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Atlas of Operational, Environmental, and Biological Data from the Gulf of Carpentaria Prawn Survey, 1963–65
Part 3. Physical and Chemical Environment

Ian S. R. Munro

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ATLAS OF OPERATIONAL, ENVIRONMENTAL, AND BIOLOGICAL DATA FROM THE GULF OF CARPENTARIA PRAWN SURVEY, 1963-65

PART 3. PHYSICAL AND CHEMICAL ENVIRONMENT

Ian S.R. Munro

Division of Fisheries Research
CSIRO Marine Laboratories
P.O. Box 21, Cronulla, N.S.W. 2230

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Preface

During 1963-65 a survey was conducted jointly by the Queensland State and Australian Commonwealth Governments to examine the prawn resources of the south-eastern corner of the Gulf of Carpentaria.

The operation was requested by the Queensland Government, and its primary object was to determine the extent of prawn fishing opportunity in this relatively remote and unexamined area.

Field survey operations were conducted over a period of twenty four consecutive months using Karumba, a tiny settlement near the mouth of the Norman River, as shore base. A commercial prawn trawler was chartered to carry out experimental fishing and to collect biological and environmental data.

The survey was planned and conducted, as far as possible, along scientific lines and thus differed from earlier Australian prawn surveys which solely involved prospecting by an experienced trawler skipper. The survey area was defined as the waters of the south-eastern part of the Gulf south of 16°24'S latitude and east of 139°06'E longitude, but some operations were extended into the area bounded on the north by 15°48'S latitude and on the west by 138°54'E longitude. The survey vessel made 2,324 experimental trawls within an area of approximately 25,000 km^2. Biological and environmental data were collected in relation to all trawl stations. Juvenile prawns and planktonic larval stages were sampled in the lower reaches of the Norman River.

The conduct of the survey and the processing of data were the responsibilities of the then CSIRO Division of Fisheries and Oceanography. The direction of field operations and supervision of scientific investigations were the responsibilities of the author who served as Project Leader. Personnel comprising graduate zoologists and technical assistants were provided by CSIRO Division of Fisheries and Oceanography and the Queensland Department of Harbours and Marine.

The survey established the presence of stocks of small prawns (greentail, York, rainbow and juvenile banana) near river mouths during the summer monsoon, stocks of larger adult prawns (tiger, banana, Endeavour and blue-leg king) in deeper waters near the Wellesley Islands, and most importantly, large concentrations of banana prawns offshore from the Smithburne River during March to November.

Commercial fisheries were established almost immediately and spectacular catches of banana prawns attracted the attention of Australian and foreign prawn fishing interests. The survey led directly into the opening up of the Gulf of Carpentaria as a major prawn trawling area which now supports large fleets of trawlers which operate from a number of centres in both Queensland and Northern Territory. The Gulf now contributes a major part of the total Australian prawn landings.

The biological and environmental research conducted during the survey in 1963-65 are unique in that they relate to an area and stocks of organisms in virgin condition. They provide a base line most valuable for comparison in future studies of stock or environmental changes as may be required for management from time to time.

Part 1 of this Atlas describes background, arrangements and circumstances of the survey and the events which led to the establishment of the commercial fishery. Part 2 describes the vessel and fishing equipment, and provides details of fishing operations, station data and catch data. It also provides an analysis of time usage and the patterns in trawl sampling. Part 3 presents the results of investigations on the physical and chemical environment. The subsequent parts present results of biological investigations on penaeid prawns and associated benthic communities.

The Atlas is being published in five parts :-

1. Introduction
2. Survey Operations
3. Physical and Chemical Environment
4. Distribution and Biology of Penaeid Prawns
5. Distribution and Abundance of Associated Benthic Organisms

Parts 1 and 2 were published as *CSIRO Marine Laboratories Reports* No. 151 (1983) and 152 (1984), respectively. Parts 4-5 will be published as *Reports* No. 154 and 155 respectively.

CONTENTS

3.1 DEPTH TOPOGRAPHY

3.1.1 REFERENCE CHARTS

Prior to the commencement of the survey little was known about the topography of the sea floor in the southern part of the Gulf of Carpentaria. The operation commenced with guidance only from British Admiralty Chart 1807, Gulf of Carpentaria Southern Part. It appears to be based mainly on surveys made by Commander J.T. Stokes R.N. in 1841, and engraved and published in 1847. Later editions and printings incorporate corrections and additions by Queensland Department of Harbours and Marine engineers between 1884 and 1918. Soundings are very sparse except in the vicinities of the river entrances to the ports of Normanton and Burketown, Investigator Road, and the western passage through the Forsyth Islands. Some of the tracks of soundings probably are attributable to Captain Matthew Flinders R.N. in H.M. Sloop *Investigator* 1802--1803 when engaged in circumnavigating and mapping the coastline of Australia. On this chart Mornington Island has an indefinite outline, and Gore Point in the middle of the southern shoreline is located at 139°57'E longitude. The 1961 edition of British Admiralty Chart 445, Gulf of Carpentaria, principally from the original chart of Terra Australis by Captain M. Flinders, provides an outline of Mornington Island, but shows Gore Point at 140°01'E longitude.

Other useful maps available during the survey period included World Aeronautical Chart 3220 Normanton (3rd edition, May 1962) and Australian Army Ordinance Map SE 54-6 Edition 1 Series R 502, Burketown, compiled in 1962 from 1951 aerial photography. Photo index sheets and individual mosaic aerial photographs (RAAF, May - September 1951) were procured from the Department of National Development. This group proved to be most useful in relation to land configuration but provided no information on depth topography.

British Admiralty Chart 1807 has now been replaced by Australian Hydrographic Office Chart Aus. 303 Nassau River to Wellesley Islands. This was published in 1971, six years after the completion of the Gulf Prawn Survey operation. It contains considerably greater detail of shoreline configuration, and has more numerous soundings, but still rather sparse coverage of depth information.

3.1.2 SAMPLING

During the fishing operations of the survey vessel an attempt was made to obtain as much information about depth topography as possible without interfering with normal work schedules. The survey was not equipped to undertake hydrographic surveying and had no expertise in that field. Depths were recorded at the commencement of trawling at every station site and were monitored throughout the duration of the trawl. Depths were recorded also while travelling between base and anchorages or work areas, and often when travelling from one trawl site to the next. While travelling, depths were recorded at intervals of 60 minutes (about 8 n. miles), and under some circumstances at shorter intervals. These procedures were followed through the full duration of the survey and thus a wide coverage of the survey area was obtained during the two-year operation.

3.1.3 METHODS

(a) Depth recordings

The survey vessel *Rama* was fitted with a *Furuno* F-710 echo-sounder. The instrument was a type commonly installed in smaller fishing vessels of the period, but was not very sophisticated by modern standards. It had a roll paper recorder calibrated in fathoms. The divisions on the scale were of sufficient size to enable the fishing skipper to estimate to the nearest quarter fathom. All recordings were made with this instrument.

(b) Chart outlines

Chart blanks marked only with an outline of the coastline and ordinates of latitude and longitude were used throughout the survey for plotting trawl station site positions and cruise tracks. As noted in Section 3.1.1 the existing hydrographic charts were inadequate and confusing, and some form of outline had to be substituted. This outline was plotted on an enlarged scale from World Aeronautical Chart 3220 Normanton 3rd edition - May 1962, being the section enclosed between latitudes 16°15'S and 18°03'S and longitudes 138°48'E and 141°23'E. The original map is drawn in Lambert Conformal Conic Projection whereas the copied blank has the lines of longitude brought to parallel, and the slightly arched lines of latitude brought to straight. The outline blank is therefore not a proper projection. Also the coastal configuration differs from that in the more recent Australian Hydrographic Chart Aus. 303.

3.1.4 DEPTH PROFILES

The depth profiles across the southern part of the Gulf of Carpentaria from west to east (Figs. 60-63) are based on the coastal outline of the blank chart described in Section 3.1.3 (b). The names of reference points have been adopted from Australian Hydrographic Office Chart Aus. 303. Depths incorporated in the profiles are those of trawl station positions. The west-east profiles are plotted at intervals of one minute latitude. Depth records from trawl station sites spread within 0.5 of a minute either side of each minute are plotted as being on that line.

Depths shown along the west-east profiles are expressed in feet and a correction has been applied for the tidal component. The measurements are echo sounder readings at a given place and time adjusted with reference to a tide gauge reading at the same time. The tidal height was taken from the recording tide gauge of the Queensland Department of Harbours and Marine which was positioned in the Norman River at Karumba.

A local datum was established by calculating the mean of low low water spring tides over the period of observation (August 1963 to July 1965). The tidal adjustments are inaccurate for two reasons. Firstly the echo-sounder readings are to the nearest quarter fathom (1.5 ft). Secondly the tidal adjustments were made on an assumption that tidal height at any position in the survey area, at any given time, was the same as at the gauge position in the Norman River.

3.1.5 DEPTH CONTOURS

Depth topography of the southern part of The Gulf of Carpentaria is also displayed in the form of a contour chart (Fig. 64). A colour version of this chart was published by the Queensland Department of Harbours and Marine in 1967 and made available to prawn fishermen participating in the newly established prawning industry in the southern part of the Gulf.

The chart uses the same coastal outline as described in Section 3.1.3 (b). It combines all data collected by the survey vessel *Rama* including measurements made at trawl station sites and along traverses when travelling between port, anchorages and working positions. It also includes depth data collected in the vicinity of Mornington Island by L.F.B. *Laakanuki* in 1965, and soundings shown on British Admiralty Charts 445 and 1807.

Contouring is in fathom intervals and no adjustments have been made for the tidal component.

3.2 SEDIMENTS

Sediments were studied solely from the viewpoint of mapping variations in the nature of the superficial layer of substrate as a habitat for penaeid prawns and associated benthic fauna and flora.

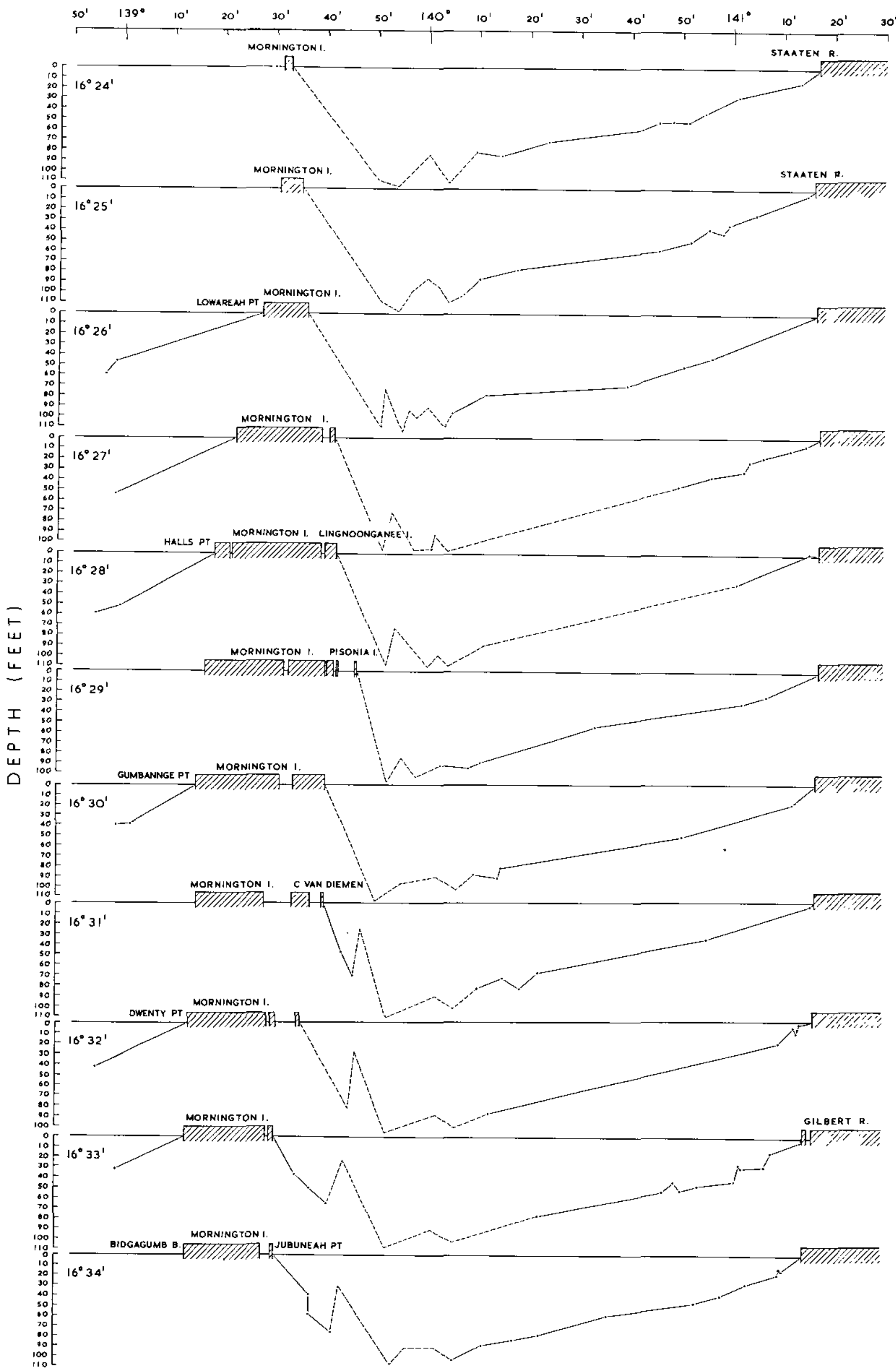


Fig. 60 Depth profiles from west to east across the southern part of the Gulf of Carpentaria at intervals of one minute latitude between 16°24' and 16°34' S Latitude. The horizontal scale is East Longitude.

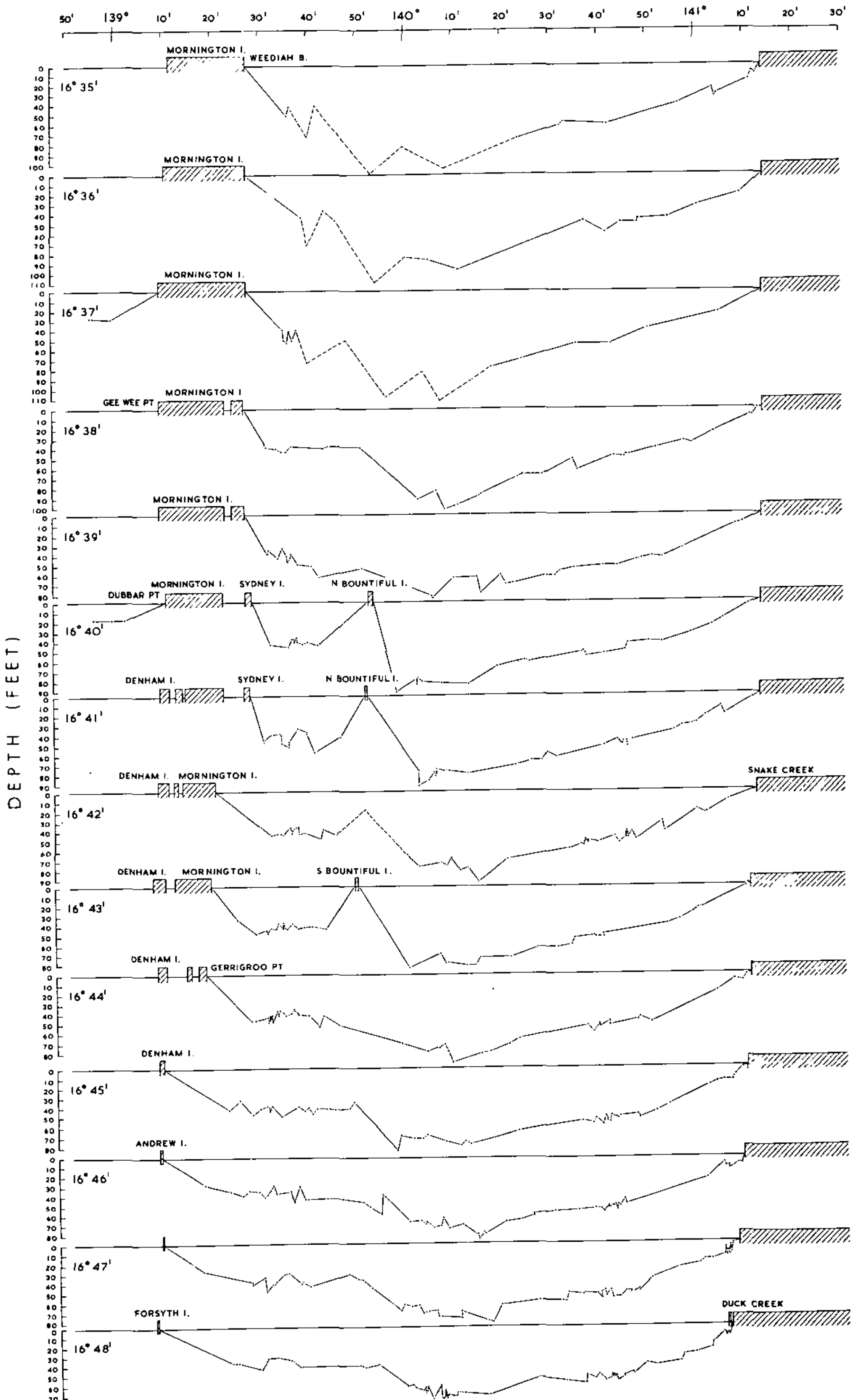


Fig. 61 Depth profiles from west to east across the southern part of the Gulf of Carpentaria at intervals of one minute latitude between 16°35' and 16°48' S Latitude. The horizontal scale is East Longitude.

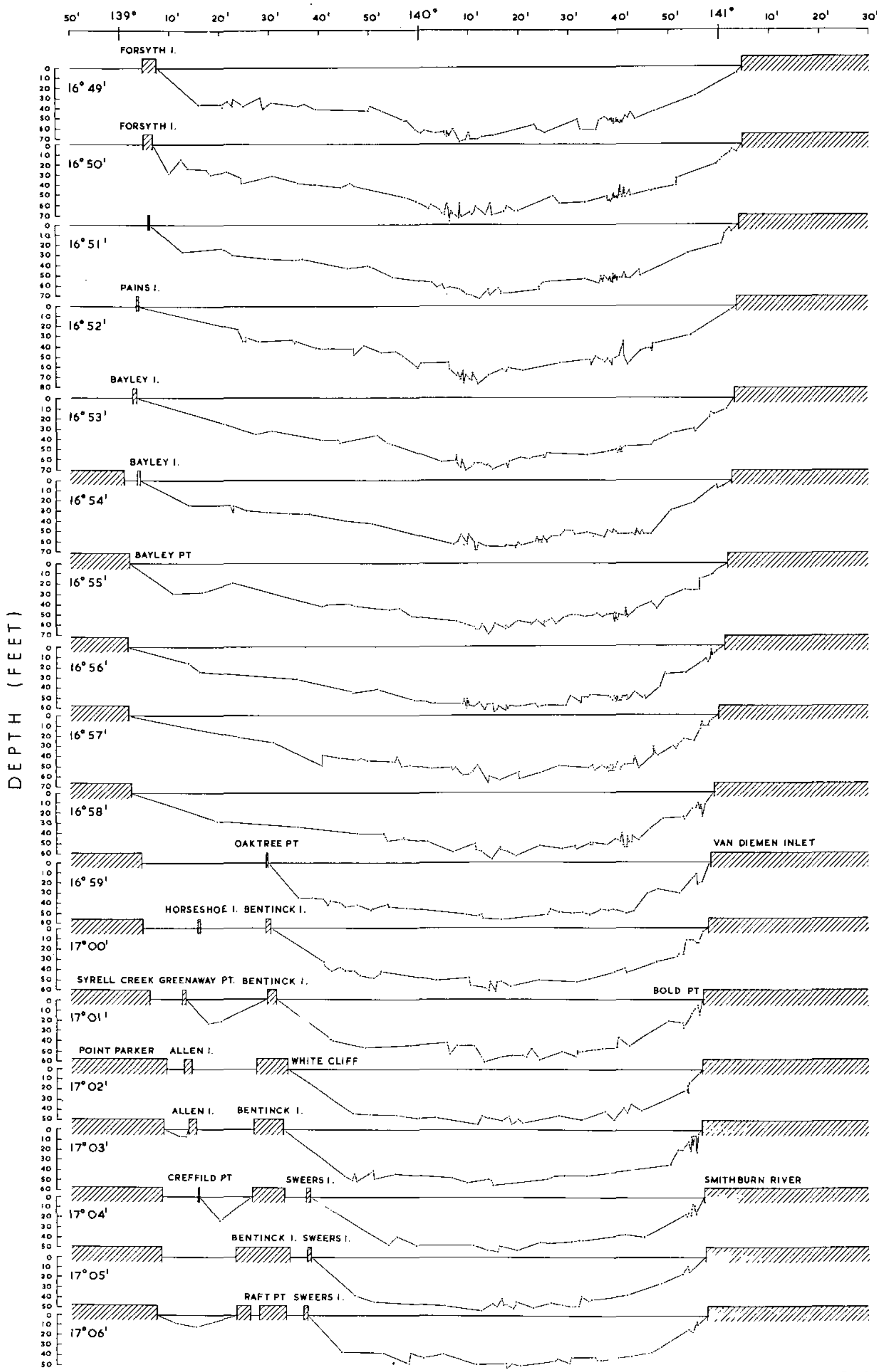


Fig. 62 Depth profiles from west to east across the southern part of the Gulf of Carpentaria at intervals of one minute latitude between 16°49' and 17°06' S Latitude. The horizontal scale is East Longitude.

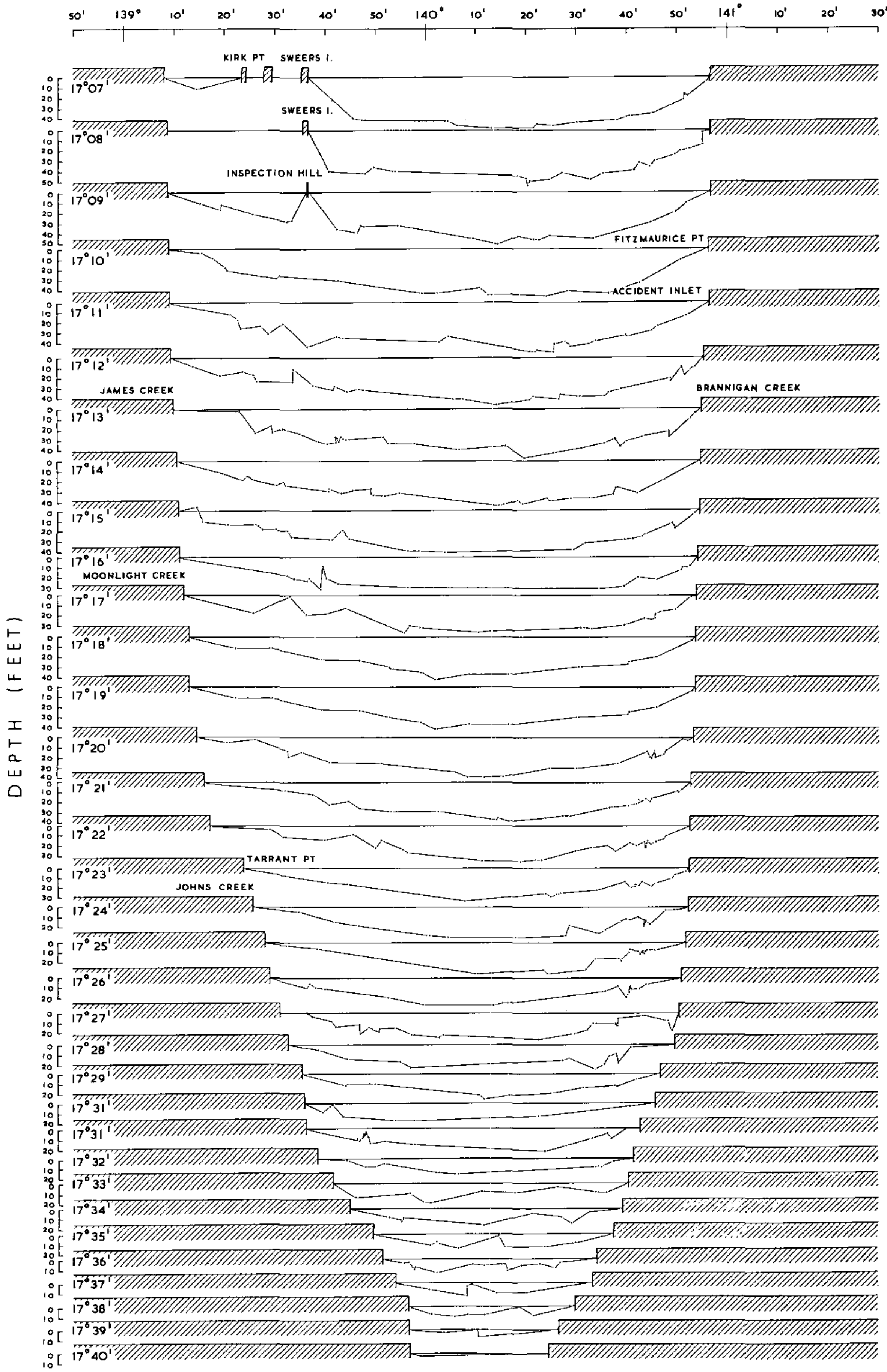


Fig. 63 Depth profiles from west to east across the southern part of the Gulf of Carpentaria at intervals of one minute latitude between 17°07' and 17°40' S Latitude. The horizontal scale is East Longitude.

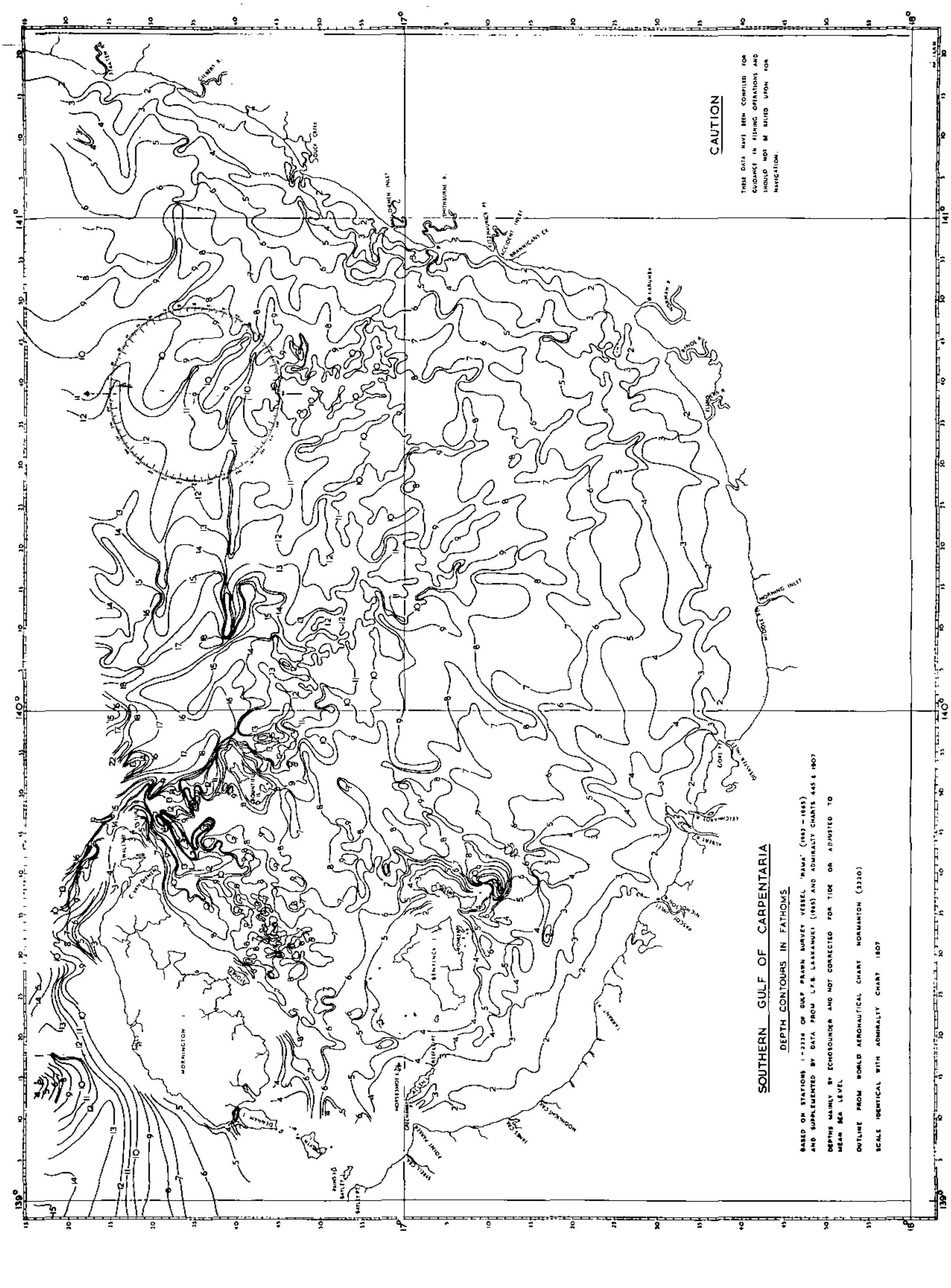


Fig. 64 Depth contours of the southern part of the Gulf of Carpentaria. Contours are in intervals of one fathom. Depths are not corrected for tide.

Accordingly the methods of sampling, analysis and classification do not conform with the more elaborate systems developed for geological purposes.

3.2.1 SAMPLING

A sediment sample was collected, as far as possible, at every trawl station site to indicate the nature of the bottom over which the trawl had passed. Trawl durations were standardized at 30 minutes which meant that, at normal trawling speed of two knots, approximately 1 n. mile of bottom was swept by the trawl. Some trawls were of shorter or longer duration. It was convenient to obtain the sample when the vessel was travelling at minimum speed relative to the sea floor. This occurred at the end of the sweep when the trawl net was being winched aboard the vessel. In addition to some accidental losses of samples, data were not obtained for some station sites because the bottom was so firm that the sampler did not operate properly. Such so called 'hard' bottom was characteristic of some areas where there was an abundance of coarse shell fragments and calcareous bryozoan skeletons.

Owing to the patchiness of the bottom in some areas and the distance of travel, especially at station sites of trawls of long duration, it seemed likely that the sample taken at the end of the trawl path might not be representative of the whole length of the trawl path. An attempt was made to check this by collecting one sample at the beginning of each trawl as well as the one normally taken at the end of the trawl. This procedure was adopted for a series of 129 consecutive stations (Stns 1212-1340) during the period 13 August to 15 September 1964 (Cruises 73-77). Data from both positions in the pairs have been used in the distribution plots, but only the standard end sample has been classified and included in the Station Lists published as Table 4 in Section 2.2.5 of this Atlas (See Part 2).

3.2.2 METHODS

A spring-loaded tripping double-jawed grab sampler was unsuitable for use in the area because of the shallow depths and texture of most of the sediments. A simple scoop sampler was devised and fabricated. It consisted of a piece of heavy steel tube about 10 cm diameter and about 45 cm long. A bottom was welded into this and a link welded to the open end. The towing link was shackled to a length of fairly heavy chain connecting the sampler with the towing cable. The sampler, when hauled slowly across a short stretch of sea floor, normally scooped up a quantity of superficial sediment. The weight of the tube and the leading chain assisted the open end to dig into the superficial layer of sediment. Samples obtained in this way were subjected to some washing while being hauled to the surface, and some of the finer fractions may have been lost. Penetration of the scoop depended on the consistency of the superficial layer. As noted in Section 3.2.1, the sampler was not very effective on 'hard' ground.

A portion of the wet sediment was placed in a glass jar and stored in darkness in the ice hold of the vessel. At the end of a cruise the samples were brought ashore and emptied on to squares of paper towel. They were then dried in the sun. Before the sample was completely dry it was crushed lightly with a roller and then stored in a plastic envelope pending analysis. The sticky clay-like content of many samples, under solar heating and dehydration of the dry tropical climate, tended to cement the sand and shell particles together to form a rock hard block. Care had to be taken to crumble the mass before this happened. Also care had to be exercised in crushing so that the size of components, particularly fragile shell inclusions, was not altered by pulverization.

Dried samples were examined visually under a low power binocular microscope and a subjective assessment made of the nature and relative abundance of constituent particles according to kind and size. The range of particle size was gauged by comparison with a set of size calibrated circles engraved on an ocular insert. In the case of pebbles, granules, sands and finer fractions, size ranges correspond fairly closely with the Wenthworth scale and terminology (Kuenen 1950). The assessments were made over a continuing period of several weeks, with constant re-checking, in order to obtain reasonable consistency in observation and minimize the human bias in such subjective judgment.

3.2.3 ANALYSIS AND COMPONENTS

In contrast to analysis oriented to more regular geological approach, treatment in the manner described in Section 3.2.2 aimed at deriving a classification applicable to the biologist's need in a particular survey exercise. The concept takes into consideration especially particle size and lutite content which could have meaning in relation to burrowing behaviour and feeding of penaeid prawns. The sediments range from silts and plastic muds through muddy sands to clean sands, and usually have a high calcium component in the form of fragmented molluscan shells and exoskeletons of other invertebrates. The sediments comprise mixtures of some or all of the following - lutite (finest unidentified silt and clay fractions), quartz sands in five particle size ranges, shell fragments in four particle size ranges, granules and pebbles of several mineral forms (mainly granules of red, possibly ferruginous material), and Foraminifera tests. Assessment of relative abundance was at five levels - absence, trace, low, moderate and dominant. While particle size range was actually measured, the levels of abundance and relative abundance of the various components were only subjective estimates.

3.2.4 CRITERIA FOR CLASSIFICATION

In general sediments were classified basically according to the lutite content. Those lacking lutite are clean sands, those with a trace of lutite are dirty sands, those with low lutite content are muddy sands, and those with a moderate lutite content are very muddy sands. Those dominating with lutite and very fine quartz sands are fine muds and silts and characterize a narrow band fringing the shoreline. In general the lutite content decreases with distance from the shore. The muddy sediments were generally grey in colour but in some areas (e.g. off the mouth of the Albert River) were chocolate brown.

The quartz sand component usually consists of a mixture within several ranges of grain size. In the narrow inshore band of fine muds and silts the very fine grains (less than 0.1 mm) predominate. Over most of the survey area fine grains (0.1 - 0.3 mm) are dominant but they are mixed with moderate to low quantities of very fine grains and medium grains (0.3 - 0.6 mm), low to trace quantities of coarse grains (0.6 -1.2 mm) and traces of very coarse grains (greater than 1.2 mm). Clean and nearly clean sands generally have a dominant component of fine to medium grains, but in the north-eastern corner of the area very coarse grains sometimes are dominant.

High calcium carbonate content in the form of molluscan and other shell fragments is fairly characteristic. Shell fragments are seldom absent and all but the very fine fragments (less than 0.3 mm) are readily visible to the naked eye. Moderate amounts of very fine fragments and fine fragments (0.3 - 3.0 mm) and moderate to low quantities of medium fragments (3.0 - 10.0 mm) are fairly typical of the sandy muds and muddy sands which pave the sea floor of most of the area. Fine fragments and medium fragments often predominate in the cleaner sands of the northern part of the area. Coarse shell is an inclusion irregularly distributed throughout the area and is usually present at low or trace quantity levels.

Small pebbles (mostly less than 5 mm) and smaller granules are irregularly distributed. The most common type have the characteristic red colour of iron oxide. At moderate to dominant levels they are associated with clean sands in the northern areas, the islands of the western sector and the south-western corner. Tests of Foraminifera are present over much of the area at trace level and appear to be absent only in the coastal belt of fine muds and silts. They may be present at moderate or even dominant levels in the cleaner sands of the northern area.

The constituent materials are included or excluded, or combined in different proportions according to area and distance from shore. For the samples from 2356 localities 1085 combinations have been noted. A classification has been adopted which is based on relative abundance of lutite, dominant grain sizes of quartz sands, and inclusions of granules, coarse shell fragments and Foraminifera. It provides for 134 types of sands and muds grouped in five major categories. Within each of the five groups, some types differ only by virtue of their coarser inclusions.

This classification is set out in detail in Table 8. It has not been practical to map sediment distribution in detail by using this classification simply because there are too many groups. Mapping is presented in other ways in the following sections. A general picture of distribution of the five major groups is the subject of Section 3.2.6.

In the Station List presented in Part 2 of this Atlas (Table 4, Section 2.2.5) the sediments associated with station sites are classified according to this system in the column under the heading 'Sediment Code'. Table 8 thus provides the key to the code numbers used in this column of the Station List.

3.2.5 TABLE OF CLASSIFICATION

Table 8. Classification of sediments based on relative abundance of lutite, dominant grain sizes of quartz sands, and inclusions of granules, coarse shell fragments and Foraminifera. One hundred and thirty-four types are arranged in five major groups.

