AN ECOLOGICAL RECONNAISSANCE OF JOHNSTON ISLAND AND THE EFFECTS OF DREDGING

BY

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Introduction

This is a preliminary report of the results of field work at Johnston Island between August 1963 and August 1964. Some seven field trips were made to Johnston Island during this period; their dates and duration are given in Appendix C. The objectives of the field work were:

1. To ascertain the major habitats of the reef and lagoon ecosystem at Johnston Island, characterize them by differences in faunal composition and physiography, and map their boundaries.

2. To measure the effects of dredging through the removal of the coral and coralline algal biocoenosis in some areas and the consequence of turbidity and siltation in others.

3. To estimate the prevalence of ciguateric[1] fishes at Johnston Island and changes in their occurrence in relation to dredging and to patterns of ecological succession following the dredging.

4. To collect the ciguateric fishes from Johnston Island as a source of ciguatera toxin for studies of its chemical structure and its physiological action.

5. To add to the knowledge of the coral reef ecosystem, initially in a qualitative way and ultimately in a quantitative way.

These objectives are interrelated to such a degree as to make their simultaneous pursuit reasonably compatible. Since a number of identifiable habitats did occur at Johnston Island, the effects of the dredging operation necessarily had to be examined separately for each habitat influenced by it. Otherwise habitat differences might well be ascribed to dredging effects. The creation of rubble, rocky, and silty areas devoid of sessile life by dredging provided a variety of new areas where sessile organisms will establish following the dredging in a pattern involving a succession of kinds, with the earlier settlers being crowded out. This pattern of species replacement is a well-known ecological event leading ultimately to a stable situation. During its course, a possibility exists that conditions may be for a time favorable to the growth of algae containing ciguatera toxin or a precursor toxin. Evidence for the existence of such toxin, and the period of its occurrence, may be found by testing herbivorous fishes for ciguatera from the areas concerned. The prevalence of ciguateric herbivorous fishes, if any, at Johnston prior to the dredging operation needed to be established, and this was done. Moray eels and sharks, which are not in the least herbivorous, were found generally to be ciguateric; the other reef and lagoon fishes tested

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[1]Ciguatera is a Spanish term originating in Cuba for a condition where normally wholesome food fishes become toxic to man and other mammals.

were found not to be. However, since only a very small part of the fish populations were sampled, the occasional occurrence of ciguateric fish of other species was a possibility.

The magnitude of the field operations and their frequency was determined by the objectives of the program and the extent of the reef and lagoon areas at Johnston Island to be studied. The existence of several programs of research concerned with the problems of ciguatera at the Hawaii Marine Laboratory made it possible to examine the abundance and kinds of ciguateric fishes at Johnston with relatively little effort or cost to the present program and served to support it in other ways.

Johnston Island has had a brief history of ciguatera. Prior to World War II, Captain William Anderson fished at Johnston Island selling his catches in the Honolulu market. There were no reported outbreaks of ciguatera as a result. The first identified cases occurred in 1950. According to Halstead and Bunker (1954, page 62), there were approximately 20 cases of ciguatera poisoning between 1950 and 1951. A recent case was reported by Dr. Heder, the Island Medical Officer, on 26 May 1964. This case involved the consumption of raw fish, a black ulua Caranx melampygus. Randall (1958, page 259) postulated that the toxin responsible for ciguatera was produced by an alga, possibly a blue-green, which occurred early and abundantly in the pattern of succession during the invasion of a newly denuded substrate by certain algal species. The blue-green algae is eaten by herbivorous animals and these by carnivorous ones. The toxin is neither excreted nor does it poison the organism consuming it. Aside from demonstrating the production of the toxin by an algal species, there is much evidence supporting the other aspects of this hypothesis (Banner, Helfrich, etc.). If the Randall hypothesis is valid, a substantial increase in the number and species of toxic fish should follow the dredging operations at Johnston Island beginning with the herbivorous species. None of these species, belonging principally to the families Acanthuridae and Scaridae, were found to be toxic during the period of field work here reported upon.

The transportation of personnel, equipment, and supplies between Johnston Island and Honolulu and food and lodging at Johnston Island were provided by the Atomic Energy Commission. Some of the equipment employed in the work was funded by the Atomic Energy Commission; much of it was from the equipment pool of the Hawaii Marine Laboratory. Personnel participating in the project were provided by the Hawaii Marine Laboratory. Permanent personnel directly connected with the project were Vernon E. Brock, Principal Investigator, Philip Helfrich, research scientist, and Robert Jones, field assistant. A number of other individuals were employed for short periods for field work at Johnston Island. A majority of these were graduate students from the University of Hawaii, Department of Zoology.

Description of Johnston Island

Johnston Island is located at 16°15' N and 169°30' W. It is 450 miles southwest of the nearest island in the Hawaiian chain, 700 miles northwest of the nearest of the Line Islands and 1300 miles east of the Marshall Islands (Gosline 1955, page 463).

