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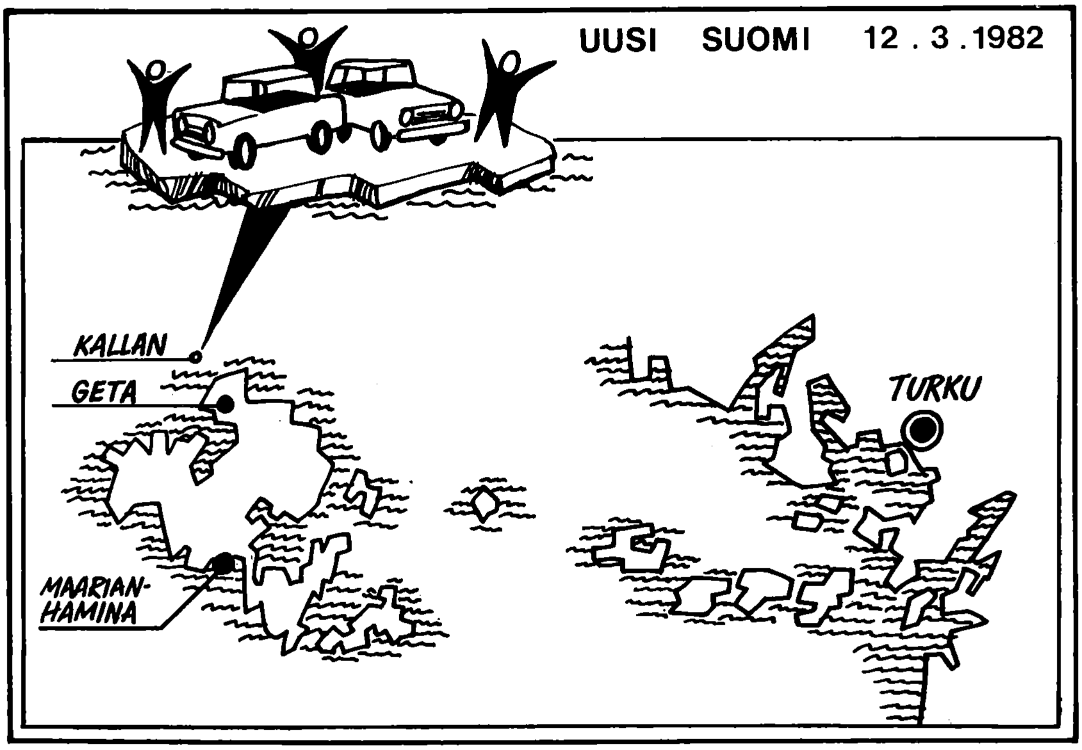
Research Report No 36

FORMATION, THICKNESS AND STABILITY OF FAST ICE ALONG THE FINNISH COAST

BY ERKKI PALOSUO, MATTI LEPPÄRANTA AND ARI SEINÄ



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FORMATION, THICKNESS AND STABILITY OF FAST ICE ALONG THE FINNISH COAST

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FOREWORD

This is report No 36 published by the Winter Navigation Research Board. The report consists of a study of the ice conditions along the Finnish coast on the basis of observation material collected by the Institute of Marine Research in Finland since 1919. The main objects of the study were the maximum thickness of level ice and the maximum thickness of moving ice in the skerries. Detailed ice charts are presented here.

This work arose from practical needs connected with the work of the Finnish Board of Navigation. Consideration of ice forces on structures such as safety devices for winter navigation requires accurate and detailed ice information.

The Winter Navigation Research Board expresses its thanks to the authors and all those who have assisted in this work.

Helsinki and Norrköping, May 1982

Jan-Erik Jansson   Kaj Janérus

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Appendix 1. Table on ice statistics along the winter fairways.

Appendix 2. Detailed charts on the maximum level ice thickness and the expected maximum thickness of moving ice in 30 years.

Abstract

Based on the ice data material collected since 1919 by the Institute of Marine Research, Finland, the maximum thickness of level ice and the expected maximum thickness of moving ice along the Finnish coast are studied. The former goes from 115 cm in the north down to a little less than 100 cm by the southern coast. The latter was very dependent on the density of island and shoals. In Appendixes detailed tables and maps of the studied quantities are given.

1. INTRODUCTION

In the beginning of the 1970s the winter navigation in Finland had expanded to the stage where all the importants harbours up to the northest part of the Baltic Sea could be kept open throughout the year. Consequently the need for accurate ice information grew. Earlier statistical works [e.g. 7, 8] were begun to be made more comprehensive considering first the ice in the open sea, and as a joint work between the Institute of Marine Research in Finland and Swedish Meteorological and Hydrological Institute (SMHI) [11] a new ice atlas has been produced [10]. However, more detailed information of the ice by the coast and outer skerries is very much needed for planning the placing of safety devices for navigation such as lighthouses and buoys.

Most of the areas by the coast and outer skerries where the safety devices are located is covered with fast ice for some part of the ice season. The present work is limited to the formation, thickness and stability of the fast ice cover. Apart from general statistics detailed tables and maps are given on the long-term values of the maximum level ice thickness and the expected maximum thickness of moving ice in the neighbourhood of the winter fairways.

Due to the lack of data the study of the mobility of ice had to be limited to the level ice in the skerries. If there are e.g. ridges in the ice field, they have not been taken into account. The calculations of maximum thickness of moving ice are here concerned with hard ice in autumn and winter. In spring rotten ice can be broken much easier.

2. THE DATA MATERIAL

Measurements of ice thickness were made already in the mid-1800s at some coastal places but regular weekly observations were started first after the Institute of Marine Research had been founded in 1918. In addition the icebreakers have described the ice conditions along the fairways in their daily reports. These data are stored in the archives of the institute. For this work the data from the years 1919-1981 collected in the archives and publications of the institute were taken as the basic material. The ice seasons 1919/20-1979/80, i.e. 61 seasons, were studied for the maximum level ice thickness and the seasons 1955/56-1980/81, i.e. 26 seasons, for the stability of the fast ice.

The observations of the coastal stations include the thickness of ice and snow and the character of the ice nearby the station. The icebreaker reports give descriptions of the ice type and thickness and of the occurrence of mechanical processes such as shifts and ridging. In 1979 new instructions for observations were given to the icebreakers and the ice in the open sea was then included.

3. MAXIMUM LEVEL ICE THICKNESS

Among the studied ice seasons several severe ones were found. Typical to them were long periods of very low temperature. In the severe season 1941/42 the ice cover was nearly snowless in many places in the Bothnian Bay and the Gulf of Finland and consequently the observed thickness represent well the long-term maximum values [9]. In the Bothnian Sea and Archipelago Sea maximum thickness was observed in the season 1940/41.

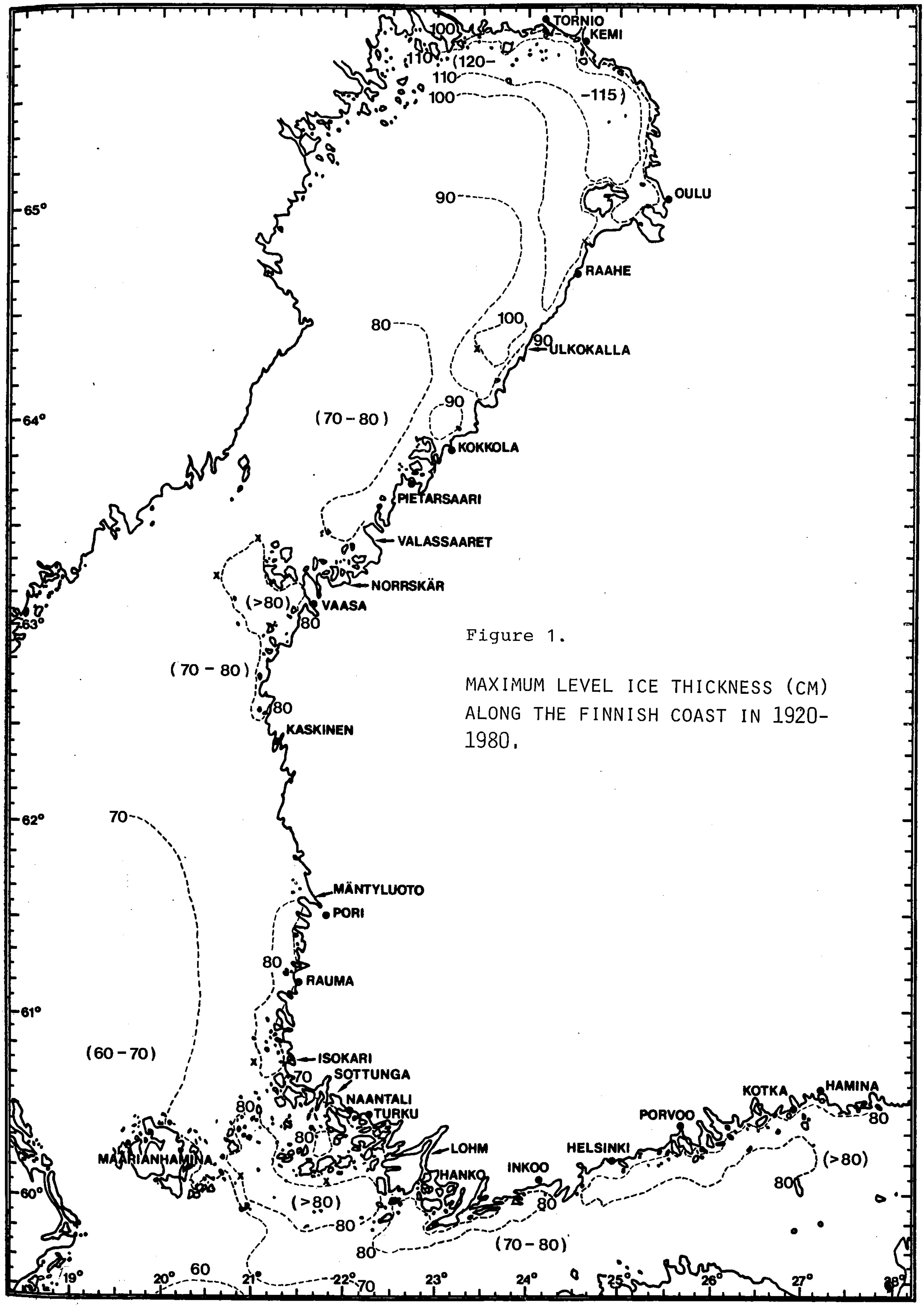

Figure 1.

MAXIMUM LEVEL ICE THICKNESS (CM) ALONG THE FINNISH COAST IN 1920-1980.

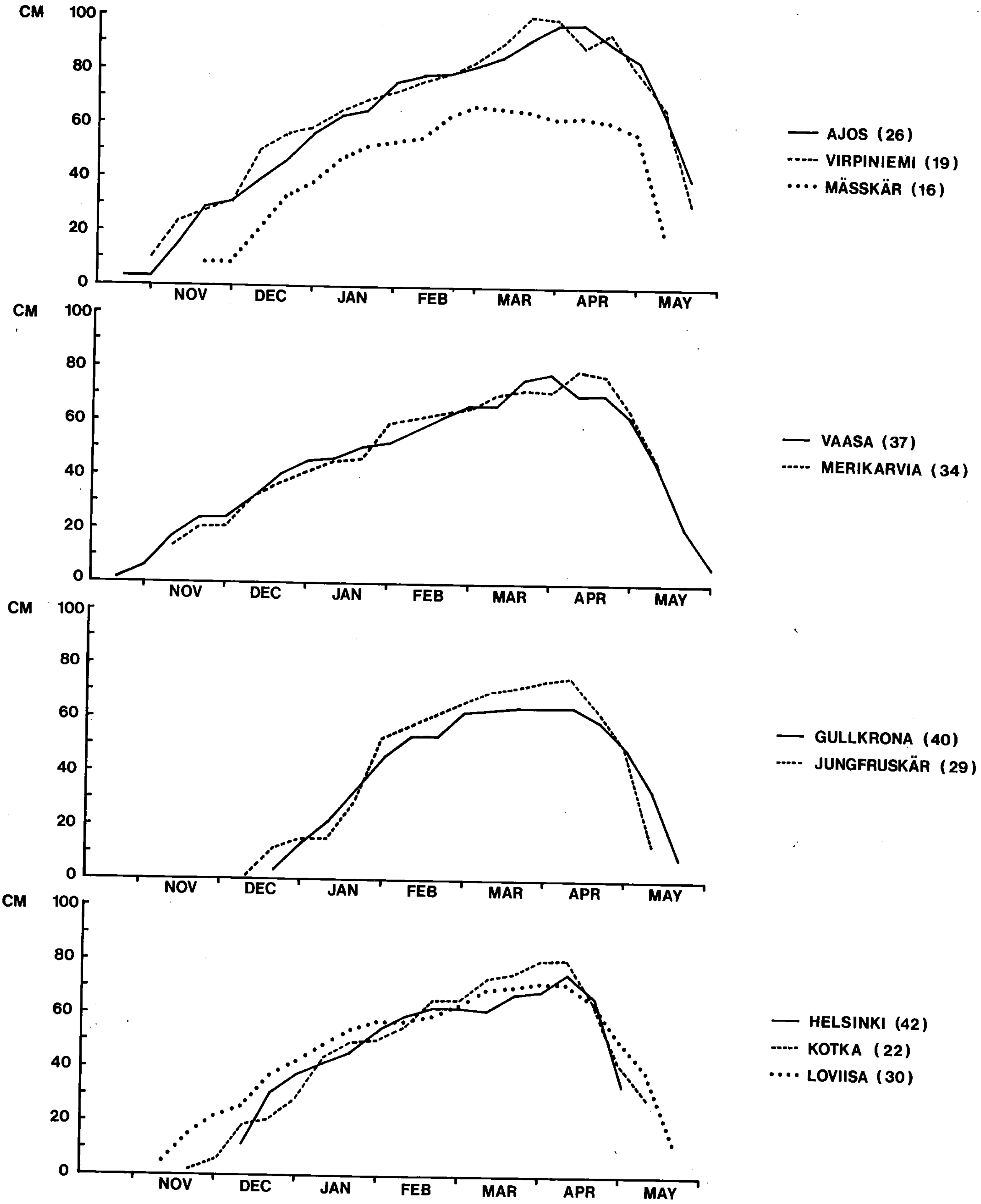

Figure 2. Time evolution of the maximum level ice thickness on the Finnish coast (after [3]). The numbers in parenthesis on the right give the number of years in the data material.

A general chart of the maximum level ice thickness along the Finnish coast is given in Fig. 1. Appendix 1 gives the maximum values in different parts of the winter fairways and detailed charts are presented in Appendix 2. The greatest level ice thickness of 115 cm on the Finnish coast was measured in 1941/42 by Tornio and Haukipudas. Let it be mentioned that on the Swedish coast by Luleå and Törefors as high value as 120 cm has been observed [4, 5]. Apart from the Bothnian Bay the maximum level ice thickness is a little less than 100 cm. Statistics of the time evolution of the thickness of coastal ice and snow have been recently published [3]. In Fig. 2 some examples are given.

4. FORMATION AND STABILITY OF FAST ICE

Fast ice forms every winter along the Finnish coast varying with respect to time and extension. The probability of fast ice formation for each month was calculated from the Baltic sea ice data bank [11] (Fig. 3). The fast ice cover is not necessarily always restricted to coastal areas and skerries but on some occasions "fast ice bridges" have formed in narrow parts of the Baltic Sea such as the Quark and the Åland Sea [6]. Even large basins as the Bothnian Bay have been immobile during calm low temperature periods [6]. In recent years the mobility of ice has been increased by the effect of the icebreaker channels. E.g. the probability of immobility of ice on March 1 in the Bothnian Bay was 0.3 for the period 1925/26-1954/55 [6] whereas it was less than 0.1 for the period 1963/64-1978/79 [10]. Except for the open sea the icebreaker channels have had a notable effect also on some parts of the coastal fairways, e.g. Kemi-Ulkokrunni-Oulu and Kotka-Orrengrund, where the wind usually blows across the fairway.

In considering the dependence of break-up of fast ice on different factors it was found in [8] that for a given place there was a linear dependence of the maximum break-up thickness h_σ on the wind speed w (Fig. 4), i.e. we have

$$h_\sigma = \alpha w \qquad (1)$$

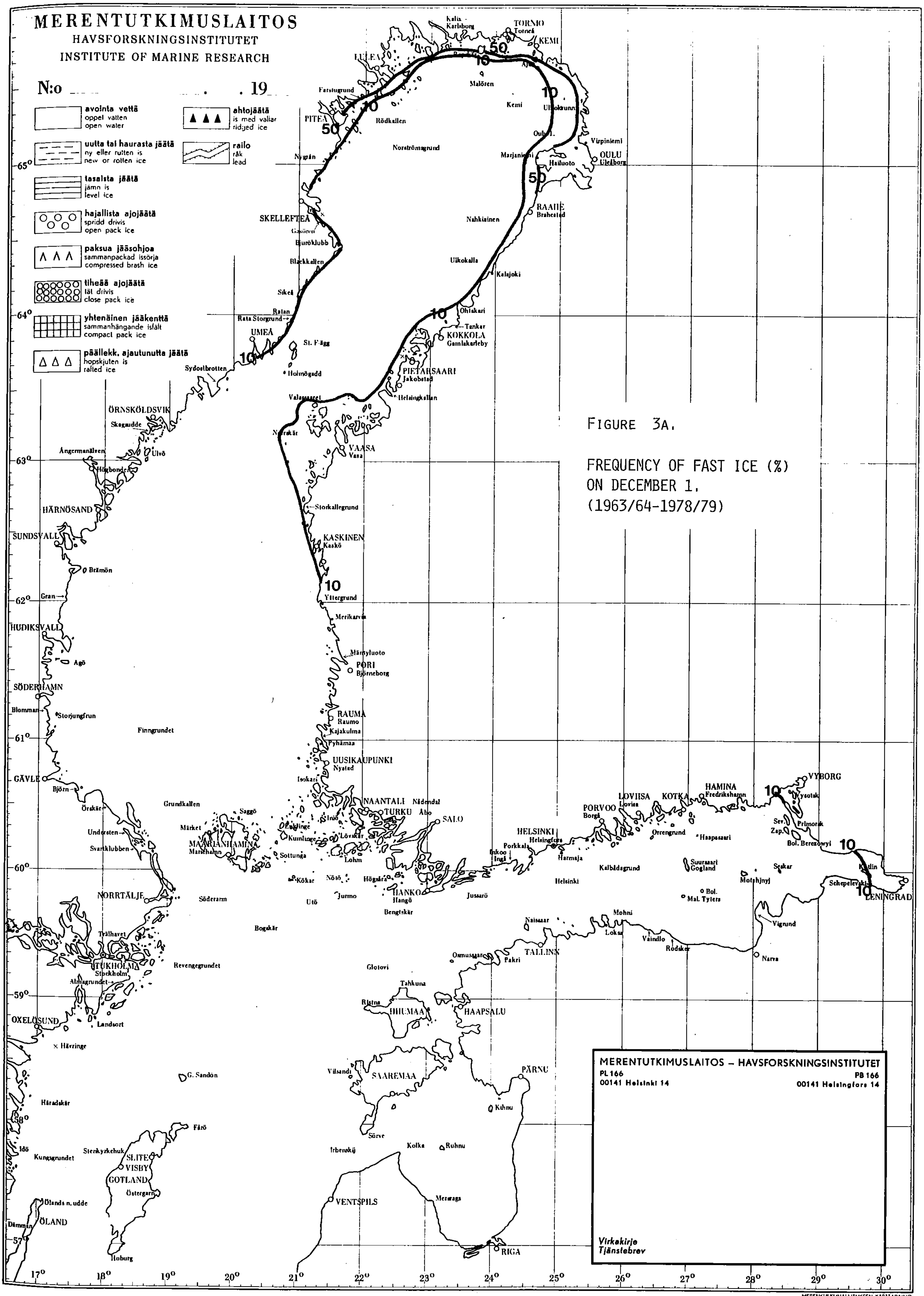

FIGURE 3A.

FREQUENCY OF FAST ICE (%)
ON DECEMBER 1.
(1963/64-1978/79)

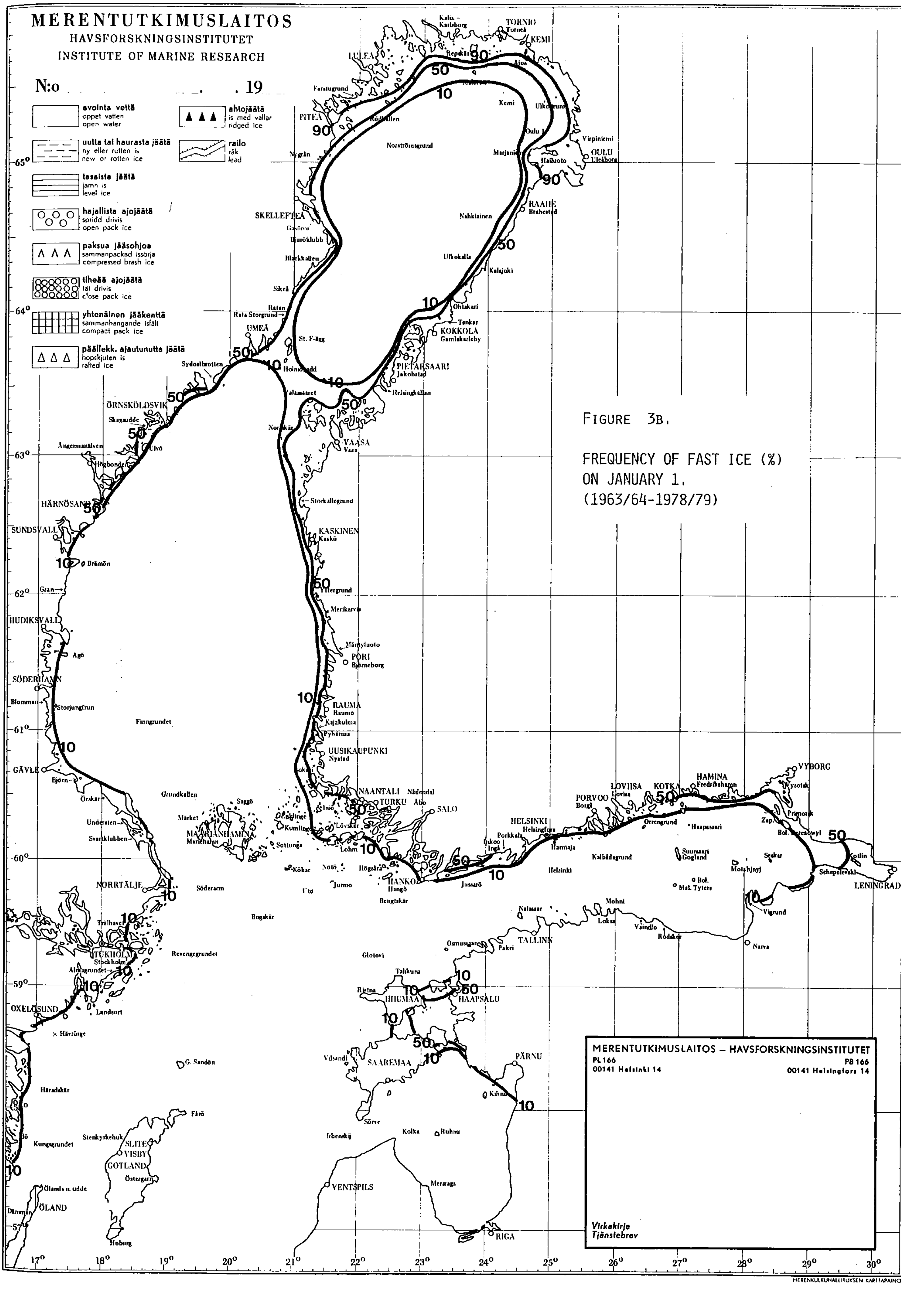

FIGURE 3B.

FREQUENCY OF FAST ICE (%) ON JANUARY 1. (1963/64-1978/79)

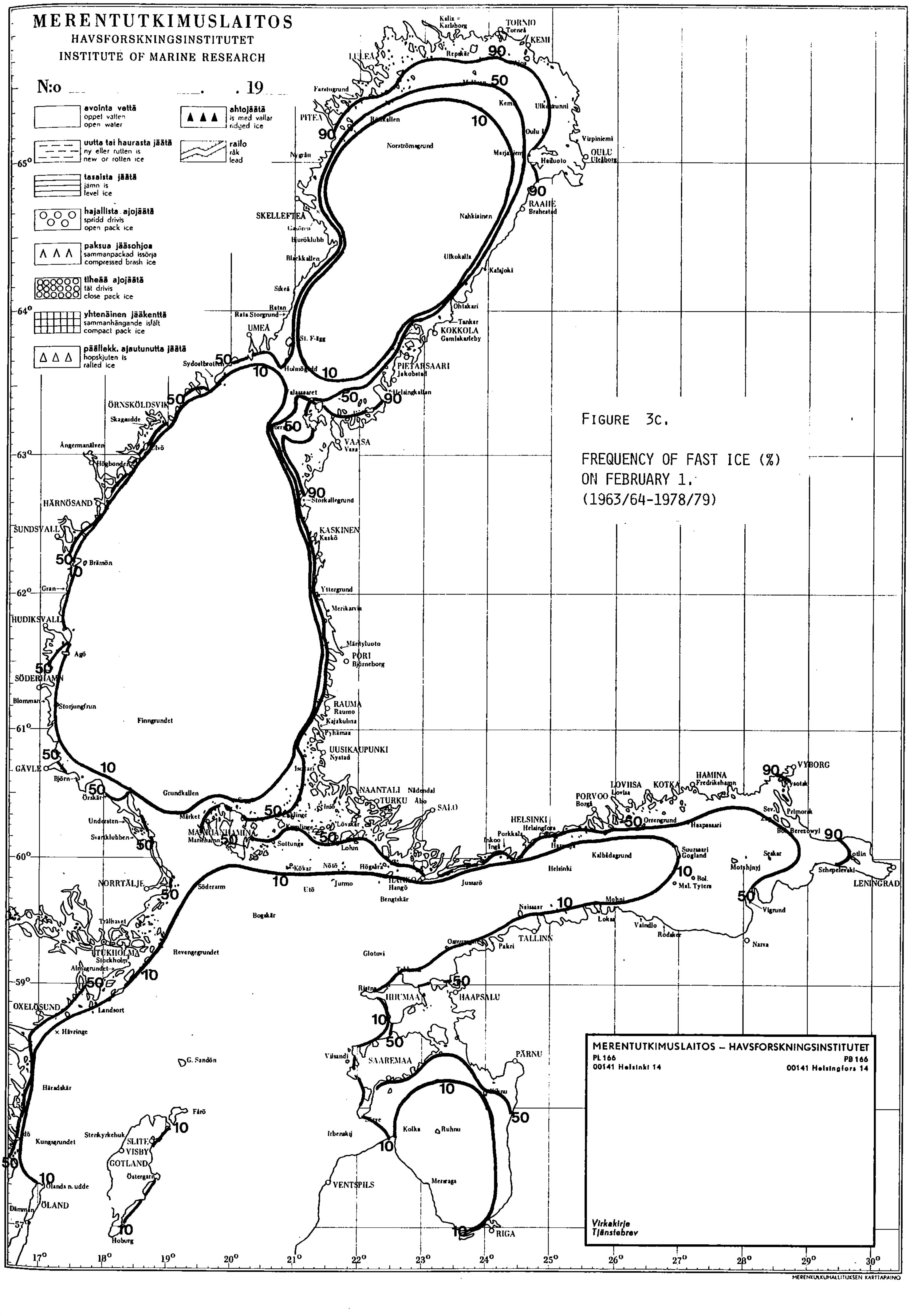

FIGURE 3C.

FREQUENCY OF FAST ICE (%) ON FEBRUARY 1. (1963/64-1978/79)

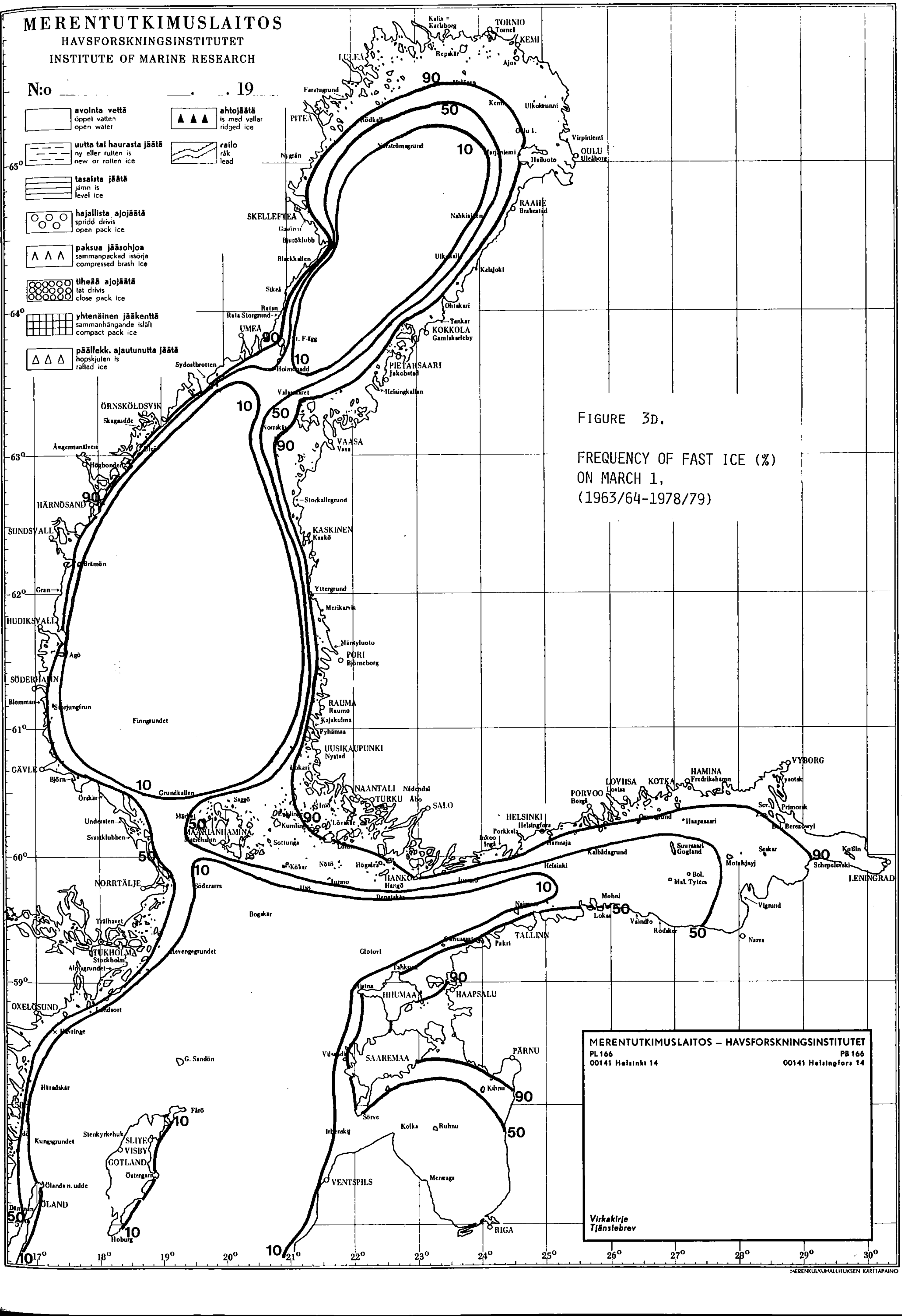

FIGURE 3D.

