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THE DISTRIBUTION OF TURBINARIA ORNATA (TURN.) J. AG. IN FANNING ATOLL LAGOON

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A variety of algae grow within the Fanning Atoll lagoon (Tsuda et al., see p. 61, this report) but only one large brown alga, Turbinaria ornata (Turn.) Ag. is found there. Although Turbinaria occurs on many Pacific atolls (Taylor, 1963, 1966), its distribution within an atoll lagoon has seldom been investigated. Rhyne (1971) noted the most abundant growth of Turbinaria conoides was near the southeastern lagoon shore of Diego Garcia, Chagos Archipelago, in the western Indian Ocean, but in other portions of the lagoon the thalli were stunted, dwarfed, or absent. Similar observations of Turbinaria ornata in the northwestern portion of Fanning Atoll were made by Bakus (1964), and DeWreede and Doty (1970) suggested causative factors for greater Turbinaria growth on the windward margin of one patch reef within the lagoon.

A study of Turbinaria ornata in the lagoon of Fanning Atoll was made with three objectives in mind: (1) to attempt to detect patterns of Turbinaria distribution within the lagoon; (2) to detect areas of "good" and "poor" growth; and (3) to detect environmental factors which may be associated with the observed distribution.

METHODS

Aerial inspection of the atoll was conducted, using a Piper Aztec flown by Dr. M. Vitousek, to observe patterns of substratum distribution. Close inspection of each reef passed by boat was made to interpret the aerial observations and to determine the presence or absence of Turbinaria. A search pattern radiating from the cable station was also conducted by boat and the distribution of the alga toward the center of the lagoon traced and recorded. Special effort was made to investigate the more remote portions of the lagoon.

Selected samples of Turbinaria were picked in the northern portion of the lagoon where Turbinaria grew well and in other areas where it was abundant but not so large. Samples were obtained by picking all thalli

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within a 46-cm diameter stainless steel ring placed around the largest individual Turbinaria thalli on the reef. Thalli were measured, sun dried, and weighed. Voucher specimens are deposited in the herbarium of the author (University of Hawaii, Honolulu, Hawaii).

Four sites were selected for a detailed study of the environmental factors that might enhance or limit the growth of Turbinaria. Each site remained submerged at lower low water and was located in the northwestern portion of the lagoon. All contained sufficient solid calcium carbonate substrata suitable for Turbinaria attachment, but differed in how well Turbinaria grew, distance from the shore, and water clarity.

Measurement of water movement was made using calcium sulfate clod cards (Doty, 1971) attached to wooden stakes or pieces of roofing tile. The dissolution of calcium sulfate and consequent field weight loss was compared to weight loss in still water and converted into a diffusion factor (DF) representing the degree to which diffusion or dissolution was enhanced by water movement during a 24-hour period.

Intervenient sites were provided by fir stakes 110 X 7.5 X 1.3 cm driven into the bottom, with a 75 X 7.5 X 1.3 cm movable cross member attached horizontally to them. The cross member was held securely in place by a "C" clamp. Four plastic clod cards were stapled upon the cross member and a maximum-minimum thermometer (see Doty and Russell, p. 85, this report) suspended below it by rubber bands. The cross members were adjusted to about 1.0 to 2.0 cm below lower low water level. The stakes were placed at various intervals at sites A and C while only one stake was used at North Pass. The values obtained from the clods on stakes were compared with the values obtained from clods placed on the bottom. The latter were taped to pieces of roofing tile for anchorage. No stakes were used at Site B. Depth measurements were recorded at each clod location using a premarked stake. The depths were later corrected to lower low water values.

Site A was an area containing large Turbinaria thalli, located 2 kilometers northeast of the Cable Station, about 400 meters south of the northern copra camp and about 200 meters east of "Q" marker (the northernmost channel marker in the lagoon used by the copra workers) (Fig. 2). Turbinaria was growing in patches on the solid calcium carbonate bottom and on mounds of calcium carbonate surrounded by silt-free sand in clear water. Three stakes were placed 7.0 meters from each other in a line perpendicular (southeast) to the shore and another stake placed 7.0 meters southwest of the center stake. Tiles with clods attached were placed on rocks adjacent to each clod stake. Thalli were removed from the rocks to prevent obstruction of water movement and/or abrasion by the algae. Maximum-minimum thermometers were attached to the innermost and outermost cold stakes. No storms passed during the period of observation.

