Ecological Observations on the Sea Cucumbers *Holothuria atra* and *H. leucospilota* at Rongelap Atoll, Marshall Islands

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IN a distributional study of the black sea cucumbers, *Holothuria atra* (Jäger) and *H. leucospilota* (Brandt), at Rongelap Atoll (Fig. 1) the beaches of most of the larger islets were surveyed during September 1959, March 1961, and September 1961. Estimates of abundance and size were made, and observations on temperature tolerance, predation, asexual reproduction by fission, and some other ecological aspects were considered.

These two species of sea cucumbers are frequently, although not always, found together in the intertidal area of the seaward sides of the islets at the edge of the reef-flat nearest shore. They occupy pools of water from a few centimeters to about one-half meter deep at low tide (Figs. 2, 3), or are occasionally entirely exposed. *H. atra* usually covers itself with a coating of light coral sand held in place by tube feet, although occasionally it is naked and black. The integument is thick and firm. This species lacks the Cuvierian organ and thus may be handled without the annoyance of adhesive threads. *H. leucospilota* is always naked and almost black, has a softer integument with fine protuberances giving it a prickly appearance. The intricate, microscopic calcareous deposits in the integument differ markedly in the two species: in *H. atra* (Fig. 4*A*) the "tables" are tall and there are no "buttons," while in *H. leucospilota* (Fig. 4*B*) the tables are short and squat, and there are many buttons.

H. atra also occurs in deeper water in the lagoon, where it does not coat itself with sand, and to an undetermined extent on the vast areas of reef-flat between islets. At high tide the water at the seaward shores of the islets usually covers both species to a depth of 1–1½ m, and they are then frequently subjected to wave action from the surf whose initial force has been broken by the outer reef. A conspicuous feature of this habitat is the churning agitation and aeration of the water. *H. atra* appears to maintain its position by inhabiting depressions and holding onto the relatively smooth reef-flat by means of its tube feet. *H. leucospilota* usually anchors the posterior portion of its body underneath a stable rock or in a hole in the reef floor. In the absence of other cover it may find its way under a cluster of *H. atra* (Fig. 3). At appropriate times it extends its highly mobile and extensible anterior end outward for feeding.

Concentrations of these two species almost always occur where large slabs of beachrock are situated on the lower edge of the sandy beach slope bordering the inner edge of the reef-flat, and where, after the recession of the tide, the sea water may be observed to issue from the sand onto the reef-flat below the slabs of rock until the next tide. Below a sandy beach without slabs of rock no such prolonged runoff is evident, and the sea cucumbers usually are few or lacking. It is in the pools fed by the relatively cool water from underneath the rock slabs that *H. atra* and *H. leucospilota* thrive. Concentrations of sea cucumbers were occasionally seen in the absence of slab-rock, and rarely slab-rock was found without sea cucumbers. They occupy an ecological niche almost devoid of other macroscopic organisms; occasionally small snails occur, but frequently the sea cucumbers are alone. There is no obvious food in the sand they ingest.

CENSUSING OF SEA CUCUMBERS

The surveying procedure consisted of observing, photographing, and taking notes on the abundance of *Holothuria* while walking around