LEGEND:	Quantity:	D = Dominant	
		M = Moderate	L = Low
		T = Trace	No entry = Absence
	Size:	Quartz sands grains	
		Very coarse sand	Greater than 1.2 mm
		Coarse sand	0.6 - 1.2 mm
		Medium sand	0.3 - 0.6 mm
		Fine sand	0.1 - 0.3 mm
		Very fine sand	Less than 0.1 mm
		Shell fragments	
		Coarse shell	Greater than 10 mm
		Medium shell	3.0 - 10.0 mm
		Fine shell	0.3 - 3.0 mm
		Very fine shell	Less than 0.3 mm

Group A - Fine muds and silts (Lutite component dominant)

Code	Matrix	Inclusions		
		Coarse Shell	Pebbles or Granules	Foraminifera
1	Fine to very fine sandy mud			
2	Fine sandy mud with shell			
3	Very fine sandy mud with shell	L		
4	Very fine sandy mud often with shell			
5	Mud lacking sands or shell			

Group B - Very muddy sands (Lutite component moderate)

Code	Matrix	Inclusions		
		Coarse Shell	Pebbles or Granules	Foraminifera
6	Very muddy medium to fine sands with shell	T		
7	Very muddy medium to fine sands with shell			
8	Very muddy medium sand with shell		T	
9	Very muddy medium sand with shell	T-L		
10	Very muddy medium sand with shell			
11	Very muddy fine to very fine sands with shell	T-L	T-L	
12	Very muddy fine to very fine sands with shell	T		
13	Very muddy fine to very fine sands with shell			
14	Shell with very muddy fine sand	L	M	
15	Very muddy fine sand with shell	T-L	T	
16	Very muddy fine sand with shell		T-L	
17	Very muddy fine sand with shell	T-L		
18	Very muddy fine sand with shell			
19	Shell with very muddy very fine sand	M	M	
20	Very muddy very fine sand with shell		T	
21	Very muddy very fine sand with shell	T-L		
22	Very muddy very fine sand with shell			M
23	Very muddy very fine sand with shell			
24	Very muddy fine sand and shell	T	L	

Group C - Muddy sands (Lutite component low)

Code	Matrix	Inclusions		
		Coarse Shell	Pebbles or Granules	Foraminifera
25	Muddy very coarse to coarse sands with shell		T	
26	Muddy very coarse to coarse sands with shell	L	T	
27	Muddy very coarse sand with shell	T	T	
28	Muddy coarse to medium sands with shell	L	L	
29	Muddy coarse to medium sands with shell	L		
30	Muddy coarse sand with shell		T-L	
31	Muddy coarse sand with shell	T-M		
32	Muddy coarse sand with shell			
33	Muddy medium to fine sands with shell	T-M	T-L	
34	Muddy medium to fine sands with shell		T-L	
35	Muddy medium to fine sands with shell	T-L		
36	Muddy medium to fine sands with shell			
37	Muddy medium sand with shell		M	
38	Muddy medium sand with shell	T-M	T-L	
39	Muddy medium sand with shell		T-L	
40	Muddy medium sand with shell	T-L		
41	Muddy medium sand with shell			
42	Muddy fine to very fine sands with shell	T	T	
43	Muddy fine to very fine sands with shell		T-L	
44	Muddy fine to very fine sands with shell	T-L		
45	Muddy fine to very fine sands with shell			
46	Muddy fine sand with shell	T-M	M-D	
47	Muddy fine sand with shell		M	
48	Muddy fine sand with shell	T-M	T-L	
49	Muddy fine sand with shell		T-L	
50	Muddy fine sand with shell	T-M		
51	Muddy fine sand with shell			
52	Muddy very fine sand with shell	T	T	
53	Muddy very fine sand with shell		T-L	
54	Muddy very fine sand with shell	T-L		
55	Muddy very fine sand with shell			
56	Muddy shell with sands	D	D	M
57	Muddy shell with sands	T-M	M-D	
58	Muddy shell with sands	T	L	M
59	Muddy shell with sands		L	

Group D - Dirty sands (Lutite present in trace amounts)

Code	Matrix	Inclusions		
		Coarse Shell	Pebbles or Granules	Foraminifera
60	Dirty very coarse to coarse sands with shell	L	L	
61	Dirty very coarse sand with shell		T	
62	Dirty very coarse sand with shell			
63	Dirty coarse to medium sands and shell	T-M	M-D	
64	Dirty coarse to medium sands and shell	T-M	T-L	
65	Dirty coarse to medium sands and shell		L	
66	Dirty shell and coarse sand	M	D	M
67	Dirty shell and coarse sand	M	M	
68	Dirty coarse sand with shell		M	
69	Dirty coarse sand with shell	T-L	T-L	
70	Dirty coarse sand with shell		T	
71	Dirty coarse sand with shell	T-L		
72	Dirty coarse sand with shell			
73	Dirty medium to fine sands with shell	T-L	T-L	
74	Dirty medium to fine sands with shell	L		
75	Dirty medium to fine sands with shell			
76	Dirty medium to very fine sands with shell			
77	Dirty medium sand and shell	L-M	M	M-D
78	Dirty medium sand and shell	T-M	M-D	
79	Dirty medium sand and shell		M	
80	Dirty medium sand and shell	T-D	T-L	
81	Dirty medium sand with shell		T	M
82	Dirty medium sand with shell		T-L	
83	Dirty medium sand with shell	T-L		
84	Dirty medium sand with shell			
85	Dirty fine to very fine sands with shell			
86	Dirty fine sand with shell	L-M	M	M-D
87	Dirty fine sand with shell	M	M	
88	Dirty fine sand with shell	T-M	T-L	
89	Dirty fine sand with shell		T	M
90	Dirty fine sand with shell		T-L	
91	Dirty fine sand with shell	T-L		
92	Dirty fine sand with shell			M
93	Dirty fine sand with shell			
94	Dirty very fine sand with shell			
95	Dirty shell with sands	L-M	M	M-D
96	Dirty shell with sands	L-D	M-D	
97	Dirty shell with sands		M	M
98	Dirty shell with sands		D	
99	Dirty shell with sands	L	L	

Group E - Clean sands (No lutite component)

Code	Matrix	Inclusions		
		Coarse Shell	Pebbles or Granules	Foraminifera
100	Clean very coarse to coarse sands with shell	T	M	
101	Clean very coarse to coarse sands with shell		D	M
102	Clean very coarse sand with shell		T	
103	Clean coarse to medium sands with shell	L	M	
104	Clean coarse to medium sands with shell	T	T	
105	Clean coarse sand with shell		T-L	
106	Clean coarse sand with shell	T		
107	Clean medium to fine sands with shell	T	T	
108	Clean medium to fine sands with shell	L		
109	Clean medium to fine sands with shell			M
110	Clean medium to fine sands with shell			
111	Clean medium sand with shell	L-M	M	M-D
112	Clean medium sand with shell	T-M	M-D	
113	Clean medium sand with shell		M	
114	Clean medium sand with shell	T-L	T-L	M-D
115	Clean medium sand with shell	T-D	T-L	
116	Clean medium sand with shell		T-L	M
117	Clean medium sand with shell		T-L	
118	Clean medium sand with shell	T		M
119	Clean medium sand with shell			M
120	Clean medium sand with shell			
121	Clean fine sand with shell	L	M	M
122	Clean fine sand with shell		M	M
123	Clean fine sand with shell	T	T	
124	Clean fine sand with shell		T	M
125	Clean fine sand with shell		T	
126	Clean fine sand with shell	T-D		
127	Clean fine sand with shell			
128	Clean very fine sand with shell			
129	Clean shell with sands	T-M	M-D	M-D
130	Clean shell with sands	L-D	M-D	
131	Clean shell with sands		M-D	D
132	Clean shell with sands	L-M	T	M
133	Clean shell with sands		T	
134	Clean shell with sands			M

3.2.6 DISTRIBUTION OF MAJOR GROUPS BY GRID SQUARES AND DEPTH

(a) Method of display

Because of the impracticability of plotting individual sampling sites according to 134 sediment types on a single map, the overall picture of sediment distribution is displayed only in terms of the five major sediment groups A-E (see also Table 8).

Group A - Fine muds and silts (118 samples)
Group B - Very muddy sands (325 samples)

Group C - Muddy sands (1480 samples)
Group D - Dirty sands (295 samples)
Group E - Clean sands (117 samples)

The data are displayed (Fig. 65) in the format of grid square maps in which individual squares are blackened to indicate presence of a particular sediment group in a particular grid square on the basis of one or more sampling sites. Because of the area dimension of grid squares (six minutes latitude by six minutes longitude) certain squares will contain pockets of sediments of various types, and a particular square may be present in more than one of the five distribution maps. Thus there appears to be considerable overlap in distribution by area of the major groups.

(b) Sampling pattern and sediment distribution according to depth

Because the primary classification of the five groups is based on relative lutite content, and display by grid squares demonstrates a gradient of decreasing lutite content in sediments from shore to seaward, group distribution is examined in relation to depth (Table 9). Frequency of sampling varied with depth as well as area because fishing was concentrated mainly in several areas which had particular depth range characteristics. The fishing pattern is the basis for the bias towards higher frequencies of sampling in certain depths.

It is to be observed that Group A type sediments, with one exception, are confined to depths of four fathoms or less. Also Group B type sediments have not been observed in depths greater than 12 fathoms. Sediments of Group C type occur at all depths of the range sampled. Sediments containing no lutite or trace quantities only (Groups E and D) are not found at depths greater than 17 fathoms but are characteristic of particular areas.

Table 9. Distribution of sediments according to depth and major group classification.

Numbers are frequencies of samples. Samples include those collected at beginning and end of trawl paths.

Depth	Number of samples					
(fm)	Group A	Group B	Group C	Group D	Group E	Total
1	19	27	15	7	13	81
2	50	49	36	20	3	158
3	37	82	46	11	5	181
4	11	56	56	11	3	137
5		32	70	15	6	123
6		27	111	23	12	173
7		25	168	29	9	231
8		11	217	31	11	270
9		8	315	33	14	370
10		2	172	23	9	206
11		4	118	24	11	157
12	1	2	68	34	9	114
13			39	10	3	52
14			15	10	4	29
15			16	4	4	24
16			6	7	1	14
17			7	3		10
18			2			2
19						
20			1			1
21			1			1
22			1			1
1-22	118	325	1480	295	117	2335

(c) Distribution of sediments according to area

The grid square method of display (Fig. 65) is sufficient to demonstrate the gradient of decreasing lutite content in sediments from shore to seaward. This is generally in accord with the topographical characteristic of the gulf floor sloping gently from the shoreline to seaward.

Group A - The lutite and very fine sand components are dominant, but there may also be sand grains of other sizes and shell fragments. However these other components are usually present in trace to low quantities. These fine muds and silts are confined to the near shore periphery of the area especially along the east and south. This band is between the shoreline and the 4-fathom contour.

Group B - The distribution of sediments of this type overlaps that of Group A and extends further from the shoreline especially in the western part of the area. This group is classified as very muddy sands because of the moderate quantity of lutite which binds a moderate to dominant matrix of one or more sizes of sand grains in the range of medium, fine and very fine. Coarse and very coarse sand grains may also be present but are usually only at trace to low levels. Shell fragments in various size and quantity combinations are invariably present. Foraminifera tests are usually present in trace quantities. Coarse shell fragments and small pebbles are inclusions in some areas.

Group C - Muddy sands combined into this group have extremely wide distribution throughout the area. This type of sediment is characterized by its low lutite content binding a mixture of sands and shell fragments in various size and quantity combinations. Foraminifera tests are usually present in trace quantities. The 35 recognized varieties form 10 sub-groups (Table 8) on the basis of sand grain size. A very high percentage of samples contained sand grains in four or five of the size categories. In samples where only one or two grain sizes are present the grains are restricted to the fine and very fine categories. A high percentage of the total samples have fine sand grains at dominant level and very fine sand grains at moderate level. Most samples contain shell fragments ranging from medium to very fine, and a high percentage are characterized by moderate quantities of the fine and very fine size categories. Inclusions of coarse shell fragments and small pebbles or granules are common, but quantity levels other than trace to low of these components are rare.

Group D - Sediments of this type have been classified as dirty sands because their major content of sand grains and shell fragments are mixed with only a trace of lutite. They occur mainly in the northern half of the area, the south-west corner, and in isolated pockets off river mouths. The sand and shell components each vary greatly in size and quantity combinations. The relative proportions, of these two components also varies greatly, with a range from coarse sands with little shell to predominantly shell grit. Sixteen sub-groups are recognized and these vary mainly according to sand grain size. Sand grains in four or five size ranges and shell fragments in three size ranges are characteristic of most samples. Coarse shell fragments and small pebbles are frequent inclusions but Foraminifera tests are usually at trace to low levels. However there are some cases where coarse shell fragments, pebbles and Foraminifera are present in moderate to dominant quantities.

Group E - Clean sands which appear to be entirely devoid of lutite are mainly characteristic of deeper water and the northern part of the area. However isolated pockets of these clean sands are found close to the eastern and southern shorelines. They differ little from sediments of Group D with respect to sand and shell composition in various combination. Coarse shell fragments and small pebbles or granules are frequent inclusions. Coarse shell fragments, when

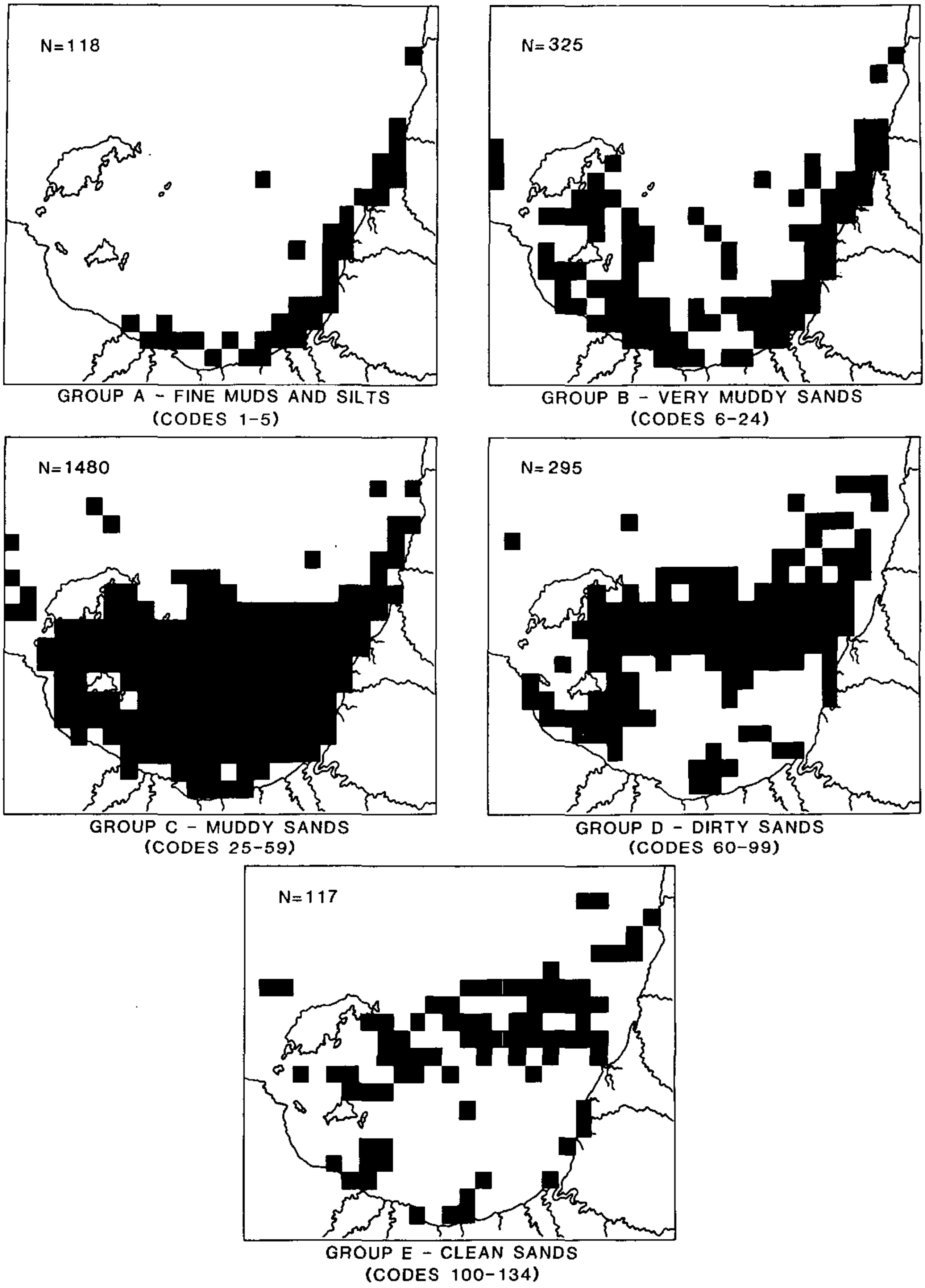


Fig. 65 Distribution of the five major groups of bottom sediments according to grid square division of the survey area. Grid squares are defined in Fig. 38 (Part 2, Section 2.3.2) and Sediment Groups A - E are defined in Table 8 (Part 3, Section 3.1.6). Blackened squares are those in which sediments of a group have been recorded from one or more station sites within that grid square.

present, are usually only in trace to low quantities, but as with the case of small pebbles and Foraminifera, may be in moderate to dominant quantities. The nine recognized sub-groups in this category vary from the fine sediment coded 128 which has dominance of very fine sand grains and traces of very fine shell fragments, to coarse shell grits containing large quantities of small pebbles and Foraminifera coded 129-134.

3.2.7 DISTRIBUTION OF INDIVIDUAL COMPONENTS BY AREA

(a) Method of display

Distributions of each of the five major components including several size range categories of sand grains and shell fragments are mapped individually by area. These distributions are presented in sets composed of four maps (Figs. 66-77). Each map in such a set features the level of abundance of the particular component or size category. These relative levels are based on subjective estimates using the categories Trace (T), Low (L), Moderate (M), and Dominant (D).

Each dot on a map represents the position of a particular sampling site plotted from coordinates of latitude and longitude. Each of the twelve sets of four maps refers to only one of the group of 12 elements which in combination categorize any particular sample. Thus any one dot in a particular site position may appear as many as 12 times through the twelve sets of four maps. The sets of maps provide data on presence only in terms of the four levels of abundance. This means that all dots in any set of four maps collectively represent the total distribution of that one particular element, though the actual sampling was more extensive because site positions where that particular element was missing are not shown. The 12 elements that characterize any sediment are as follows (see also Table 8):

Lutite

Very coarse sand grains
Coarse sand grains
Medium sand grains
Fine sand grains
Very fine sand grains

Coarse shell fragments
Medium shell fragments
Fine shell fragments
Very fine shell fragments

Pebbles and granules

Foraminifera tests

(b) Effects caused by sampling

In this group of maps it will be noticed that one or more of the distributions in each set of four is characterized by denser clustering in one or more general areas. This clustering is caused simply by an uneven pattern of sampling throughout the area. Whereas the whole area has been sampled during reconnaissance in a systematic manner, fishing operations were concentrated in several areas so increasing the density of sampling sites in those areas. Such areas include the coastal periphery between the mouths of the Albert and Gilbert Rivers, the sector between Sydney, Bountiful and Bentinck Islands, the deeper central area, and the gutter system offshore from the Smithburne River delta system.

3.3 SALINITY

3.3.1 SAMPLING

During the fishing operations of the survey vessel an attempt was made to obtain as much information as possible about salinity characteristics with respect to area and season without interfering with normal work schedules. Water samples were collected at most trawl station site positions. The normal practice was to obtain samples from both surface and bottom layers. In a few instances when the vessel was working in

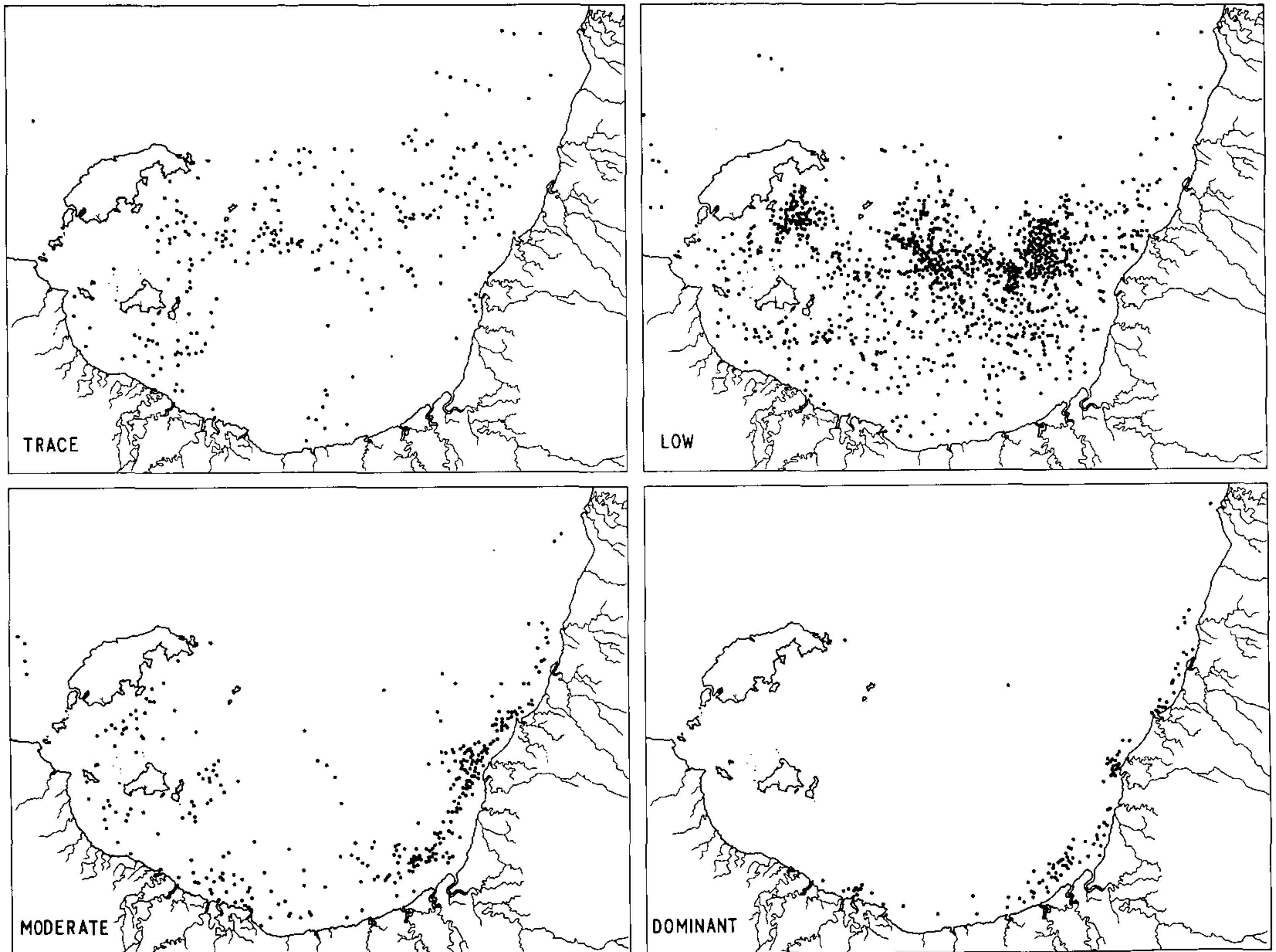


Fig. 66 Distribution by area of the sediment component LUTITE at four levels of relative abundance. Individual dots are positions of station sites where this component was present at the level indicated.

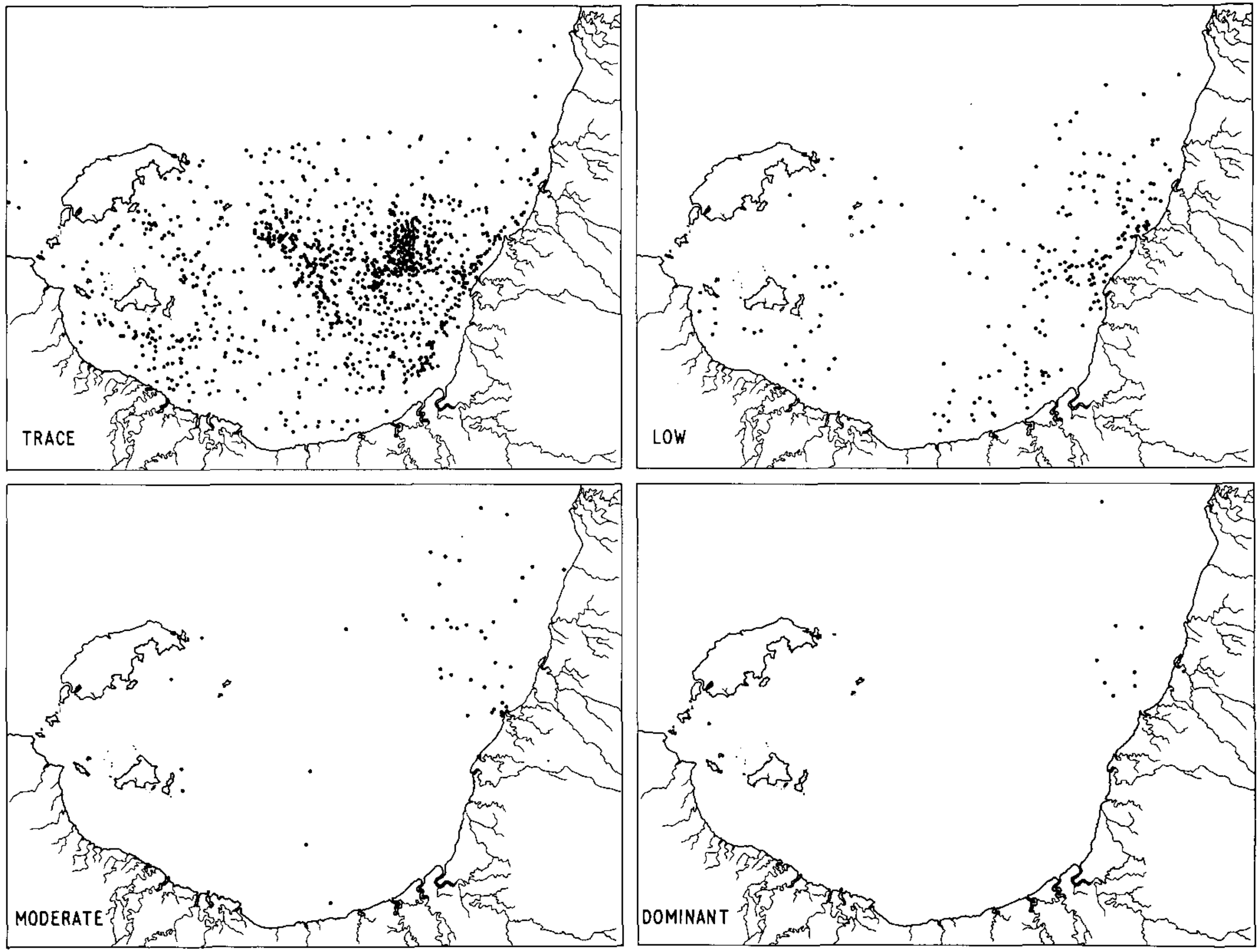


Fig. 67 Distribution by area of the sediment component VERY COARSE SAND (quartz sand grains greater than 1.2 mm) at four levels of relative abundance. Individual dots are positions of station sites where this component was present at the level indicated.

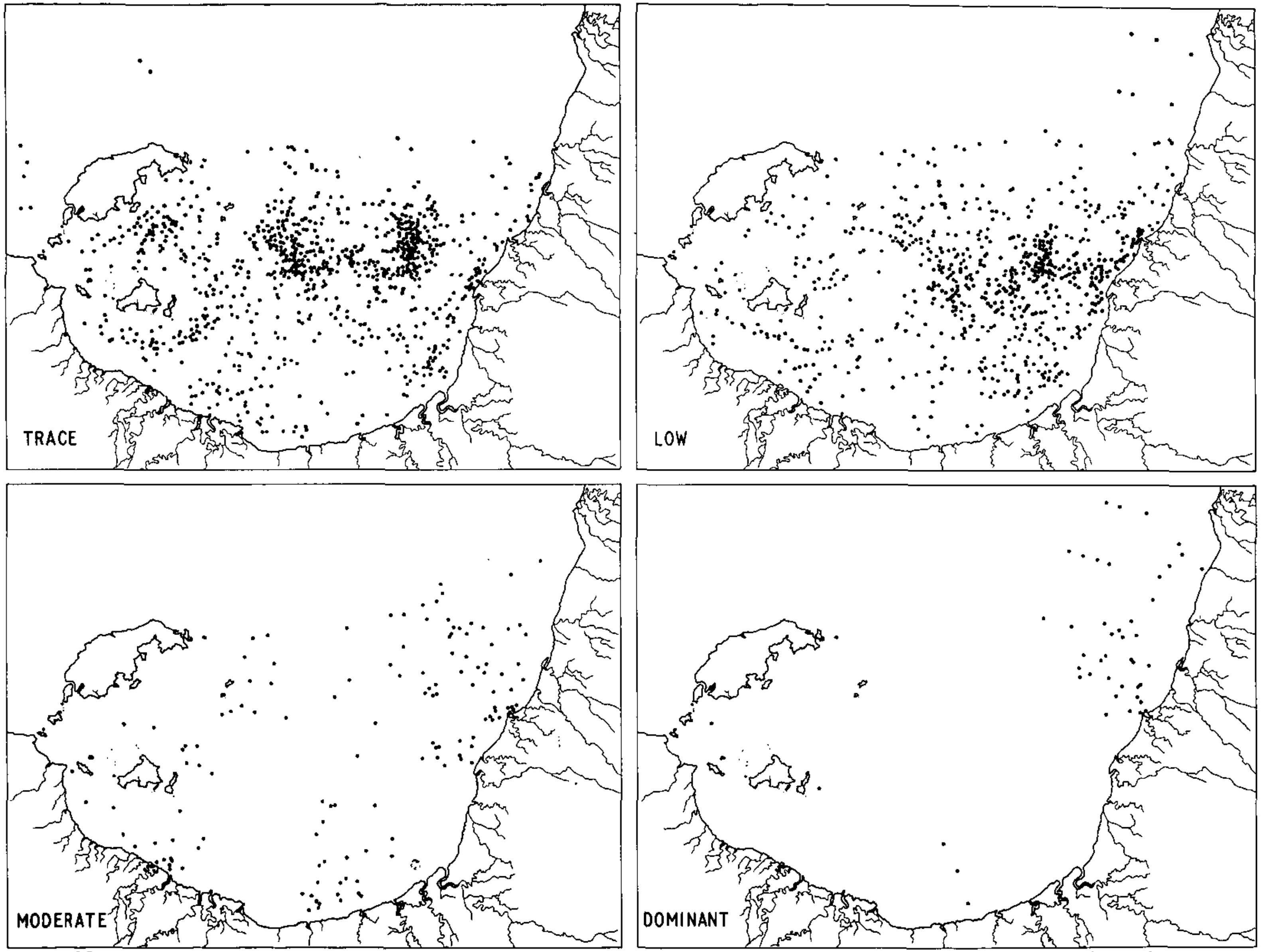


Fig. 68 Distribution by area of the sediment component COARSE SAND (quartz sand grains 0.6 - 1.2 mm) at four levels of relative abundance. Individual dots are positions of station sites where this component was present at the level indicated.

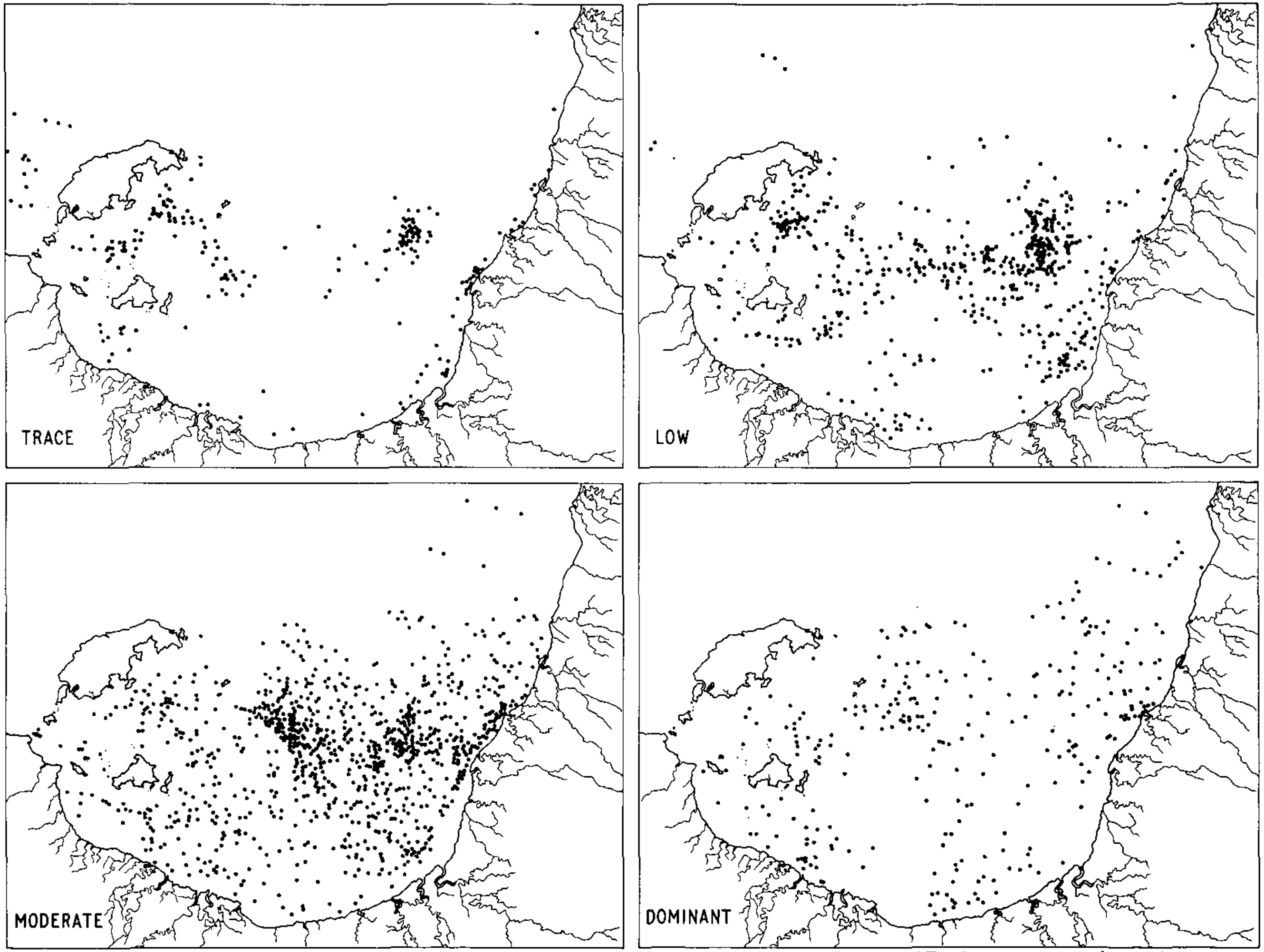


Fig. 69 Distribution by area of the sediment component MEDIUM SAND (quartz sand grains 0.3 - 0.6 mm) at four levels of relative abundance. Individual dots are positions of station sites where this component was present at the level indicated.

