several hundred juvenile *Cerithium nodulosum* settled and grew there after the mass mortality, some of which attained the adult stage by April 1975. Growth and migration of this species was studied by tagging individuals from February to November 1975 and will be reported separately. In contrast to these gastropods, cone and auger shells did not recover their populations along the inner flat during the three year period, although recrutiment of some *Conus* (such as *C. sponsalis*, *C. miliaris*, and others) was apparent on the outer flat by January 1975. Indeed, I have not seen any *Conus* in the inner flat, except for a few *C. pulicarius* and *C. virgo* (the latter may be immigrant from the outer flat) during frequent visits for the tagging experiments with *Cerithium nodulosum*.

An attempt to investigate the recovery of the auger shell populations was made in October 1975. None of the three formerly inhabited species, *Terebra dimidiata, T. crenulata*, and *T. areolata*, was found at the habitat section (Fig. 1) during two consective one-hour searches. However, a smaller species, *T. affinis*, (Fig. 6) was found which had not been recorded among the dead gastropods in October 1972. Sixteen other small gastropod species and two bivalve species were collected with *T. affinis* which was the predominant species, followed by *Cerithium asperum* and *Strombus gibberulus*.

A live specimen of the pen shell *Pinna muricata* with a shell length of 11.5 cm was collected in the inner flat in January 1974. Since this was as big as the largest individual killed in 1972, this individual must have had a high growth rate. Unfortunately, this species is never abundant anywhere and a study of its growth in the field is unfeasible. Freshly-killed shells of bivalves *Scutarcopagia scobinata, Quidnipagus rugosa* and *Gafrarium pectinatum* became common in the inner flat by January 1974. Occasionally, *Fimbria fimbriata, Periglypta reticulata, Epicodakia divergens*, and *Fragum fragum* were seen in early 1975. Bivalves in general are uncommon at Pago Bay except for a mussel *Modiolus auriculatus* (identified by Dr. B. R. Wilson of the Western Australian Museum) which occurs in abundance on the outer reef flat.

In conclusion, the 1972 mass mortality was very extensive and probably caused more damage to the inner reef flat community than did the previous one in 1968. The macro-benthic fauna in the inner reef flat became impoverished by the mass mortality. Recovery to the pre-existing community was incomplete within a three year period.

Fluctuations and Drops of Sea Level on Guam

Available sea level records for Guam, as monthly means from 1948 through 1973 (recorded by a gage in Apra Harbor and supplied from National Ocean Survey, NOAA), indicate marked seasonality, i.e., high sea level in summer months and low in winter. The mean of each monthly level for 20 years (1952–1971) has a peak in July and a bottom in December. The sea level of Eniwetok has a seasonal fluctuation similar to that of Guam and appears to follow approximately

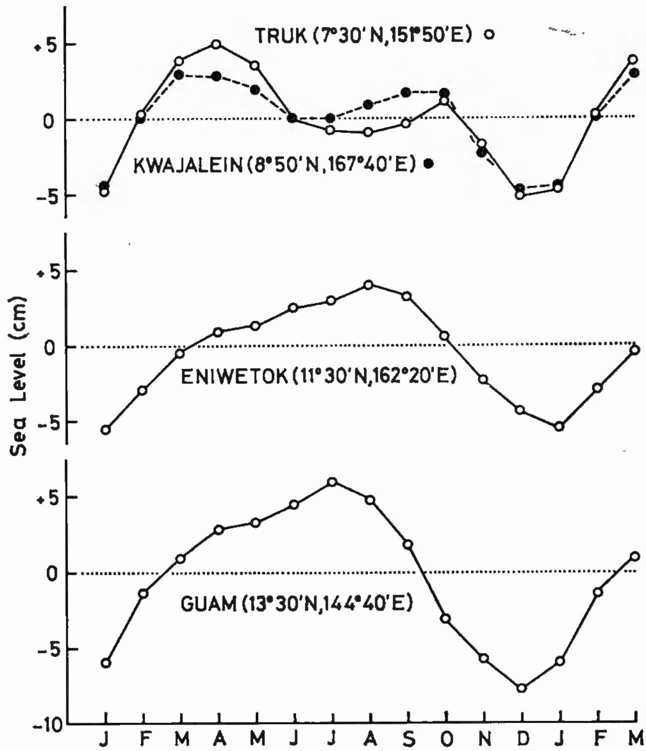

Fig. 7. Seasonal sea level fluctuations on Guam and other western Pacific Islands. Monthly mean sea levels for the period from 1952 to 1971 (20 years) are shown relative to the entire mean sea level for the same period.

one month out of the phase (Fig. 7). The monthly mean sea level records for the twelve months (as 20 year means) correlate very well between the two islands: $r=0.90$ in a month to month correlation and $r=0.93$ if the monthly means from Guam are correlated with those from the following month from Eniwetok.