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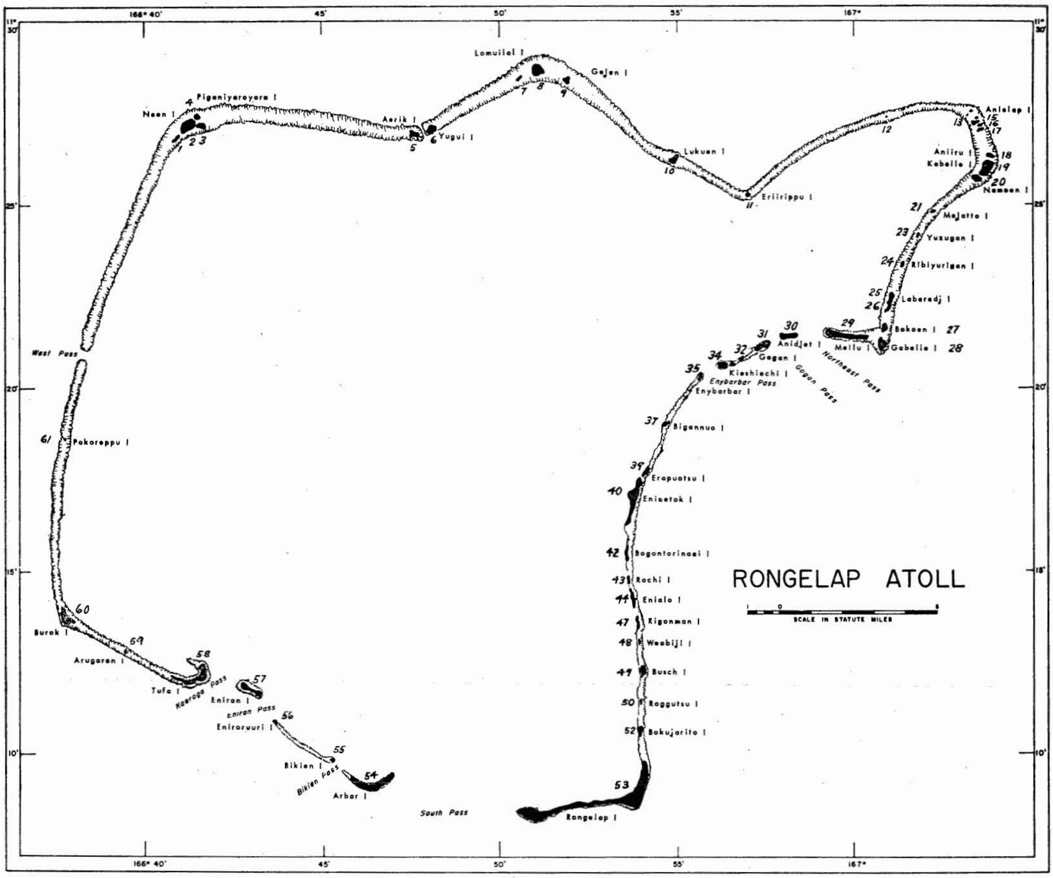


FIG. 1. Map of Rongelap Atoll showing islet names and numbers.

the periphery of 16 islets completely, and 5 others partially, thus covering 67% of the seaward shores of all islets in the atoll. The islets are numbered clockwise on the map of Rongelap Atoll shown in Figure 1 starting at the northwest extremity. Only about 2% of the inter-islet reef area and shallower lagoon bottom regions supposedly suitable for *H. atra* was censused.

Distances were measured by chain on the seaward shores of four islets, Aniiru, Kabelle, Namoen, and Rongelap, while at other islets distances were either determined by pacing, or, in most cases, estimated. On the east rim of the atoll high-altitude vertical, and elsewhere low-altitude oblique, aerial photos were employed to aid in orientation. Photographs taken on the reef-flat of undisturbed sea cucumbers were sometimes used in the estimations of abundance. The places of concealment under overhanging ledges were inspected, but rocks were seldom lifted to check for specimens.

Table 1 shows the distribution of *H. atra* and *H. leucospilota* at the localities surveyed. Section numbers representing 100-m units of seaward shoreline appear under the appropriate frequency group. The central frequency groups increase by a factor of 10 while smaller ranges of numbers delimit the extremes. Along with the range in the column headings are the means in parentheses—geometric except for the first, where the zero limit precludes use of the geometric mean. Geometric and arithmetic means were tested for agreement with totals of the last two columns showing sums by localities taken directly from a previous tabulation, which also supplied the data for the body of Table 1.

TABLE 1

DISTRIBUTION OF *H. atra* AND *H. leucospilota* ON THE SEAWARD SHORES OF ISLETS BY 100-M SECTION NUMBERS

(The body of the table shows section numbers in which the abundance of sea cucumbers fell within the range indicated in the column heading. Sections for each islet were numbered clockwise starting at the counterclockwise extremity (left-hand end when facing seaward) of the seaward shore.)