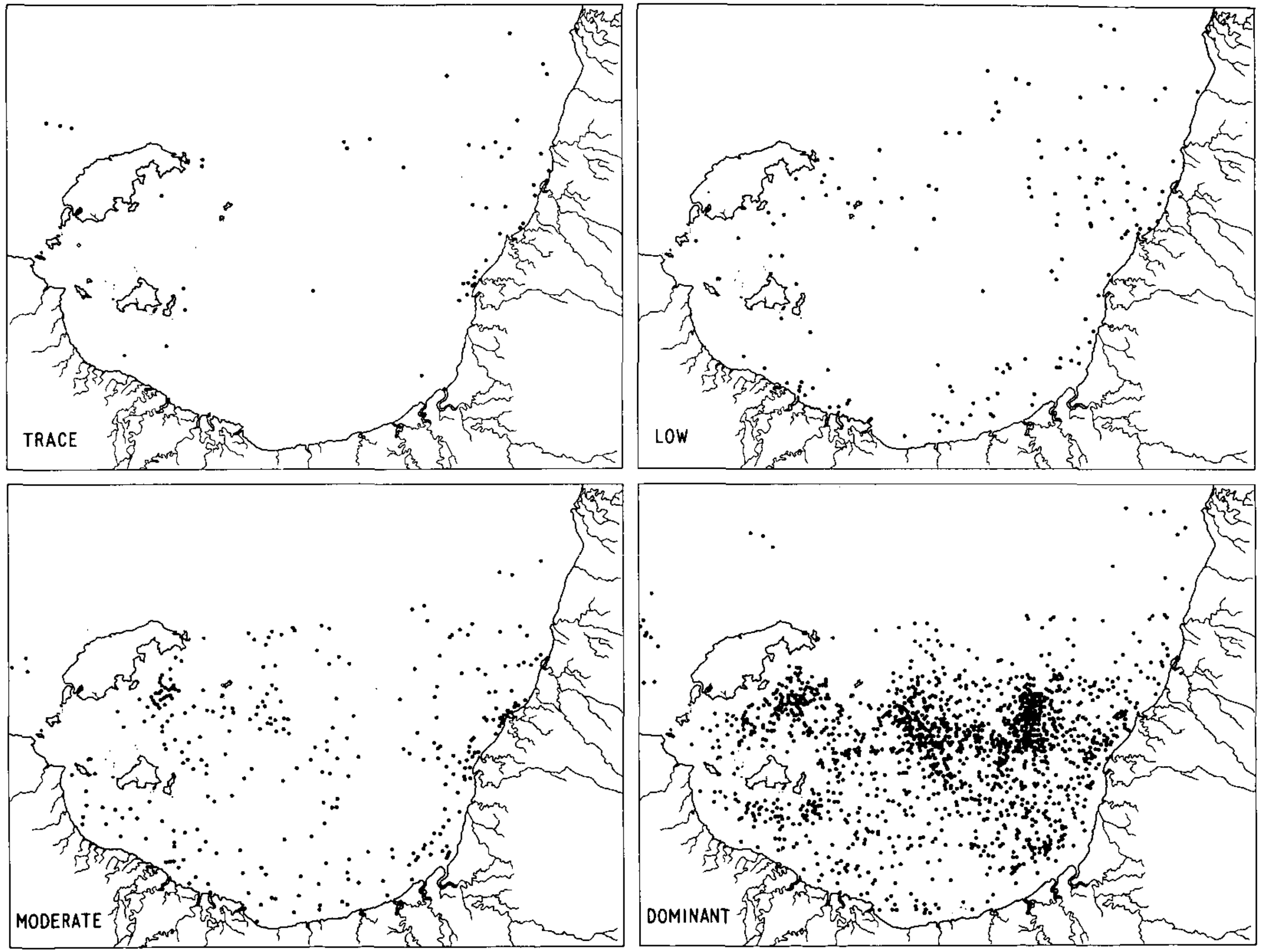


Fig. 70 Distribution by area of the sediment component FINE SAND (quartz sand grains 0.1 - 0.3 mm) at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

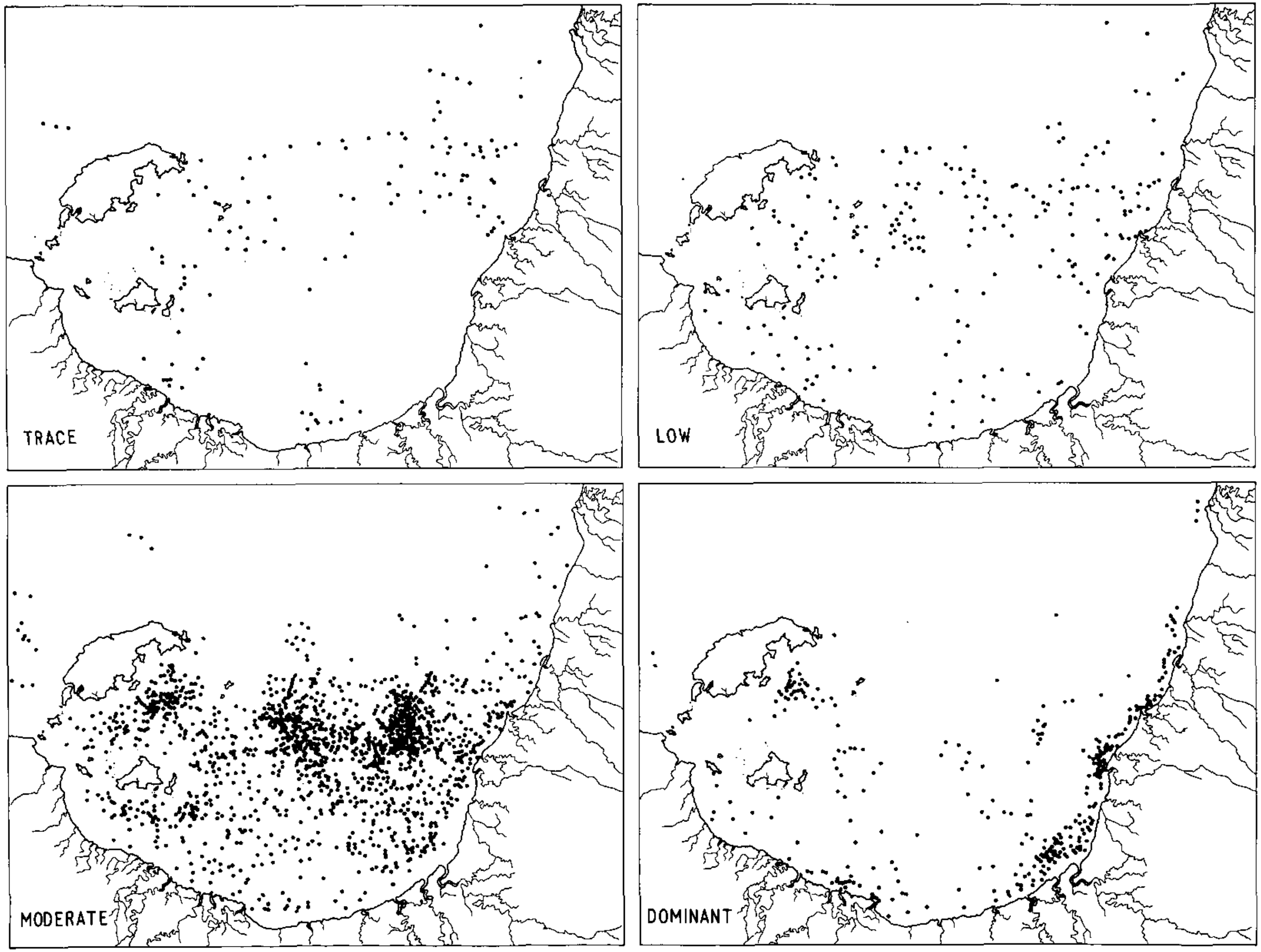


Fig. 71 Distribution by area of the sediment component VERY FINE SAND (quartz sand grains less than 0.1 mm) at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

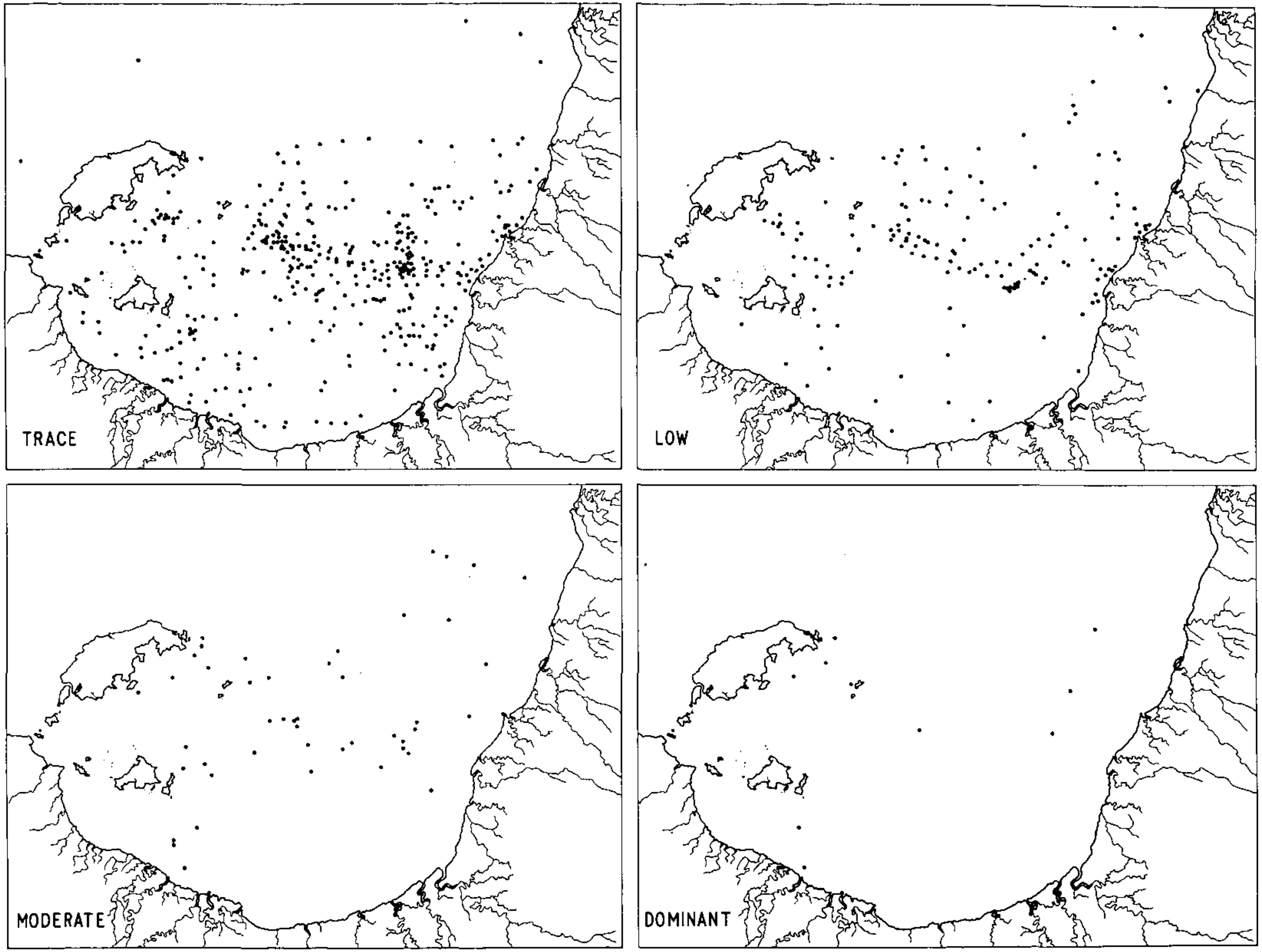


Fig. 72 Distribution by area of the sediment component COARSE SHELL (fragments greater than 10 mm) at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

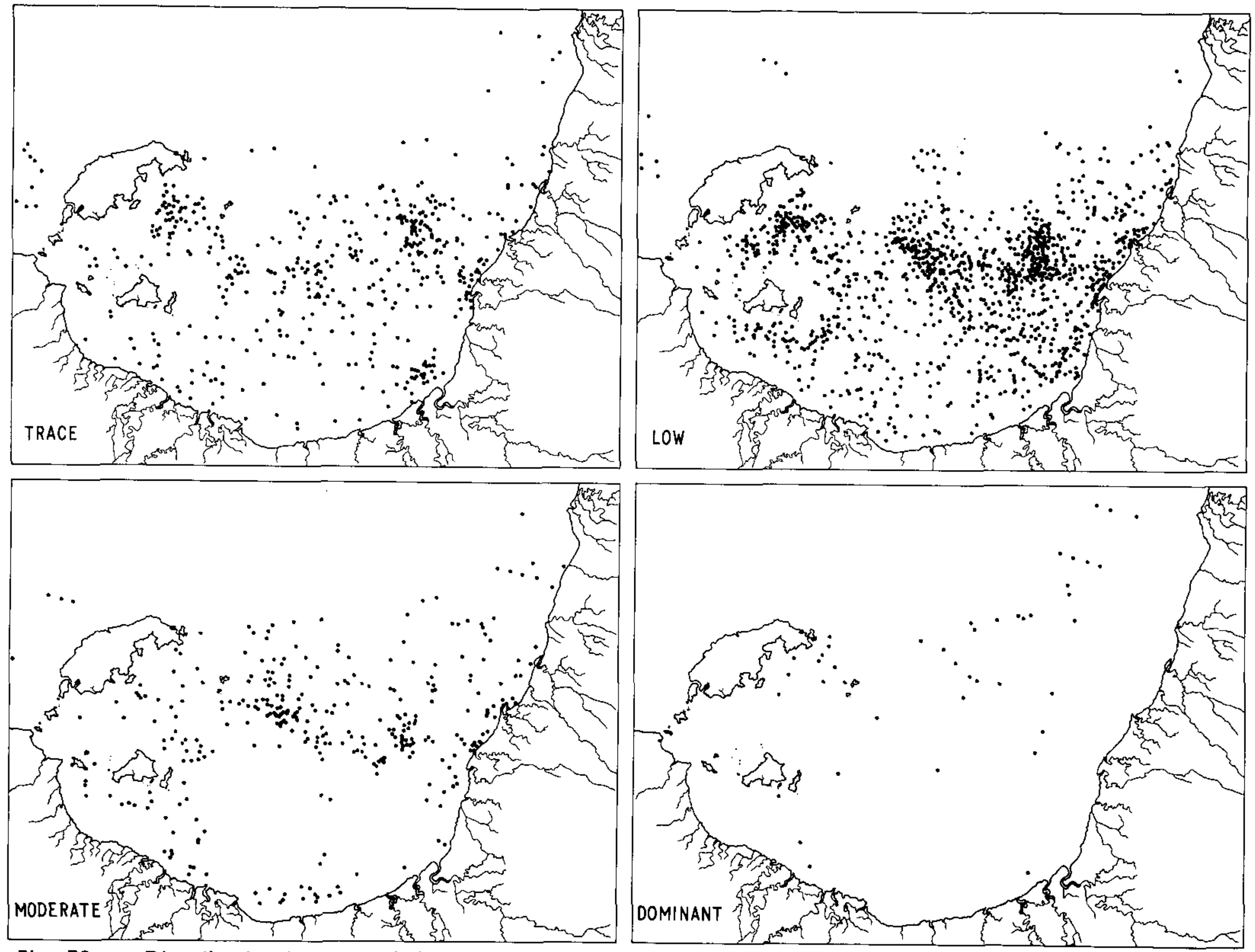


Fig. 73 Distribution by area of the sediment component MEDIUM SHELL (fragments 3.0 - 10.0 mm) at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

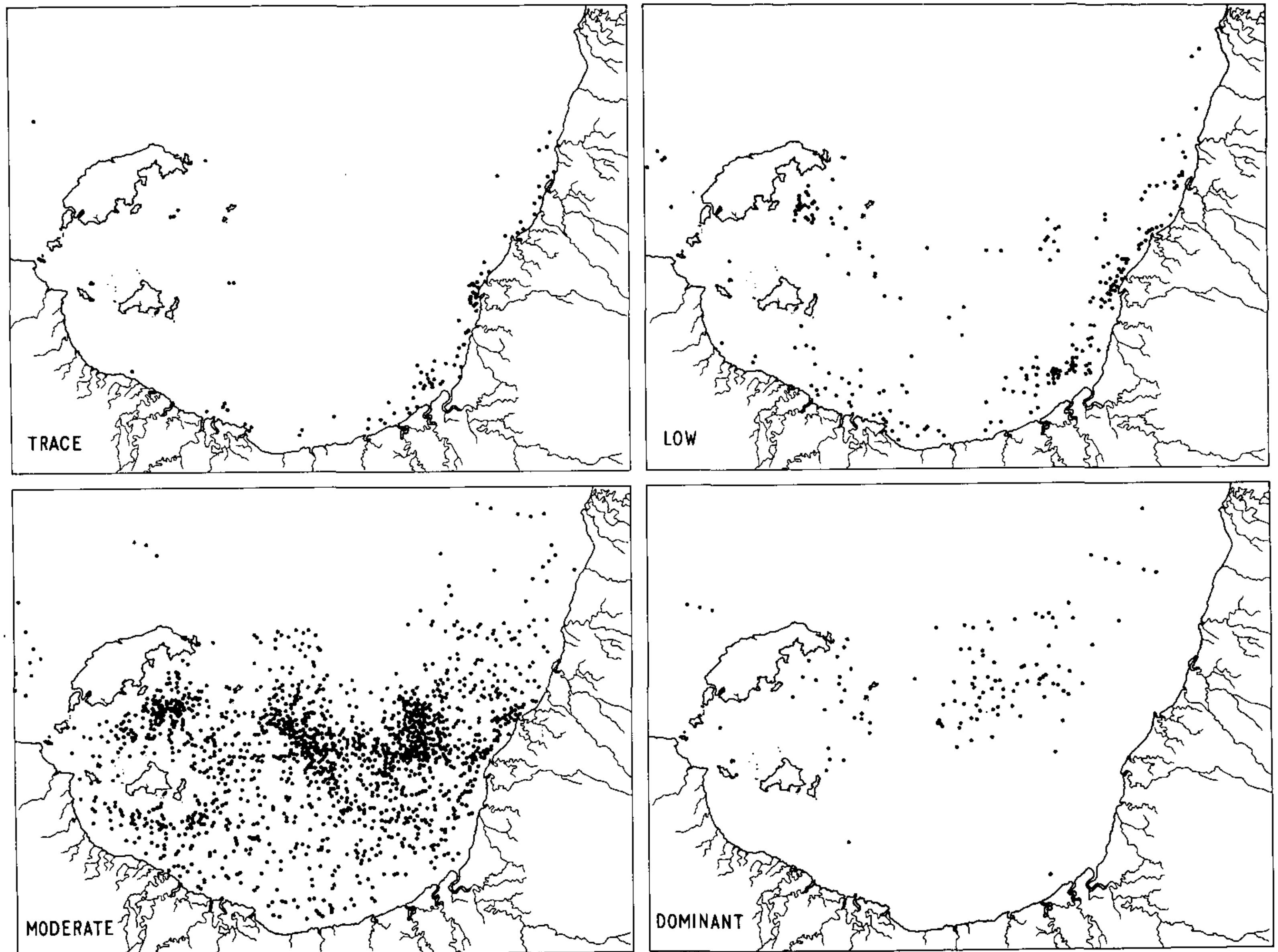


Fig. 74 Distribution by area of the sediment component FINE SHELL (fragments 0.3 - 3.0 mm) at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

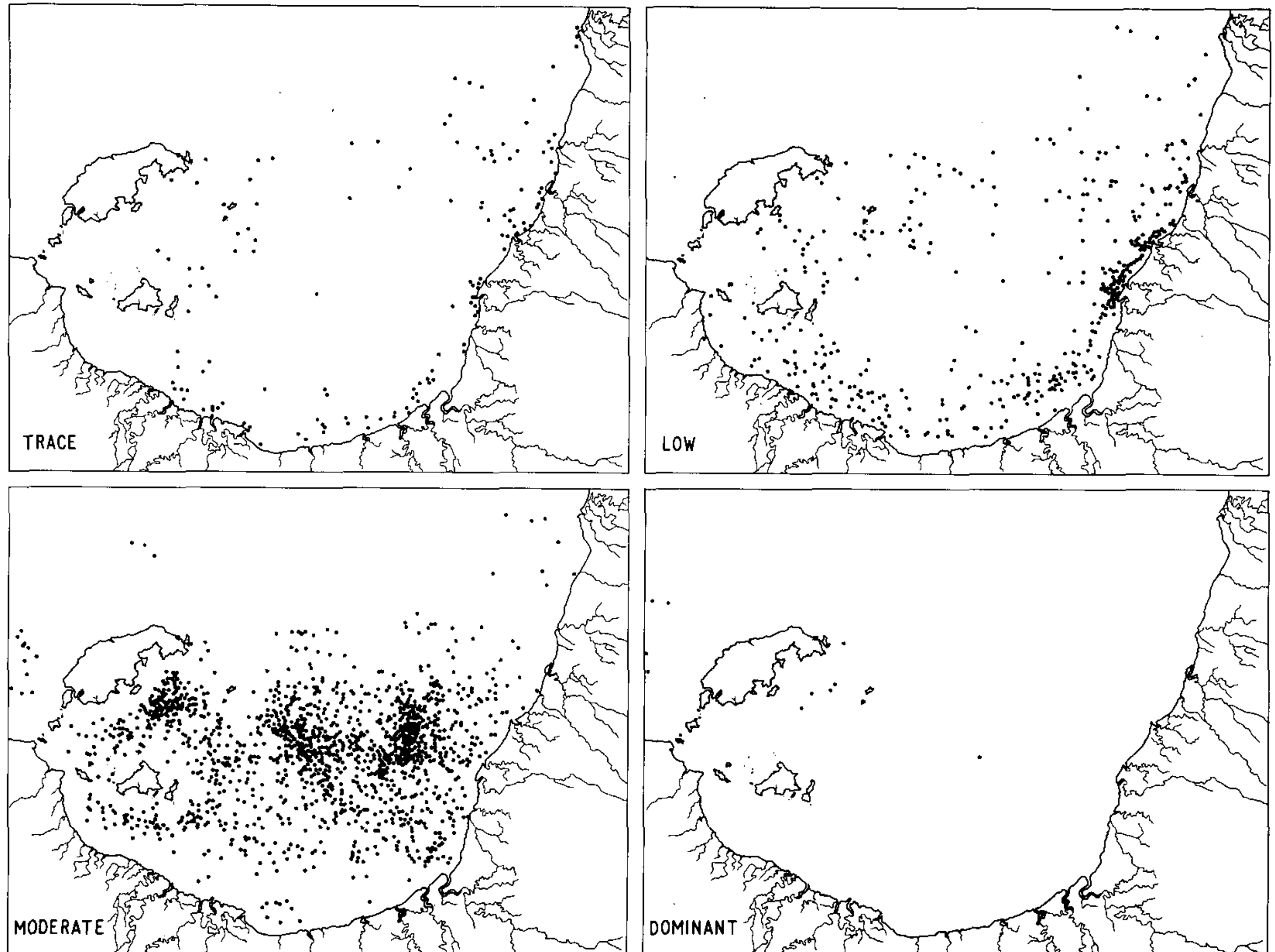


Fig. 75 Distribution by area of the sediment component VERY FINE SHELL (fragments less than 0.3 mm) at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

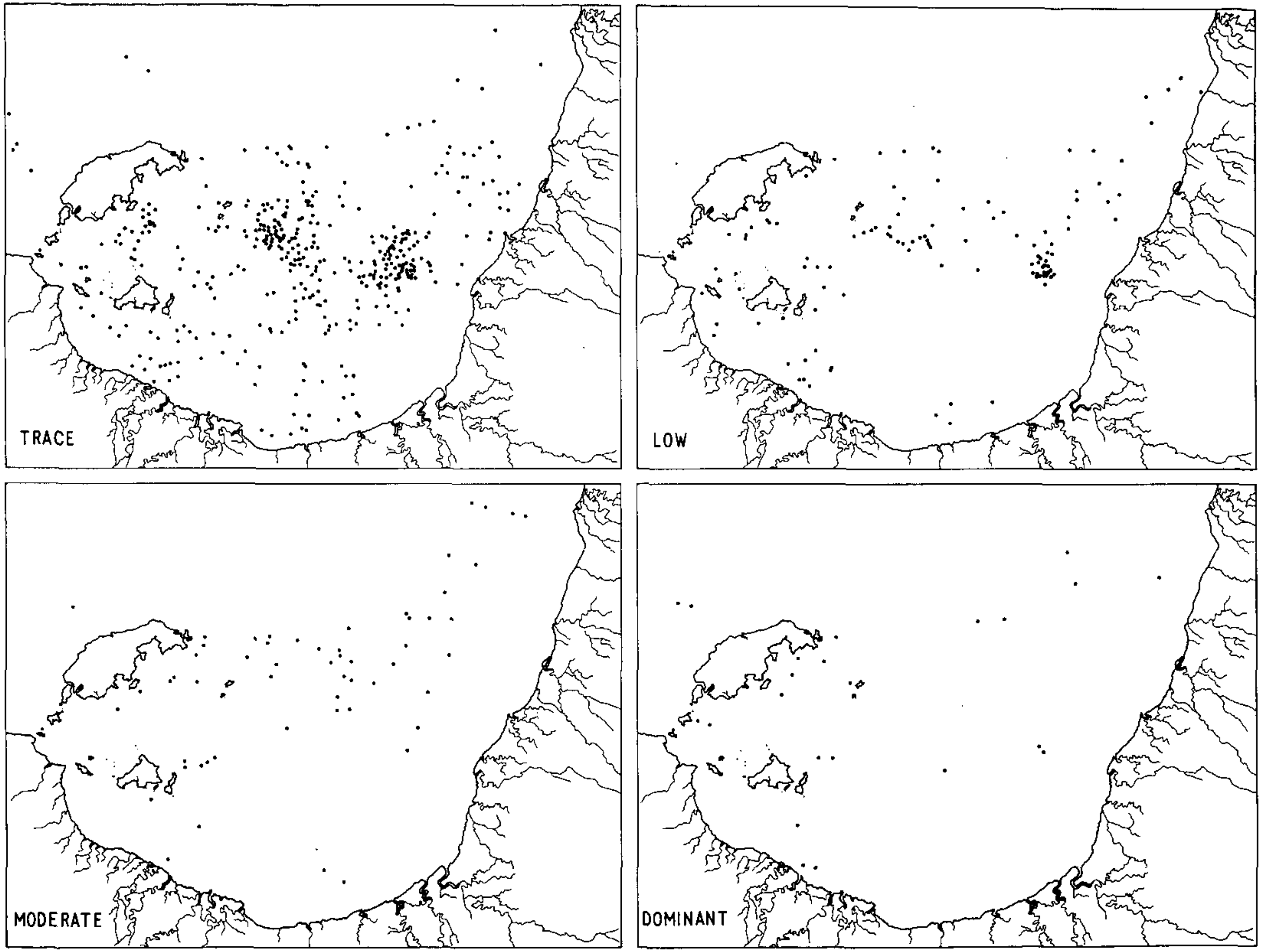


Fig. 76 Distribution by area of the sediment component PEBBLES AND GRANULES at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

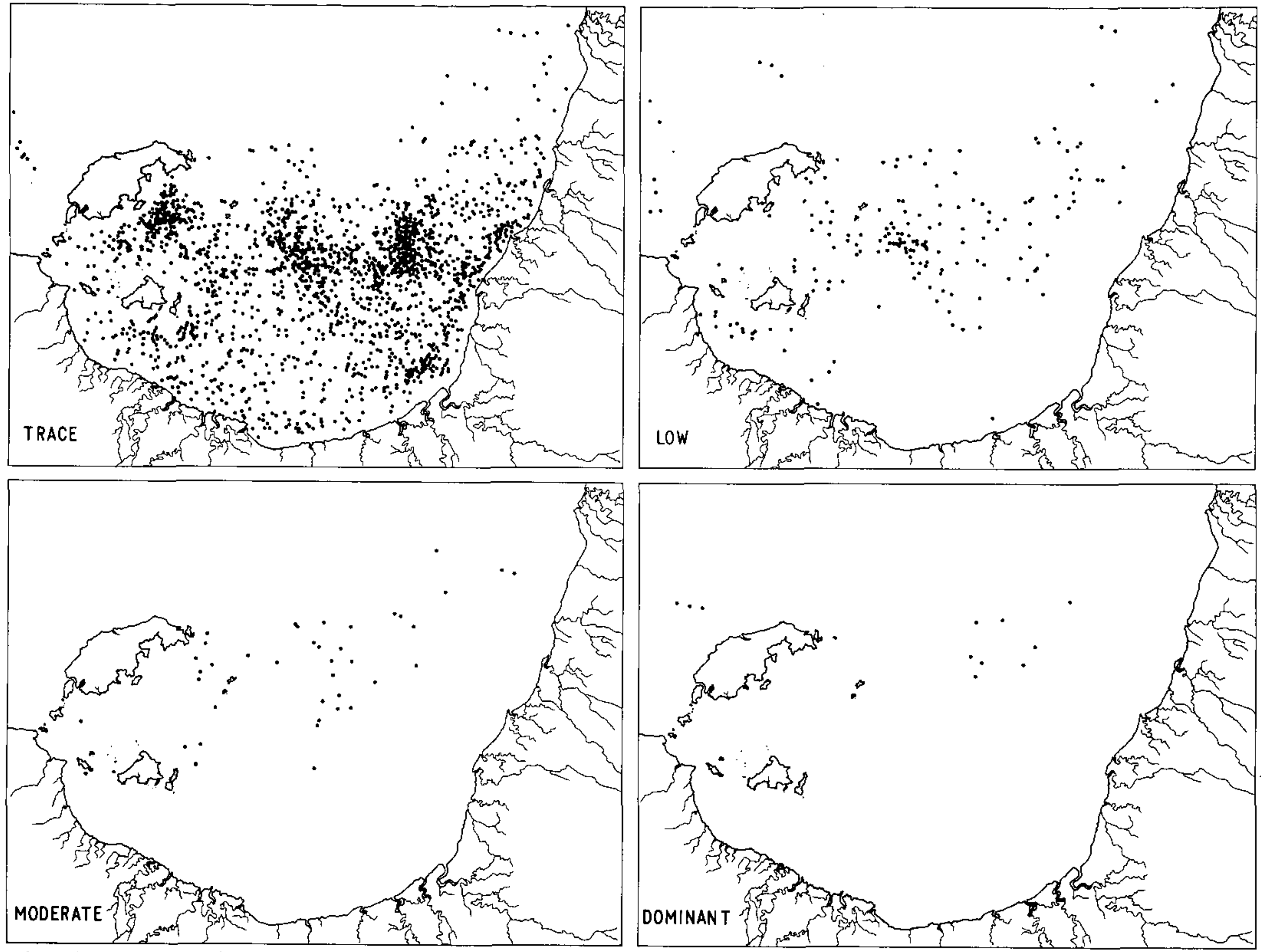


Fig. 77 Distribution by area of the sediment component FORAMINIFERA at four levels of relative abundance. Individual dots are positions of station sites where the component was present at the level indicated.

extremely shallow water (less than 2 fathoms) a single sample was collected from midwater only. Towards the end of survey operations when the vessel was making a number of consecutive trawl shots at a single site position around a dahn buoy, samples were taken but not repeatedly with every net shot.

3.3.2 METHODS

(a) Analysis of samples

Because of limitations imposed by time and space on a small vessel engaged in commercial style trawling operations, water samples collected at sea were brought ashore for analysis at the termination of each cruise.

Samples were collected with a Nansen type water sampler at positions of 1m below the surface and about 1m above the bottom. The samples were stored in numbered rubber-sealed bottles according to normal practice.

In the laboratory ashore chlorinities of samples were determined by conductivity measurements with a Hamon S-T Meter (a type of portable temperature-chlorinity bridge) (Hamon 1956). Corrected meter readings were then converted from chlorinity to salinity. All recommended procedures were followed including checks against sub-standard sea--water. Hypersaline samples from areas with high evaporation rates were treated according to the dilution method.

(b) Display of data

The salinity regime of the survey area has been described in earlier publications (Munro 1966, 1972) where seasonal values and gradient patterns were expressed as isohaline contours. The data are now displayed in Section 3.3.3 (surface) and Section 3.3.4 (bottom) as monthly maps. These maps employ grid squares for subdivision of the area.

Only those grid squares which were sampled during each monthly period are included. The data combine all measurements made during the consecutive years 1963 (July-December), 1964 (January-December) and 1965 (January--July) at station sites in any particular grid square.

Values are expressed as salinities in parts per thousand in terms of arithmetic mean, number of observations and standard deviation. The numbers read from top to bottom in each grid square represent these values respectively.

3.3.3 SURFACE SALINITIES BY GRID SQUARES BY MONTH

Data of the kind described in Section 3.3.2 (b) are displayed in the accompanying set of twelve monthly maps (Figs. 78--83).

3.3.4 BOTTOM SALINITIES BY GRID SQUARES BY MONTH

Data of the kind described in Section 3.3.2 (b) are displayed in the accompanying set of twelve monthly maps (Figs. 84-89).

3.4 WATER TEMPERATURE

3.4.1 SAMPLING

As in the case of salinities, an attempt was made to obtain as much information as possible about temperature characteristics with respect to area and season without interfering with normal work schedules during fishing operations of the survey vessel. When taking water samples, temperature measurements were made at most trawl site positions. The normal practice was to obtain readings from both surface and bottom layers. In a few instances when the vessel was working in extremely shallow water (less than 2 fathoms) a single measurement was made in the midwater layer only. Towards the end of survey operations when the vessel was making a number of consecutive trawl shots at a

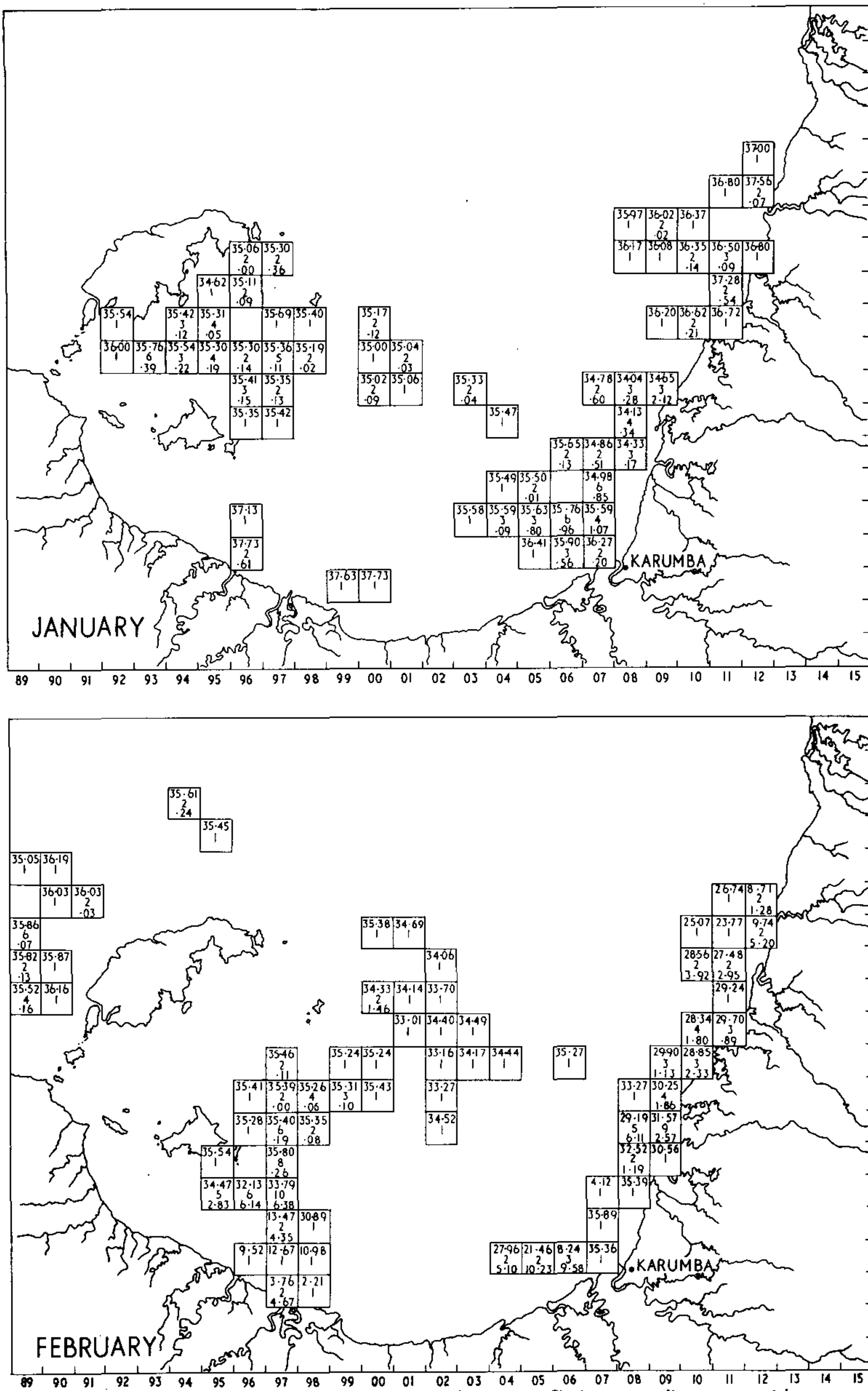


Fig. 78 Distribution of surface water salinities (‰) according to grid squares for January and February. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

