SPATIAL VARIABILITY OF SNOW AND ICE ON LAKES AND A STRATEGY FOR MEASUREMENT BASED ON THREE YEARS' DATA FROM ELIZABETH LAKE, LABRRADOR.

by

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PREAMBLE FOR THE 50th ANNIVERSARY OF THE WESTERN SNOW CONFERENCE

For the benefit of our hosts from the Western Snow Conference, I would point out that an important part of the "territory" of the Eastern Snow Conference is the Quebec-Labrador Peninsula on the northeast corner of mainland North America. This is a large Peninsula which is a very significant part of the continent for anyone interested in snow and ice. Among other things, it is the base of three large hydro projects, the Manicouagan, the Churchill Falls and the Baie James. The last mentioned has a potential of over 13,000 megawatts. Also, the Peninsula played a key role in the initiation and decay of the Laurentide Ice Sheet which covered most of North America. That ice sheet was, in fact, initiated in Quebec-Labrador. Our western colleagues will no doubt be interested to know that the only glaciers on mainland North America, east of the cordillera, today, are to be found in the northeastern portion of this Peninsula.

In the centre of Quebec-Labroador, on the border between the provinces of Quebec and Newfoundland, is the iron mining town of Schefferville, formerly known as Knob Lake, after the body of water beside which the town is situated. This town is the site of the McGill Subarctic Research Station which has been a focus for snow and ice research since 1954. The work has included studies of various aspects of snow hydrology, permafrost and lake ice.

Papers based on work in the Peninsula have appeared in the Proceedings of the Eastern Snow Conference for more than three decades. I refer our western colleagues to those papers and to such useful bibliographic sources as Granberg (1978). The following paper is a contribution to the study of snow and ice on lakes which has been one of the important threads of scientific activity in central Quebec-Labrador over the years.

INTRODUCTION

During the three winters 1979-81, the lake winter cover of Elizabeth Lake, Labrador (8km southwest of Schefferville, Quebec) was studied in unusual detail. This is a lake which has received considerable attention in recent years in connection with various biological-limnological studies (e.g., Chenard 1981, English 1982, Rigler 1980, Roulet 1981) and hydrological studies. In this paper, three sets of data obtained through elaborate, late-February, surveys of the snow and ice cover of the lake, are brought together. These data sets provide an unusual opportunity for generalizing about the spatial variability of snow and ice on lakes in central Quebec-Labrador and in other regions in which lake ice develops in a snowy environment.

The general principles of the initiation and evolution of spatial patterns in the winter cover of such lakes are now well established. The early work of Andrews 1962, Jones 1969, Adams and Brunger 1975 and others on Knob Lake, Quebec, and adjacent lakes, formed the basis for more sophisticated studies in other regions (e.g., Adams and Prowse 1981) and on Elizabeth Lake (e.g., Adams and Roulet 1980 and Roulet 1981). An importnat feature of the recent work has been the development of a practicable procedure for obtaining large random samples of conditions across the lake to provide a sound basis for generalizations about spatial patterns in its winter cover.

With various qualifying assumptions (Adams 1981), the evolution of spatial patterns in a winter lake cover can be envisaged as follows.

When a lake first freezes over completely in the early winter, the ice sheet tends to be thicker around the lake margins and thinner towards its centre. Snow falling on this

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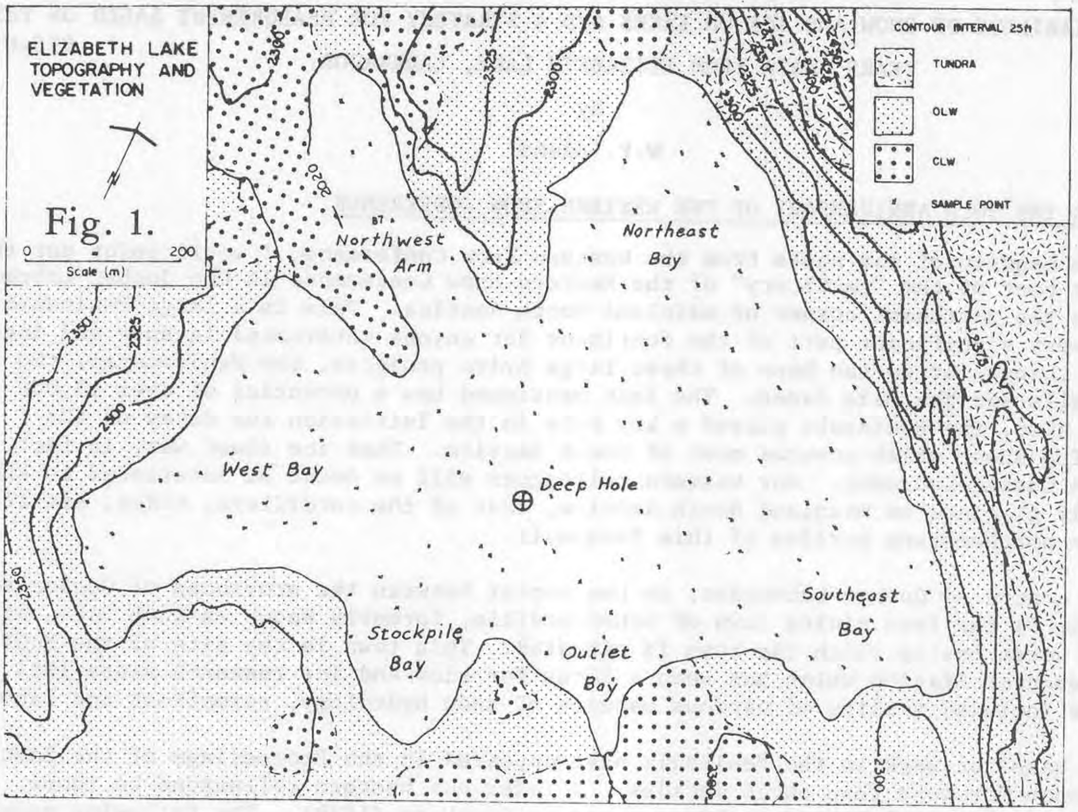


Fig. 1.

