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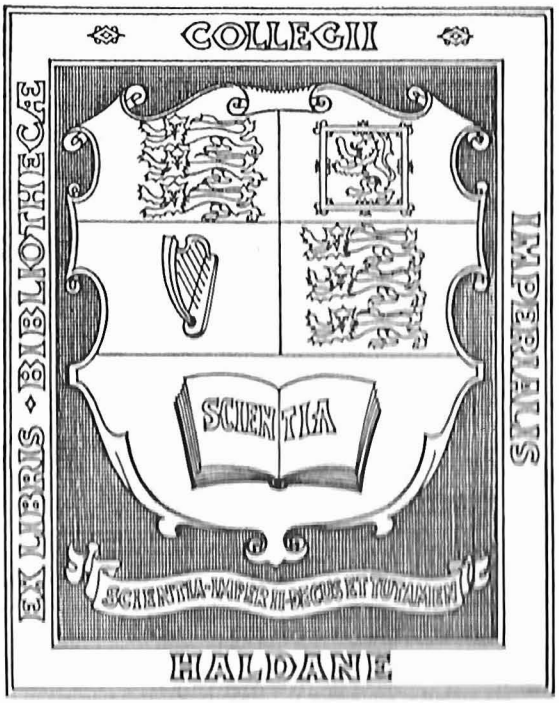
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PHYSICAL FACTORS AFFECTING INSECT PESTS IN SHIPS' HOLDS DURING A VOYAGE FROM TEMPERATE TO TROPICAL WATERS.

BY

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MAY, 1959.

IMPERIAL COLLEGE EXPLORATION BOARD

PHYSICAL FACTORS AFFECTING INSECT PESTS IN SHIPS' HOLDS DURING A VOYAGE FROM TEMPERATE TO TROPICAL WATERS.

I. INTRODUCTION.

In the summer of 1957, the first Royal College of Science Natural History Society Ghana Expedition was run, sponsored in part by Imperial College Exploration Board. As part of this project, Matthews carried out a preliminary investigation into the insect infestation between West Africa and the United Kingdom with reference to the physical factors inside the ships holds. (Matthews, 1958).

In 1958, the second Ghana Expedition went out, consisting of a party of seven. The author carried out further investigations of the physical factors in the holds, assisted by the rest of the party on the outward journey and by two of the party on the homeward voyage. The work was carried out under guidance and advice from the Infestation Control Division of the Ministry of Agriculture, Fisheries and Food and the Pest Infestation Laboratory, Department of Scientific and Industrial Research. The expedition desires to thank these Departments for their assistance, as well as Elder Dempster Lines, Ltd., and Unilever Ltd.

II. PRELIMINARY TRAINING.

Three of the party, R.F.Sturrock, J.M.Webster and the author, spent several days at Infestation Control Division, Tolworth, training in identification of insect pests, under the supervision of Mr.G.A.Brett. They also accompanied Mr.Roberts of I.C.D. (London Office) on two ship inspections, in East India and Tilbury Docks.

III. PROBLEM.

The principal object of the work, which was carried out on the M.V. SANGARA by kind permission of Elder Dempster Lines, Ltd., Liverpool, was to investigate the physical factors affecting insect pests in the holds. The occurrence of insects in residues of previous cargoes was studied and attempts were made to assess movements of beetles, the latter without much success; Matthews' (1958) statement that detailed population studies on a ship at sea were almost impossible, was confirmed. Much more work is needed on the problem of cross-infestation and infestation build-up during voyages; an understanding of the physical factors of the habitat is the first stepping stone in the study of this aspect of applied entomology.

IV. PREVIOUS HISTORY OF M.V.SANGARA.

The nature of infestation in residues in the holds of ships may be explained by the infestations which have been introduced on previous cargoes. Information regarding previous cargoes carried in the ship were obtained from the Chief Officer of the M.V.SANGARA and from the files of the Infestation Control Division of the Ministry of Agriculture, Fisheries and Food.

The infestations recorded on voyages 38 (May 1956) to 42 (July, 1958) are set out in Appendix I.

At the July, 1958 inspection, i.e. the one immediately preceding the expedition's outward voyage, no long-standing residual infestation was found. VF Tribolium castaneum, Necrobia rufipes, and Ephestia cautella were found on and about dunnage from the cargo discharged at Avonmouth. Recommendation was that a thorough cleaning of food residues should be carried out, followed by routine BHC (Lindane) smoke treatment. These were carried out in Liverpool. General remarks were that the general residual infestation on discharge of cargo would be very light, though a moderate one of Dermestes ater, Necrobia rufipes and Ephestia cautella could be expected in the cargo space of No. 3 Shelter Deck,

forward end, where the Copra had been stored. Details of the loading plan for voyage 42 are given in Appendix II, together with a more detailed history of cargo carried in hold 2A from voyages 36 to 42 inclusive.

V. WORK DONE ON THE OUTWARD VOYAGE

(a) Route of Voyage. The work was carried out on Elder Dempster Lines' M.V. SANGARA sailing from Liverpool on July 17th. 1958 for Takoradi, Ghana, and calling at Las Palmas, Canary Isles. On the return journey, M.V. SANGARA sailed from Takoradi on Sept. 15th. 1958, for Liverpool, calling at Freetown, Sierra Leone, Bathurst, Gambia, Dakar, Senegal, and Avonmouth, England.

The outward-bound cargo was of a general nature, consisting of currency, machinery and cars, etc. The homeward-bound cargo was of timber, rubber, copper and 700 tons of Groundnut Cake, loaded at Dakar.

M.V.SANGARA is an ocean-going cargo-passenger ship of 4,189 tons net.

(b) Residual infestations. Residual infestations were studied by scraping residues of previous cargoes from the floor of the hold and counting the number of insects present. The work was confined to the shelter deck of hold No. 2A.

Residue was scraped off the floor of the hold, from a length of one yard, for as far as the residue extended into the hold from the wall; as a rule, the maximum was 1 foot. The residue was not thicker than one inch. Ten samples were collected in Polythene bags from the edge of the hold, and three scrapes along the edge of the hatch board were also carried out. There was very little residue around or on the hatch boards in the hold centre; this would be expected, as these boards are removed every time the lower holds are loaded or unloaded; thus there is very little food available for

beetles here. Also, the light coming through the top hatch boards during loading and unloading, would drive the beetles towards the sides and fore and aft of the hold; therefore, an estimation of the total residual infestation by area of ceiling, would in this case be erroneous.

Results from these scrapes are shown in Table 1. Appendix IV. The location of the scrapes is shown in Fig. 2,

From Table 1, the percentages of species have been worked out, and are as follows:-

Tribolium castaneum 95%
Typhaea stercorea 0.3%
Cyclorraphan larvae & puparia 2.2%
Alphitobius diaperinus.....1.4%
Necrobia rufipes.....0.5%
Ahasverus advena.....0.3%
Periplaneta americana.....0.1%

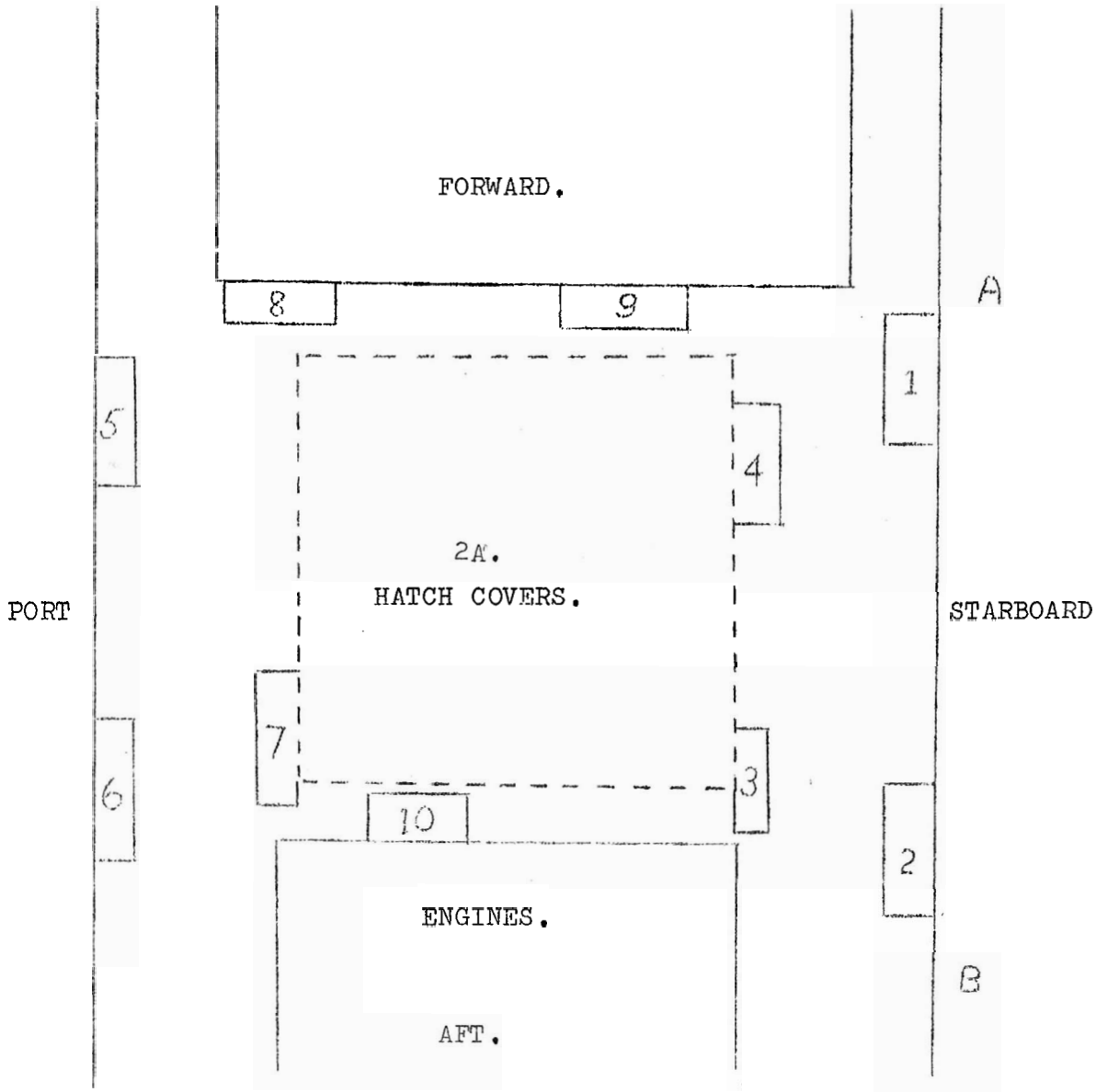
Live specimens were separated from the rest; only one species was represented in this sample:-

% Tribolium castaneum alive = 0.25%
% " " dead = 99.7%

All other stored products pests were dead: the dead beetles probably belonged to several different generations.

There is here an example of selection to some extent of T. castaneum in favour of other species, by its resistance to BHC. This is probably due to the very resistant larval stage of this species.

Apart from recognised pests, the percentage of Cyclorraphan larvae alive was 100%. These probably survived smoking as eggs or larvae, (probably as the latter, as they were fully grown and commencing pupation). Several adults were reared out, and found to be species of Muscidae.



PLAN OF HOLD NUMBER 2A TO SHOW LOCATION OF SCRAPES.

FIG. 2.

Diagram of forward end of Upper Tween Deck 3 to show location of scrapes.

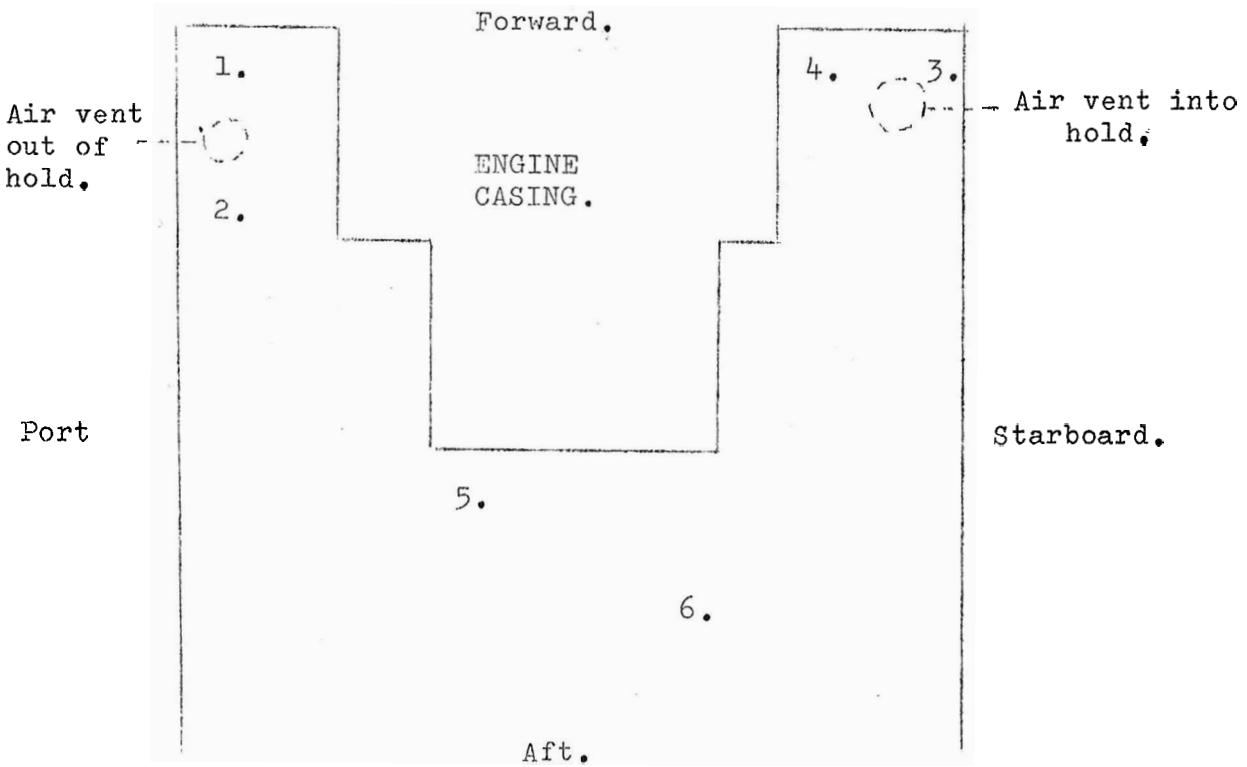


FIG. 3.