Wyrtki (1973 and 1974) has demonstrated that the seasonal fluctuations in the sea level reflect the variations in sea water transport within the tropical current systems, i.e., N. Equatorial, Counter, Under, and S. Equatorial Current. These currents flow roughly parallel to the Equator and produce a zonal pattern of flow. The seasonal sea level fluctuations are similar among the records for islands located within the same zone, e.g., between those of Truk and Kwajalein at about the boundary zone between the N. Equatorial and the Counter Currents; between Guam and Eniwetok which are both located in the N. Equatorial Current zone (Fig. 7).

Mean sea levels of Guam for the three peak months (June, July and August) and the three bottom months (November, December, and January) were analyzed as to time-series correlation between the alternate pair. The peak-to-bottom correlation is high ($r=0.86$, Fig. 8) but the bottom-to-peak correlation is low ($r=0.08$,

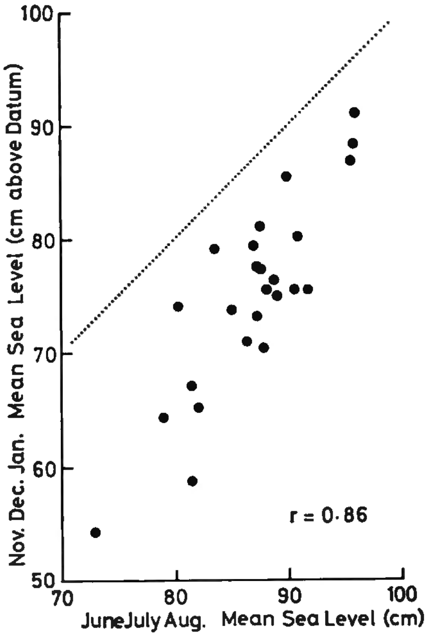

Fig. 8. Scatter diagram between the mean sea level of the peak months (June, July, and August) and that of the following bottom months (November, December, and January) on Guam from 1948 to 1973. Sea levels in cm above datum.

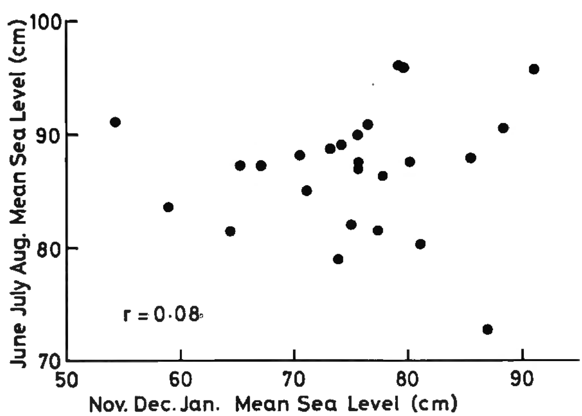

Fig. 9. Scatter diagram between the mean sea level of the bottom months (November, December, and January) and that of the following peak months (June, July, and August) on Guam from 1948 to 1973.

Fig. 9). These correlations indicate that the sea level in winter months follows in good accord with that in summer months but that the opposite is not the case. Thus, an extensive sea level drop in winter may be predicted from a preceding lower

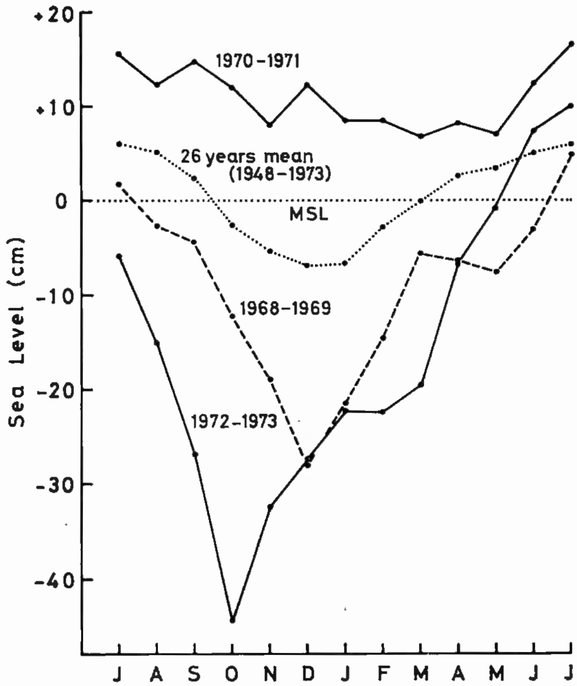

Fig. 10. Changes of the monthly mean sea level on Guam during extreme drops in 1968–1969 and 1972–1973 and a high sea level period in 1970–1971, relative to the mean sea level for 1948–1973 (26 years).

than average summer sea level. This may indicate that the sea level begins to drop much in advance of the actual minimum level in winter months.