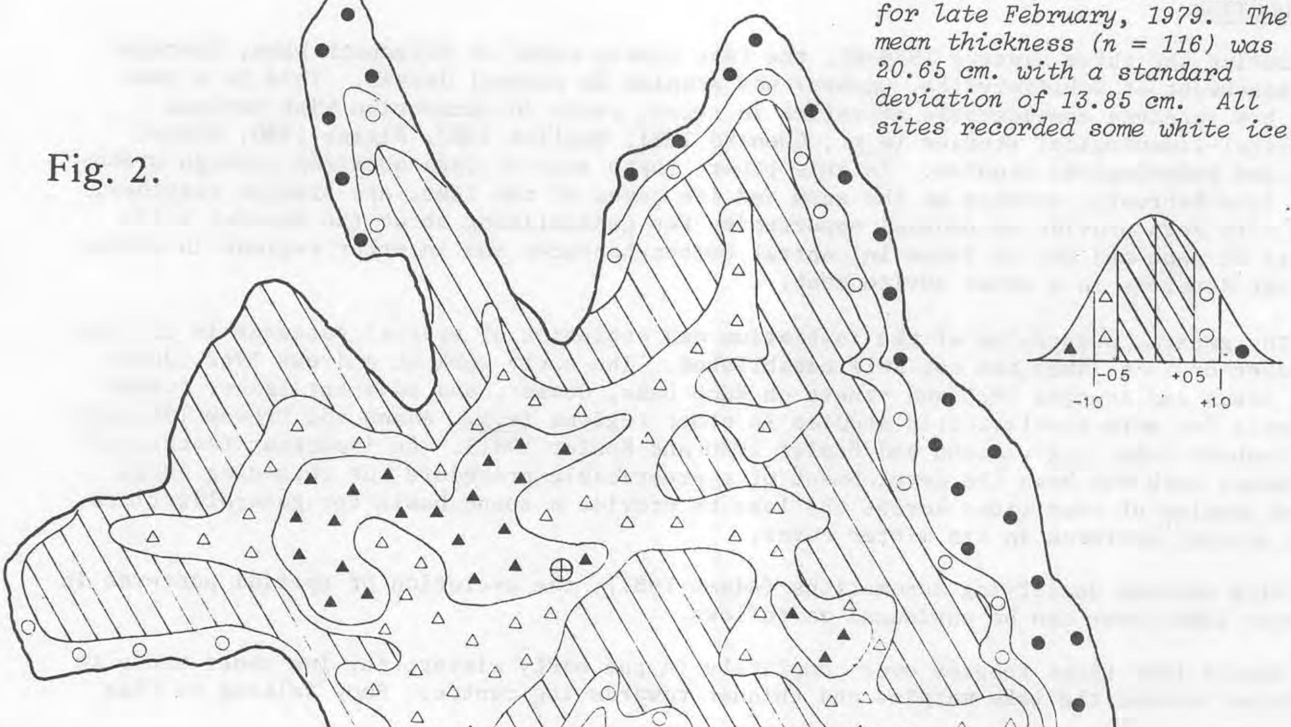


Fig. 2.

Spatial pattern of white ice thickness of Elizabeth Lake for late February, 1979. The mean thickness (n = 116) was 20.65 cm. with a standard deviation of 13.85 cm. All sites recorded some white ice.

sheet tends to be quickly redistributed so that margins and downwind portions of the lake develop a substantially thicker cover of it and the central area, notably the zone upwind of lake centre a thinner cover. The differential insulating effect of this uneven snow cover results in more rapid ice growth in the relatively exposed central area which eventually reverses the spatial pattern of ice thicknesses developed at freeze-up. The insulated marginal and downwind zones become areas of relatively thin ice.

However, the load of snow depresses the ice sheet, the areas with deepest snow (and, therefore, as ice growth proceeds, with thinner ice) being depressed most. If cracking occurs while all or part of the ice sheet is depressed below the hydrostatic water level of the lake, the base of the overlying snow is flooded. The slush so formed freezes to produce a layer of new ice, "white ice," on top of the original "black ice" sheet. The white ice, like the snow from which it was formed, tends to be thicker at marginal and downwind locations. Immediately after a widespread slushing-white ice event, the snow cover of the lake can be envisaged as being relatively uniform in depth as the slushing will have had the effect of reducing snow depth at deep snow locations. Also, after a phase of white ice formation, the distribution of total ice thickness over the lake can be conceived as being relatively uniform as the new white ice has the effect of increasing thickness as sites where black ice was relatively thin.

Once the white ice phase is complete however, redistribution of new and old snow continues so that a margin→centre, downwind→upwind, (deeper→shallower) pattern of snow depth develops again. This can be envisaged as having the same effect as before, differentially insulating and depressing the ice sheet so that a further slushing-white ice phase may be initiated. Several of these phases may occur during a winter although, of course, larger amounts of snow become necessary to depress the thickening ice sheet.

In this scenario, towards the end of the winter, the snow and ice cover of a lake can be expected to exhibit the broad spatial patterns indicated in Table 1.

Table 1

Late Winter Trends Expected in the Snow and Ice Cover of a Lake (See Text)

	Centre→Margins	Upwind→Downwind	Notes
Black Ice	thicker→thinner	thicker→thinner	
White Ice	thinner→thicker	thinner→thicker	
Total Ice	<u>relatively</u> even distribution	<u>relatively</u> even distribution	patterns will tend to be dominated by the thicker of white ice or black ice.
Snowcover	probably thinner→thicker	probably thinner→thicker	this will depend on the extent of redistribution of snow since the last slushing event.

It has been shown (Adams and Prowse 1981, Figure 11) that the trends of black ice and white ice are established early and become more pronounced as the winter proceeds. The spatial variability of the snow cover <u>does</u> tend to fluctuate. As a rule, except during the decay of the winter cover, the spatial variability of white ice is the greatest, that of total ice least. It is worthy of note here that spatial variability of the white ice can be viewed as being produced by the persistent tendency of snow to accumulate in certain patterns during winter, promoting slushing. The distribution of black ice can be viewed as a response to the insulating effect of these persistent patterns. The snow

Table 2

Elizabeth Lake Winter Cover Statistics 1979-81

(All values in cm except coefficient of variation)

		23-25 Feb.1979	20-21 Feb.1980	1981	Two or three-year value*
Snow Depth	Mean	26.88	19.50	34.74	26.68
	Std.Deviation	9.07	10.80	17.29	8.29
	Coeff.of Var.(%)	33.75	55.38	49.77	31.10
	Maximum	65.00	53.00	91.50	57.00
	Minimum	2.50	0.50	13.00	14.00
	Range	62.50	52.50	78.50	43.00
	n	126	112	115	98
White Ice Depth	Mean	20.65	19.63	25.50	21.18
	Std.Deviation	13.82	19.93	18.08	13.52
	Coeff.of Var.(%)	66.94	101.53	70.90	63.80
	Maximum	67.00	83.00	92.00	72.50
	Minimum	0.00	0.00	0.00	5.00
	Range	67.00	83.00	24.00	67.50
	n	116	110	121	97
Black Ice Depth	Mean	73.66		68.42	72.82
	Std.Deviation	17.82		24.34	16.74
	Coeff.of Var.(%)	24.18		35.57	22.99
	Std.Error	3.11		2.22	
	Maximum	103.50		118.00	110.00
	Minimum	40.00		0.00	21.00
	Range	63.5		118.00	89.00
	n	126		121	109
Total Ice Depth	Mean	94.23		96.89	95.56
	Std.Deviation	12.89			9.79
	Coeff.of Var.(%)	13.68			10.25
	Maximum	118.00		155.50	117.00
	Minimum	66.00		76.50	76.00
	Range	52.00		79.00	41.00
	n	126		122	109

* Calculation based on average of 1979 + 1981 or 1979 + 1980 + 1981 (see text). The n values are lowest in this column because the omission of a site in any of the years results in an omission here.

Table 3

Selected Climatological Data for the Three Survey Winters with Respect to Longterm Means

		October				November				December			
		(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Temp(°C)	Mean	-3.1	-2.2	-1.7	-1.5	-12.3	-9.4	-10.5	-9.9	-17.7	-17.0	-23.7	-19.0
	Max.	14.2	0.5	6.0	2.4	3.1	-5.4	1.5	-4.7	-1.0	-13.3	-7.7	-11.3
	Min.	-17.0	-4.9	-9.4	-6.6	-27.5	-13.7	-30.6	-30.3	-33.1	-20.6	-36.4	-27.3
Precip(mm)	Rain	12.0	90.7	51.6	30.9	6.2	16.2	2.3	5.2	0.2	0.0	0.0	1.1
	Snow	74.1	57.4	74.2	63.1	63.1	39.5	85.1	68.7	51.7	24.3	58.3	52.6
	Total	86.1	148.1	125.8	94.0	63.3	55.7	87.4	73.9	51.9	24.3	58.3	53.7

		January				February			
		(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Temp(°C)	Mean	-19.7	-18.8	-21.8	-22.3	-23.9	-21.2	-12.3	-21.0
	Max.	1.2	-13.9	-3.5	-15.9	-1.0	-16.1	5.1	-10.4
	Min.	-40.9	-23.6	-36.0	-30.1	-39.6	-26.2	-33.4	-26.1
Precip(mm)	Rain	1.8	0.0	0.0	0.2	0.1	0.0	1.2	0.2
	Snow	60.6	70.9	84.1	57.4	61.6	35.4	50.9	51.9
	Total	62.4	70.9	84.1	57.6	61.7	35.4	53.1	51.9

(1) = 1978 - 1979

(2) = 1979 - 1980

(3) = 1980 - 1981

(4) = 25 year means (1953-1978) for temperature, 10 year mean for precipitation (1971-1980)

present on a lake at any particular time, for example that envisaged in Table 1, represents total snow received by the lake since freeze-up minus snow incorporated into the white ice and minus snow deflated from the lake. At any particular time, snow present on the lake, as snow, may represent only a small proportion of the total snow received since freeze-up.