The percentage of beetles on the starboard side was 93%. On the starboard side, 2 yards of scraped residue contained 808 beetles. Therefore, the length of wall on the starboard side from A to B on Fig 2, probably contained somewhere in the region of 1600 beetles, over 99% of which were dead. The fact that most of the beetles were present at the side of the hold, rather than towards the centre, is explicable, as mentioned above, in terms of there being residue at the sides, in the corners; and also that these corners are darkest - a favourable condition for the beetles.

Similar scrapes were made on 25/7/58 on the starboard side of 2A Shelter Deck. The percentages were as follows:-

Tribolium castaneum.....	94%
Alphitobius diaperinus.....	2%
Dermaptera.....	1%
Carpophilus dimidiatus.....	1%
Typhaea stercorea.....	1%
Ahasverus advena.....	1%

Total percentage of beetles dead = 100%
" " " " living = 0%

These percentages are very similar to the ones found on 19/7/58 above. Again, a scrape of sawdust in the centre of 2A produced no beetles at all.

Similar scrapes were carried out in Upper Tween Deck 3 on 21/7/58. The results of 6 scrapes are tabulated in Table 2, Appendix IV. The location of the scrapes is shown in Fig. 3.

The percentage of each species, living and dead in each of samples 1 and 2 was as follows:-

Species.	Sample 1		Sample 2	
	Living	Dead	Living	Dead
Necrobia rufipes	5.32	94.68	1.05	98.95
Alphitobius diaperinus	-	-	0	100
Tribolium castaneum	34	66	0.475	99.525
Oryzaephilus mercator	3.5	96.5	0	100
Ahasverus advena	1.32	98.68	0	100
Ephestia cautella	-	-	0	100
Dermestes ater (l)	1.18	98.82	-	-
" " (a)	100	0	0	100
Carpophilus dimidiatus	0	100	0	100
Dermaptera	0	100	0	100

The mean percentages of each species in hold 3 were as below:-

Necrobia rufipes..... 7.3%
Alphitobius diaperinus..... 0.0725%
Tribolium castaneum.....23%
Oryzaephilus mercator.....53%
Ahasverus advena.....14.6%
Ephestia cautella..... 0.453%
Dermestes ater (l)..... 0.375%
Dermestes ater (a)..... 0.081%
Carpophilus dimidiatus..... 0.509%
Dermaptera..... 0.76%

Total percentage of pests living.

Sample site	1	2	3	4	5	6
	8.2	0.392	0	50	14	0

Total percentage of pests dead.

Sample site	1	2	3	4	5	6
	91.8	99.608	100	50	86	100

Total percentage of pests living (average over hold)

$$= \frac{\text{Total living}}{\text{Total living \& total dead}} \times 100$$

$$= \frac{380}{5517} = 6.9\%$$

This value is high because of the large numbers of beetles in the corner, which was unrepresentative of the hold as a whole. As the amount of residue in samples 1 and 2 was too great to be sorted through by hand, sample 1 was divided into 15' 2"x1" specimen tubes and one of these examined with a binocular microscope for insects. The total was multiplied by 15. Similarly, sample 2 was divided into 4.

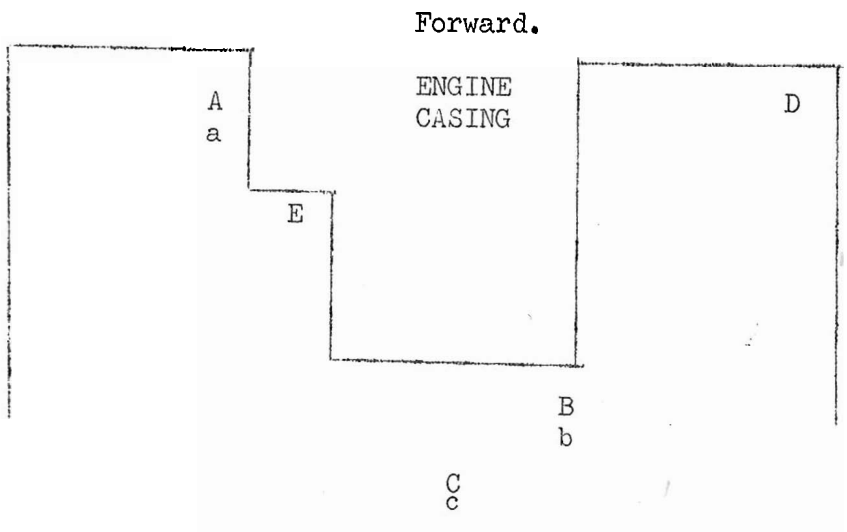
(c) Experiments on release and recapture of marked beetles.

Marking Experiment in Hold 3, 24/7/58.

The object of the experiment was to trap beetles in empty tins containing traces of food residue, laid in the hold, the beetles having been previously marked and released.

The experiment was set up as shown in the diagram below:-

FIG. 5



KEY

A,B,C were empty tins with beetles released nearby. These empty food tins were placed on their sides to allow easy access to the beetles. D was a half coconut shell, with some mould developing. E was another empty tin.

Released: 10 marked T.castaneum at 'a' near tin 'A'.
10 " " " 'b' " " 'B'.
10 " " " 'c' " " 'C'.
2 " N.rufipes " 'a' " " 'A'.

Recaptures: 25/7/58. No marked beetles.

A - 1 Dermestes ater.
B - 1 T.castaneum. 1 Oryzaephilus mercator.
C - 1 " 1 "
D - -
E - 1 Oryzaephilus mercator.

Re-examination: 26/7/58. No marked beetles.

	D.ater.	T.castaneum.	O.mercator.	Temp. °F.
A	1	1	7	101.0
B	-	1	3	83.5
C	-	1	1	85.5
D	-		-	85.5
E	-	-	1	104.0

Although no marked beetles were recaptured, the experiment was not a total failure, as it showed that cross-infestation could occur within 24 hours. The infestation rate here was low, however, as there was only one T.castaneum at A, a point near to a fair residual infestation of this species.

(d) Physical Observations. Temperature measurements were made by the use of thermocouples installed at various points in Hold 2A Shelter Deck; temperature and humidity recordings were obtained from Casella thermohygrographs in holds 2,3 & 4. The thermocouple potentials were measured either by a Sunvic R.S.P. 2

self-balancing potentiometer or a Doran mini potentiometer. The positions of the thermocouples were as follows:-

Thermocouple 1 ..... On wall in air 3'9" from starboard side of engine covering.
Thermocouple 2 ..... In rolls of felt.
Thermocouple 3 ..... On top of drum.
Thermocouple 4 ..... Along starboard side of engine covering.
(Thermocouples 1 - 4 were linked together).
Thermocouple 5 ..... Starboard side - spar ceiling.
Thermocouple 6 ..... Starboard side - spar ceiling.
(Thermocouples 5 & 6 were linked together).
Thermocouple 7 ..... Under crew's deck - starboard side.
Thermocouple 8 ..... 17 rungs down from top of ladder.
Thermocouple 9 ..... 10 rungs down ladder.
(Thermocouples 8 & 9 were linked together).
Thermocouple 10 ..... Under edge of hatch boards to L.T.D.

Readings for these positions were taken on 21/7/58. The hold was opened at 9.0 a.m. and readings taken with the Doran Mini thermocouple potentiometer at 10 a.m. A further set of readings were taken at 11.0 a.m. with the Sunvic R.S.P.2 self-balancing potentiometer. Thus the hold had been open for about two hours when the readings were taken with the latter instrument, and the air temperature in the empty hold had time to drop lower than when the Doran readings were taken. (The point for thermocouple 4 was next to the engine casing, and therefore did not drop so low when the hatch cover was opened). Results (Table 5, Appendix IV) are graphed, Fig. 7, Appendix VIII. Similar readings were taken on 26/7/58 and 28/7/58. The results are tabulated (Table 6, Appendix IV) and graphed, Fig. 8, Appendix VIII.

The graphs show that the temperatures of surfaces at each point in the hold retain a more or less constant relationship to the other points in the hold, though all may increase or decrease as a whole.

Thermograph records - Outward voyage.

A Casella thermohygrograph was installed amidships next to the engine casing in Hold 2A on 17/7/58. After allowing the instrument two days in which to settle down, to the movements of the ship and to the conditions in the hold, it was standardised as described above. The results from this instrument are shown corrected in Fig. 9, Appendix VIII.

Another Casella thermohygrograph was set up in Upper Tween Deck 4, 15'6" from the forward and standing on boxes of coins amidships. The results from this instrument are shown corrected in Fig. 10, Appendix VIII.

A further Casella thermohygrograph was set up in Upper Tween Deck 3, also in the centre of the hold, on the hatch boards over the Lower Tween Deck, and 21' aft of the engine casing, the corrected results of which are shown in Fig.11, Appendix VIII.

Matters relating to the calibration of the instruments and practical difficulties in use are dealt with in Appendix III.

Thermocouple readings in 2A Shelter Deck. Outward Voyage.

The Sunvic R.S.P.2 self-balancing potentiometer had to be calibrated against known reference temperatures for each separate wire length (for reasons described below). The calibration was carried out with hot and cold water in thermos flasks and with air temperatures. Wires of equal length were linked together and standardised as a unit calibration data for thermocouples 1 - 10 in Table 3, Appendix IV and Fig. 14, Appendix VIII.

Temperatures in the holds fluctuated over a range of 66 - 93, being highest just before dusk. Mean maxima and minima were about 85 and 75 respectively. Relative humidities fluctuated over a range 38 - 79% being most extreme in hold 4. Mean maxima were about 65% and minima 57% in holds 2A and 3, but much lower (43%) in hold 4.

Whereas the temperature range is very suitable for development of storage pests the humidity conditions tended to be on the low side.

VI. WORK DONE ON THE HOMEWARD VOYAGE.

(a) Physical measurements. The work of the homeward voyage was carried out in the Shelter Deck of Hold No. 1. This contained sacks of Groundnut Cake, which were loaded at Dakar. 8 thermocouples were installed, two of which were broken during loading, in the positions given in Table 7, Appendix IV. The lengths of wire used were 15, 25, 35 feet etc. - chosen to give accurate readings as described later. (Appendix III).

The readings from these thermocouples are given in Table 8, Appendix IV, and are graphed in Figs. 16 and 17, Appendix VIII.

A Casella thermohygrograph was installed in Shelter Deck No. 1 just beneath the hatch boards. The results from the instrument are given in Fig. 12, Appendix VIII. The shaky lines were caused by force 8 gales in Biscay, the latter causing vibration of the marking needles. Ventilation of the hatch at 8.30 a.m. on 29/9/58, by the removal of the side hatch boards on Hold 1, resulted in the temperature continuing to rise steadily; this can be seen from Fig. 12. After a few hours, however, the temperature steadied, and then began to fall gradually.

As the Casella in the hold was measuring air temperature, it was decided to compare the air temperature fluctuations in the tally office aft of the main deck, with those in the hold. This was done with the aid of another Casella set up in the former; this instrument gave an identical record to that of the one in the hold, showing that the air temperature in the hold must depend upon the heat of the sun for fluctuations, as in the tally office.

Spear thermocouple readings in sacks of Groundnut Cake.

A spear thermocouple was used to measure the variation in temperature within sacks of Groundnut Cake at various depths

of sacks. The following readings were taken on 27/9/58.

No. of sacks down from top of hold.	Deflection on Sunvic.	Temp. in °F.
2	49.5	94.0
3	49	93.6
4	50	94.4
5	44	89.0
6	45	90.0
7	47	91.8
8	48.5	93.1
9	51	95.3
10	52	96.1
11	50.5	94.9

(b) Biological observations.

Snaking of Groundnut Cake sack, 26/9/58.

2 sacks of Groundnut Cake from the top of hold 1 were snaked out on to the deck on 26/9/58, and the following species collected:-

Sack 1 ..... 1 live Tribolium castaneum.

Sack 2 ..... 5 live Tribolium castaneum.

1 dead " "

It was not possible to carry out further scrapes on the homeward journey, because the holds were all full. Hold No. 1 where the experimental work was carried out, was full to the hatch boards with Groundnut Cake.

GENERAL RESULTS

1. There is a gradual rise in both temperature and relative humidity as Latitude decreases and the equator is approached. (Fig. 13, Appendix VIII).

2. The maximum temperature in the hold occurs at about 5.0 p.m. after the heat of the sun all day (G.M.T.); the minimum occurs at 7.0 a.m. just before sunrise. A daily fluctuation of 20°F was not uncommon.

3. The daily temperature maxima follow the sea temperature fairly closely, the sea temperature increasing towards the tropics.

4. The homeward temperature at each Latitude was higher than the outward temperature; and the homeward relative humidity was lower than the outward relative humidity. This is possibly caused by heating and moisture absorption by the groundnut cake (700 tons of which was loaded at Dakar on the way home).

5. Condensation occurs when the temperature is low, and the relative humidity high - i.e. from about 5.0 a.m. to 9.0 a.m. Some depreciation of cargo may result from condensation.

6. Hatch Ventilation. This was found to have an immediate effect at the top of the shelter deck of an increase in temperature and a drop in relative humidity, when the hold was full. The temperature later steadies, and then falls gradually. If the hold was empty, a freer circulation of air occurred and the overall hold temperature dropped.

7. The temperature of each point in an empty hold retained a constant relative relationship to other points in the hold, though all could increase or decrease as a whole.

8. In residue scrapes, high percentages of Tribolium castaneum, both living and dead, were found.

9. Although marking experiments were unsuccessful, it was shown that beetles could locate and move into empty food cans in the holds in one day.