Islet		Date			100-m section number										Remarks	Total individuals observed or estimated	
No	Name	Sept. '59	March '61	Sept. '61	Numbers of H. atra					Numbers of H. leucospilota						H. atra	H. leucospilota
					0-2 (1)*	3-10 (5.62)	11-100 (33.2)	101-1000 (318)	1001-3000 (1730)	0-2 (1)*	3-10 (5.62)	11-100 (33.2)	101-1000 (318)	1001-3000 (1730)			
2	Naen	15, 22		19	1-5					1-5						0	0
3	W. Yugui	15														0	0
4	Pigani-yaroyaro	15		19	1-4		5	6		1-4		5		6	E. shore, many	210	2000
5	Aerik	22			1-3						1-2	3			12 atra on W. shore	12	40
6	E. Yugui	22				1-4					2-4	1			8 atra on E, 16 on W. shore	24	64
8	Lomuilal	14			1-5					1-5						0	0
9	Gejen	14				1-4					1-4					32	20
13	13 Inner	12			(10,000 atra in lagoon, I. 13 & I. 15)											10000	0
13	13 Outer	12		17		1	2						2			60	240
18-	Reef area			13	(700 meters north of Aniiru I. had 83,000 atra, 2600 leuco. and 4300 Stichopus chloronotus)											83000	2600
18	Aniiru	12		12			1-2					1-2				200	60
19	Kabelle	10-13	14	12	2	7	3,8,9	0,1,4,6	(10)	2-10		0,1			200 atra & 100 leuco. in N.E. channel	3000	150
20	Namoen			12		2			1	2		1			4 leuco. S. side	2300	16
29	Mellu	17		18	2-5	1,15	6-9,13,14,16-18,21	10-12,19,20,22,23		1-23					3 atra, 3 leuco., E channel	3500	13
31	Gogan	18					1-8			3-6	1-2, 7-8				8 atra, E. channel. Slab rock at 1-3 & 5.	330	32
34	Kieshi-echi	18					1-6			1-6						600	0
39	Eniaetok	8		9	2-3, 5-8	1,12, 13,15-23	4,9	11,14	10	1-9, 11-13 15-23	10,14	0			5 atra & 1 leuco. N. side	3600	24
53	Rongelap	5		8-11, 20, 21	1-2, 8-14, 16-21, 31-35, 37,53, 67-69, 83-92	3-5, 36,42, 45,55, 57,61, 66,71	6,7,15, 22,27, 37,43, 47-52, 54,58-60,62-65,70, 72-79, 81,82	28-30, 39-41, 44,46, 80		1-24, 26-40, 42-43, 53,67-71,83, 84,88-92	25,41 44,45 49,56 63,66 72,74 76	46-48, 50-52, 54,55, 57-62, 64,65, 73,75, 77-79, 80-82, 85-87			some atra, lagoon side	3400	990
54	Arbar	19			1, 2, 6-12, 27-29	3-5, 13-26				1-26	27-29					73	38
58	Tufa	20					19			19					200 atra, lagoon, mid-islet only, seen	20	0
60	Burok	20				1-12					1-12				1 atra, lagoon side	60	40
61	Pokoreppu			20	1					1						0	0
Total sections					76	65	66	23	3	160	41	36	1	1		(Total 110421	6327)

*Arithmetic mean. Means in other columns are geometric.

Better agreement resulted from the use of geometric than from arithmetic means.

Analysis of the table shows that the islets had an estimated 1.7×10^4 *H. atra* and 3.7×10^3 *H. leucospilota.* In addition, an extensive area ($4 \times 10^4 m^2$) of shallow (4–6 m) lagoon bottom off Island 13 and Island 15 (Fig. 1) was observed from a skiff to be populated with an estimated 10^4 30-cm black (not sand-coated) *H. atra* lying on the light sandy portions among the darker predominating, staghorn corals. The estimate for the 700 m of reef-flat north of Aniiru I., as far as a transverse ridge across the reef, was based on three traverses from 3 to 6 m wide: first, walking north along the middle of the reef; then back, one-third of the way in from the seaward edge of the reef; and finally, pacing west across the reef on a line 200 m north of Aniiru I., for a distance of 500 m lagoonward from the seaward reef edge. Extrapolations of the above observations to the entire atoll suggest the following numbers of *H. atra* and *H. leucospilota,* respectively: for islet shores, 2.5×10^4 and 5.5×10^3; for inter-islet reefs, 4×10^6 and 10^5; and for shallow lagoon bottom areas, 5×10^5 *H. atra,* or a total for the entire atoll of 4.5×10^6 *atra* and 1.6×10^5 *leucospilota.*

