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Summer Air Temperature and Number of Vascular Species in Arctic Canada

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ABSTRACT. Exceptionally high correlations (r = 0.90-0.97) between number of vascular species and various indices of summer warmth at 38 localities in the Canadian Arctic support Young's contention that summer thermal regime is the most important ecological factor controlling the broad zonation of arctic flora. Highest correlations (r = 0.97) are with July mean temperature and mean number of degree-days above 0°C in July. Regression equations relating July mean temperature and number of species indicate a diversity gradient of about 25 species per degree. These equations provide estimates of species numbers or July temperatures in areas with poor climate or botanical data and may also be used to identify anomalous conditions.

Key words: vascular species, floristic diversity, Canadian Arctic

RÉSUMÉ. Des corrélations exceptionnellement élevées (r = 0.90-0.97) entre le nombre d'espèces vasculaires et divers index de chaleur estivale à 38 localités dans l'Arctique canadien appuient l'assertion de Young selon laquelle le régime thermique estival est le facteur écologique le plus important contrôlant la grande zonation de la flore arctique. Les corrélations les plus élevées (r = 0.97) proviennent de la température moyenne de juillet et du nombre moyen de degrés-jours de 0°C en juillet. Des équations de régression reliant la temperature moyenne de juillet au nombre d'espèces indiquent un gradient de diversité de quelque 25 espèces par degré. Ces équations fournissent des approximations du nombre d'espèces ou des temperatures en juillet pour des régions avec un mauvais climat ou pour lesquelles peu de données biologiques sont disponibles. Elles peuvent aussi être utilisées afin d'identifier des conditions anormales.

Mots clés: espèces vasculaires, diversité florale, Arctique canadien

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INTRODUCTION

A general relationship between floristic diversity and summer temperature regime in the Arctic has been noted in many studies. Savile (1972a) used data from six localities in the Canadian Arctic and adjacent areas of Greenland to show that diversity (represented by number of vascular species) declines with July mean air temperature. Young (1971) and Edlund (1983) suggested that arctic vegetation zones may be bounded by specific isotherms analogous to the commonly cited association between the treeline in Canada and the 10°C July mean isotherm. Summer warmth was a major variable used by Tuhkanen (1984) to delimit circumboreal phytogeographical regions.

Summer temperature regime, while of obvious importance, is a simplistic representation of the complex environmental conditions for plant growth, neglecting as it does variations in moisture availability, length of growing season, site exposure, nature of substrate, nutrient status, variety of available habitats, photoperiod, etc. In the Arctic, time available for recolonization following deglaciation and isolation from centres of dispersal might be expected to be factors in determining floral richness. Nevertheless, after reviewing the potential roles of these other variables in controlling the broad distribution of vascular flora in the Arctic, Young (1971:95) concluded that

> . . . floristic zones are correlated with the amount of summer warmth to the point that other ecological factors are insignificant by comparison.

The objective of this paper is to test this assertion in the Canadian Arctic, using number of vascular species as a measure of floristic diversity.

METHODS

Data for the number of vascular species were obtained from the literature for 38 localities in the Canadian Arctic (Fig. 1, Table 1). The only restriction placed on acceptance of reported data was that the collections attempted complete inventories as opposed to expeditions of a reconnaissance nature or studies restricted to specific community types. For each locality, summer temperature data were obtained from one of the following sources: (1) published station normals for the period 1951-80 (Atmospheric Environment Service, 1982); (2) field records of varying length reported by research parties; or (3) interpolation from a map of July mean temperature isotherms presented by Maxwell (1980). The imperfections of such a varied temperature data base are clear and will not be elaborated upon here. Nevertheless, they do not appear sufficiently problematic to alter the main conclusions reached below.