FREQUENCY OF FAST ICE (%) ON MARCH 1, (1963/64-1978/79)

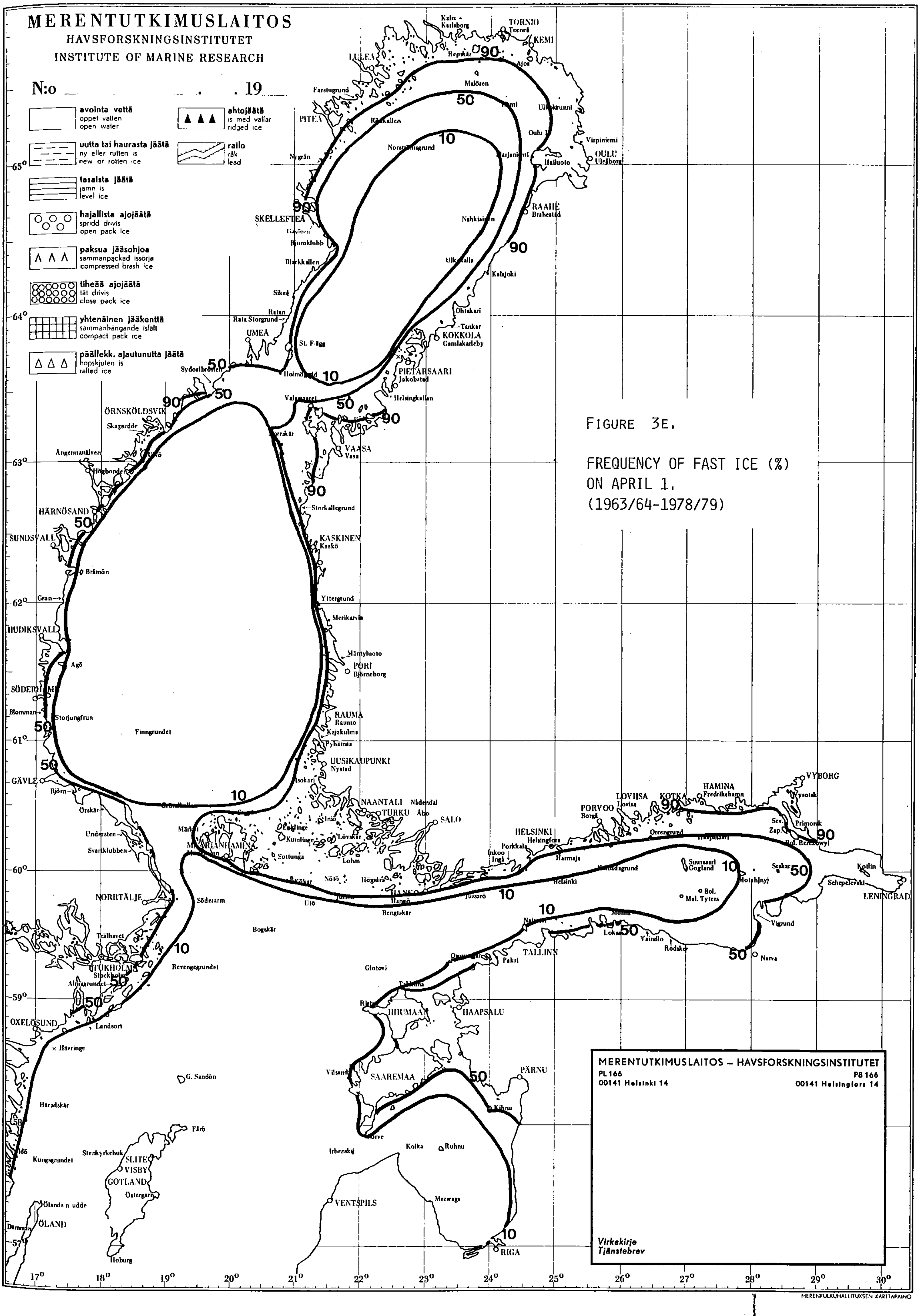

FIGURE 3E.

FREQUENCY OF FAST ICE (%)
ON APRIL 1.
(1963/64-1978/79)

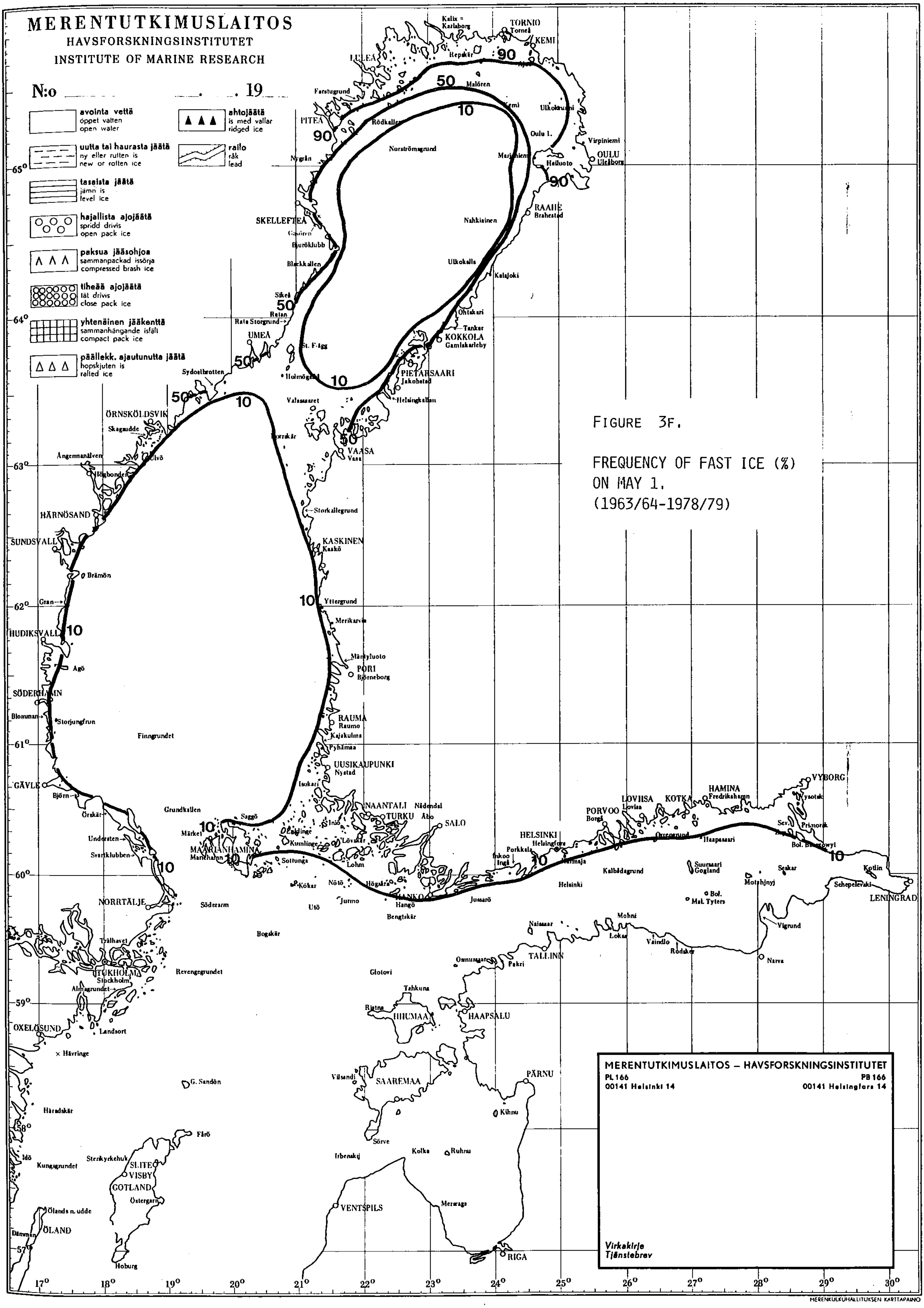

FIGURE 3F.

FREQUENCY OF FAST ICE (%) ON MAY 1. (1963/64-1978/79)

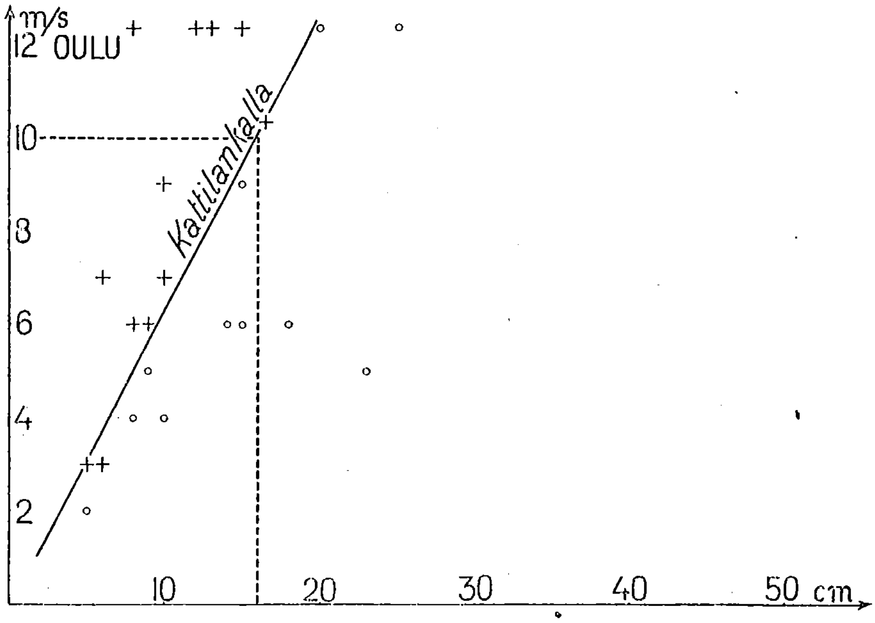

Figure 4. The interdependence of the thickness of the ice cover and the one-day-mean wind speed at the break-up of the ice on the Saapaskari - Kattilankalla section of Oulu fairway. The circles indicate that the ice did not break; the crosses, when it broke up. After [8], e.g. the wind 10 ms^{-1} will break the ice less than 16 cm thick.

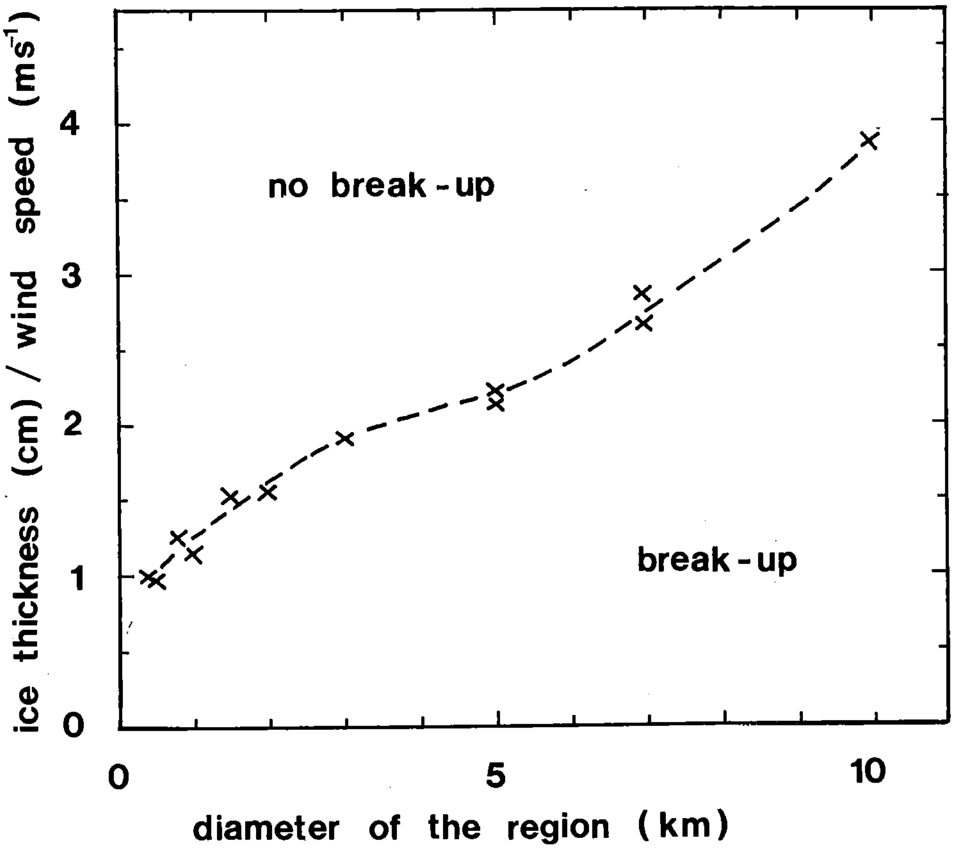

Figure 5. The stability of fast ice. After[2].

The proportionality factor α was later showed [2] to be a nonlinear function of the distance between islands and shoals where grounded ridges occur,

$$\alpha = \alpha(L) \tag{2}$$

(Fig. 5). These studies presumed that the ice was hard and not rotten spring ice. The penetration of sea waves into the ice and water-level variations were not considered. However, their effect is implicitely included in the wind speed. Local variations of fast ice thickness are not well known. Fig. 6 shows an example where level ice thickness was observed to range by about 40 cm in an area of 1 km^2 size.

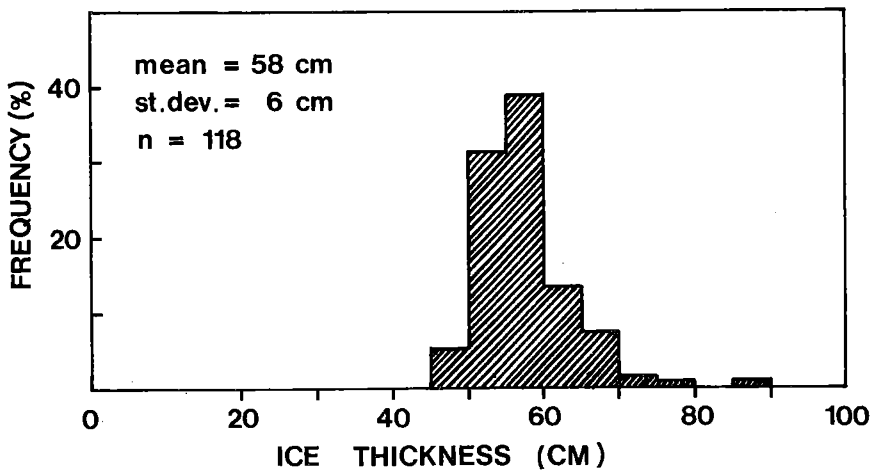

Figure 6. Observed distribution of fast ice thickness in 1 km^2 area (near Ulkokalla, 2 April 1978).

In areas where observations had been made a clear single-valued relationship was found between the stability of fast ice and external factors. Where only a few or no observations were available interpolation or extrapolation had to be used. The results were then checked by comparing with each other areas of similar density of islands and shoals. The stability conditions for different areas were then normalized to the maximum break-up thickness for the wind speed of 10 ms^{-1}, h_{10} (Appendix 1). Through Eq. (1) we have

$$\alpha = h_{10}/10\ ms^{-1} . \tag{3}$$

To estimate the maximum thickness of moving ice in a given number of years the length of the period when the ice may move and the probability distribution of wind speed must be known. For the former the average time given in [8] was chosen and is shown in Appendix 1. This is a slight overestimation to the present problem but anyway the results are not very sensitive to the length of the time interval (see Eq. 6 below). Wind speed distributions on the Finnish coast have been earlier published [12]. In the present work it suffices the approximate them with the Rayleigh distribution which states that during T days the maximum expected wind speed is

$$w_{\mathrm{T}} = \tilde{w}\left[\frac{4}{\pi}\log T\right]^{1/2}, \qquad (4)$$

where $\tilde{w}$ is the mean wind speed. The representative value of $\tilde{w} = 7.8\ \mathrm{ms}^{-1}$ was taken from [12] on the basis of the observations in Ulkokalla, Utö and Katajaluoto. The use of a constant wind speed for the whole Finnish coast should be accurate to within 5-10 per cent. As a comparison, the maximum wind speed ever recorded on the Finnish coast is 30 ms^{-1} [1] and for a period of one hundred years Eq. (4) gives $w_{\mathrm{T}} = 28.5\ \mathrm{ms}^{-1}$. Now we take

$$T = \mathrm{n}\Delta T \quad , \qquad (5)$$

where n is the number of years and ΔT the length of the period when the ice may move. Combining Eqs. (1), (4) and (5), we have

$$h^{(\mathrm{n})} = \alpha\,\tilde{w}\left[\frac{4}{\pi}\log(\mathrm{n}\Delta T)\right]^{1/2}, \qquad (6)$$

the maximum expected thickness of moving ice in n years. The values for $h^{(1)}$, $h^{(10)}$ and $h^{(30)}$ are shown in Appendix 1, a general chart on $h^{(30)}$ is shown in Fig. 7 and in Appendix 2 detailed maps on $h^{(30)}$ are given. The thickness is as smallest near the coast due to that there the density of islands and shoals is generally large and the ice is easily anchored into fast ice. This is reflected in the coefficient α in Eq. (16) (see Eq. 1).

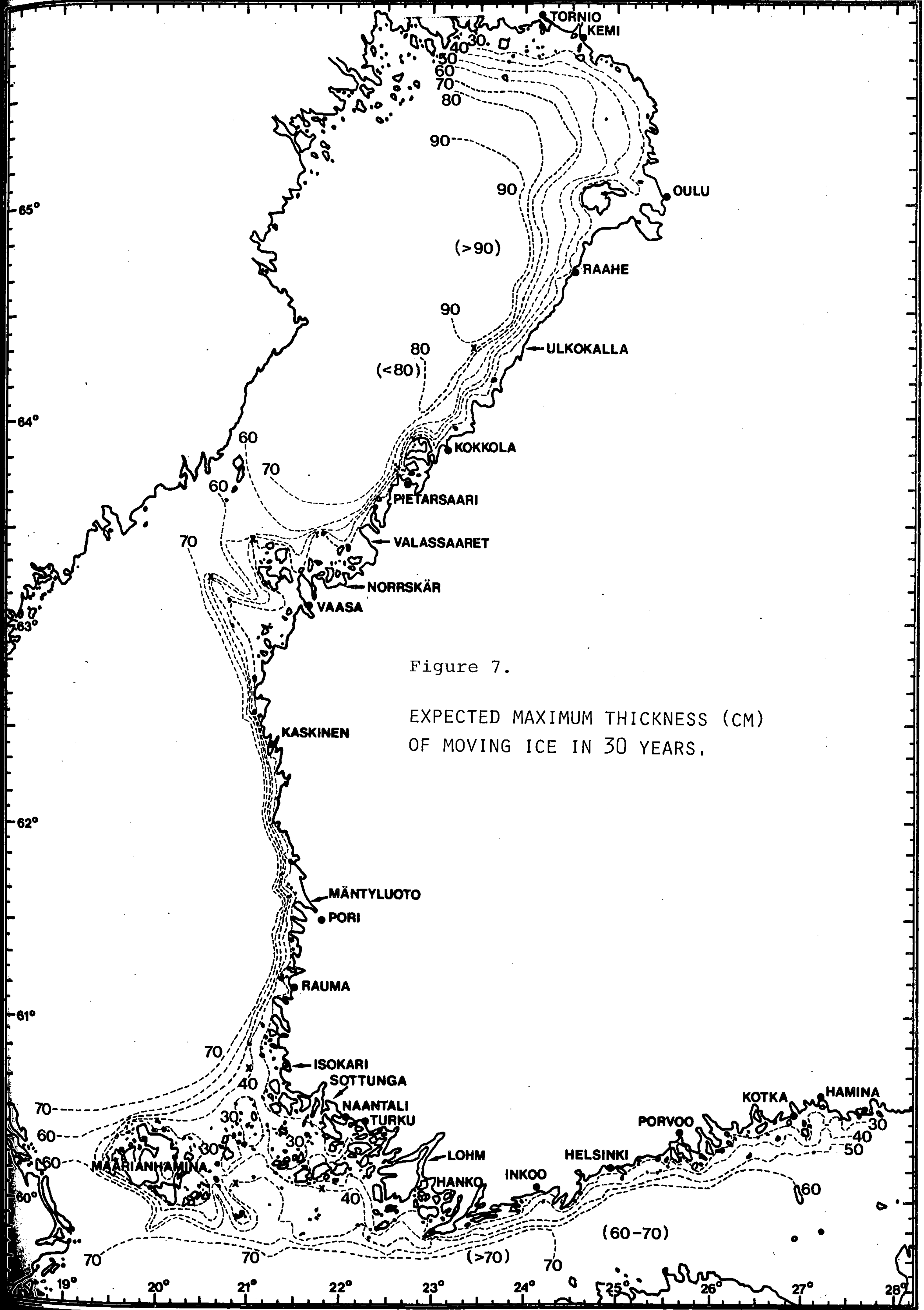

Figure 7.

EXPECTED MAXIMUM THICKNESS (CM) OF MOVING ICE IN 30 YEARS.

The presently existing data did not allow us to estimate the size of ridges in the coastal areas and here laser profilometer measurements have to be made in future. Instead, the probability of occurrence of ridges was taken from [8] and the average greatest wind fetch over the ice in the period when ice may move was estimated. The results are shown in Appendix 1.

5. ACKNOWLEDGEMENTS

We are greatly indebted to the chief engineer Paavo Sarkkinen, Finnish Board of Navigation, for presenting us the problem and the practical needs for its solution. Special thanks are due to Mrs. Marja Eronen for drawing the figures.

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Appendix 1. Ice along the winter fairways in autumn and winter. T_0 - average date of freezing, T_1 - average date of fast ice formation, ΔT - average length of the period of mobile ice (days), H_{max} - maximum observed ice thickness (cm), h_{10} - maximum thickness of mobile ice for the wind speed of 10 ms^{-1} (cm), $h^{(n)}$ - maximum expected thickness of moving ice in n years (cm), L - the greatest wind fetch over ice cover during the period of mobile ice (km), PA - probability of occurrence of ridged ice (per cent; X = no data).

PLACE	T_0	T_1	ΔT	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
TORNIO										
inner harbour	30.10	17.11	18	100	8	12	16	18	5	0
Röyttä	03.11	25.11	22	110	10	15	20	22	10	1
Kuusiluoto	11.11	28.11	17	115	13	19	26	29	15	1
Iso Huituri	19.11	05.12	16	115	15	22	30	33	20	1
Sarvensaaret	28.11	14.12	16	110	20	29	40	44	25	9
Sandskär	03.12	28.12	25	110	25	40	52	57	50	18
Malören	09.12	19.01	41	102	30	51	65	70	170	13
-off	19.12	31.01	43	95	47	80	95	95	280	17
KEMI										
inner harbour	02.11	20.11	18	100	8	12	16	18	6	0
centr. roadstead	07.11	26.11	19	100	10	15	20	22	6	1
Ajos	16.11	04.12	18	102	12	18	24	27	10	3
Inakari	22.11	10.12	18	106	15	22	30	33	15	7
Keminkraaseli	27.11	19.12	22	115	19	29	39	43	35	14
Mutkanmatala	04.12	10.01	37	115	25	42	54	58	100	16
Kemin matalat	12.12	23.01	42	105	32	55	69	75	200	9
-off	19.12	29.01	41	100	42	71	91	99	280	8
HAUKIPUDAS										
Kraasukka	27.11	17.12	20	115	16	24	32	36	40	5
Ulkokrunni	30.11	27.12	27	115	25	40	52	57	50	10
-off	07.12	11.01	35	110	32	53	68	74	100	14
Artunmatala	19.12	29.01	40	100	42	71	91	98	250	X
OULU										
Toppila, sound	12.11	29.11	17	92	10	15	20	22	5	0
- " - , roadstead	17.11	02.12	15	100	12	17	24	26	15	0

PLACE	T_0	T_1	ΔT	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
Saapaskari	20.11	07.12	17	105	14	21	28	31	20	1
Kattilankalla	27.11	20.12	23	106	16	25	33	36	30	2
Kohomatala	03.12	13.01	41	115	23	39	50	54	100	8
Merikallat	21.12	05.02	46	100	34	59	74	81	200	12
-off	27.12	09.02	44	95	48	82	95	95	230	16
RAAHE										
inner harbour	09.11	02.12	23	97	10	16	21	23	2	0
Lapaluoto	23.11	21.12	28	100	13	21	27	30	2	0
Ulkopauha	27.11	28.12	31	100	17	28	36	39	25	1
Jyry	04.12	13.01	40	100	20	34	43	47	60	7
Maanahkiainen	13.12	25.01	43	97	25	43	54	59	125	6
Ulkonahkiainen	25.12	09.02	46	97	36	62	79	85	180	8
-off	01.01	16.02	46	90	50	86	90	90	180	11
KALAJOKI										
Kainu,harbour	16.11	16.12	30	89	10	16	21	23	5	0
Leppänen	13.12	11.01	29	100	14	23	29	32	30	2
Välimatala	20.12	27.01	37	100	22	37	47	51	100	4
Maakalla	27.12	07.02	42	100	24	41	52	56	125	5
Ulkokalla	30.12	13.02	45	100	29	50	63	68	125	6
-off	03.01	23.02	51	88	51	88	88	88	125	12
HIMANKA										
Himanka	19.11	27.12	38	86	9	15	19	21	2	0
Ohtakari	13.12	21.01	39	90	16	27	34	37	60	5
KOKKOLA										
Ykspihlaja	23.11	15.12	22	82	10	16	20	22	2	0
Hungerberg	02.12	25.12	23	85	13	20	27	29	15	0
Repskär	09.12	06.01	28	90	16	26	33	37	30	1
Tankar	16.12	18.01	33	82	23	38	49	53	50	8
Kredens	28.12	11.02	45	80	32	55	70	76	100	6
Tankar,5´NW	04.01	22.02	48	80	42	73	80	80	180	12
- " - ,10´NW	09.01	25.02	47	78	50	78	78	78	180	15

PLACE	T_0	T_1	ΔT	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
PIETARSAARI										
Leppäluoto	25.11	16.12	21	90	10	15	20	22	2	0
Ådöskatan	04.12	26.12	22	90	13	20	27	29	2	1
Mässkär	13.12	08.01	26	82	16	25	33	36	15	1
Kallan	27.12	02.02	37	81	23	39	49	53	150	6
Mässkär,5´W	05.01	23.02	49	80	42	73	80	80	200	14
- " - ,10´W	10.01	25.02	46	78	50	78	78	78	200	15
RITGRUND,fairway										
St. Iskmo	03.12	19.12	16	77	11	16	22	24	5	0
Truthällan	10.12	26.12	16	78	16	24	32	35	20	1
Ritgrund	24.12	31.01	38	77	23	39	49	54	280	4
THE QUARK										
Valassaaret	22.12	24.01	33	73	16	26	34	37	20	2
- " - ,5´NW	27.12	11.02	46	75	42	72	75	75	280	5
- " - ,10´NW	29.12	20.02	53	76	50	76	76	76	280	7
VAASA										
inner harbour	17.11	07.12	20	78	9	14	18	20	2	0
Vaskiluoto	25.11	12.12	17	80	11	16	22	24	2	0
Nagelprick	02.12	17.12	15	80	13	19	26	28	5	0
Storhästen	09.12	22.12	13	80	15	21	29	32	15	0
Ensten	14.12	06.01	23	90	19	30	39	43	35	6
Norra Gloppsten	21.12	28.01	38	90	26	44	56	61	40	4
Norrskär	06.01	16.02	41	75	30	51	65	70	250	2
- " - ,5´W	12.01	20.02	39	72	42	71	72	72	330	4
- " - ,10´W	18.01	28.02	41	72	50	72	72	72	330	4
RÖNNSKÄRI,fairway										
archipelago	05.12	22.12	17	81	13	19	26	29	10	0
Rönnskär	19.12	11.01	23	90	19	30	39	43	25	1
Strömmingsbådan	31.12	14.02	45	72	30	52	65	71	250	X
Rönnskär,5´W	11.01	01.03	49	72	42	73	72	72	330	5
- " - ,10´W	15.01	02.03	46	72	50	72	72	72	330	4

PLACE	T_0	T_1	ΔT	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
KASKINEN										
harbour	03.12	23.12	20	76	10	15	20	22	2	0
Sälgrund	21.12	30.01	41	78	12	20	26	28	30	3
- " - ,2´SW	29.12	19.02	52	75	23	40	51	55	100	5
- " - ,5´SW	07.01	04.03	56	72	34	60	72	72	230	7
- " - ,10´SW	14.01	04.03	49	72	48	72	72	72	230	9
KRISTIINANKAUPUNKI										
harbour	25.11	12.12	17	75	10	15	20	22	2	X
Ådgrund	02.12	17.12	15	78	12	17	24	26	5	X
Härkmeri	21.12	30.01	41	70	16	27	35	38	30	X
Mösbådan	07.01	04.03	56	70	34	60	70	70	230	X
MERIKARVIA										
Halluskeri	25.11	12.12	17	75	10	15	20	22	2	X
Karvian Ourat	21.12	30.01	41	70	16	27	35	38	40	X
PORI										
Mäntyluoto	17.12	07.02	52	70	21	37	46	50	100	2
Kolmikulma	25.12	15.02	52	70	23	40	51	55	125	4
Kaijakari	04.01	20.02	47	70	26	45	57	62	175	5
- " - ,2´W	13.01	05.03	51	70	35	61	70	70	200	6
- " - ,5´W	18.01	05.03	46	70	48	70	70	70	200	6
- " - ,10´W	26.01	06.03	39	70	50	70	70	70	200	8
SÄPPI, fairway										
Outoori	30.12	09.02	41	80	23	39	50	54	150	3
Säppi	05.01	18.02	44	80	26	45	57	61	175	3
- " - ,2´W	12.01	04.03	51	70	35	61	70	70	200	6
- " - ,5´W	18.01	05.03	46	70	48	70	70	70	200	7
- " - ,10´W	25.01	05.03	39	70	50	70	70	70	200	7
RAUMA										
harbour	13.12	31.12	18	80	12	18	24	27	3	0
Valkeakari	24.12	23.01	30	90	16	26	34	37	25	3