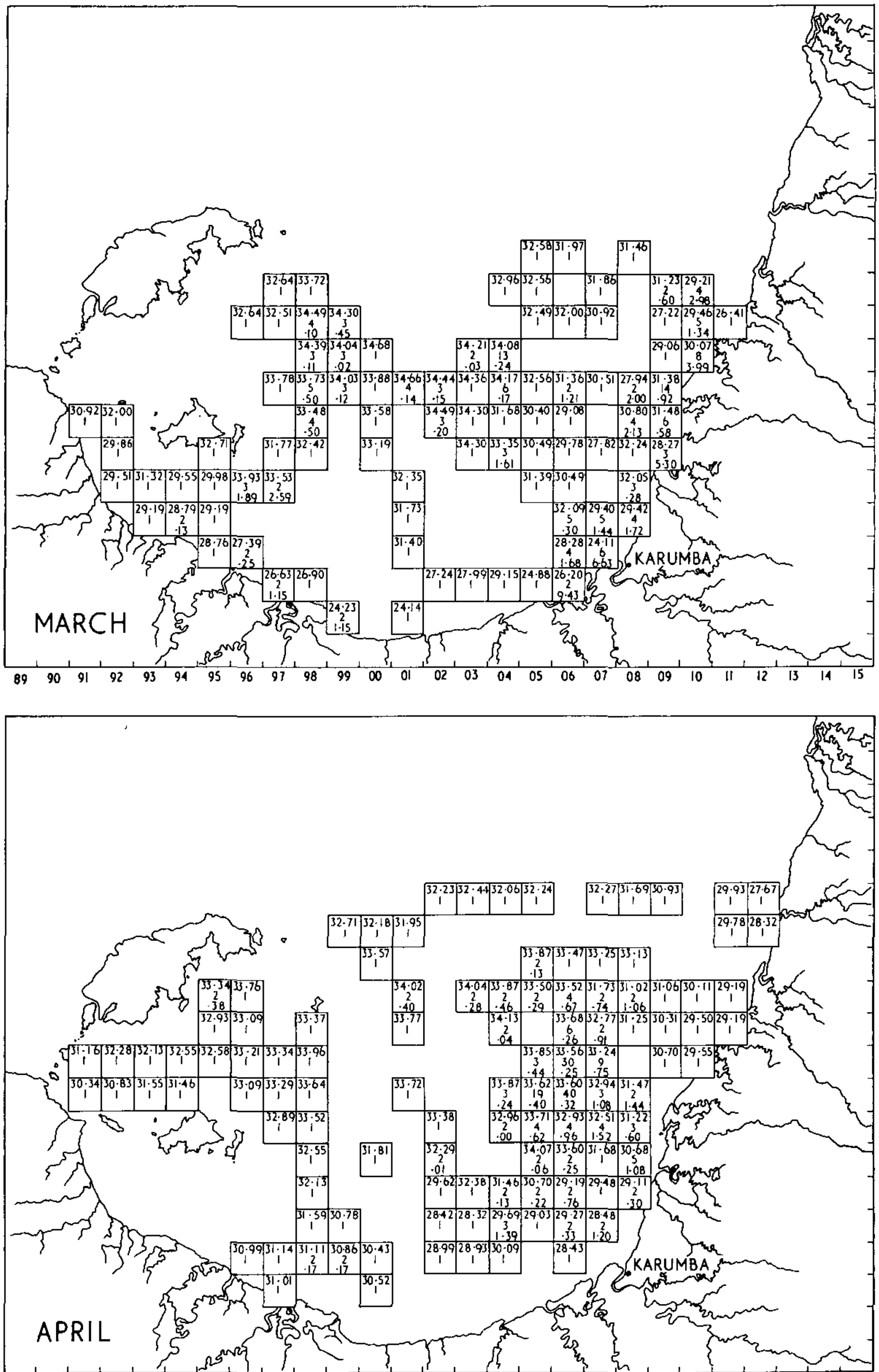
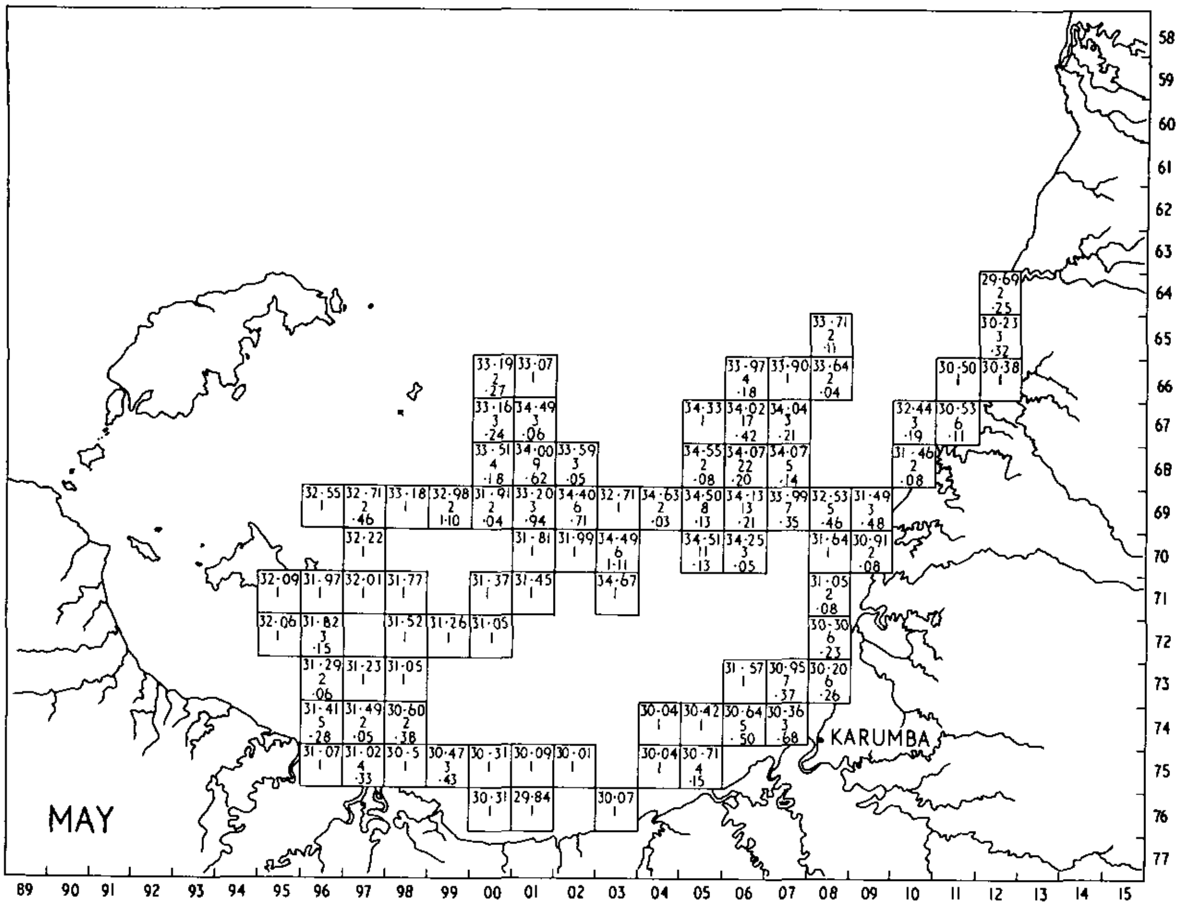


Fig. 79 Distribution of surface water salinities (%.) according to grid squares for March and April. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



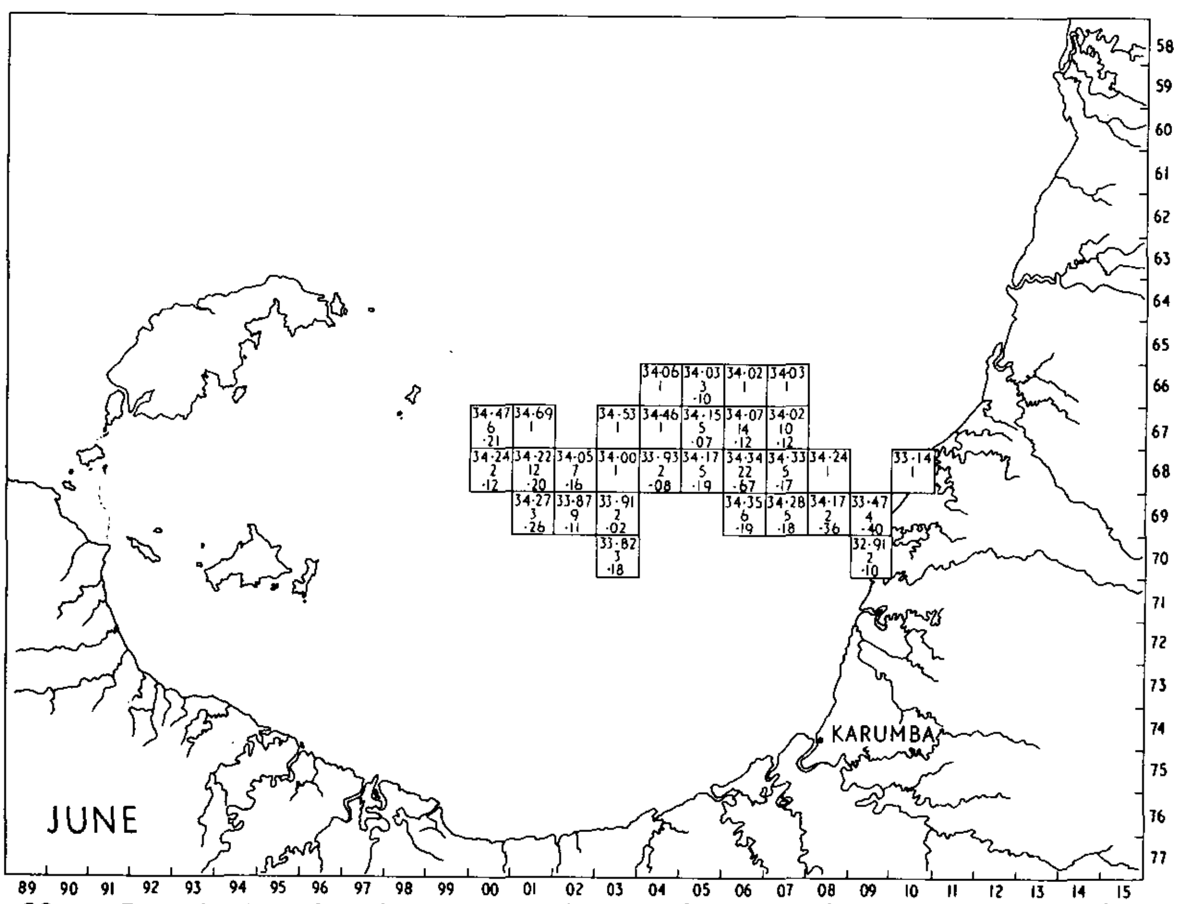


Fig. 80 Distribution of surface water salinities (‰) according to grid squares for May and June. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

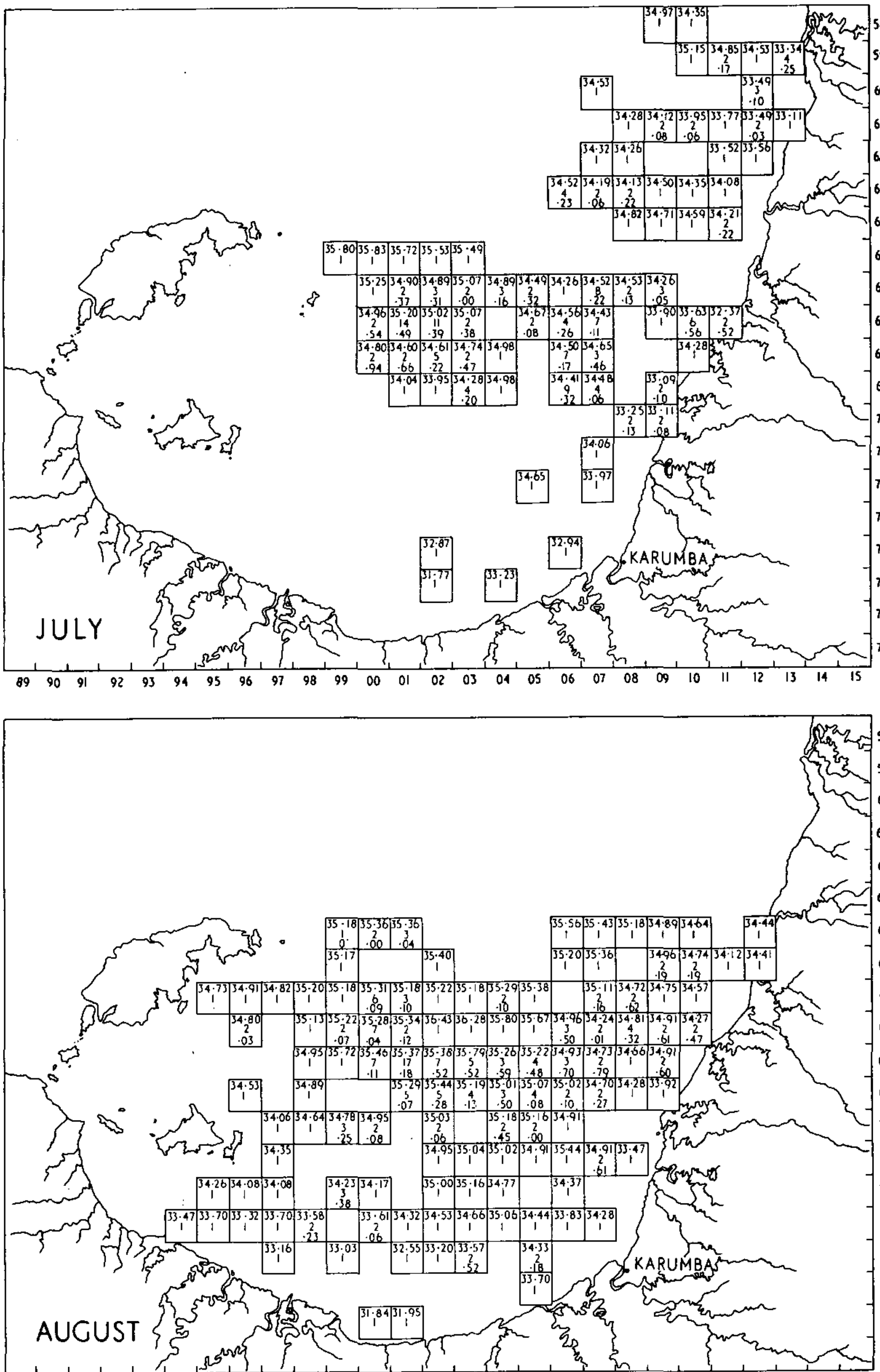
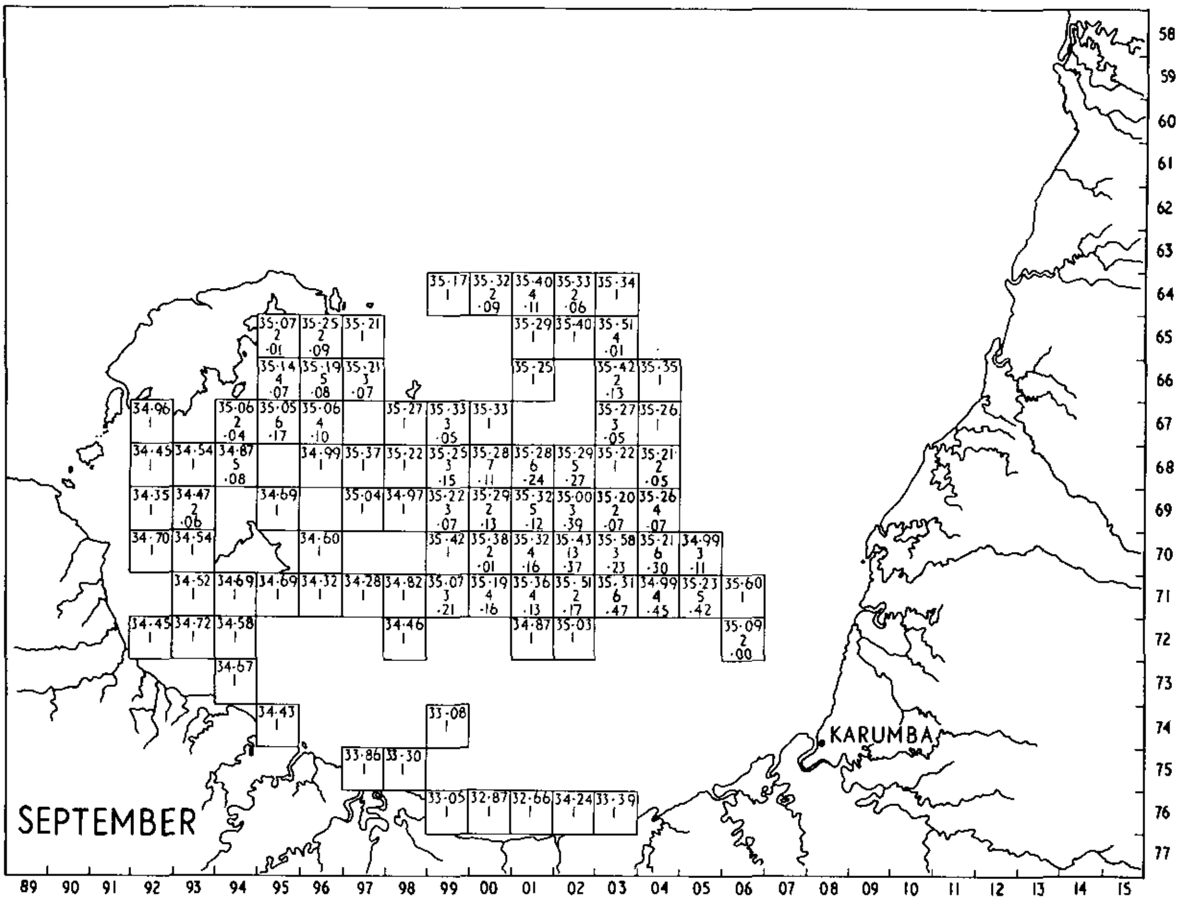


Fig. 81 Distribution of surface water salinities (‰) according to grid squares for July and August. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



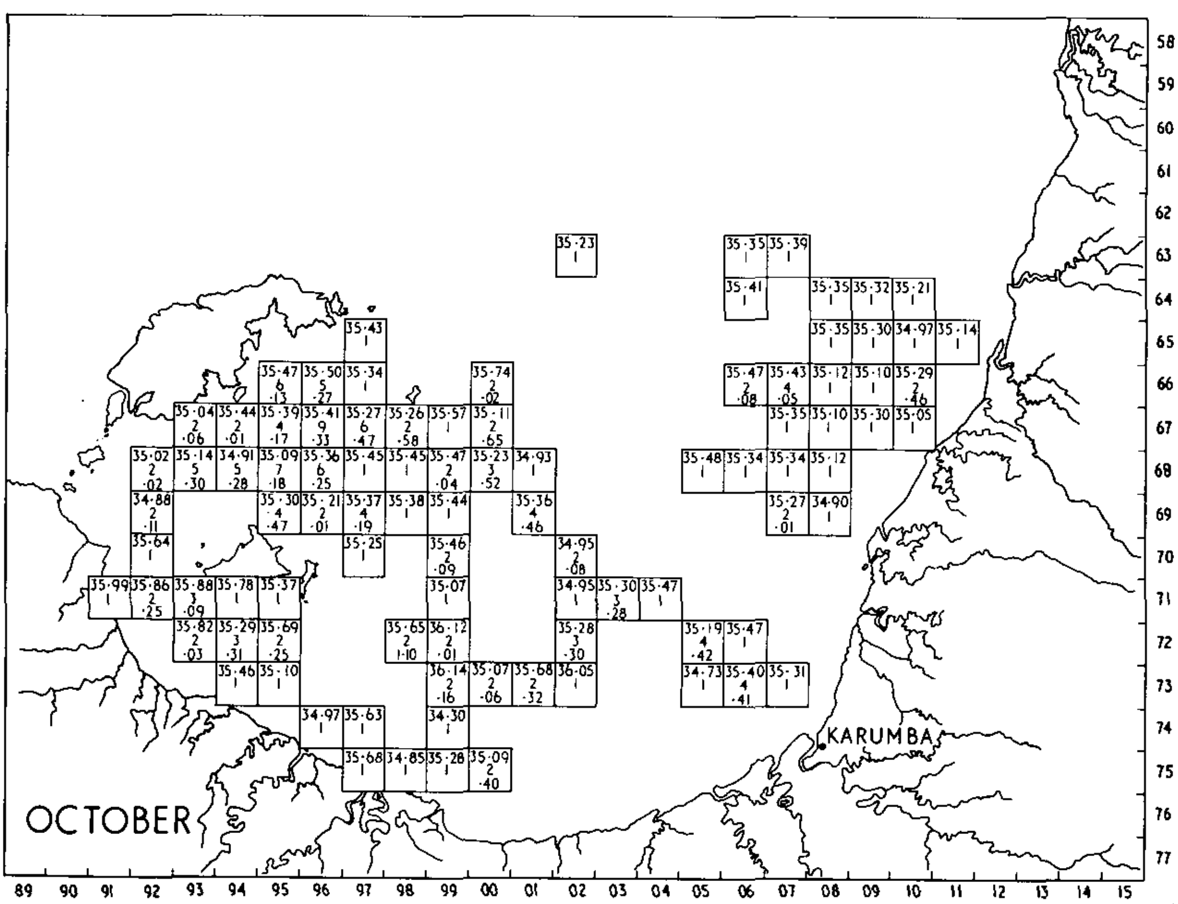
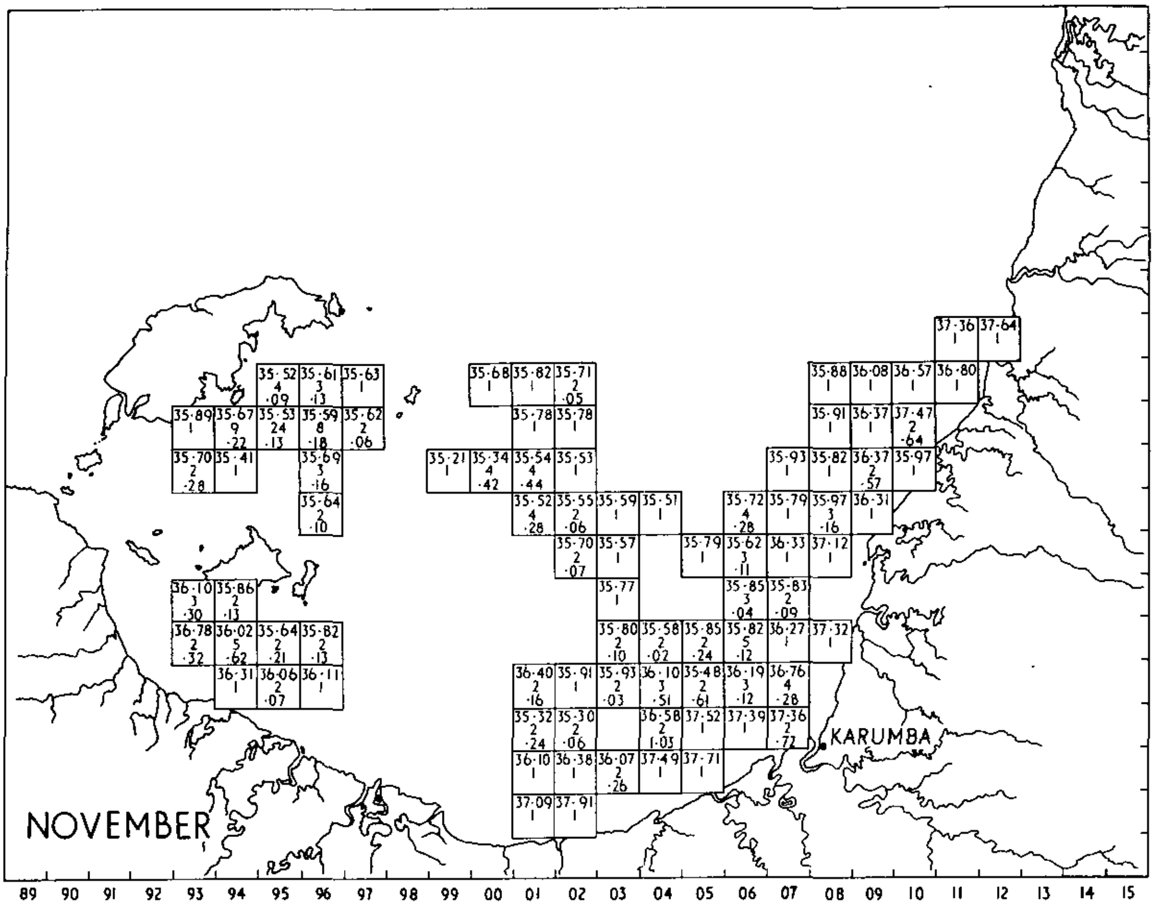


Fig. 82 Distribution of surface water salinities (‰) according to grid squares for September and October. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



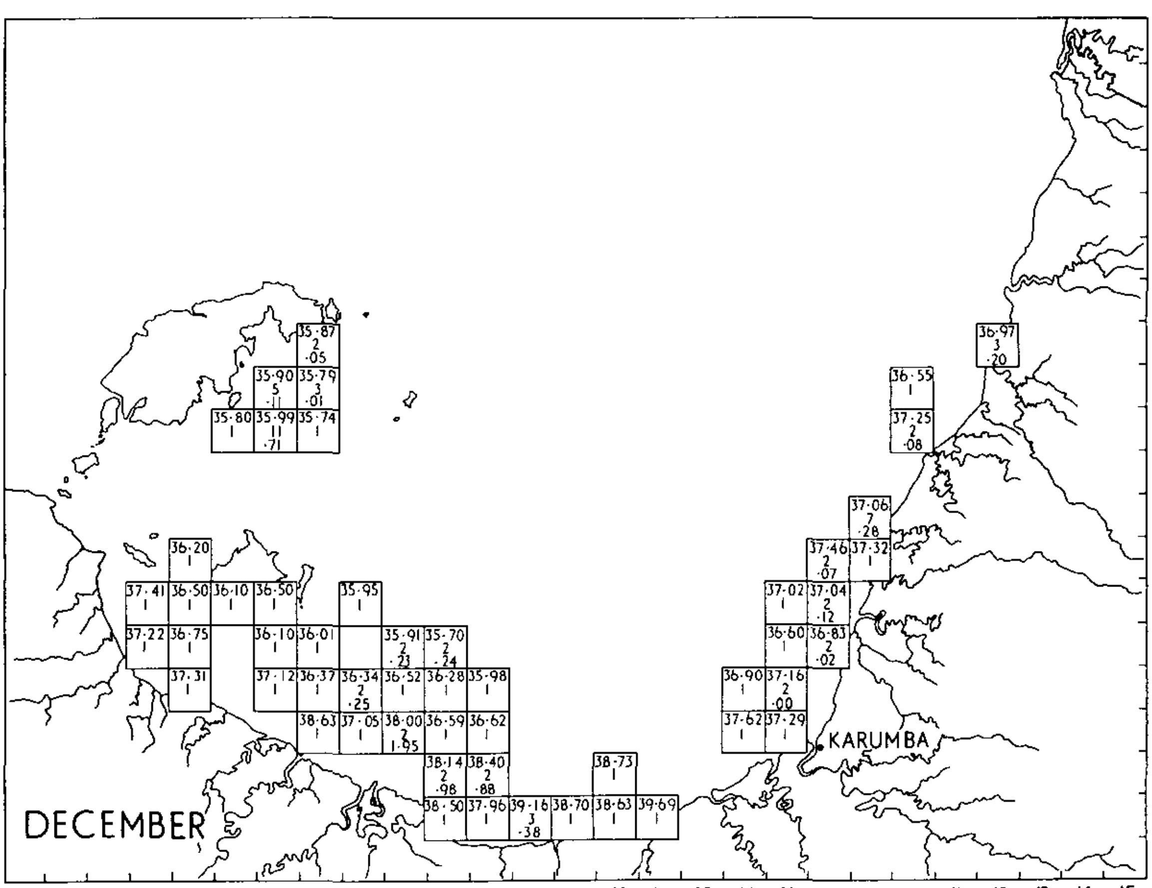


Fig. 83 Distribution of surface water salinities (‰) according to grid squares for November and December. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

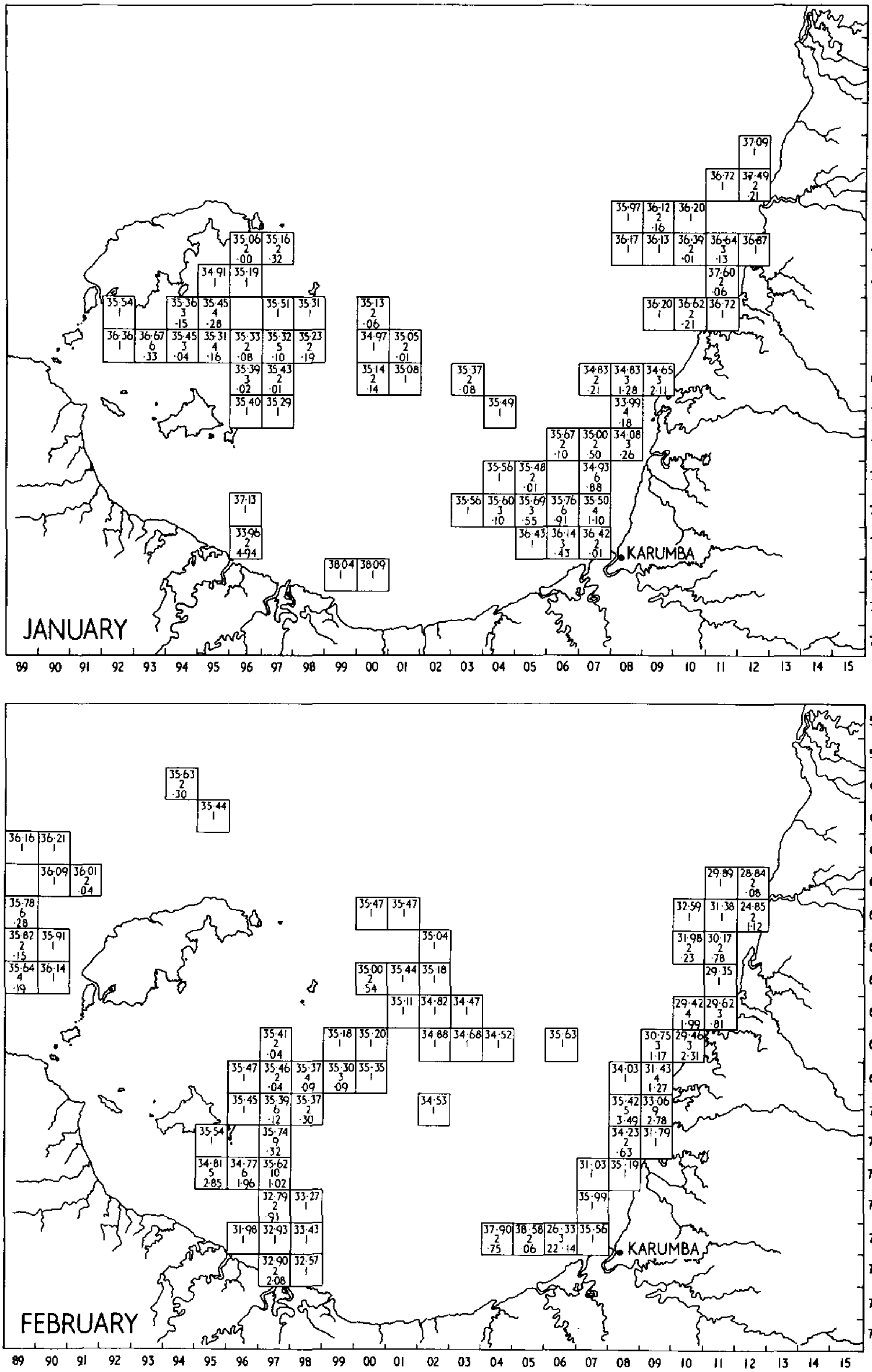
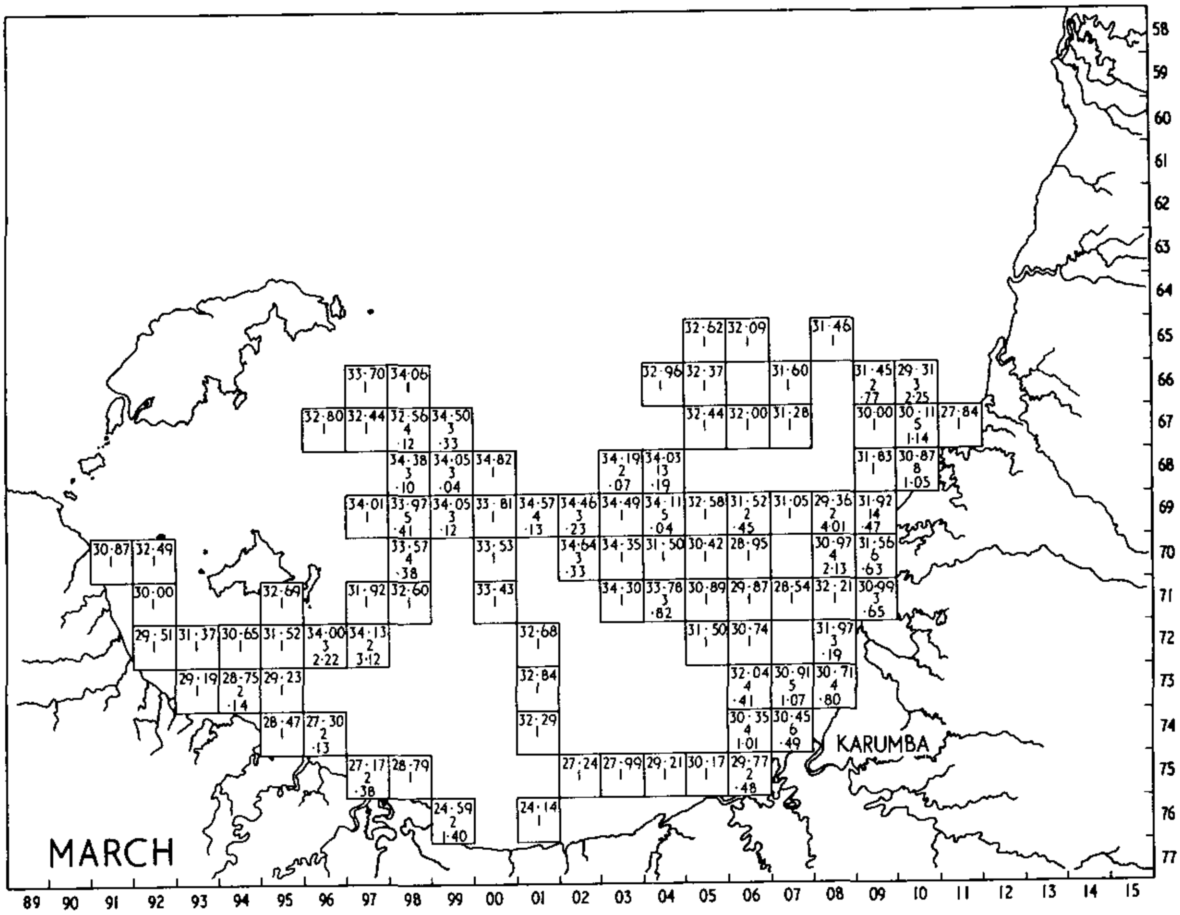


Fig. 84 Distribution of bottom water salinities (%o) according to grid squares for January and February. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



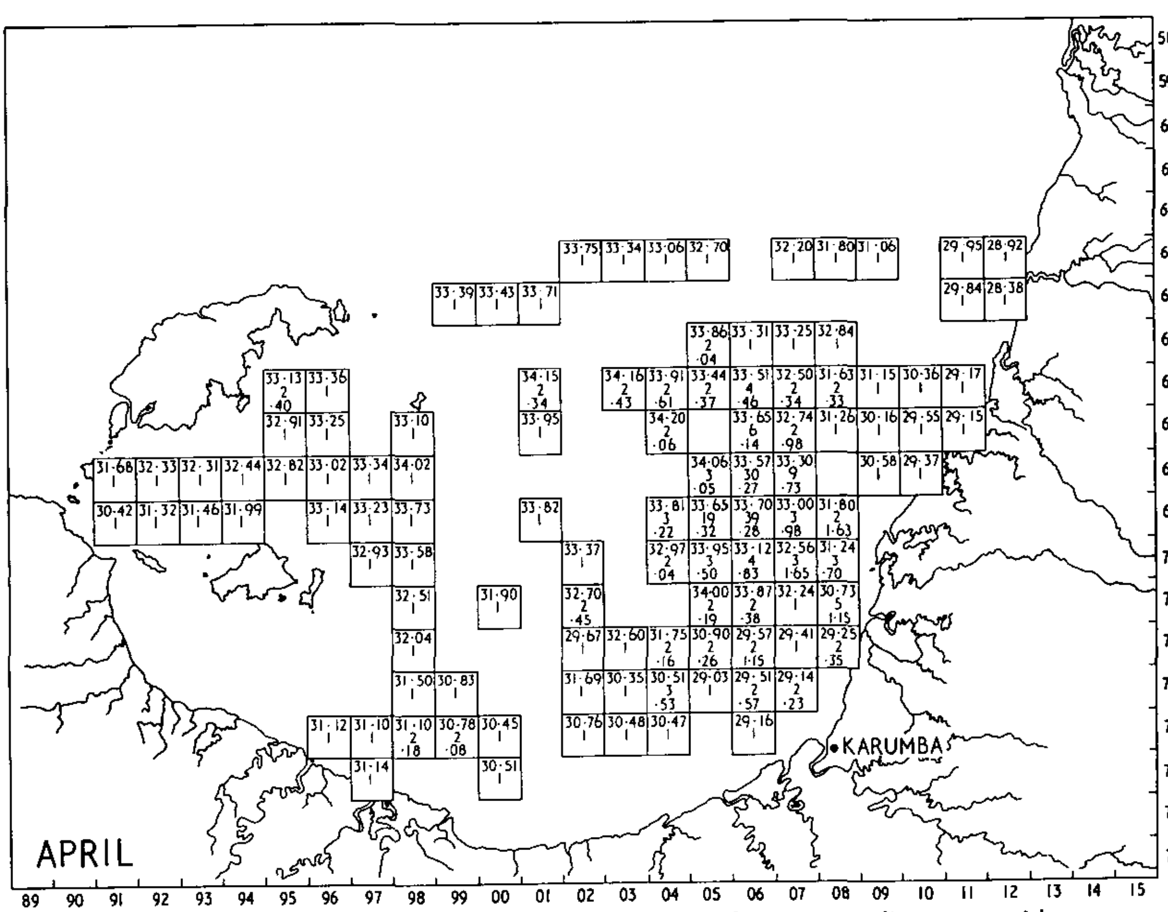


Fig. 85 Distribution of bottom water salinities (‰) according to grid squares for March and April. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