This spatial variability of the ice and snow components of the lake cover, throughout the winter, has important implications from various points of view. For example, in terms of trafficability, the variability of snow depth and of the two main components of the ice sheet, which have markedly different strength properties, combine to produce a wide variety of travel conditions. Similarly the different properties of snow, white ice and black ice with respect to light (see Roulet 1981) means that the light regime, upon which photosynthesis in the lake depends, is very different in different parts of a lake. Also, in terms of the atmospheric loading of a lake, the inputs of precipitation landing on the lake, with its constituent nutrients and pollutants, the wide variety of combinations of snow, white ice (which includes precipitation) and black ice (which does not include precipitation) across a lake need to be known before accurate loading assessments can be made.

Each of these examples presents a sampling problem. Most regular lake ice surveys involve measurements at a single site or perhaps at a few sites on a lake. The same is true for most winter limnological studies. The sampling problem can be solved through the use of a large number of sampling sites, as was the case in the surveys discussed here, but this is generally not a practicable solution.

How can measurements at one or a few sites be placed in a lake-wide perspective given the diversity of the cover? Is it possible to select one or a few sites which will provide average values for the various lake cover components or which will encompass the range of conditions present on a lake? The fact that systematic trends have been demonstrated in the winter cover of lakes suggests that it should, in principle, be possible to generalize about lake-wide conditions from measurements made at a few sites.

This paper addresses the questions posed in the last paragraph with respect to the late winter snow and ice cover of Elizabeth Lake, Labrador, with a view to developing practical, effective, sampling procedures for snow and ice on lakes in general.

STUDY LOCATION AND METHODS

Elizabeth Lake (54°46'N, 56°54'W, 616m a.s.l.) has an area of 11.08ha a mean/maximum depth of 8.7m/27.1m and a volume of 2.45 x 10^6m^3 (Bryan 1966). The nature of its surrounding topography and vegetation is apparent from Figure 1. The region of Quebec-Labrador within which the lake is situated receives an average of 36cm w.e. of snow per winter. Its lakes typically develop 110cm of ice, including 45cm of white ice. Peak ice thickness is achieved in late April (Adams and Shaw 1966).

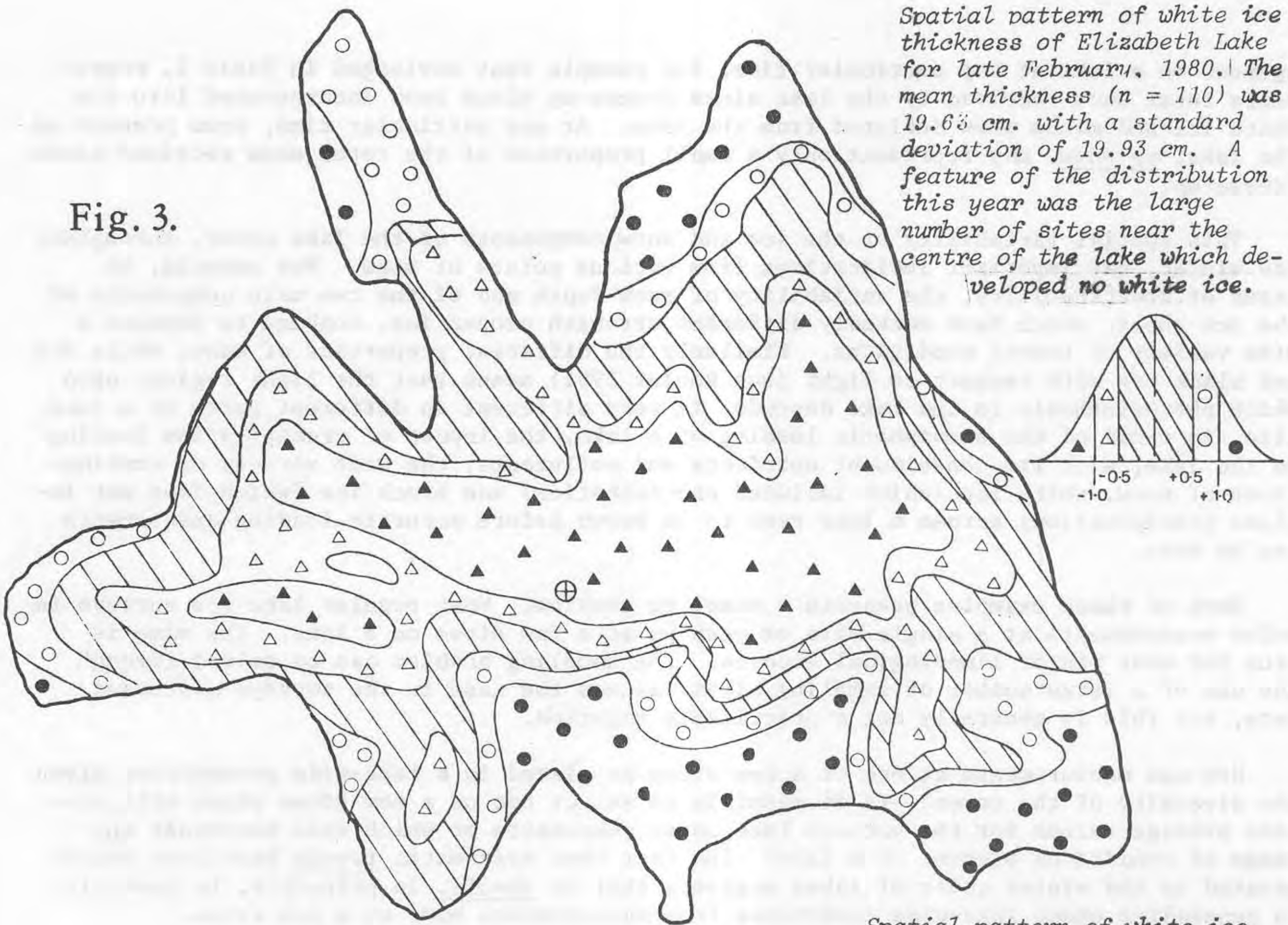
The snow and ice cover of the lake was surveyed, using the random sample shown in Figure 1, in late February of 1979, 1980, and 1981. In the first and last of these years the depths of snow, white ice, black ice and total ice were measured, in 1980 only snow and white ice depth was obtained. The procedures used for field measurement, calculating sample size, allocating sample points across the lake and locating sites in the field are described in Adams and Roulet 1981. A maximum of 126 sites (11.1/ha) were used, less for some cover components in some years because of errors in the field (see n values in Table 2).

Data were processed using the S.P.S.S. (Statistical Programs for the Social Sciences) and SYMAP computer packages. The latter provides isopleth and trend surface maps (see Roulet 1980). The summary maps which are the focus of this paper were drawn by hand.