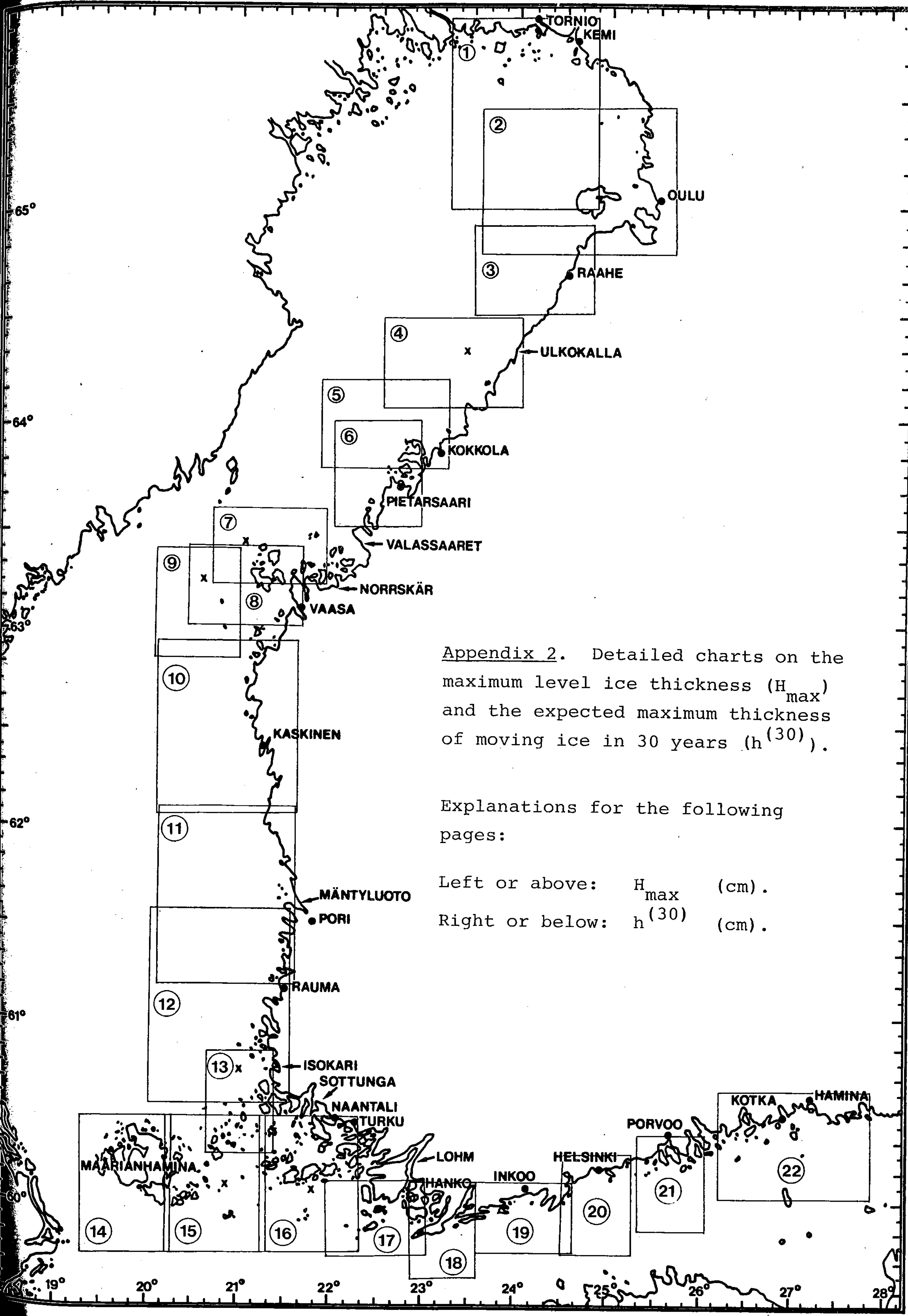
PLACE	T_0	T_1	ΔT	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
Kylmäpihlaja	02.01	11.02	40	75	20	34	43	47	115	5
Pihlus	11.01	26.02	46	70	24	41	52	57	200	5
Raumanmatala	19.01	04.03	43	70	34	58	70	70	200	8
- " - ,5´W	25.01	04.03	38	70	48	70	70	70	200	9
- " - ,10´W	30.01	06.03	35	70	50	70	70	70	200	9
<u>UUSIKAUPUNKI</u>										
harbour	06.12	25.12	19	73	10	15	20	22	2	0
Kirsta	23.12	09.01	17	80	14	21	28	31	10	0
Isokari	10.01	13.02	34	75	25	41	53	58	125	4
- " - ,2´NW	16.01	27.02	42	70	30	51	65	70	200	5
- " - ,5´NW	19.01	02.03	42	70	37	63	70	70	300	7
- " - ,10´NW	23.01	03.03	39	70	48	70	70	70	300	8
<u>KUSTAVI, fairway</u>										
Lypyrtti	25.12	13.01	19	69	10	15	20	22	2	0
Laupunen	31.12	18.01	18	76	13	20	26	29	25	0
Porkankari	05.01	21.01	16	75	14	21	28	31	30	2
Vähä Hauteri	08.01	26.01	18	75	18	27	36	40	40	5
Keskikallio	10.01	10.02	31	75	20	33	42	46	100	4
<u>FINBO, fairway</u>										
Dånö	05.01	23.01	18	60	10	15	20	22	4	0
Finbo	13.01	08.02	26	62	19	30	39	43	15	1
Sälskär	05.02	25.02	20	55	30	46	55	55	200	2
- " - ,5´N	12.02	07.03	23	60	50	60	60	60	300	6
- " - ,10´N	12.02	07.03	23	65	50	65	65	65	300	5
<u>TORPÖ</u>										
West of Torpö	06.01	27.01	21	65	10	15	20	22	5	0
Signilskär	27.01	16.02	20	66	25	38	51	56	60	1
Märket	03.02	02.03	27	66	30	48	63	66	300	3
- " - ,5´N	08.02	02.03	22	60	37	57	60	60	300	2
- " - ,5´W	07.02	02.03	23	60	37	58	60	60	300	2
- " - ,5´S	10.02	02.03	20	60	48	60	60	60	300	1

PLACE	T_0	T_1	ΔT	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
MARIEHAMN										
Western harbour	23.01	13.02	21	60	14	22	29	31	5	0
Korsö	03.02	21.02	8	62	19	28	38	42	30	2
Kobbaklintarn	08.02	25.02	17	62	28	42	56	62	40	4
- " - ,2´SW	12.02	02.03	18	60	36	54	60	60	80	7
- " - ,5´SW	14.02	02.03	16	60	48	60	60	60	80	6
- " - ,10´SW	16.02	02.03	14	60	50	60	60	60	80	5
DEGERBY										
Degerby	7.01	1.02	25	70	10	16	21	23	5	2
Ledsund	26.01	22.02	27	62	19	30	40	43	15	4
Nygrund	8.02	25.02	16	62	23	34	46	50	30	3
Nyhamn	13.02	1.03	16	61	28	41	56	61	80	2
Lågskär	16.02	27.02	11	65	34	46	65	65	120	5
- " - ,5´S	18.02	(1.03)	11	60	48	60	60	60	(500)	4
- " - ,10´S	19.02	(1.03)	10	60	50	60	60	60	(500)	8
SAGGÖ,fairway										
Bomarsund	31.12	18.01	18	60	10	15	20	22	2	X
Prästösund	7.01	22.01	15	60	12	17	24	26	15	X
Lumparn	8.01	22.01	14	65	20	29	39	43	40	X
Lappvesi	10.01	26.01	16	80	16	24	32	35	15	X
Yxskär	19.01	4.02	16	70	26	38	52	57	40	X
NAANTALI										
inner harbour	1.12	31.12	30	60	10	16	21	23	2	0
Tupavuori	25.12	11.01	17	60	13	19	26	29	10	0
Kuuva	29.12	14.01	16	65	15	22	30	33	30	0
TURKU										
harbours	10.12	12.01	33	60	10	17	21	23	2	0
Rajakari	4.01	22.01	18	65	15	22	30	33	35	0
Orhisaari	11.01	27.01	16	80	18	26	36	39	40	0
Lövskär	13.01	29.01	16	70	19	28	38	42	40	0
Grisselborg (Lohm)	19.01	4.02	16	50	21	31	42	46	40	1

PLACE	T_0	T_1	T	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
Snökubben	3.02	15.02	12	80	23	32	44	49	60	5
Knivskär	8.02	23.02	15	80	28	41	55	61	75	2
Utö	8.02	25.02	17	75	34	50	68	75	100	2
Svartbådan	11.02	28.02	17	75	37	55	74	75	160	4
Utö, 5´S	14.02	3.03	17	70	42	62	70	70	200	10
Utö, 10´S	15.02	4.03	(17)	70	50	70	70	70	(500)	12
Bogskär	22.02	(7.03)	(13)	60	(50)	60	60	60	(500)	14
Bogskär, S	25.02	(7.03)	(10)	55	(50)	55	55	55	(500)	9
KIHTI										
Smörgrund	16.01	31.01	15	74	16	23	32	35	30	0
Rödskär	23.01	8.02	11	78	24	33	46	51	60	2
Kihti	28.01	12.02	15	81	28	41	55	61	80	1
Bogskär (Kihti)	30.01	12.02	13	86	28	40	54	60	80	2
Enskär	28.01	7.02	10	79	22	29	42	46	25	0
HANKO										
harbour	13.01	8.02	26	80	10	16	21	23	2	0
Gustafsvärn	18.01	10.02	23	80	14	22	29	32	20	2
Tistron	20.01	12.02	23	80	20	31	41	45	50	1
Russarö	24.01	17.02	24	80	26	41	54	59	60	4
Lilla Tärnskär	24.01	23.02	25	75	30	47	62	68	120	4
Russarö, 5´S	3.02	2.03	27	70	42	67	70	70	200	15
Russarö, 10´S	6.02	2.03	27	70	50	70	70	70	200	X
MORGONLAND, fairway										
Morgonland	28.01	21.02	24	80	30	47	62	68	60	4
Bengtskär	30.01	26.02	27	80	32	51	67	73	120	5
HIITTINEN, fairway										
Area Hanko - Hiittinen	10.01	29.01	19	90	24	36	48	53	50	0
Gullkrona	15.01	30.01	15	70	20	29	39	44	50	1

PLACE	T_0	T_1	T	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
TAMMISAARI										
harbour	6.12	25.12	19	60	10	15	20	22	5	X
Hästö Busö	27.12	15.01	19	80	14	21	28	31	20	0
Jussarö	13.01	6.02	24	78	19	30	39	43	50	0
Sundharu	21.01	15.02	25	75	26	41	54	59	120	5
-, 5´S	29.01	2.03	32	70	48	70	70	70	200	13
-, 10´S	2.02	3.03	29	70	50	70	70	70	200	16
INKOO										
harbour	10.12	2.01	23	70	10	16	21	23	2	X
Barösund	11.12	6.01	26	100	12	19	25	27	4	0
Bågaskär	8.01	31.01	23	80	17	27	35	38	30	2
Svartbådan	18.01	12.02	25	69	21	33	43	48	60	6
Hästen	19.01	14.02	26	70	30	48	62	68	120	8
-, 5´S	27.01	28.02	30	70	34	55	70	70	200	12
-, 10´S	29.01	1.03	31	70	48	70	70	70	250	10
PORKKALA										
Kantvik	10.12	2.01	23	70	10	16	21	23	10	X
Ytter Ådgrund	18.12	11.01	24	75	19	30	39	43	35	0
Flatgrund	27.12	20.01	24	80	21	33	43	47	40	1
Gråkubbar	9.01	4.02	26	80	22	35	46	50	50	1
Rönnskär	9.01	2.02	24	69	20	31	41	45	40	1
Mäkiluoto	17.01	11.02	25	65	25	40	52	57	80	2
Porkkalan majakka	25.01	18.02	24	65	28	44	58	63	120	9
-, 5´S	27.01	25.02	29	70	48	70	70	70	250	15
HELSINKI										
harbours	22.12	16.01	25	70	10	16	21	23	5	0
Suomenlinna	5.01	26.01	21	70	12	18	24	27	10	1
Harmaja	10.01	6.02	27	80	20	32	42	46	30	3
Gråskärskådan	17.01	19.02	33	80	26	43	55	60	50	10
Helsinki lighthouse	24.01	23.02	30	75	42	68	75	75	120	15
-, 5´S	28.01	24.02	27	70	45	70	70	70	150	12
-, 10´S	29.01	25.02	27	70	45	70	70	70	150	9

PLACE	T_0	T_1	T	H_{max}	h_{10}	$h^{(1)}$	$h^{(10)}$	$h^{(30)}$	L	PA
PORVOO										
Tolkkinen	15.12	1.01	17	70	10	15	20	22	10	X
Äggskär	25.12	25.01	31	84	16	26	34	37	30	1
Glosholm	5.01	30.01	25	80	18	28	37	41	40	3
Örskär	8.01	3.02	26	85	20	32	42	45	50	2
Söderskär	14.01	11.02	28	75	26	42	54	59	80	2
-, 5´S	19.01	23.02	35	75	44	73	75	75	120	14
Kalbådagrund	22.01	23.02	32	75	45	74	75	75	120	17
LOVIISA										
Valko	7.12	26.12	19	70	10	15	20	22	10	0
Svartholm	19.12	2.01	14	85	12	17	24	26	30	0
Täktaren	27.12	19.01	23	84	18	28	37	41	40	2
Skarven	2.01	26.01	24	80	22	35	45	50	60	1
Hamnskär	11.01	7.02	27	80	26	42	54	59	80	5
KOTKA										
harbours	10.12	7.01	28	81	12	19	25	27	2	0
Viikari	29.12	20.01	22	80	17	26	35	38	20	3
Kaunissaari	3.01	24.01	21	80	22	34	45	49	50	3
Boistö	1.01	23.01	22	75	24	37	49	54	60	2
Orrengrund	7.01	2.02	26	75	28	45	58	64	80	4
Tiiskeri	16.01	15.02	30	80	34	55	72	78	100	8
-, 5´S	20.01	22.02	33	75	40	66	75	75	120	10
-, 10´S	23.01	23.02	31	75	45	73	75	75	120	10
HAMINA										
inner harbour	26.11	22.12	26	65	10	16	21	23	4	0
Hillo, Laku-lahti	12.12	27.12	15	70	13	19	26	28	10	0
Suurmusta	27.12	12.01	16	82	16	24	32	35	20	0
Haapasaari	7.01	31.01	24	80	27	42	56	61	40	2
-, 5´S	11.01	15.02	35	75	35	58	75	75	80	12
-, 10´S	14.01	16.02	33	75	40	66	75	75	120	11
Gogland, E	15.01	18.02	34	80	40	66	80	80	100	8

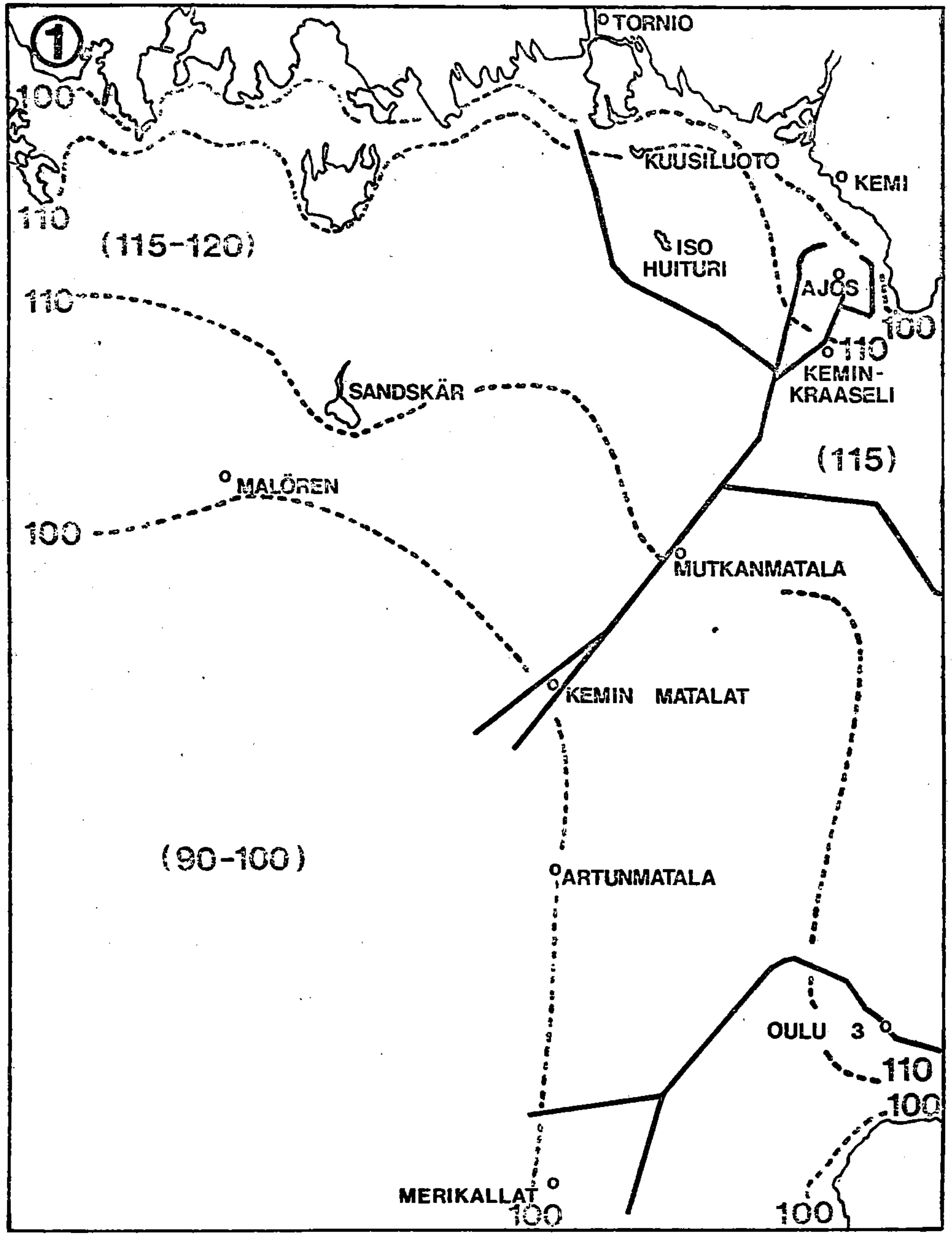


Appendix 2. Detailed charts on the maximum level ice thickness (H_{max}) and the expected maximum thickness of moving ice in 30 years ($h^{(30)}$).

Explanations for the following pages:

Left or above: H_{max} (cm).