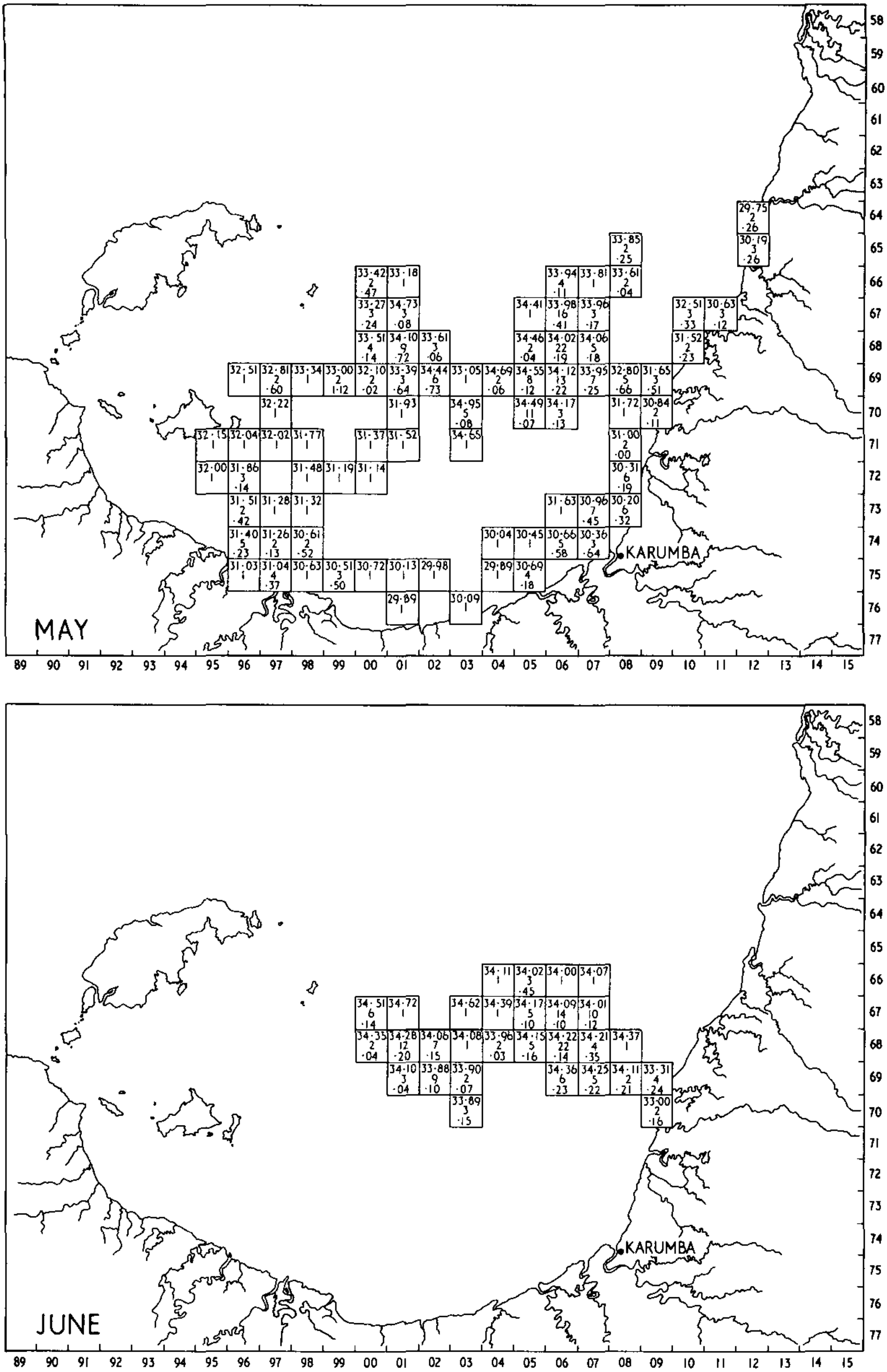


Fig. 86 Distribution of bottom water salinities (‰) according to grid squares for May and June. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

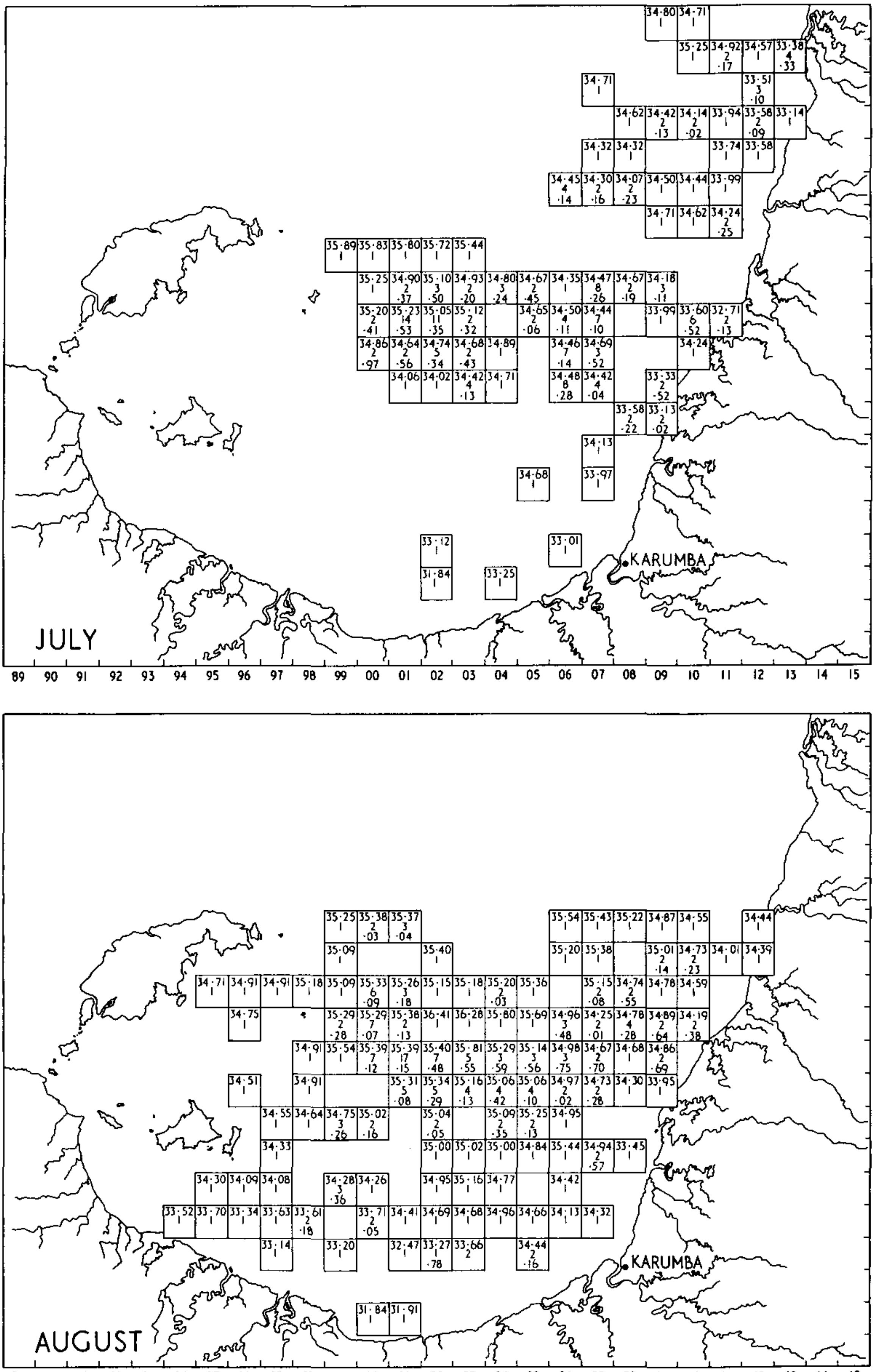
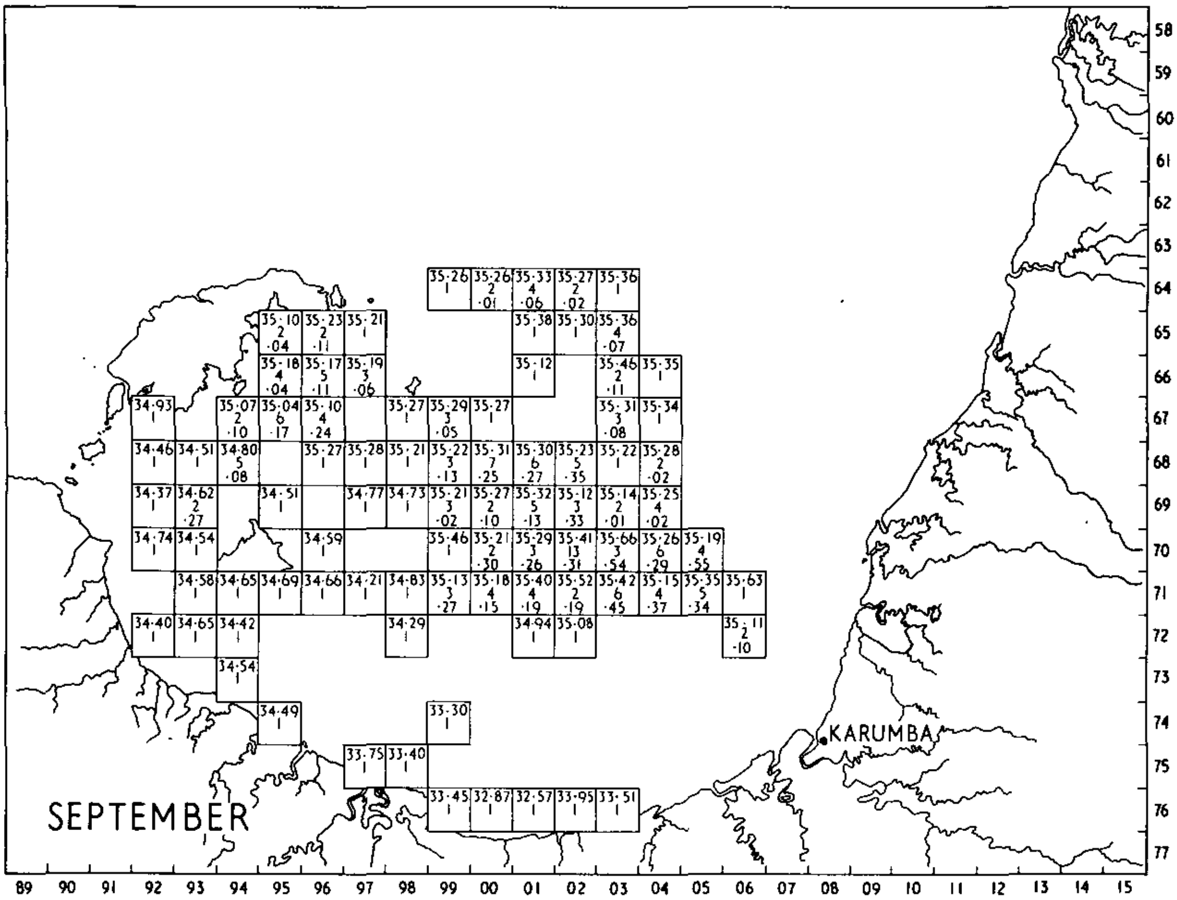


Fig. 87 Distribution of bottom water salinities (‰) according to grid squares for July and August. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



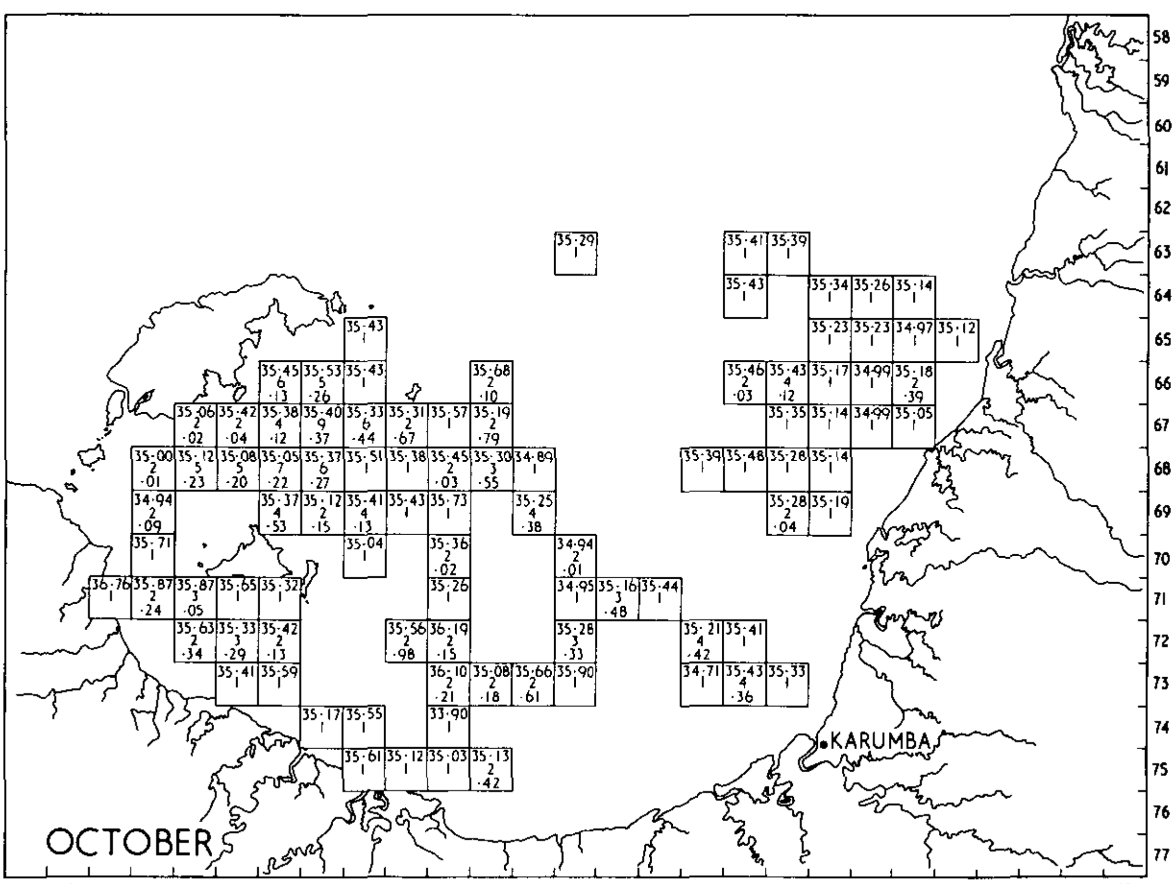


Fig. 88 Distribution of bottom water salinities (‰) according to grid squares for September and October. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

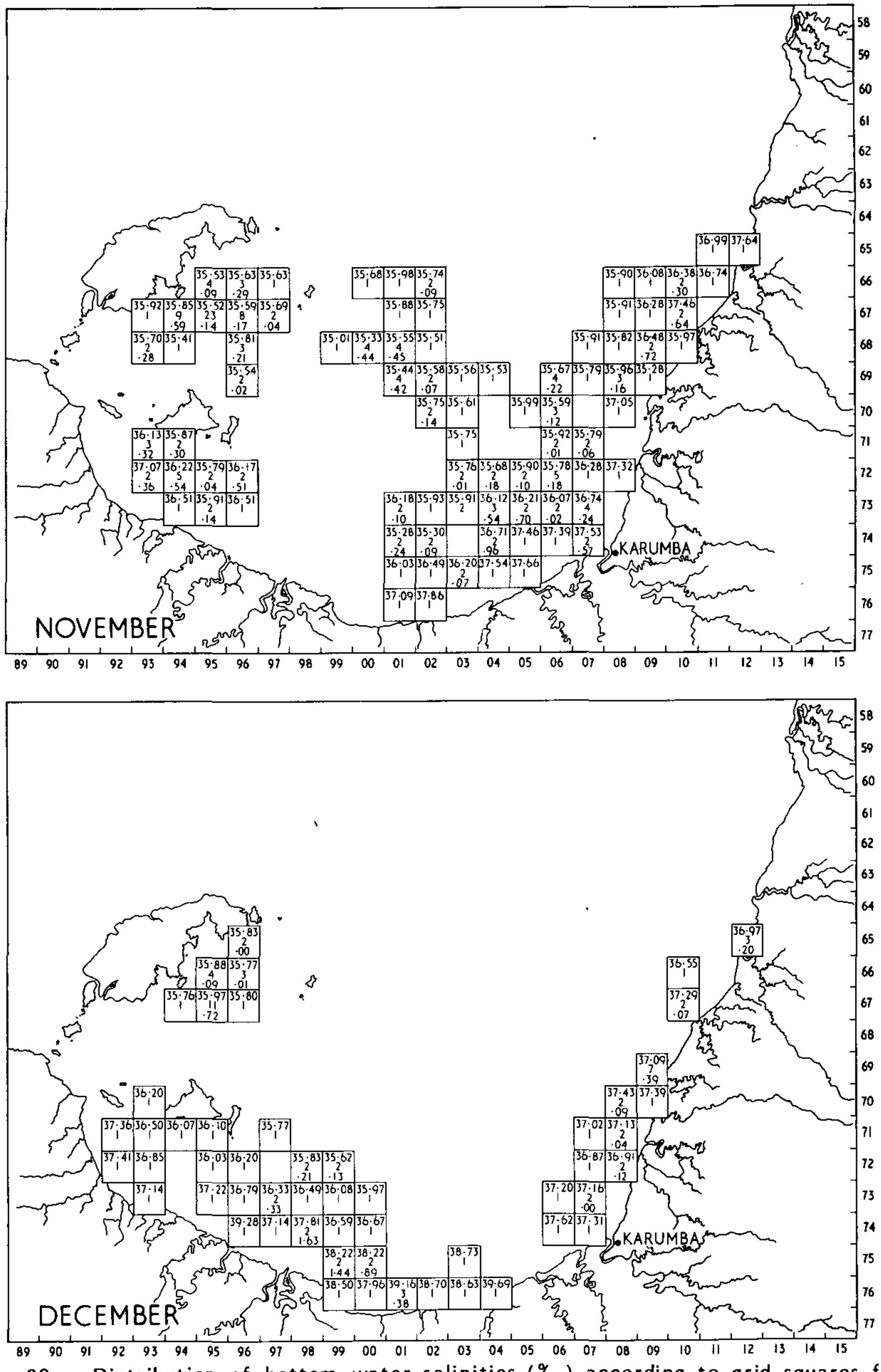


Fig. 89 Distribution of bottom water salinities (‰) according to grid squares for November and December. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

single site position around a dahn buoy, measurements were made but not repeatedly with every net shot.

Unfortunately temperature data are missing for some cruises (e.g. Stns 627--641, 781-885, 1325-1471) because of malfunction or lack of replacement thermometers.

3.4.2 METHODS

(a) Field measurements

Nansen bottles were used to collect water samples and these instruments were fitted with a reversing thermometer. Temperature measurements of surface and bottom water were obtained directly from these. (see Section 3.3.2 (a)).

(b) Display of data

Bottom temperatures for most station sites are tabulated in the station lists (Part 2, Section 2.2.5, Table 4). The temperature regime of the survey area has been described in earlier publications (Munro 1966, 1972) where seasonal values and gradient patterns are expressed as isothermal contours. The data are now displayed in Section 3.4.3 (surface) and Section 3.4.4 (bottom) as monthly maps. These maps employ grid squares for subdivision of the area.

Only those grid squares which were sampled during each monthly period are included. The data combine all measurements made during the consecutive years 1963 (July-December), 1964 (January-December) and 1965 (January--July) at station sites in any particular grid square.

Temperatures are expressed in degrees Celsius in terms of arithmetic mean, number of observations and standard deviation. The numbers read from top to bottom in each grid square represent these values respectively.

3.4.3 SURFACE TEMPERATURES BY GRID SQUARES BY MONTH

Data of the kind described in Section 3.4.2 (b) are displayed in the accompaying set of twelve monthly maps (Figs. 90-95).

3.4.4 BOTTOM TEMPERATURES BY GRID SQUARES BY MONTH

Data of the kind described in Section 3.4.2 (b) are displayed in the accompanying set of twelve monthly maps (Figs. 96-101).

3.5 WATER COLOUR

3.5.1 METHODS AND SAMPLING

(a) Field observations

As survey operations got into swing it was soon realized that spatial and seasonal variations occurred in the transparency or opacity of the water. Light penetration depended largely on the amount of suspended matter, and particulate matter could be brought into suspension by bottom sediments being stirred in shallow water by wind and tidal movement or silt of terrestrial origin being carried to sea by river discharge. Opacity could be expected to be greater closer to the coast in shallow areas and especially near river mouths.

Observations of water colour were not adopted as regular routine procedure until mid February 1964 (Stn 598) and then continued until the end of survey operations in July 1965. Scattered observations were made prior to February 1964 especially during October and December 1963.

Observations were entirely of a subjective nature and depended on judgment of individual observers. Early attempts tended to describe colour tints rather than degree of opacity.

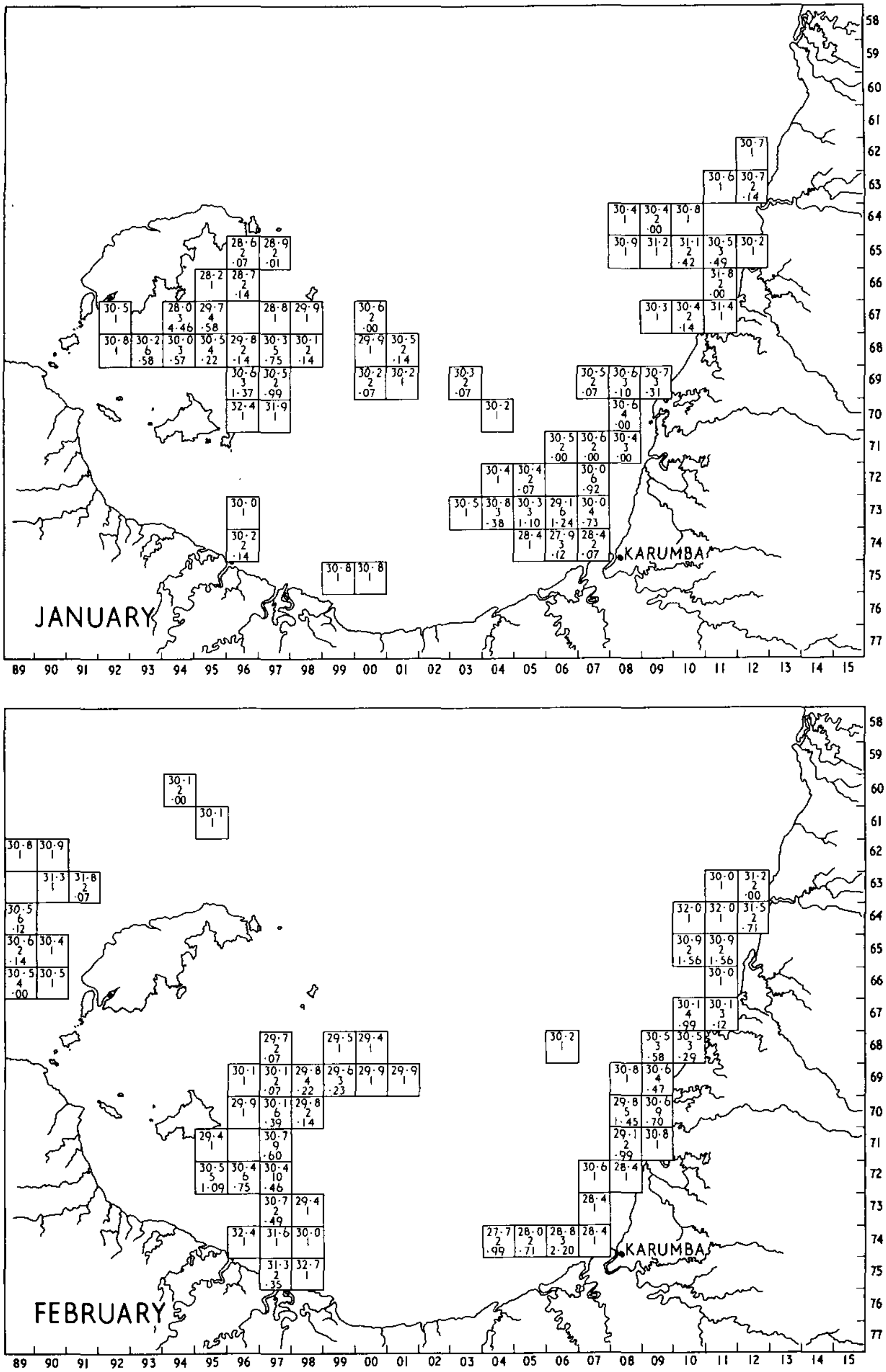
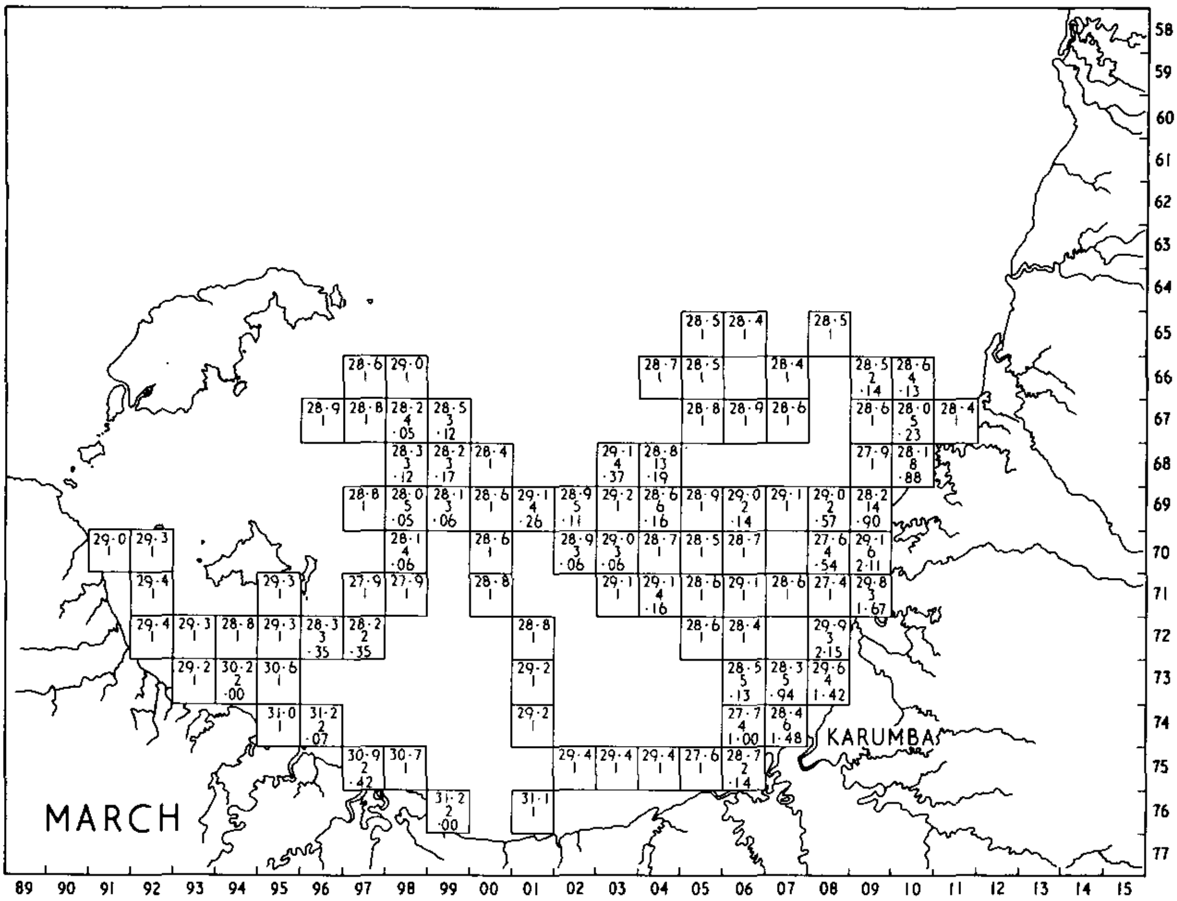


Fig. 90 Distribution of surface water temperatures (°C) according to grid squares for January and February. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



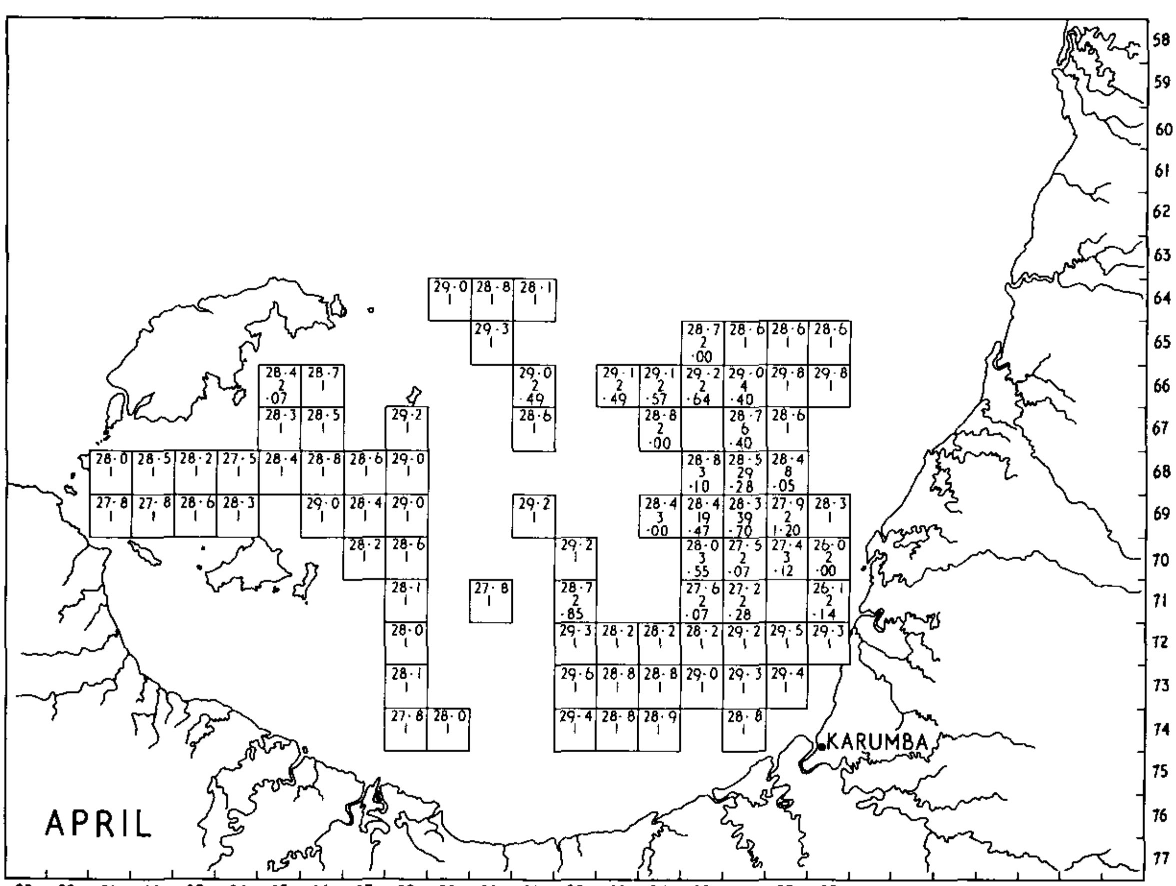
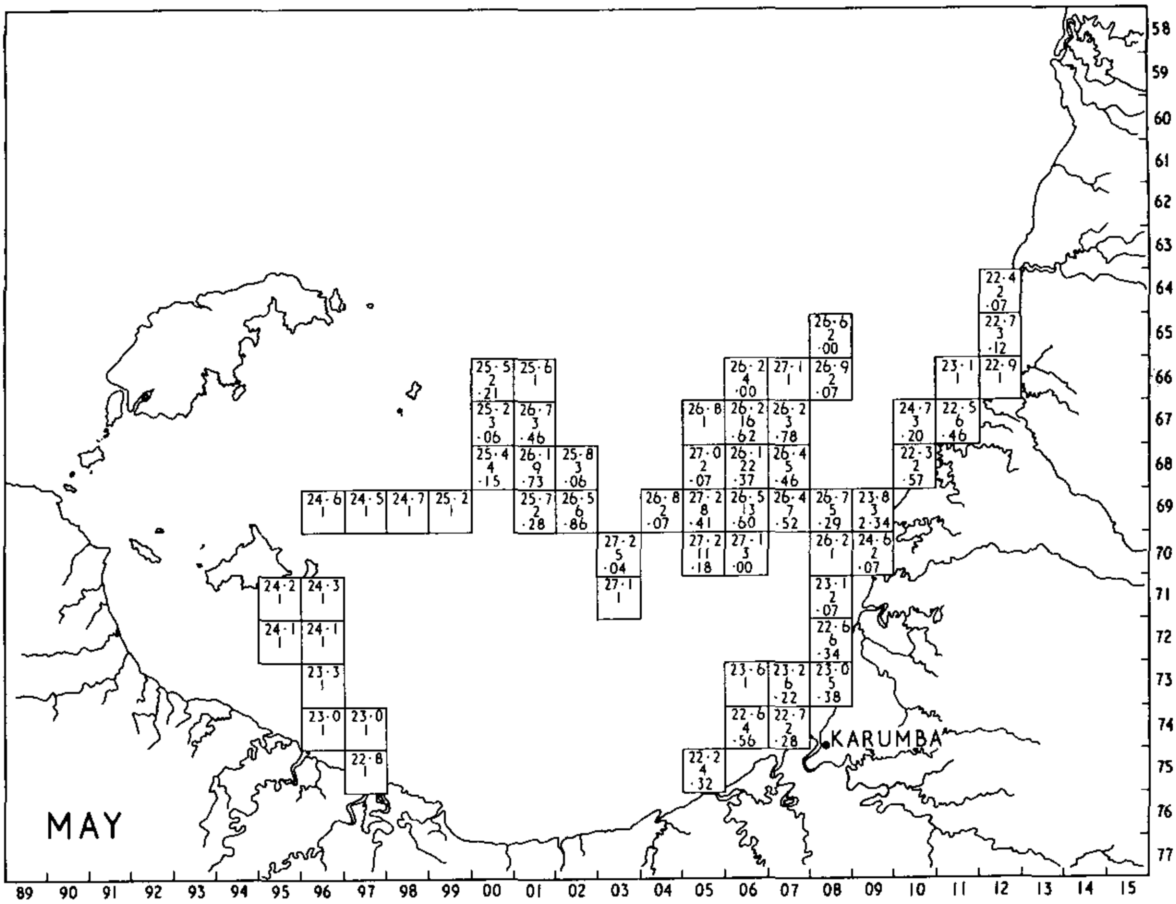


Fig. 91 Distribution of surface water temperatures (°C) according to grid squares for March and April. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