Site B was an area containing small Turbinaria thalli, formerly studied by DeWreede and Doty (1970). It was located 1.25 kilometers southeast of the cable station adjacent to "Suez Canal", a man-made boat passage traversing the northwestern line reef of Suez Pond (Figs. 1 and 2). Here, Turbinaria was growing on solid calcium carbonate substrata along the margin of the 20-meter-wide reef in murky water. No stakes or thermometers were

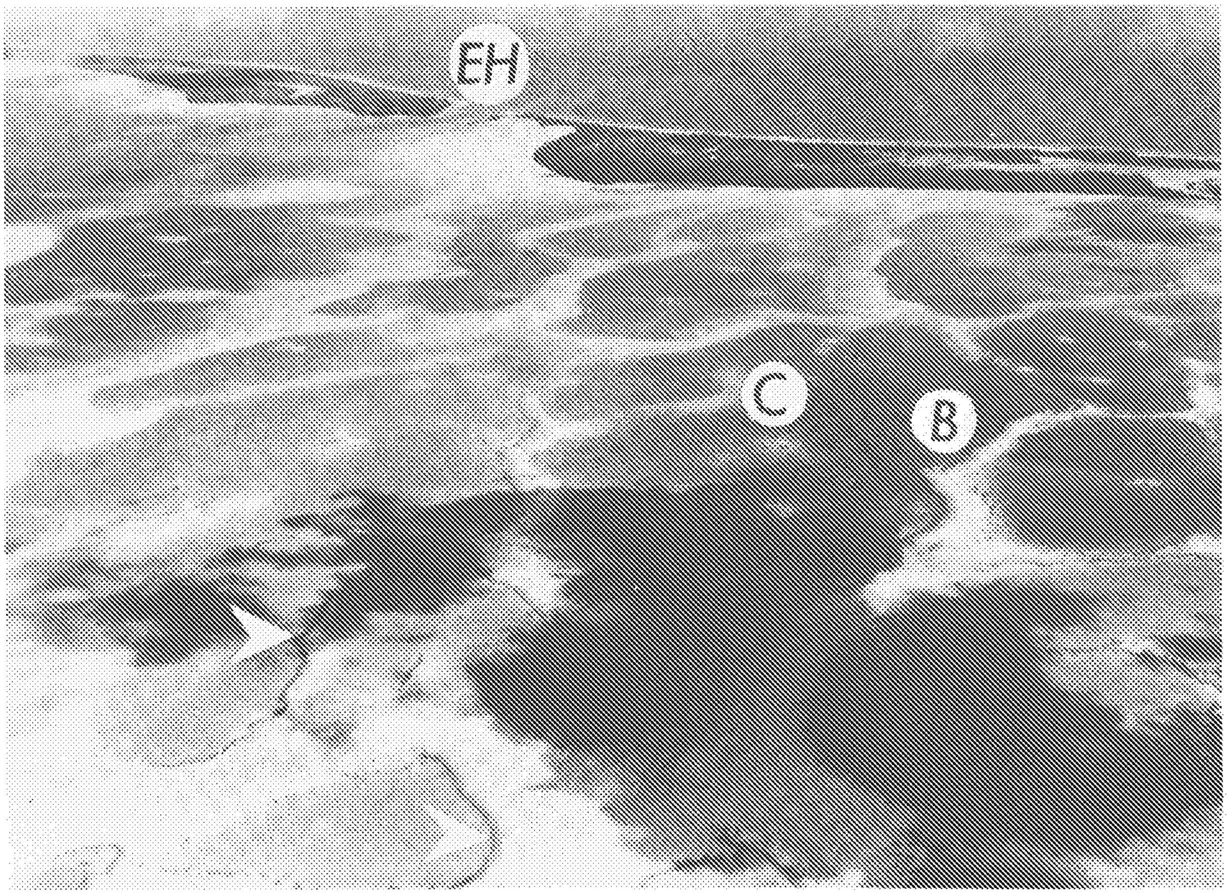

FIG. 1. Fanning Atoll lagoon. Arrows indicate the darker edges of coarse material along the line reefs. Sites B and C within Suez Pond are indicated and English Harbor (EH) is in the background. The large dark irregular shadow in the lower right corner was caused by a cloud.