Right or below: $h^{(30)}$ (cm).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TORNIO
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ISO HUITURI
AJOS
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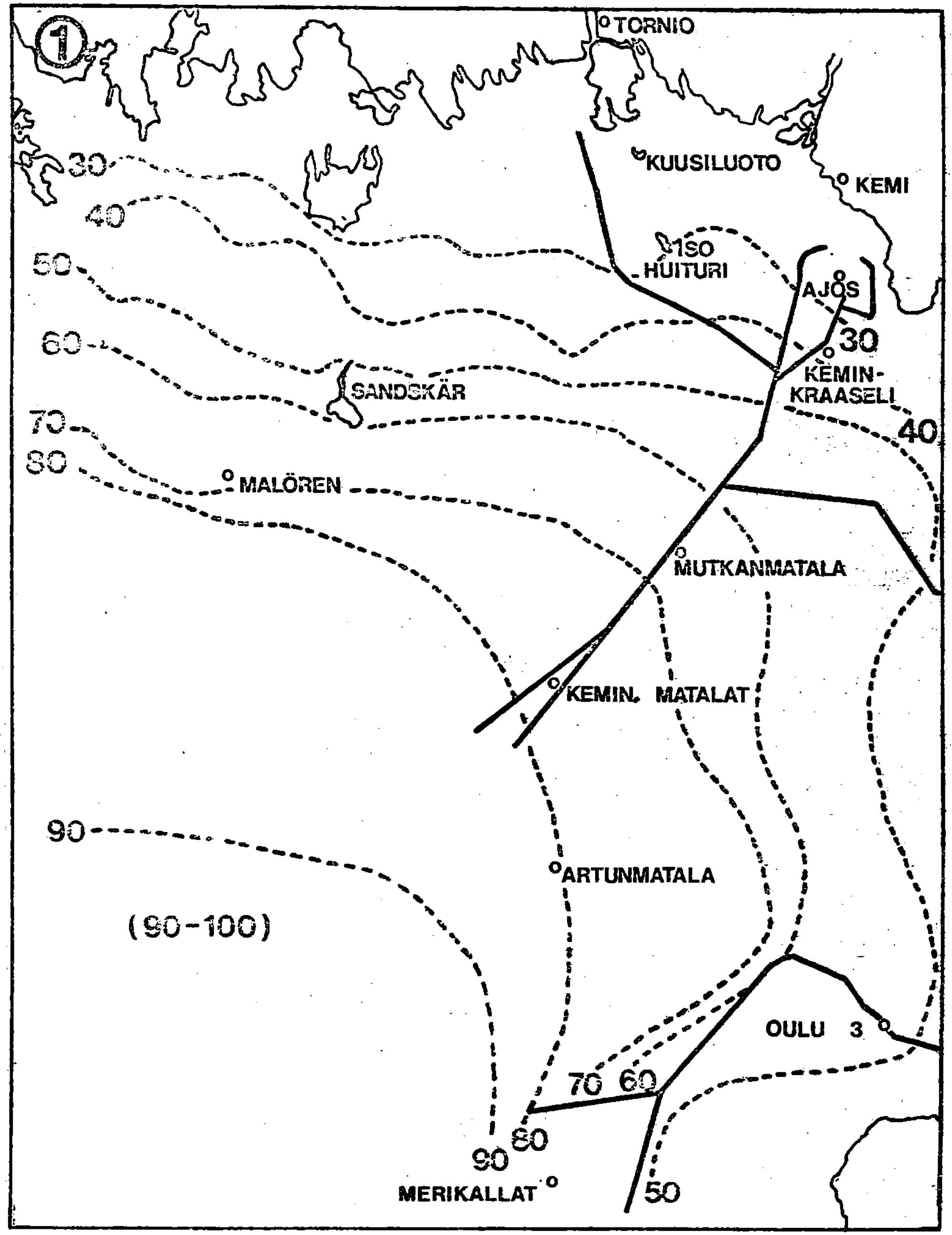
100
KEMIN-KRAASELI
(115-120)
(115)
SANDSKÄR
MALÖREN
MUTKANMATALA
KEMIN MATALAT
(90-100)
ARTUNMATALA
OULU 3
MERIKALLAT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KEMI
ISO HUITURI
AJOS
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KEMIN-KRAASELI
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SANDSKÄR
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KEMIN MATALAT
(90-100)
ARTUNMATALA
OULU 3
MERIKALLAT
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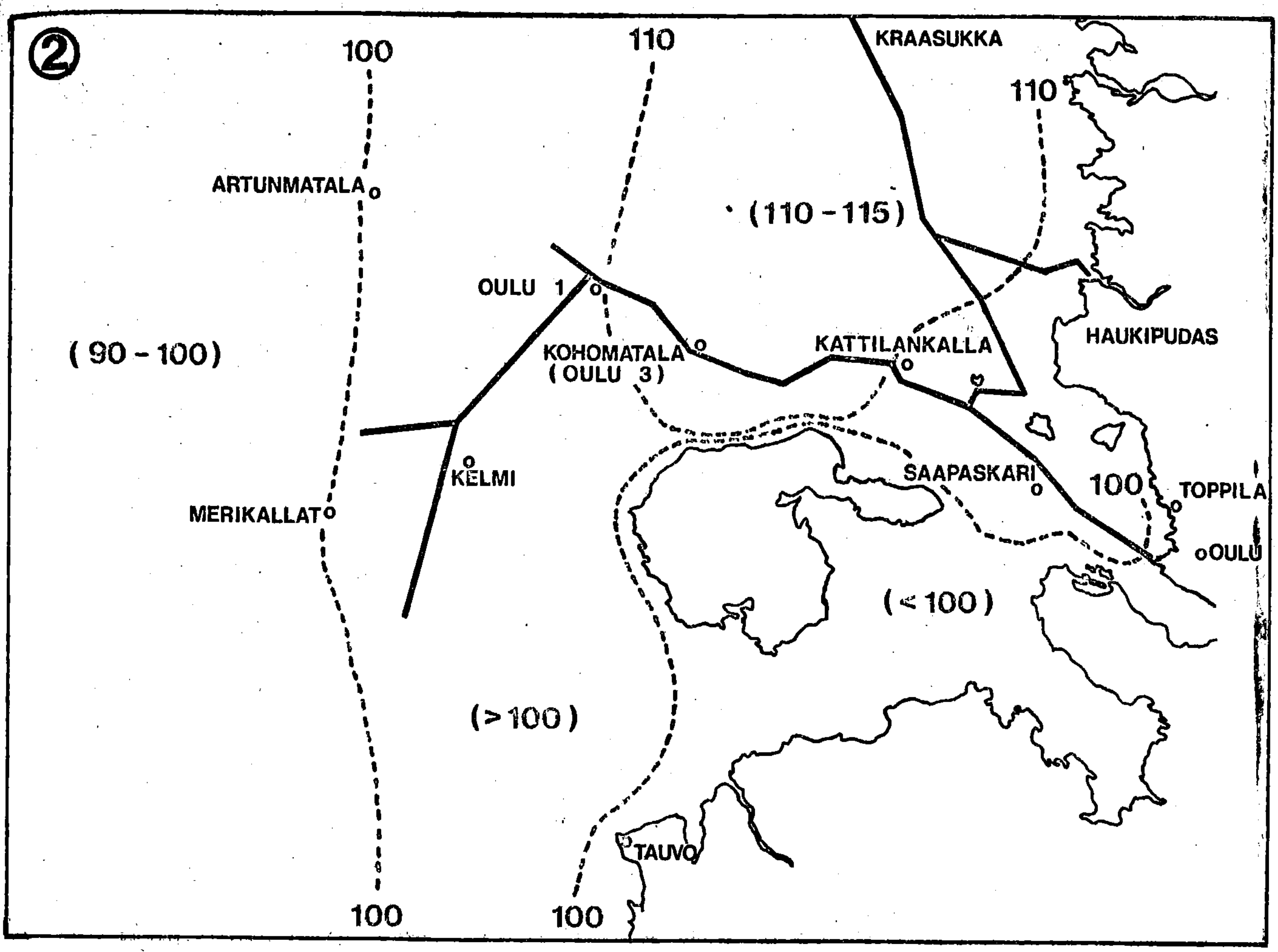
70
80
90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110
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OULU 1
KOHOMATALA
(OULU 3)
KATTILANKALLA
HAUKIPUDAS
(90 - 100)
KELMI
SAAPASKARI
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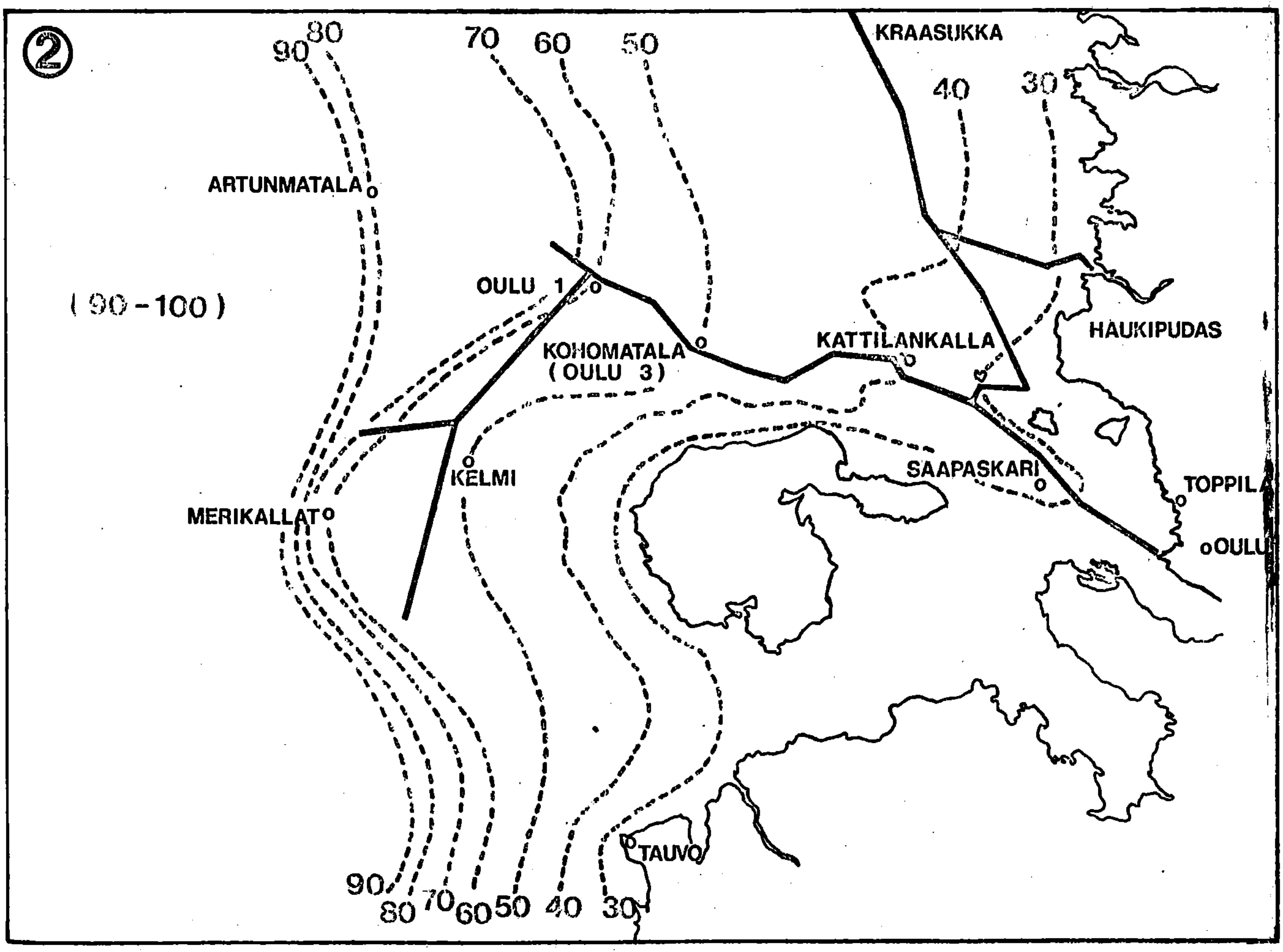
TOPPILA
MERIKALLAT
OULU
(< 100)
(> 100)
TAUVO
100
100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(OULU 3)
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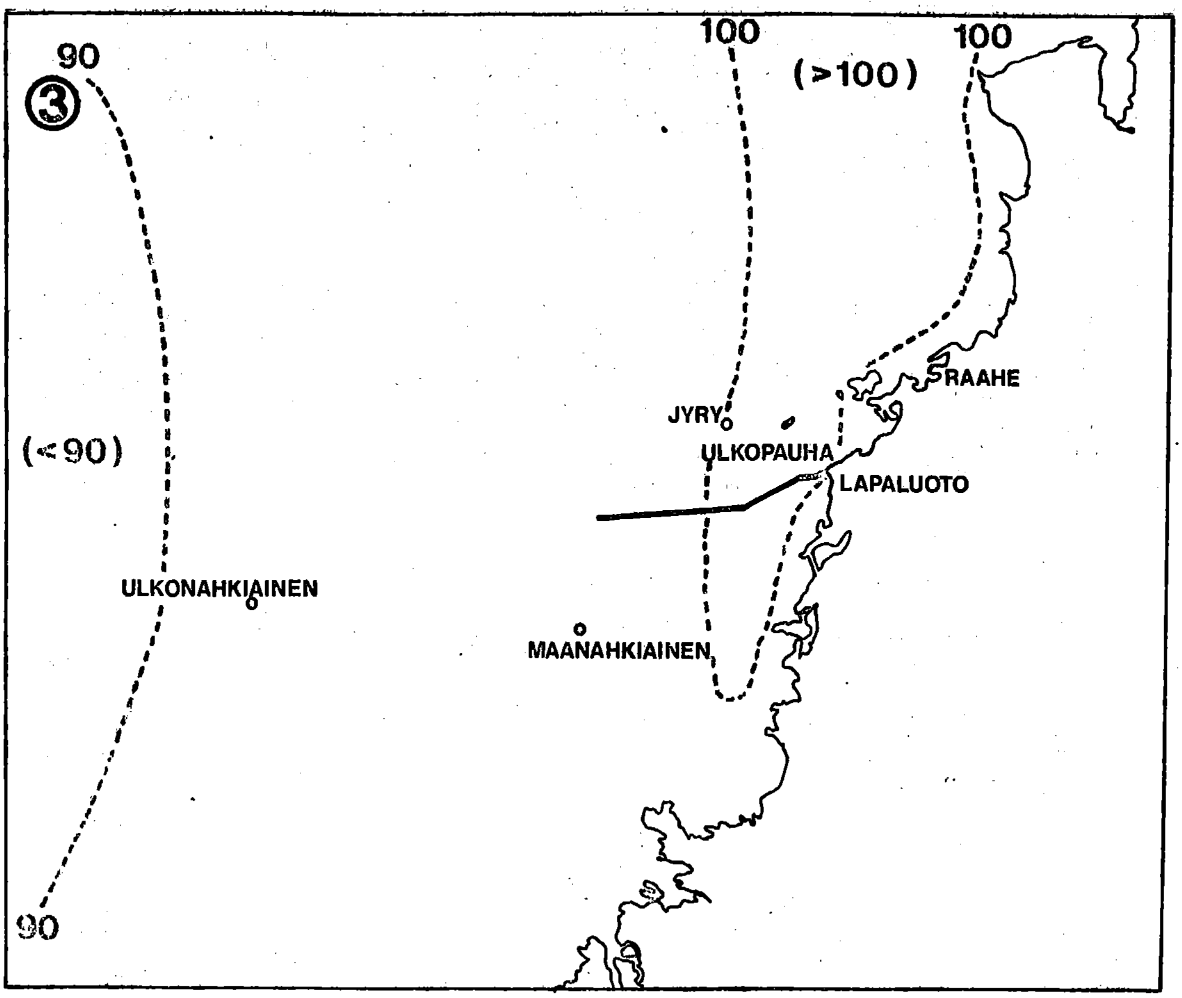
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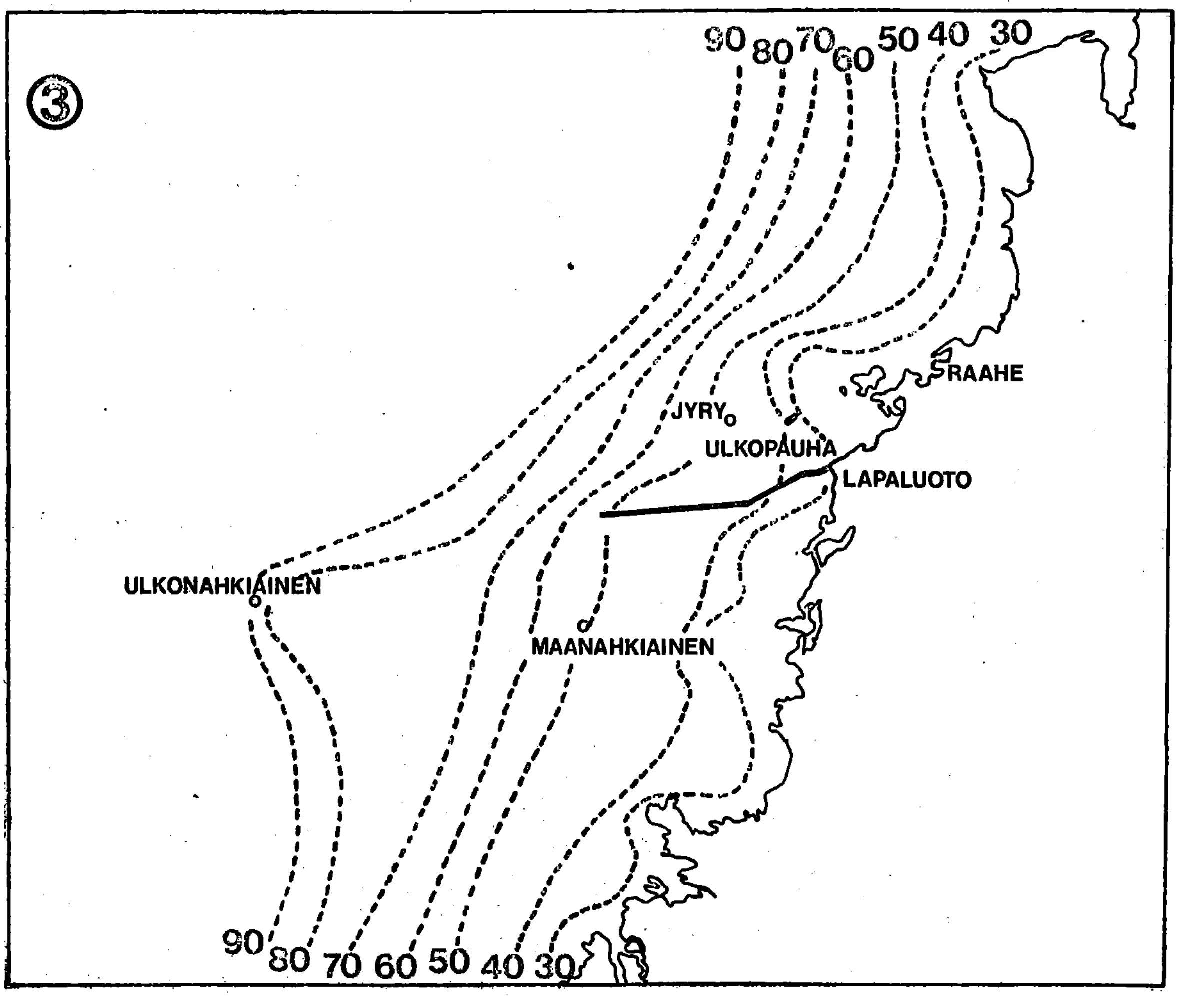
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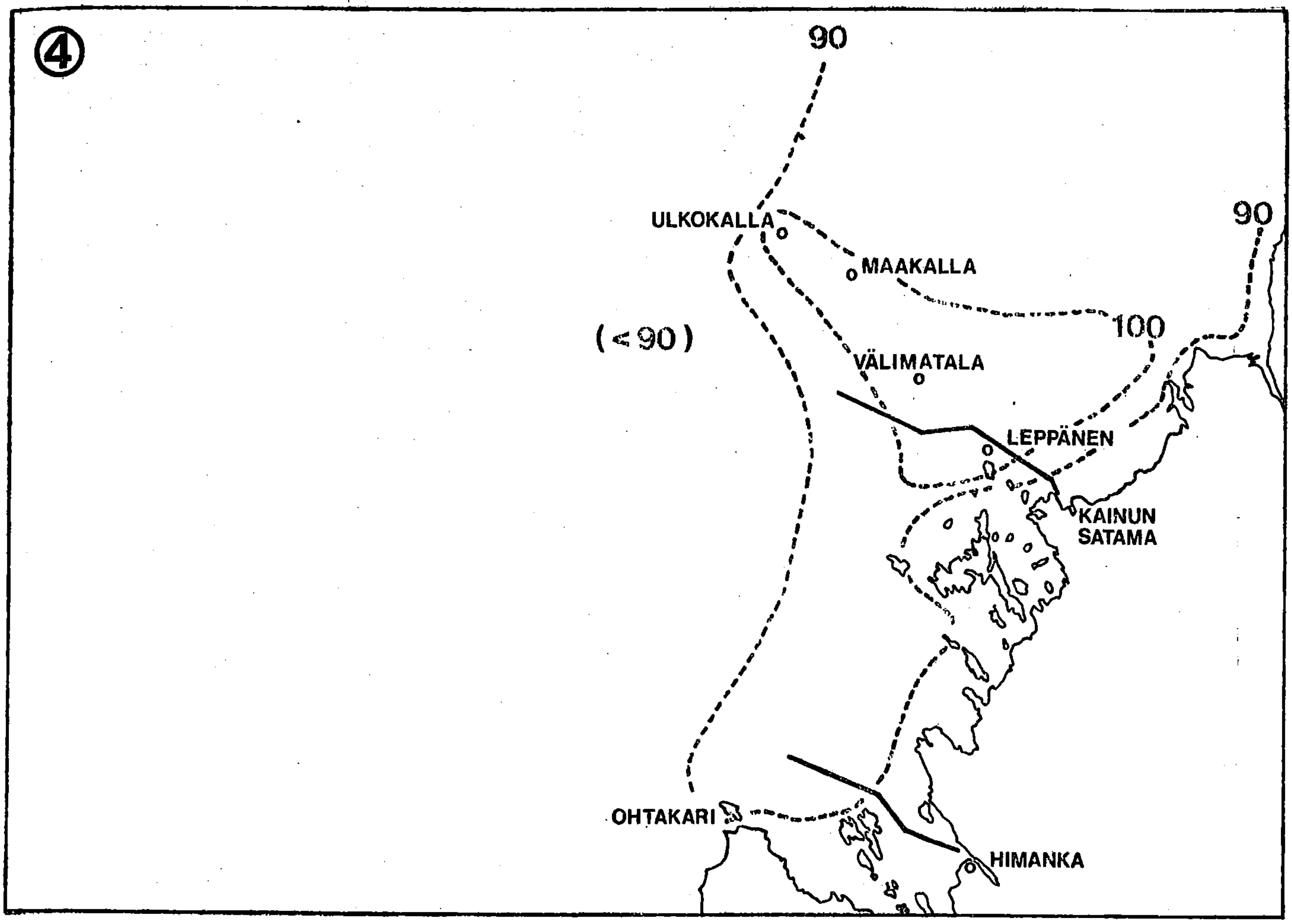
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MAAKALLA
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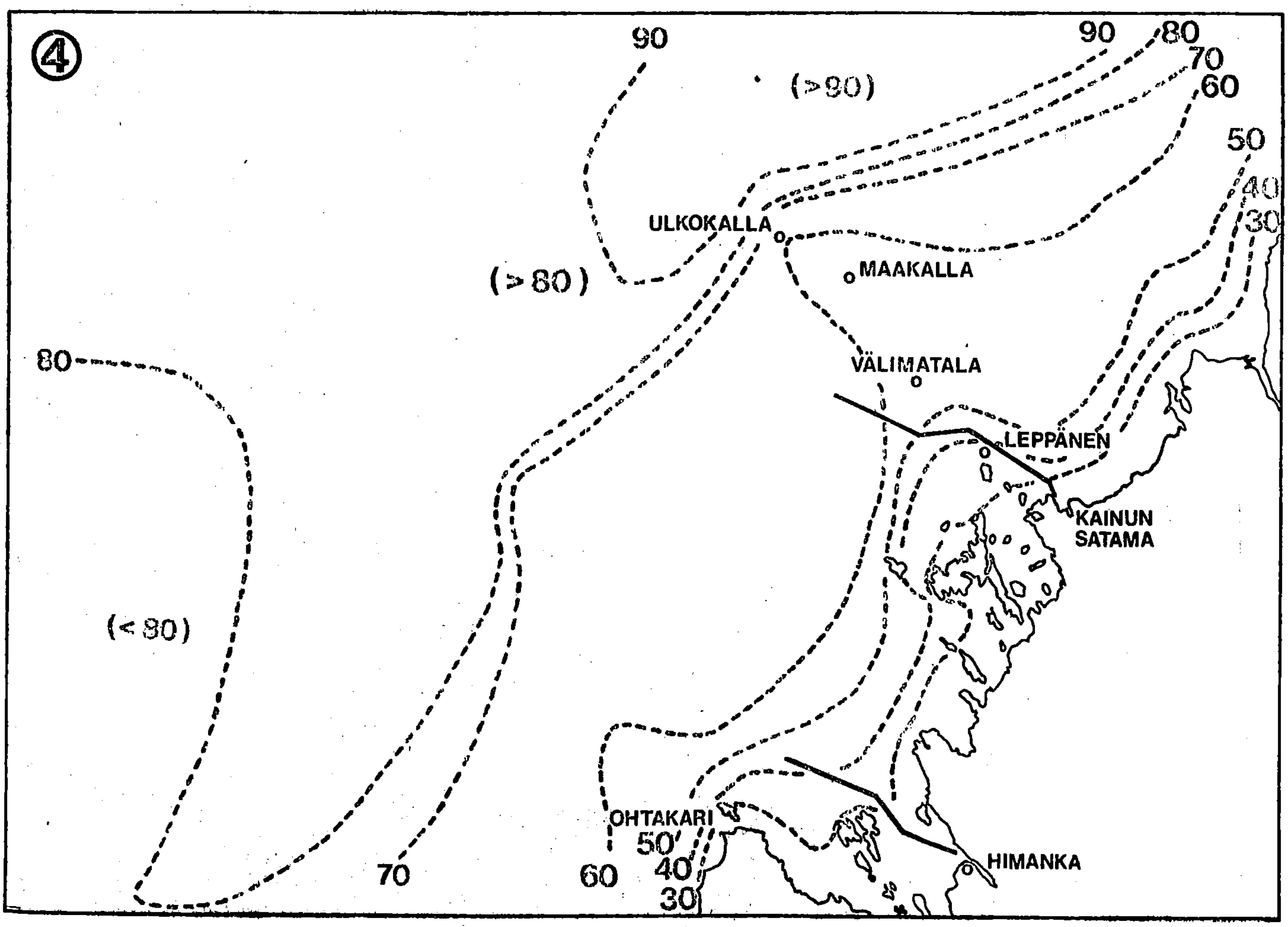
HIMANKA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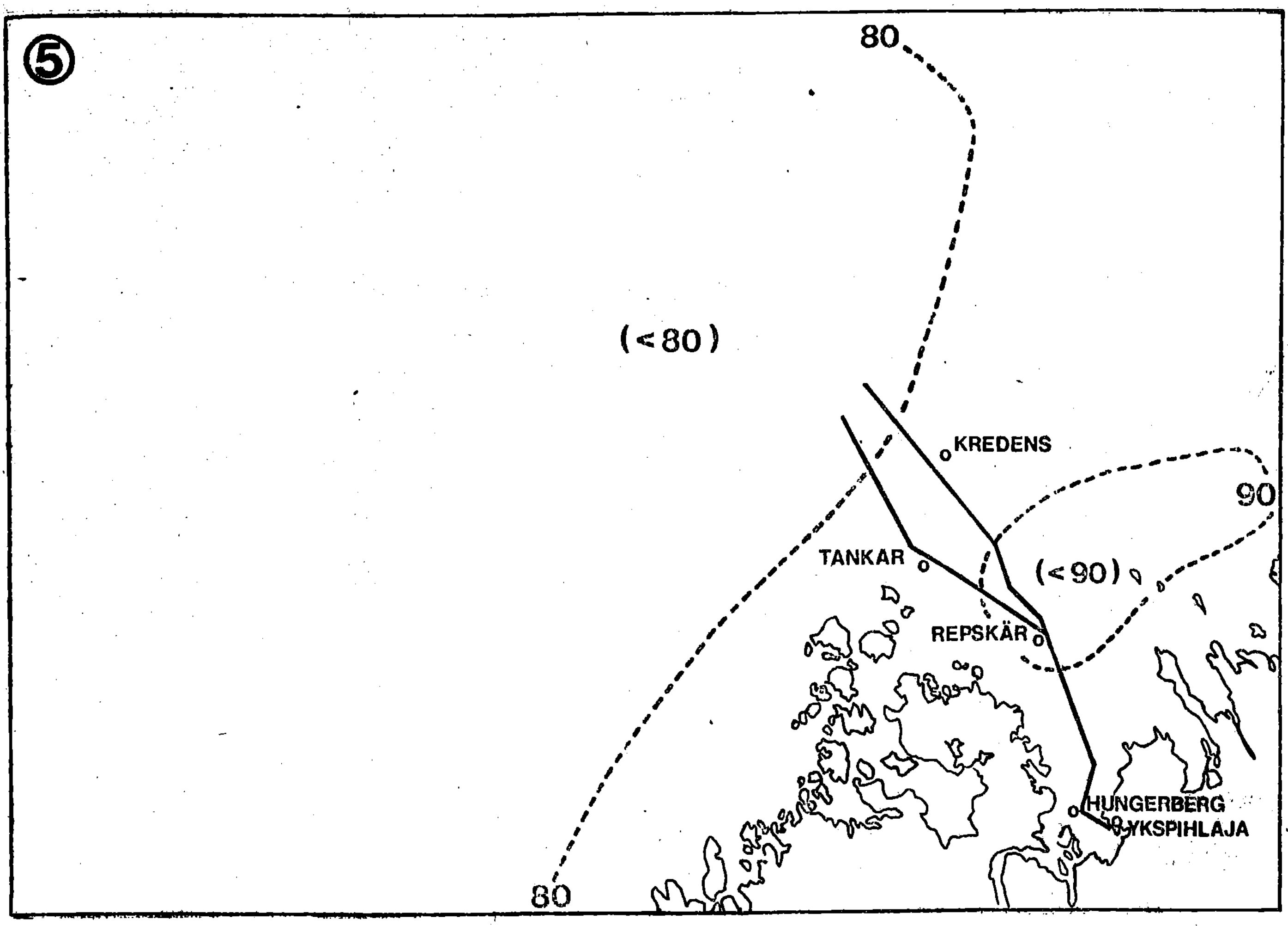
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HUNGERBERG
YKSPIHLAJA
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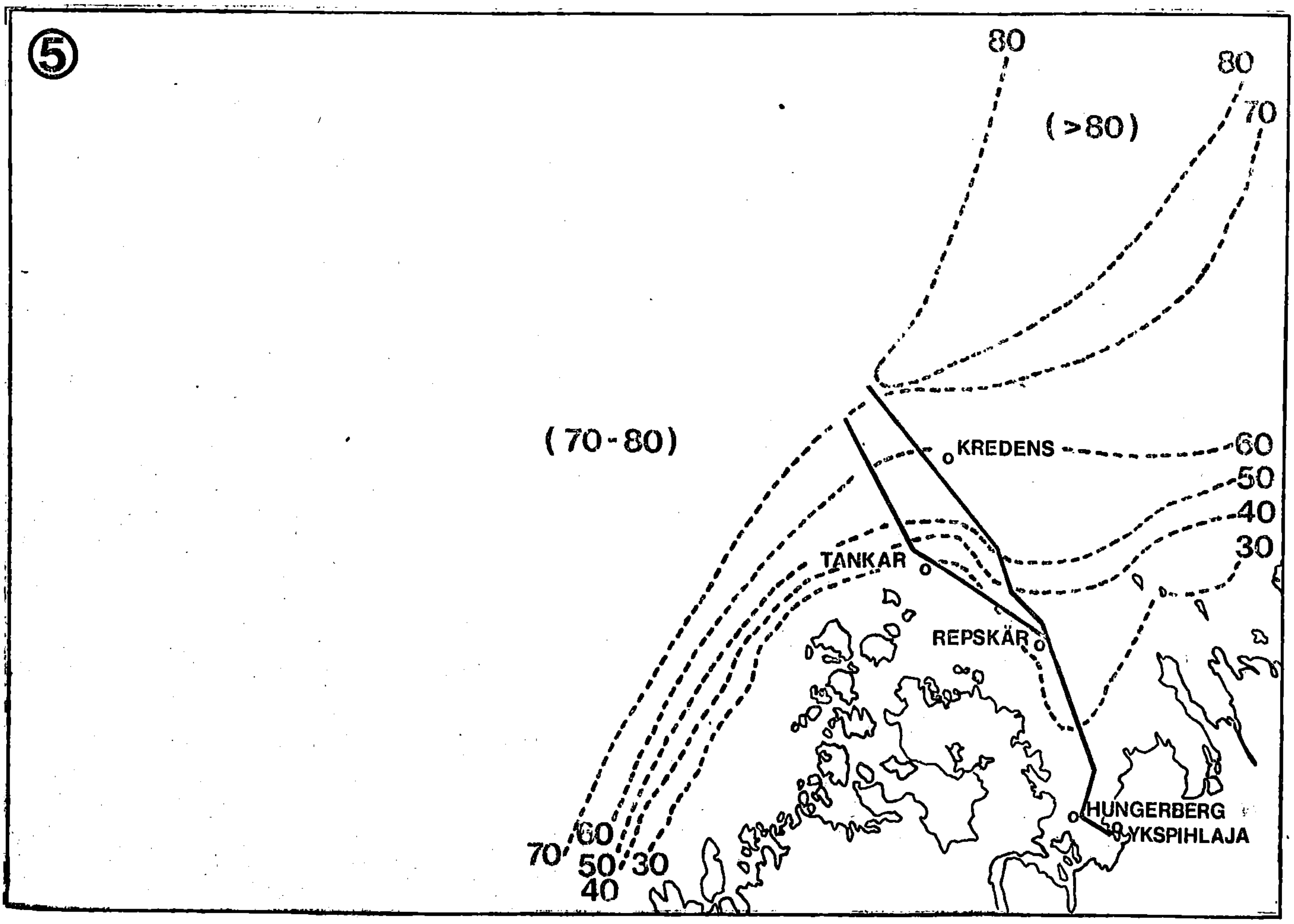
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(70-80)
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YKSPIHLAJA
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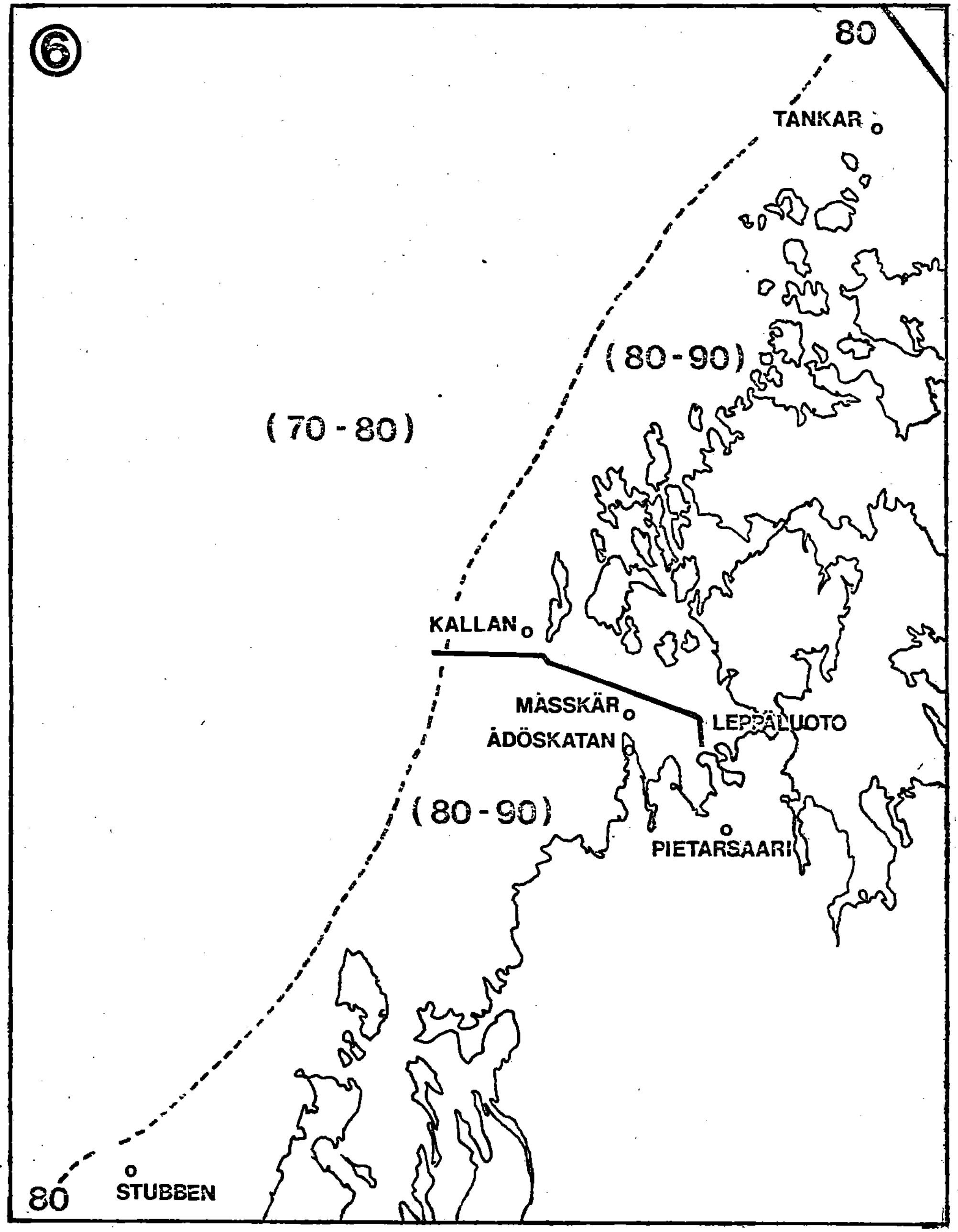

6
80
TANKAR
(80-90)
(70-80)
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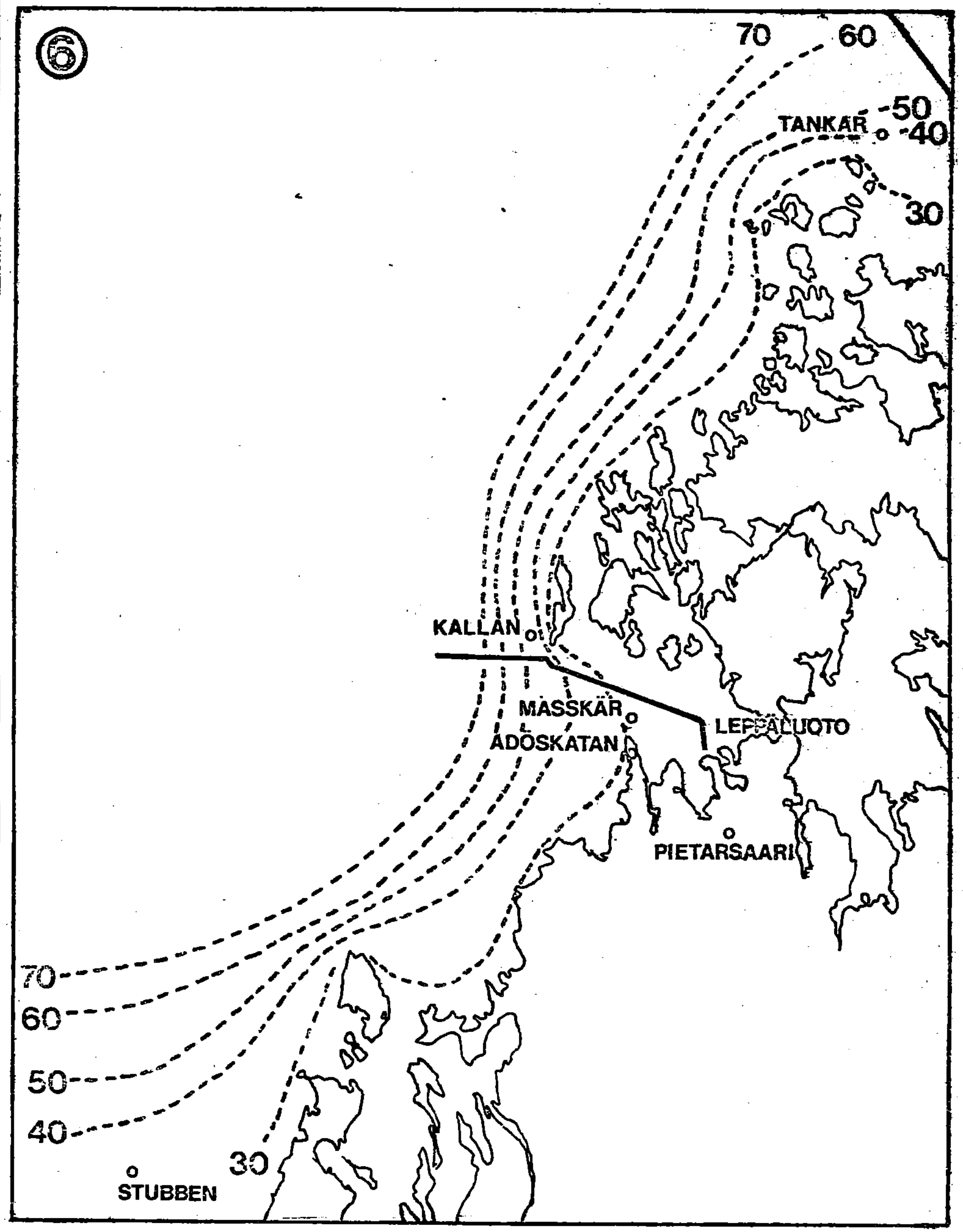
MÅSSKÄR
LEPPÄLUOTO
ÅDÖSKATAN
(80-90)
PIETARSAARI
80
STUBBEN