10. Thermocouple wire anomalies were discovered; it was found that a sine wave relationship held between galvanometer deflections and wire length; thus maximal temperature readings were found with lengths of 10,20,30, feet of thermocouple wire, whilst lengths of 5,15,25 feet gave minimal readings.

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APPENDIX I.

PREVIOUS HISTORY OF M.V.SANGARA

Voyage 38. (From West Africa). 15/5/56.

Palm Kernels.

Tribolium castaneum	few	live	adults.	
Necrobia rufipes	"	"	"	
Necrobia ruficollis	"	"	"	
Dermestes maculatus	"	"	"	& few live larvae.
Ephestia cautella	"	"	"	

Voyage 39. 22/2/57

Inspection of goods on Quay. No insects.

Kola nuts, Calabar beans, Coffee beans.

Voyage 40. 4/9/57.

	Cottonseed.	Gnt.Cake.	Palm Kernels
Tribolium castaneum	F/MN.	F/MN.	VF/F.
Oryzaephilus mercator.....	VF.	VF.	-
Necrobia rufipes.....	VF.	VF.	F.
Ephestia cautella.....	F(p); VF(a).	VF(p).	VF(p).

Voyage 41. 31/3/58.

Groundnuts.

Tribolium castaneum (a).....	MN/FN.
Tribolium confusum(a).....	VF.
Oryzaephilus mercator (a).....	VF.
Ahasverus advena (a).....	VF.
Necrobia rufipes (a).....	VF.
Ephestia cautella (a) (l).....	F.

[illegible] residues.

Voyage 42. 4/7/58.

Inspected: Cottonseed, Peas, Copra, Coconuts.

Not inspected: Timber and cargo discharged in Avonmouth.

Dermestes ater (a) (l)	in	Copra	.....FN.
Necrobia rufipes (a).....	"	"	.....MN.
Carpophilus obsoletus (a).....	"	"	.....MN.
Ahasverus advena (a).....	"	"	.....F-MN.
Tribolium castaneum (a).....	"	"	.....F.
Oryzaephilus mercator(a).....	"	"	.....VF-F.
Typhaea stercorea (a).....	"	"	.....VF.
Ephestia cautella (a).....	"	"	.....MN.

APPENDIX II.

PREVIOUS LOADING PLANS

Loading plan for voyage 42. 10/6/58.

Hold 1.	2.	2A.	3.	4.
Shelter Deck.				
Cottonseed	Bales Rubber.	Bags Peas.	Copra	Cottonseed
Palm Kernel Meal.		Bags Cotton-seed.	Groundnut Cake.	
Tween Deck.				
Cotton Lintels		Bags Ground-nut Cake.		Bales of Cotton Lintels.
Bags Copal.				

NB. Only food cargoes are included in this plan (i.e. infestable cargoes).

Voyage 36. October 1956.
Bags of crushed bones in 2A. Shelter Deck.

Voyage 37. February 1957.
Cocoa in 2A Shelter Deck.

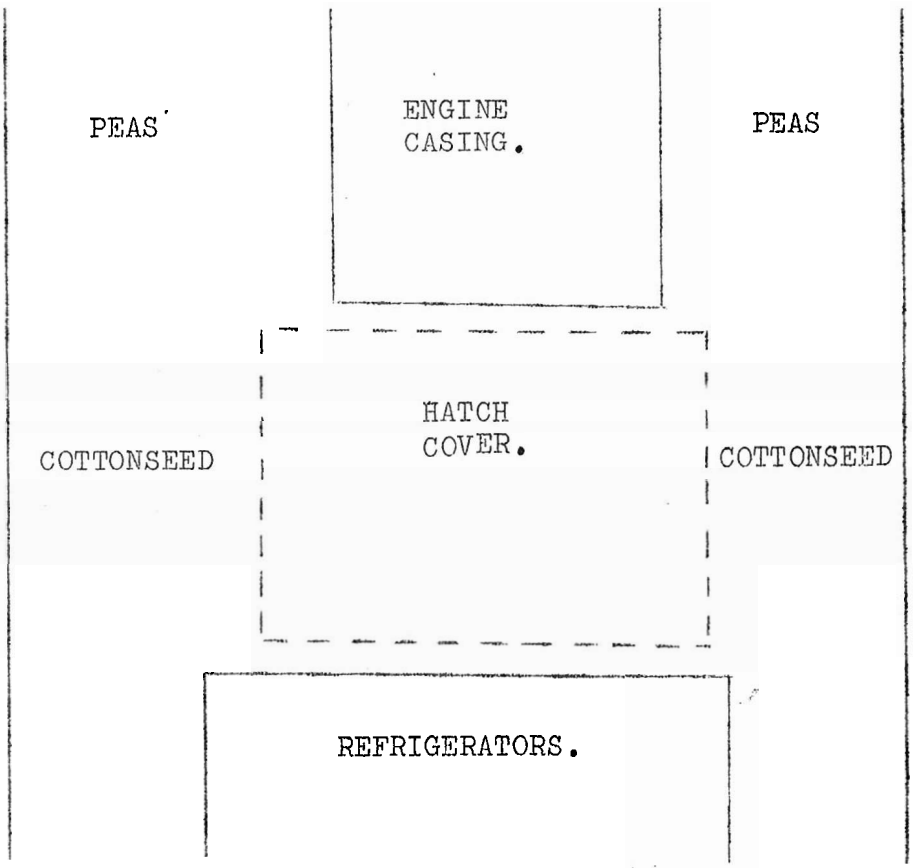
Voyage 38. May 1957.
Cocoa in 2A Shelter Deck.

Voyage 39. August 1957.
Some skins in 2A Shelter Deck.

Voyage 40. November 1957
Groundnut Cake in 2A Shelter Deck.

Voyage 41. March 1958.
Cottonseed in 2A Shelter Deck.

Voyage 42. June 1958.



DIAG. of NO.2A SHELTER DECK. VOYAGE 42.

FIG. 1.

APPENDIX III

NOTES ON APPARATUS.

Sunvic R.S.P.2 self-balancing potentiometer. As this instrument runs off an A.C. electrical supply, the ship's D.C. 210 volt supply was transformed into 210 volt A.C., 50 cycles, by means of a rotary converter. An ice-water $0^{\circ}C$ junction was used as a standard reference point. Fig. 4. The recorder then measured temperature in units which had to be converted into degrees Farenheit. For this a conversion graph, plotted from a series of readings at known temperatures, had to be constructed. This was done by taking readings with a copper-constantan thermocouple immersed in a thermos flask with warm water and two thermometers. The calibration data is given in Tables 3 and 9, Appendix IV and Figs. 14 and 15, Appendix VIII.

As the calibration was found to vary with the length of thermocouple wire employed, separate correction graphs were plotted for each wire. (See below under Doran Mini thermocouple potentiometer results of experiments using different wire lengths.)

Doran Mini thermocouple potentiometer. This instrument was used on the outward journey to take readings from thermocouple wires in No. 2A Shelter Deck. This instrument gave satisfactory readings even in a moderate sea; it was found that the galvanometer needle could be steadied from the ship's movements by setting the instrument along the axis about which the ship was moving, e.g. set the instrument along the pitch axis when the ship is pitching and along the roll axis during rolling. If both motions occur at the same time, and the observer is still in a condition to take readings, it was found that this is possible by setting the galvanometer at 45° to both axes. Readings taken under these conditions were found to agree with those from the Sunvic R.S.P.2.

It was found that the deflection varied with the length of wire employed in each reading. A constant temperature junction was therefore set up in a thermos flask with warm water, and the effect of varying lengths of wire was investigated.

The results, Table 4, Appendix IV are plotted in Fig. 6, Appendix VIII. It was found that maximal readings occurred with wire lengths of 10,20,30 feet etc. and minimal readings occurred at lengths of 5,15,25 feet etc. Thus, in order to obtain accurate readings odd lengths were used on the way home for readings in Shelter Deck No. 1 using the Sunvic R.S.P.2.

Casella thermohygrographs. These instruments worked successfully even in a very rough sea, giving complete temperature and relative humidity graphs, running for a week on one winding. Purple ink was used in preference to green, as recommended by Matthews (1958). As the ink levers could not be set exactly in position on the graph, at the temperature and relative humidity prevailing at the time of setting, the graphs had to be corrected later by means of readings taken at set times with several thermometers and Cobalt thiocyanate papers at the position where the Casella had been set up. The Cobalt thiocyanate papers were read with a Lovibond Comparator; corrections were later applied to the graphs.

Minor fluctuations of both temperature and relative humidity were recorded by these instruments. Vibrations caused by gales and very rough seas were registered on graphs of the homeward voyage.

DIAGRAM SHOWING CONNECTIONS FROM MILLIVOLTMETER TO ICE & WATER REFERENCE JUNCTION.

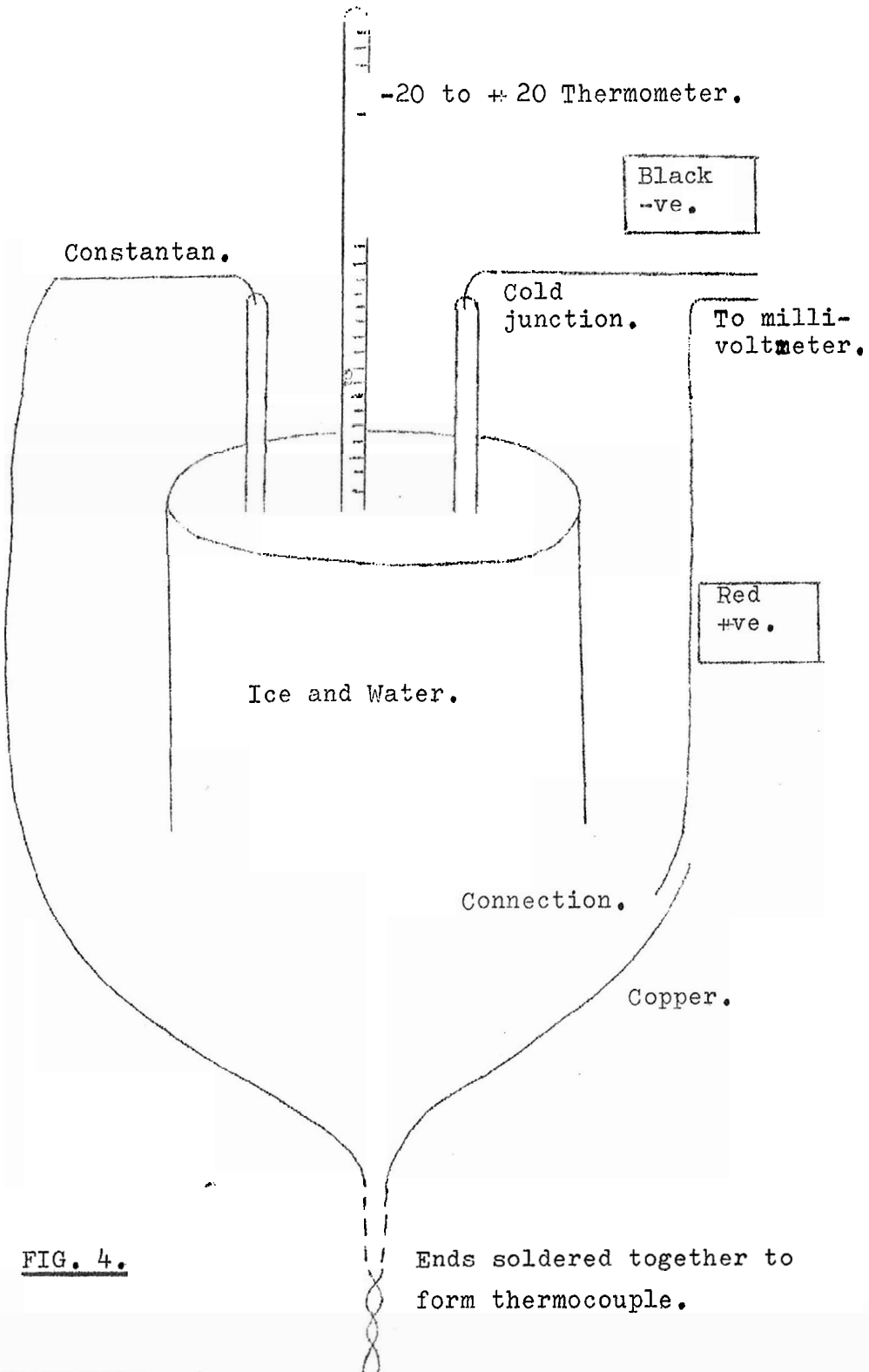


FIG. 4.

APPENDIX IV

TABLE 1.

	Sample.										
Species.	1	2	3	4	5	6	7	8	9	10	Total.
Tribolium castaneum.	285	498	6	1	3	20	-	-	12	1	826
Typhaea stercorea.	3	-	-	-	-	-	-	-	-	-	3
Cyclorrhaphan (larvae & puparia).	5	-	-	-	-	-	-	-	-	14	19
Alphitobius diaperinus.	2	8	-	-	-	2	-	-	-	-	12
Uroobia rufipes.	1	3	-	-	-	1	-	-	-	-	5
Ahasverus advena.	-	3	-	-	-	-	-	-	-	-	3
Periplaneta americana.	-	-	-	-	-	1	-	-	-	-	1
Totals.	296	512	6	1	3	24	0	0	12	15	869.

APPENDIX IV

TABLE 1.

	Sample.										
Species.	1	2	3	4	5	6	7	8	9	10	Total.
Tribolium castaneum.	285	498	6	1	3	20	-	-	12	1	826
Thaea stercorea.	3	-	-	-	-	-	-	-	-	-	3
Chlorrhaphan larvae & puparia).	5	-	-	-	-	-	-	-	-	14	19
Ephitobius diaperinus.	2	8	-	-	-	2	-	-	-	-	12
Corobia rufipes.	1	3	-	-	-	1	-	-	-	-	5
Casverus advena.	-	3	-	-	-	-	-	-	-	-	3
Periplaneta americana.	-	-	-	-	-	1	-	-	-	-	1
Totals.	296	512	6	1	3	24	0	0	12	15	869.