RESULTS

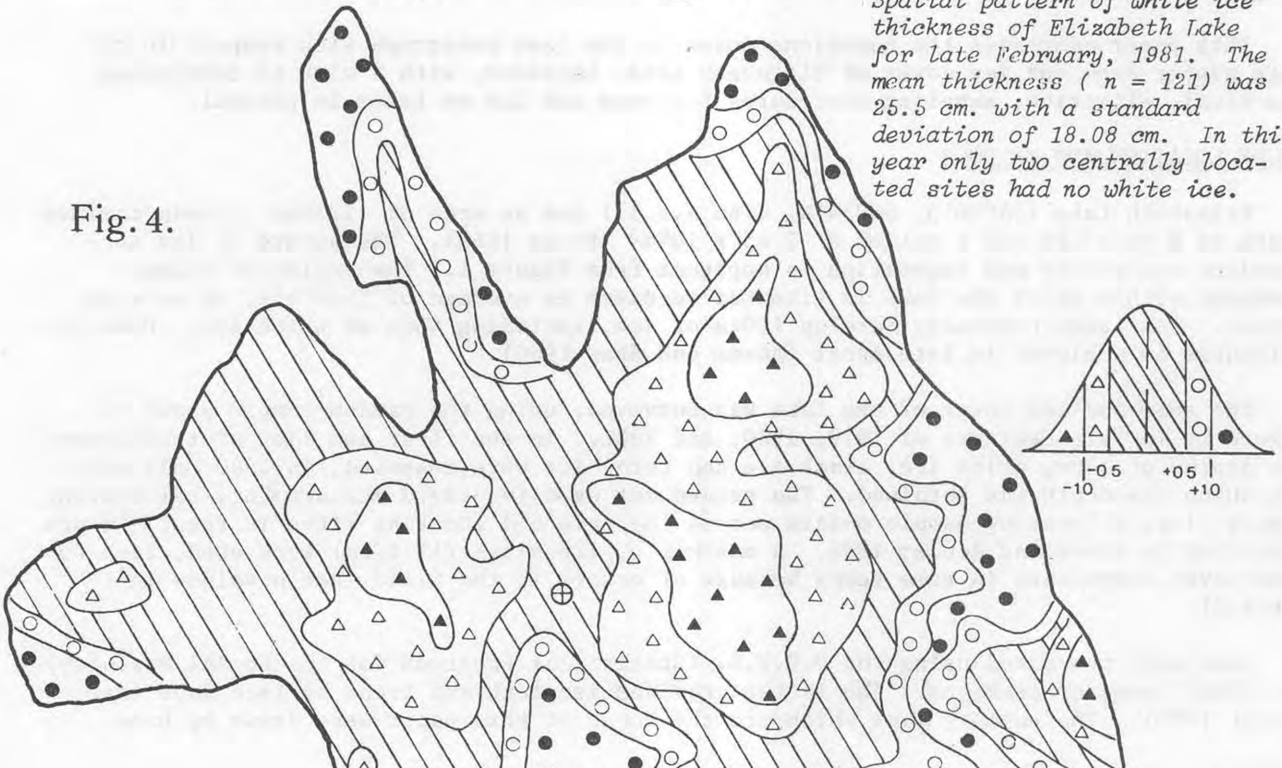
The overall statistical results of the three surveys are presented in Table 2. Although it is not possible to fully account for differences between the winter covers of

Fig. 3.



Spatial pattern of white ice thickness of Elizabeth Lake for late February, 1980. The mean thickness (n = 110) was 19.63 cm. with a standard deviation of 19.93 cm. A feature of the distribution this year was the large number of sites near the centre of the lake which developed no white ice.

Fig. 4.



Spatial pattern of white ice thickness of Elizabeth Lake for late February, 1981. The mean thickness (n = 121) was 25.5 cm. with a standard deviation of 18.08 cm. In this year only two centrally located sites had no white ice.

individual lakes within the same region (see Roulet 1981, Russell 1980), it would appear that the values in the Table are comfortably within the range of lake ice and snow conditions which would be expected at this time of year in central Quebec-Labrador (see, for example, Adams and Shaw 1966). The survey dates were approximately 7 weeks prior to peak ice. The winters concerned were not exceptional (Table 3).

There was not a great deal of difference between mean cover values for the three years (Table 2). Mean snow depth varied the most between years, total ice the least. In terms of the distributions present on the lake at the time of the surveys, white ice showed the greatest relative variability, it consistently had the highest coefficient of variation, with total ice, again, having the lowest.

The statistics in Table 2 represent the spatial patterns and trends discussed in the introduction. These are shown using normal interpolation maps and trend surface maps, for 1979 and 1980, in Adams and Roulet 1980 and Roulet 1981, respectively. The principal features of the spatial patterns concerned are summarized in Table 4.

For the purpose of general discussion of the way in which snow and ice depths vary across any lake and for the purposes of inter-year comparisons, it is interesting to portray such spatial distributions in terms of standard deviations from the mean rather than in terms of actual values or trends based on actual values. It will be recalled that for a normal frequency distribution, 34.14% of value should lie within plus or minus one-half of a standard deviation of the mean and 68.27% within plus or minus one standard deviation of the mean and 95.45% within plus or minus two standard deviations of the mean.

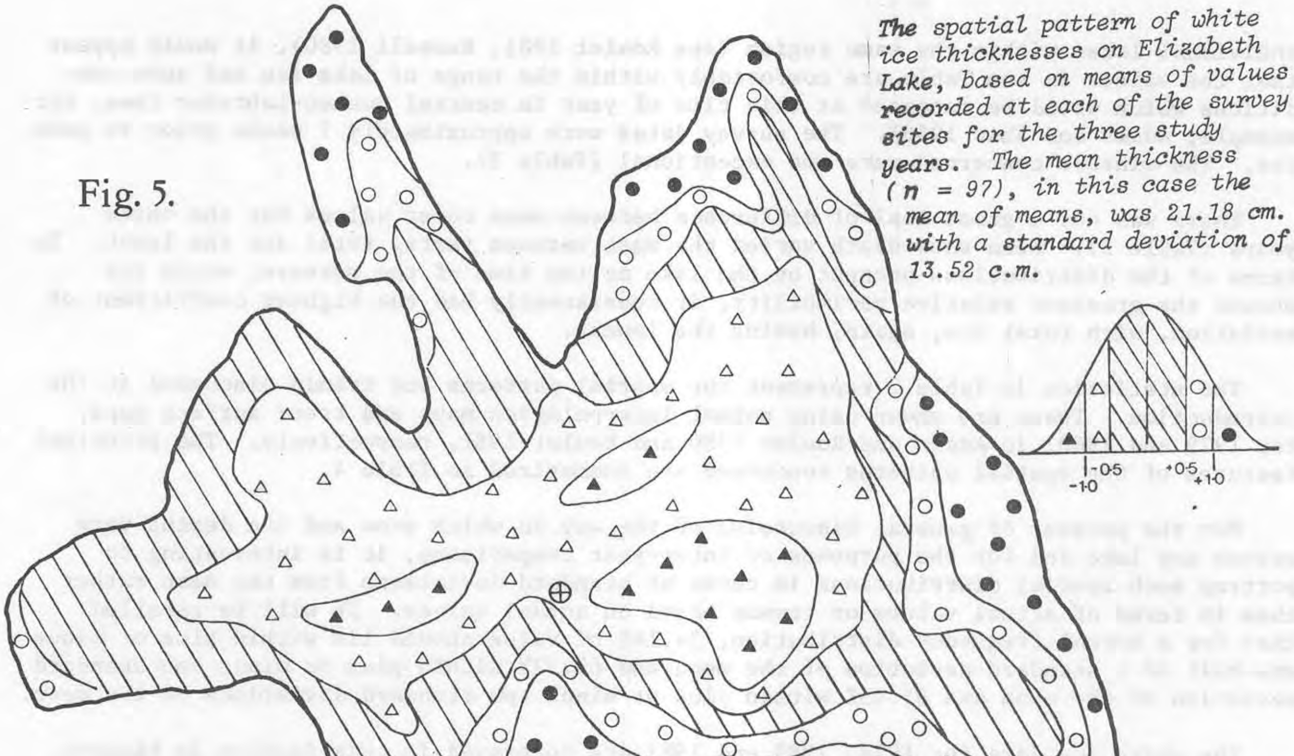
The white ice data for 1979, 1980 and 1981 are portrayed in this fashion in Figures 2, 3 and 4. The broad similarities between years are immediately apparent, the generally below average central zone, the generally above average margins, tendency for the downwind, eastern and southern, shorelines to be zones of thicker white ice. The mean white ice values for each of these years were quite similar (Table 2) but the 1980 cover had a much higher coefficient of variation. This last shows up in Figure 3 through the larger areas with values more than one standard deviation from the mean. With some exceptions, notably part of the shoreline of West Bay and Stockpile Bay, the zone of values within half a standard deviation of the mean forms a band around the centre, away from the shoreline.