The reef area is quite extensive and has its long axis oriented in a northeast-southwest direction (Chart I). This orientation essentially places the shoal parallel to the prevailing northeast trade winds. The shoal is approximately nine to ten miles long and seven to eight miles wide (HO chart No. 5356). The shoal area can be broken into three major regions: 1) The marginal reef, a narrow frequently awash strip which forms part of the northern, all of the northwestern, and part of the eastern boundary of the shoal. 2) The land masses, the natural islets of Johnston and Sand Islands and the two recently man-made islets called North and East Islands. 3) And the shoal, the extensive submerged coral area behind the marginal reef and surrounding the islets. The latter area is by far the largest and the major area of interest for our ecological consideration. The area is discussed in detail in sections to follow.

Johnston Island does not fit the description of a "typical" atoll (if any area does). It has a marginal reef only on one side. There is no deep lagoon area in the center but instead the reef simply drops away gradually to deep water on the southeast side. Wells (1954, page 404) states, "Johnston Island reef has an algal ridge or platform, but its inner slope to leeward and the ocean beyond give its inner parts a distinct ecological situation, which is very similar to Yonge reef (on the barrier reef of Australia), such as might be produced were the leeward half of an atoll to be cut away."

A heavy surf is common along the marginal reef in the winter. These surf conditions tend to moderate in the summer months.

Field Methods

The field methods employed at Johnston Island involved a roughly quantitative estimate of the abundance of reef organisms, the collection of fish for work on ciguatera, and measurements of selected physical characteristics both in dredged and undredged areas of the lagoon. Underwater photography was freely employed as well as illustrations to identify and characterize the significant differences among various habitat areas (Chart I) in the Johnston Island lagoon. The preliminary location and mapping of the boundaries of these areas required a rather thorough exploration of the reef area adjacent to the island (Chart I).

Faunal Survey

Fishes - Fishes were collected by a number of methods and estimates of the abundance of the various species were obtained by certain of these methods along with rough estimates of the abundance through sight identifications. Many of the food fishes or potential food fishes were frozen for laboratory tests for ciguatera at the Hawaii Marine Laboratory. A list of fishes recorded from Johnston Island is found in Appendix D.

Rotenone for poisoning fish on a wholesale basis was used in some areas. This method has the advantage of making those species of fish that ordinarily remain hidden in coral recesses easily obtainable. The source of the rotenone was powdered derris root, which was mixed with seawater to the consistency of thick mud, taken to the bottom of semi-enclosed areas in the