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TANKAR
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50
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STUBBEN
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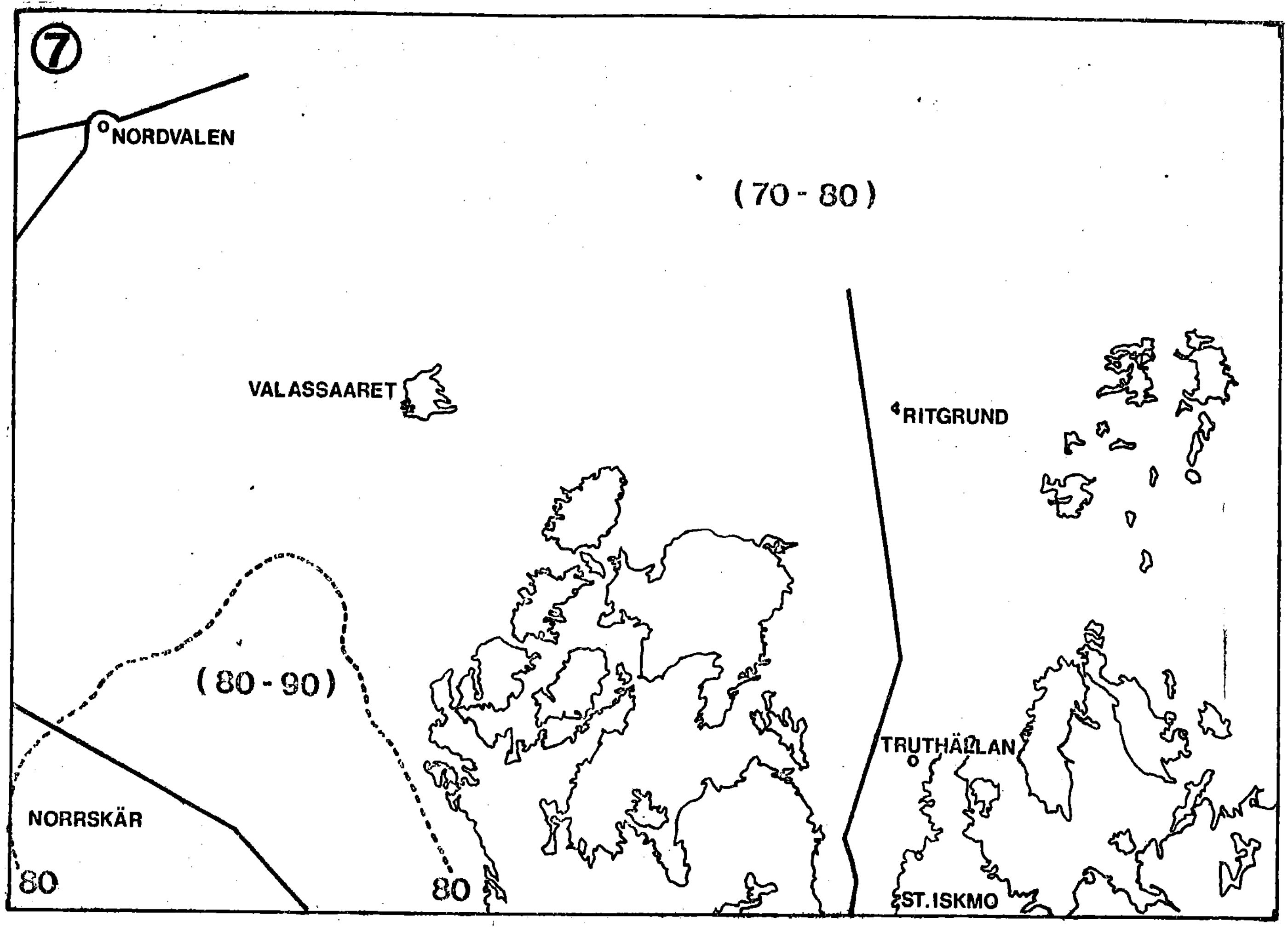
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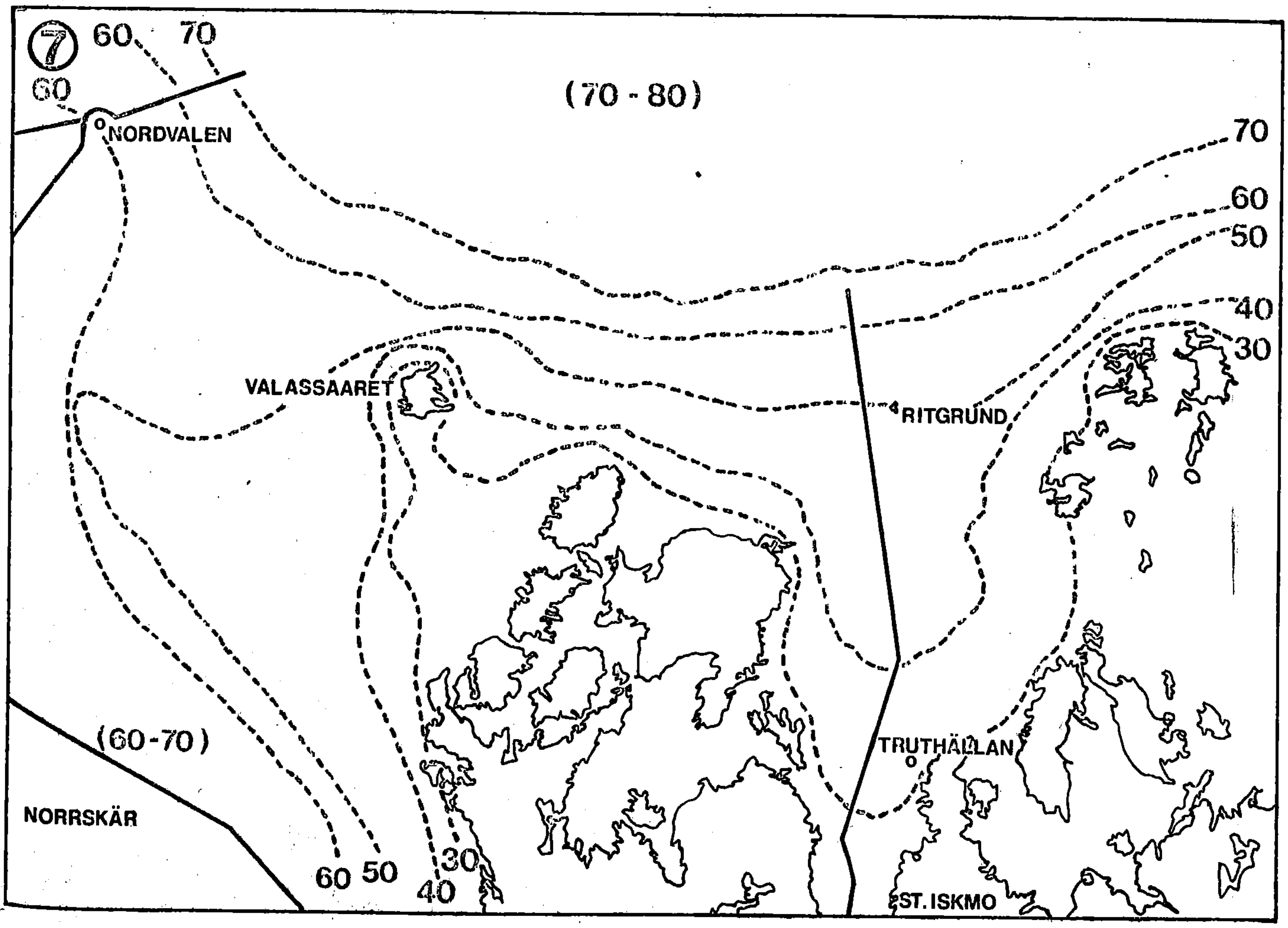
VALASSAARET
RITGRUND
(80 - 90)
TRUTHÄLLAN
NORRSKÄR
80
80
ST. ISKMO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VALASSAARET
RITGRUND
(60-70)
TRUTHÄLLAN
NORRSKÄR
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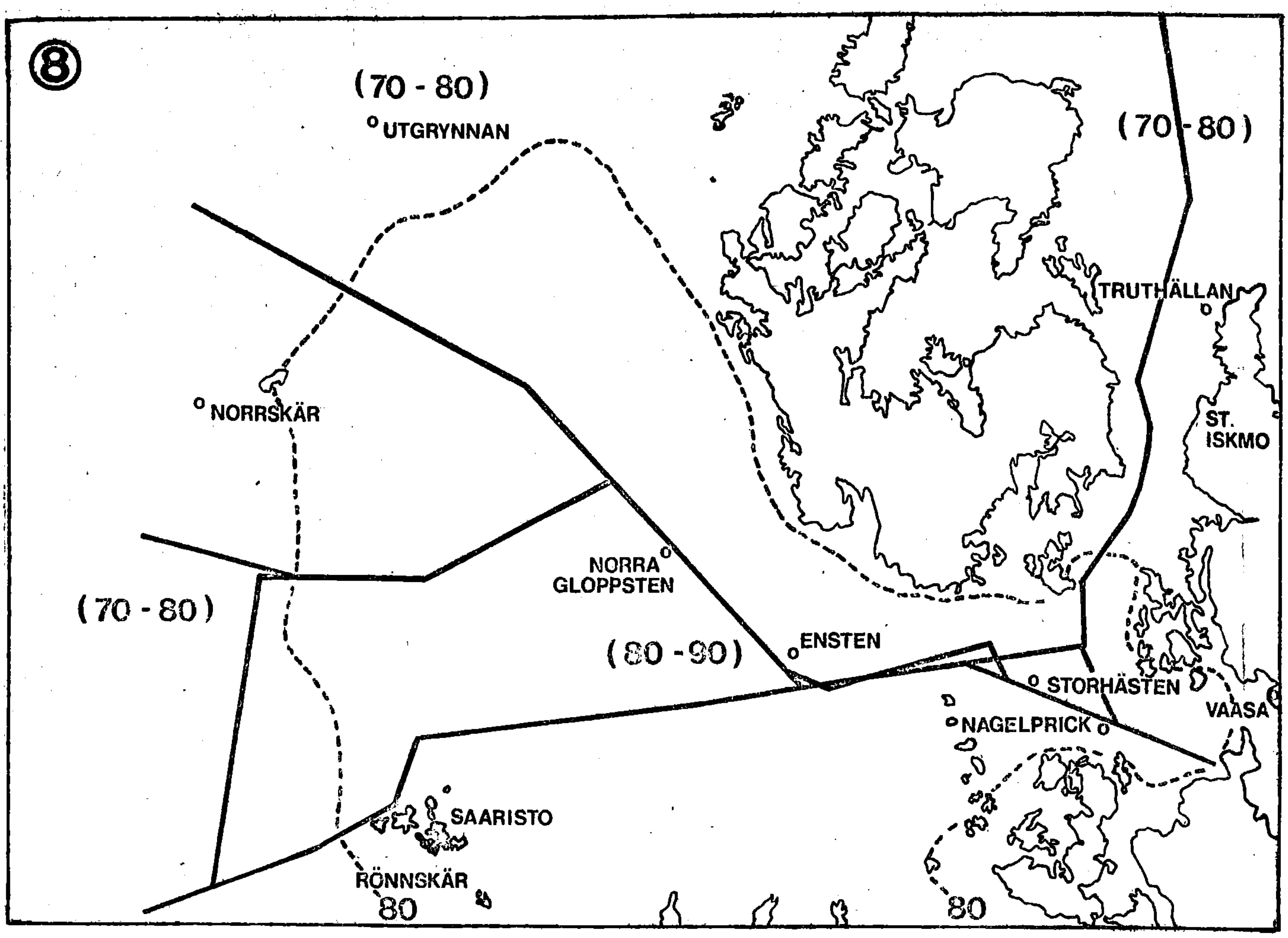
ST. ISKMO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(70 - 80)
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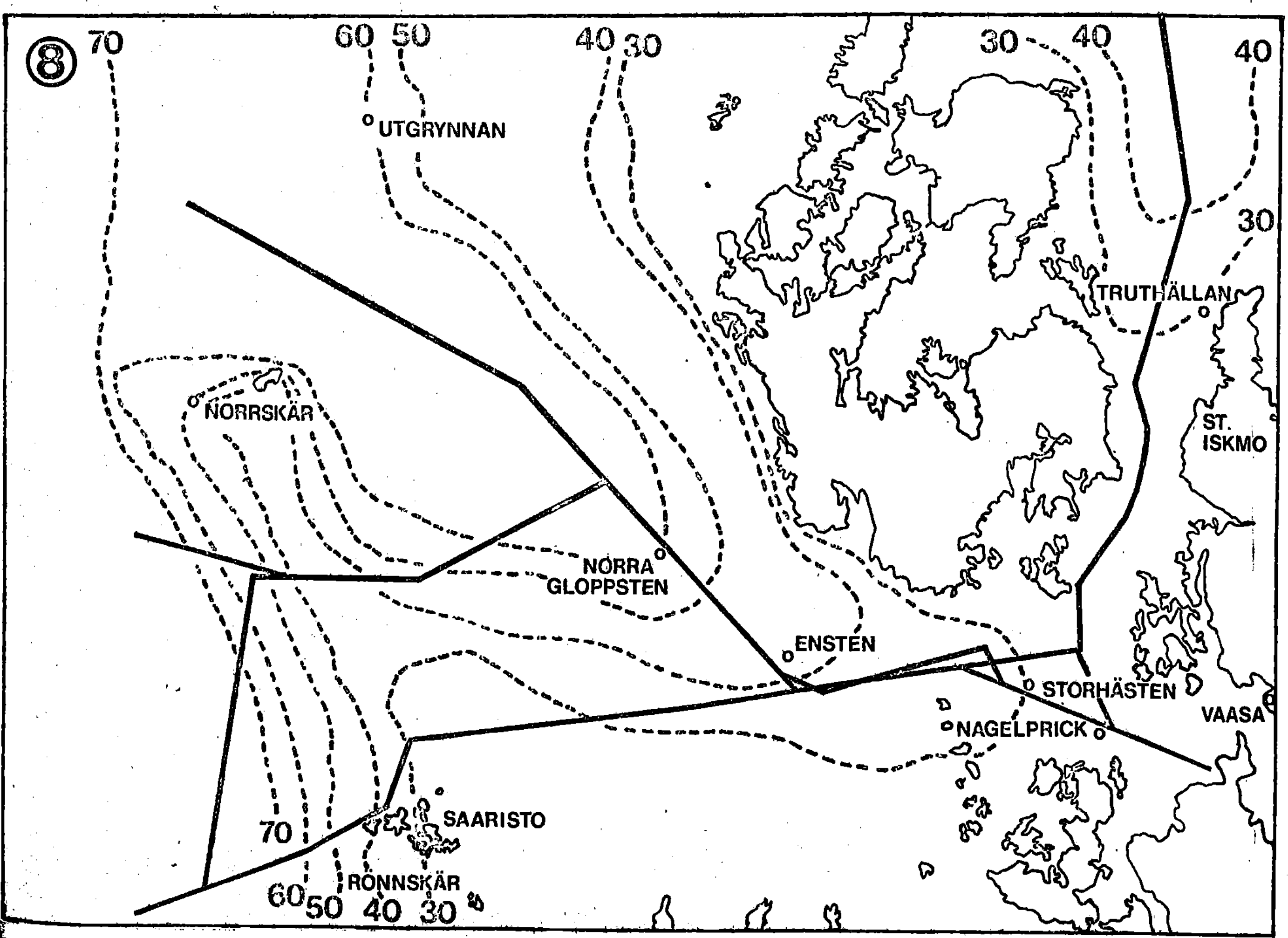
NORRSKÄR
ST. ISKMO
NORRA GLOPPSTEN
(70 - 80)
ENSTEN
(80 - 90)
STORHÄSTEN
VAASA
NAGELPRICK
SAARISTO
RÖNNSKÄR
80
80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TRUTHÄLLAN
NORRSKÄR
ST. ISKMO
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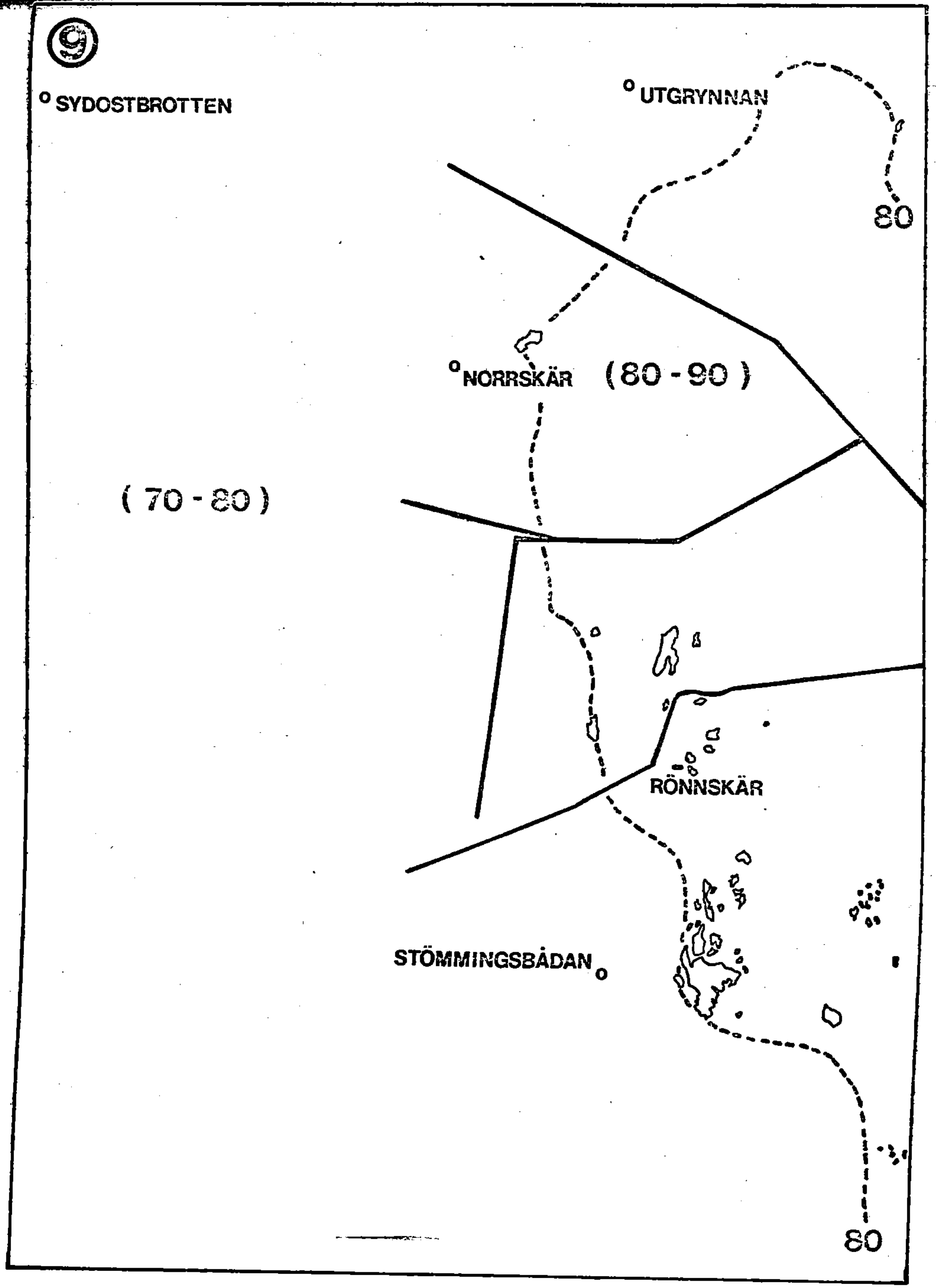
ENSTEN
STORHÄSTEN
VAASA
NAGELPRICK
SAARISTO
70
RÖNNSKÄR
60 50 40 30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(70 - 80)
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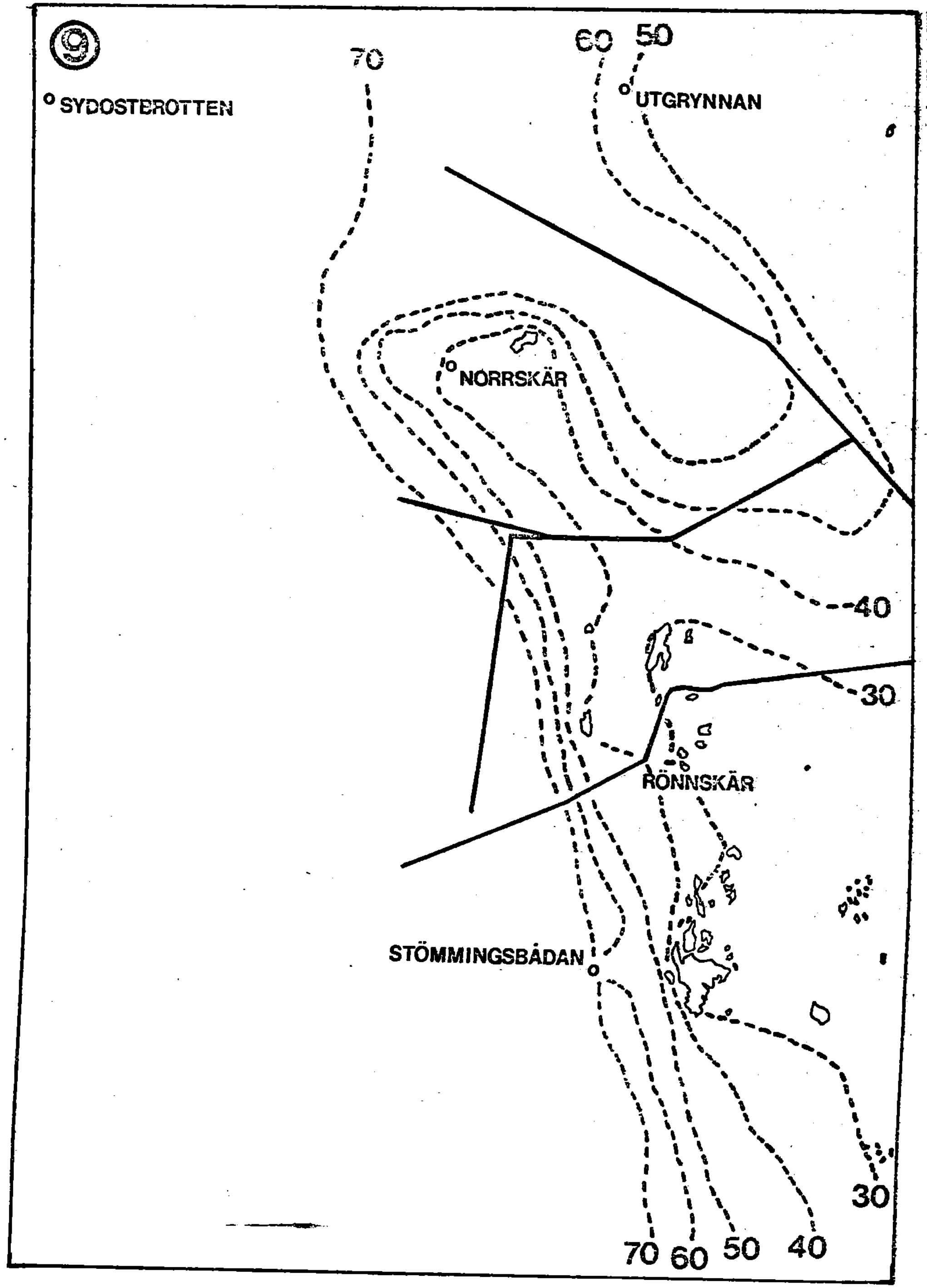
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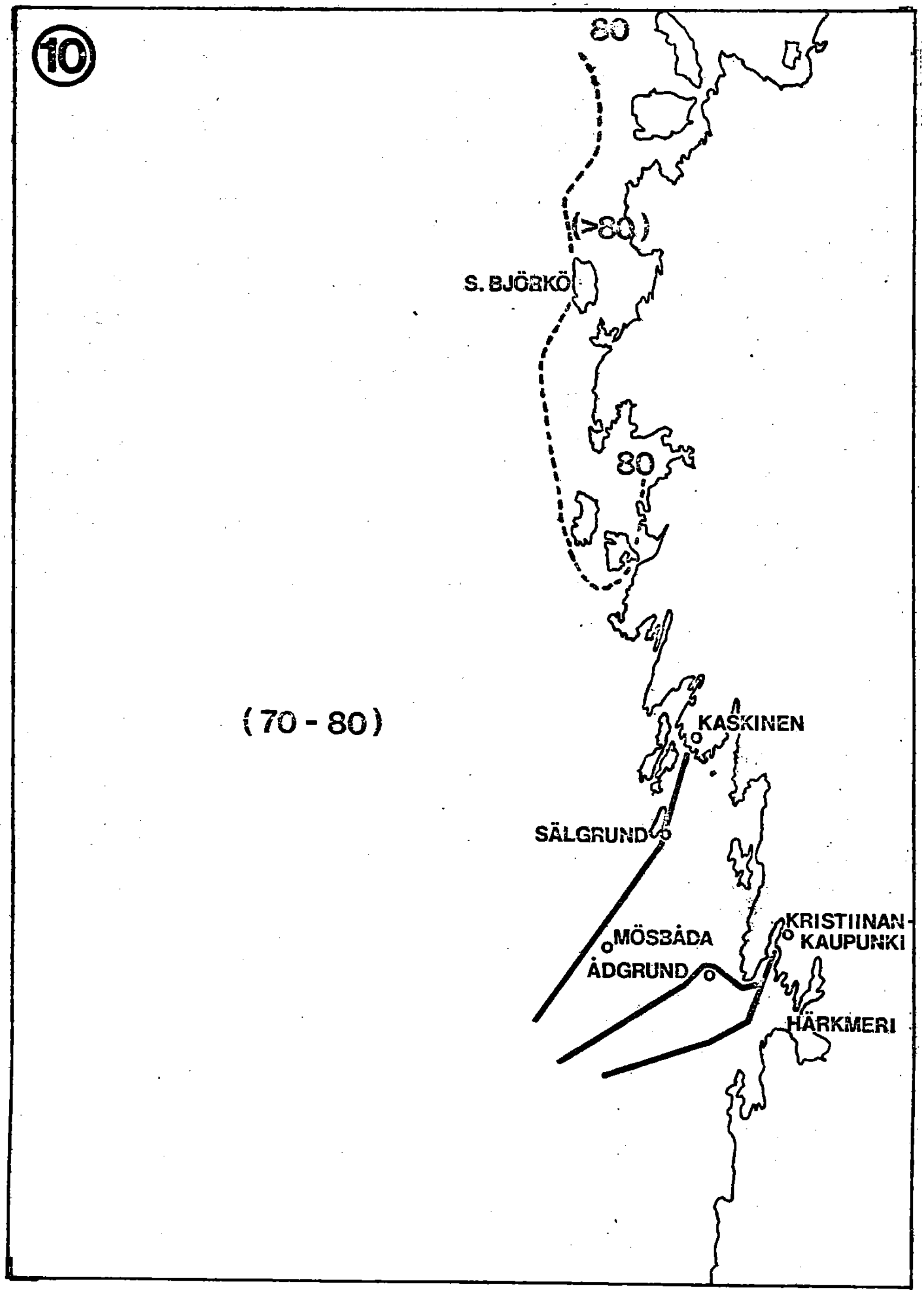
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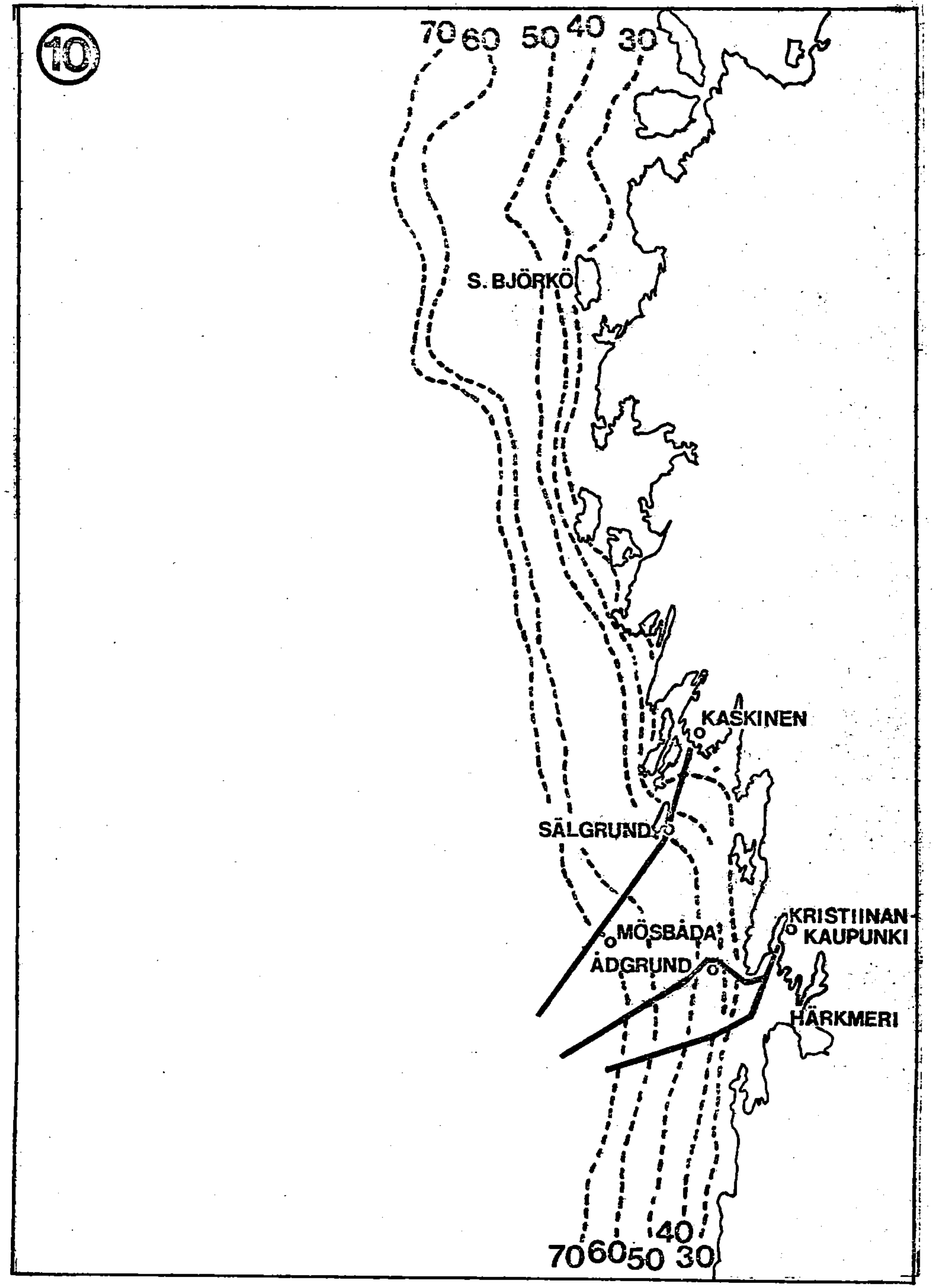
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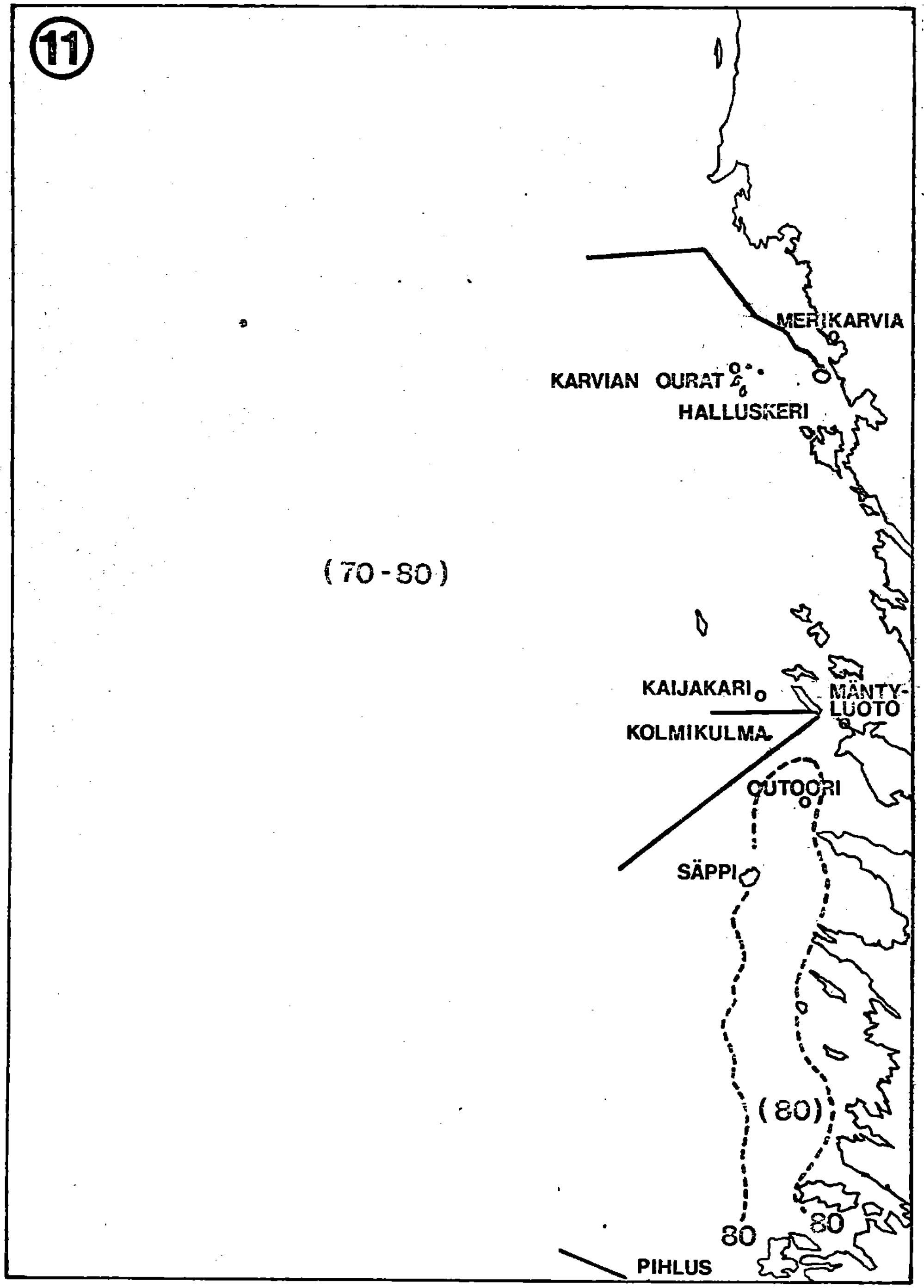
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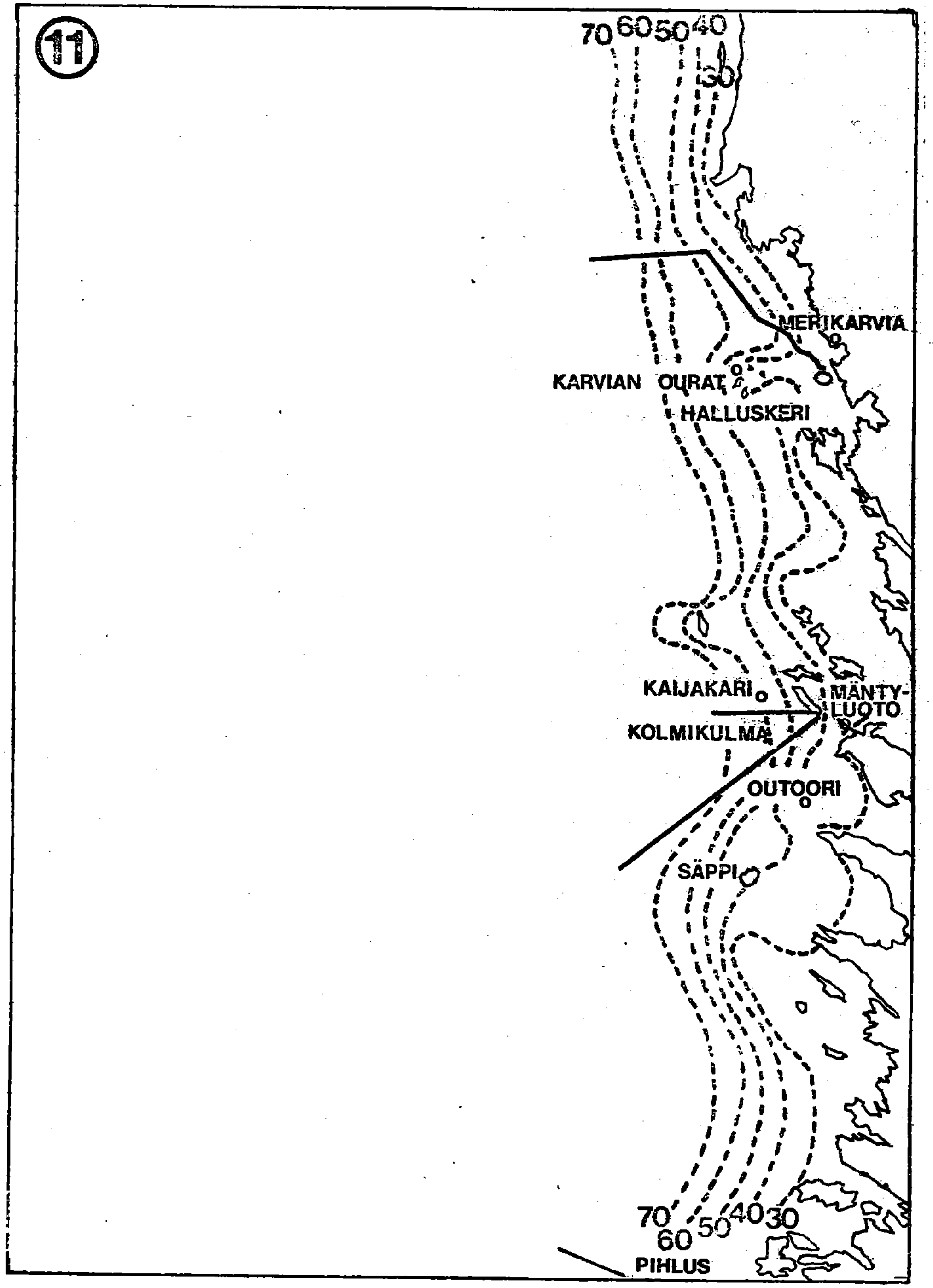
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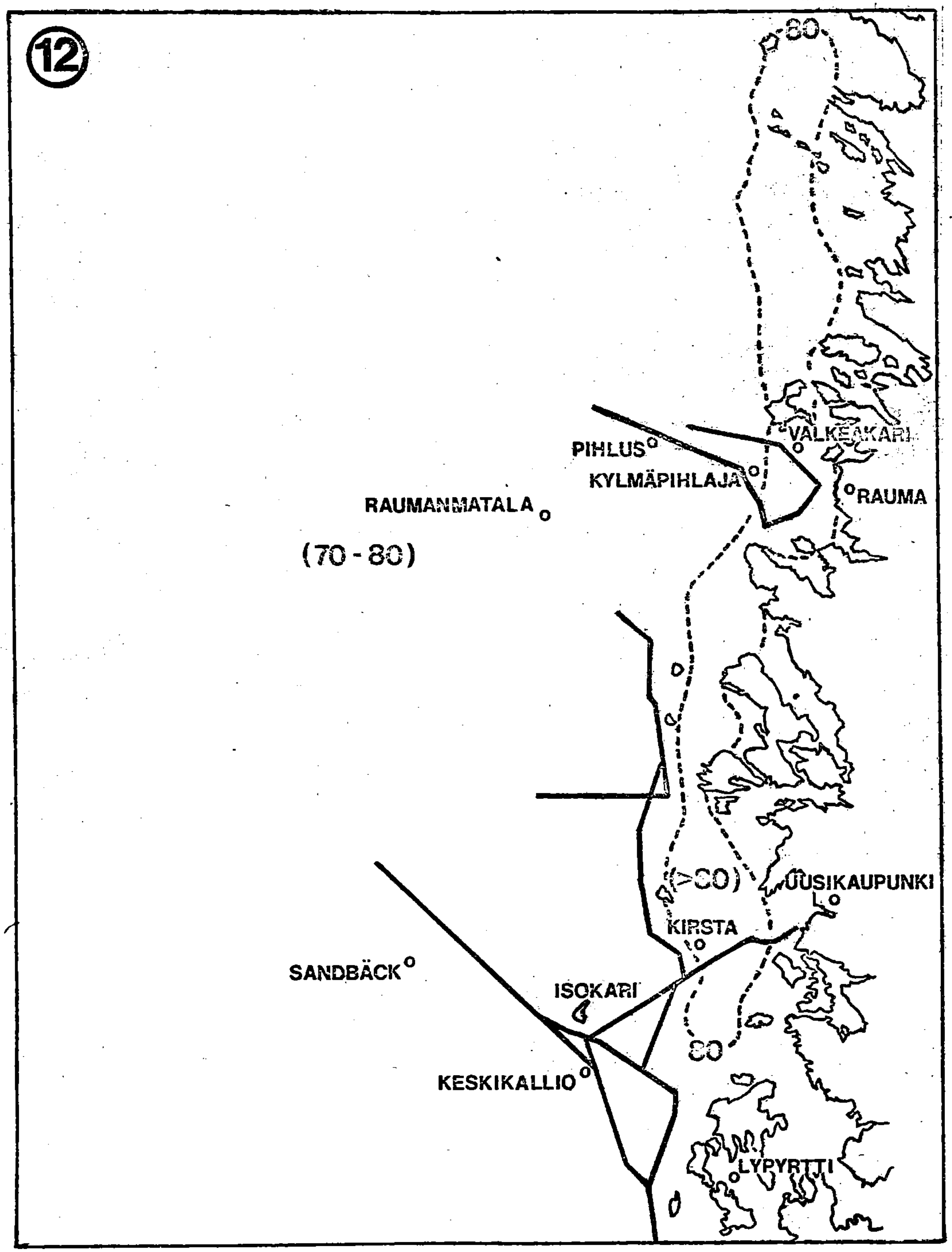