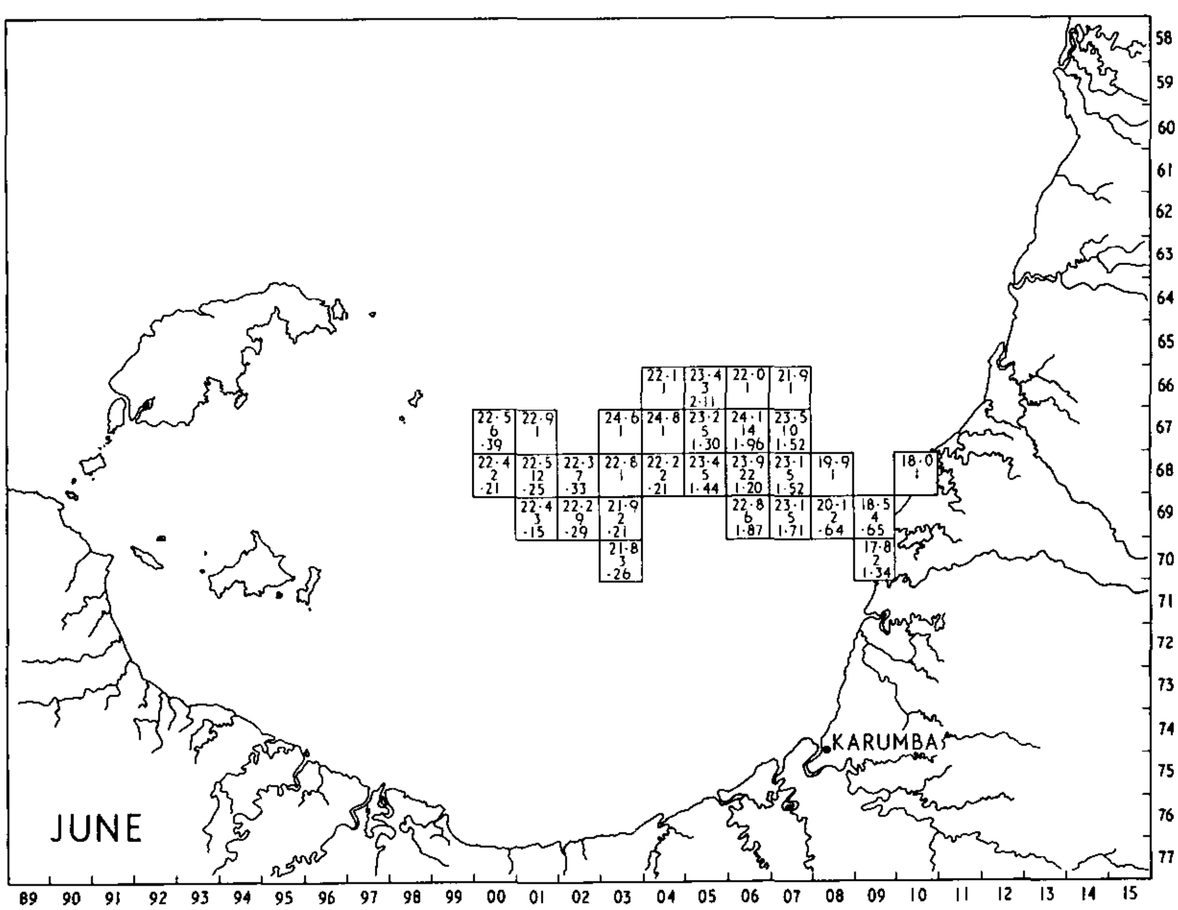
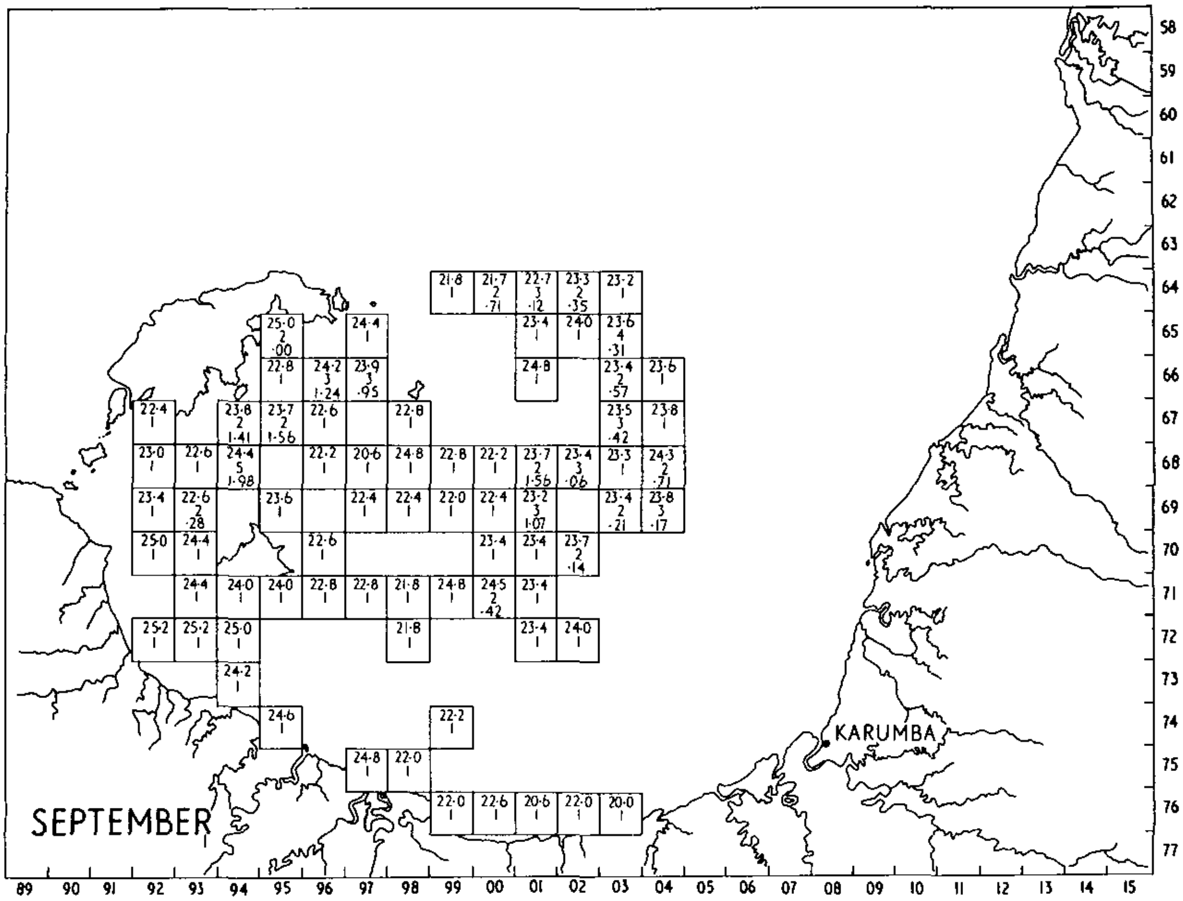


Fig. 92 Distribution of surface water temperatures (°C) according to grid squares for May and June. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

Fig. 93 Distribution of surface water temperatures (°C) according to grid squares for July and August. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



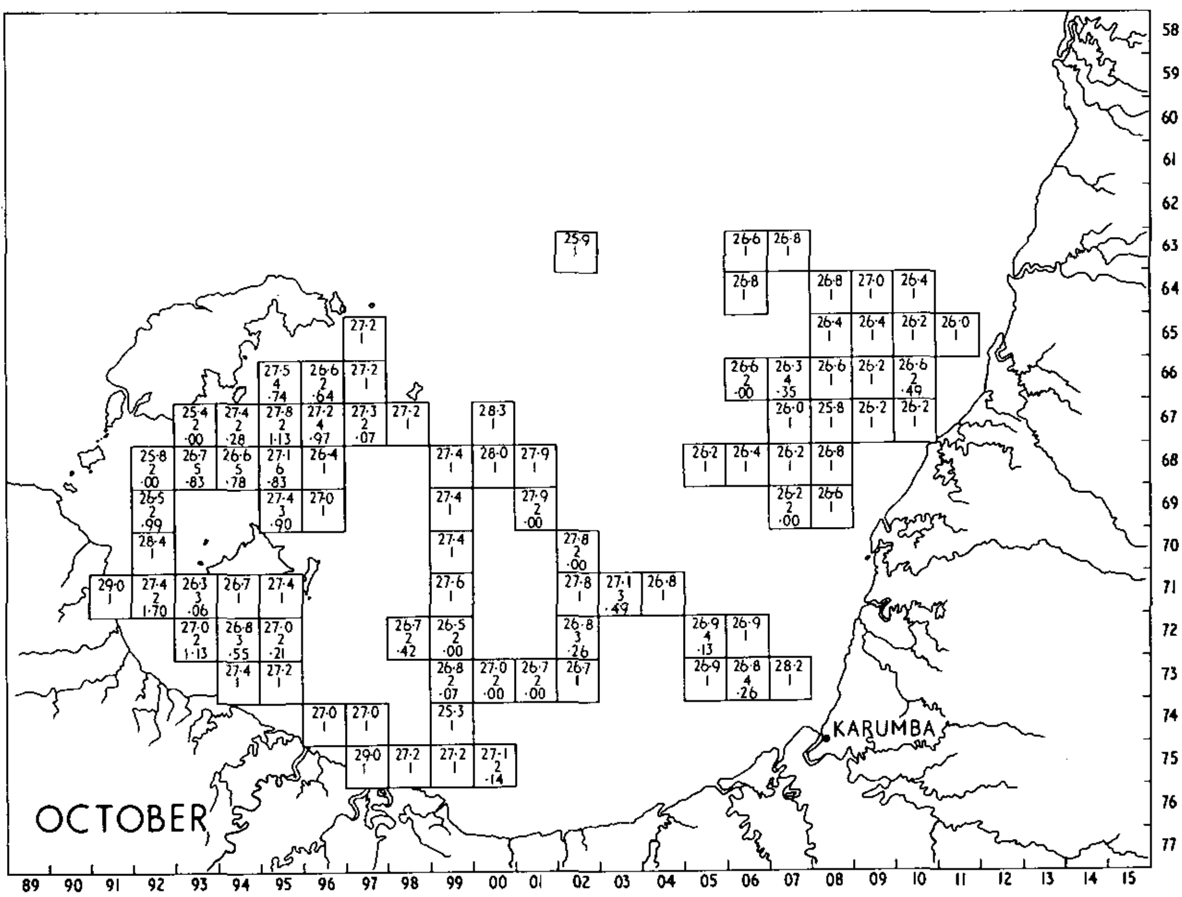
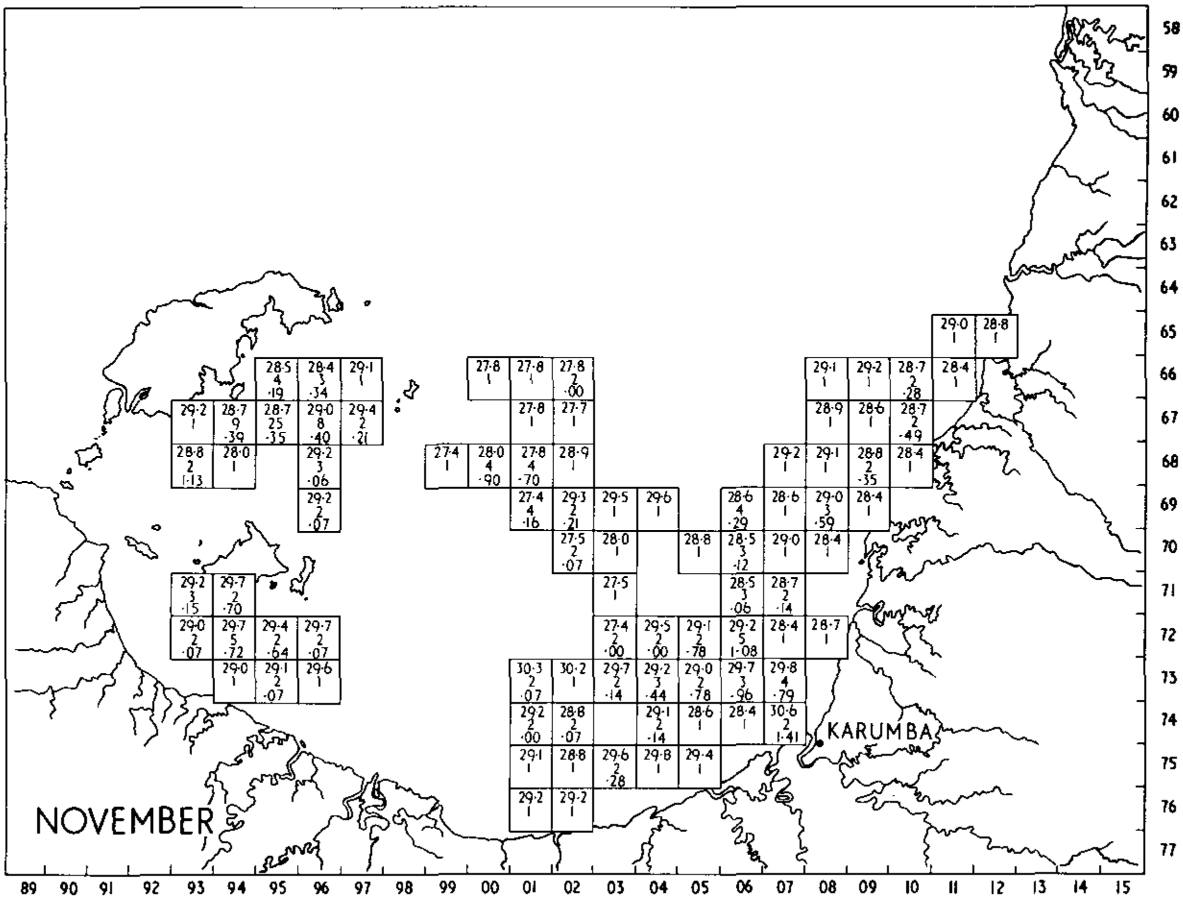


Fig. 94 Distribution of surface water temperatures (°C) according to grid squares for September and October. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



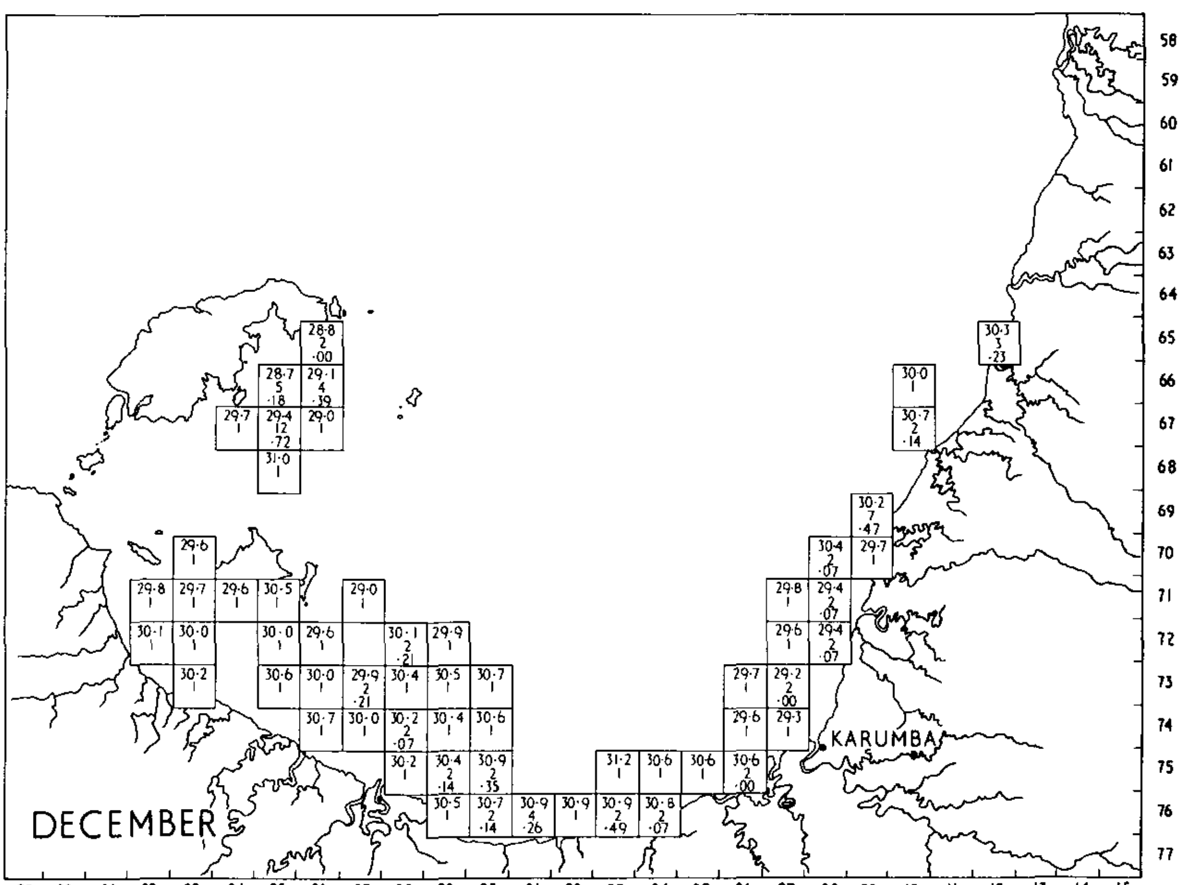


Fig. 95 Distribution of surface water temperatures (°C) according to grid squares for November and December. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

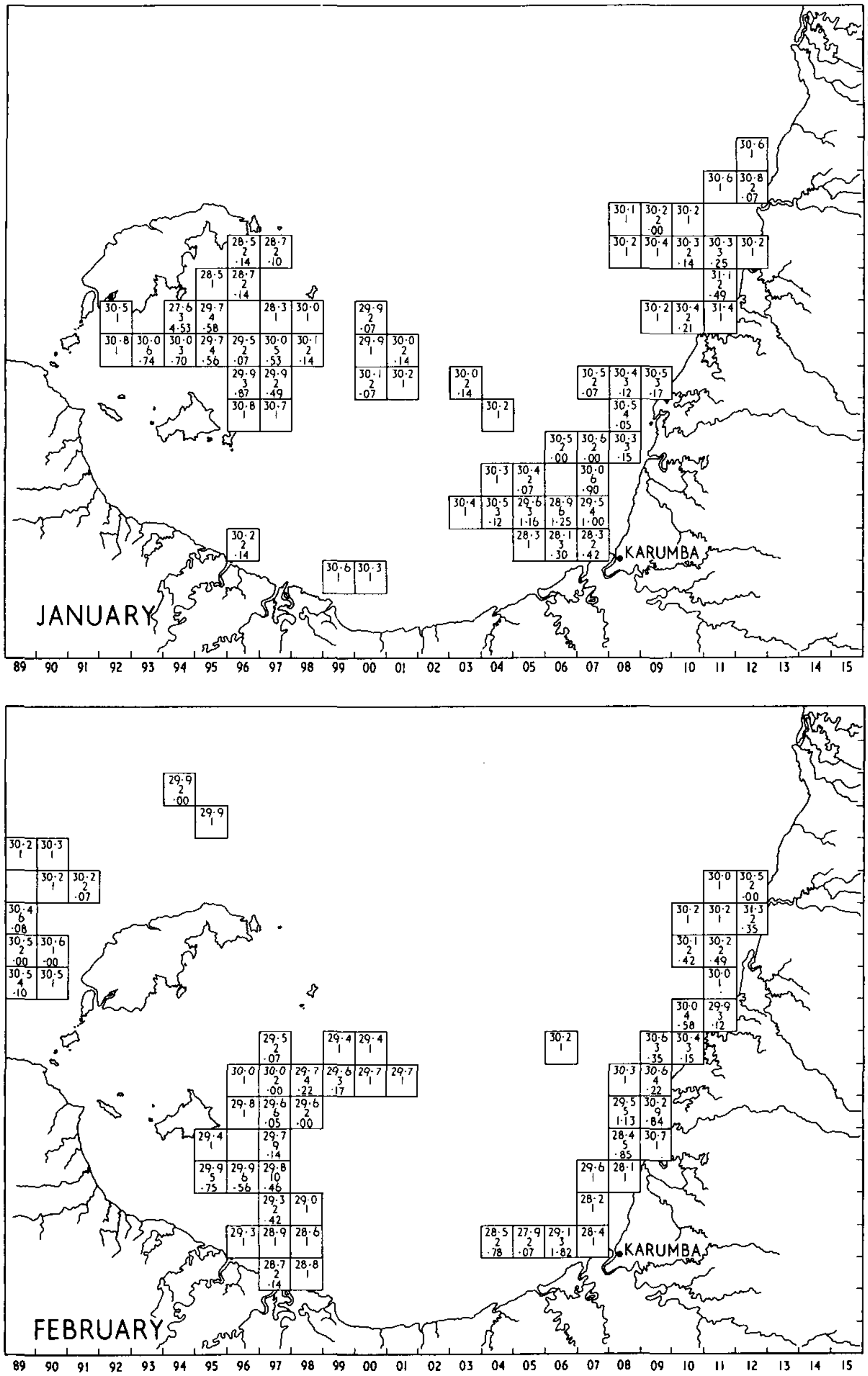
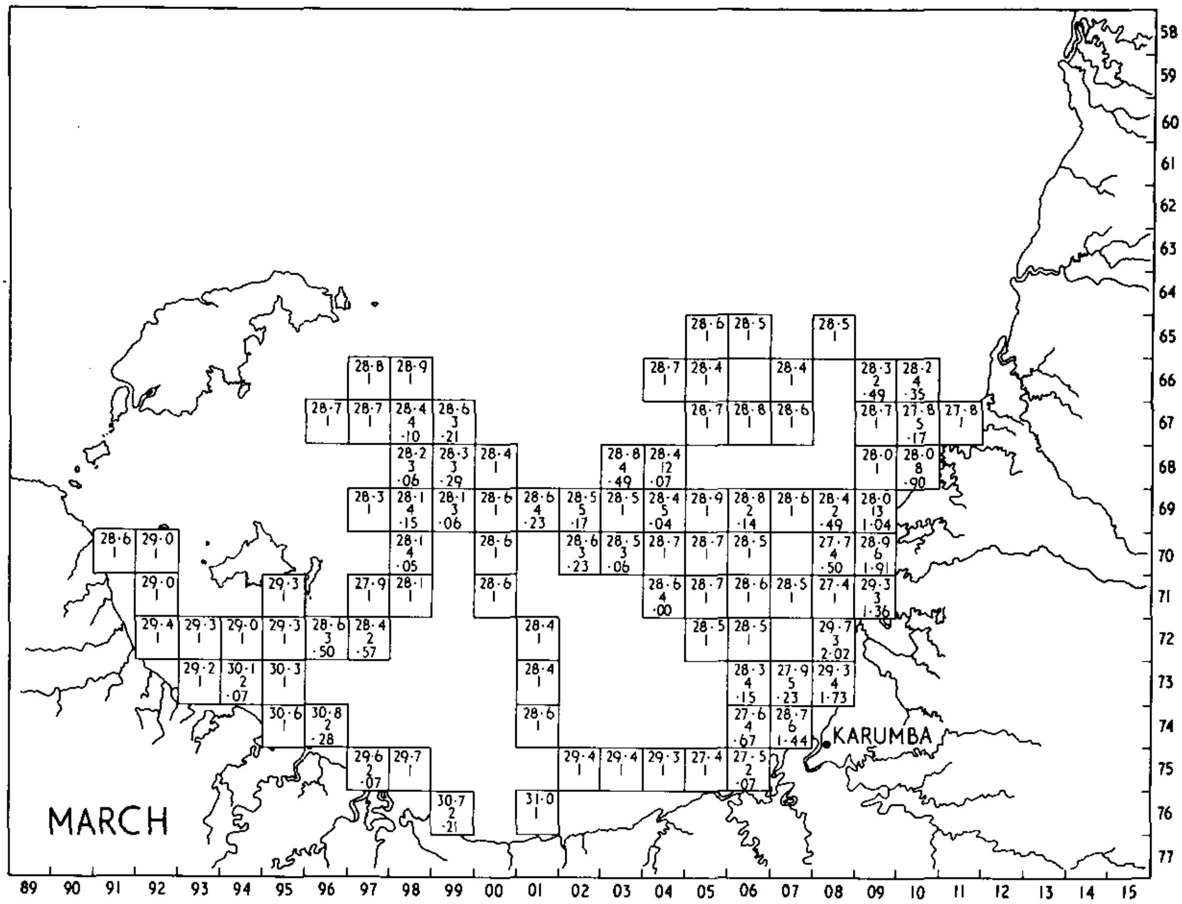


Fig. 96 Distribution of bottom water temperatures (°C) according to grid squares for January and February. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



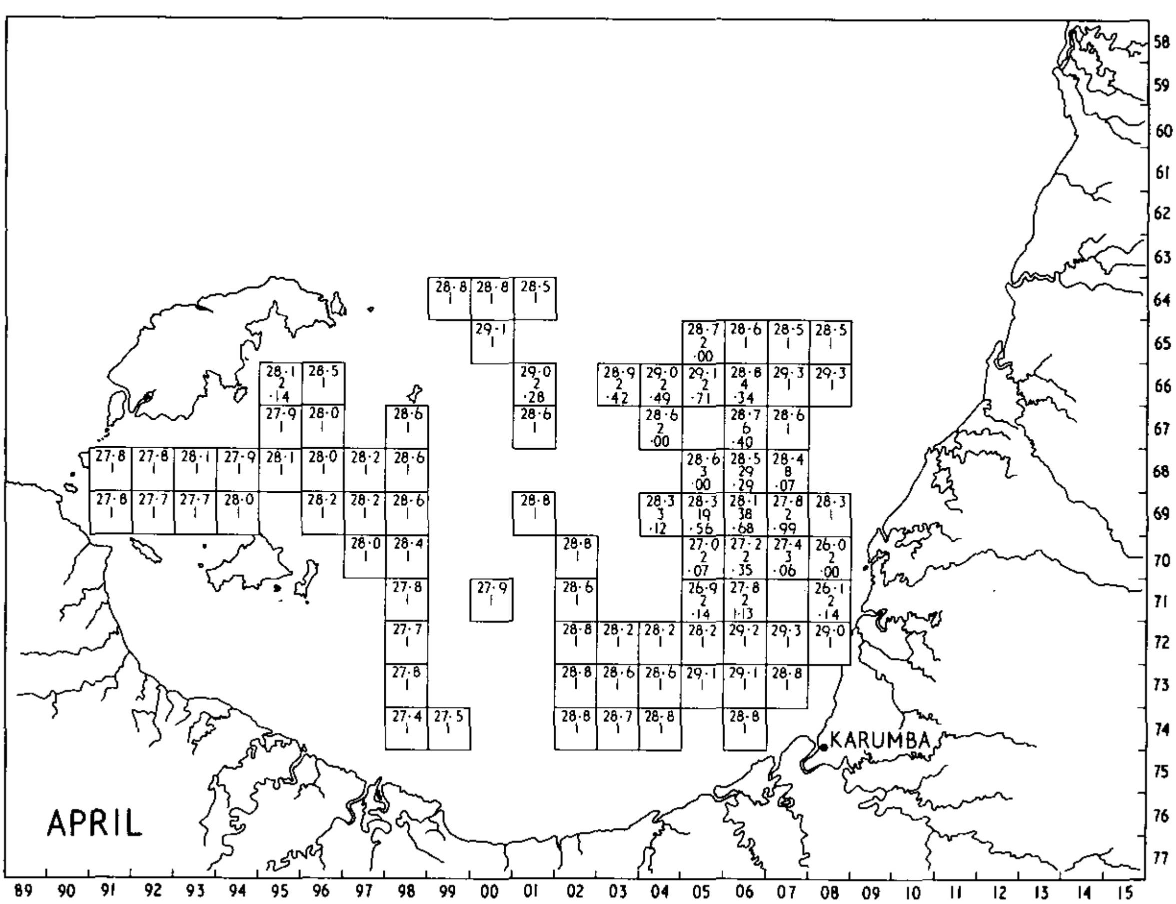


Fig. 97 Distribution of bottom water temperatures (°C) according to grid squares for March and April. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

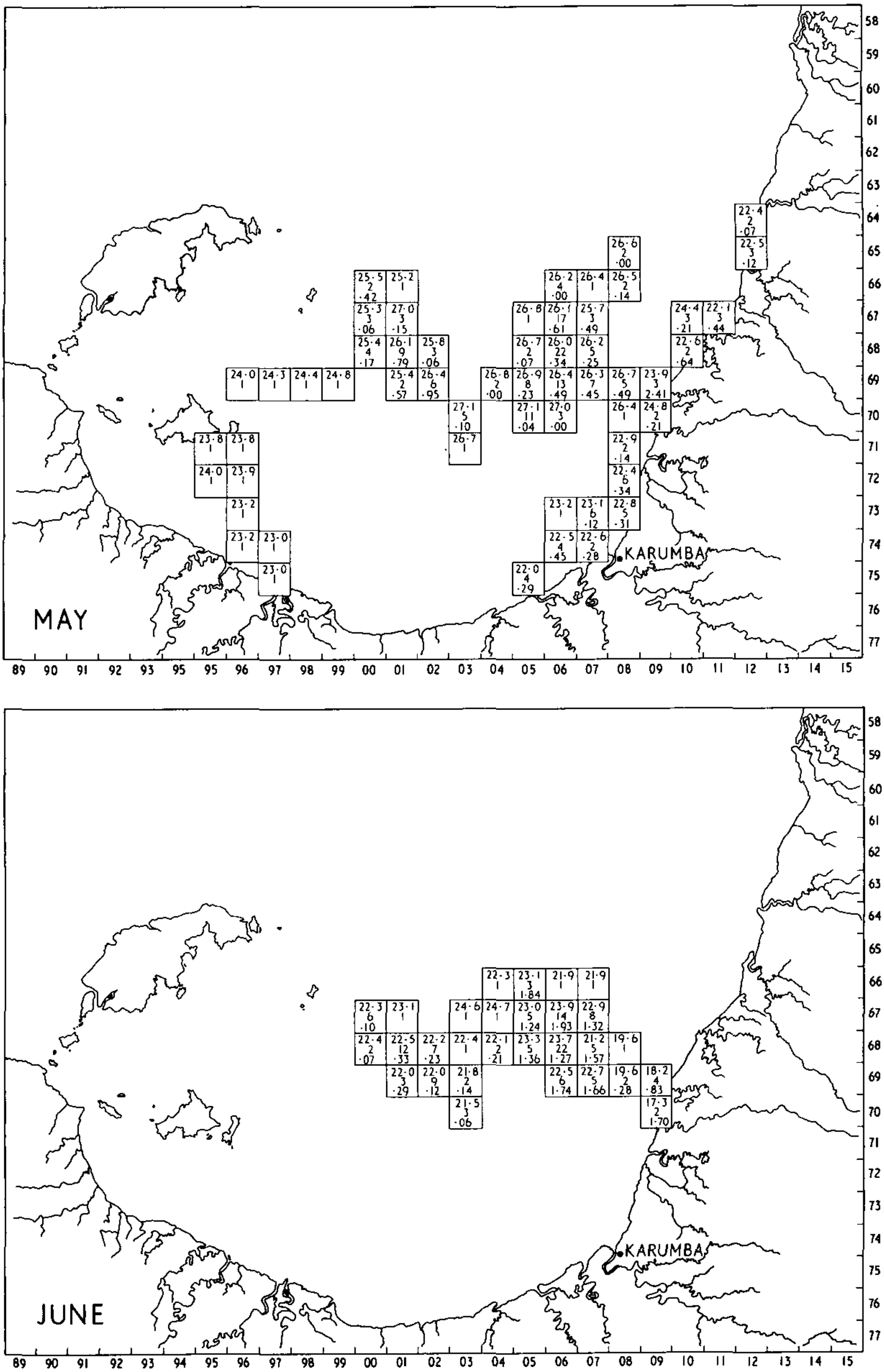
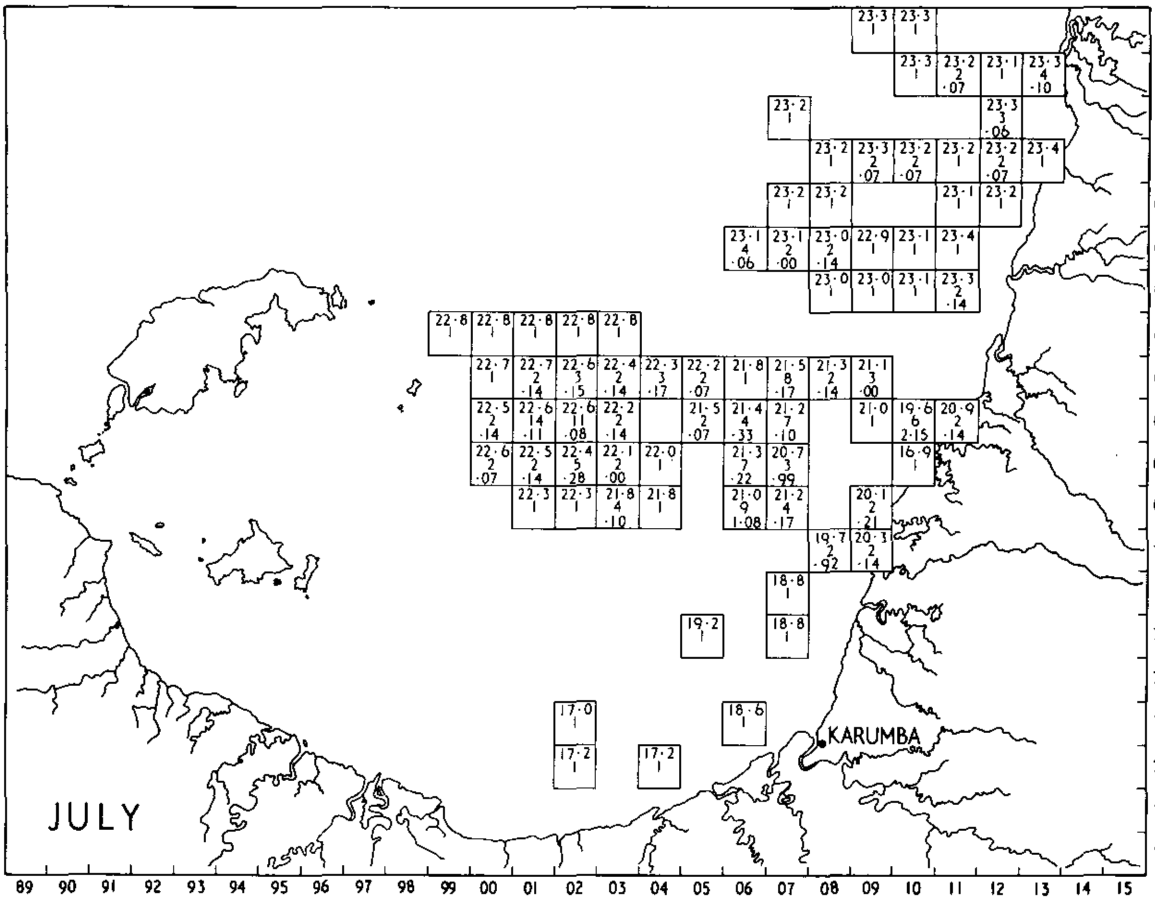


Fig. 98 Distribution of bottom water temperatures (°C) according to grid squares for May and June. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



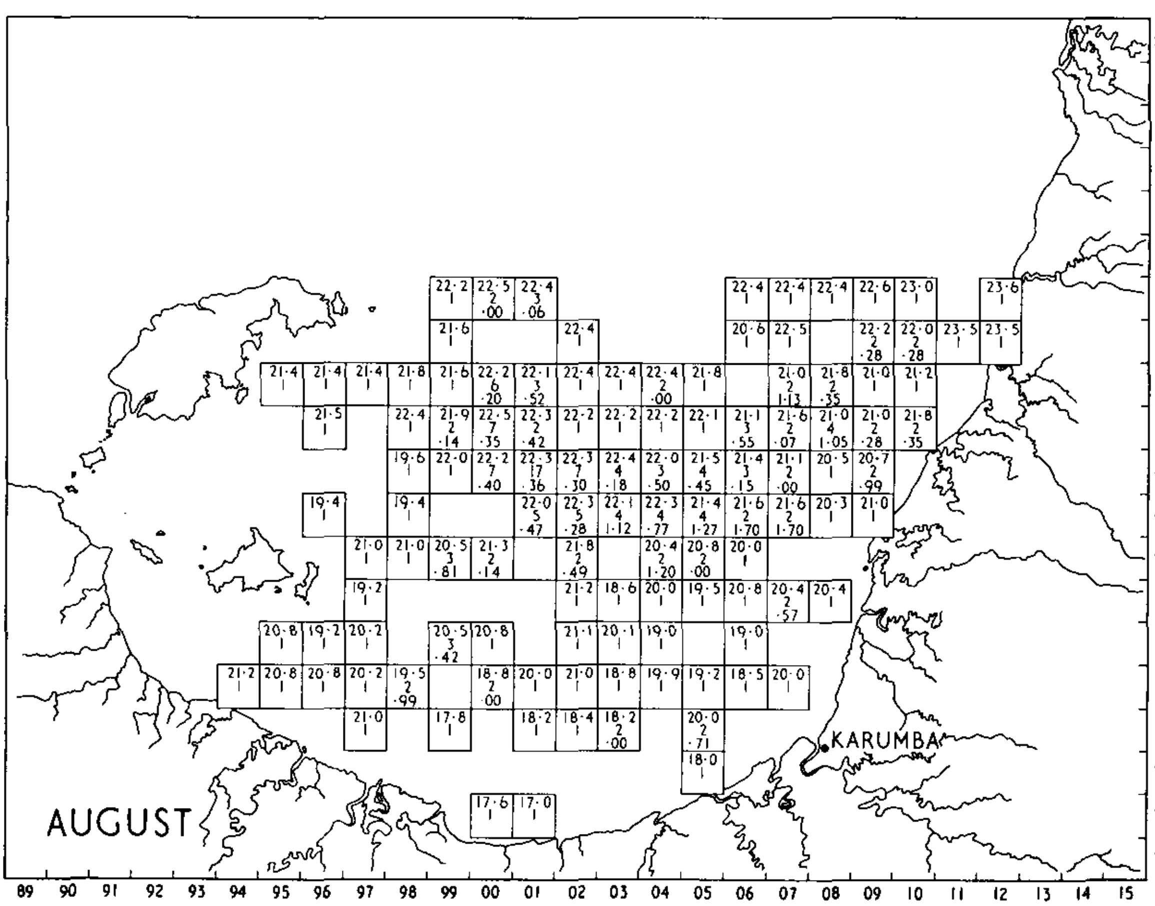
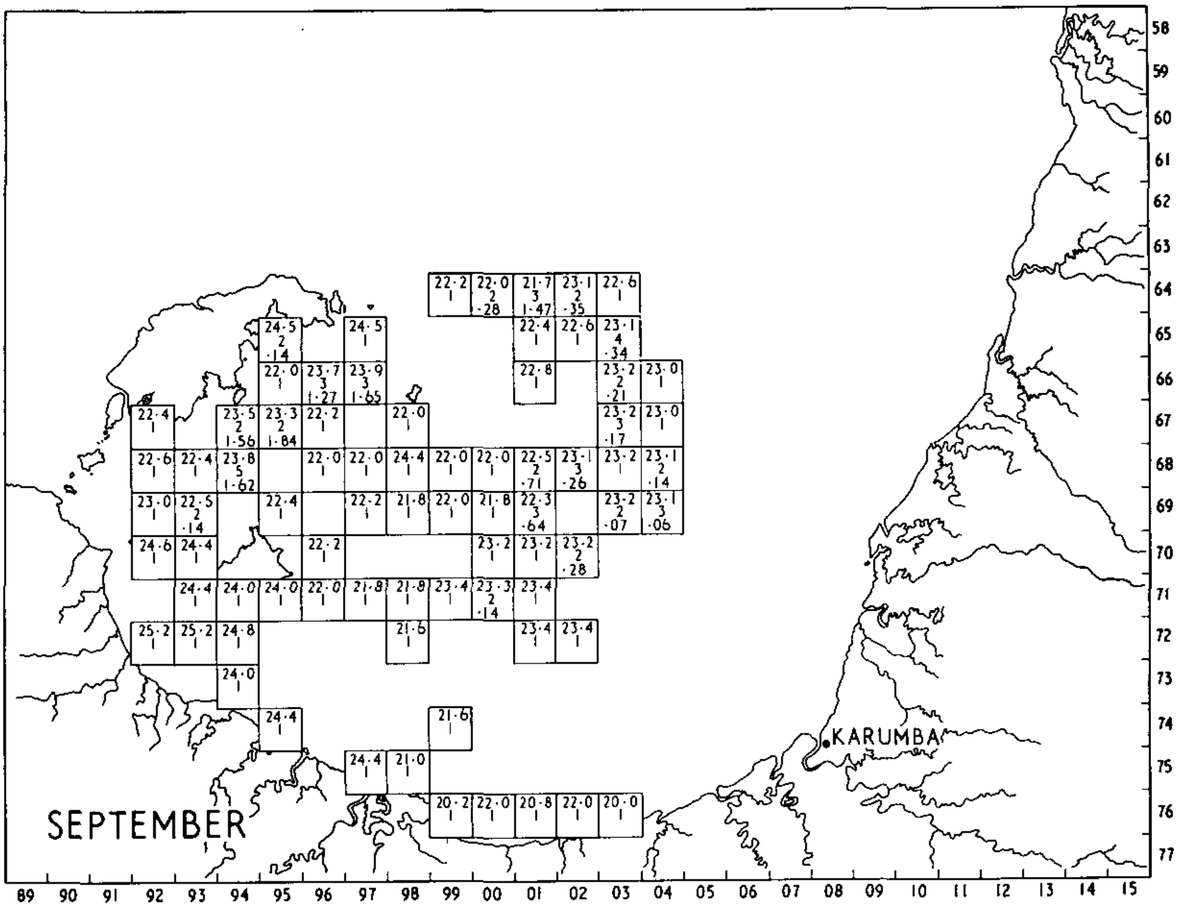


Fig. 99 Distribution of bottom water temperatures (°C) according to grid squares for July and August. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.