TABLE 2.

Species.	Sample:- 1. 1/15 Full D	1. 1/15 Full L	1. 1/4 Full D	2. D	2. L	2. D	3. L	3. D	4. L	4. D	5. L	5. D	6. L	6. D	Totals. L & D
Necrobia rufipes.	13	11	195	47	2	188	-	6	-	1	-	1	-	-	404
Alphitobius diaperinus.	-	-	-	1	-	4	-	-	-	-	-	-	-	-	4
Tribolium castaneum.	39	244	585	105	2	420	-	4	-	1	1	5	-	2	1264
Oryzaephilus maecator.	183	100	2745	17	-	68	-	3	2	-	-	-	-	-	**2918**
Ahasverus advena.	35	7	525	68	-	272	-	1	-	-	-	-	-	-	805
Ephestia cautella.	-	-	-	6	-	24	-	1	-	-	-	-	-	-	25
Dermestes ater (1).	1	2	15	-	-	-	-	-	-	-	-	-	-	-	17
" " (a).	-	1	-	1	-	4	-	4	-	-	-	-	-	1	10
Carpophilus dimidiatus.	1	-	15	3	-	12	-	-	-	-	-	-	-	1	28
Dermaptera.	1	-	15	6	-	24	-	3	-	-	-	-	-	-	42
Totals.	273	365	4095	254	4	1016	-	22	2	2	1	6	0	4	
		4460			1020		22		4		7		4		5517.

N.B. D = Dead & L = Living.

TABLE 3.

Data for calibration of Sunvic R.S.P.2 millivoltmeter 19/7/58.

Thermo-couple No.	T_1 °F	T_1 °C	T_o °C	Range (T_1-T_o) °C	Deflection (divisions).
1-4	CW. -	11.9	0.6	11.3	27.5
	A. 79.5	26.35	0.6	25.75	37.6
	WW.95.0	35.0	0.6	34.4	55.0
5-6	CW. -	11.9	0.6	11.3	30.0
	A. 76.0	24.4	0.6	23.8	30.5
	WW. -	35.0	0.6	34.4	58.0
7	CW. -	11.9	0.6	11.3	29.5
	A. 72.0	22.2	0.6	21.6	37.4
	WW. -	35.0	0.6	34.4	56.0
8-9	CW. -	11.9	0.6	11.3	27.0
	A. 72.0	22.2	0.6	21.6	36.4
	WW. -	35.0	0.6	34.4	58.0
10	-	10.8	0.9	9.9	17.2
	-	12.4	0.9	11.5	19.8
	-	15.3	0.9	14.4	24.1
	-	18.5	0.9	17.6	29.0
	70.0	21.1	1.0	20.1	35.0
	72.0	22.2	0.9	21.3	35.8
	77.0	25.0	1.0	24.0	42.4
	89.0	31.7	1.0	30.7	54.5
	93.0	33.9	1.0	32.9	58.0
	98.0	36.7	1.0	35.7	61.2
	101.0	42.2	1.0	41.2	69.0

Abbreviations.

CW. = cold water

A. = air.

WW. = warm water

T_1 = hot junction.

T_o = cold junction.

The air temperatures were found to be inaccurate when graphs of deflection/T^o range were plotted, and so just the hot and cold readings were used as standardisation points.

Investigation of variation in deflection with Doran Mini Thermocouple Potentiometer with varying length of thermocouple wire, using a constant temperature junction.

Temp. of constant ref. junction of hot water in thermos. °F.	T°C ref. junction on Doran.	Deflection.	T° Range. from tables °C.	Temp. °C.	Temp. °F.	Length of Thermocouple wire. (Feet).
94	27	0.285	7.4	34.4	93.9	5
94	27	0.327	8.4	35.44	95.8	10
94	27	0.29	7.5	34.5	94.2	15
94	27	0.31	8.0	35.0	95.0	20
94	27	0.324	8.38	35.38	95.7	9
94	27	0.31	8.0	35.0	95.0	8
94	27	0.305	7.9	34.9	94.9	18
94	27	0.301	7.82	34.82	94.7	13
94	27	0.301	7.82	34.82	94.7	2
94	27	0.297	7.71	34.71	94.5	1

TABLE 5.

Thermocouple readings for Shelter Deck 2A, 21/7/58.

Doran, 10.00 a.m.

rmo- .ple io.	Deflection.	Temp. from tables(graph). °C	Temp. of reference junction °C.	Final Temp. °C.
1	0.160	4.2	21.4	25.6
2	0.023	0.6	21.4	22.0
3	0.080	2.1	23.0	25.1
4	0.128	3.3	23.0	26.3
5	0.010	0.3	23.0	23.3
6	-0.098	-2.5	24.0	21.5
7	-0.074	-1.9	24.0	22.1
8	-0.098	-2.5	24.0	21.5
9	-0.120	-3.2	24.0	20.8
10	-0.040	-1.1	24.0	22.9

Sunvic, 11.00 a.m.

1	41.0	22.75	0.55	23.3
2	36.4	19.00	0.55	19.55
3	40.0	22.00	0.55	22.55
4	43.6	25.5	0.55	25.8
5	37.8	18.0	0.55	18.55
6	35.6	16.0	0.55	16.55
7	37.6	19.25	0.55	19.8
8	38.0	19.5	0.55	20.05
9	37.0	18.5	0.55	19.05
10	37.4	18.75	0.55	19.3

TABLE 6.

Doran Mini Thermocouple readings in 2A Shelter Deck.

10.0 a.m. - 10.30 a.m. July 26th. 1958.

Thermo-couple No.	T°C ref. junction.	Deflection mv.	T° range from tables.	Final temp. °C.
1.	27.0	0.205	5.35	32.35
2.	27.0	0.035	0.95	27.95
3.	27.4	0.147	3.8	31.2
4.	28.0	0.258	6.6	34.6
5.	28.0	0.020	0.5	28.5
6.	28.2	-0.067	-1.7	26.5
7.	28.7	0.020	0.5	29.2
8.	28.9	0.079	2.1	31.0
9.	28.9	0.059	1.6	30.5
10.	29.0	-0.078	-2.1	26.9
	10.0 a.m. - 10.30 a.m. July 28th. 1958.			
1.	26.0	0.177	4.6	30.6
2.	27.0	0.047	1.2	28.2
3.	27.0	0.123	3.2	30.2
4.	27.0	0.31	8.0	35.0
5.	28.0	-0.04	-1.1	26.9
6.	28.0	-0.135	-3.55	24.45
7.	28.0	0.005	0.15	28.15
8.	28.0	0.05	1.3	29.3
9.	28.0	0.03	0.8	28.8
10.	28.0	-0.1	-2.6	25.4

TABLE 7.

Position of Thermocouples in Hold 1. Homeward voyage.

Thermo-couple No.	Distance from Forward end of hatch.	Distance from starboard edge of hatch.	Depth.	Position.
1.	1'0"	8'0"	6'0"	Between bags of Groundnut Cake.
3.	2'0"	-	4'0"	In timber under edge of hatch.
4.	5'6"	5'6"	10'0"	Between bags of Groundnut Cake.
6.	2'0"	9'0"	3'0"	Under hatch edge.
7.	1'6"	3'0"	3'0"	Under hatch edge.
8.	8'0"	5'6"	7'3"	Between bags of Groundnut Cake.

(Thermocouples 2 & 5 failed to give a reading as they were broken during loading).

TABLE 8.

Thermocouple readings from Hold 1 - Homeward voyage.

Deflection.		Thermocouple No.	Temp. from graph.
26/9/58.	10.0 a.m.		
54.5		1	98.5
48.5		3	93.0
49		4	93.5
43.5		6	88.5
56		7	99.6
59		8	102.2
	5.0 p.m.		
59		1	102.2
45.5		3	90.4
52.5		4	96.6
50		6	94.4
58.5		7	101.8
61		8	104.0
27/9/58.	9.30 a.m.		
57.5		1	101.0
46		3	90.8
48		4	92.6
46		6	90.8
56		7	99.6
59.5		8	102.6
	5.0 p.m.		
55		1	98.8
44		3	89.0
51		4	95.2
46		6	90.8
50.5		7	94.8
59.5		8	102.6

TABLE 8. (Cont.)

Deflection.		Thermocouple No.	Temp. from graph.
28/9/58.	10.0 a.m.		
56.5		1	100.2
46.5		3	91.3
55.5		4	99.3
48.5		6	93.0
50		7	94.4
60		8	103
	5.00 p.m.		
60		1	103.0
49.5		3	94.0
57		4	100.6
52		6	96.1
56		7	99.6
66		8	108.5
29/9/58.	10.0 a.m. (Taken after hatch ventilated for 1 hour).		
51		1	95.4
53		3	97
53		4	97
48		6	92.6
52.5		7	96.5
63		8	105.7
	5.0 p.m.		
45		1	90.0
44		3	89.0
43		4	88.2
39		6	84.6
45		7	90.0
56		8	99.6

TABLE 8. (Cont.)

30/9/58.	10.0 a.m.	
Deflection.	Thermocouple No.	Temp. from graph
46	1	90.8
34	3	80.3
43.5	4	88.6
53.5	6	97.5
45	7	90.0
56	8	99.6
(No reading 5.0 p.m.; too rough to open hatch).		
1/10/58.	10.0 a.m.	
47	1	91.7
32	3	78.5
47	4	91.7
57	6	100.6
50	7	94.4
59	8	102.2

TABLE 9.

Standardisation of Sunvic R.S.P.2. Homeward voyage. 25/9/58.

Ref. junction (ice and water = 0°C. = 32°F.)

Temperature °F.	Deflection.
100	54
95	48
87	41
84	40
82	38
80	35
79	34
78	33.5
67	19
68	20
69	21
72	23
74	26
76	28
77	30
81	36
83	38

APPENDIX V

WEATHER RECORDS.

(Supplied by Chief Officer from ship's log.)

OUTWARD BOUND

18/7/58. Cloudy, overcast and clear. Moderate Southerly breeze, sea and swell.

19/7/58. Moderate Southerly breeze and sea, low swell, overcast and hazy.

20/7/58. Light WNW breeze, slight sea, low swell, fine and clear.

21/7/58. Gentle NNW breeze, slight sea, low swell, cloudy, fine and clear.

22/7/58. Moderate NNE breeze and sea, low swell, overcast/cloudy, fine and clear.

23/7/58. Gentle NNE breeze, overcast and clear.

24/7/58. Moderate NNE breeze, slight sea, low swell, overcast and clear.

25/7/58. Fresh Northerly breeze, rough sea, moderate swell, fine and clear.

26/7/58. Light breeze, slight sea, low swell, cloudy and fine.

27/7/58. Gentle breeze. Moderate sea; swell, heavy rain at first.

28/7/58. Light breeze. Slight sea with swell, cloudy, fine and clear.

29/7/58. Light breeze, slight sea, low swell, Cloudy/overcast, clear, with occasional light rain.

30/7/58. Rippled sea, low swell. Cloudy, fine and clear.

31/7/58. Arrived Takoradi.

WEATHER RECORDS

HOMEWARD BOUND.

Dakar.

25/9/58. Rippled sea: low swell. Overcast and clear.

26/9/58. Rippled sea: low swell. Light cloud, fine and clear.

27/9/58. Slight sea, low swell. Light cloud, fine and clear.

28/9/58. Rippled sea, low swell. Cloudy, fine, clear.

29/9/58. Calm sea, low swell, few clouds, fine and clear.

30/9/58. Moderate sea, heavy NW swell, mainly overcast.

1/10/58. Rough sea, heavy swell, mainly overcast.

2/10/58. Very rough sea, heavy swell, shipping water forward and aft; light cloud, fine and clear.

3/10/58. Rough sea, heavy swell, cloudy and fine.

WEATHER RECORDS : OUTWARD BOUND.

Date.	Barometer.	Latitude.	Longitude.	Temp.(Wet).	Temp.(Dry).	Sea Temp.
18/7/58	30.02"	Liverpool	Liverpool	60	62	66
19/7/58	29.89"	45°58'N	8°38'W	62.5	65	67
20/7/58	30.23"	41°31'N	10°26'W	63	70	68
21/7/58	30.16"	37°54'N	12°24'W	65	73	72
22/7/58	30.08"	32°26½'N	13°52'W	73	78	75
23/7/58	30.02"	Las Palmas	Las Palmas	69	71	74
24/7/58	30.08"	24°38'N	16°23'W	69	74	76
25/7/58	29.99"	19°57'N	17°35'W	68	73	78
26/7/58	29.92"	15°15'N	17°39'W	75	82	83
27/7/58	29.94"	10°47'N	16°55'W	72	74	82
28/7/58	30.00"	7° 54'N	14°0'W	71	81	81
29/7/58	29.97"	5° 16'N	9° 48'W	76	81	81

WEATHER RECORDS : HOMEWARD BOUND.

Date.	Barometer.	Latitude.	Longitude.	Temp.(Wet).	Temp. (Dry).
23/9/58	29.92"	14°14'N	17°20'W	81	88
24/9/58		Dakar	Dakar		
25/9/58	29.92"	18°11'N	17°39'W	80	86
26/9/58	29.94"	22°36'N	17°13'W	68	70
27/9/58	30.04"	26°45'N	15°48'W	71	76
28/9/58	30.05"	30°56'N	14°15'W	69	75
29/9/58	30.09"	35°16'N	12°42'W	70	80
30/9/58	29.86"	39°21'N	10°52'W	63	70
1/10/58	29.81"	43°08'N	9°47'W	62	67
2/10/58	29.70"	47°03'N	7°41'W	57	65
3/10/58	29.42"	50°52'N	5°04'W	60	62

NB. All temperatures expressed in degrees Farenheit.
Barometric pressures are in inches of water, corrected to 40 feet above sea level.

APPENDIX VI

List of species found on board M.V.Sangara, July - October,1958.

Coleoptera.

Tribolium castaneum.
Typhaea stercorea.
Alphitobius diaperinus.
Necrobia rufipes.
Ahasverus advena.
Dermestes ater.
Oryzaephilus mercator.
Carpophilus dimidiatus.
Lasioderma serricorne.