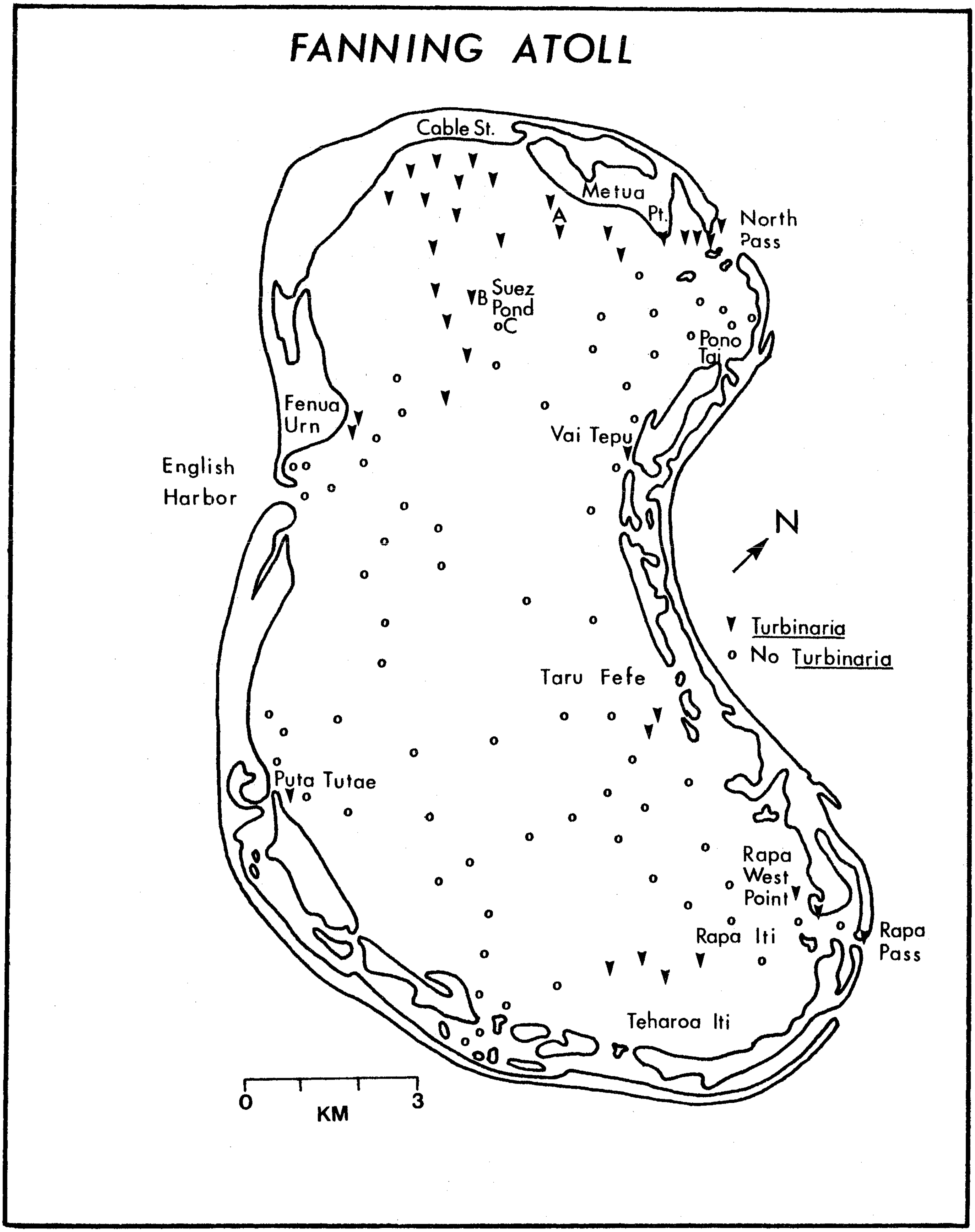

Fig. 2. Distribution of Turbinaria ornata within Fanning Atoll lagoon.

placed at this site. Tiles with clods attached were placed at 3.0-meter intervals in an "I" formation similar to the one used by DeWreede and Doty (1970). Three pairs of clods were also placed in the boat channel and one pair on the southwestern bank. Storms prevailed during the period of this investigation.

Site C was an area with no Turbinaria located within the northern portion of Suez Pond 0.5 kilometers northeast of "Suez Pond" (Figs. 1 and 2). Several large calcium carbonate mounds were present on this sandy patch reef and much Acropora rubble and large dead Porites heads lay along the southeastern edge in murky water. Five stakes were placed along an east-west line extending the length of the patch reef. Two were placed near the center, one at each end of the reef and one in the sand about 5.0 meters beyond the eastern edge. A sixth stake was placed about 10 meters north of the center stake. Tiles with clods attached were placed at 5.0-meter intervals perpendicular to the east-west line of clod stakes until a grid of twenty locations had been covered. Maximum-minimum thermometers were attached to the two easternmost stakes. Current direction and rate were detected by observing the movements of seven submerged plastic gallon bottles as they passed over the reef. Investigations at Sites B and C were conducted during the same 24-hour period.

A fourth site was located at North Pass in mid-channel at the second stake used in a separate investigation (See p. 85, this report). Turbinaria was growing on large calcium carbonate stones and mounds in clear water. One maximum-minimum thermometer was attached to the stake.

RESULTS

Turbinaria ornata is not distributed evenly throughout the lagoon. It is most abundant in the northwestern sector of the lagoon (Fig. 2), but is absent from the central portion of the lagoon and only infrequently encountered along the shoreline south and east of English Harbor. It occurs in a large area near Teharoa Iti, but few thalli were encountered at Rapa Pass.