An interesting synthesis of the three distributions of white ice can be obtained by calculating three year means for the values of each sample point, then producing a map showing deviations from the three year lake-wide mean (Figure 5). It should be noted that this procedure results in a loss of data points (as the absence of data for any single year requires the elimination of the point concerned) and a reduction in the range of values of which the three year spatial mean is a measure of central tendency (Table 2). It is notable, for example, that no site shows zero white ice in the three year case although many sites were without white ice in individual years. Insofar as three years of data can be assumed to approach the "climatic" norm for this region, this suggests that some white ice is normal all over Elizabeth Lake. Years and sites without white ice are the exception.

In Figure 5, the broad trends outlined in the introduction and portrayed, for example, in Adams and Roulet 1980, are confirmed. The margin→centre, downwind→upwind (that is approximately South East → North West) pattern of decreasing thickness is clearly apparent. In terms of the persistent redistribution of snow which was suggested as the control of white ice distribution in the introduction, the pattern here can be viewed with respect to snow accumulating in Southeast Bay under the influence of prevailing NW/WNW winds and being removed from the exposed upwind and central lake areas. Lee effects at the heads of West and Northeast Bays and in Northwest Arm account for drifting with resultant white ice growth there.

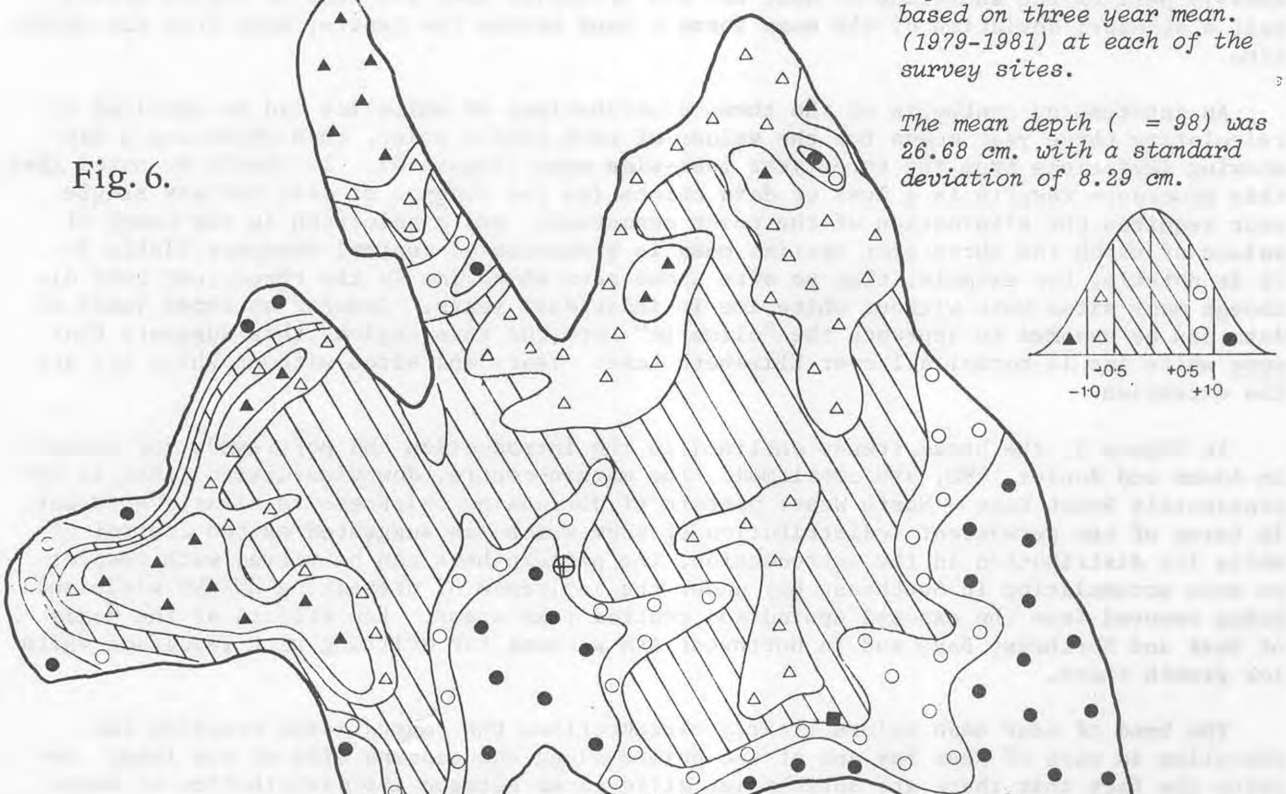
The band of near mean values clearly circumscribes the central area reaching the shoreline in part of West Bay and at two points along the eastern side of the lake. Despite the fact that there are substantial differences between the distribution of white ice as portrayed in Figure 5 and the equivalent map of snow present on the lake in late

Fig. 5.



The spatial pattern of white ice thicknesses on Elizabeth Lake, based on means of values recorded at each of the survey sites for the three study years. The mean thickness (n = 97), in this case the mean of means, was 21.18 cm. with a standard deviation of 13.52 c.m.

Fig. 6.



The spatial pattern of snow depth on Elizabeth Lake, based on three year mean. (1979-1981) at each of the survey sites.