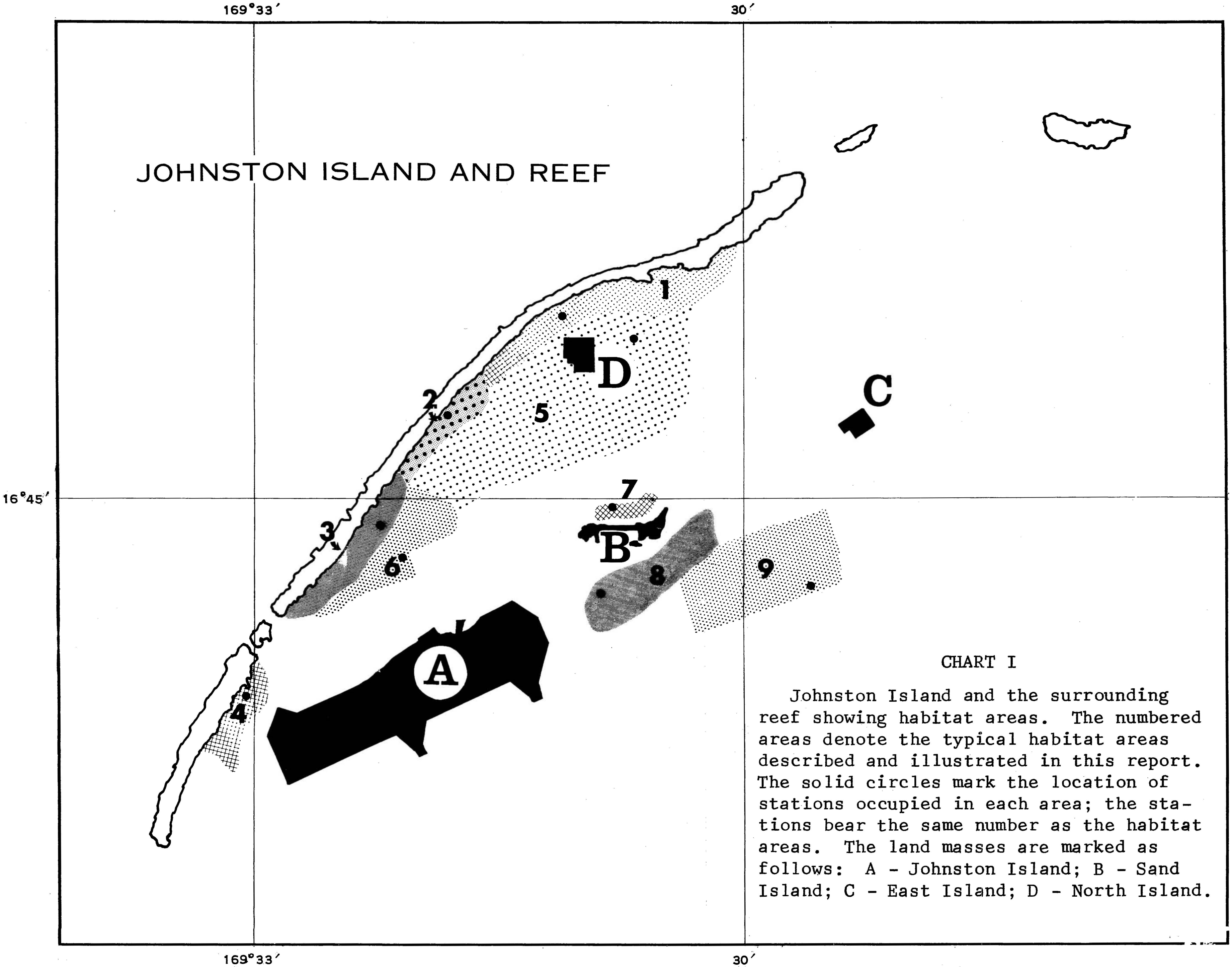

CHART I

Johnston Island and the surrounding reef showing habitat areas. The numbered areas denote the typical habitat areas described and illustrated in this report. The solid circles mark the location of stations occupied in each area; the stations bear the same number as the habitat areas. The land masses are marked as follows: A - Johnston Island; B - Sand Island; C - East Island; D - North Island.

the reef by divers in depths usually between 10 to 20 feet, and scattered about. The pattern of scattering was such that the effect of any current was minimized and the reef pothole being poisoned was covered almost simultaneously. A period near low water was selected to reduce current flow. Often the fish would come to the surface of the water as they began to suffocate and could be taken there by dipnets. If not caught, they would sink, struggling weakly or darting erratically, to the bottom where divers could pick them up. The first major poison station was conducted in Area 4, southwest of the small boat channel (Chart I), in August 1963 and resulted in a catch of several thousand individuals belonging to 86 species. The second large poison collection was taken in Area 3 in June 1964.

In some instances, as a means of confirming sight identifications, limited amounts of rotenone were used to take a fish or a few fish in small areas, i.e., individual coral heads. One poison station was done to get an idea of the difference between sight records and poison station records; these data are given in Appendix F.

Many fishes were taken by the use of spears underwater (Plates V and IX, Appendix A). For the smaller fishes, Hawaiian slings were used and for the larger fishes, the heavier Arbaletes with the spear secured by a length of line to the Arbalete. Many of the less abundant fishes in open water and along the reef outside of the lagoon were taken by spearing. In a number of instances species not heretofore recorded from Johnston Island were thus obtained. The use of Arbaletes for taking the large moray eels, Gymnothorax javanicus, at Johnston Island proved to be advantageous. Since these eels can be quite dangerous when aroused, the spearing of a large eel required the coordinated efforts of two divers. Ordinarily these eels would be sighted with the head partially protruding from a hole in the coral. When so sighted, the preferred plan of attack was for one diver to approach from ahead and the other at right angles to the eel. The first diver would attempt to sink a spear into the eel's head, preferably into the mouth at a slight angle above the horizontal. The second diver would shoot immediately after the spear of the first diver had struck and would aim for the side of the head, just anterior to the gill opening. If both spears were firmly embedded, the eel would be pulled from the hole in the coral and the lines attached to each spear would be kept taut to hold the eel between the two divers and sufficiently far from each so that the danger of being bitten would be minimized.

Traps (Figs. 1-3 and Plate I, Appendix A) were also employed to take some fish and were the most successful means for taking Gymnothorax javanicus, the largest of the morays found at Johnston Island. These traps were usually rectangular in shape, their dimensions were about 3.5' by 3.5' by 18", and a large cone shaped entrance in the front was directed into the trap. A small door was provided in the back for removing the catch. The trap frames were heavy galvanized wire of about 3/16 of an inch diameter with a covering of galvanized expanded welded fabric with a 1 x 2 inch mesh. The traps were baited with fresh octopus when available, or, as a second choice, parrot fish. On some occasions frozen octopus purchased in the Honolulu market were used as bait. The frozen octopus proved to be decidedly inferior to the fresh octopus. Table 1 shows typical trap results for one trip. In addition to trapping and spearing, some hook and line fishing was done. Set lines (Plate I, Appendix A) were placed out by attaching a line made up of telephone cable, a