The largest dry-weight values of Turbinaria (1983 gms/m^2) were encountered at Site A southwest of North Pass (Table 1). Similar large dry-weight values were obtained at North Pass (up to 1313 gms/m^2) and in one small area on the northeastern edge of the entrance to Rapa Pass (811 gms/m^2). This latter area is adjacent to high concentrations of alcyonarian corals that covered most of the solid calcium carbonate rock bottom. Only 15 mm tall Turbinaria thalli were growing on the few large rocks exposed amidst the soft corals.

Patches of Turbinaria in densities of 379 gms/m^2 were growing near Fenua Urn on solid calcium carbonate pavement in murky water, but were absent from similar seemingly suitable substrata away from shore. Similar distribution patterns were seen at Taru Fefe, Vai Tepu and Puta Tutae. All were in murky water.

Table 1

Weights and Sizes of *Turbinaria ornata* within the Lagoon of Fanning Atoll

Location	Dry Weight (gms/m^2)	Maximum Thallus Height (mm)	Water Clarity	Lower Low Water mm Above Bottom
Site A	1983	320	clear	300
Site B	191*	---	murky	---
North Pass (moat)	1313	300	clear	500
North Pass	828	350	clear	1000
North of Metaua Pt.	607	150	clear	300
Rapa Pass	811	220	clear	400
Fenua Urn	379	170	murky	200
Taru Fefe	329	200	murky	600

*This is 14% of the largest wet weight value given by DeWreede and Doty (1970) for this location. The percentage is based on weight retained upon drying of *Sargassum* and is most likely the same for *Turbinaria*.

Table 2

Maximum-Minimum Water Temperatures (°C)

Thermometer No.	Site A 1	Site A 2	Site C 1	Site C 2	North Pass 1
High	29.0	29.0	28.0	28.5	32.0
Low	26.5	26.0	26.2	27.0	27.0

The area between Teharoa Iti and Rapa Iti consists of large calcium carbonate mounds with Turbinaria growing on them, however a similar area north of Pono Tai was devoid of Turbinaria. Both areas were in murky water.

The English Harbor area does not have any Turbinaria growing in the clear, deep water there, although suitable substrata are available. This area was not as thoroughly searched as desired because of the depth and uncertain currents encountered. Nevertheless, Turbinaria thalli were not present in the areas of English Harbor examined.

A pattern of substratum distribution is easily seen from the air. Patch and line reefs are darker on the eastern to northeastern (windward) edges except where they are influenced by currents flowing through the passes (Fig. 1). The darker edges of the reefs consist of coarse material; lighter areas are sand.

Diffusion enhancement by water movement values (see Appendix) are given in relation to reef topography in Figures 3 to 5. Diffusion values (DF) were generally higher on the windward side of each reef studied. The DF value at North Pass (30.5) was probably lower than the correct value because the clods were washed off the stake and fell to the slower moving waters on the bottom during part of the exposure time.

All maximum-minimum water temperature readings during the investigation were between 32.0-26.0^{o} C (Table 2).

DISCUSSION

Turbinaria ornata is unevenly distributed throughout Fanning Atoll lagoon, and its distribution appears to be associated more closely with factors derived from land runoff than with water movement, substratum availability, water clarity, temperature, or depth.

Turbinaria is most abundant and grows larger (as measured in gms/m^2) near the large land mass along the northwestern rim of the atoll than in the southern and eastern portions of the lagoon. The land/lagoon ratio and therefore the runoff/lagoon ratio is higher in the northwestern sector of the lagoon than in the latter sectors, and salinities are lower (see p. 85, this report).

Water movement may also affect the growth pattern of Turbinaria. Although Turbinaria was found to be abundant on the windward side of a reef at Suez Pond (DeWreede and Doty, 1970), its occurrence there may be due to the availability of coral rubble caused by greater water movement on that side of the reef. Aerial inspection of the atoll and inspection of lagoon reefs by boat confirmed that the coarser material upon which Turbinaria usually grows is more abundant on the windward side of reefs.

DF values were quite different at North Pass and Site A where standing crops of Turbinaria were highest. High values (30.5) at North Pass and moderate values (14.5) at Site A accompanied the greatest growth of

Turbinaria found in the lagoon. DF values between these (about 20.0) were measured by both DeWreede and Doty (1970) and the author at Site B, a place of low Turbinaria growth. These observations would indicate some factor other than water movement limits Turbinaria growth in that portion of the lagoon.

The availability of solid calcium carbonate substratum is not the complete explanation of the uneven distribution of Turbinaria. Coral rock was available at all four sites investigated, but Turbinaria was absent from one of the sites, and at English Harbor, an area with much coral rock and clear water.

Water clarity is apparently also important in the distribution of Turbinaria. The greatest dry weights of Turbinaria were found not only near shore, but also in clear water. All of the murky water areas sampled yielded less dry weight per square meter than the clear water areas.