The 1972 sea level drop in Guam was greater in magnitude than any other low sea level for the entire 26 years of record, having the lowest monthly sea level of 44.2 cm below the mean sea level (MSL). The next most extensive sea level drop was registered at 28.0 cm below MSL in December 1968. On the other hand, the sea level remained higher than average with a maximum peak of 16.8 cm above MSL during 1970 and 1971, between the two most extensive drops (Fig. 10). These fluctuations are impressive in comparison with the records of previous years when the seasonal fluctuations were more regular and smaller in amplitude.

A similar trend was found in the sea level records of Eniwetok. There, the mean sea level for December, January, and February (winter bottom) correlates well ($r=0.63$, $p<0.01$) with the previous mean sea level for July, August, and September (summer peak) but the summer peak level correlates poorly with the previous winter bottom ($r=0.14$). However, the sea level fluctuations of Eniwetok are smaller in amplitude and more irregular than those of Guam. Unfortunately, the tide gage at Eniwetok went out of order in August 1972 and it is not recorded whether the sea level also dropped to a record low magnitude as it did at Guam.

Nevertheless, the sea level of Eniwetok behaved like that of Guam: a marked low level in January 1969, high levels during 1970 and 1971, and a decline beginning in late 1971. In general, sea level records of Kwajalein and Truk showed a similar pattern to those at Guam and Eniwetok during 1968 through 1973. This period appeared to be most remarkable with regard to irregularities in sea level fluctuations of those islands within the registered records in the past quarter century.

The trends indicated above support Wyrtki's (1973) "teleconnection" hypothesis, emphasizing that large scale oceanographic conditions are reflected by sea level fluctuations at the islands in the tropical Pacific. It may certainly account for the seasonality of the sea level fluctuations and for the wide-range similarity of fluctuations. However, there are still some recognizable local variations in amplitudes and phases of sea level drops and rises. For example, the 1972 drop on Guam bottomed out in October (24th, the lowest level 51.2 cm below MSL) but the lowest month of Kwajalein and Truk was December.

It is interesting to examine the degree of coincidence between the marked sea leavel drops of the four islands discussed above and the El Niño phenomenon off Peru since Wyrtki (1973) discussed the latter in connection with the fluctuations of sea level differences between north and south edge of the Counter Current trough. Wyrtki (1974) further discussed that the Counter Current and the North Equatorial Current are fluctuating in phase, with regard to water transport activities, which may be reflected in sea level fluctuations. Wooster and Guillen (1974) identified three major El Niño years as 1957, 1965, and 1972. Marked sea level drops were registered in December 1957 for Kwajalein (23 cm below MSL) and Truk (24 cm below MSL) and in January 1958 for Eniwetok (15 cm below MSL) but the sea level of Guam (12 cm below MSL) did not drop markedly during the period. The records of sea level drops for Kwajalein (17 cm) and Truk (22 cm) further coincide well with the second major El Niño in 1965 but those of Eniwetok and Guam do not. Finally, those of all four islands dropped markedly in 1972 (Eniwetok records were incomplete due to tide gage failures but showed a trend of drop). Thus, the extensive sea level drops of Kwajalein and Truk coincided well all the four major El Niño years while those of Guam and Eniwetok were more independent except for those in 1972 which was perhaps one of the most remarkable years with respect to global anomality in meteorological conditions in recent years (Kukla & Kukla, 1974).

As indicated clearly by the raised reefs (Tracey *et al.*, 1964), the island of Guam is tectonically active. However, earthquake records did not indicate any strong tectonic activities during 1972 (data from the local seismological observatory). Because the sea level of Guam returned about to the MSL by May 1973 and also because the sea level drop in 1972 was a wide-spread phenomenon, it is probably related to anomalities in wide scale oceanographic conditions rather than local tectonic movements. Perhaps, the local weather conditions, mentioned in the earlier section, accentuated the sea level drop of Guam in 1972, particularly along the windward coast.

ACKNOWLEDGEMENTS

I thank the following persons for information related to this report: Dr. S. C. Berkman of National Ocean Survey Tides Branch, Rockville, Mr. J. F. T. Saur of National Marine Fisheries Service Southwest Fisheries Center, La Jolla, Prof. K. Wyrtki of University of Hawaii Department of Oceanography, Dr. W. S. Wooster of University of Maiami School of Marine and Atmospheric Science, Dr. G. R. Miller of Joint Tsunami Research Effort, Hawaii Institute of Geophysics, Mr. P. Hattori of Guam Seismological Observatory, Mrs. H. Larson of Australian Museum, Mr. C. Huxel of U. S. Geological Survey, Guam, Dr. R. S. Jones of Harbor Branch Foundation, Fort Pierce, and personnel at National Weather Service Guam Observatory.