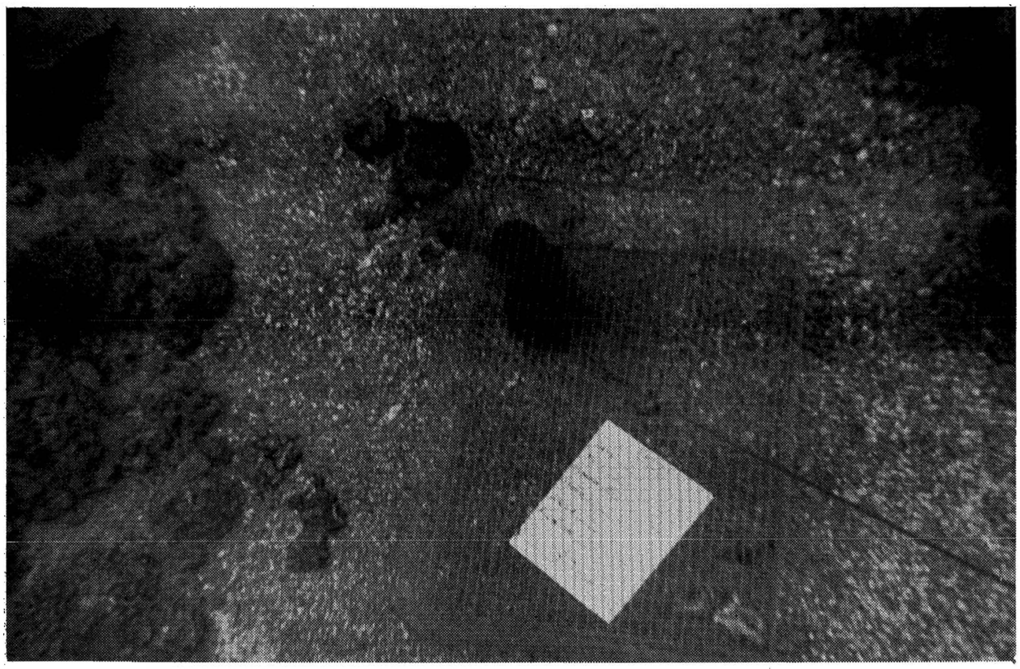

Figure 1. A moray eel, Gymnothorax javanicus, in a wire trap of the type described in the text.

Figure 2. Two moray eels, Gymnothorax javanicus, caught in a single trap.

Figure 3. A moray eel, Gymnothorax javanicus, captured in the North Island Trap Area (vicinity of Area 1).

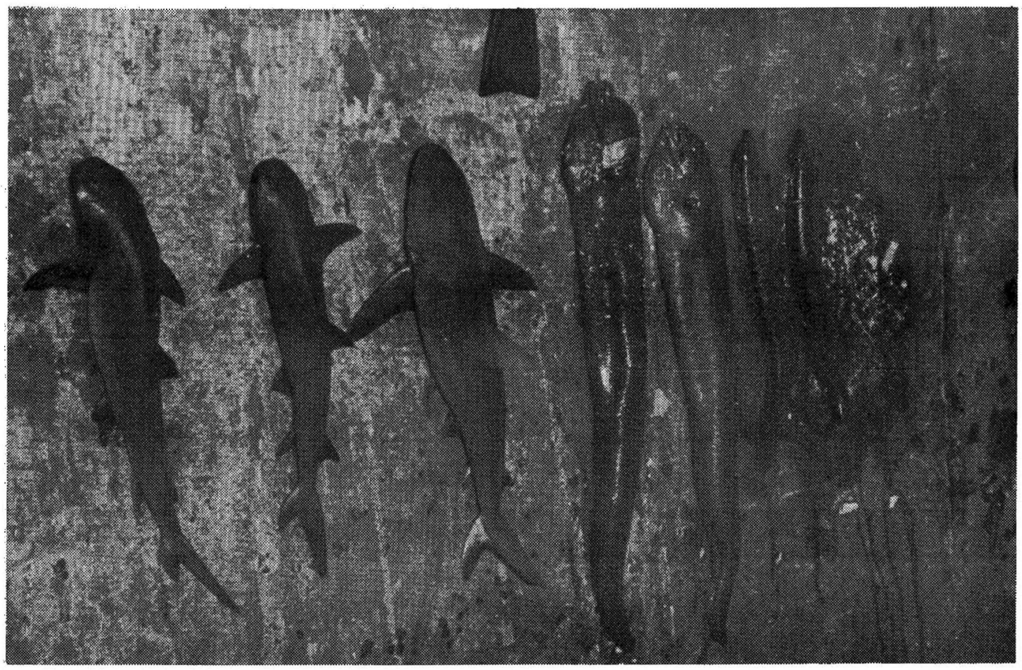

Figure 4. A catch of moray eels, Gymnothorax javanicus, and sharks, a Carcharhinus menisorrah (center) and two Triaonodon obesus (bottom).

rubber sling, and a plastic covered wire leader (250-pound test) to a cast cylinder of concrete weighing 29 pounds. The hook employed was a Japanese Tankichi #48. These set lines were marked with a float attached to the weight also by a length of telephone cable. The rubber sling was added later when it was found that sharks on becoming hooked would frequently drag the lines into coral formations and break the hooks off. The sling provided a degree of stretch to the gear which reduced but did not completely eliminate this problem. The setlines were commonly baited with fish, most often parrot fish and squirrel fish, which were speared on the reef for this purpose. In addition to the capture of fish by the field parties directly engaged in the Johnston Island program, arrangements were made to purchase eels taken by sport fishermen at Johnston Island. A price of 50 cents per pound was paid for all eels over ten pounds. Large eels, Gymnothorax javanicus, and two common reef dwelling sharks, the white tip shark, Triaenodon obesus, and the grey shark, Carcharhinus menisorrah, were obtained in substantial quantity as a source of raw material for the extraction of ciguatera toxin (Fig. 4). Most of the fishing for these groups was conducted in the areas shown on Chart II. Incidentally, their collection also added to our knowledge, in a rough quantitative way, of the abundance and distribution of these species at Johnston Island.