Lepidoptera.

Ephestia cautella.

Dictyoptera.

Periplaneta americana.

Dermaptera.

Unidentified sp.

Diptera.

Muscidae.

APPENDIX VII

List of members of Imperial College Natural History Society Biological Expedition to Ghana, 1958.

Botanists.

Mr.K.Loach, B.Sc., A.R.C.S.

Miss J.L.Stevens, B.Sc., A.R.C.S.

Entomologists.

Mr.A.C.Neville, B.Sc., A.R.C.S., F.R.E.S.

Mr.J.C.Taylor, F.R.E.S.

Parasitologists.

Mr.J.D.Jones, B.Sc., A.R.C.S.

Mr. R.F.Sturrock, B.Sc., A.R.C.S. (Leader)

Mr.J.M.Webster, B.Sc., A.R.C.S.

ACKNOWLEDGEMENTS.

To compile a complete list of all the people who have contributed towards this project would be a difficult task. I am particularly grateful to the following for their very great help, without which the investigation would never have been possible.

Mr.G.A.Brett, Infestation Control Div., M.A.F.F., Tolworth.

Mr.J.A.Freeman, " "

Mr.D.Hall, Pest Infestation Lab., D.S.I.R., Slough.

Mr.W.B.Woodward, " "

Mr.T.A.Oxley, " "

Dr.W.F.Jepson, Imperial College Field Station, Silwood.

Mr.J.Siddorn, " "

Mr.M.M.Senior and the staff of Infestation Control Division, M.A.F.F., Liverpool.

Mr.R.Roberts and Infestation Control Division, M.A.F.F., London Office.

The Captain and crew of Elder Dempster Lines'M.V. 'SANGARA'.

The members of Imperial College 1958 Ghana Expedition, a separate list of whom appears in the Appendix.

Mr.D.H.Tod, Elder Dempster Lines Ltd., Liverpool.

Mr.L.R.Chisnell, Passenger Manager, Elder Dempster Agencies Ltd., Takoradi, Ghana.

Mr.J.Rawnsley, Ghana Cocoa Marketing Board.

I am very grateful to the following organisations for financial assistance:-

Imperial College Exploration Board.

Elder Dempster Lines Ltd.

The Cocoa, Chocolate and Confectionery Alliance Ltd.

Unilever Ltd.

Nigerian Produce Marketing Co.Ltd.

Ghana Cocoa Marketing Co.Ltd.
L.Rose & Co.
F.Hills & Sons,

I also wish to thank the following people and organisations for equipment and technical assistance:-

Pest Infestation Laboratory, Dept. of Scientific and Industrial Research.
Ministry of Agriculture, Fisheries and Food, Infestation Control Division.
Professor O.W.Richards, Imperial College, London.
Dept. of Zoology and Applied Entomology, Imperial College.
Mr.E.Hughes, Infestation Control Division, M.A.F.F., Bristol.
Winsor and Newton Ltd.
Vidor Ltd.
Mr.H.Clifford, Pest Infestation Lab., D.S.I.R., Slough.
H.M.Customs Authorities, Liverpool and Bristol.
The Liverpool Warehousing Co.Ltd.
Many Dockers in Liverpool and Avonmouth, Bristol.
Mr.F.W.G.Annas, of Imperial College Exploration Board.
Mr.P.F.Taylor, " "
The General Manager & Harbours Authority, Takoradi,Ghana.
Elder Dempster Agencies Ltd., Takoradi, Ghana.
Produce Inspection Dept., Takoradi, Ghana.

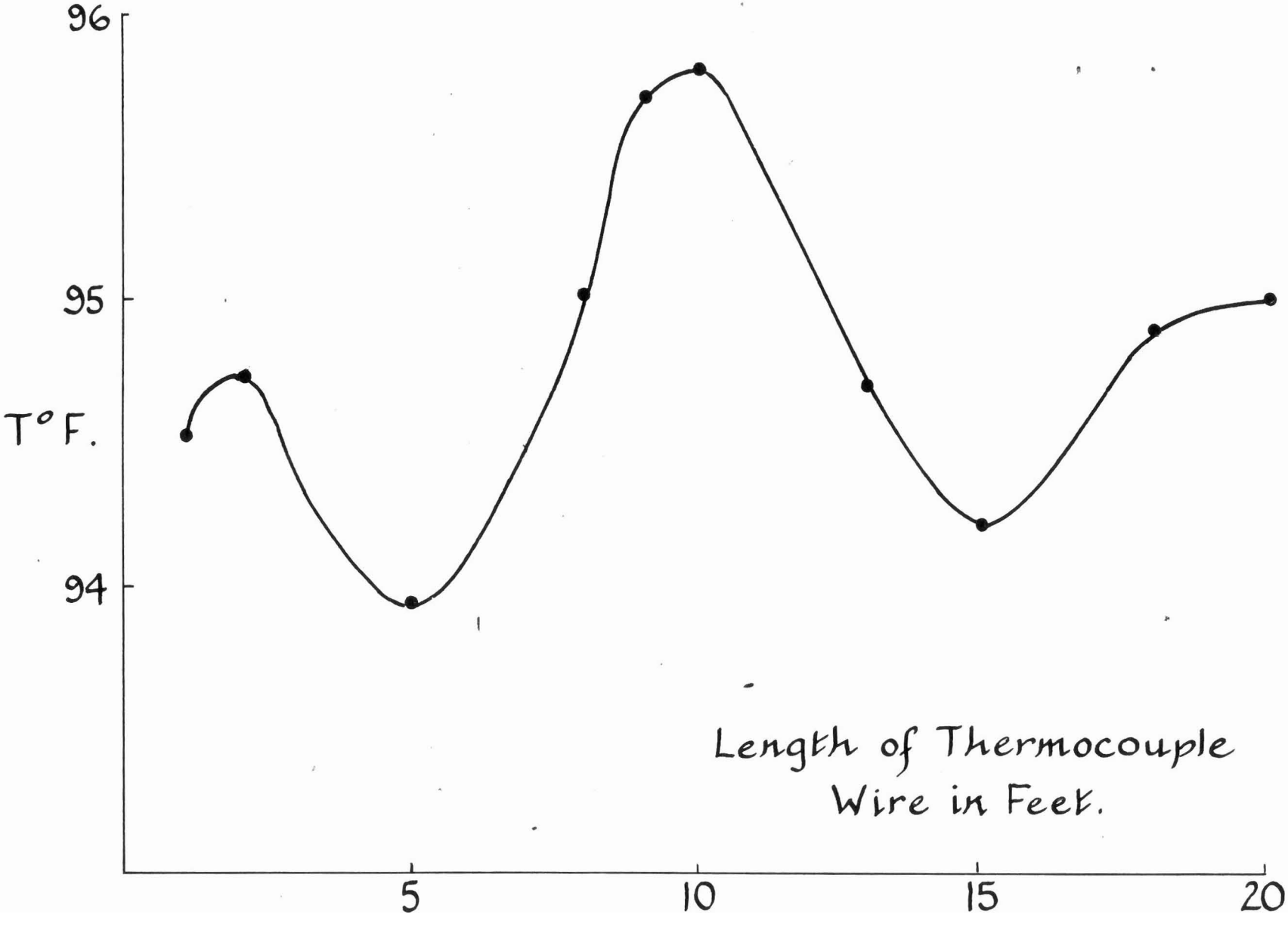


Figure 6

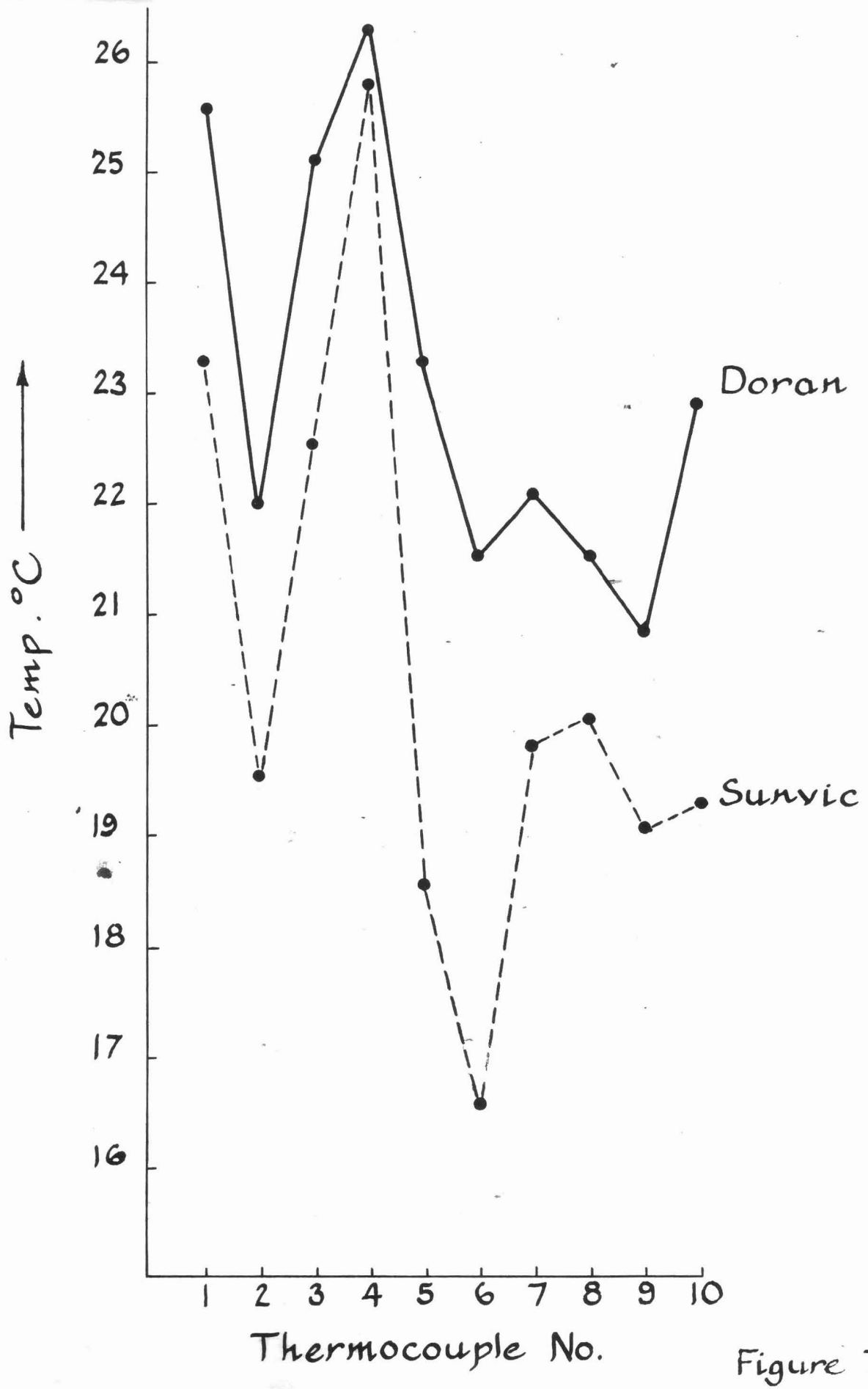

26
25
24
23
22
21
20
19
18
17
16
Temp. °C
Doran
Sunvic
1 2 3 4 5 6 7 8 9 10
Thermocouple No.