Water temperature varied between 26.0-32.0, a range easily tolerated by Turbinaria. Depth may also play a minor role at the sites studied and may have prevented the growth of Turbinaria in the large shallow sandflat areas adjacent to the passes.

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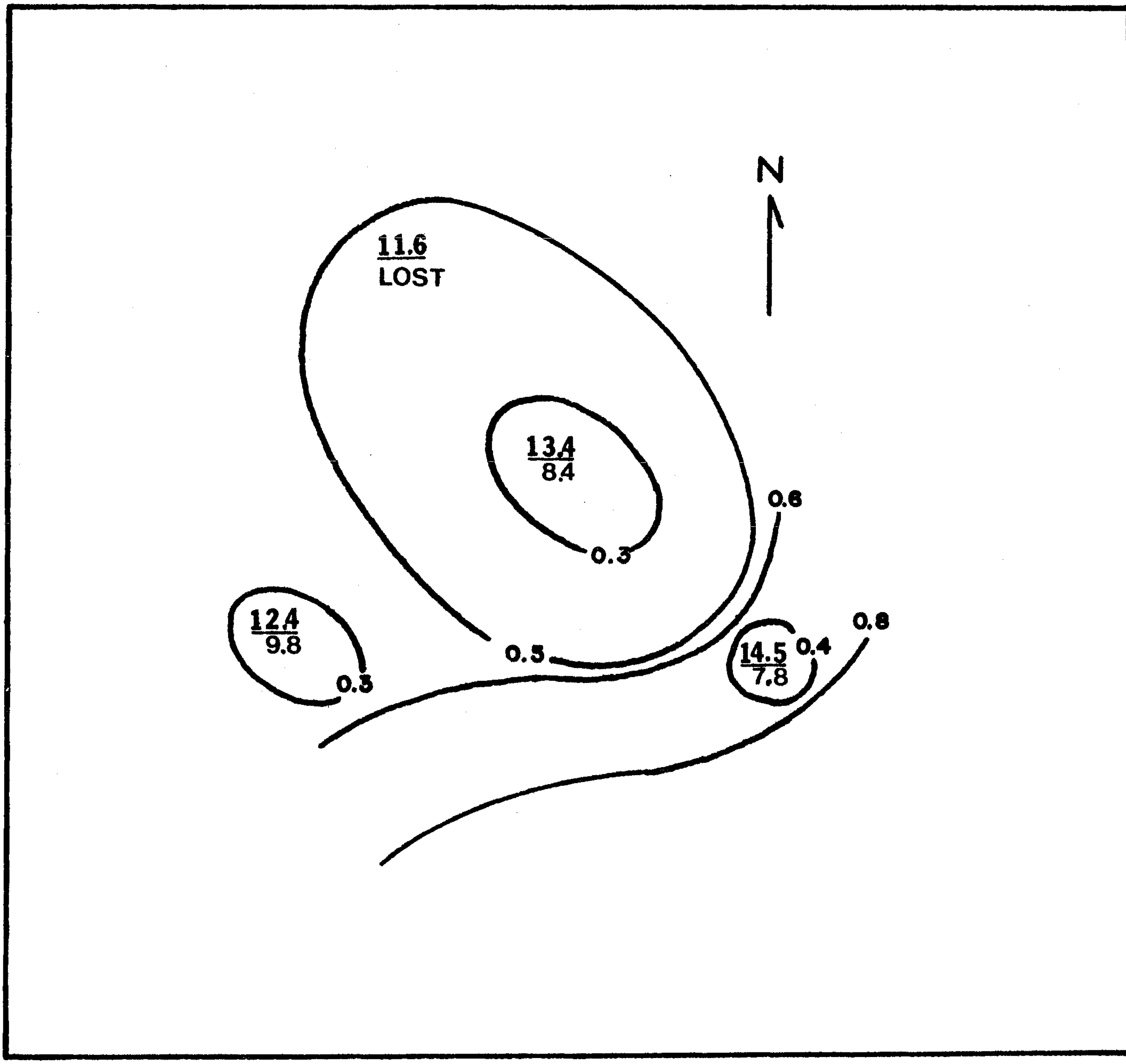

Fig. 3. Site A bottom contours (given in meters). DF values on stakes are underlined, those on tiles are not.