TABLE 1

Trap Data Taken on Trip 5
These data are typical of those for the other trips

Number of traps used	7
Number of sets made	50
Number of days fished	5+
Number of hours that all seven traps were set	908.5
Number of eels trapped	18
Number of trap hours to trap one eel	50.47

During the surveys of the reef habitats, records were kept concerning the species and abundance of the fishes (Appendix B) and of some of the marine invertebrates (Appendix A). These records were used to develop a rough scale of abundance for the various habitat areas. The scale used had four categories, i.e., dominant, common, present, and rare. Since this is based on sight identifications, it obviously gives greater weight to those species of fish which do not remain concealed in cavities in the coral and so it constitutes a relative measure with a bias of unknown magnitude due to this cause (see Appendix F).

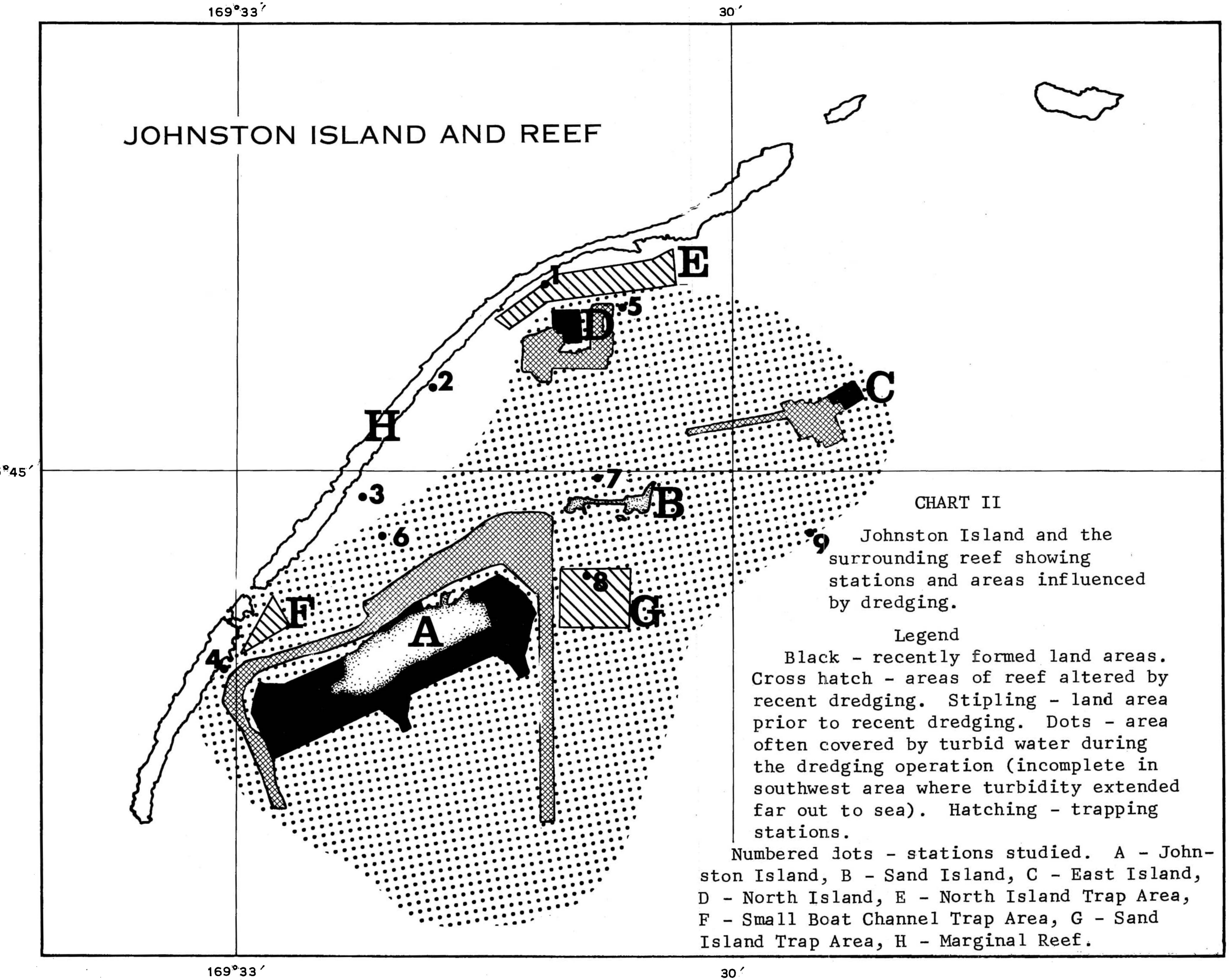

CHART II

Johnston Island and the surrounding reef showing stations and areas influenced by dredging.

Legend

Black - recently formed land areas. Cross hatch - areas of reef altered by recent dredging. Stipling - land area prior to recent dredging. Dots - area often covered by turbid water during the dredging operation (incomplete in southwest area where turbidity extended far out to sea). Hatching - trapping stations.

Numbered dots - stations studied. A - Johnston Island, B - Sand Island, C - East Island, D - North Island, E - North Island Trap Area, F - Small Boat Channel Trap Area, G - Sand Island Trap Area, H - Marginal Reef.