Mean July temperatures were obtained from one of the above sources for all localities. More complete representation of summer warmth was possible for a subset of 19 localities for which station normals were available. At these, indices based on mean temperatures and degree-day totals throughout the summer period similar to those used by other writers were examined. For example, Holdridge (1966) defined a variable

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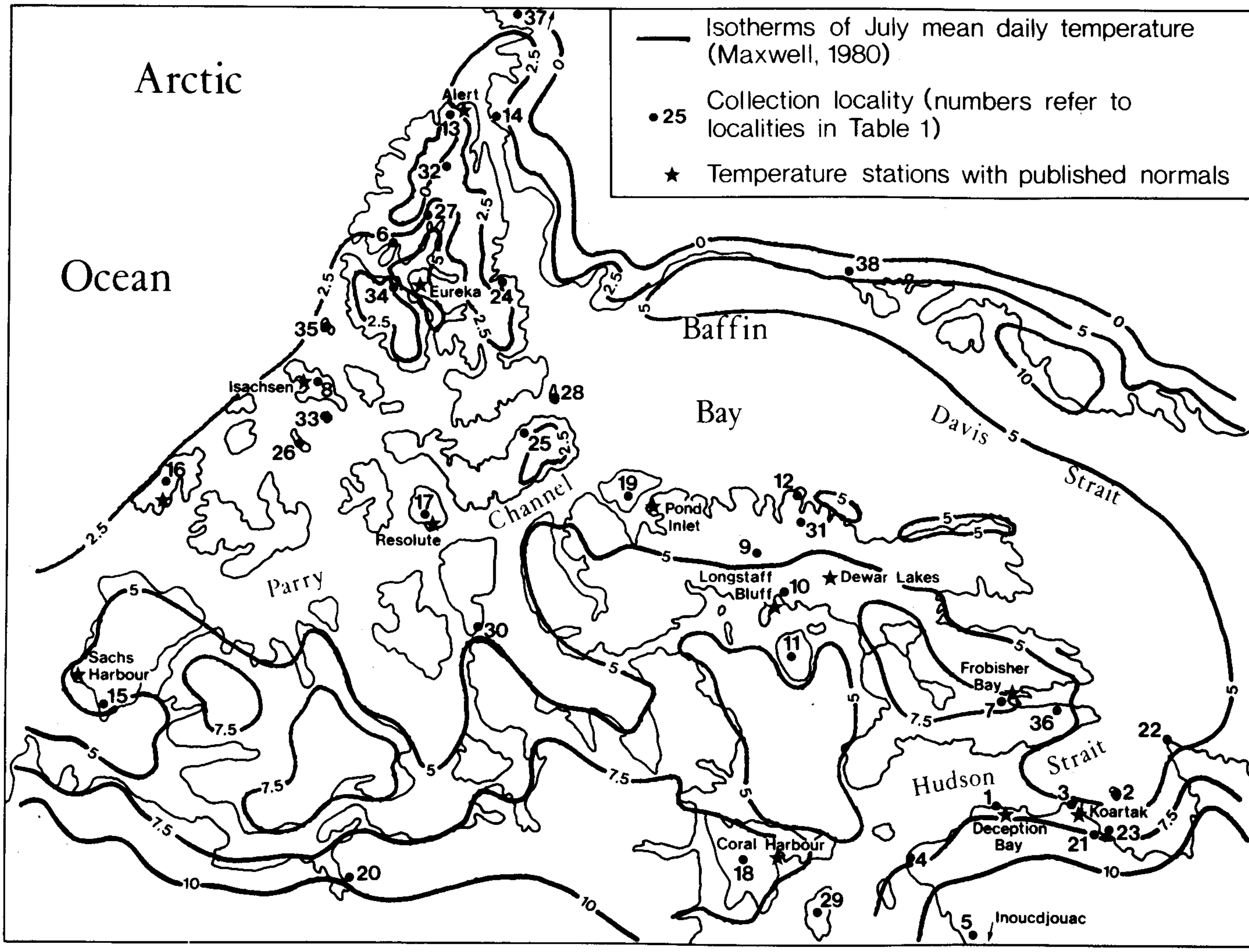

FIG. 1. Location of collection sites and temperature stations. Isotherms of July mean temperature reproduced from Maxwell (1980).