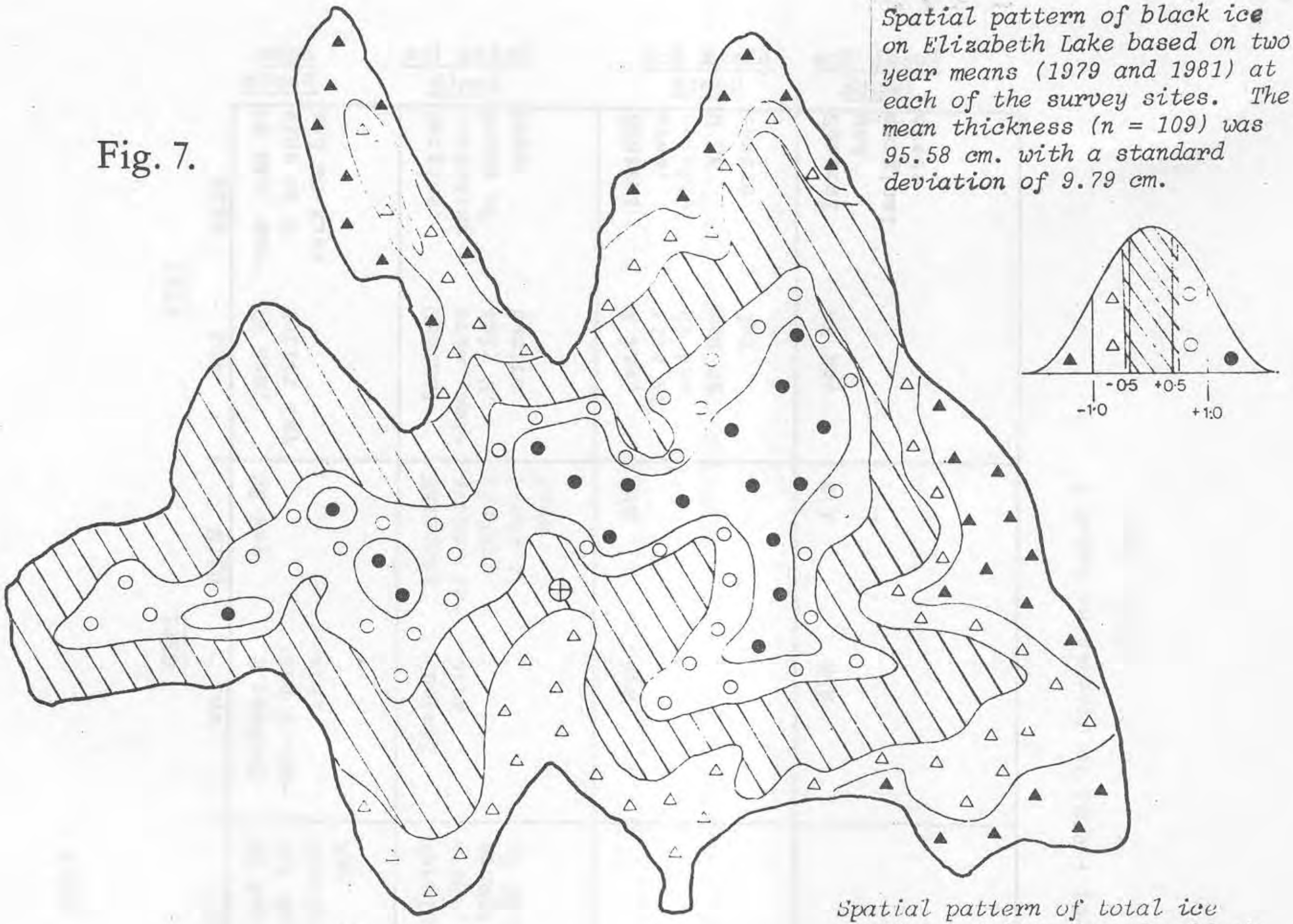
The mean depth (=98) was 26.68 cm. with a standard deviation of 8.29 cm.

Table 4

	1979		1980		1981		2 or 3 Year Pattern*		Notes
	High	Low	High	Low	High	Low	High	Low	
Snow Depth	SE Bay, margins of W and NE Bays	NW Arm, Outlet Bay	SE Bay	N.central and S.central	SE Bay, Outlet Bay, Stockpile Bay	Central area notably W. of centre	SE Bay, S. Shore, margin of W. Bay	NE Bay, tip NW arm, W. Bay	
White Ice Depth	Margins, including heads of bays	Central area, notably W. centre	Marginal areas, including heads of bays	Central area	Marginal areas, except side of SE Bay	Central area, plus E. side of SE Bay	Marginal areas, including heads of bays	Central area	Marked centre-margin pattern
Black Ice Depth	Central area, notably W of centre	W Bay, tips of NW Arm and NE Bay	N/A	N/A			Central area, notably E of centre	Marginal areas, except W Bay	Marked centre-margin pattern
Total Ice Depth	Central and marginal areas	NE Bay	N/A	N/A			W Bay, strip E of centre	NE Arm, NW Bay	The most broken pattern

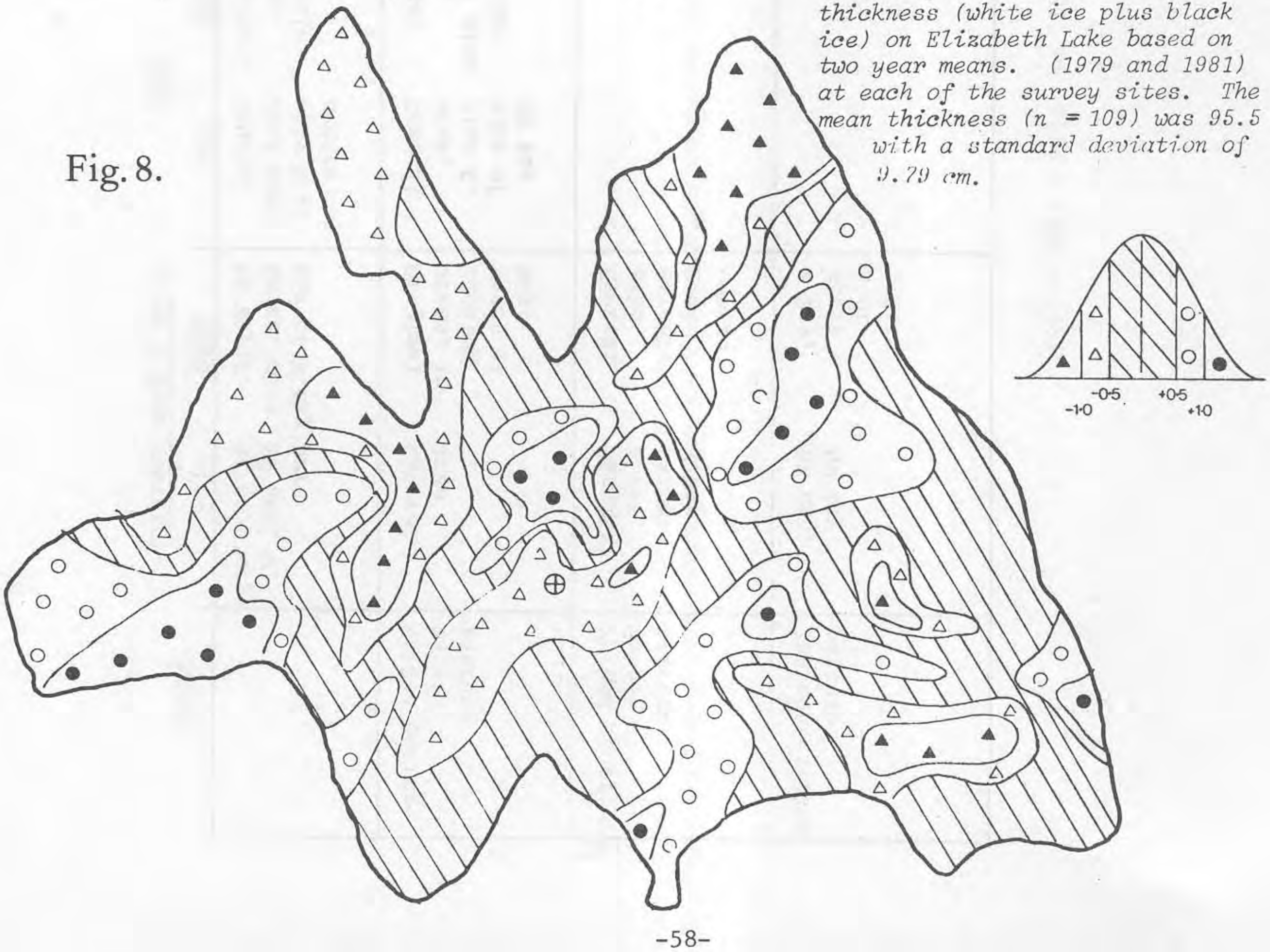
* Based on average of 1979 + 1981 or 1979 + 1980 + 1981 (see text).