Figure 7

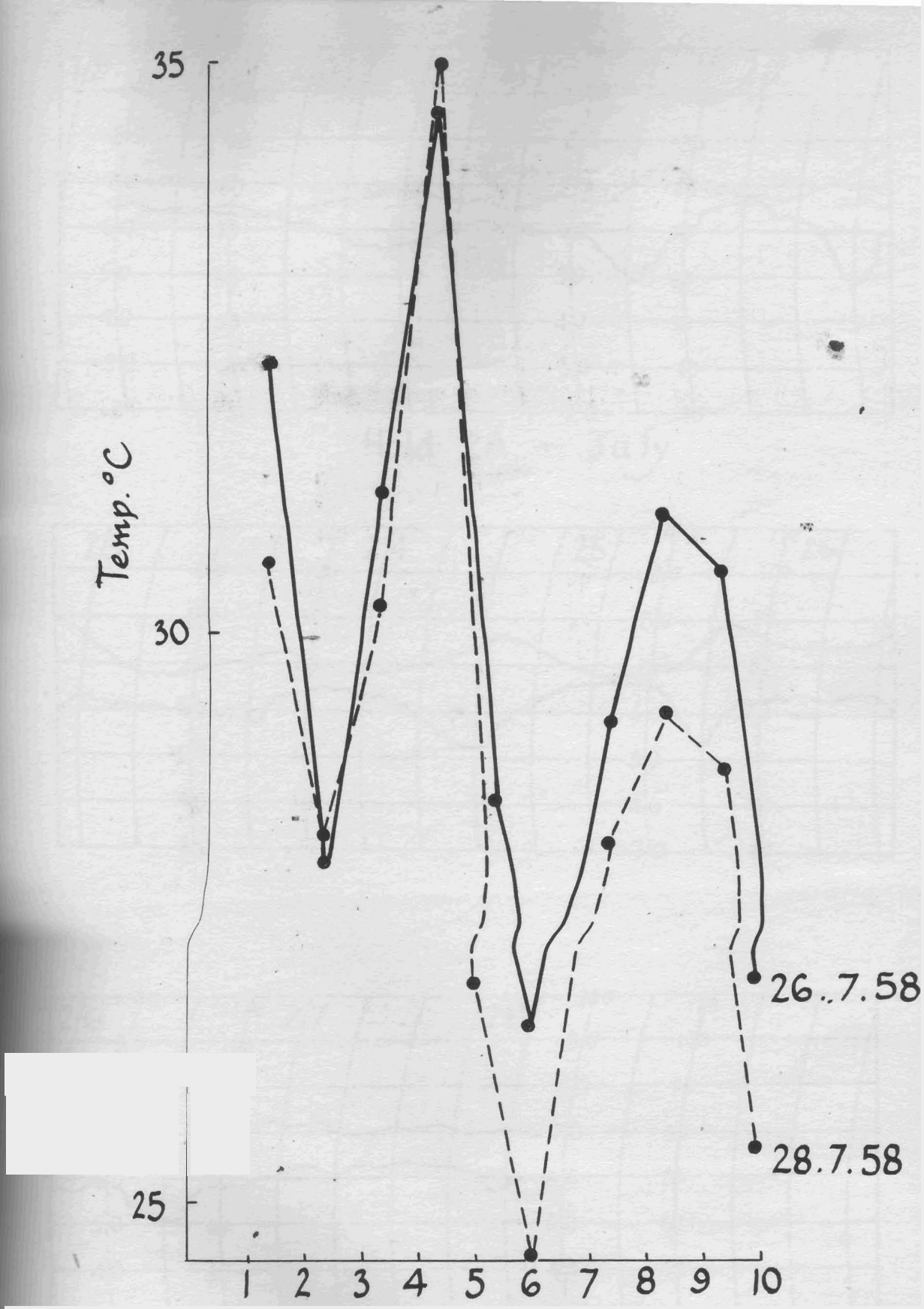
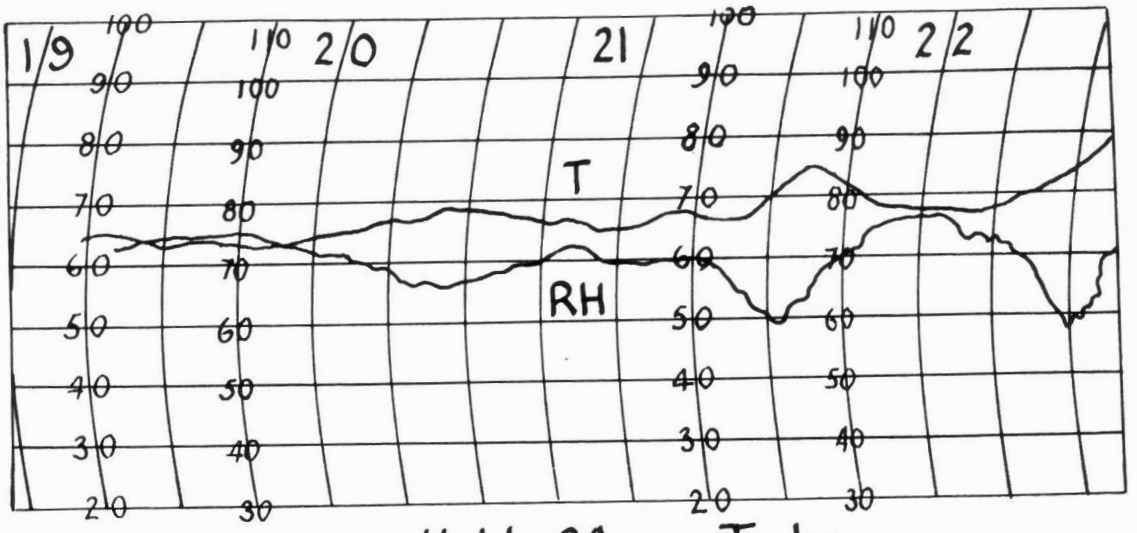
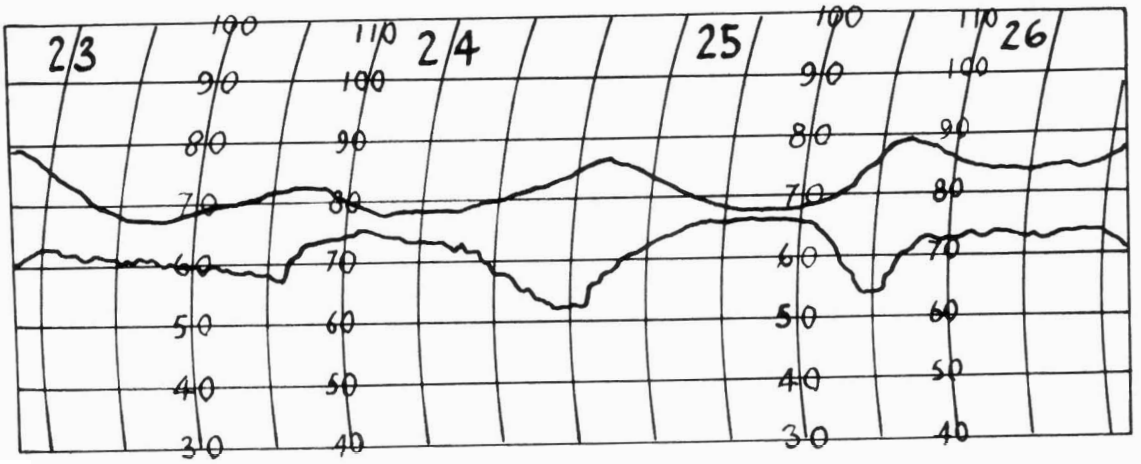


Figure 8



Hold 2A ~ July



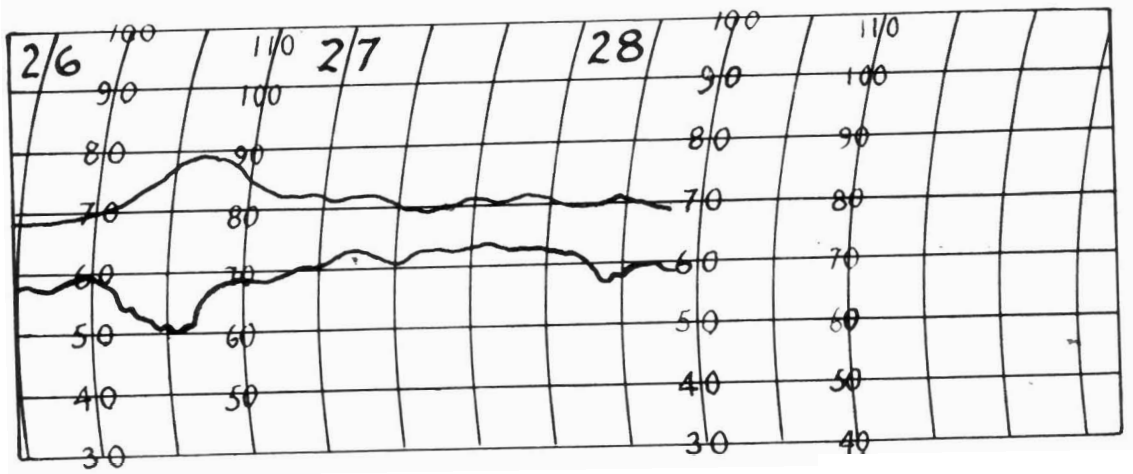
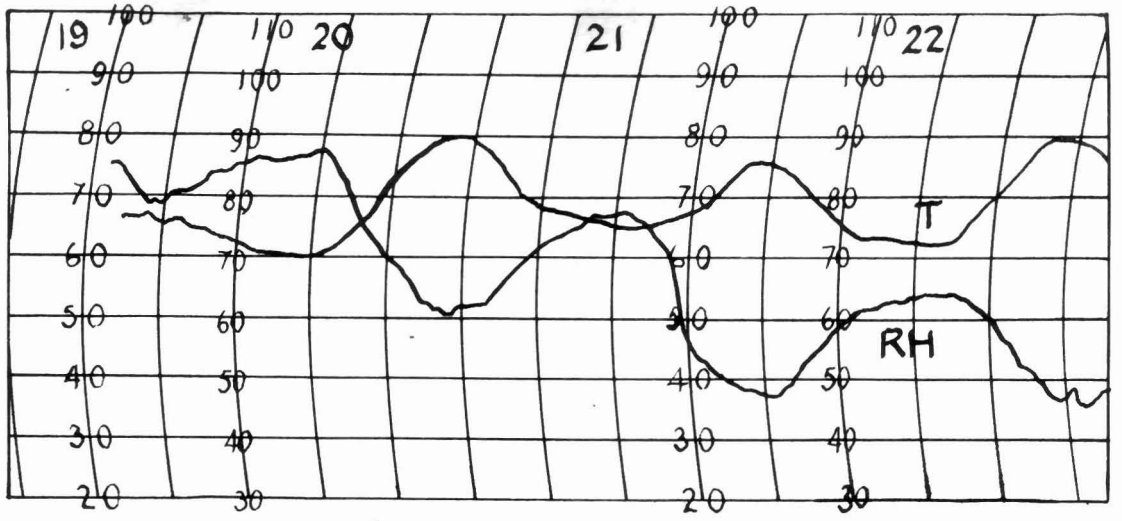
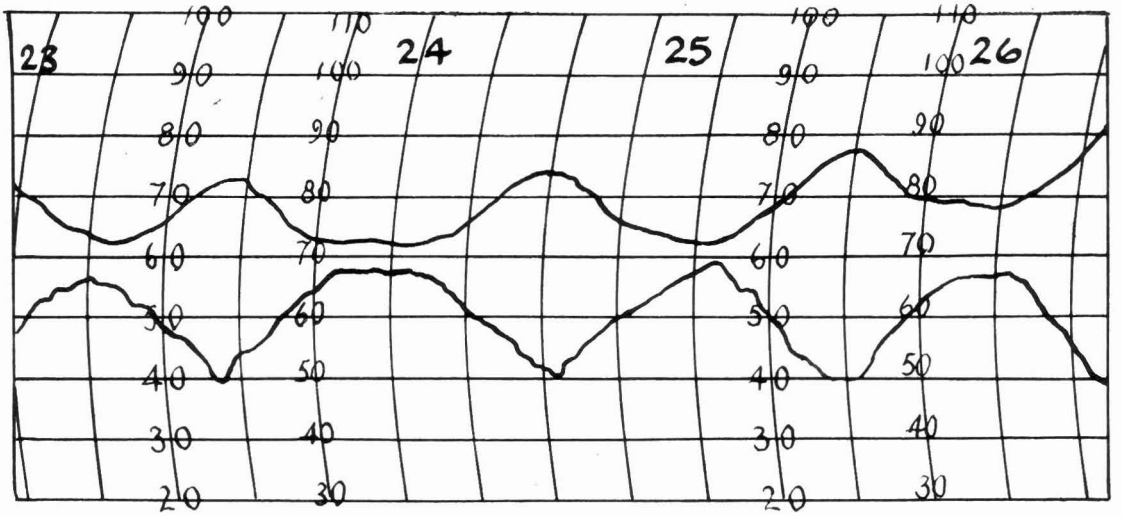


Figure 9



Hold 4 ~ July



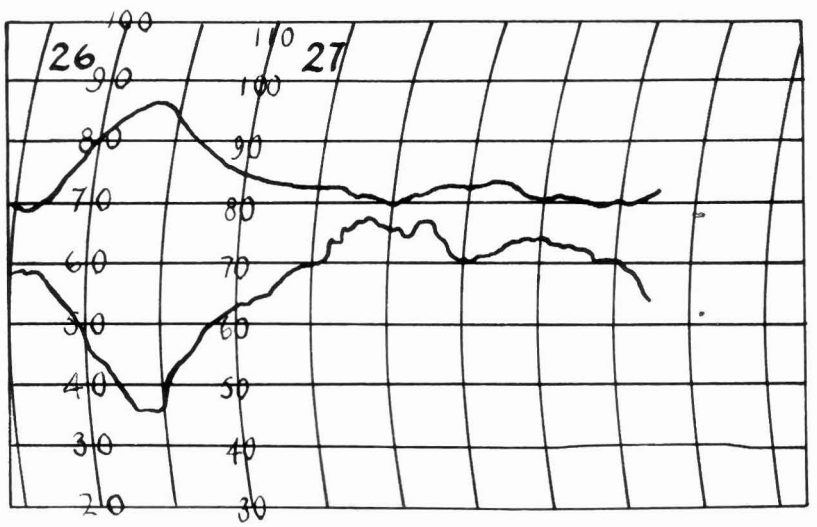
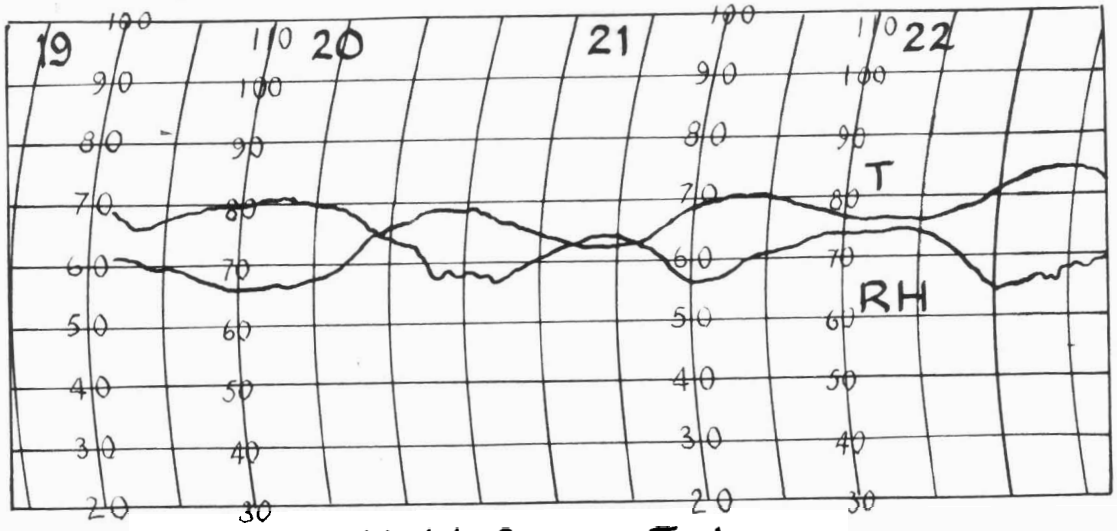
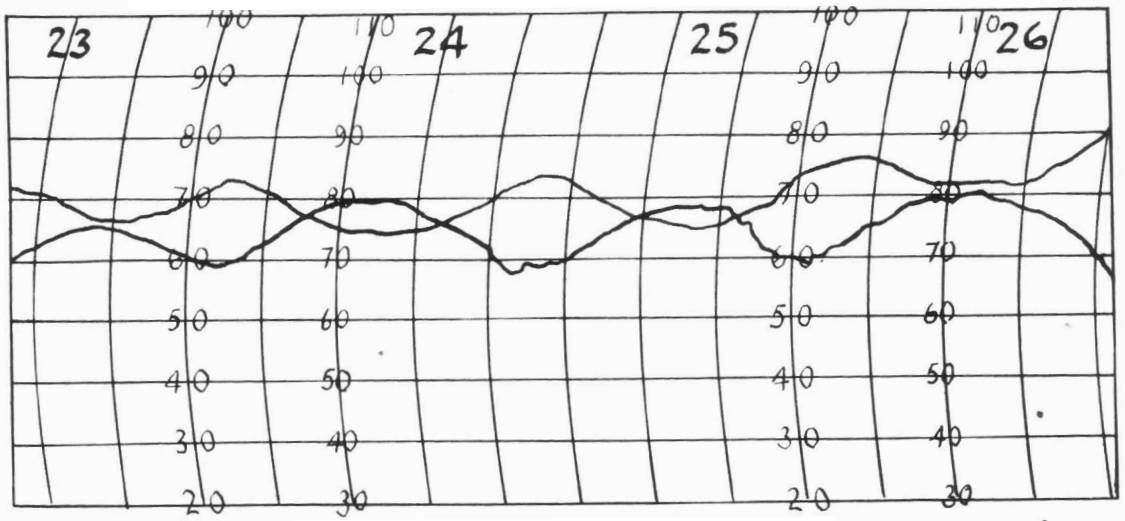