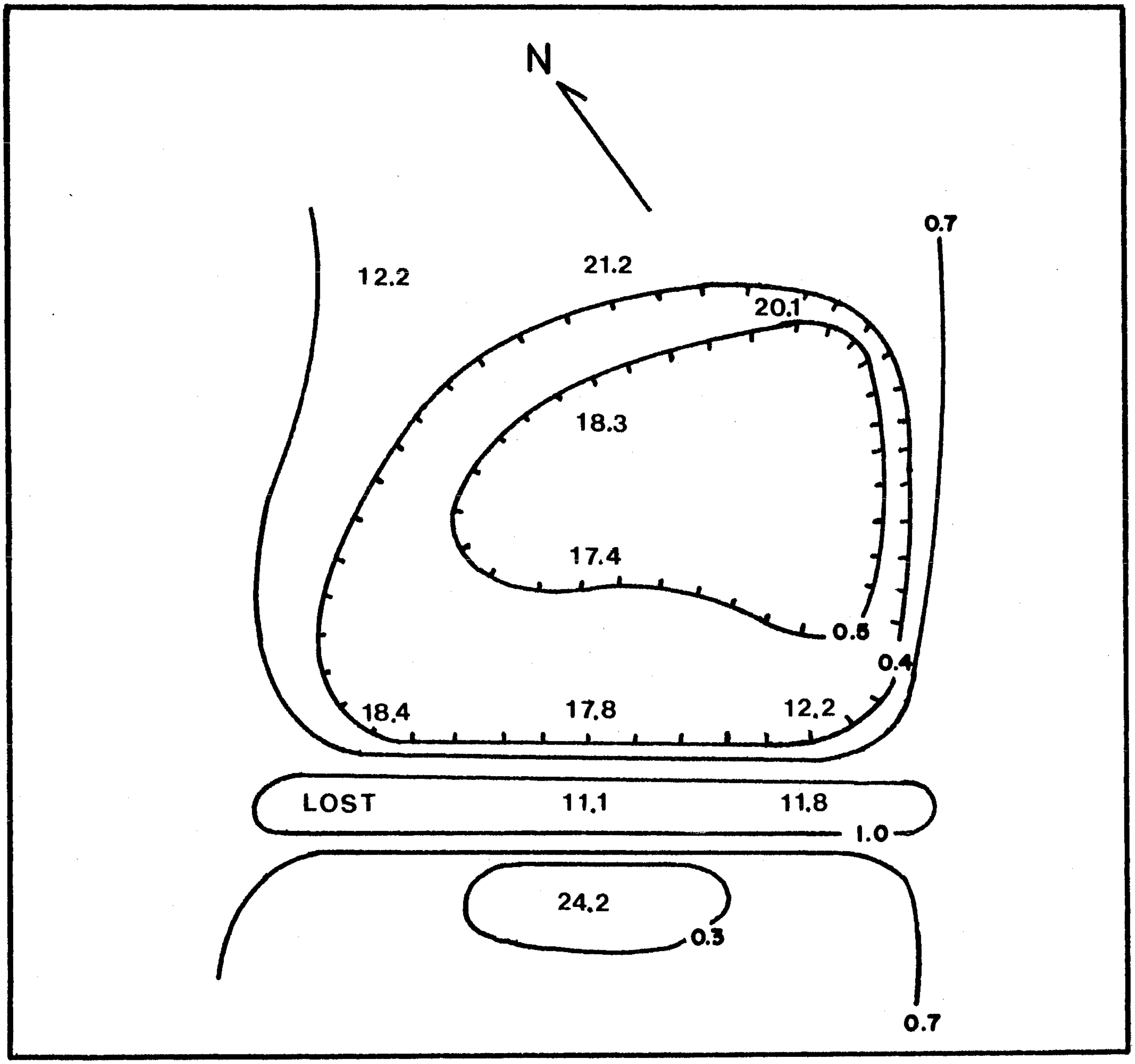

Fig. 4. Bottom contours at Site B at "Suez Canal" (in meters). DF values on stakes are underlined, those on tiles are not.