Fig. 7.



Spatial pattern of black ice on Elizabeth Lake based on two year means (1979 and 1981) at each of the survey sites. The mean thickness (n = 109) was 95.58 cm. with a standard deviation of 9.79 cm.

Fig. 8.



Spatial pattern of total ice thickness (white ice plus black ice) on Elizabeth Lake based on two year means. (1979 and 1981) at each of the survey sites. The mean thickness (n = 109) was 95.5 with a standard deviation of 9.79 cm.

February (Figure 6), it can be argued that the white ice pattern provides the best basis for deciding where mean snow depths could be found throughout the winter. In fact, in broad terms, the two distributions are not dissimilar despite the fact that Figure 6 is an attempted synthesis of three quite varied, rather ephemeral, spatial patterns.

The three year pattern for black ice (Figure 7) forms an interesting reversal of the pattern of white ice in Figure 5 with thinner ice around the margins and downwind. This illustrates the point that these two types of ice tend to be compensatory. Again, the zone of near mean values is found to encircle the central area of the lake, reaching the margins in West Bay and along the eastern shore.

The three year total ice thickness map (Figure 8) does not contain similar, easily described, lake-wide patterns. The range of values shown is very much less than in the preceding maps - a coefficient of variation of only 10% - reflecting the compensatory nature of white ice and black ice growth. This is a much more bland distribution. In this case a full range of thickness values can be found at both marginal and central sites.

DISCUSSION

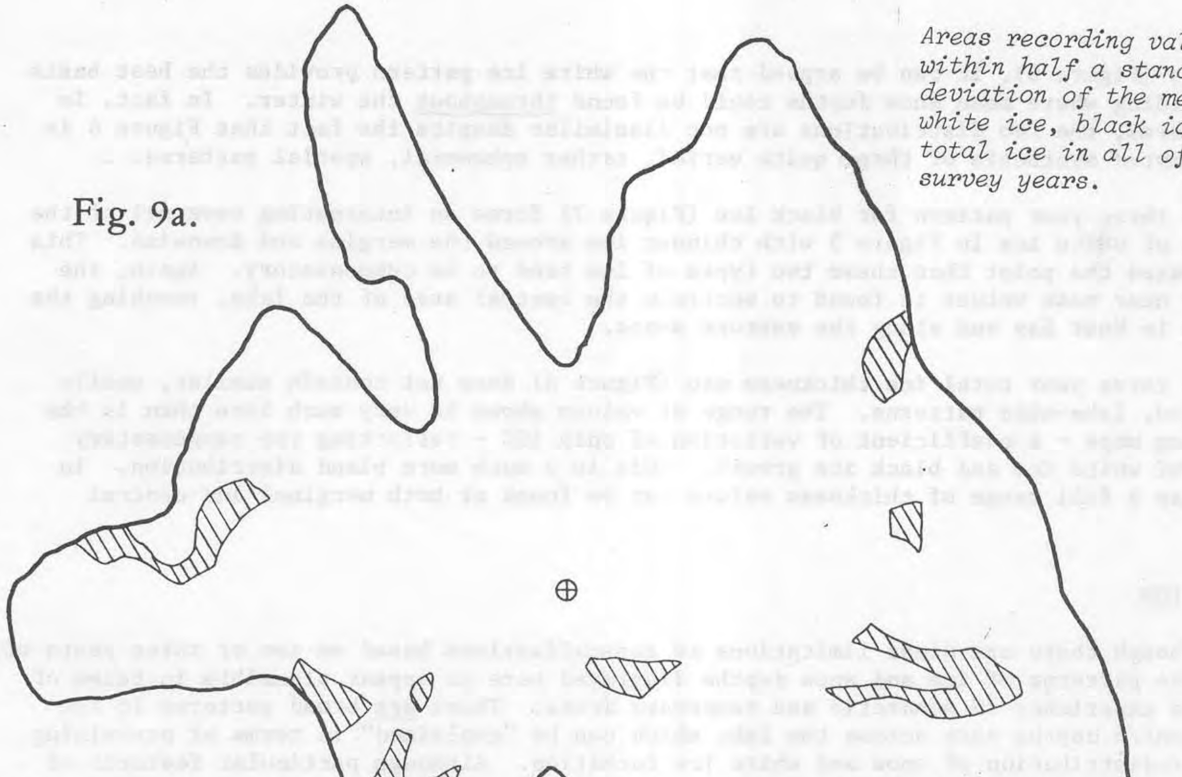
Although there are clear limitations to generalizations based on two or three years of data, the patterns of ice and snow depths displayed here to appear plausible in terms of previous experience in subarctic and temperate areas. There are broad patterns in the way in which depths vary across the lake which can be "explained" in terms of prevailing winds, redistribution of snow and white ice formation. Although particular features of the environment of Elizabeth Lake, such as the location and nature of its bays, its surrounding topography and vegetation, complicate the pattern in detail, the broad trends are clear. There is a substantial central zone which has above average thickness black ice and below average thickness white ice and snow, there is a marginal zone of thin black ice and above average white ice and snow. The marginal zone tends to be more complex than the central one. Between these two zones, reaching the margins in only one or two cases, is a zone of near mean white ice and black ice values.

The three ice distributions shown here, as distinct from the distribution of snow at the time of the surveys, can, on the basis of previous studies, be assumed to represent a culmination of the evolution of distinct patterns established early in the ice season. In this light the patterns shown give an indication of the relative variability which can be expected across the lake for a considerable portion of the winter. One example of the significance of this is the implications of the white ice pattern shown (Figure 5) at the "deep hole" of this particular lake (see Figure 1). On this lake the deep hole, which is commonly used by limnologists as the sole site for routine sampling programs, is located close to the centre of the lake in a zone of consistently low white ice. As white ice and the snow which it "represents," are effective barriers to light (in contrast to black ice which is effectively transparent), the deep hole here appears to receive consistently more light than most of the lake. Indeed, Roulet (1981) calculated that sites near the centre of Elizabeth Lake received, in the 1979-1980 winter, several hundred per cent more light than the margins. Chenard (1980) draws attention to this same point with respect to studies of lake oxygen.

Overlaying Figures 5, 7 and 8 to determine areas which were consistently near average in terms of all three ice components of the cover, produces the pattern shown in Figure 9. The sites shown here are those at which, in the three years in question, values within half a standard deviation of the mean could be expected for white ice, black ice and total ice. Inclusion of the depth of snow at the time of the surveys from Figure 6, reduces the possibilities even further (Figure 9).