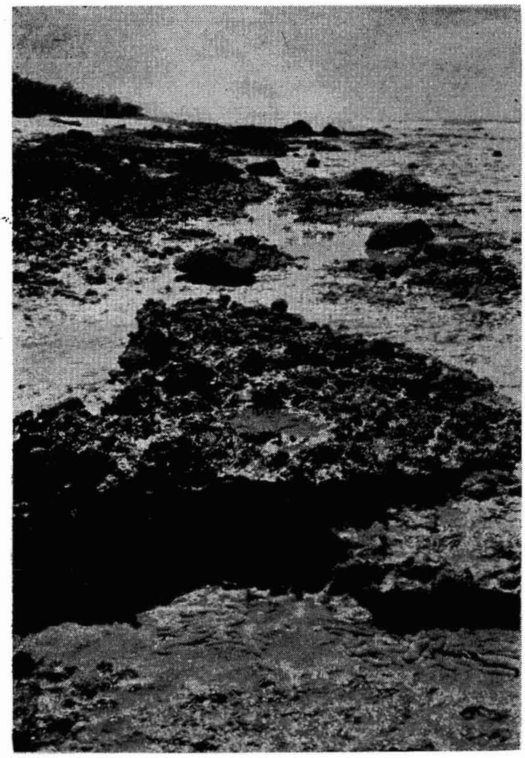


FIG. 2. Inner edge of reef-flat, Rongelap I., section 29, showing *Holothuria* in pools. Sept. 5, 1959, 1025 hr.

OTHER SPECIES OF SEA CUCUMBERS

Species observed other than *H. atra* and *H. leucospilota* are mentioned in order of decreasing abundance. *Stichopus chloronotus,* the greenish-black prickly sea cucumber on the inter-islet reef-flat and on the sandy, shallow lagoon shore near the north channel of Kabelle I. was most common. Also on the shallow, sandy bottom, lagoonward from Kabelle I. we observed in mid-September 1961, during a period of extreme tides, a heavy concentration (about $1/m^2$) of 10 to 20-cm specimens of a light-colored *Actinopyga* sp. with small brown spots. Dead specimens were common on the lagoon shore of Kabelle I. The large brown *Actinopyga mauritiana* occupied the outer edge of the reef-flat. *Holothuria gyrifer,* a small tan-colored sea cucumber with white spots, was common under rocks on the seaward reef and especially in the channel north of Kabelle I. Occasional specimens of *Ophiodesoma spectabilis* were encountered under rocks.

SAND PASSING THROUGH HOLOTHURIA

The holothurians have been called the earthworms of the sea. The amount of sand passing through the gut of *Holothuria* is of interest because of the possibility of profound alteration of the ecology in those areas where sea cucumbers are abundant. Crozier (1918) has estimated that in 1.7 sq miles of bottom in Harrington Sound, Bermuda, 500–1000 tons of sand pass through *Stichopus moebii* annually (considering their average length to be 27 cm and the dry weight of the contained sand to be 46 g). He concluded that the primary effect of the feeding habits upon the environment is the moving of sand from one place to another.

Trefz (1958:14) timed the passage of sand through captive *H. atra* at about 12 hr for an average-sized specimen of 30 cm. Assuming an

FIG. 3. *H. leucospilota* (black) extending from underneath *H. atra* in a pool on the eastern shore of Rongelap I., Aug. 23, 1958, 1700 hr.

average gut content of 100 g dry weight, this would be equivalent to 1 gram in 7.2 min. Larger specimens required more time for passage of sand through the gut than did smaller specimens, according to the following relationship derived from her data for specimens of 25–38 cm (omitting two outlying observations):

$$t = 5.3 + 0.233\,L$$

where t represents time in hours for passage through the gut, and L is length of sea cucumber in cm.

Yamanouti (1939:614) weighed the gut contents of 65 small (5–25 cm) *H. atra* and recorded an average of 17.1 g dry weight (range, 0.4–40.5 g). Time required for passage through the gut of captive specimens averaged 4.8 hr. Thus, 1 gram would be ingested every 16.8 min on the average.

Direct observation during low, daytime tides of undisturbed, feeding individuals of *H. atra* 30 cm long in their natural habitat at Rongelap Atoll showed egestion of sand at the rate of 1 g (dry basis) in from 5 to 10 min, agreeing with deductions from the data of Trefz on captive specimens. Assuming continuous feeding, at Rongelap Atoll the estimated 5×10^6 *H. atra* and *H. leucospilota* probably ingest and egest about 2.4×10^8 kg of sand yearly.

It has been pointed out by Crozier (1918) for *Stichopus moebii,* by Yamanouti (1939) for *H. atra* and other species, and by Trefz (1958) for *H. atra,* that there is virtually no grinding action or reduction in size of sand particles upon passing through the gut. Trefz has demonstrated that even such minute and delicate calcareous structures as the integumental "anchors and plates" of the sea cucumber, *Ophiodesoma spectabilis,* do not undergo perceptible dissolution in the gut of *H. atra,* but that they appear the same after egestion as before ingestion, thereby negating the idea of chemical dissolution in the gut.