Corals - In each of the nine areas, field workers have attempted to determine the percentage of live corals growing on the reef surfaces. Estimates were obtained by randomly dropping a meter square quadrant (Plate IX, Appendix A) on various parts of the reef and calculating the percent by area of live coral within this square meter (Appendix A and Table 6). Collections of the dominant species were made in each area. Dominant genera for the areas are listed in Appendix A.

Live samples of coralline algae (Porolithon) and the common species of vasiform coral (Acropora) were collected from each area. The samples were selected to be of approximately the same size each time. Whole heads of Acropora measuring between 25 and 30 cm. in diameter were enveloped in plastic bags and broken off at the base with a geology pick. Similarly pieces of Porolithon of as nearly the same size as possible were broken off and placed in plastic bags. Each of these samples was returned to the operating base where its volume was measured by displacement. They were then carefully broken up with hammers to remove the small invertebrate inhabitants (Table 2 and 3).

Other Invertebrates - A list of invertebrate animals known from Johnston Island is found in Appendix E. The sources used for this list were collections made during the present investigation, from Edmondson, et al. (1925), and Wells (1954).

Two types of collections were made. One represents the organisms taken from coral and coralline algae (see section above and Tables 2 and 3). The second collection was made simply by picking up the dominant macro-invertebrates from each area. These data are listed by area in Appendix A. The same abundance ranking system used for the fishes has been applied to the echinoderms in each area. The echinoderms and particularly the holothuroids and echinoids, like the fishes, are a component of the areas studied that can be identified in the field and the species related to one another in terms of abundance.

Some of the common organisms found at Johnston Island are shown in underwater photographs found throughout the report. Where possible these organisms are identified in the captions. The photos were made with a Nikonos 35 mm underwater camera using Plus X film. (Plate IX, Appendix A).

Physical Measurements

Depth - The water depth and heights of the reef masses were measured with a weighted line marked in meters. This line was carried by a diver who made depth surveys at critical points in each area (Plate V, Appendix A). Results of these surveys are found in Appendix A.

Temperature - Temperatures were measured with a mercury in glass thermometer in each area to the nearest tenth of a degree Celsius. The readings were made at the surface (upper 10 cm.) and at the bottom (deepest part) by a diver. The results are discussed in the Reef and Lagoon Environments section.

TABLE 2

Invertebrate Fauna Inhabiting Living Acropora Heads
(Vasiform type) and Living Porolithon (Coralline algae)

Area Number	Head Displacement Volume (ml)	Acropora Organisms	Number	Weight (g.)	Totals (g.)
1	570	Xanthid crabs	7	1.0	
		Pontonid shrimp	2	.1	
		Alpheid shrimp	1	.1*	1.1
2	800	Xanthid crabs	2	1.1	
		Pontonid shrimp	5	.6	1.7
3	450	Xanthid crabs	2	.9	
		Pontonid shrimp	3	.2	1.1
4	750	Xanthid crabs	5	.8	
		Pontonid shrimp	2	.1	
		Alpheid shrimp	1	.1*	.9
5	870	Xanthid crabs	3	.7	
		Pontonid shrimp	14	1.0	1.7
6	1150	Xanthid crabs	4	.3	
		Pontonid shrimp	2	.1	.4
7	1320	Xanthid crabs	7	1.1	
		Pontonid shrimp	4	.1	
		Polychaets	1	.2	1.4
8	625	Xanthid crabs	6	1.8	
		Pontonid shrimp	6	.7	2.5
9	No Acropora in this area.				
	Totals		75		10.8

TABLE 2 (cont.)

Area Number	Head Displacement Volume (ml)	Porolithon Organisms	Number	Weight (g.)	Totals (g.)
1	960	Xanthid crabs	22	.7	
		Alpheid shrimp	16	.4	
		Ophiuroids	8	.4	
		Polychaets	9	.8	2.3
2	870	Xanthid crabs	36	1.8	
		Alpheid shrimp	21	.9	
		Ophiuroids	1	2.2	
		Polychaets	8	.2	
		Actiniarians	5	.1	5.2
3	625	Xanthid crabs	20	1.6	
		Alpheid shrimp	18	.8	
		Polychaets	10	.8	
		Actiniarians	3	.1*	3.2
4	No coralline algae found in this area				
5	870	Xanthid crabs	52	2.4	
		Alpheid shrimp	37	1.4	
		Ophiuroids	3	.1	
		Polychaets	6	.5	
		Actiniarians	1	.1	4.5
6	870	Xanthid crabs	24	1.0	
		Alpheid shrimp	4	.1	
		Ophiuroids	4	.2	
		Polychaets	16	3.4	
		Actiniarian	14	.1	4.8
7 & 8	No coralline algae found in these areas				
9	No coralline algae found in this area				
	Totals		419		20.0

* = less than .1 g.

TABLE 3

Check List of Animals Inhabiting Coral Heads
Collected from All Areas Studied

Phylum Coelenterata
- Class Anthozoa
  - Subclass Zoantharia
    - Order Actiniaria

Phylum Sipunculoida

Phylum Echinodermata
- Class Ophiuroidea
  - Order Gnathophiuroida
    - Family Amphiuridae
      - *Distichophis clarki*
      - *Ophiocomella clippertoni*
      - *Ophiocoma* sp.