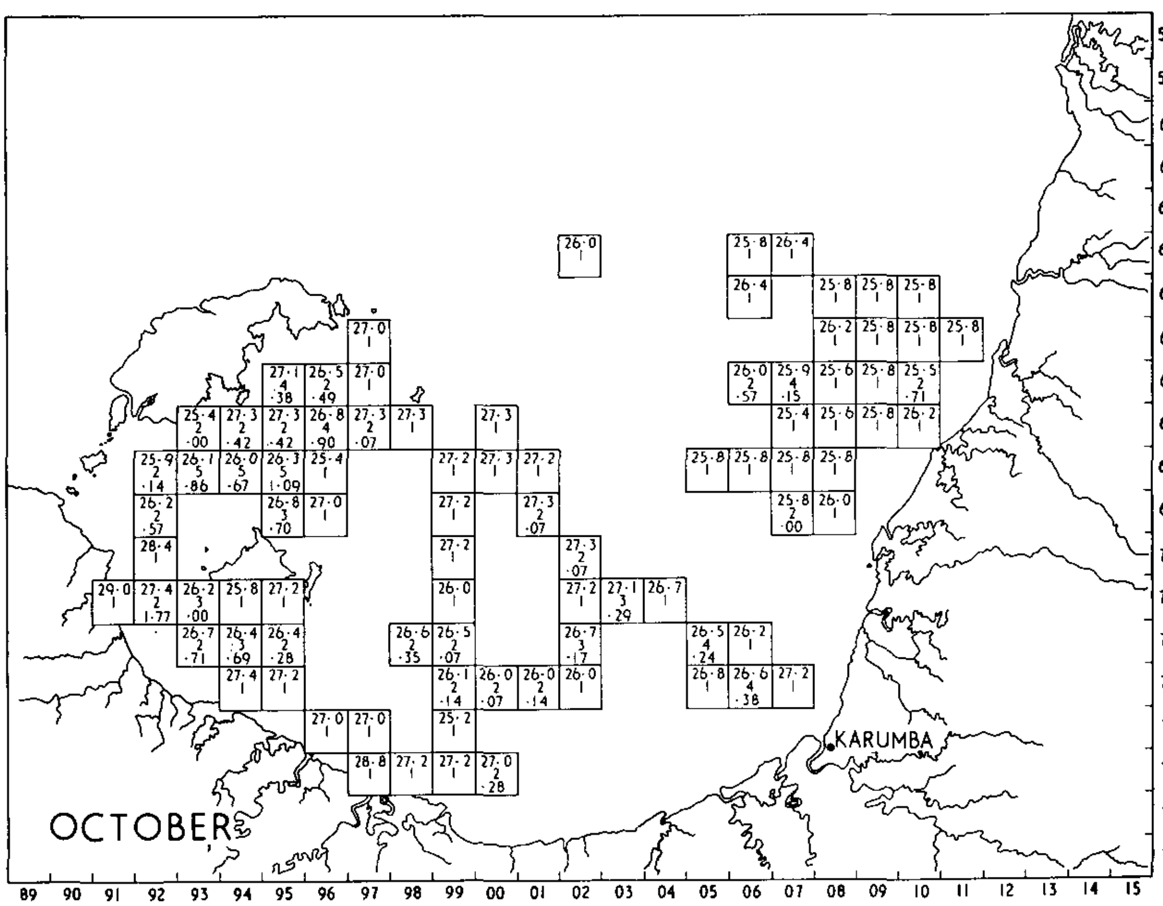


Fig. 100 Distribution of bottom water temperatures (°C) according to grid squares for September and October. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

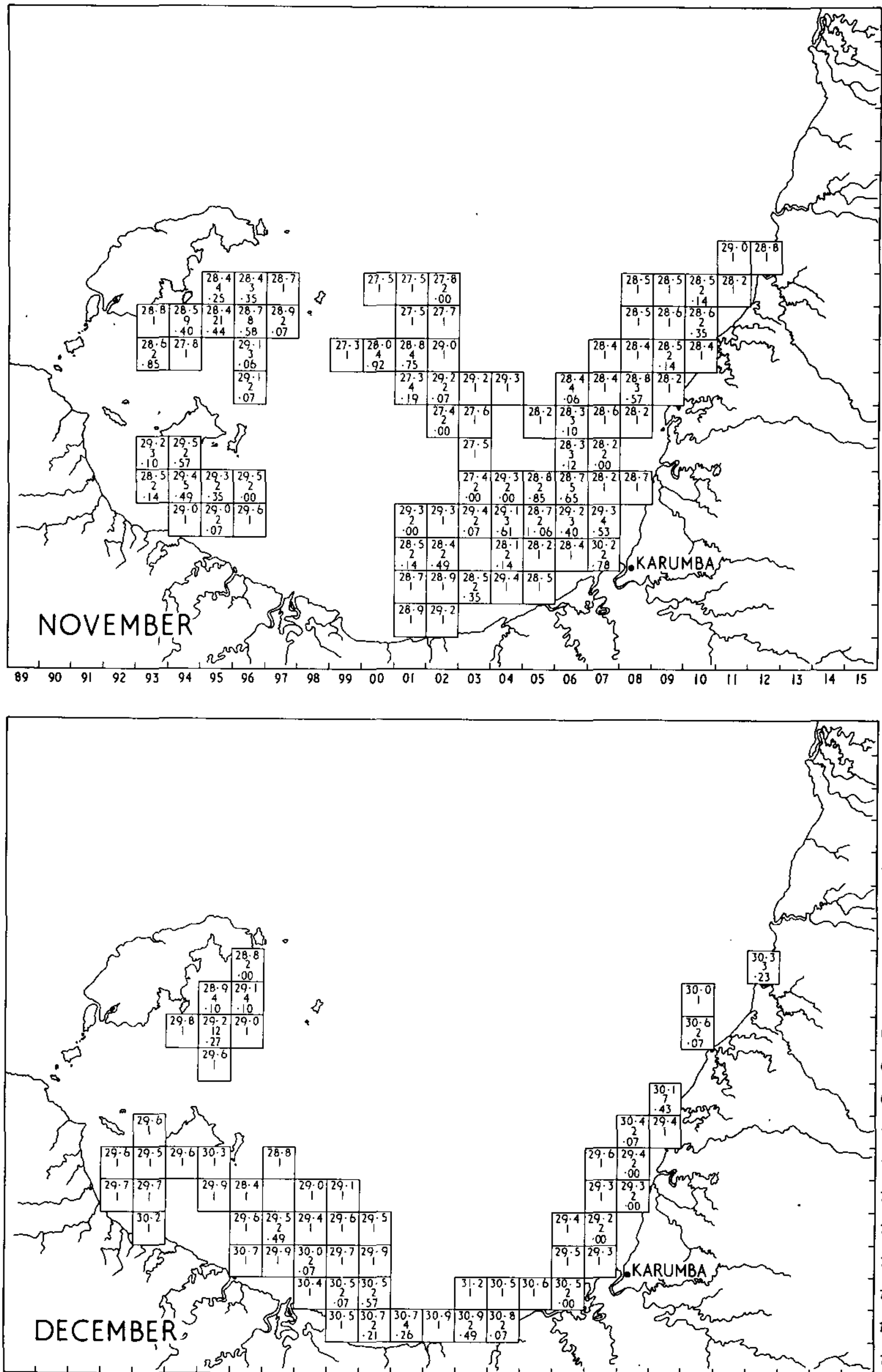


Fig. 101 Distribution of bottom water temperatures (°C) according to grid squares for November and December. The values in the squares are arithmetic mean, number of observations and standard deviation based on all observations during the month for years 1963, 1964 and 1965 combined.

Rationalization came with adoption of only four categories, namely:

Clear blue or green
Milky blue or green
Slightly muddy
Very muddy

Observations could be made only during daytime when illumination from sunlight was good.

(b) Display of data

Data are displayed as a set of maps representing the 12 calendar months in order to give seasonal coverage. For each month the data combine all observations made in that period over the consecutive years 1963 (July-December), 1964 (February-December) and 1965 (January-July). Individual observations are shown by coded symbols positioned at trawl station sites plotted from co-ordinates of latitude and longitude.

3.5.2 WATER COLOUR BY AREA BY MONTH

Water colour observations are displayed in the accompanying set of 12 maps representing the calendar months (Figs. 102-104). The legend identifying the four broad categories is included on the maps.

3.6 TIDES

3.6.1 METHODS AND SAMPLING

(a) Tide gauge records

The Queensland Government, through the Chief Engineer of the Department of Harbours and Marine, had maintained a 'Munro' recording tide gauge machine in the Norman River. This instrument traced changes in tidal amplitude during consecutive 24-hour periods on a graph paper sheet attached to a rotating clockwork driven drum. The machine was located a short distance upstream from the river mouth close to the disused flying-boat service ramp at the settlement of Karumba. The Department collected records during 1957-60, and from these the Liverpool Tidal Institute selected the 1957-58 series for calculation of harmonic constants. The first tidal prediction tables were issued in the year 1966 so it was necessary for the survey team to obtain its own tidal records by continuing operation of the machine throughout the survey period 1963-65.

(b) Time for sun, moon and tides

During the survey period Australian Eastern Standard Time was used during all months throughout the state of Queensland. EST is based on Longitude 150° E and is thus Greenwich Mean Time minus ten hours (GMT-1000). The approximate centre of the survey area coincides with Latitude 17°S and Longitude 140° E. Local longitudinal time is thus 40 minutes later than local clock time (EST + 0040 or GMT - 0920).

Tidal graphs were synchronized with local clock time, namely EST. Times of sunrise and sunset, moonrise and moonset are events relative to local longitudinal time at 140° E. The Nautical Almanac for the years 1963, 1964 and 1965 was used as the source of times of these events expressed in GMT. The times of these events were adjusted for local longitude (140° E) and latitude (17° S) using the corrections described in the almanac. In this way these local events are expressed in EST because local longitudinal time and EST are both relative to GMT.

The dates and times of new moon, first quarter, full moon and last quarter were also derived from The Nautical Almanac and converted to EST by adding 10 hours. This had the effect of moving the date one day ahead in cases where the event occurred later than 1400hr GMT.

3.6.2 DATUM

Datum level for the Port of Karumba is 2.93 ft below State Datum (Queensland)

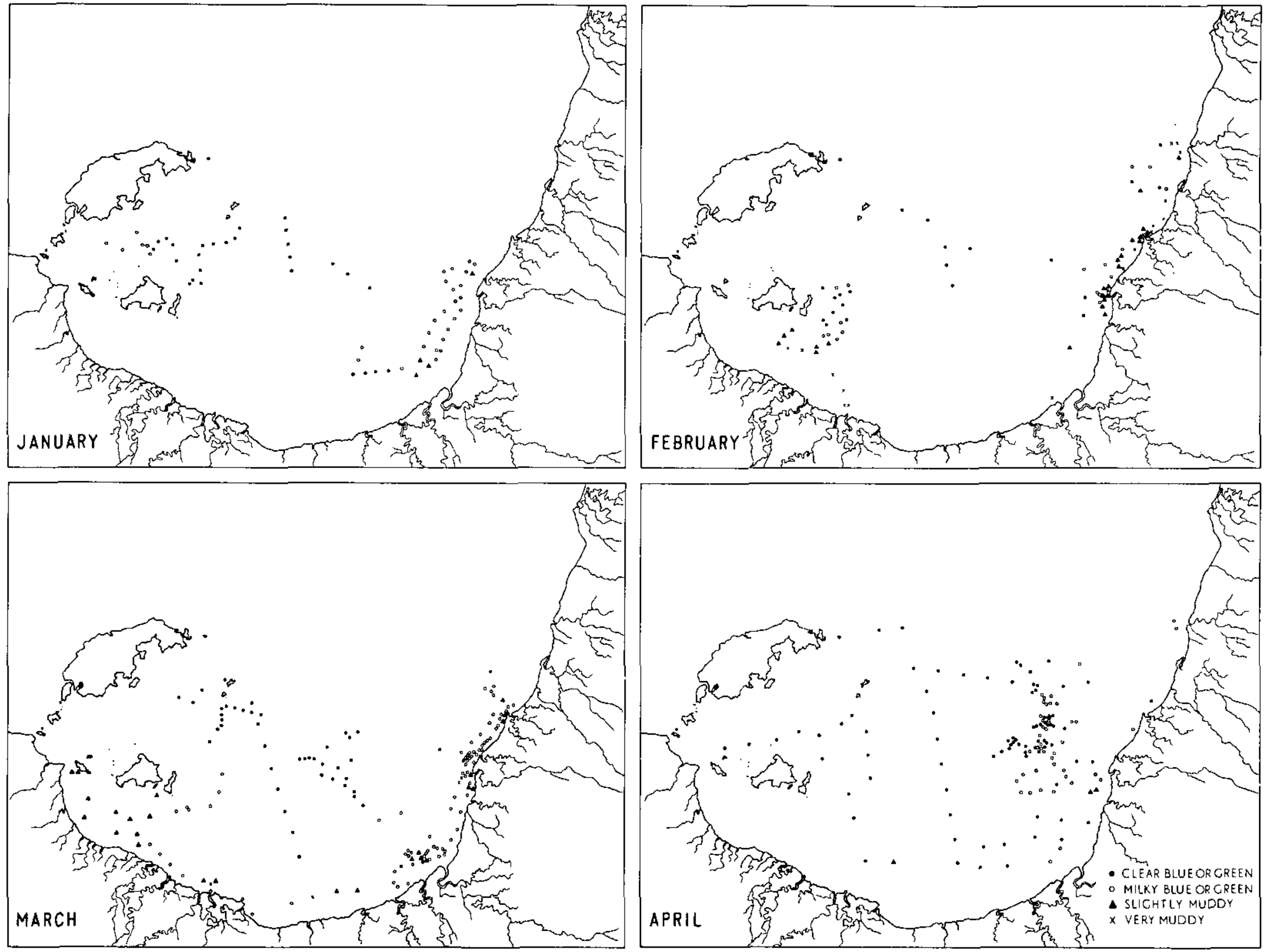


Fig. 102 Water colour according to area for the months January to April. The individual coded marks are positions of station sites where a colour in the category indicated was observed in daylight during the month for the years 1963, 1964 and 1965 combined.

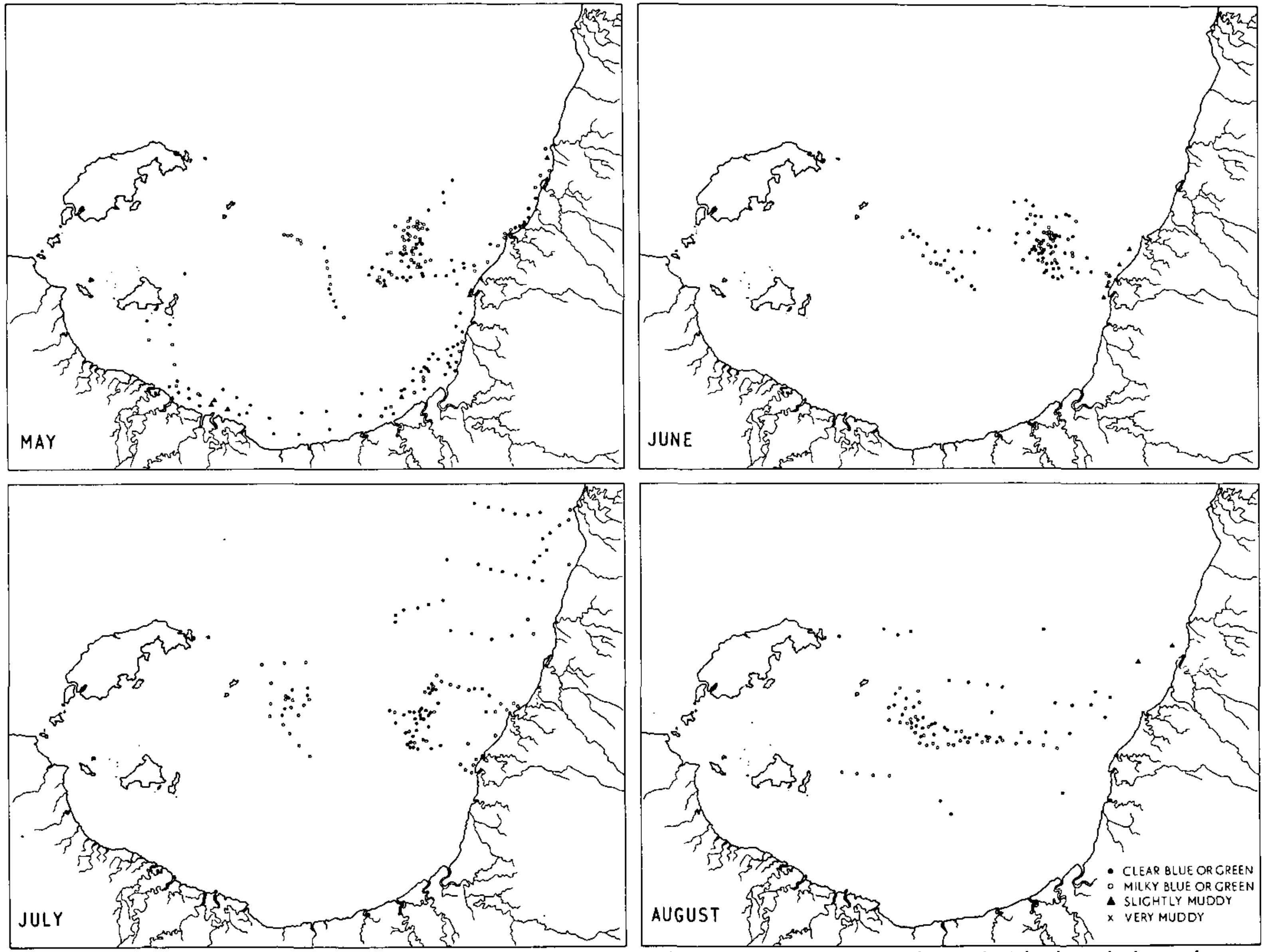


Fig. 103 Water colour according to area for the months May to August. The individual coded marks are positions of station sites where a colour in the category indicated was observed in daylight during the month for the years 1963, 1964 and 1965 combined.

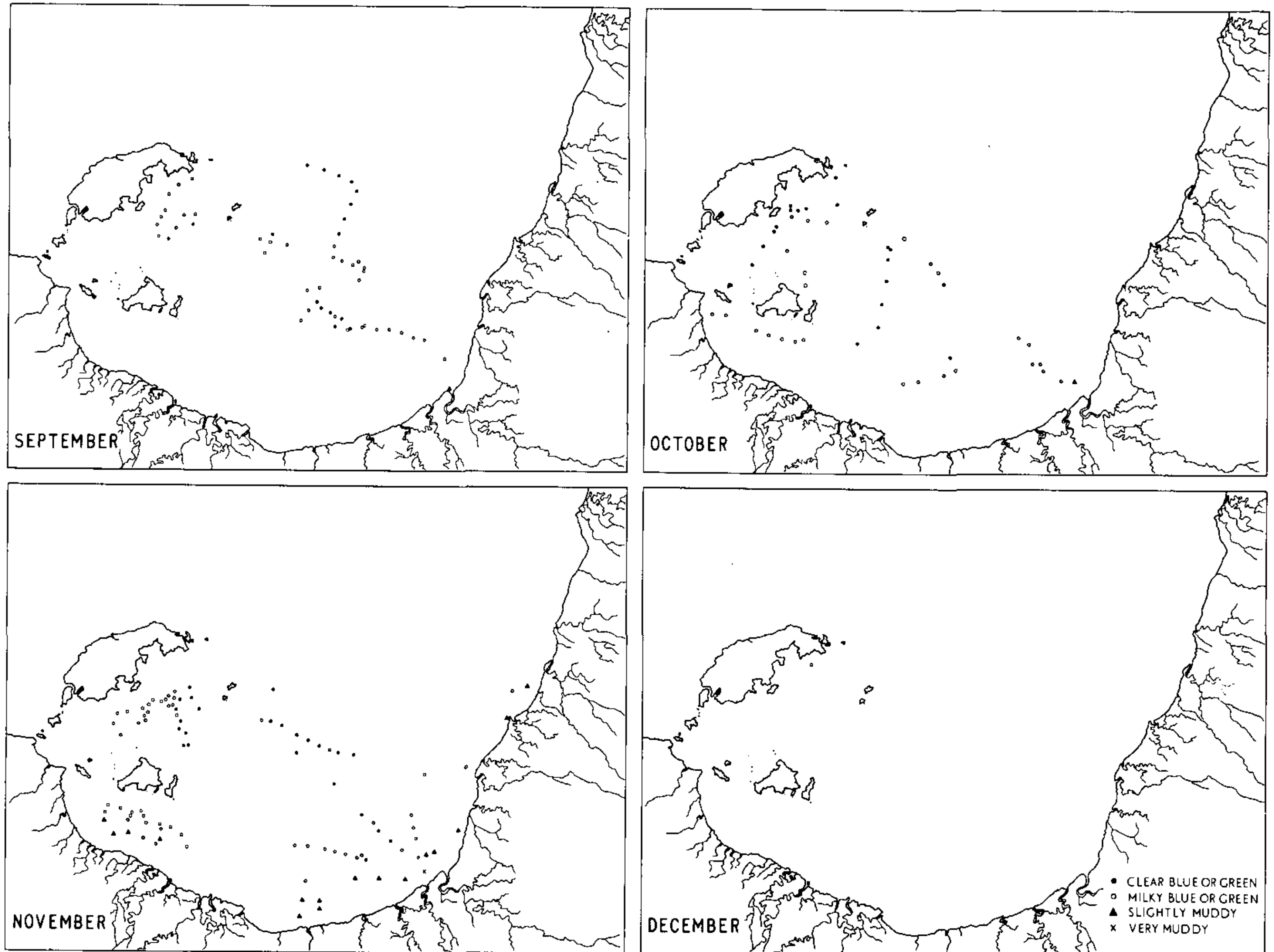


Fig. 104 Water colour according to area for the months September to December. The individual coded marks are positions of station sites where a colour in the category indicated was observed in daylight during the month for the years 1963, 1964 and 1965 combined.

and 20.53 ft below a nearby bench mark comprising a brass plug set in concrete (State Permanent Mark No. 601).

The tide gauge machine at Karumba was mounted on a jetty that had fallen into disrepair. When the machine was installed originally the base line on the graph paper was adjusted with reference to a mark on the jetty structure and a calibrated tide scale also attached to the jetty. The height of this reference mark on the jetty had been determined in relation to the bench mark quoted above and hence local datum level was known in relation to State Datum.

The wharf piles which supported the superstructure bearing the reference mark were subject to vertical movement because they were embedded in a substratum of silt. There was evidence that some subsidence occurred during cyclonic weather so it is uncertain whether the reference mark on the jetty (and datum in relation to the base line on the graphs) changed in height relationship to the permanent bench mark during the term of the survey (1963-1965).

While this does not affect measurements of height changes in a relative way, it does have bearing on the accuracy of heights measured in relation to the established datum. As the actual gauge height above datum was not checked through 1963-1965 and remained unknown for the duration of the survey, tidal height measurements and mean sea levels were measured from an artificial zero which corresponded to the lowest point reached at lowest low water during springs. This value was recorded at 0245 hr on 20 July 1965.

This artificial zero is in fact the base line on tidal graph sheets and corresponds to two feet below zero on the calibrated tide scale attached to the jetty. The zero mark on this tide scale apparently represented Karumba datum, at least at the time of installation of the instrument. The artificial zero thus corresponds with a level of 4.93 ft below State Datum, and for part of the 1963--1965 period could be even lower.

3.6.3 TIDAL CYCLES IN RELATION TO SUN AND MOON

(a) General characteristics

The general characteristics of the tidal cycle in relation to the lunar cycle and the passage of time have been discussed elsewhere (Munro 1966, 1972). These characteristics are displayed graphically in the accompanying diagrams (Fig. 105) reproduced from one of these earlier accounts (Munro 1966). The display is in two parts and refers to a fairly stable period with little wind influence, namely from mid-April to mid-May 1965.

As observed from continuous records over a period of two years in the Norman River the tide is basically lunar and diurnal in periodicity. Both diagrams (Fig. 105) cover two consecutive cycles occupying together one lunar month. The upper diagram shows daily progress through this period in terms of changes in amplitude in relation to time of day and calendar date. Zero on the height scale is Karumba datum or some inches below it (see Section 3.6.2). In this example it will be noted that differences in amplitude between LW and HW are of the order of 11ft during springs and less than 1ft during neaps. In the two springs illustrated, HHW and LLW occurred on different days. In the first cycle there is evidence of strong south-east winds depressing the height to which water level would normally have reached at HW. Also it will be noted that periodicity is diurnal throughout most of the duration of each cycle, and there is a change to semi-diurnal periodicity during the neaps. This may show as two HW and two LW during a single day or one or more of each over several consecutive days. The phenomenon is known to local residents as "double tides", and is often manifest as a period of one or more days during which there is little change in tidal amplitude but frequent changes in direction of flow.

The lower diagram (Fig. 105) displays the actual tide gauge tracings from 0000 hr to 2400 hr for each of the consecutive days in the period 17 April to 14 May 1965. In order to condense the data and emphasize other features, the daily graphs are not equated to their datum (cf. upper diagram). However the HW and LW are marked on each graph in relation to time of day. Times of sunrise, sunset, moonrise and moonset are indicated in EST (local clock time) for Longitude 140° E (as position of events). The circles representing the moon are blackened to indicate phase and progression through the lunar month (actually the last half and first half of two consecutive months). The direction of the arrows indicate moonrise and moonset. The arrows are positioned in relation to the horizontal time scale to indicate the predicted time of the event at 140° E longitude.

(b) Tidal oscillation in relation to moon progression

The close relationship between rise and fall of tide and the presence of the moon is demonstrated in the lower diagram (Fig. 105). Times of HW closely follow the times of either moonrise or moonset, alternating with consecutive cycles. In the first cycle in this example, times of HW are very close to times of moonset, and in the second cycle they are close to times of moonrise. Similarly times of LW occur a few hours after moonrise in the first cycle, and at a similar interval after moonset in the second cycle.

(c) Tidal cycle in relation to moon phases

Both diagrams (Fig. 105), especially the upper, might suggest that all tidal cycles are in phase with the quarters of the moon. In this particular example it so happens that the neaps correspond in calendar date with the events of new moon and full moon, while springs correspond in calendar date with the events of the first and last quarters of the moon. Dates of moon phases have been compared with dates of HHW and LLW (spring tide) and dates of LHW and HLW (neap tides) (Fig. 106). LHW and HLW usually occur on the same day or on consecutive days but dates of HHW and LLW tend to have wider spread especially when wind is a contributing factor. Comparisons are made on the basis of moon phase date coinciding with date of tidal event (on actual date, falling between pairs of dates, or being one day before or after date). During the 25-month observation period there are periods when tidal cycles are in phase with the moon quarters, either with dates of springs coinciding with new and full moon (5.viii.63 - 10.ix.63, 22.i.64 - 27.ii.64, 8.viii.64 - 6.ix.64, 3.i.65 - 3.iii.65, 14.vii.65 - 30.vii.65), or with dates of neaps coinciding with new and full moon (10.x.63 - 16.xi.63, 19.iv.64 - 4.vi.64, 6.x.64 - 4.xi.64, 9.iv.65 - 15.v.65). It is to be noted that the two kinds of periods alternate with one another and each pair is interspaced by a period where dates of spring and neap tides are out of phase with the moon quarters.

This is demonstrated further in the diagrams accompanying Section 3.6.5 (Fig. 110). In this group of figures, the upper shows the neaps in phase with new and full moon, the lower shows the springs in phase with new and full moon, and the middle shows a period of transition.

(d) Seasonal characteristics

The amplitude of the range in height differences during rise and fall of tide varies with season. This range has been calculated by subtracting height at LLW (lowest value) from height at HHW (highest value) during the springs in every tidal cycle during the period of observation. These data are displayed as a group of three histograms representing successive spring tides during the calendar years 1963 (July-December), 1964 (January-December), and 1965 (January-July) (Fig. 107). The observed times of HHW and LLW of springs

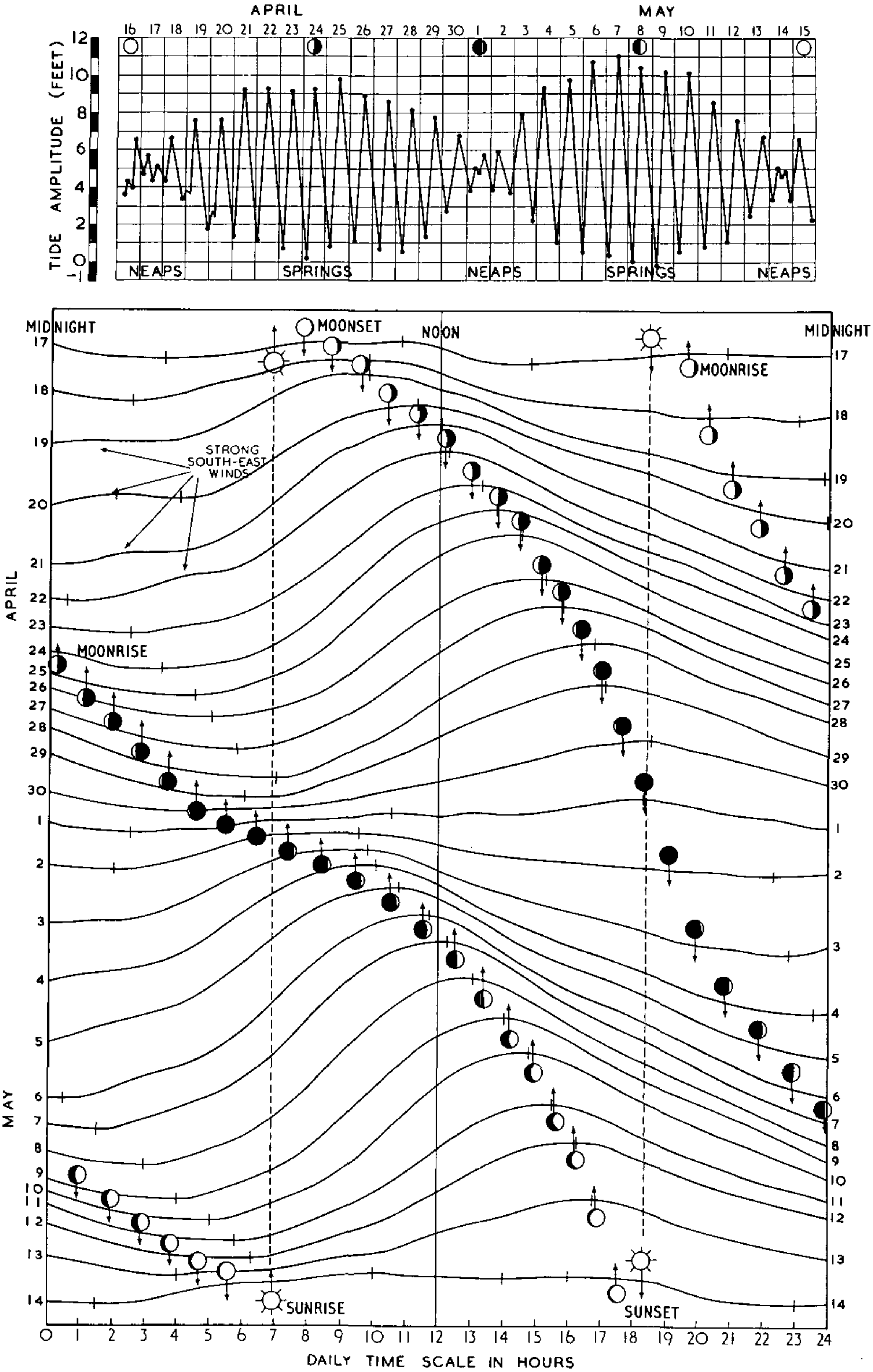

APRIL
MAY
TIDE AMPLITUDE (FEET)
NEAPS
SPRINGS
NEAPS
SPRINGS
NEAPS
MIDNIGHT
MOONSET
NOON
MIDNIGHT
MOONRISE
STRONG SOUTH-EAST WINDS
MOONRISE
APRIL
MAY
SUNRISE
SUNSET
DAILY TIME SCALE IN HOURS

Fig. 105 Characteristics of the tidal cycles in the Norman River at Karumba as demonstrated in two complete successive cycles during the period midnight 15 April to midnight 15 May 1965. Both figures show progression of the tidal cycles in relation to progression of the moon during one complete lunar cycle.

Upper - Progression of two complete successive tidal cycles through three neaps and two springs from full moon at 0902 hr EST on 16 April to full moon at 2152 hr EST on 15 May. Heights of HW and LW above Karumba datum are shown in relation to date and time of day.

Lower - Details of shapes of daily tidal graphs for the same pair of cycles from the neaps of 17 April to the neaps of 14 May. Times of HW, LW, sunrise, sunset, moonrise and moonset are marked for each 24-h period. Times of rise and set of the sun and moon are indicated by the direction of the arrows. Progression of the moon through four phases is indicated by the extent of blackening of the moon symbol. The daily tide curves are grouped in a condensed format (for heights above datum see upper figure) to demonstrate the form of the oscillations and transition between successive cycles, and the relationship between times of HW and LW and times of moonrise and moonset.