References Cited

Bonham, K., and E. E. Held. 1963. Ecological observations on the sea cucumbers *Holothuria atra* and *H. leucospilota* at Rongelap Atoll, Marshall Islands. Pacif. Sci. 17:305–314,

Emery, K. O. 1962. Marine Geology of Guam. Geol. Survey Prof. Pap. 403–B:1–76.

Fishelson, L. 1973. Ecological and biological phenomena influencing coral-species composition on the reef tables at Eilat (Gulf of Aqaba, Red Sea). Mar. Biol. 19:183–196.

Frank, P. W. 1969. Growth rates and longevity of some gastropod mollusks on the coral reef at Heron Island. Oecologia (Berl.) 2:232–250.

Glynn, P. W. 1968. Mass mortalities of echinoids and other reef flat organisms coincident with midday, low water exposures in Puerto Rico. Mar. Biol. 1:226–243.

Kohn, A. J. 1959. The ecology of *Conus* in Hawaii. Ecol. Monogr. 29:47–90.

Kohn, A. J., and J. W. Nybakken. 1975. Ecology of *Conus* on eastern Indian Ocean fringing reefs: Diversity of species and resource utilization. Mar. Biol. 29:211–234.

Kukla, G. J., and H. J. Kukla. 1974. Increased surface albedo in the northern hemisphere. Did satellites warn of the weather troubles of 1972 and 1973? Science 183:709–714.

Stephenson, T. A., and A. Stephenson. 1933. Growth and asexual reproduction in corals. Sci. Rep. Great Barrier Reef Exped. 1928–29. 3:167–217.

Tracey, J. I., Jr., S. O. Schlanger, J. T. Stark, D. B. Doan, and H. G. May. 1964. General geology of Guam. Geol. Survey Prof. Pap. 403–A:1–104.

Tsuda, R. T. 1968. Distribution of *Ulva* (Chlorophyta) on Pacific Islands. Micronesica 4:365–368.

Wooster, W. S., and O. Guillen. 1974. Characteristics of El Niño in 1972. J. Mar. Res. 32:387–404.

Wyrtki, K. 1973. Teleconnections in the equatorial Pacific Ocean. Science 180:66–68.

————. 1974. Sea level and the seasonal fluctuations of the equatorial currents in the western Pacific Ocean. J. Phys. Oceanogr. 4:91–103.

Yamaguchi, M. 1974. Reef kill on Guam, October 1972. Guam Recorder New Ser. 1:52–53.

————. 1975. Coral reef asteroids of Guam. Biotropica 7:12–23.

INSTRUCTIONS FOR CONTRIBUTORS

Research reports, review papers, bibliographies, notes, and book reviews in anthropology and biology are accepted on the bases of their originality and their pertinence to Micronesia and adjacent Pacific areas. The language of publication is English, but summaries in another language are acceptable. Each manuscript received will be acknowledged and reviewed by at least two members of the editorial board or by specialists other than board members in whose field the paper lies. Authors will be notified as soon as possible on the decision reached. Contributors are asked to follow the instructions below and, in general, should adhere to the style and quality of papers in professional journals in their own fields. Manuscripts should be sent via airmail to the General Editor, *Micronesica*, The Marine Laboratory, University of Guam, P.O. Box EK, Agana, Guam 96910.

Manuscript: An original copy and one duplicate of each manuscript should be submitted. Text, tables, and legends should be typed on 8–1/2" by 11" nonerasable, white bond paper, double-spaced throughout. An abstract of not more than 300 words should be included for each research report. In the text, citations are to be made as follows: "it was stated (Smith, 1951) that..." or "Smith (1951) states...". References should be listed in alphabetical order by authors at the end of the text under the heading REFERENCES CITED as follows:

Gosline, W. A., and V. E. Brock. 1960. Handbook of Hawaiian fishes. Univ. Hawaii Press, Honolulu. ix+372 p., 277 figs.

Lessa, W. A. 1955. Depopulation of Ulithi. Human Biol. 27(3):161–183.

Illustrative Matter: All line drawings must be executed in ink and photographs must be of high-gloss finish. Illustrations in color will be printed only if the author bears the cost of reproduction. Legend for figures should be supplied on a separate page and placed with all figures at the end of text.

Proof: Page proofs should be corrected immediately by the authors and returned via airmail to the General Editor. Authors are reminded that only a minimum number of corrections and alterations are acceptable.

Reprints: Reprints may be ordered on a form sent out with the author's page proof.

Printed by the International Academic Printing Co., Ltd.,
8–8, 3-chome, Takadanobaba, Shinjuku-ku
Tokyo 160, Japan