Phylum Annelida
- Class Chaetopoda
  - Order Polychaeta
    - Family Nereidae
      - *Nereis kobiensis*
    - Family Amphinomidae
    - Family Leodocidae
      - *Leodice* sp.
      - *Lysidice* sp.

Phylum Arthropoda
- Class Crustacea
  - Subclass Malacostraca
    - Order Decapoda
      - Suborder Natantia
        - Tribe Caridea
          - Family Pontoniidae
            - *Harpiliopsis depressus*
          - Family Alpheidae
            - *Alpheus brevipes*
            - *A. clupeatus*
            - *A. lottini*
          - Family - other families may be Pandalidae and Hippolytidae
    - Order Reptantia
      - Tribe Anomura
        - Family Galatheidae
          - *Galathea spinosorostris*
        - Family Paguridae

TABLE 3 (cont.)

Tribe Brachyura
- Superfamily Oxyrhyncha
  - Family Maiidae
    - *Schizophrys hilensis*
- Superfamily Brachrhynche
  - Family Xanthidae
    - *Acantea speciosus*
    - *Domecia hispida*
    - *Tetralia* spp.
    - *Trapezia cymodoce*
    - *T. digitalis*
    - *T. maculata*

TABLE 4

Results of Secchi Disc Readings from Areas
Where the Water was Visibly Turbid (20 June 1964)

Locality	Time	Cloud Cover	Disappearance Depth (M)	Extinction Coefficient
Area 6--Approximately one mile from nearest dredge	1530	5/10	3.5	0.48
Area 8--Approximately 0.25 miles upwind of nearest dredge	1600	5/10	3.25	0.52
In anchorage 200 yards from dredge working in ship channel	1630	5/10	1.66	1.02
Area 7--Approximately 0.25 miles from nearest dredge and 1.66 miles downwind from East Island	1645	5/10	4.0	0.42
In the lee of East Island shoreline (21 June)	1300	8-9/10	3.5	0.48

Currents - The direction of currents was estimated through the use of fluoricine dye released from a bottle by a diver standing on a reef top. After a short period (3 to 5 minutes) an angle was taken from the point of release with one line lying along the axis of the dye setline and the other through a known reference point ashore. The point of release is then plotted on the Johnston Island chart (HO 5356) using the methods described under mapping below. Next the angle is plotted from the point of origin and the line representing the dye axis is moved with parallel rules to the true bearing circle of the nearest compass rose. The true direction of set is read directly. See Reef and Lagoon Environments section for a further discussion of currents.

Light Penetration - To gain an idea of the turbidity caused by suspended silt from dredging operations, several readings were taken with a 20 cm. secchi disk in each of the areas and at an additional series of points downstream from a working dredge. The secchi disk extinction coefficient defined by the formula of Poole and Atkins (1929) was $K = \frac{1.7}{D}$, where D is the depth of disappearance in meters. These results appear in Table 4. In some areas, the water was clear with no indication of suspended silt while in other areas the silt was obvious but the density was not great enough for disappearance to occur before the secchi disk reached the bottom. The approximate boundaries of areas covered at various times by water bearing suspended sediment are found in Chart II.

Sedimentation - A study of deposition of silt in various areas was begun in April 1964. One gallon cans, ballasted with concrete, were set with the top opening as flush with the substratum as possible in Areas 3, 6, and 8. The first of these areas was never influenced by silty water, the second one was occasionally, and the third was influenced constantly during dredging. Sedimentation rates estimated by this simple method are given in Table 5 for these areas.

TABLE 5

Silt Deposition Rates in Selected Areas
During Dredging Operations at Johnston Island

Station	Millimeters Per Month
3 & 6	.186
8	.556

Mapping - The location of the various stations taken in the lagoon was ascertained by the use of a position finder (manufactuered by Ilon), a compact and rugged field instrument which through a system of fixed and moveable mirrors can be used to measure angles between landmarks as can a sextant. These field measurements were later plotted on the Johnston Island chart (HO 5356) using a three armed protractor to ascertain the location of stations. The positions obtained by this means seemed to be accurate to within a few feet.

Landmarks most often used were: Loran A & C towers on Sand Island; water, aero beacon, and control towers on Johnston Island; the two range beacons in the ship channel; and tangents from Johnston, Sand, North and East Islands.

These stations were also buoyed which permitted their rapid relocation; however, occasionally buoys did go adrift.

The Reef and Lagoon Environments at Johnston Island

The mineral part of Johnston Island is largely calcium carbonate deposited by corals and coralline algae. Its presence is the result of living processes. The pattern of reef and lagoon and the orientation of the island is the result of the interaction through the prevailing seas and current and the varying rates of growth of the calcium carbonate depositing organisms. These factors have produced patterns of zonal growth providing regions where the marine communities differ one from the other in varying degrees.