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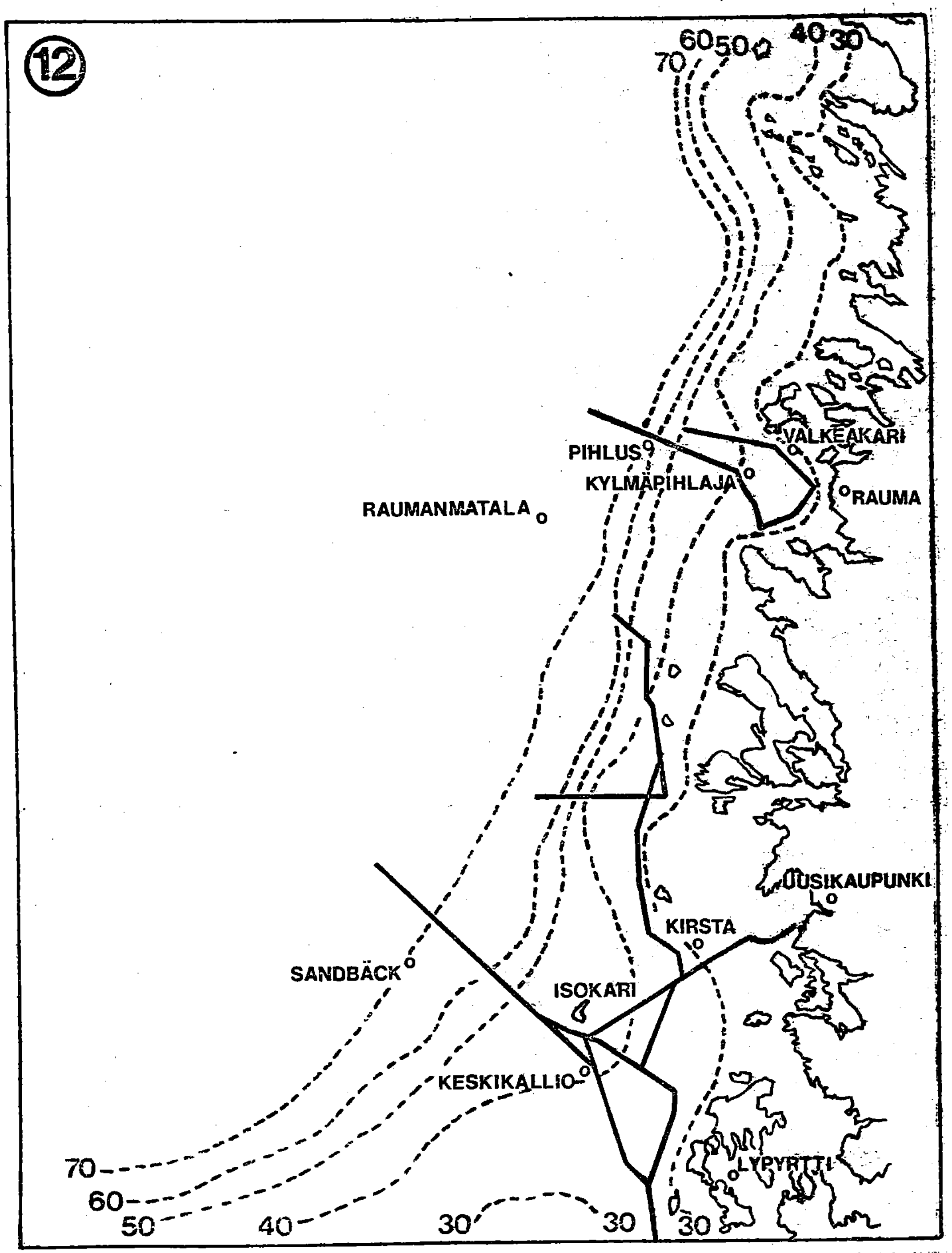