Figure 10



Hold 3 ~ July



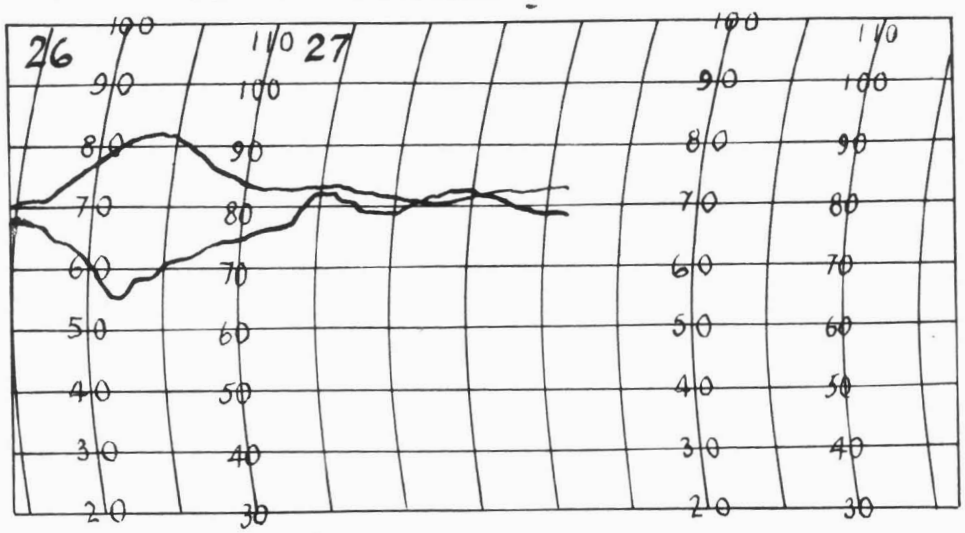
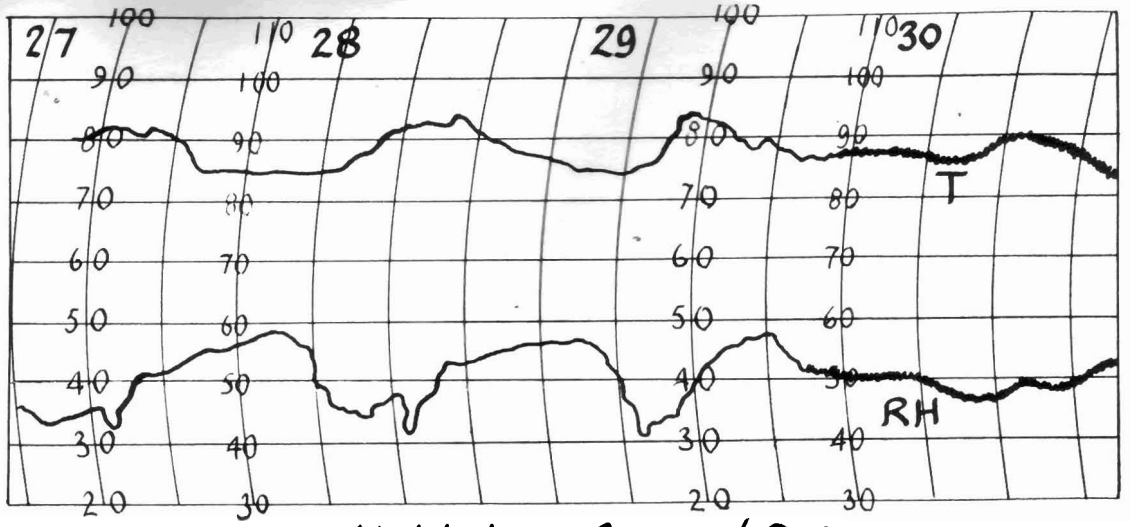
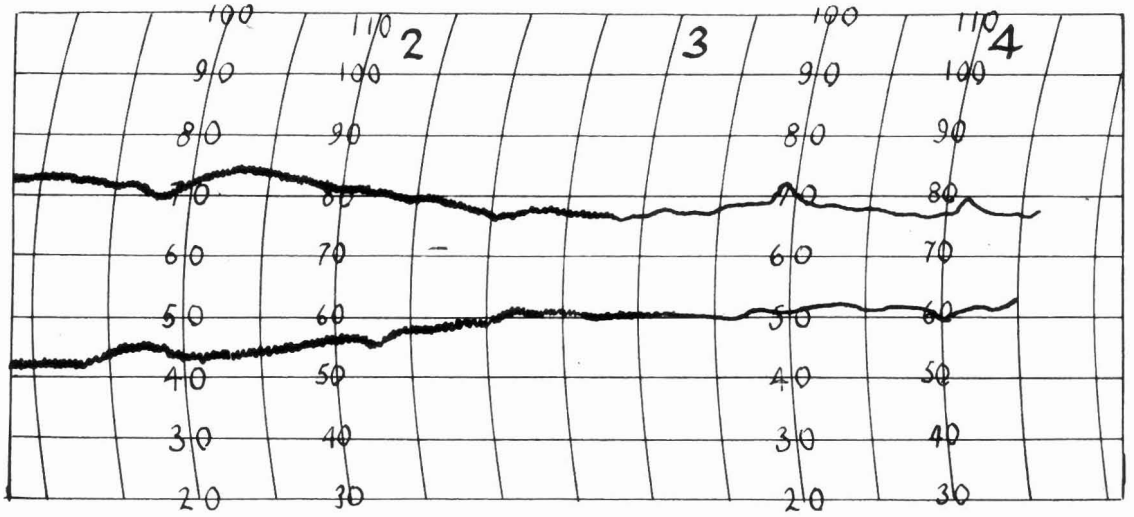


Figure 11



Hold 1 ~ Sept. / Oct.



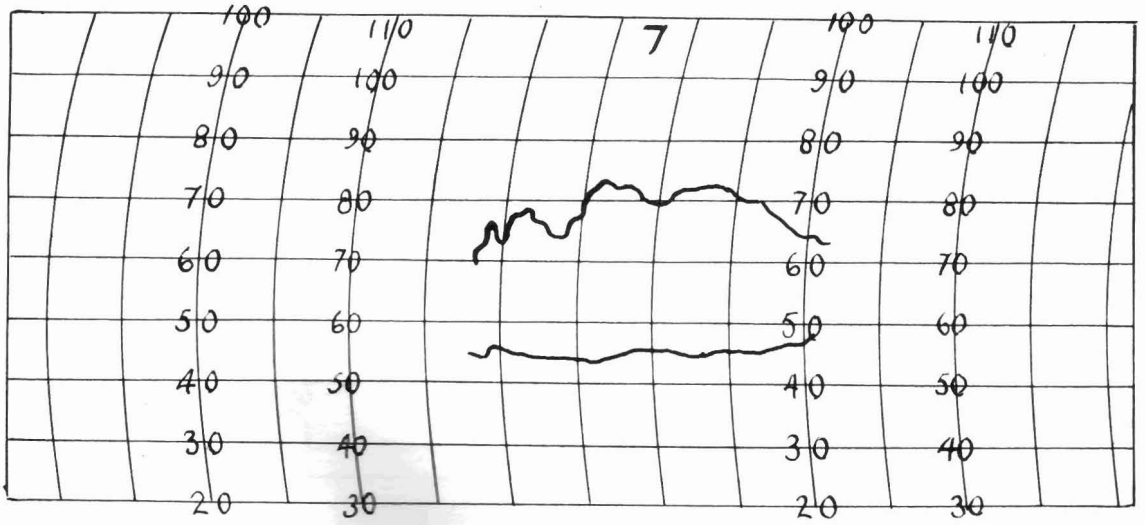
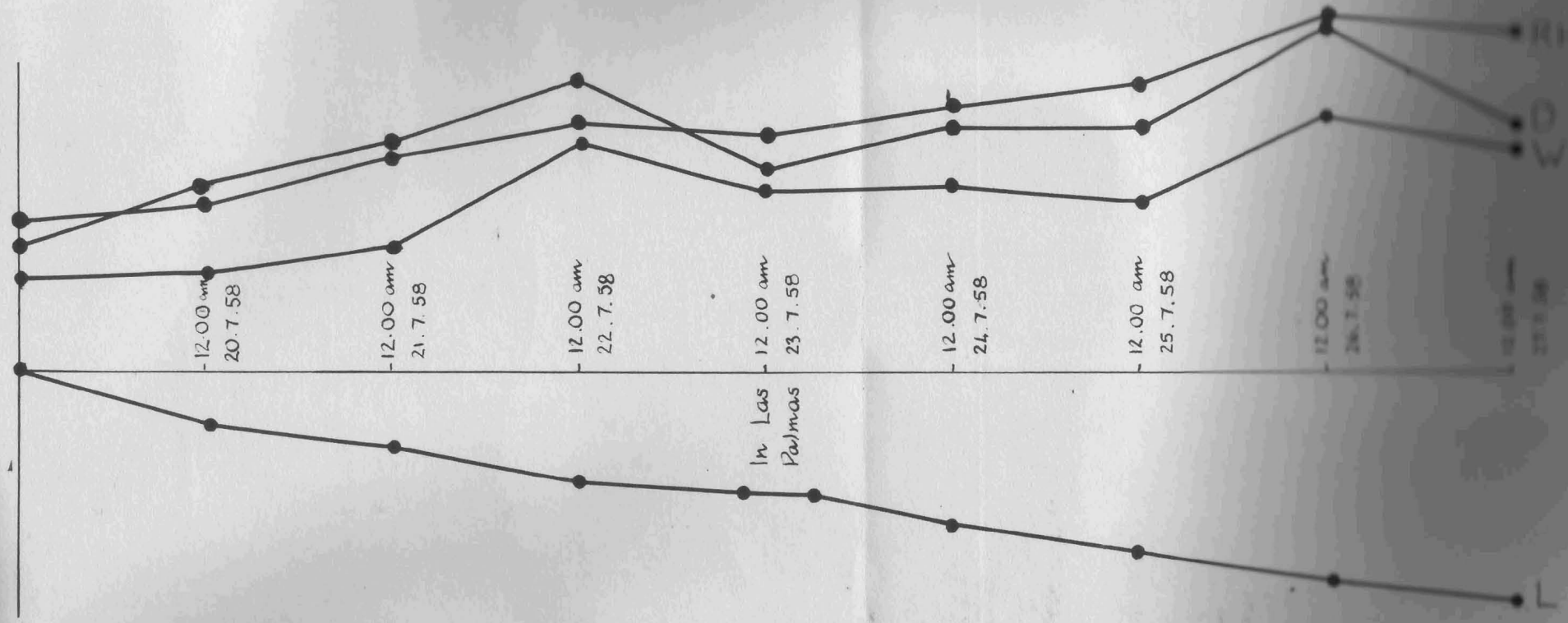


Figure 12



KEY

RH = Relative Humidity plotted at noon each day.
D = Dry Temp on ship's bridge.
W = Wet Temp on ship's bridge.
L = Latitude.

Top scale represents both temperature and humidity.