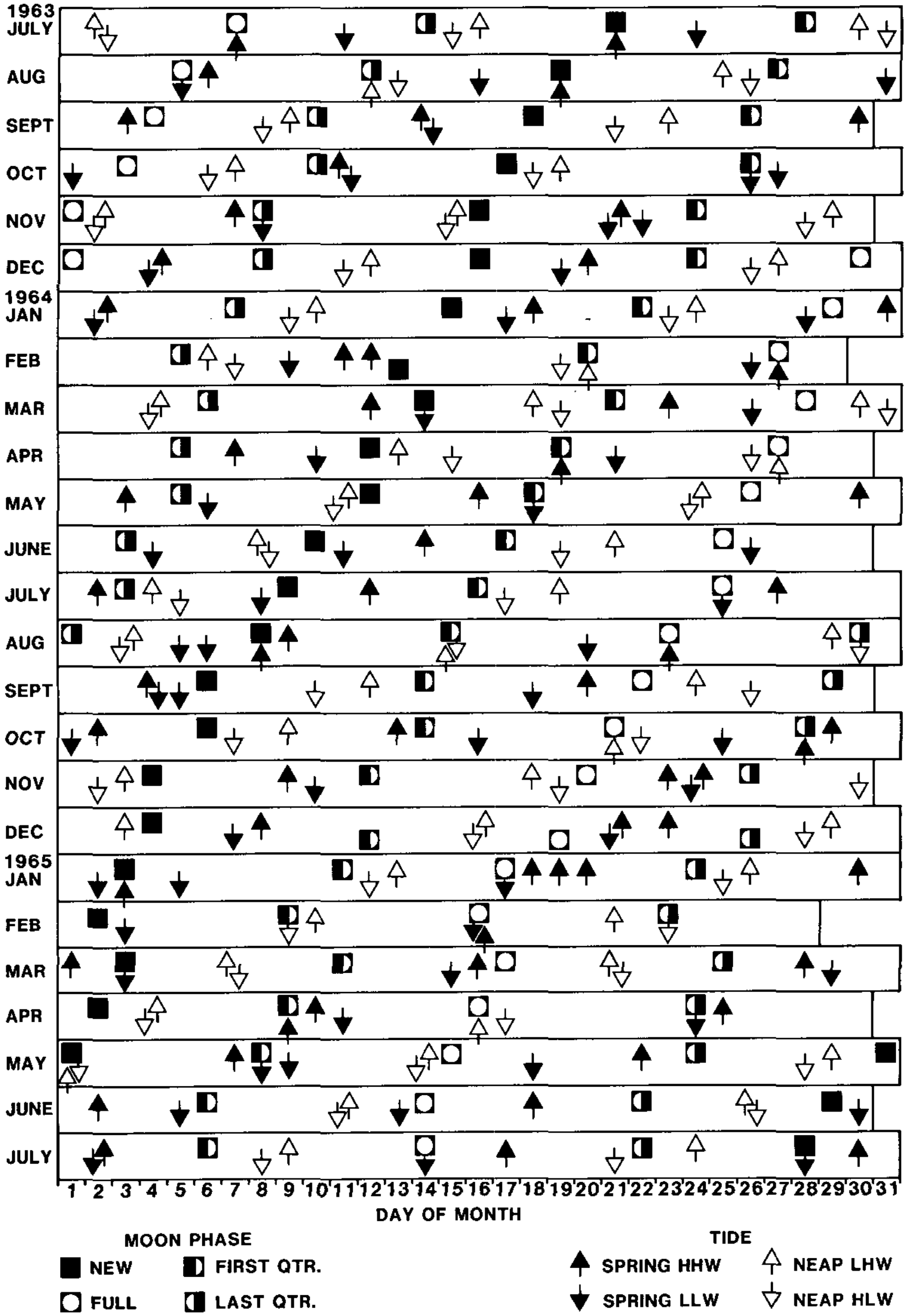


Fig. 106 Relationship between dates of springs HHW and LLW and neaps LHW and HLW and dates of the four phases of moon for 25 consecutive calendar months from July 1963 to July 1965 inclusive. Dates for moon phases are according to EST (GMT - 1000). *Symbols for moon phases and tidal events are* identified in the accompanying legend. Periods during which springs and neaps are in phase either with new and full moon or with first and last moon quarters are listed in the accompanying text (Section 3.6.3 (c)). Data are derived from observations on the Norman River at Karumba.

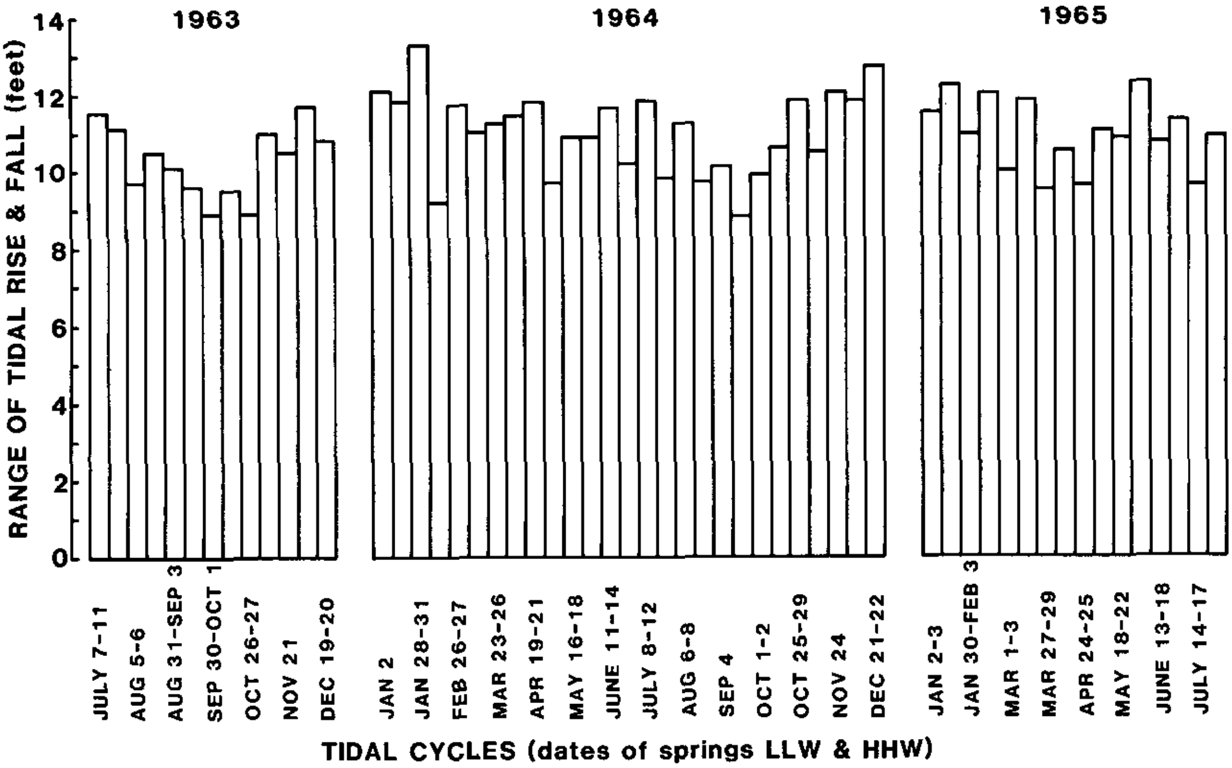


Fig. 107 Seasonal variations in range of amplitude of tidal rise and fall during 56 consecutive cycles in 25 calendar months from July 1963 to July 1965 inclusive. Each column represents one tidal cycle and its height is the difference between levels at HHW and LLW of the springs of that cycle irrespective of their relation to local datum or mean sea levels. Dates (alternate cycles) are those on which HHW and LLW were observed (see also text, Section 3.6.3 (d)). Data are derived from observations on the Norman River at Karumba.

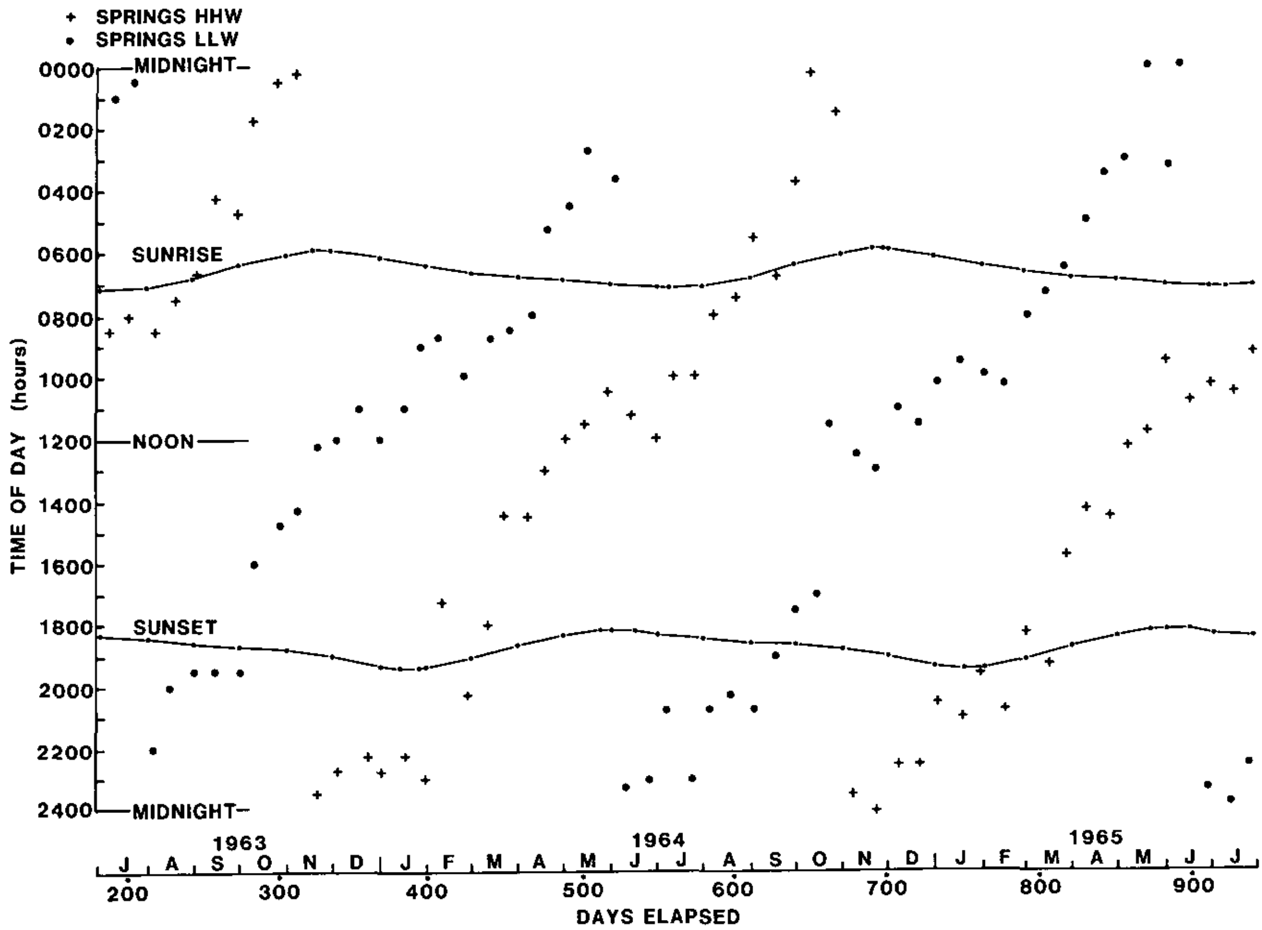


Fig. 108 Seasonal variations in time of day at which HW and LW occurred during 56 consecutive tidal cycles in 25 calendar months from July 1963 to July 1965 inclusive. The points represent the time of day and date on which HHW and LLW were observed during the springs of consecutive cycles. The upper and lower graph lines respectively represent seasonal variations in times of sunrise (upper) and sunset (lower) at 140°E Longitude. Points along these graph lines represent the first day of each calendar month, dates of earliest rise and latest set during summer solstices, and dates of latest rise and earliest set during winter solstices. Data are derived from observations on the Norman River at Karumba. See also comments in accompanying text (Section 3.6.3 (d)).

occurred in most cases on different days as indicated by the date ranges marked on the diagram (Fig. 107). In any pair of observations the LLW occurred either before, on, or after the date of the HHW. Spring tide height differences are displayed for every tidal cycle within the period of observation, but pairs of dates are marked on the diagram only for alternate cycles.

From the data displayed (Fig. 107) the differences in heights between LLW and HHW during spring tides fall with the range of 8.8 ft and 13.3 ft (Mean 10.8 ft). Values tend to fall below the mean mainly during August, September and October, and less markedly during March and April. Values are generally above the mean during the summer months of November to February, the period which corresponds with the wet season.

Also there are seasonal differences in the time of day at which HW and LW occur. This phenomenon is displayed as a graph in which observed times of HW and LW are plotted against time of day (Fig. 108). The values are the observed HHW and LLW of springs, being the mid-points of the successive cycles when fully in phase with diurnal periodicity. As can be noted from Section 3.6.3 (a) (Fig. 105, lower diagram) times of HW and LW become progressively later on successive days during each cycle, and then set back a number of hours (*c.* 9) with the start of the next successive cycle. In the example illustrated HW is at 0945 hr on 18 April and progresses to 1830 hr on 30 April (advances 8 h 45 min in 13 days). During the second cycle HW is at 0930 hr on 2 May and progresses to 1615 hr on 13 May (advances 6 h 45 min in 12 days). The observed time of HW on the first day after neaps in the second cycle (2 May) is 15 min earlier than the equivalent point in the first cycle (18 April). Time of HW has set back 9 h from the end of the first cycle to the start of the second cycle. In this manner the start of every new cycle becomes earlier as the season progresses.

The data (as displayed in Fig. 108) demonstrate that HW occurs during daylight and LW occurs during night at certain seasons (April to September). Similarly HW occurs during night and LW occurs during daylight for the remaining months (October to March). Within each period and during the change over from one to the other there is gradual transition. The partitioning is not as sharply defined as the diagram (Fig. 108) might imply because the points plotted are the mid-points (Springs HHW and LLW) of cycles. HW and LW during any cycle can occur some hours (± 5) distant from the plotted times. This means, for example, that within a cycle with time of HHW between sunrise and noon, some times of HW (early part of cycle) may be before sunrise. Similarly within a cycle with time of HHW between noon and sunset, some times of HW (late part of cycle) may be after sunset. Also because of the set back in time with successive cycles there is transition in times of HHW and LLW from sunset through noon to sunrise and from sunrise through midnight to sunset respectively for the two seasonal periods.

In the example of two successive cycles used to illustrate Section 3.6.3 (a) (Fig. 105, lower diagram) the condition, except during the neaps which are a transition between successive cycles, is that HW occurs only at times between sunrise and sunset, and LW occurs only at times between sunset and sunrise. In general, during the six months centred around winter, HW occurs from a few hours before sunrise to a few hours after sunset, and LW occurs from a few hours before sunset to a few hours after sunrise. The condition concerning times of HW and LW are reversed during the six months centred around summer.

3.6.4 MEAN SEA LEVELS AND TIDAL AMPLITUDES

Seasonal changes in range of amplitude have been illustrated in Section 3.6.3 (d) (Fig. 107). In an earlier publication (Munro 1972) it was shown that river and adjacent gulf levels varied with season. The prevailing wind direction is south to south east during winter and mainly north to north east during summer. Correspondingly there is a fall in mean monthly sea level during winter and a rise in the summer. The sea level heights and tidal ranges quoted therein were derived from the data incorporated in the accompanying diagram (Fig. 109) which covers the period 1 July 1963 to 31 July 1965 for the Norman River at Karumba. Local tidal datum at Karumba corresponds approximately with the 2ft level on the tidal height scale used in this diagram (see Section 3.6.2).

Some extrapolated values have been used in calculations relating to June and December 1964 and January and April 1965 when the recording gauge malfunctioned for brief intervals. During periods of high wind and choppy water conditions in the river graph tracings were subject to minor irregularities. Two sets of calculations have been incorporated in the accompanying diagram (Fig. 109) with respect to monthly ranges and means for the period of 25 consecutive months, and the biennial means on the right hand side of the diagram. Adjustments to observed values have been made by smoothing out the minor irregularities (by eye only).

The pairs of vertical lines for each month represent respectively the range in tidal height at HW (left) and the range in height at LW (right). As there are normally two complete tidal cycles in a calendar month spring HHW, neap LHW, spring LLW and neap HLW each normally occurs twice, and it is rare for any pair to have equal values. The full vertical lines are thus marked with heights (cross bars) for all spring HHW (top of left line), neap LHW (bottom of left line), neap HLW (top of right line) and spring LLW (bottom of right line). The full lines represent ranges after minor irregularities have been eliminated, and the dotted parts below LHW (left line) and above HLW (right line) cover observed extension of the ranges due to the irregularities.

The three horizontally disposed graph lines respectively represent monthly variations in mean heights at HW (upper) and LW (lower) and mean sea level (middle) after elimination of minor irregularities. The isolated dots associated with points along these lines cover the variations caused by the minor irregularities. These monthly means have been calculated by dividing the sum of observed heights by the number of observations in the cases of HW and LW. Mean sea level has been obtained by dividing the sum of all HW and LW heights by the total number of observations.

Observed maximum and minimum heights attained during springs HHW and LLW and neap LHW and HLW together with dates of occurrence are given in the accompanying table (Table 10). This table also gives maximum and minimum monthly mean heights for HW, LW and sea level. These data complement those displayed in Fig. 109, but it should be noted that the tabulated data refer to the official datum at Karumba and the zero position on the graph scale (Fig. 109) is 2ft below the official datum. Earlier published figures (Munro 1972) differ slightly because they refer to a datum based on the biennial mean spring LLW which is 0.1 ft below the official Karumba datum.

3.6.5 EFFECTS OF WIND AND HEAVY RAINFALL ON TIDAL AMPLITUDE (NORMAN RIVER)

(a) *Effects of wind*

The general effects of seasonal changes in prevailing wind direction on sea level and the heights to which tides rise and fall have been displayed in Section 3.6.4. During the winter season (April to August) the prevailing wind flow is predominantly from the east to south east and periodically the wind blows strongly (10-20 knots) and continuously over several consecutive days. Under such conditions the wind force tends to lower the water levels in streams such as

Table 10. Tidal heights of the Norman River at Karumba during the period 1 July 1963 to 31 July 1965.

Measurements are in feet. Heights refer to datum for the Port of Karumba which is 2.93 ft below Queensland State Datum.

		Minimum	Date	Maximum	Date	Range	Biennial Means
Observed heights	Springs HHW	8.1	17 July 1965	13.5	31 January 1964	5.4	10.8
	Springs LLW	-2.0	20 July 1965	2.0	3 March 1965	4.0	-0.1
	Springs HHW-LLW					15.5	
	Neaps LHW	2.3	3 August 1964	8.8	26 January 1965	6.5	5.4
	Neaps HLW	1.6	1 July 1963 3 August 1964	6.3	19 March 1964	4.7	3.9
	Neaps LHW-HLW					7.2	
Monthly means	HW	6.6	September 1963	11.0	January 1965	4.4	8.4
	LW	0.0	July 1965	5.2	February 1964	5.2	1.7
	Sea level	3.6	July 1963	10.3	May 1964	6.7	5.0

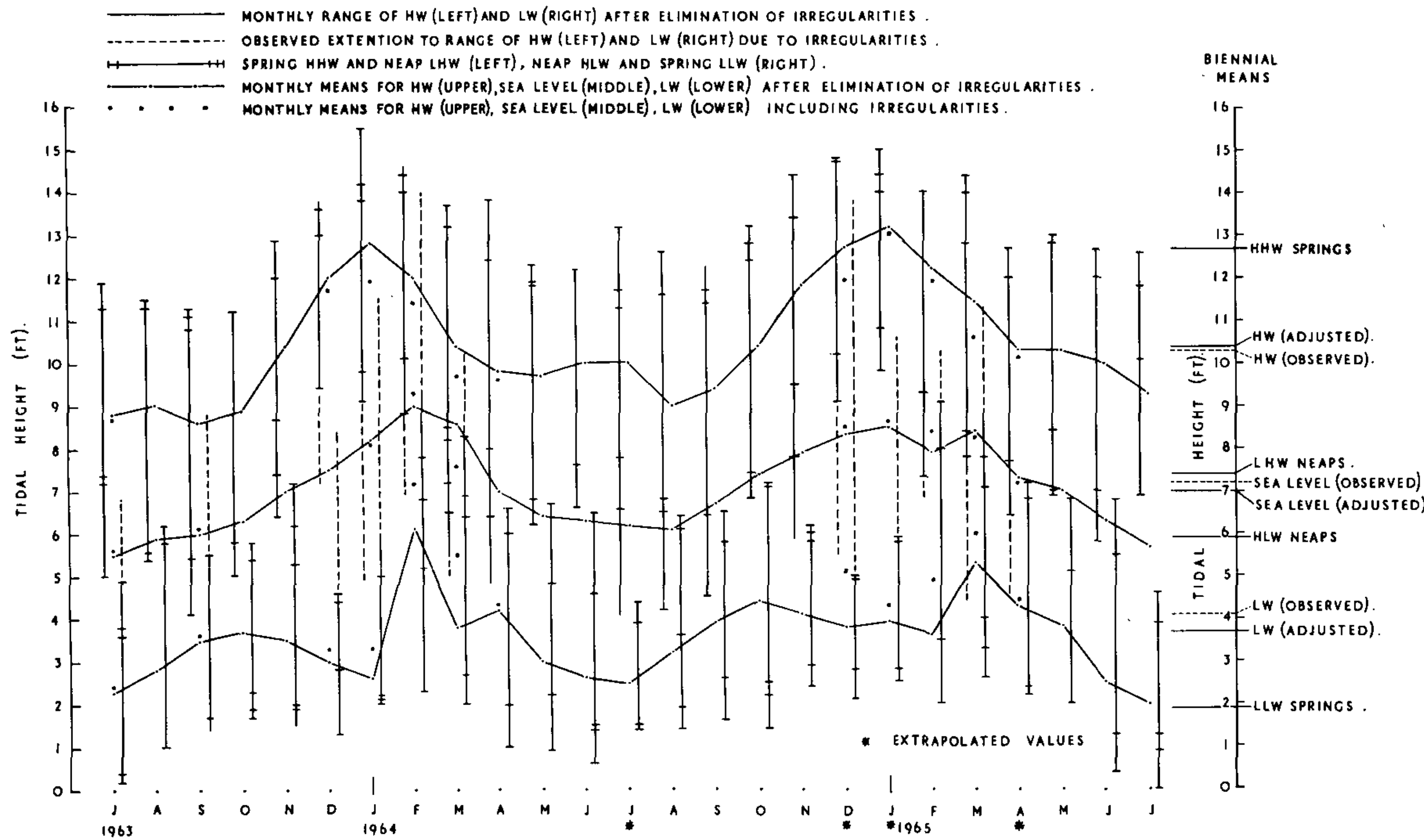


Fig. 109 Monthly variations in tidal height ranges for the Norman River at Karumba, and monthly and biennial mean heights for sea level, HW, LW, springs HHW and LLW and neaps LHW and HLW for 25 consecutive calendar months from July 1963 to July 1965 inclusive. The 2.0 mark on the tidal height scale corresponds with Karumba datum. Monthly ranges in heights at HW and LW are represented by the pairs of vertical lines and seasonal variations in monthly mean heights for HW (upper), LW (lower) and sea level (middle) by the horizontal graph lines. Data include observed values and adjusted values derived from elimination of irregularities. Detailed explanations are in the accompanying text (Section 3.6.4).

the Norman River. The phenomenon is described by local residents of the district as 'blowing the water out of the river'. The effect is sufficiently pronounced to restrict movements of small ships through shallower reaches of this river.

The effect of these windy periods on tidal oscillations is demonstrated in the upper and middle figures of the accompanying set of diagrams (Fig. 110). These diagrams show daily rise and fall of tide in terms of height, time of day and date progression. The lines joining the plotted points for HW and LW indicate the amplitude and period of tidal oscillations through successive cycles. Wind direction and force as observed at Karumba are shown along the horizontal axis.

In the upper figure the cycle between 1 May and 14 May shows virtually no distortion to the oscillation pattern, but in the cycles prior to and subsequent to it there is evidence of depression of heights of HW and LW when wind force has increased. The middle diagram represents a period when the south east wind flow was stronger and very persistent, thus distortion of oscillations are very marked, especially during the periods 22-25 June and 9-19 July.

(b) Effects of heavy rain and river flooding

Rain is markedly seasonal and the wet period extends from December to March, with a virtually rainless period from July to September. Mean annual rainfall for Normanton (1872-1965) is 37.00 inches and for Burketown (1887-1965) is 28.86 inches. Rainfall is usually distributed over one quarter of the days during the wet season, and extremely heavy falls occur on only very few of these days. As a result of such concentration the runoff of water from land can be considerable over a period of a few days and flooding is inevitable.

The effects of wind of cyclonic origin and the raising of river levels by flooding is demonstrated in the lower figure of the accompanying set (Fig. 110). Daily rainfall, in addition to wind direction and force, is indicated along the horizontal axis. The effects of the strong wind and heavy rain on the tidal oscillations from the full moon in January to the first quarter of moon in February are most marked. The runoff of flood water is evident through the whole tidal cycle between 5 and 20 February. It is to be observed that the rise in river height from flooding generally increases heights at HW through all this cycle and the second half of the previous one. A more noticeable feature is the effect of elevation of heights at LW during the springs and the general damping effect on the amplitude of the tidal oscillations.

3.7 GULF WATER CIRCULATION

3.7.1 METHODS AND SAMPLING

Neither of the fishing skippers of the small prawn trawler *Rama*, which was chartered as survey vessel, was a trained navigator, and the vessel was not equipped with instrumentation for accurate determination of site positions.

As noted in Section 2.2.4 of Part 2 of this Atlas, station positions were determined at the end of each cruise by method of dead reckoning. This process took into consideration the factors of tidal movement and wind in displacing the vessel from its intended course. Tracks of whole cruises were manipulated for best fit in relation to positions which could be determined from bearings on land marks. Tidal components were determined from direct observations of direction of set at station sites at sea and from the recordings of the tide gauge at Karumba. Wind direction and strength were also recorded at station sites. These observations were taken into consideration when making allowances for drift of vessel from station sites and deviations from compass course when steaming between sites.

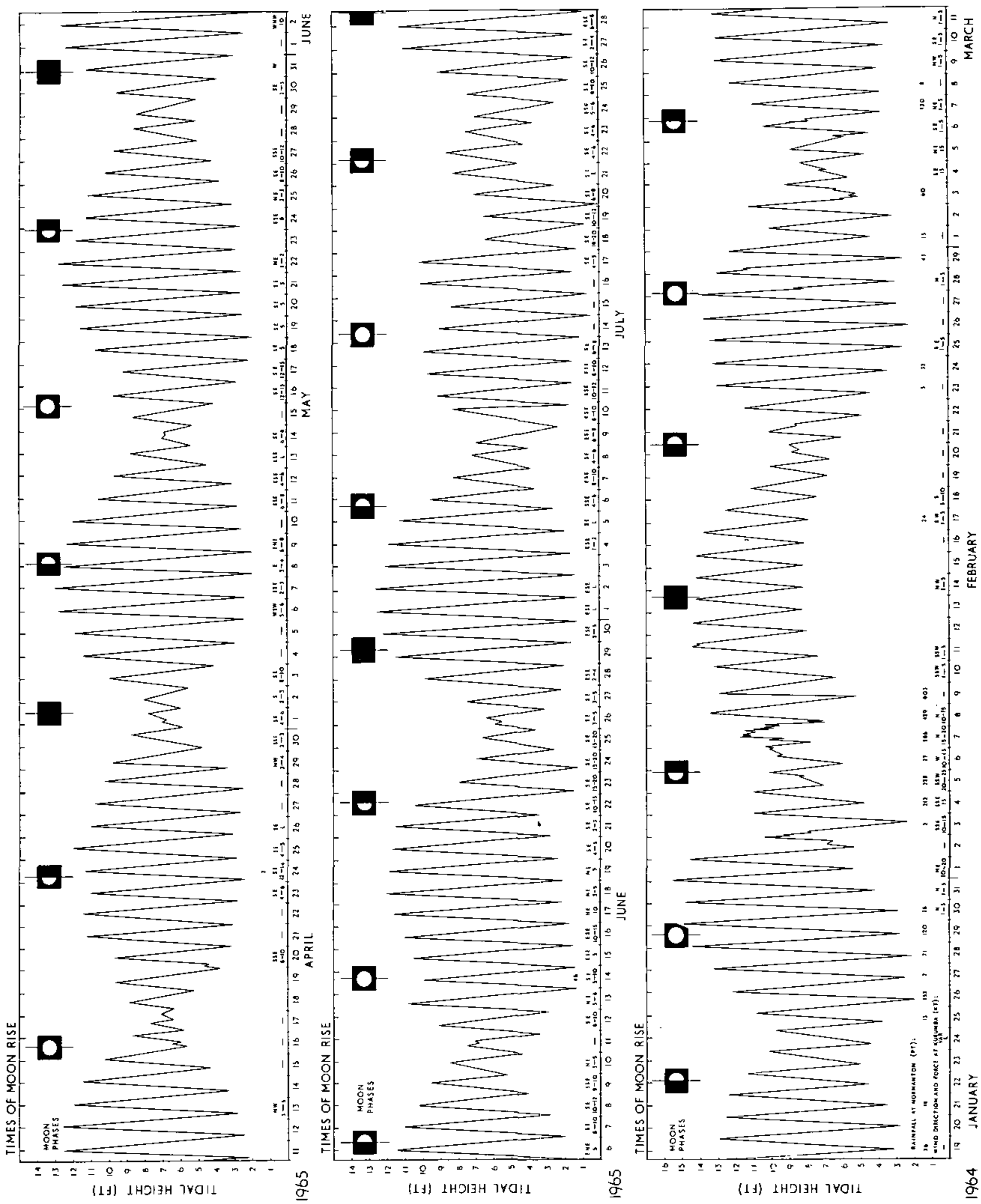

TIMES OF MOON RISE
MOON PHASES
TIDAL HEIGHT (FT)
1965
APRIL
MAY
JUNE
1965
JUNE
JULY
1964
JANUARY
FEBRUARY
MARCH

Fig. 110 Effects of strong winds and river flooding on heights reached during HW and LW in the Norman River at Karumba illustrated in three selected sets of consecutive tidal cycles. Heights of HW and LW are shown in relation to time of day, date, and lunar progression. Daily rainfall at Normanton and wind direction and force at Karumba are indicated along the horizontal scale.

Upper - 11 April to 2 June 1965 when neaps of tides are in phase with new and full moon and springs are in phase with first and third moon quarters. The tidal oscillation for the cycle 1-14 May is regular but adjoining cycles show evidence of depression of heights of HW and LW when wind force has increased.

Middle - 6 June to 28 July 1965 when neaps and springs of tides are out of phase with the moon quarters and midwinter SE winds have been strong and persistent. Distortion of tidal oscillations and depression of heights at HW and LW are very marked, especially during 22-25 June and 9-20 July.

Lower - 19 January to 11 March 1964 when springs of tides are in phase with new and full moon and neaps are in phase with first and third moon quarters. The period represents the centre of the summer monsoon when strong winds and heavy rainfall accompanied a cyclonic disturbance in the Gulf. Distortion of tidal oscillation from wind is very marked and there is elevation of heights at HW and LW accompanying a general rise in river height during runoff of flood water. The flooding has had a strong damping out effect on the tidal cycle oscillation during 6-21 February.

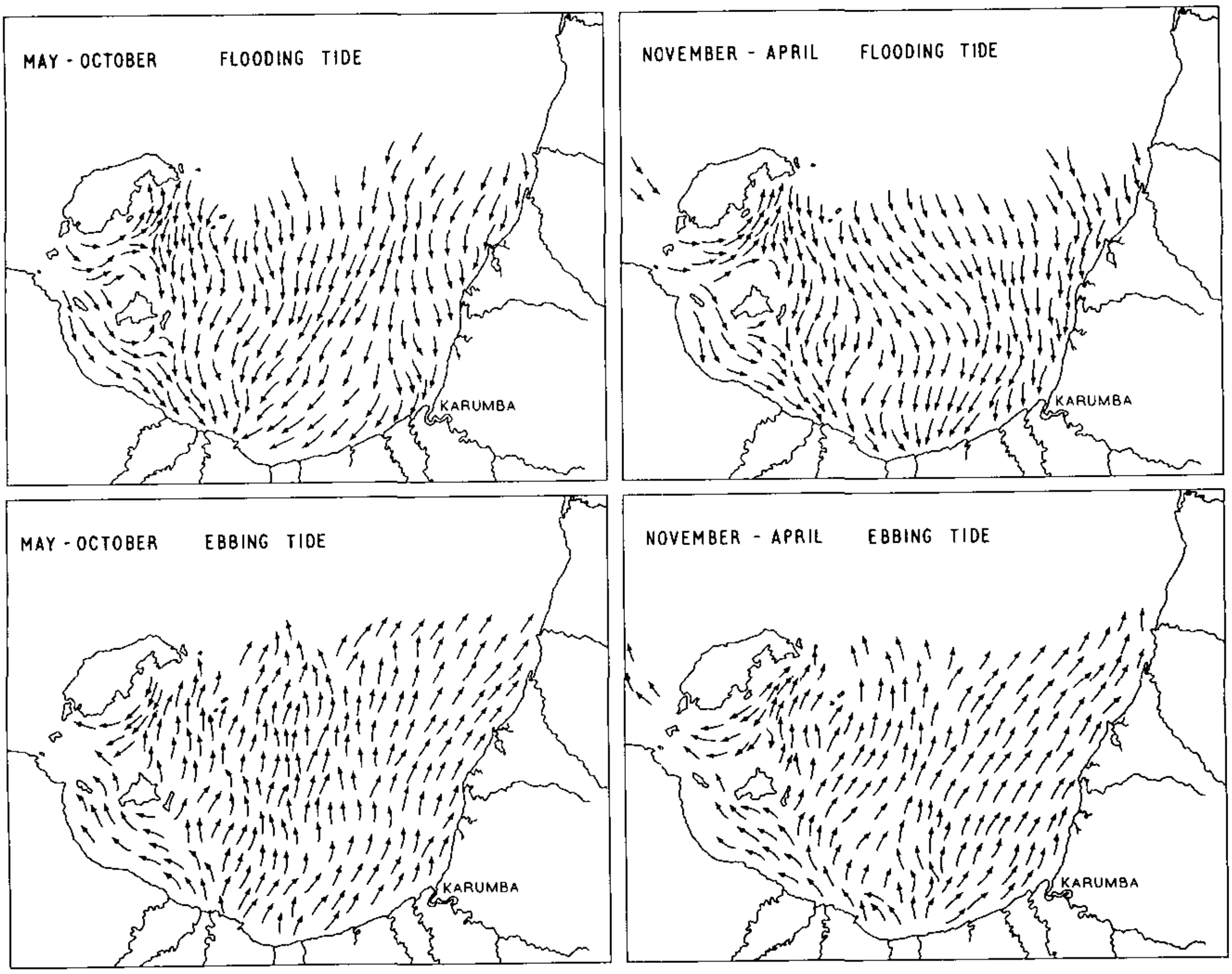


Fig. 111 A hypothetical concept of seasonal changes in water circulation patterns in the southern part of the Gulf of Carpentaria. The concept is based entirely on allowances made for vessel deviation from course and drift off position at station sites in track chart plots by method of dead reckoning. The effects of tide and wind in combination are grouped in sets representing ebb and flood phases of tide and summer and winter prevailing wind circulations.

Note - The system was devised mainly as an aid for fitting probable positions to sites and has no basis from flow meter measurements or theoretical modelling.

These corrections for drift direction were plotted according to area, season and state of tide. They were then grouped on the basis of tide ebb and flood in combination with two seasonal periods. The seasons were May to October and November to April representing winter and summer periods and correponding generally with the dominance of prevailing wind conditions of flow from east or south east and north or north east respectively.

Direct observations on water flow in particular areas were made in certain areas, e.g. an apparent reversal of flow on either side of a shallow bank between Mornington and Bountiful Islands, and entry and exit of water between Mornington Island and the mainland in the south western sector. These flow observations have been incorporated into the four patterns.

3.7.2 HYPOTHETICAL CIRCULATION PATTERN BASED ON VESSEL DRIFT

The patterns of water circulation derived in the manner described above for the two seasons and two states of tidal flow are displayed in the accompanying set of four maps (Fig. 111). It is stressed that these are hypothetical and thus may be partly, or even completely, inaccurate. They are included in the Atlas because of their historical interest. The acceptance during the term of the survey of this particular concept of wind and tide effects on water circulation assisted decisions in the determination of trawl site positions. No studies of water circulation based on measurements with flow meters had been made in the area prior to or during the actual survey. Confidence in the accuracy of 'best fit' placing of trawl station site positions is governed to a large extent by acceptance of these hypothetical circulation patterns.

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Division of Fisheries Research
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TASMANIAN LABORATORY
Castray Esplanade, Hobart, Tas
G.P.O. Box 1538, Hobart, Tas 7001, Australia

NEW SOUTH WALES LABORATORY
202 Nicholson Parade, Cronulla, NSW
P.O. Box 21, Cronulla, NSW 2230

QUEENSLAND LABORATORY
233 Middle Street, Cleveland, Qld
P.O. Box 120, Cleveland, Qld 4163

WESTERN AUSTRALIA
Leach Street, Marmion, WA
P.O. Box 20, North Beach, WA 6020

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