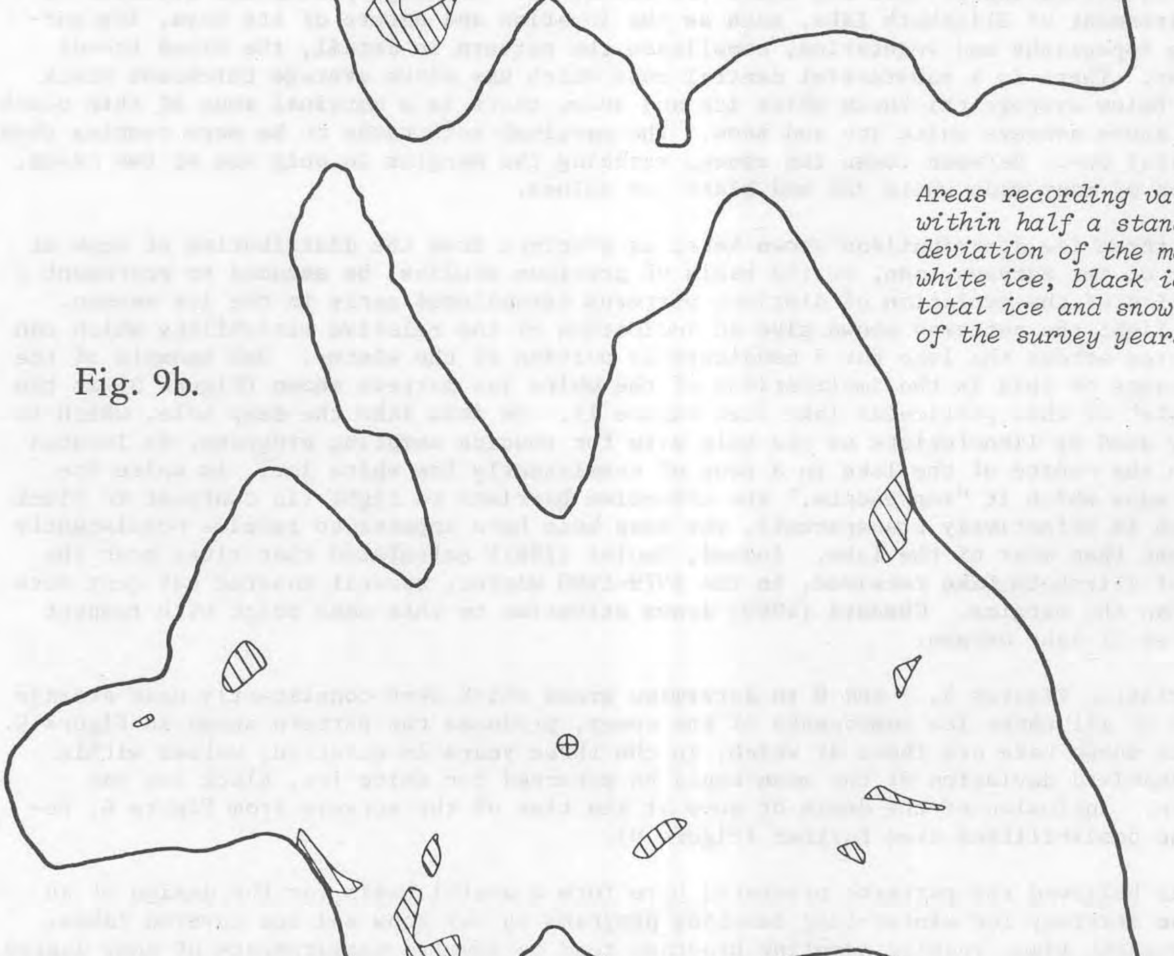
It is believed the patterns presented here form a useful basis for the design of an effective strategy for winter-long sampling programs on any snow and ice covered lakes. At the present time, routine sampling programs tend to involve measurements of snow depths and total ice thickness at a single site chosen for convenience or because it happens to coincide with the deep hole of a lake. There is no need here to reinforce the point that the differentiation of the black ice and white ice components of total ice greatly

Fig. 9a.



Areas recording values within half a standard deviation of the mean for white ice, black ice and total ice in all of the survey years.

Fig. 9b.



Areas recording values within half a standard deviation of the mean for white ice, black ice and total ice and snow in all of the survey years.

enriches the observation concerned from the point of view of many ice data users (Adams 1977).

The criteria for selection of one or a few sampling sites for a routine ice survey program will naturally vary with the objectives of the work. For example, the operation of a winter road across a lake requires knowledge of snow, white ice and black ice. On the other hand the thickness of black ice is largely irrelevant for the study of the light regine of a lake.

Where mean values of all components are desired, rules of thumb for site selection can be developed on the basis of Figure 9. Sites should be selected away from the lake margin (beyond, for example, the influence of shoreline snowdrifting which can be quickly determined by a depth survey) and yet well clear of the centre of the lake. This general conclusion has been reached by others using different arguments (e.g., Adams and Brunger 1975, Adams and Prowse 1981). As upwind→downwind patterns are a feature of spatial patterns in winter cover, it has been suggested (Adams 1977) that it is often useful to make the above selection of sites along a line across the centre of the lake perpendicular to prevailing winds.

In many cases, surveys of the winter cover of lakes seek extreme rather than mean values. Given presumed mean values, a knowledge of the range of conditions which those means represent is difficult as published values of coefficients of variation for the various components show that the relative variability tends to vary. Knowledge of the range of conditions across a lake is most easily obtained, on a routine basis, by means of transects which are the equivalent of snow courses on land. The maps presented here form a useful basis for the design of an upwind→downwind "ice and snow course" for Elizabeth and other lakes in snowy environments.

ACKNOWLEDGEMENTS

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REFERENCES

Adams, W.P. 1977. Measuring Ice and Snow on Lakes. Proc. 2nd International Conference on Hydrometeorology, American Meteorological Society, 225-230.

Adams, W.P. 1981. Snow and Ice on Lakes. In: Handbook of Snow (D.M. Gray and D.H. Male, eds.), Pergamon Press, 437-474.

Adams, W.P. and A.G. Brunger 1975. Variation in the Quality and Thickness of the Winter Cover of Knob Lake, Subarctic Quebec. Revue de Geographie de Montreal, XXIX(4), 335-346.

Adams, W.P. and T.D. Prowse 1981. Evolution and Magnitude of Spatial Patterns in the Winter Cover of Temperate Lakes. Fennia 159:2, 343-359.

Adams, W.P. and N.T. Roulet 1980. Illustration of the Roles of Snow in the Evolution of the Winter Cover of a Lake. Arctic, 33:1, 100-116.

Adams, W.P. and J.B. Shaw 1966. Studies of Ice Cover on Knob Lake, Quebec. Cahiers de Geographie de Quebec, 11, 22, 88-96.

Andrews, J.T. 1962. Variability of Lake Ice Growth and Quality in the Schefferville Region, Central Labrador-Ungava. Journal of Glaciology, 34:4, 337-347.

Bryan, M.L. 1966. The Morphology and Morphometry of Lakes in the Schefferville, Quebec, Area. McGill Subarctic Research Papers, 22, 154-182.

Chenard, P.G. 1980. Oxygen Consumption in Two Subarctic Lakes. M.Sc. Thesis, Biology, McGill University, Montreal, 133p.

English, M. 1982. The Role of Snowpack in the Nutrient Budget of a Subarctic Ecosystem. Ph.D. Thesis, McGill University, Montreal (in prep.).

Granberg, C. (ed.) 1978. Annotated Bibliography of Recent Research Undertaken in the Labrador-Ungava Area, Near Schefferville, Quebec. McGill Subarctic Research Papers, 28, 63p.

Jones, J.A.A. 1969. The Growth and Significance of White Ice on Knob Lake, Quebec. Canadian Geographer, 13, 354-372.

Rigler, F.H. 1980. Prediction of Effect of Increased Phosphorus Loading on Subarctic Lakes. Report submitted to Department of Indian and Northern Affairs, 15p.+ attachments.

Roulet, N.T. 1980. Use of a Computer Mapping Package in Displaying Areal Representations of Snowcover Characteristics. Proc. Eastern Snow Conference, 37, 118-120.

Roulet, N.T. 1981. Variability of the Quality and Quantity of Light Penetrating a Winter Lake Cover. M.Sc. Thesis, Watershed Ecosystems Program, Trent University, Peterborough, Canada. 291p.

Russell, B. 1980. Cover Development on Elizabeth Lake, Labrador. Trent Student Geographer, 8, 100-109, Trent University, Peterborough, Canada.