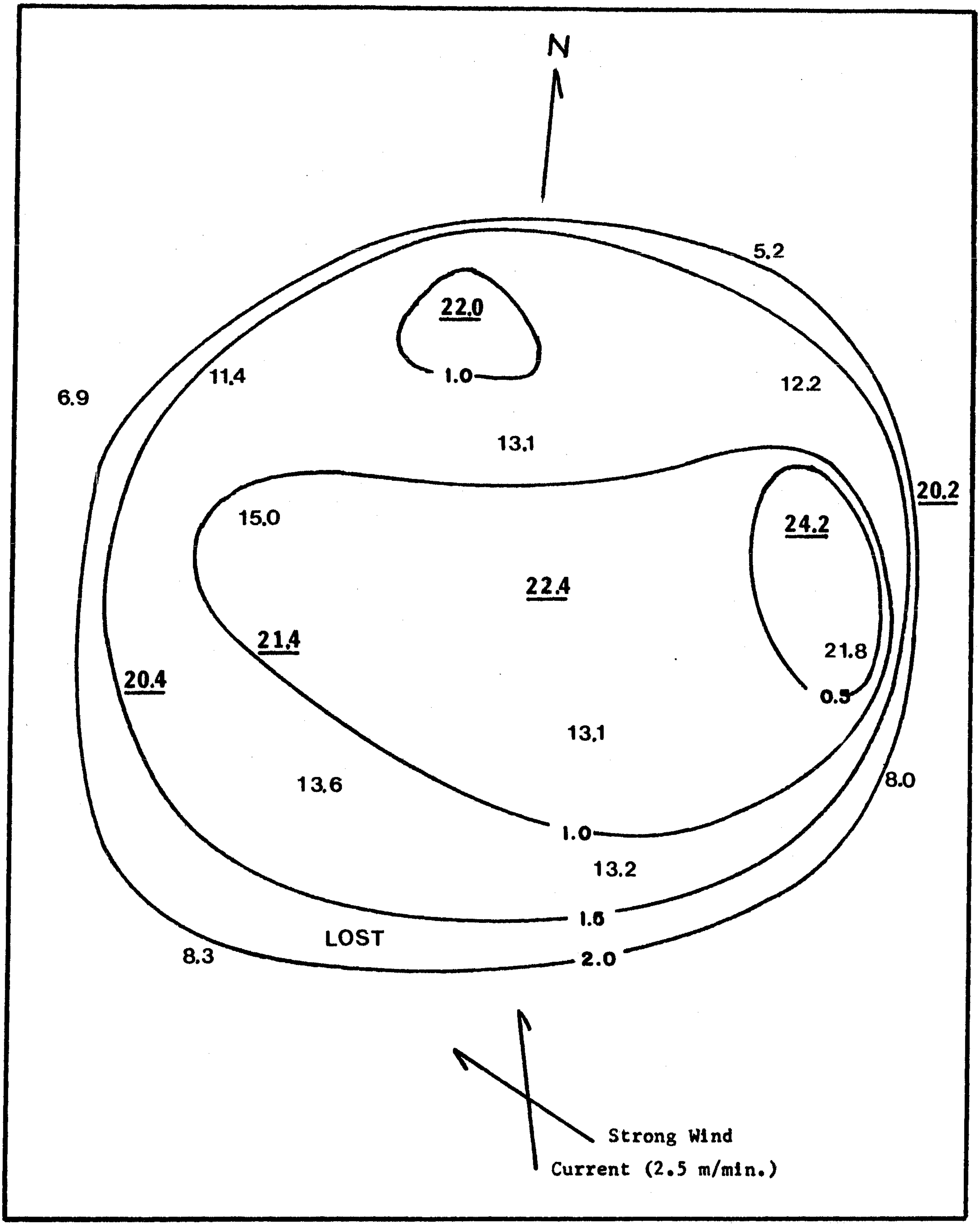

Fig. 5. Bottom contours at Site C in Suez Pond (in meters). DF values on stakes are underlined, those on tiles are not.

APPENDIX

Site A: these data represent the clods on the stakes shown in Figure 3 and are given in order from West to East as they are drawn.

Original Weight (gms)	Final Weight (gms)	Weight Lost (gms)	Immersion Time (hrs)	Individual DF Values	Average DF Values
42.2	33.4	8.8	24.00	10.6	
43.4	31.0	12.4	24.00	14.9	
42.2	30.7	11.5	24.00	13.9	
43.5	35.2	8.3	24.00	10.0	12.4
42.8	30.1	7.4	24.00	8.9	
43.2	31.7	11.5	24.00	13.9	
42.2	32.2	10.0	24.00	12.0	11.6
40.0	29.0	11.0	24.00	13.3	
42.5	32.4	10.1	24.00	12.2	
41.2	29.9	11.3	24.00	13.6	
43.3	31.2	12.1	24.00	14.6	13.4
42.8	32.0	10.8	24.00	13.0	
42.6	30.7	11.9	24.00	14.3	
43.5	30.0	13.5	24.00	16.3	14.5

Site A: these data represent the clods on tiles shown in Figure 3 and are given in order from West to East as they are drawn.

43.3	35.1	8.2	24.00	9.9	
42.6	34.6	8.0	24.00	9.6	9.8
Lost	Lost	Lost	Lost	Lost	Lost
44.2	37.2	7.0	24.00	8.4	
42.9	36.0	6.9	24.00	8.3	8.4
42.0	35.1	6.9	24.00	8.3	
43.5	37.4	6.1	24.00	7.3	7.8

Site B: these data represent the clods on tiles shown in Figure 4 and are given in order from West to East as they are drawn.