''biotemperature'' based on the sum of positive daily temperatures and Tuhkanen (1984) defined ''effective temperature sum'' as the sum of daily degrees in excess of 5°C. These indices are equivalent to cumulative sums of degree-days above 0°C and 5°C respectively, data that are available in station normal summaries. Tuhkanen (1984) calculated these indices from monthly mean temperatures and thus his version of Holdridge's biotemperature was equivalent to Young's ''a'' index of warmth during the growing season, defined as the sum of positive mean monthly temperatures (Young, 1971). More elaborate, and perhaps physically more meaningful, indices could be attempted but would be of limited application given the sparsity of data. Furthermore, all such measures are merely surrogates for the thermal regime at ground level, itself a simplification of the plant's environment; lack of pretension and simplicity of calculation are virtues in climatic indices of these types.

RESULTS

Correlation coefficients between number of species and several indicators of summer thermal conditions are given in Table 2. The degree of correlation is remarkably high, exceeding 0.90 for all measures other than those based only on June data. For several of these indices, coefficients greater than 0.95 were obtained, implying that 90% or more of the variation in number of species may be accounted for by ''summer warmth.'' Strongest correlations were obtained between species number and July conditions alone, suggesting that within the arctic biome, temperatures during the warmest month are more significant than growing season length or total available ''warmth.'' Thus indices such as Holdridge's ''biotemperature'' or Young's ''a'' offer no apparent advantage over measures based only on July temperatures. Furthermore, the simplest and most widely available measure, July mean temperature, yielded the highest correlation ($r = 0.97$), equalled only by mean July degree-days above 0°C.

The above conclusions are based upon the subsample of 19 localities for which station data were available. For an additional 19 localities, July mean temperatures were determined from field data reported in the literature or from a map of July isotherms (Maxwell, 1980). The correlation coefficient for the larger sample was somewhat lower ($r = 0.92$, $n = 38$, Table 2), but the scattergram of these data (Fig. 2) indicates that most or all of this reduction may be attributed to one anomalous outlier, Killineq Island, at the northern tip of Labrador. When Killineq is excluded, the correlation coefficient between species number and July mean temperature is the same as for the subsample using only station data ($r = 0.97$; Table 2, $n = 37$).