Figure 13

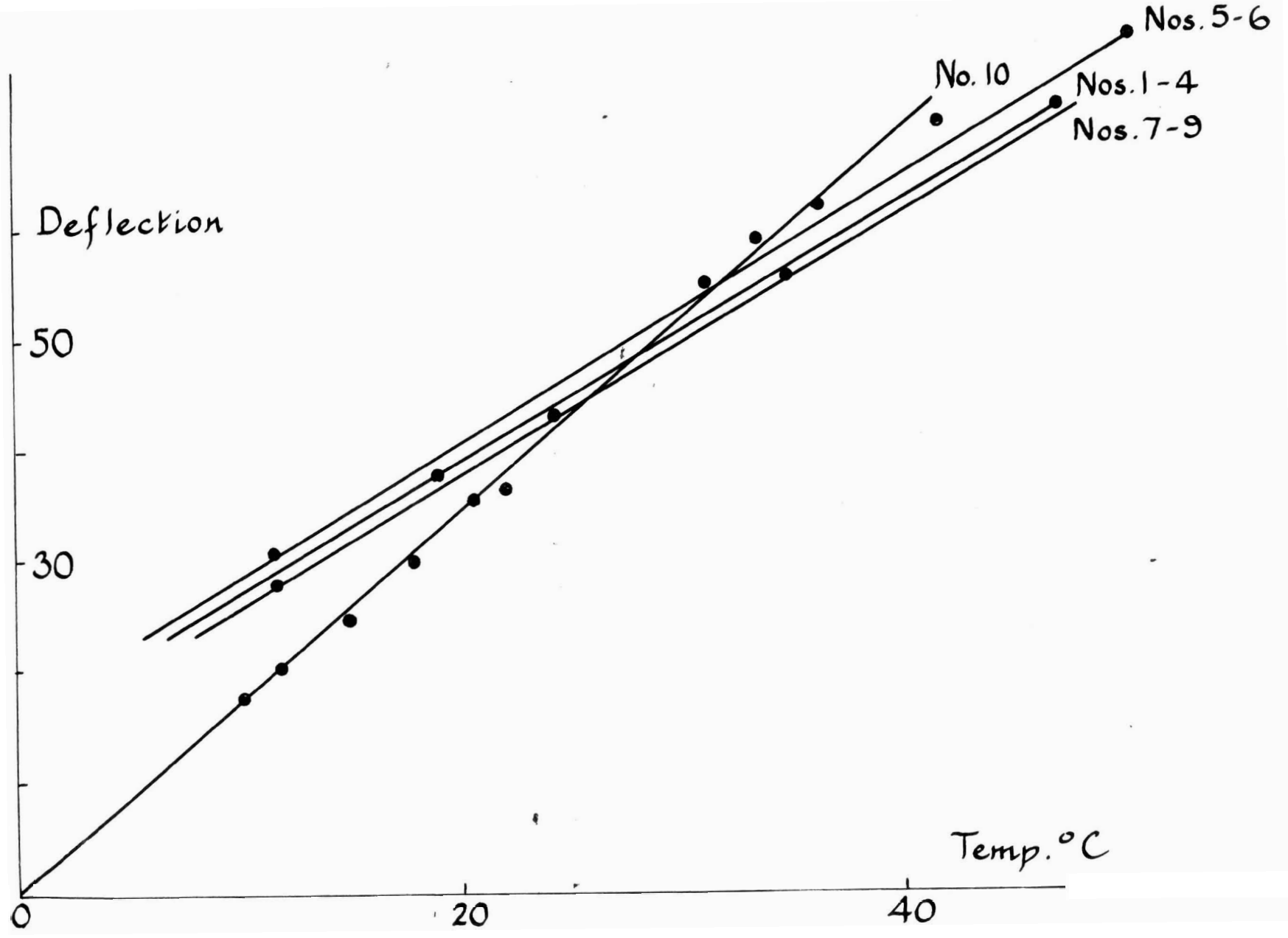


Figure 14

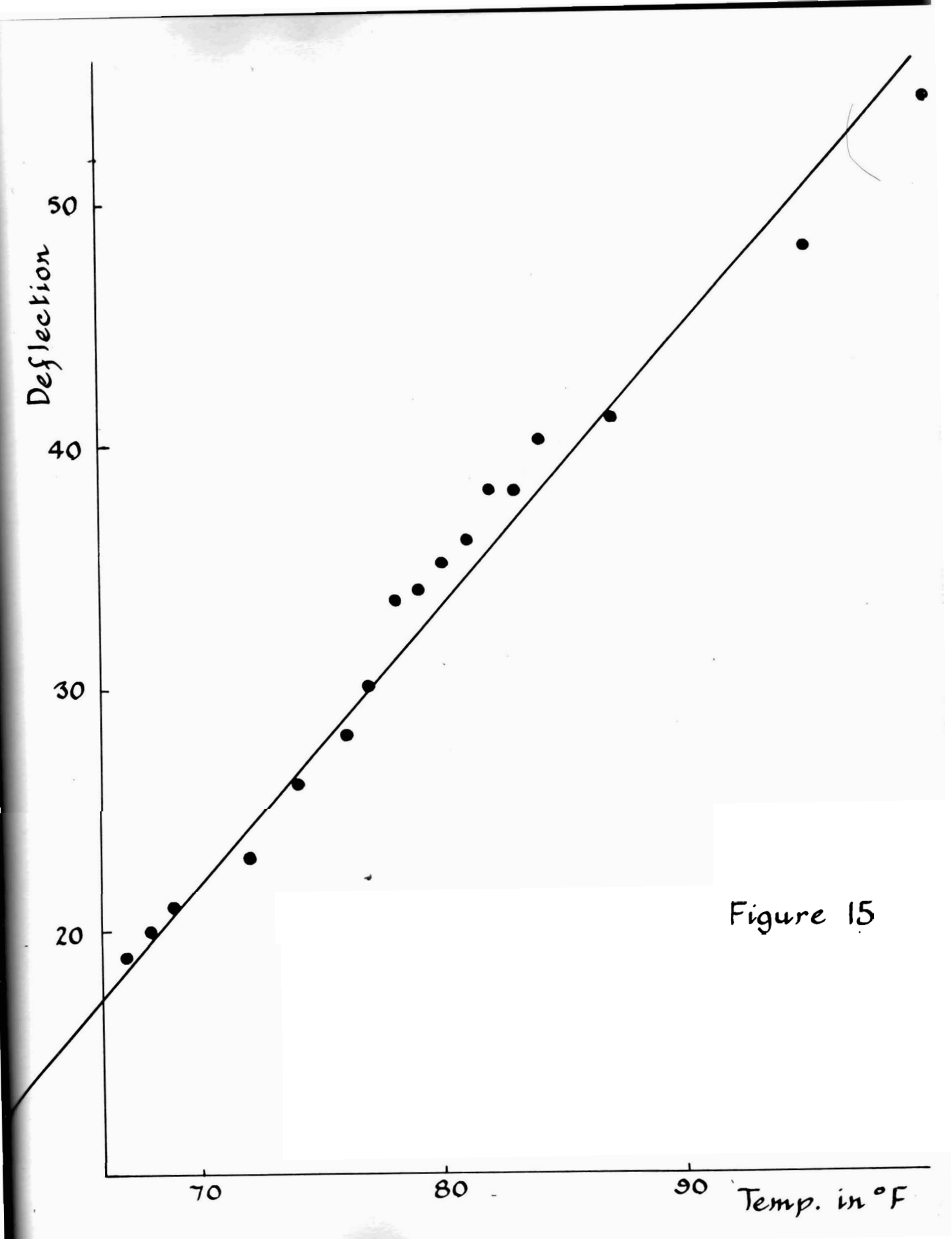


Figure 15

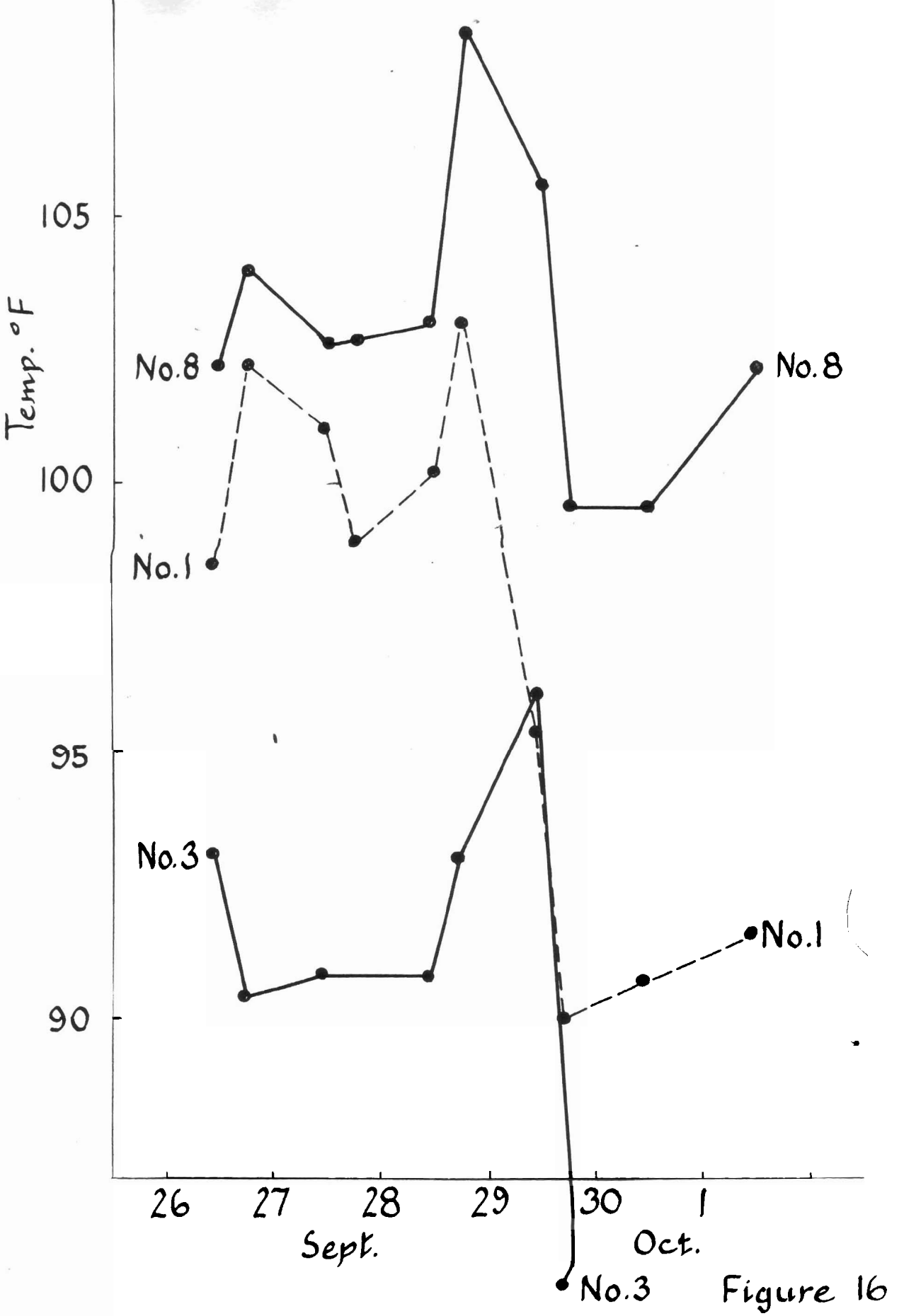

105
100
95
90
Temp. °F
No.8
No.1
No.3
No.8
No.1
No.3
26
27
28
29
30
1
Sept.
Oct.

Figure 16

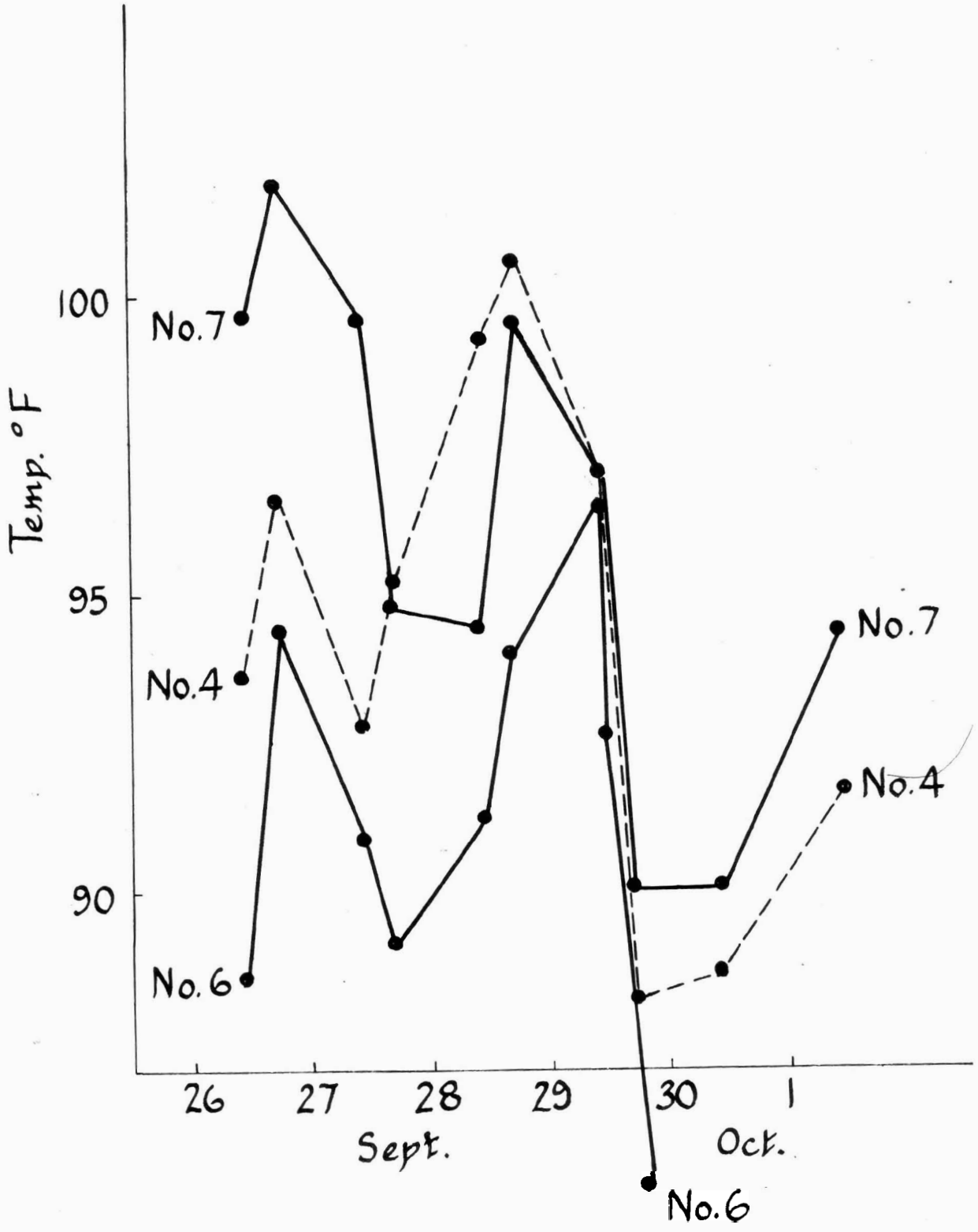


Figure 17