In some of the scoured depressions on the seaward reef where very little sand is present, *H. atra* serves an additional function by retaining within and around itself much of the sand required in its feeding that might otherwise be washed away.

SIZE OF SPECIMENS

The length of undisturbed *H. atra* in the open ranged from about 2 to 60 cm, with estimated weights of 10 to 2000 g. We have not observed smaller ones. Frequent estimates of length during the censusing led to the opinion that the geometric mean length of *H. atra* on the islet shores is about 17 cm and of the more slender *H. leucospilota* about 25 cm. In contrast to the elongate shape of the larger specimens, the smaller specimens of *H. atra* were short and thick; in fact, the smallest (2 cm) were as thick as they were long. At the northeastern reef of Kabelle I. on September 14, 1961, 407 specimens of *H. atra* in a single pool were individually measured or estimated for length and diameter in inches, while still undisturbed, and were then placed in a container of water for volume measurement in cm³ by displacement. The temperature of the pool ranged from about 35 to 39 C during the 5 hr re-

TABLE 2

LENGTH-FREQUENCIES OF 407 *H. atra* MEASURED IN A POOL ON THE NORTHEASTERN SHORE OF KABELLE ISLAND, SEPT. 14, 1961

LENGTH INCHES	NUMBER	LENGTH INCHES	NUMBER
2	5	6	98
3	8	7	29
4	78	8	14
5	159	9	8
		10	2

quired for measuring. Both the high temperature and the slight, unavoidable disturbance of adjacent individuals when picking up specimens for volume measurement resulted in a small amount of contraction. After handling, the specimens were deposited in another part of the pool. Table 2 gives the length-frequencies. These measurements show a single major peak at about 5 inches (12.7 cm), and fail to affirm the presence of other expected frequency groups.

Figure 5 is a histogram showing the volume-frequency. As with length-frequency there is a single peak (at about 60 cm^3).

From lines fitted by inspection to the scatter diagram of Figure 6 the relationship of volume (V) to length (L) in the size range 5–15 cm was estimated to be:

$$V = 5.4\ L^{0.94}$$

The rather abrupt increase in slope beyond 15 cm is emphasized by the visually fitted line:

$$V = 0.019\ L^{3.0}$$

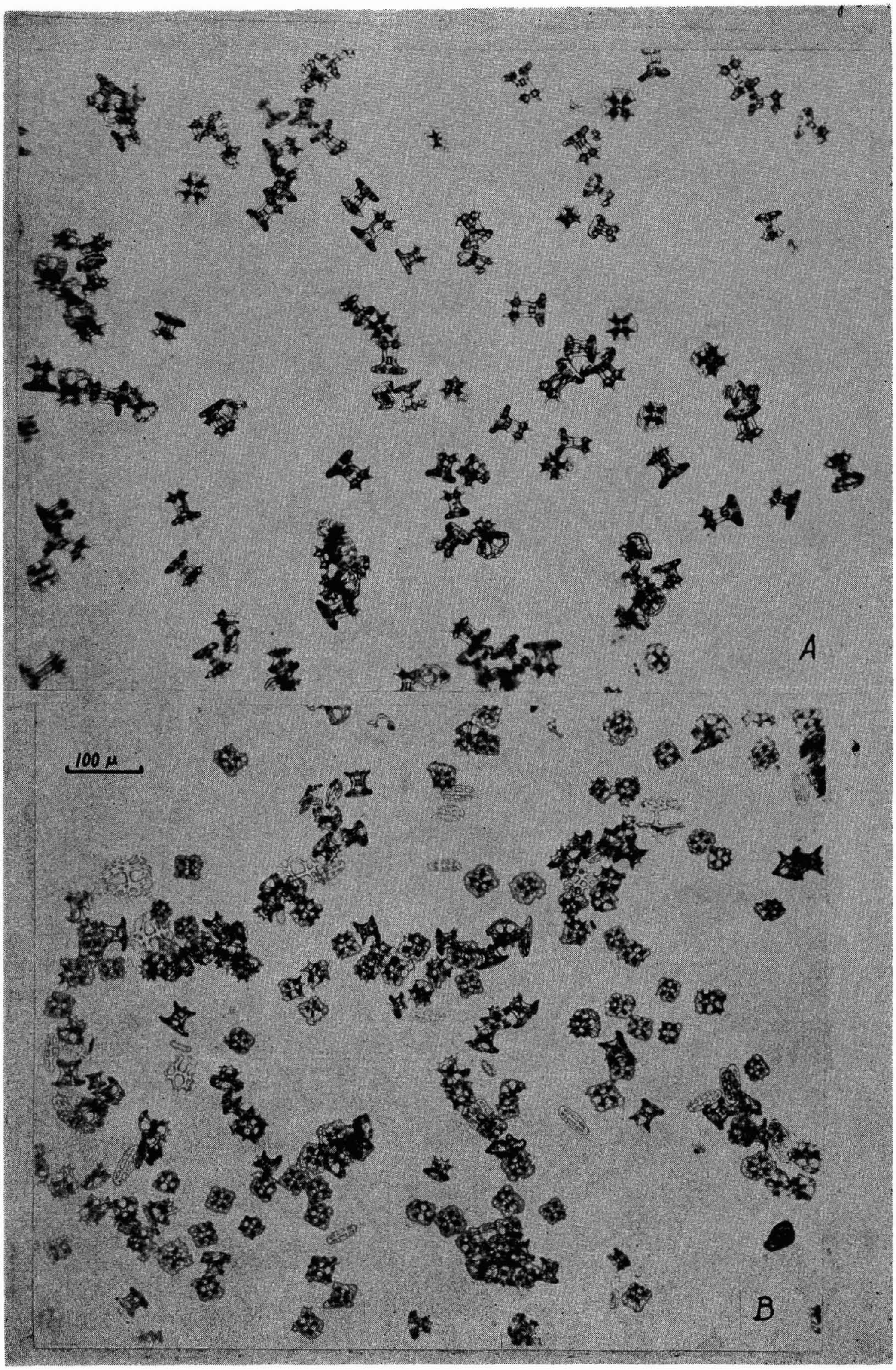
A few additional measurements of specimens longer than 25 cm suggest that this slope of 3.0 continues throughout the upper size-range.

TEMPERATURE TOLERANCE

Consideration of their habitat, exposed to the sun in shallow pools at low tide, would suggest a high temperature tolerance for *H. atra.* On partly cloudy days after at least 2 hr of continuous sunshine, the temperatures of 69 pools containing *H. atra* ranged from 31.1 to 39.4 C, with mean and standard deviation of 36.19 and 2.14 C. The temperatures, determined with clinical centigrade thermometers, of eight black sea cucumbers were consistently higher than simultaneous temperatures in the sand-coated sea cucumbers alongside them (by an average of 0.25 C, standard deviation 0.16 C). After more prolonged exposure to sunlight this differential would be expected to increase. Shaded thermometers on the bottoms of the pools gave readings lower than within the sand-coated sea cucumbers, while thermometers in direct sunlight on the pool bottoms approximated those within the black sea cucumbers. Extreme differences between pool- and specimen-temperatures at any one place and time barely exceeded 1 C. Some degree of reflective insulation from the radiation of the sun is imparted to *H. atra* by the coating of light-colored sand with which it habitually covers its body, enabling it to retain a slightly lower body temperature than it does when not sand-coated, or than does the naked, black *H. leucospilota* when out in the open.

The warmest pool in which a *H. leucospilota* was found was 38.4 C, but the animal was not feeding. The usual habitat of *H. leucospilota* is cooler than that of *H. atra* because of its habit of seeking the shade and protection of rocks. Water coming in over the reef at high tide has a temperature of about 29 C. When this cool water saturates the beach it remains cool if overlain by strata of slab rock, but is warmed by the sun if the sand is exposed. *H. atra* occurred in pools of higher temperature, 39.4 C. The upper limit was not determined. Crozier (1915: 281) gives the maximum temperature of the habitat of *H. surinamensis* as 31.8 C and states that muscle coagulates at 42 C. This is only about 3 C above the highest pool temperatures in which *H. atra* has been encountered. *H. atra* is unusually tolerant of heat, and is almost the only macroscopic organism living in these warm pools at low tide on the warmest days.