The existence of these regional habitat differences in the reef ecosystem at Johnston Island made it necessary that the differences be well enough identified so that the possible effects of dredging, especially those effects related to siltation would not be confused with normal differences among these habitats. This problem of defining habitat regions was attacked by estimating the abundance of the dominant organisms for each. The corals were further classified by the percentage of living head area as well as by the relative number of the various genera. The fishes present were identified and grouped according to a scale of abundance into four categories. The important marine invertebrates were also grouped. For each of the habitat types as mentioned under methods, selected vasiform heads of Acropora coral a and masses of Porolithon coralline algae were broken apart and the number of animals by species and their biomass was ascertained. The habitat regions and their approximate areas are shown in Chart I and the dredged areas in Chart II. Tables 2 and 3 are lists of animals taken from coral heads and living masses of coralline algae. The regions are individually described in the attached Appendix A to this report.

The habitat regions are, to a degree, arbitrarily defined. The boundaries are not sharp but are rather areas of transition. However, each of these regions had a characteristic appearance when viewed beneath the water, an appearance that reflected the kinds and relative vigor of growth of various corals and coralline algae, and the kinds and abundance of the associated invertebrates and fishes. These are differences that are easy to see once a good acquaintance with the regions has been obtained, but somewhat difficult to measure, and more difficult to describe. Hence, it was decided to employ underwater photography as a means of representing to the degree practical, the characteristics of the habitat regions. While this technique proved excellent for the environmental features of moderate size, between a foot to about twenty feet across, it would not serve for features larger than this because of the relatively restricted range of sharp vision possible underwater. The patterns of coral and coralline algal growth from fifty to a hundred feet or more provided the most striking differences among the regions. To represent these differences it was necessary to develop a series of illustrations of them based on photographs, sketches, and verbal descriptions. Where building profiles are shown on Johnston Island, they are imaginary. A detailed discussion of the habitat regions with photographs and pen and ink illustrations (Plates I-IX) is given in Appendix A.

For some environmental parameters the conditions at Johnston Island are quite uniform. This was, for example, true of seawater temperature. Temperatures measurements made at the surface and bottom from March to June, 1964, ranged from 26° to 27.5° Celsius. There were no significant variations between surface and bottom water or between the various stations. Halstead and Bunker (1954, page 63) recorded a low of 25.5° Celsius in February of 1951. Barkley (1962) plotted the bimonthly averages of sea surface temperatures from Johnston Island from 1959 through 1961 showing the extremes of about 24.3 to 27.9 with the annual means of about 26.1° Celsius.

Johnston Island is situated almost in the middle of the trade wind belt and winds from the east and northeast are almost constant. Velocities encountered range from 5 to 25+ knots. Wind shifts of short duration with accompanying rain squalls were not infrequent. The general pattern of current flow in the lagoon was during the summer months towards the southwest, paralleling that of the trade wind. Current velocities were low, generally less than .5 knots, except in the ship channel where they were estimated to exceed 1 knot. During the winter, swells were breaking over the reef on the north and northwest side of the atoll. Extremely strong currents, in excess of 2 knots, were encountered setting south and southeast, often at right angles to the trades. It is likely that a heavy surf breaking on this reef results in a large volume of water being transported into the lagoon, which then flows rapidly off the shoal to deep water on the south and southeasterly sides. A pattern of sand deposits, as seen on aerial photographs, reflects this direction of flow. The incongruent direction of wind and current, at times during the winter, generates some extremely rough seas within the lagoon. Tidal currents were found to be strong in the ship channel and small boat channel during ebb tides.

As mentioned under Methods, secchi disc readings were taken to estimate turbidity produced by the dredging operation; the readings obtained are shown in Table 4. Silt deposition as measured in Areas 3, 6, and 8 is given in Table 5. The rate of sediment deposition varied from .55 mm per month to .185 mm per month. This is a low rate and suggests that the movement of water in the lagoon was sufficiently vigorous to keep the bulk of the material churned into the water by the dredging in suspension. However, the rather simple method employed to measure rate of siltation may not have provided dependable results.

Habitat Areas and the Effects of Dredging

Some nine areas, not all contiguous, were selected as representative of distinctive habitats. The nine habitat areas do not include all those present at Johnston Island but they did serve as examples of areas with important environmental differences in or adjacent to the dredged areas. Their location and extent are given in Chart I. Some of the environmental differences of habitat areas are shown in Table 6. Four of the habitat areas were

TABLE 6

Habitat Areas with Estimate of Coral Density, Number of Fish Species, and Preliminary Effect of Dredging

Habitat Areas		Percentage Living Coral	No. of Fish Species	Effect of Dredging (Preliminary)
ZONE I	1	Mound tops, 70-100 Lower sides, 40-50	60	None
	2	Ridge tops, 99 Channel floor, about 1	45	None
	3	80-90	30	None
	4	20	42	Definite effect--coral and sessile animals largely dead. Fish not obviously affected.
ZONE II	5	90-95	28	Covered by silty water on occasion. No observed damage
	6	50-75	35	None
	7	20	38	Covered intermittently by silty water. *Fungia* beginning to die.
ZONE III	8	20-30	36	Reef with deposit of silt. Damage not yet obvious.
	9	50-60	28	Reef covered by fine layer of silt. Dominant coral species *Montipora* (Only area where this species is dominant)