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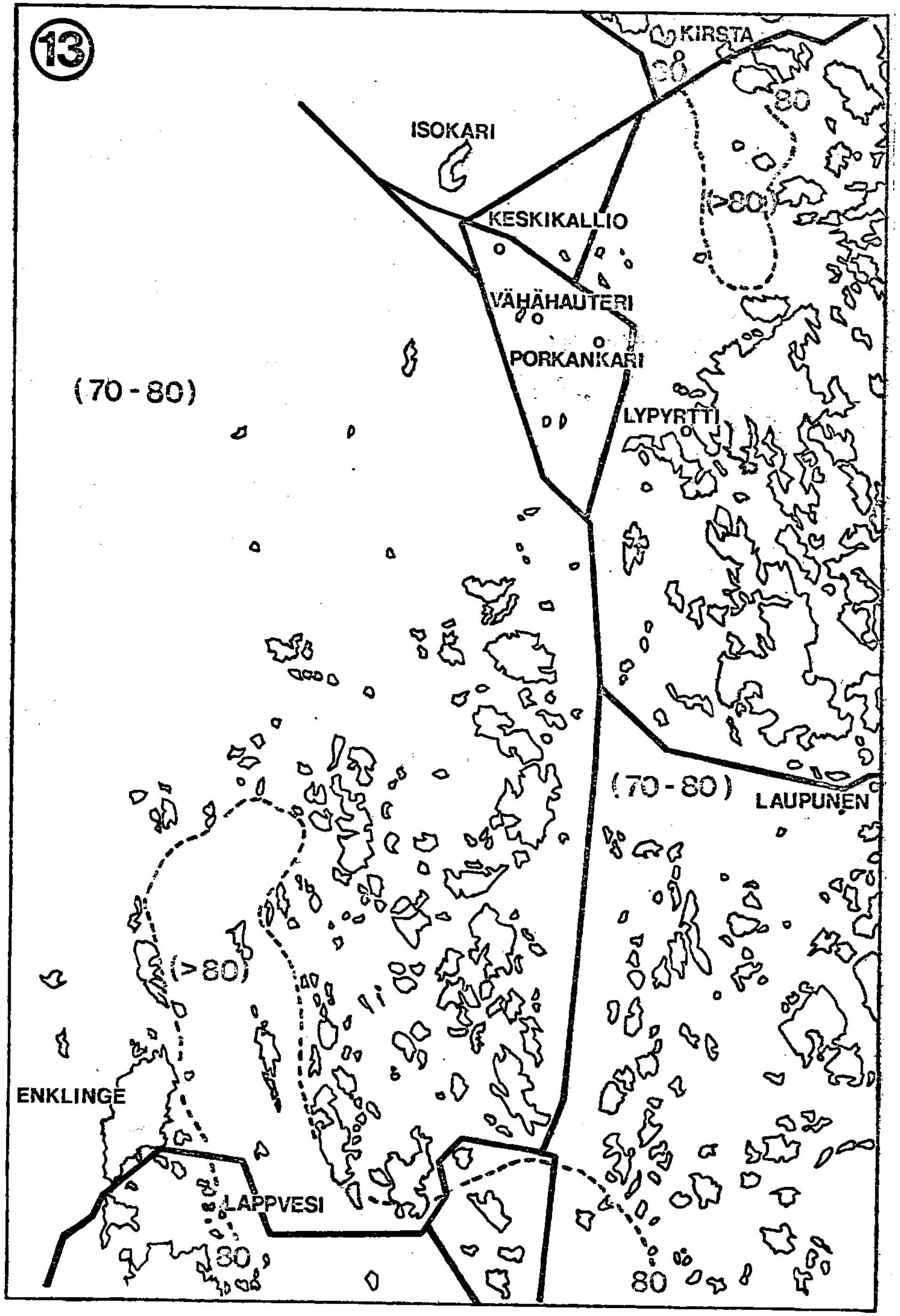
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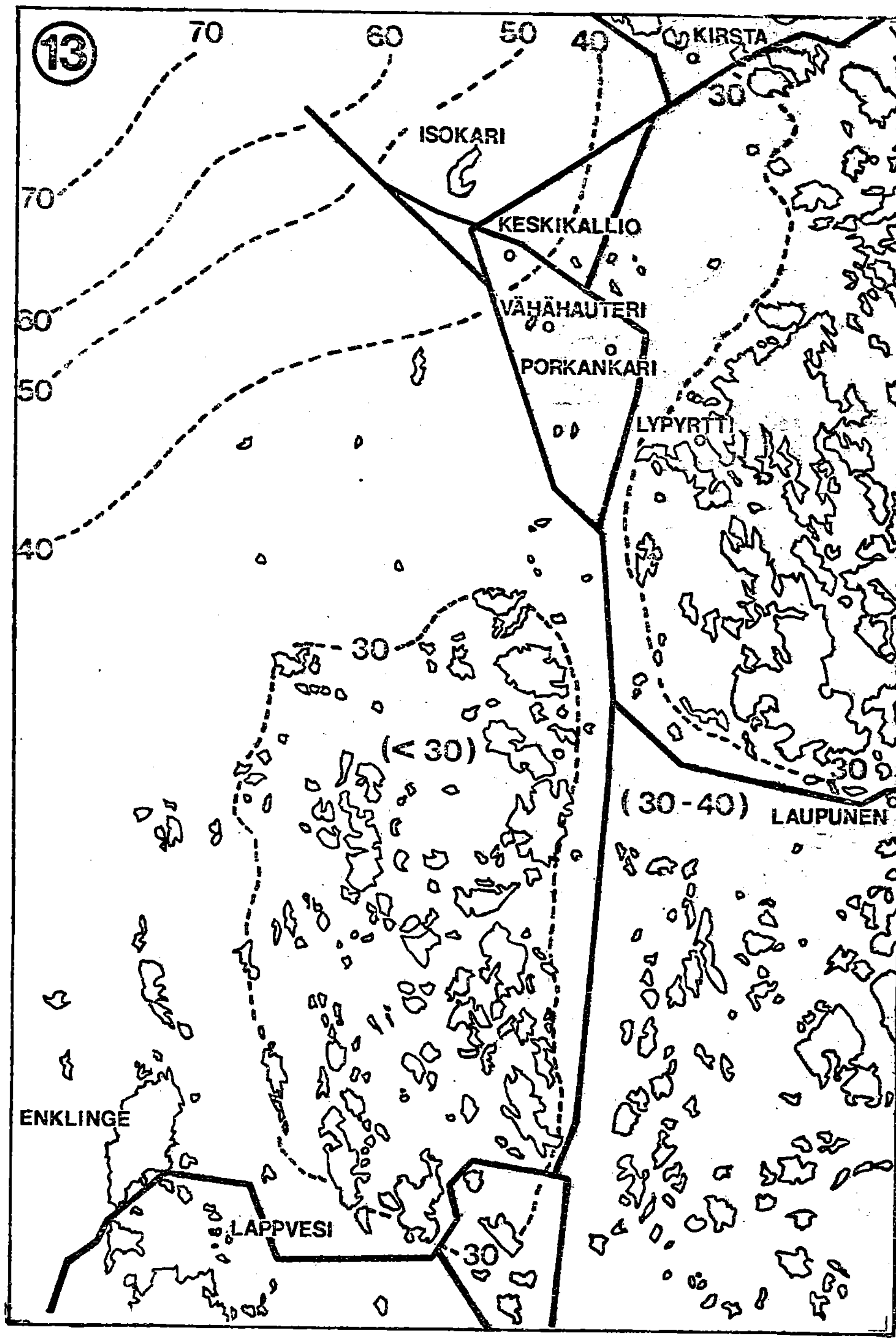
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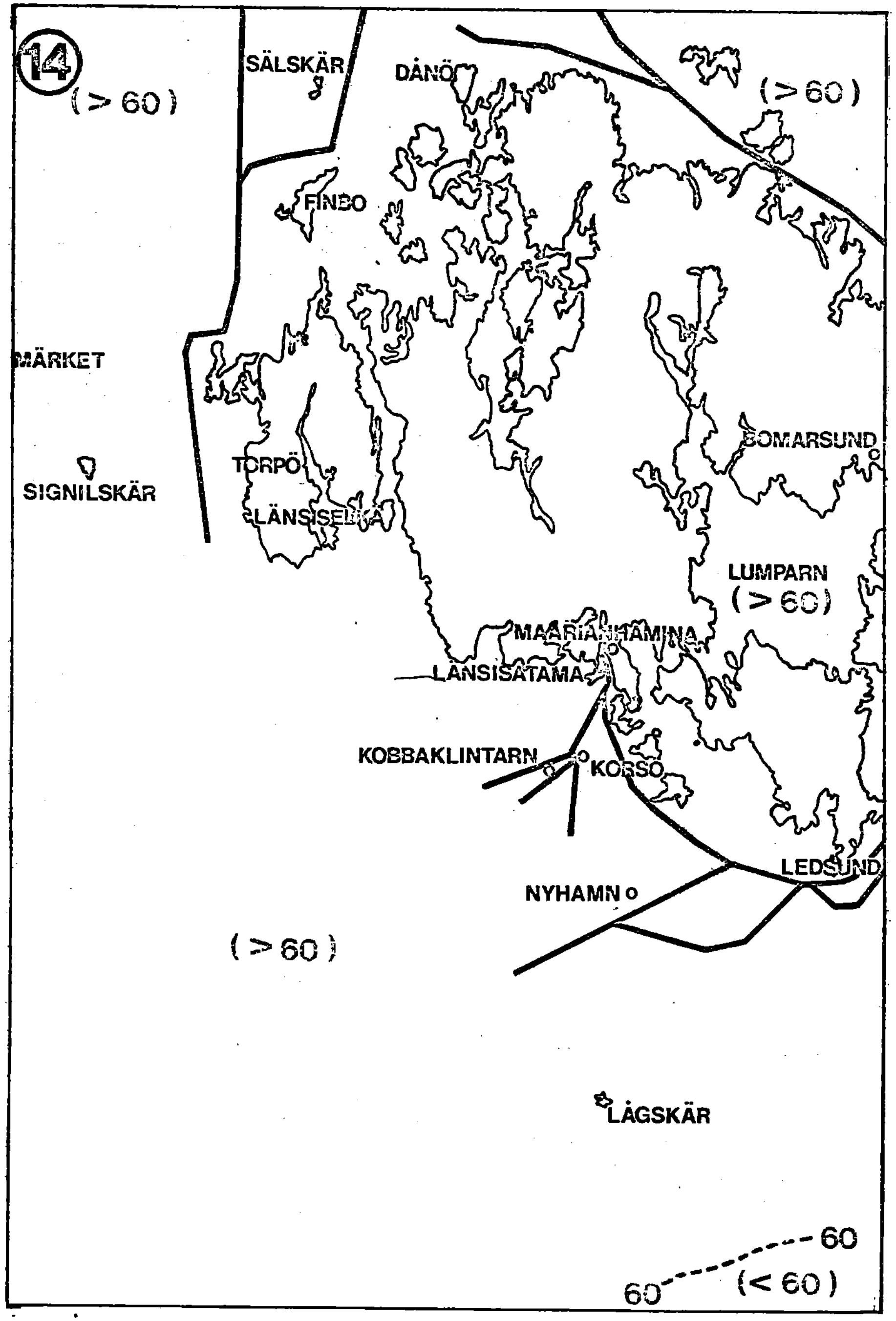
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MAARIANHAMINA
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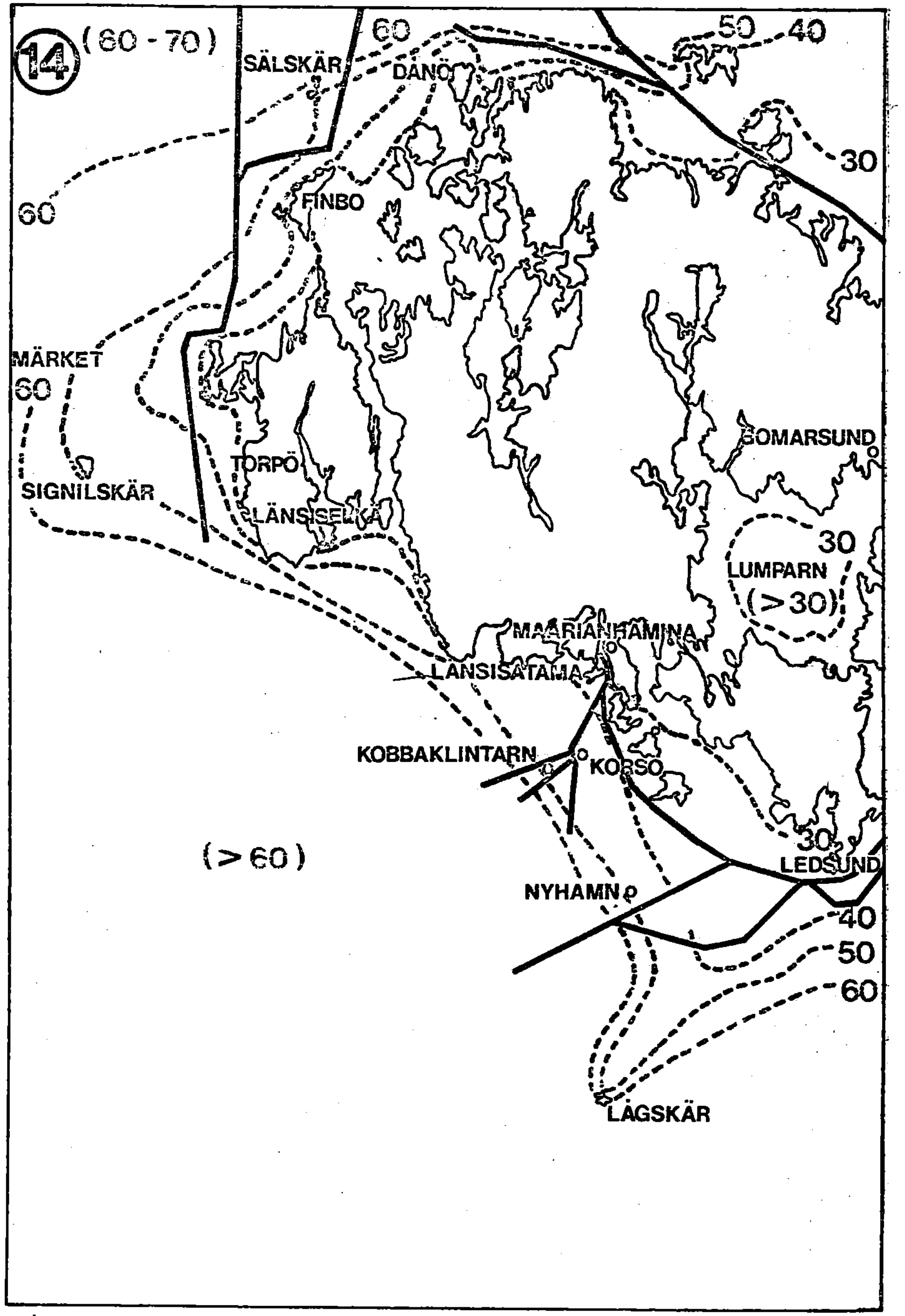
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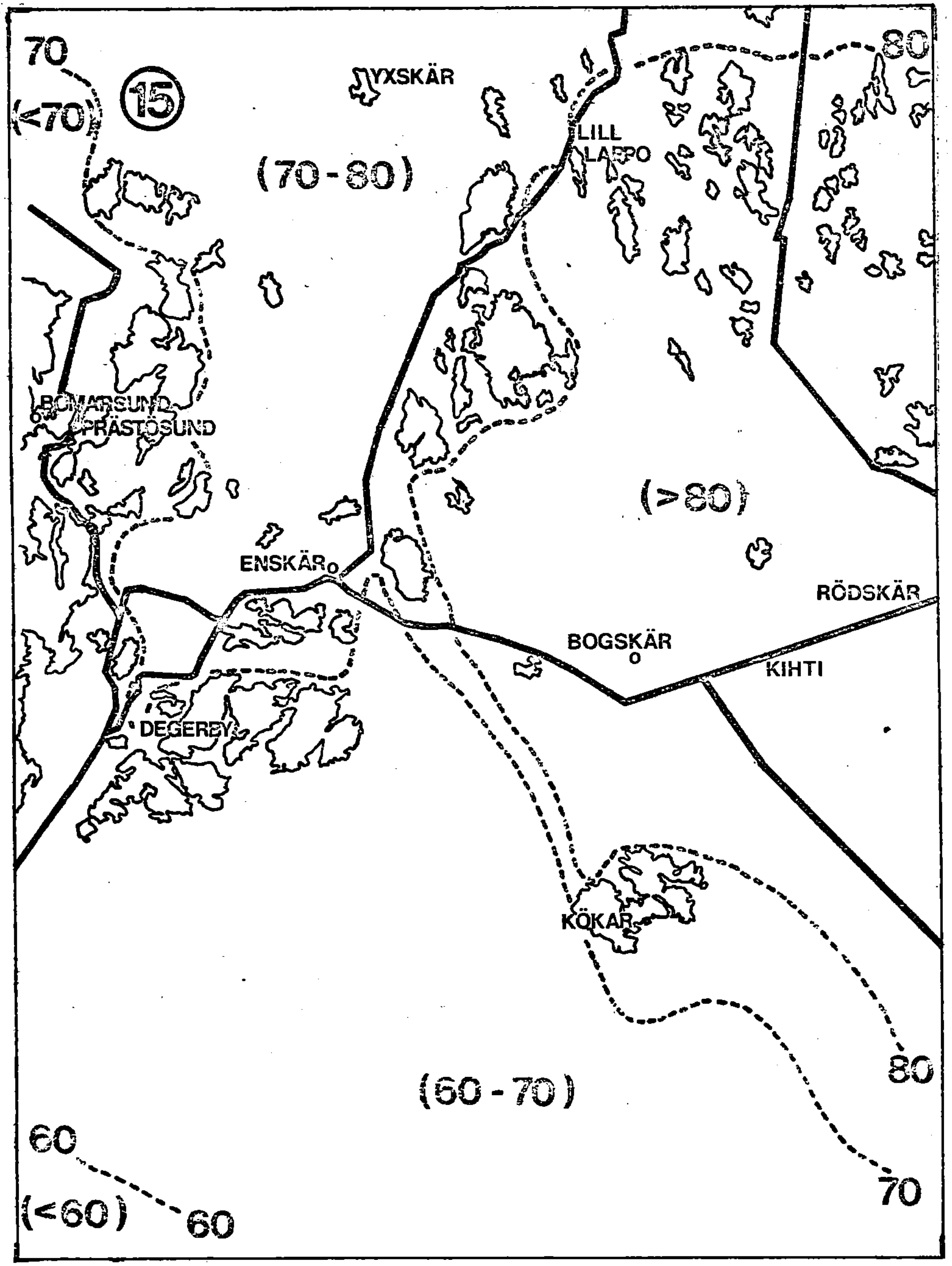
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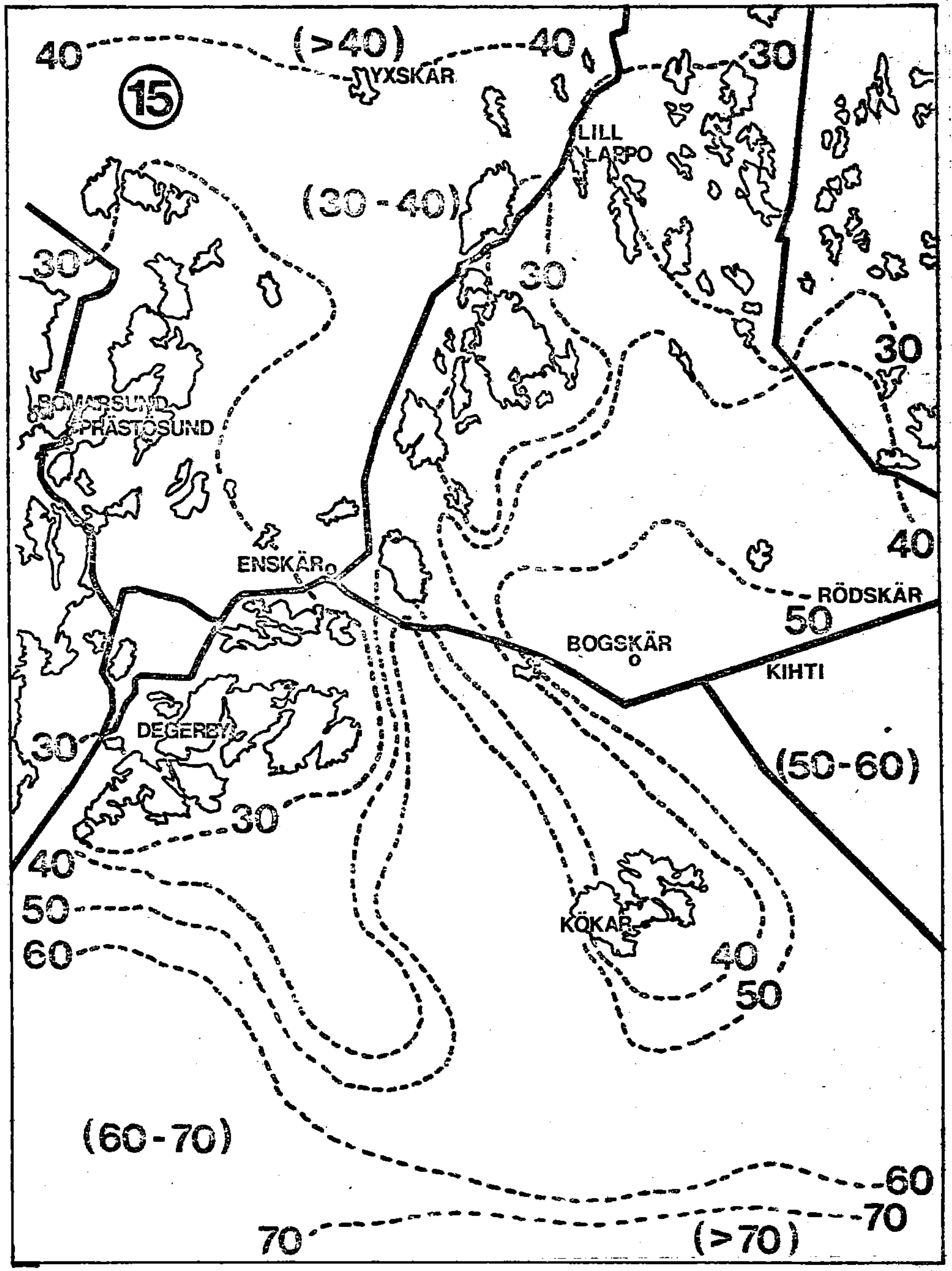
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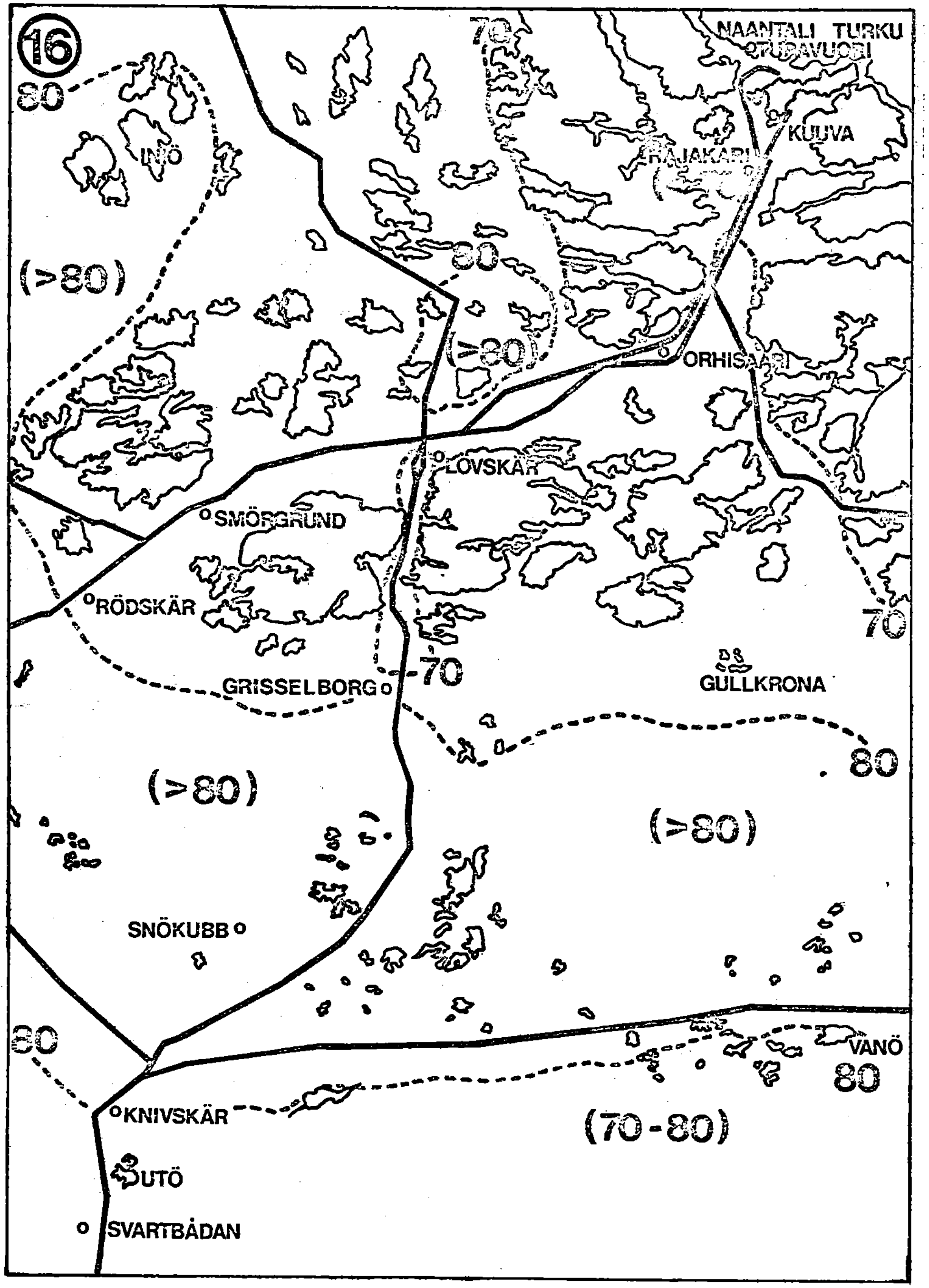
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SMÖRGRUND
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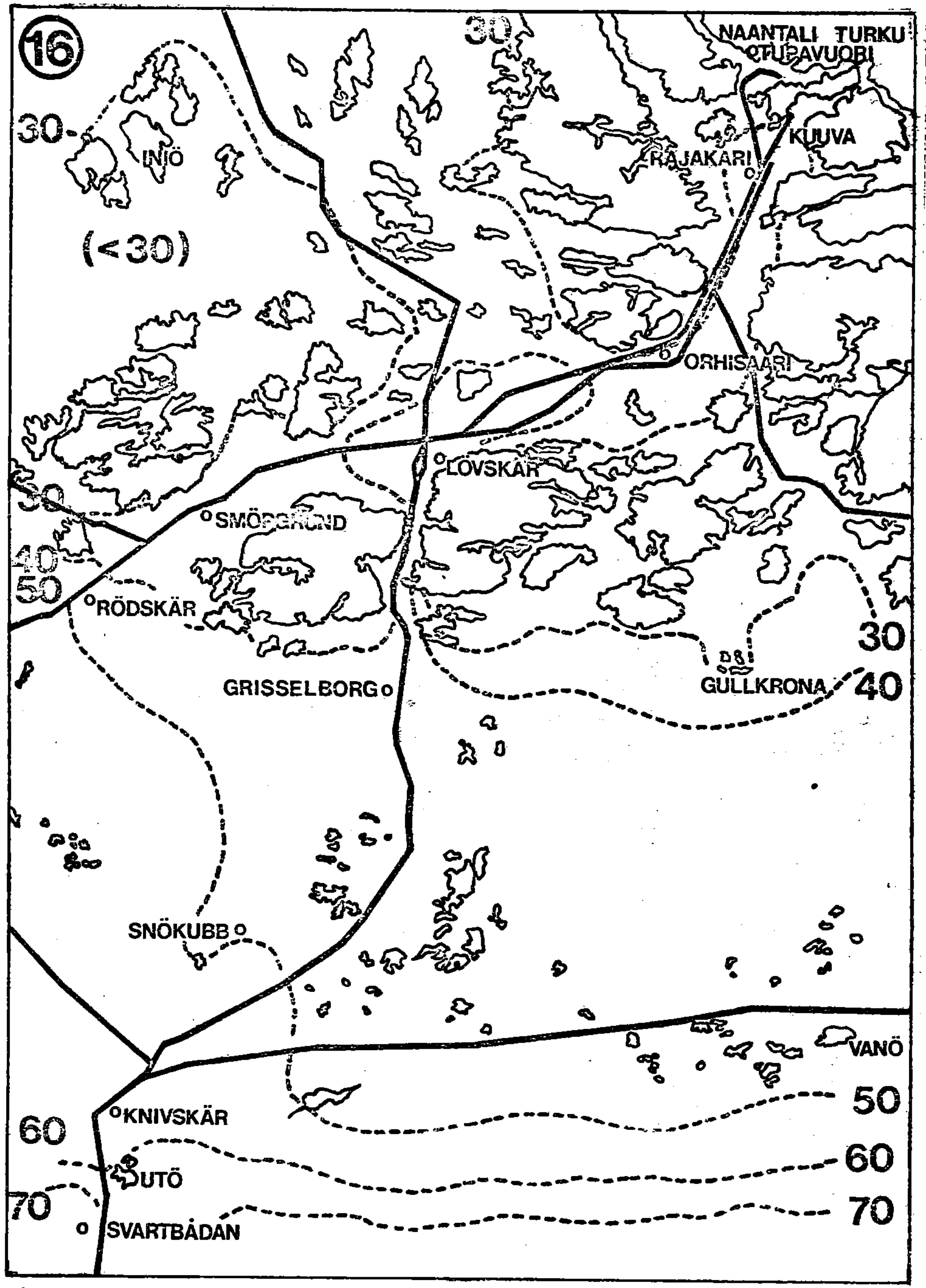
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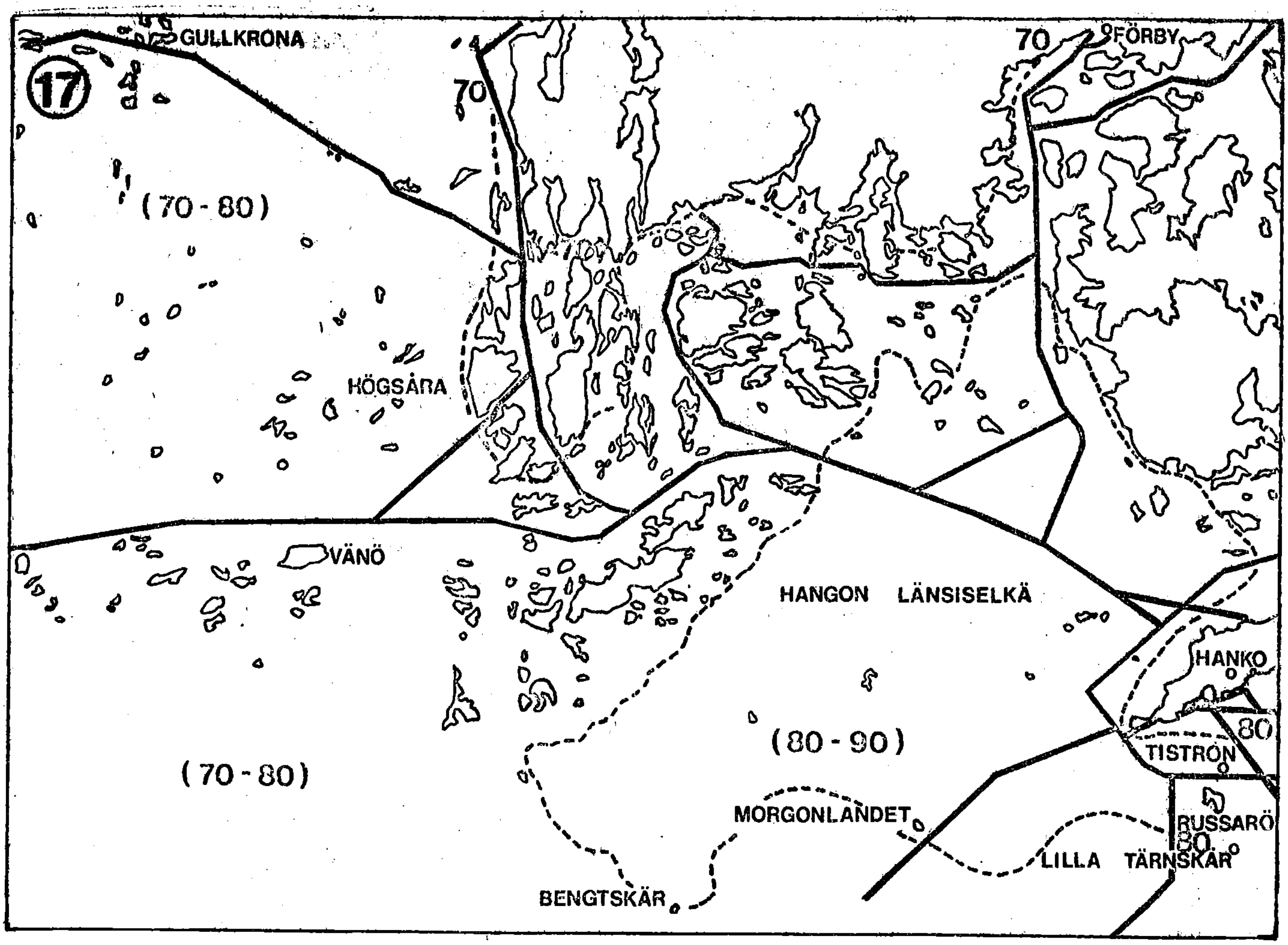
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VÄNÖ
HANGON LÄNSISELKÄ
HANKO
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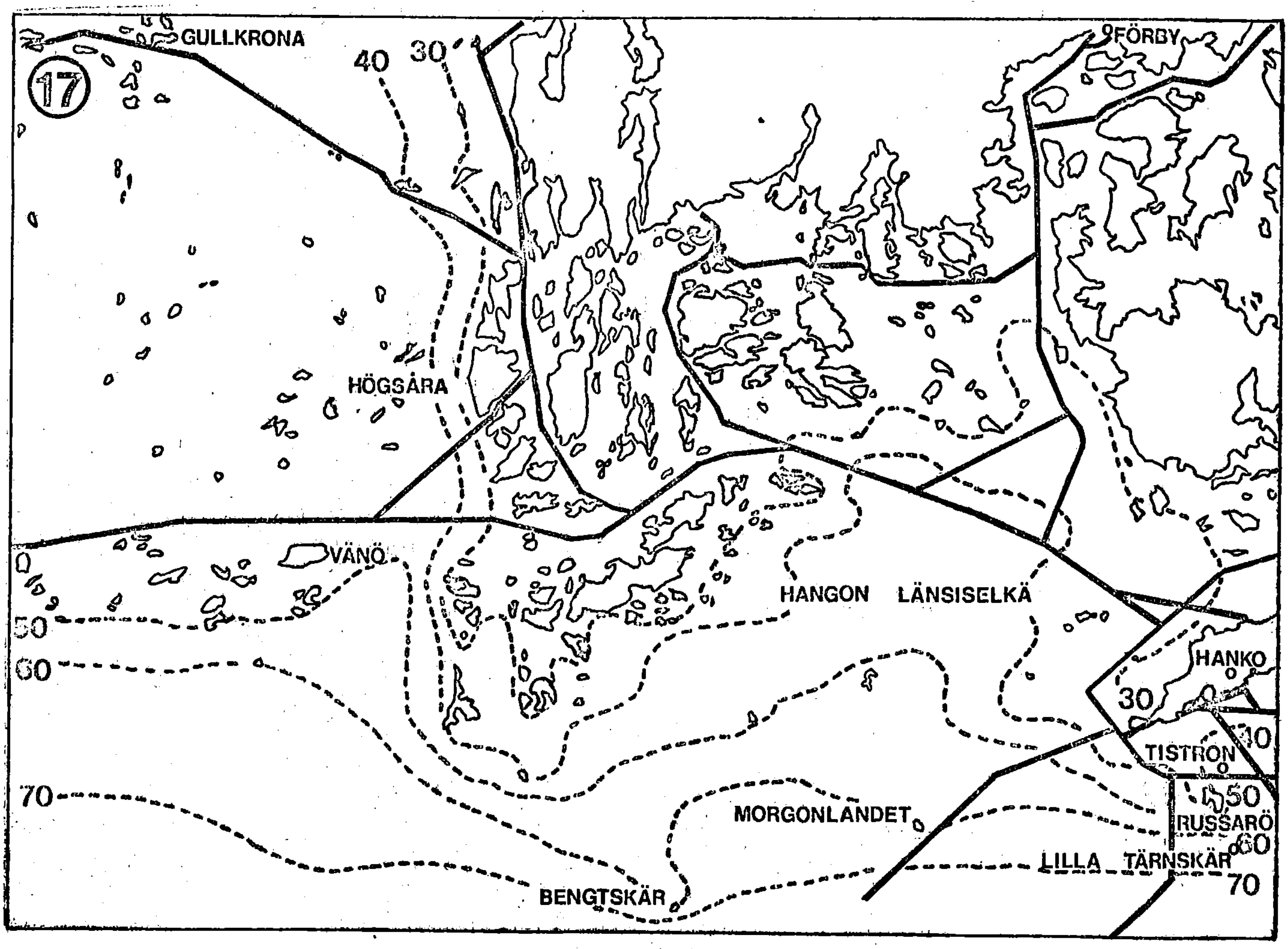
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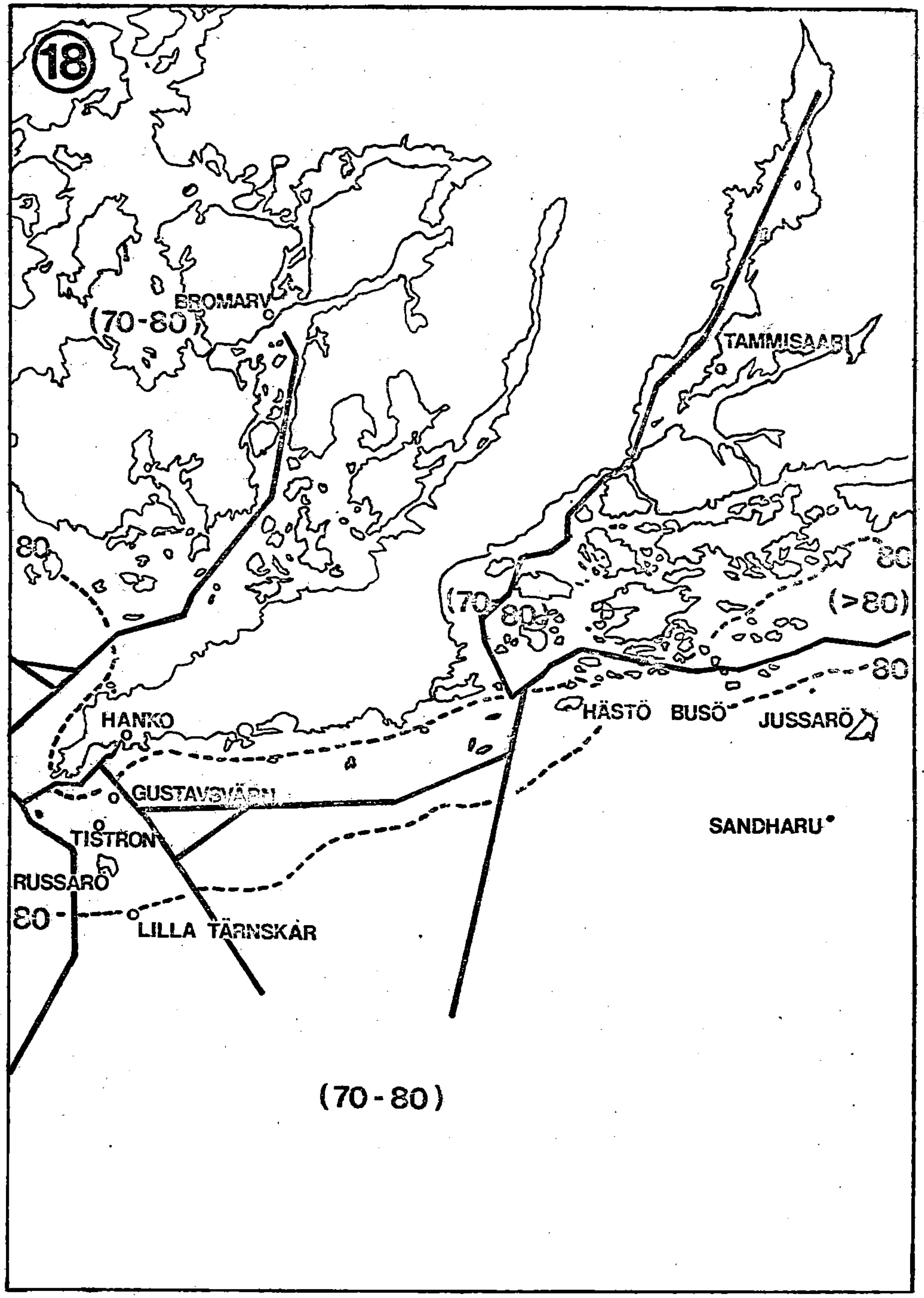
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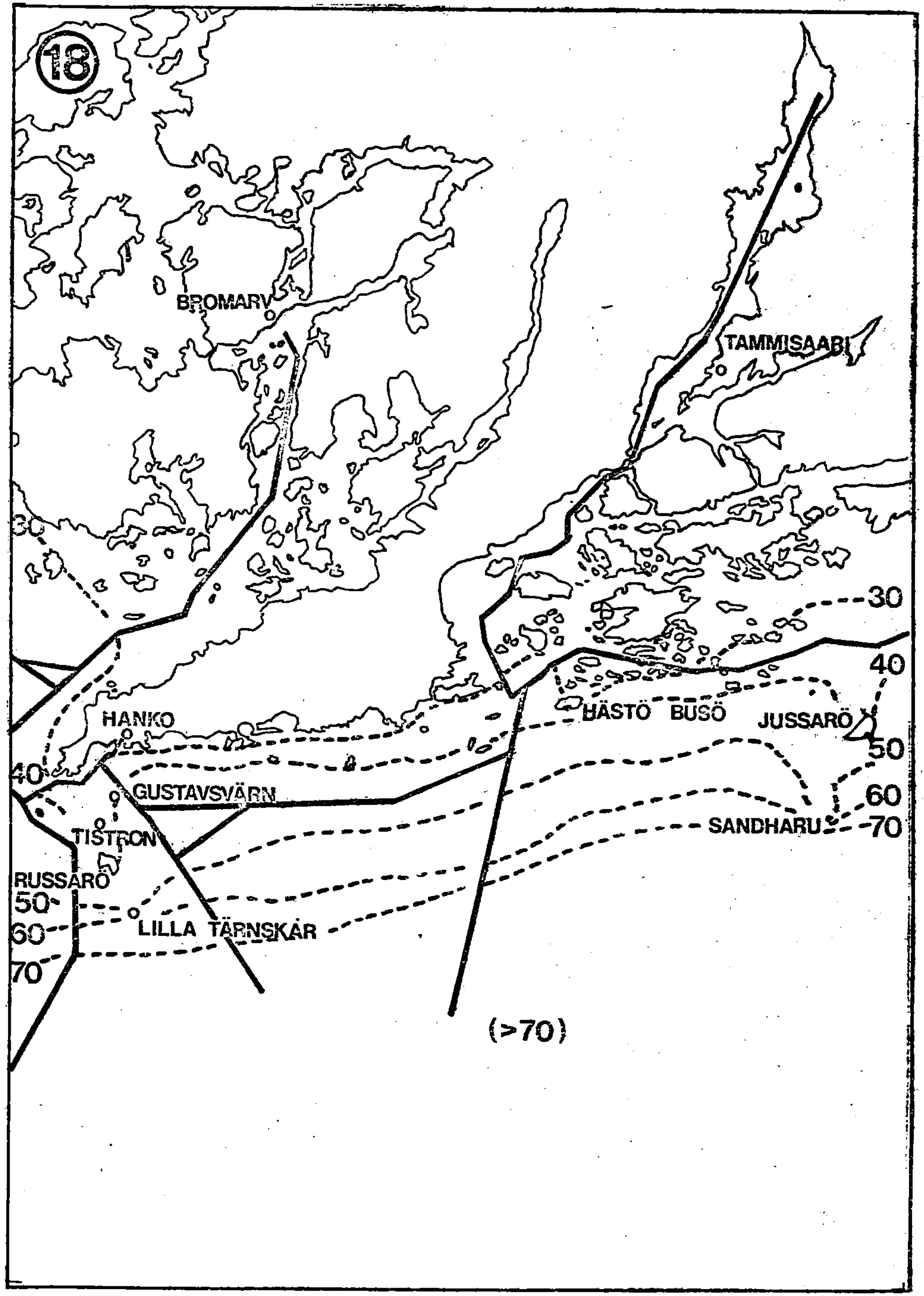
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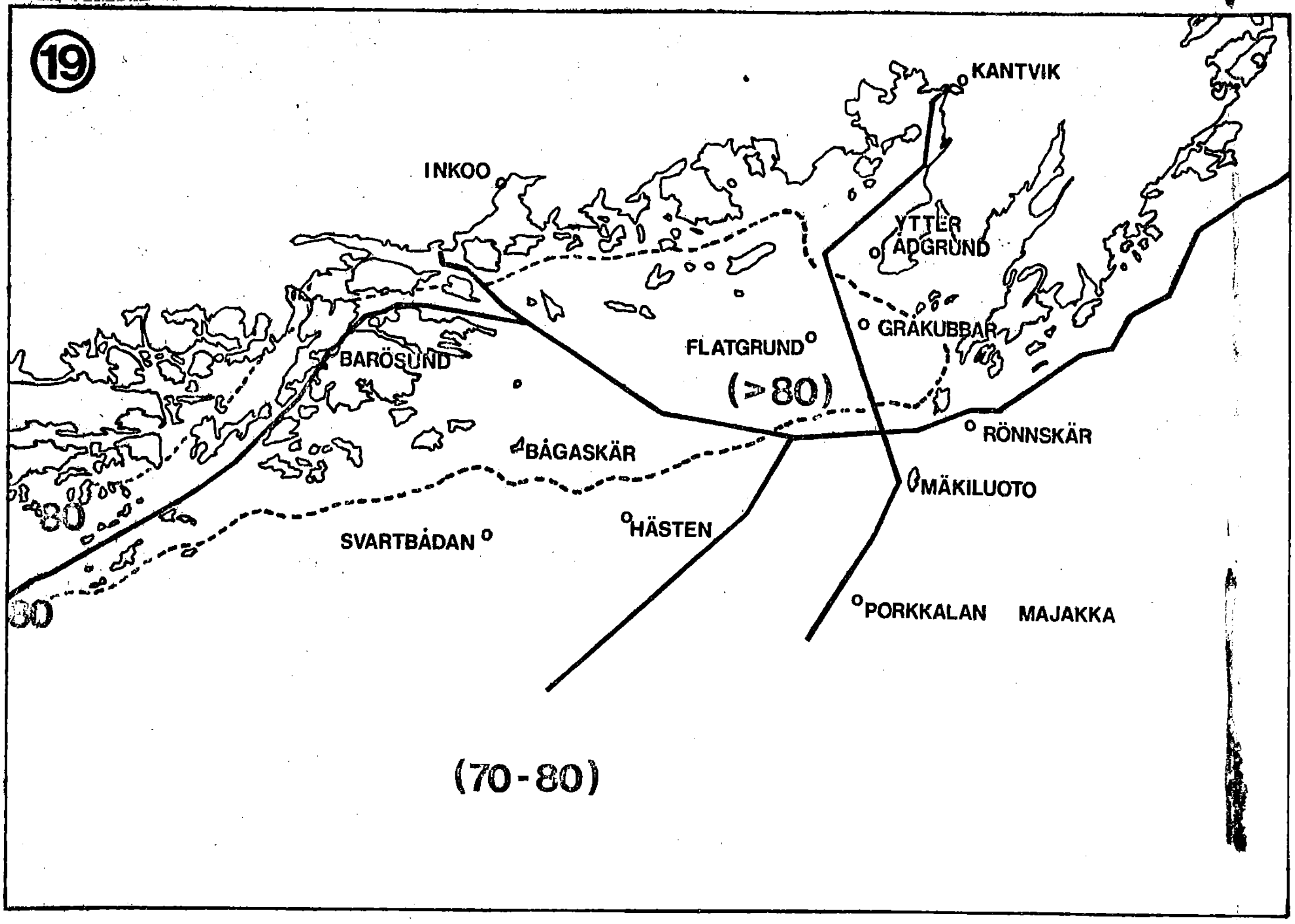