FIG. 4. Photomicrographs showing calcareous deposits in the integument. *A,* Tables of *H. atra. B,* Tables and buttons of *H. leucospilota.*


A
100 μ
B

PHOTOTROPISM

H. atra, and to an even greater extent, *H. leucospilota* are negatively phototropic since both protect themselves from strong light, *H. atra* by its sand coating, and *H. leucospilota* by seeking shelter. They usually react to quick changes in light intensity, as by withdrawal of tentacles when covered by a shadow during feeding. *H. leucospilota* reacts to a shadow by suddenly contracting under the protection of the rock where its posterior end is anchored, thus frequently requiring a quick grasp and a firm pull in order to collect this species.

PREDATION

Besides reflective insulation the sand coating of *H. atra* affords concealment. This function, however, would seem to be subordinate to that of insulation, because of the small amount of predation to which *H. atra* is apparently subjected, unless, of course, the converse obtains, that the small amount of predation may be due to the concealing effect of the sand coating. A damaged sea cucumber has been observed only once. This specimen, presumably pecked by a bird, occurred in an area where curlews had been active. In no case has an animal been observed actually preying upon *H. atra.* Crozier (1915:246) observed lightly colored parts of *H. surinamensis* which he suspected of being regenerated following either autotomy or injury by enemies such as fishes or crabs, but states that there is no evidence that *Holothuria* has enemies of this kind. Frizzell and Exline (1955: 29) ascribe predation on intertidal sea cucumbers to sea gulls, and note the general concurrence among authors that predation is slight, but propose that the apparent protective mechanisms of holothurians suggest predation to be more common than is supposed.

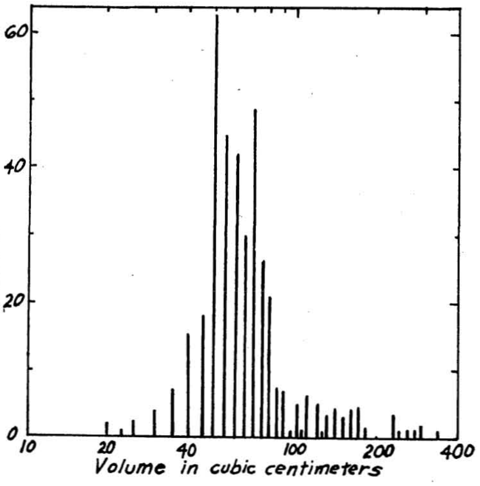


FIG. 5. Histogram showing volume-frequency of 407 *H. atra* from a pool at Kabelle I., Sept. 14, 1961.

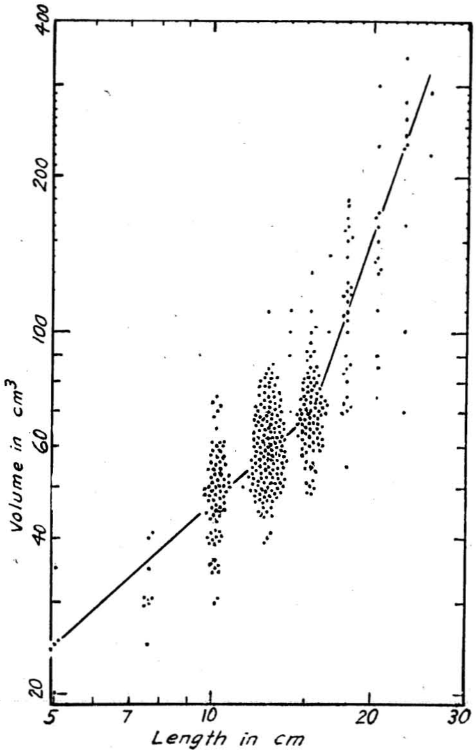


FIG. 6. Relationship of volume to length of 407 *H. atra* at Kabelle I., Sept. 14, 1961. Lines drawn by inspection.

TRANSVERSE FISSION

Fission has been reported in holothurians by Crozier (1915:291), who found regeneration of either end of the body in about 10% of the *H. surinamensis* encountered. Frizzell and Exline (1955:15 and 27) state that a few forms including *Holothuria parvula* (Selenka), *Cucumaria lactea,* and *C. planci* (Brandt) sometimes reproduce by transverse fission, and that *Holothuria difficilis* Semper of the tropical Pacific commonly does so.

In September 1959 in a warm pool of about 37 C on the southwest shore of Burok I. two short specimens of *H. atra* were encountered lying end to end. The integument of the two adjacent terminal end portions was devoid of sand because of the absence of tube feet. The specimens were saved, and later examination revealed a calcareous oral ring in only one, indicating that the two individuals resulted from transverse fission. Another specimen in an adjacent pool was photographed in an advanced stage of constriction; but without disturbance by even so slight a stimulus as a shadow it voluntarily relaxed the constriction and resumed normal shape within a period of about 5 min.