Young (1971) suggested that the association between summer

TABLE 1. Number of vascular species and mean July temperature

Locality	No. of species	Source	July mean (°C)	Temperature station or other data source
1. Wakeham Bay	202	Deshaye, 1983	9.4	Deception Bay
2. Akpotak Island	127	Deshaye, 1983	6.2	Koartuk
3. Diana Bay	106	Deshaye, 1983	5.6	Cape Hopes Advance
4. Wolstenholme	133	Deshaye, 1983	6.2	Nottingham Island
5. Povungnituk	190	Bournerias, 1975	9.3	Inoucdjouac
6. Van Hauen Pass	80	Brassard and Longton, 1970	5.4	Eureka
7. Frobisher Bay	149	Calder, 1951	7.6	Frobisher Bay
8. Ellef Ringnes Island	49	Savile, 1961	3.2	Isachsen
9. Lewis River	86	Webber, 1964	5.3	Dewar Lakes
10. West Baffin Island	145	Webber, 1964	6.7	Longstaff Bluff
11. Foxe Basin Islands	77	Webber, 1964	5.3	Rowley Island
12. Outer Inugsuin Fiord	61	Hainault, 1966	4.1	Clyde
13. Alert	65	Bruggeman and Calder, 1953	3.6	Alert
14. Polaris Bay	50	Powell, 1971	3.6	Alert
15. Masik River	122	Mason *et al.*, 1972	5.9	Sach's Harbour
16. Prince Patrick Island	81	Tedrow *et al.*, 1968	3.9	Mould Bay
17. Resolute	70	Savile, 1972a	4.1	Resolute
18. Southhampton Island	185	Brown, 1953	8.7	Coral Harbour
19. Bylot Island	101	Barrett and Teeri, 1973	4.6	Pond Inlet
20. Bathurst Inlet	260	Cody *et al.*, 1984	10.0	Bird and Bird, 1961
21. Bellin	175	Deshaye, 1983	7.5	Map, Maxwell, 1980
22. Killineq Island	194	Deshaye, 1983	5.0	Map, Maxwell, 1980
23. Ivik Island	117	Deshaye, 1983	6.5	Map, Maxwell, 1980
24. Hayes Sound	117	Bridgeland and Gillett, 1983	6.2	Field Data, Freedman *et al.*, 1983
25. Truelove Lowland	96	Bliss, 1977	5.2	Field Data, 1966-73, Courtin and Labine, 1977; Hussell and Holroyd, 1974
26. Lougheed Island	33	Edlund, 1980	3.0	Field Data, King Christian Island, Addison and Bliss, 1980
27. Tanquary Fiord	119	Brassard and Beschel, 1968	6.1	Field Data, 1963-67, Barry and Jackson, 1969
28. Coburg Island	36	Muller, 1979	3.7	Field Data, 1972-76, Muller, 1979
29. Coats Island	116	Gillett, 1976	6.5	Map, Maxwell, 1980
30. South Somerset Island	68	Savile, 1959	4.5	Map, Maxwell, 1980
31. Inner Inugsuin Fiord	84	Hainault, 1966	5.0	Map, Maxwell, 1980
32. Hazen Camp	115	Savile, 1972b	6.8	Field Data, 1958, 1961-63, Savile, 1972b
33. King Christian Island	35	Bell and Bliss, 1980	3.0	Field Data, 1973-74, Addison and Bliss, 1980
34. Expedition Fiord	130	Nettleship and Smith, 1975	6.7	Field Data, 1960-62, Muller, 1963
35. Meighen Island	33	Kuc, 1970	3.0	Map, Maxwell, 1980
36. Ogac Lake	124	McLaren, 1964	7.0	Map, Maxwell, 1980
37. Central Peary Land	106	Savile, 1972a	6.4	Savile, 1972a
38. Ella O	184	Savile, 1972a	9.0	Savile, 1972a

TABLE 2. Correlation coefficients between number of species and various indicators of summer warmth

	n	Mean temperature	Degree-days greater than 0°C	5°C	Young's "a"
June	19	0.87	0.85	0.83	—
July	19	0.97	0.97	0.95	—
July	37	0.97	—	—	—
July	38	0.92	—	—	—
August	19	0.90	0.92	0.93	—
June-July	19	0.95	0.96	0.94	—
July-August	19	0.95	0.96	0.95	—
June-August	19	0.95	0.96	0.94	—
Total	19	—	0.95	0.94	0.93

warmth and number of species was sufficiently strong that knowledge of one variable would permit an estimate of the other. The high correlations and relatively narrow scatter about the regression lines in Figure 2 support this suggestion. Equations estimating July mean temperature (T) and the number of vascular species (N), with each treated as the independent variable, are given below using both station data ($n=19$) and total data without Killineq ($n=37$):

1. $N = 24.2\,T - 29.1$ ($n = 19$; $r^2 = 0.94$; S.E. $= \pm 11.9$)
2. $N = 25.8\,T - 41.8$ ($n = 37$; $r^2 = 0.95$; S.E. $= \pm 12.2$)
3. $T = 0.039\,N + 1.47$ ($n = 19$; $r^2 = 0.94$; S.E. $= \pm 0.48$)
4. $T = 0.037\,N + 1.84$ ($n = 37$; $r^2 = 0.95$; S.E. $= \pm 0.46$)

These equations appear to be valid throughout the entire range of data and indicate a diversity gradient of 24-26 species per degree.

With an independent knowledge of the approximate July mean temperature, Equations 1 and 2 permit an estimate of the number of vascular species that might be expected in a locality (assuming that a representative range of habitats is available) and thus provide an approximate guideline for evaluating the completeness of a collection in a new locality. The standard error of each equation is 12 species. Conversely, if an apparently complete collection of vascular species is made in an area with no temperature data, July mean temperature may be estimated from Equations 3 or 4, with a standard error of 0.5°C. In addition, the equations may be used to identify abnormal conditions of diversity that might not otherwise be apparent (for example, at Killineq Island, which has about twice as many species as would be predicted from the apparent summer temperatures).