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GRÅKUBBAR
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BARÖSUND
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SVARTBÅDAN
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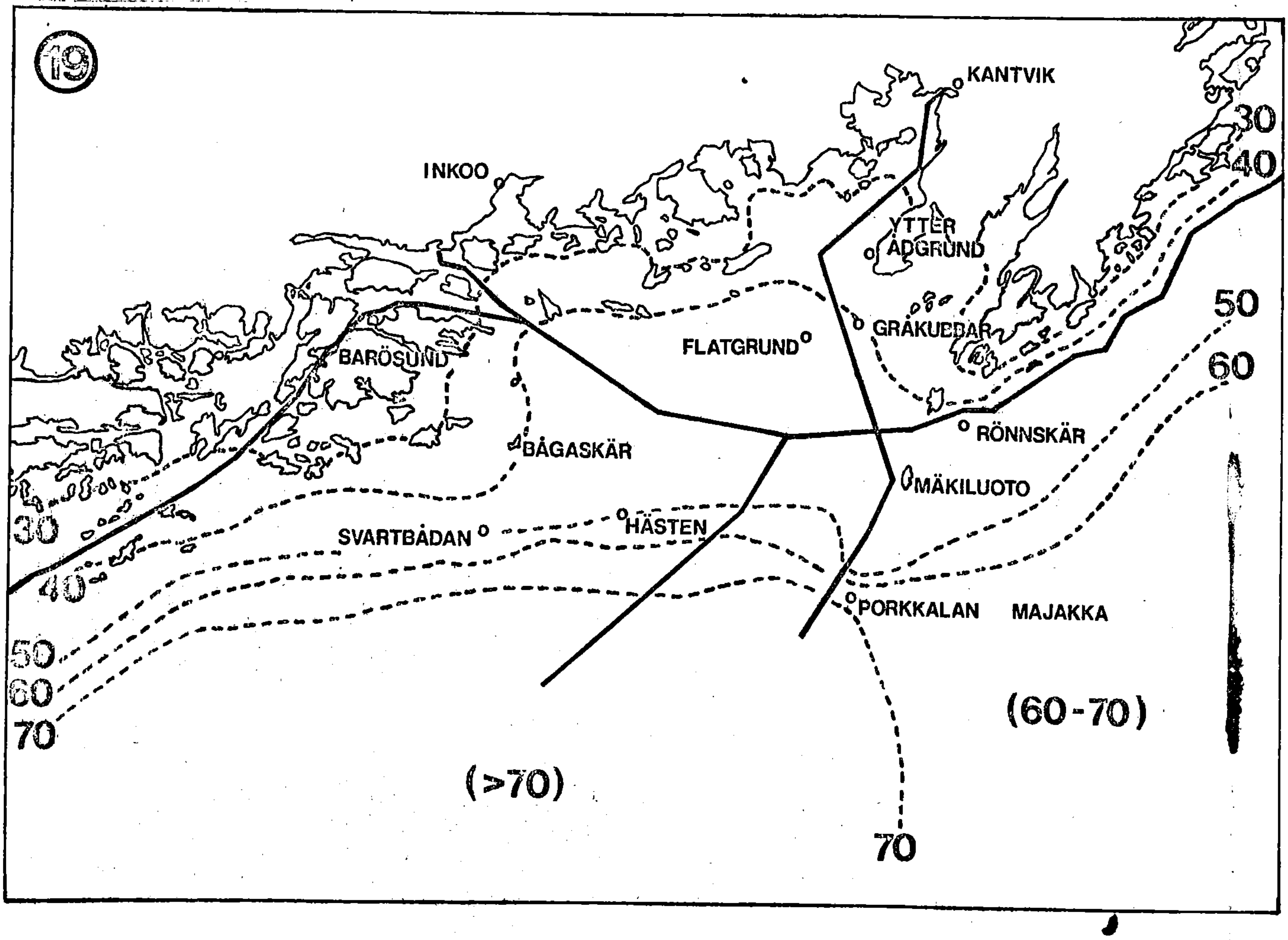

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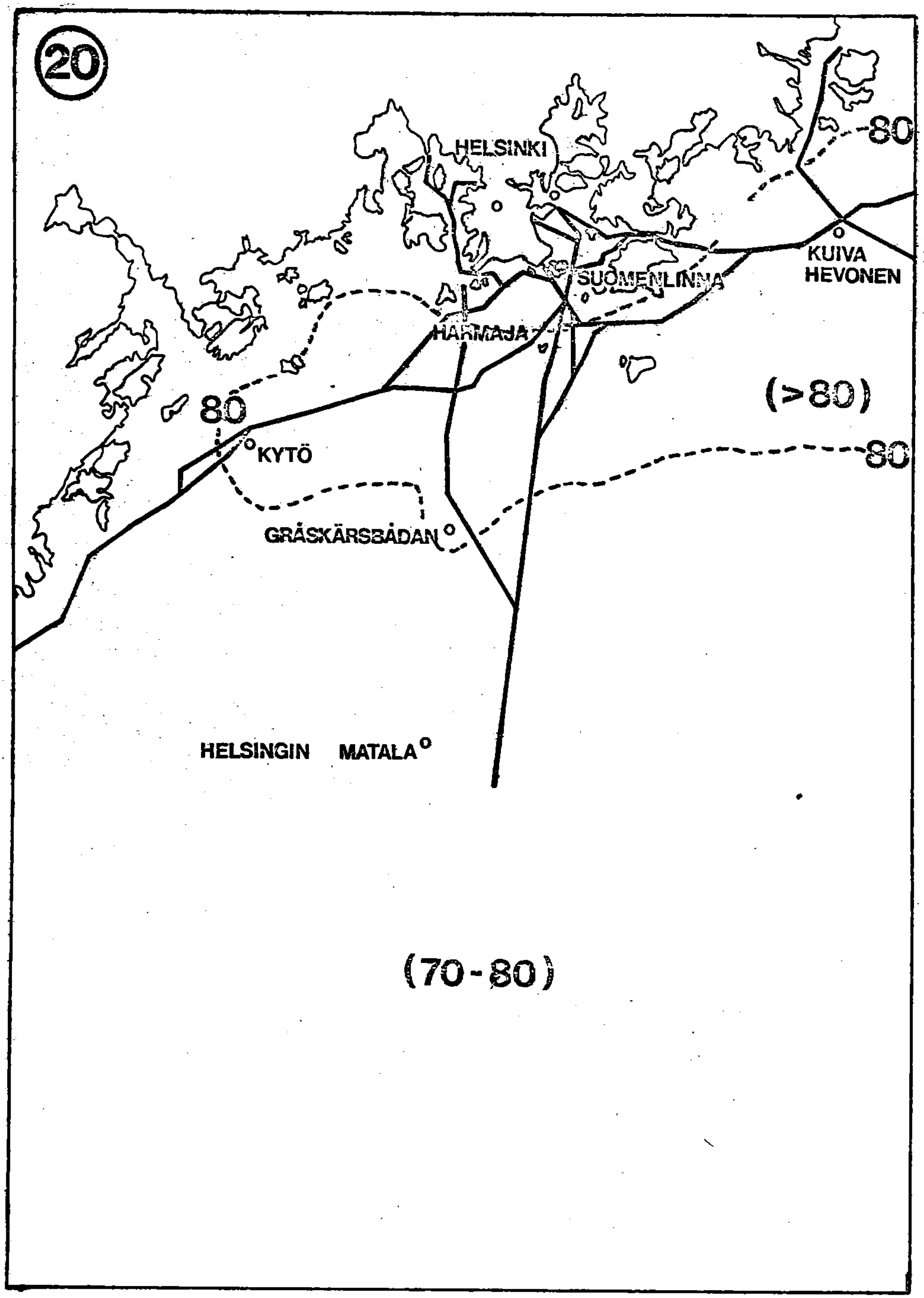
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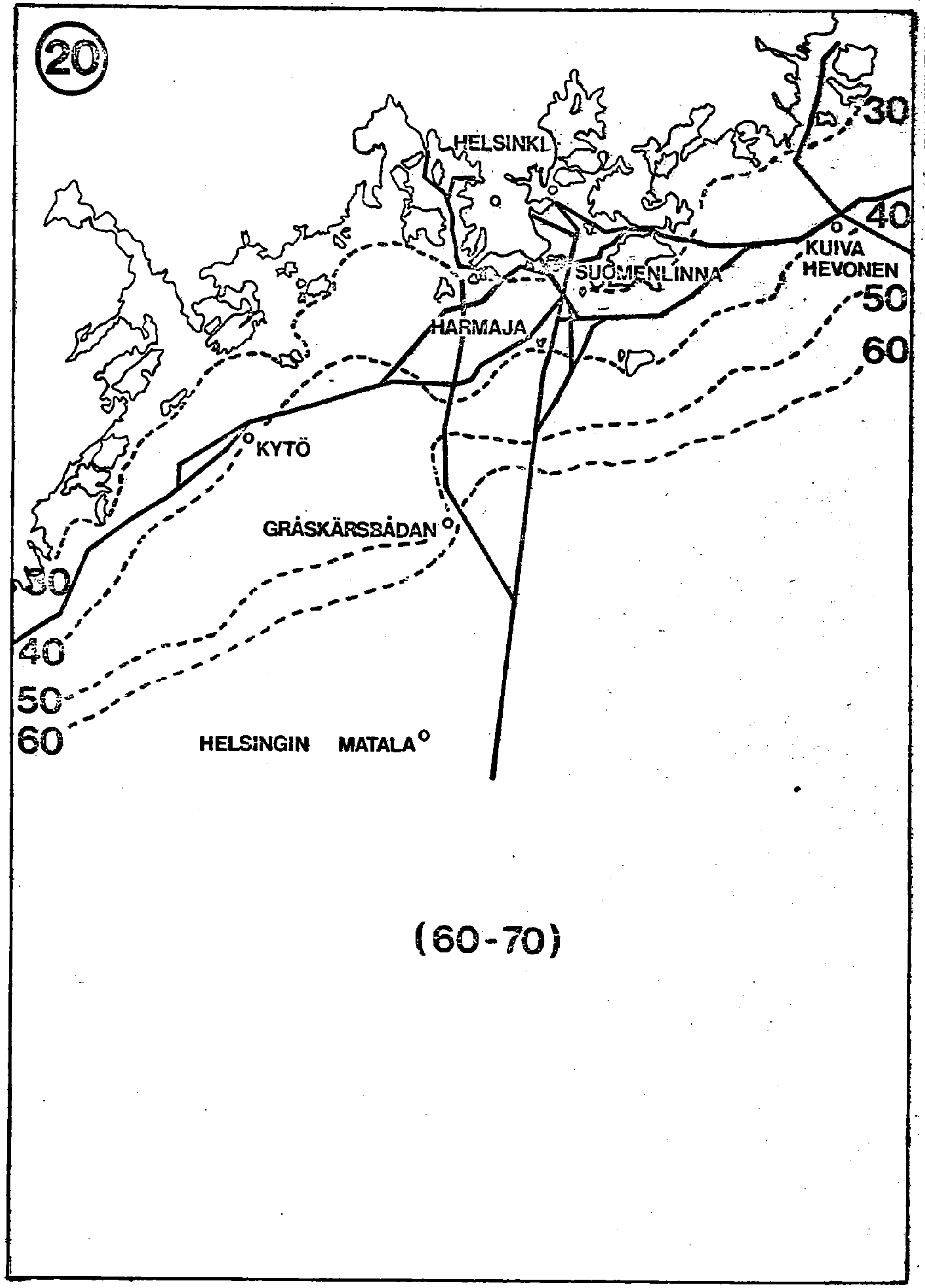
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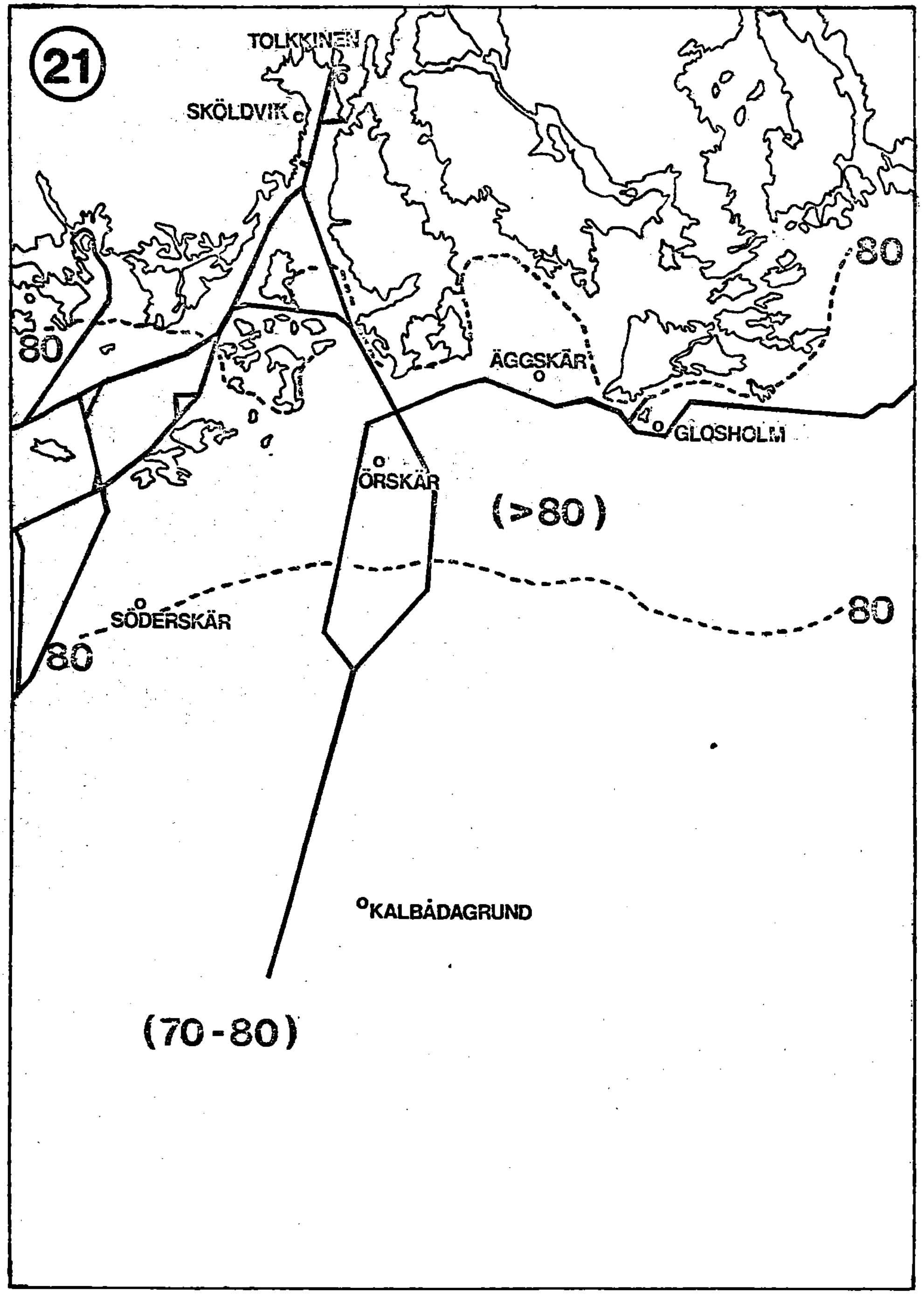
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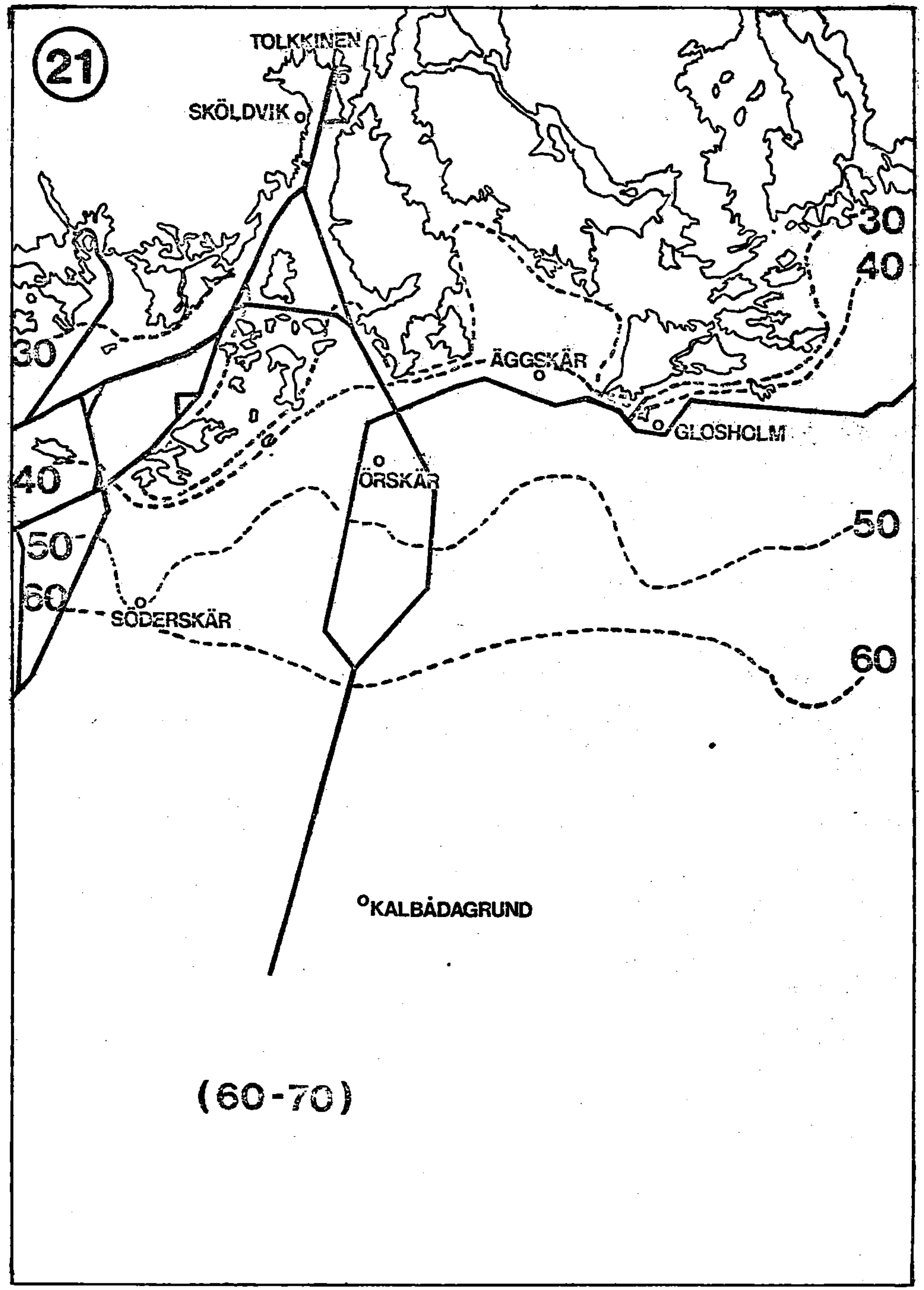
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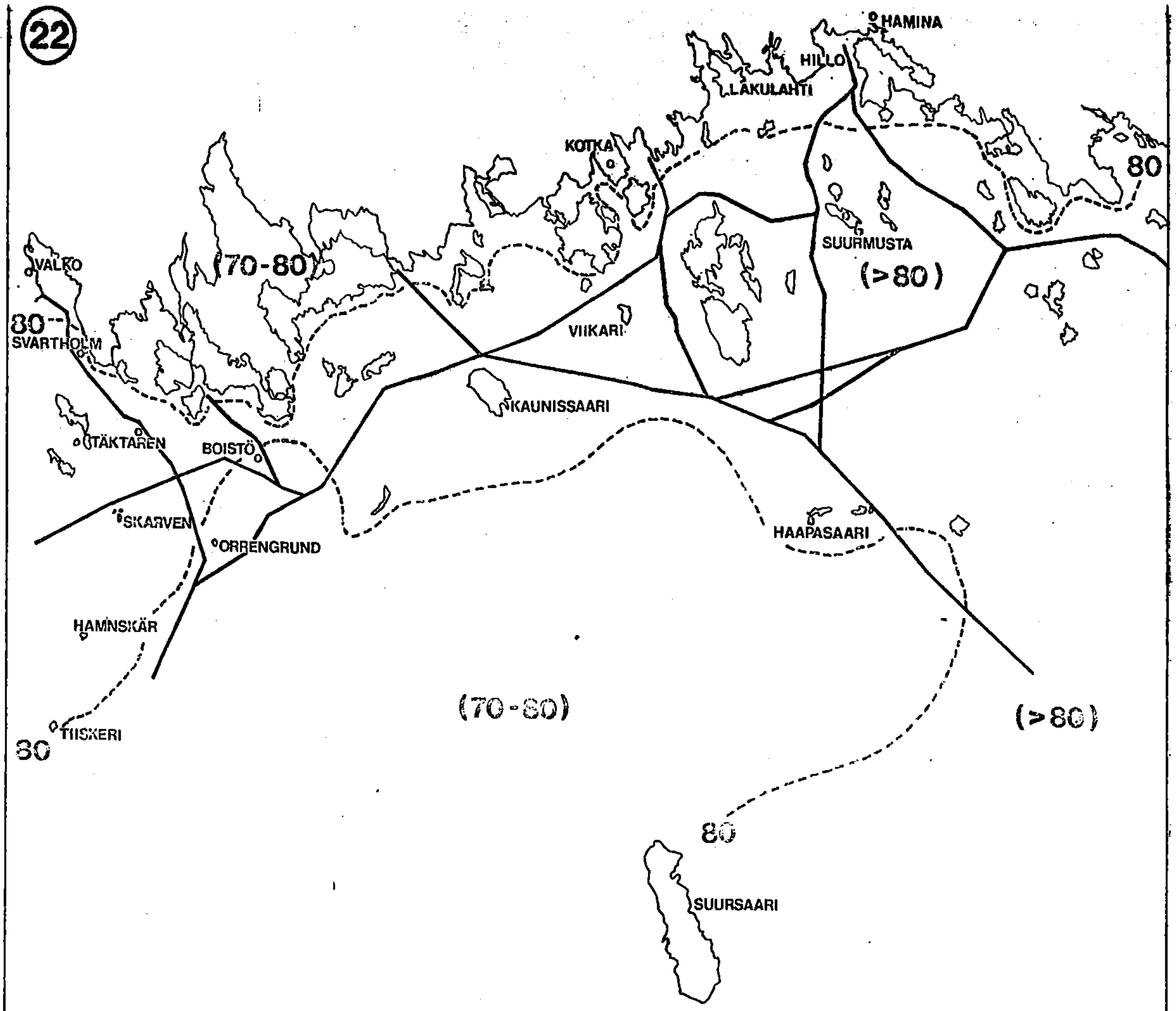
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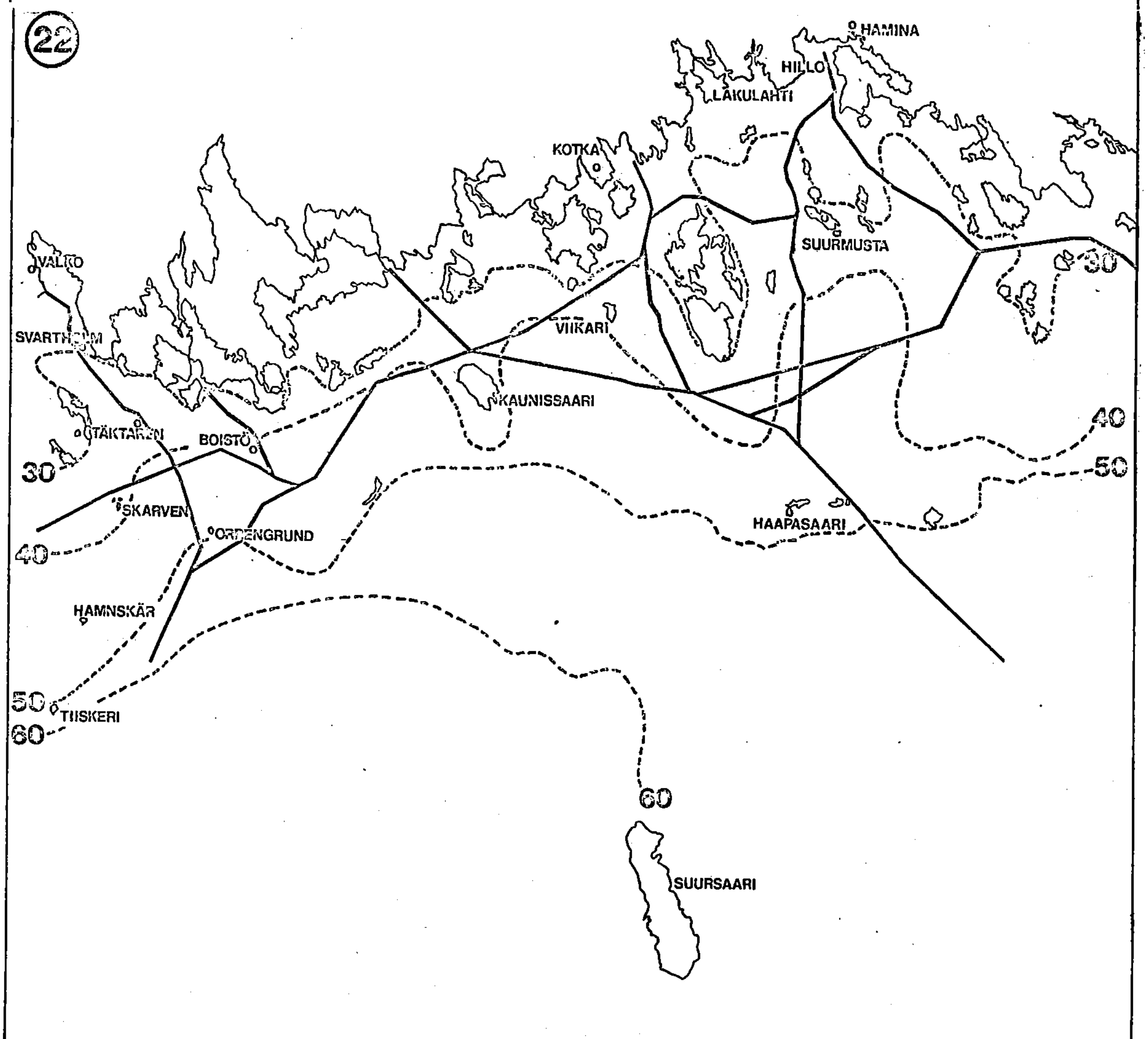
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