During the September 1961 census, enough fissioning (Fig. 7) and fissioned specimens were encountered to verify that fission, or asexual reproduction, does commonly occur in *Holothuria atra.*

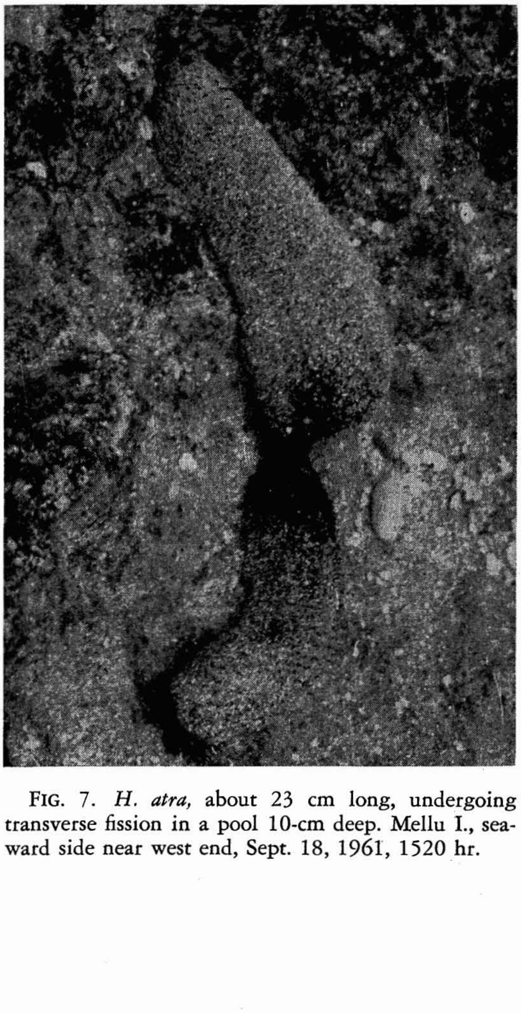


FIG. 7. *H. atra,* about 23 cm long, undergoing transverse fission in a pool 10-cm deep. Mellu I., seaward side near west end, Sept. 18, 1961, 1520 hr.

The importance of fissioning as a means of reproduction is emphasized in Figure 6 by the relative thickness of the small specimens and the consequent reduced slope (0.9) of their logarithmic relationship of volume to length as compared to the usual cubic relationship (slope of 3) for the larger specimens.

If it may be assumed that sexual reproduction would be seasonal in nature, while fissioning would occur at all seasons, then the lack of apparent age classes or frequency modes in the volume-frequency histogram of Figure 5 is also consistent with the concept of reproduction by fissioning.

SUMMARY

1. The preferred habitat for *H. atra* and *H. leucospilota* on the seaward reef-flat is described and is linked with the presence of slabs or shelves of rock at the junction of the sandy beach with the reef-flat. On hot days runoff water from such areas is of relatively low temperature (because of the insulating effect of the slabs of rock).

2. Estimates of numbers of these two sea cucumbers are based upon notes and photographs made while traversing the peripheries of the larger islets and some reef and lagoon areas, resulting in an estimated total of about 5×10^6 *H. atra* and 2×10^5 *H. leucospilota.*

3. The passage of sand through the gut of *H. atra* is at the rate of 1 g (dry weight) in from 5 to 10 min, resulting in an estimate for the atoll of about 2×10^8 kg of sand ingested and egested yearly. The primary ecological role of the sea cucumbers in this feeding action is to move the sand from one place to another.

4. Length of *H. atra* observed ranged from 2 to 60 cm. Measurements of 407 specimens in one pool showed that for specimens up to 15 cm in length, volume increased slowly with length, while for those from 15 to 25 cm, volume increased almost as the cube of length. This is construed as evidence of reproduction by fissioning.

5. *H. atra* appeared healthy and feeding in small pools with temperatures up to 38.9 C.

The internal temperature is slightly lower in the sand-coated than in the naked black specimens because of the reflection of light and heat by the coating of sand characteristic of this species.

6. Evidence of predation upon *H. atra* or *H. leucospilota* is practically lacking.

7. Transverse fission in *H. atra* has been observed in various stages of progress, and is considered to be an important means of reproduction.

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