42.0	32.3	9.7	24.00	11.7	
42.0	31.5	10.5	24.00	12.7	12.2
41.8	27.2	14.6	24.00	17.6	
42.5	26.6	15.9	24.00	19.2	18.4
Lost	Lost	Lost	Lost	Lost	Lost
42.5	25.3	17.2	24.00	20.7	
43.4	25.4	18.0	24.00	21.7	21.2
42.0	27.2	14.8	24.00	17.8	
42.1	26.6	15.5	24.00	18.7	18.3
44.2	29.0	15.2	24.00	20.7	
42.7	29.0	13.7	24.00	21.7	21.2
43.2	28.2	15.0	24.00	18.1	
42.1	27.6	14.5	24.00	17.5	17.8
42.0	33.0	9.0	24.00	10.8	
41.9	32.4	9.5	24.00	11.4	11.1
43.5	23.9	19.6	24.00	23.6	
43.5	23.0	20.5	24.00	24.7	24.2
43.0	26.1	16.9	24.00	20.4	
44.3	27.9	16.4	24.00	19.8	20.1

Original Weight (gms)	Final Weight (gms)	Weight Lost (gms)	Immersion Time (hrs)	Individual DF Values	Average DF Values
42.5	36.7	5.8	24.00	7.0	
42.5	28.0	14.5	24.00	17.5	12.2
43.5	34.5	9.0	24.00	10.8	
43.5	33.0	10.0	24.00	12.7	11.8

Site C: these data represent the clods on the stakes shown in Figure 5 and are given in order from West to East as they are drawn.

43.8	27.0	16.8	24.75	19.6	
43.4	25.0	18.4	24.75	21.5	
44.0	23.4	18.4	24.75	21.5	22.0
42.2	25.4	16.8	24.30	20.0	
42.8	26.4	16.4	24.30	19.5	
43.0	26.0	17.0	24.30	20.2	
43.5	25.6	17.9	24.30	21.3	20.4
41.5	23.9	17.6	24.80	20.6	
42.9	25.0	17.9	24.80	20.9	
42.7	25.2	17.5	24.80	20.5	
44.5	24.3	20.2	24.80	23.6	21.4
43.0	23.3	19.1	25.25	22.7	
41.5	22.3	19.2	25.25	22.1	22.4
43.0	20.3	22.7	26.00	25.2	
43.5	20.6	22.9	26.00	25.4	
42.0	20.3	21.7	26.00	24.1	
43.0	23.1	19.9	26.00	22.1	24.2
43.3	25.8	17.5	26.00	19.4	
40.8	22.8	18.0	26.00	20.0	
43.4	24.1	19.3	26.00	21.4	
42.5	24.2	18.3	26.00	20.3	20.3

Site C: these data represent the clods on tiles shown in Figure 5 and are given in order from West to East as they are drawn.

42.6	37.2	5.4	24.10	6.5	
41.5	35.4	6.1	24.10	7.3	6.9
43.5	46.7	6.8	24.10	8.2	
42.8	35.9	6.9	24.10	8.3	8.3
43.5	34.0	9.5	24.50	11.2	
42.3	32.5	9.8	24.50	11.6	11.4
43.0	30.4	12.6	24.50	14.9	
43.2	30.4	12.8	24.50	15.1	15.0
42.2	30.3	11.9	24.70	13.9	
41.3	30.0	11.3	24.70	13.2	13.6
Lost	Lost	Lost	Lost	Lost	Lost
43.0	31.5	11.5	25.00	13.3	
43.5	32.4	11.1	25.00	12.9	13.1
42.2	30.9	11.3	25.20	13.0	
42.8	31.4	11.4	25.20	13.1	13.1
45.0	33.6	11.4	25.00	13.2	
41.2	29.9	11.3	25.00	13.1	13.2
43.2	38.6	4.6	25.80	5.2	
43.0	38.4	4.6	25.80	5.2	5.2
42.8	32.5	10.3	25.96	11.4	
42.9	31.3	11.6	25.96	12.9	12.2

Original Weight (gms)	Final Weight (gms)	Weight Lost (gms)	Immersion Time (hrs)	Individual DF Values	Average DF Values
44.2	27.1	17.1	25.50	19.3	
42.8	21.4	21.4	25.50	24.2	21.8
43.5	37.0	6.5	25.50	7.3	
43.2	35.6	7.6	25.50	8.6	8.0

North Pass: these data represent the clods on the second stake used in a separate investigation located in mid-channel as indicated in the text.

Original Weight (gms)	Final Weight (gms)	Weight Lost (gms)	Immersion Time (hrs)	Individual DF Values	Average DF Values
43.4	20.0	23.4	23.20	29.0	
43.4	19.9	23.5	23.20	29.2	
42.5	18.5	24.0	23.20	29.8	
42.5	15.2	27.3	23.20	33.9	30.5

Calibration:

Lagoon Water

39.8	36.4	3.4	Average Weight Lost	3.3800
39.8	36.6	3.2		
39.8	36.2	3.6	K Value	0.8450
39.8	36.4	3.4		
39.8	36.5	3.3		

Ocean Water

38.9	35.8	3.1	Average Weight Lost	3.2400
38.9	35.5	3.4		
38.9	35.5	3.4	K Value	0.8100
38.9	35.8	3.1		
38.9	35.7	3.2	Pooled K Value	0.8275