CONCLUSIONS

While an association between arctic floristic diversity and

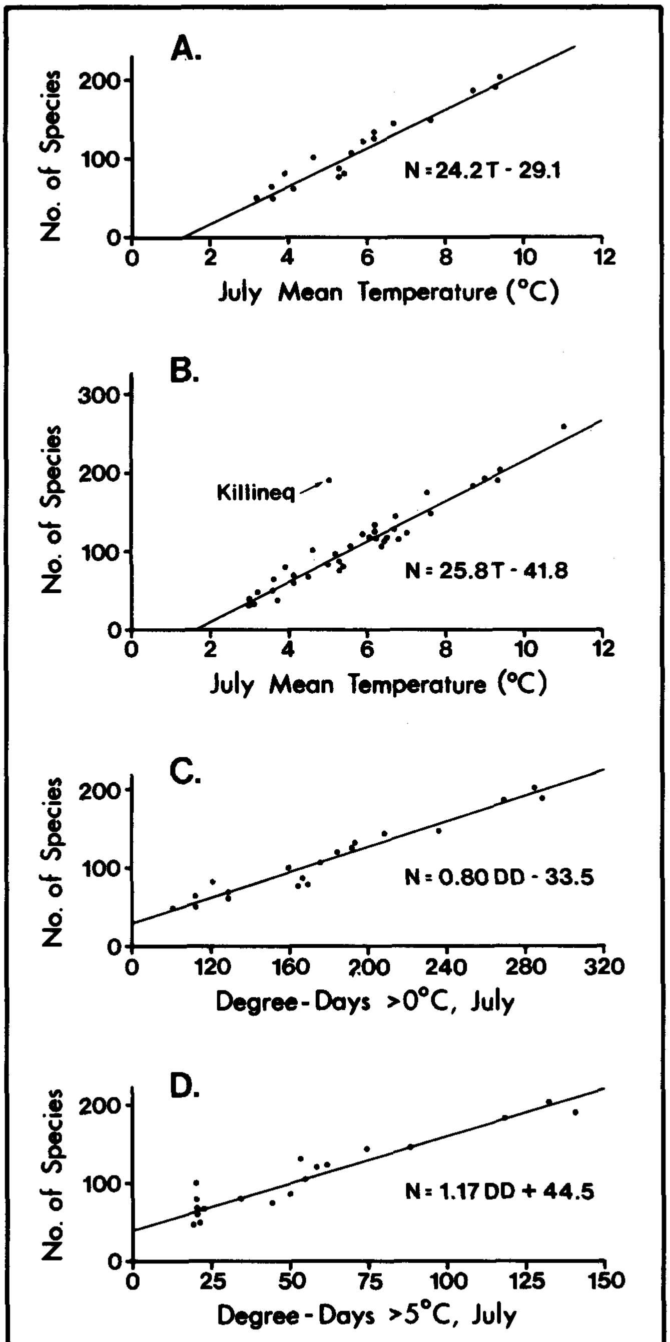

FIG. 2. Scattergrams of number of vascular species versus (A) July mean daily temperature (station normal data); (B) July mean daily temperature (all data); (C) July degree-days greater than 0°C; and (D) July degree-days greater than 5°C. The significance of Killineq is explained in the text.

summer warmth might be almost self-evident, the exceptional correlations found between these two variables in arctic Canada verify Young's assertion that most of the variations in numbers of vascular species may be "explained" by summer warmth alone. While all measures of summer warmth exhibit this high correlation, none are higher than July mean temperature ($r=0.97$). Regression lines relating July mean temperature and number of vascular species permit estimates of each variable from the other for areas where one of these data is presently unavailable and may be used to identify anomalous circumstances.

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