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Arctic Insects as Indicators of Environmental Change

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ABSTRACT. The great diversity of terrestrial arthropods in the Arctic suggests that these organisms are especially useful to monitor environmental change there, where warming as a result of climatic change is expected to be especially pronounced and where current conditions are limiting for many organisms. Based on existing information about arctic faunas and how they differ from temperate ones, this paper suggests several elements, including ratios and other quantitative indexes, that can be used for long-term evaluations of change. These elements include composition indexes, range limits, marker species, interspecific ratios, relationship shifts, phenological and physiological indicators, and key sites. Using such elements in a planned way would exploit the diversity of arctic insects and emphasize their importance in arctic systems.

Key words: arctic arthropods, arctic insects, arctic fauna, climatic change, environmental change, monitoring, indicator species, long-term research

RÉSUMÉ. La grande diversité d'arthropodes terrestres dans l'Arctique suggère que ces organismes se prêtent particulièrement bien à la surveillance des changements qui prennent place dans cet environnement, où l'on s'attend à un réchauffement assez prononcé suite aux changements climatiques et où les conditions actuelles sont défavorables à beaucoup d'organismes. En s'appuyant sur l'information actuelle concernant les espèces arctiques et la façon dont elles diffèrent des espèces tempérées, cet article propose divers éléments, y compris des rapports et d'autres index quantitatifs, à utiliser pour effectuer une évaluation à long terme des changements. Ces éléments comprennent les index de composition, les limites de territoire, les espèces repères, les rapports interspécifiques, les modifications des liens, les indicateurs phénologiques et physiologiques ainsi que les sites clés. L'utilisation planifiée de ces éléments permettrait d'exploiter la diversité des insectes arctiques et de souligner leur importance dans les systèmes arctiques.

Mots clés: arthropodes, insectes arctiques, faune arctique, changement climatique, changement environnemental, surveillance, espèces indicatrices, recherche à long terme

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INTRODUCTION

The Arctic is a critical region for interpreting environmental change, because conditions are close to the limits for life and relatively small changes might be expected to produce highly visible effects on the biota. Moreover, climatic warming is predicted to be especially pronounced in the Arctic (e.g., Royal Society of Canada, 1988).

The diversity of the arctic fauna is reduced relative to that in temperate regions, but even so there are thousands of arctic species, most of them insects and related arthropods. Consequently, the fauna is rich enough and the ecosystem complex enough to provide a potentially wide variety of insights into arctic environmental change. Such studies require both a conceptual base to provide hypotheses and testable measures of change, and continuing commitment to acquire the basic information necessary for long-term evaluations. Based on what we know about the terrestrial arthropods of the Arctic, this paper suggests some biological indexes that can be used to look for and evaluate the effects of changes in conditions.

ARTHROPODS IN THE ARCTIC

Over 2000 species of insects, spiders, mites and springtails have been reported from north of the tree line in North America (Table 1), and apparently nearly as many again remain to be recorded (Danks, 1981, 1990).

Organisms have several advantages for monitoring change. They integrate a variety of effects over time in a way that individual short-term chemical or physical measures cannot do (e.g., Lehmkuhl *et al.*, 1984; Williams *et al.*, 1990). Moreover, although models of climatic change can forecast temperatures, even the most sophisticated models indicate the effects of moisture less effectively and are unreliable in predicting patterns of cloud cover. Yet cloud cover in the Arctic is especially important to organisms, because remarkable increases in the temperatures of ground-surface habitats result from solar heating (Corbet, 1972; Danks, 1987a). The occurrence and abundance of organisms thus integrate the effects of temperature, insolation, moisture and other factors over prolonged periods. In a broader sense, too, faunas respond in distinctive ways to physical and chemical environmental elements by selection and adaptation.

Terrestrial arthropods are integrated widely into arctic systems. They play many biological roles, including decomposition, predation and other trophic activities. Therefore, arthropods interact with other organisms, even in the High Arctic, to a much greater degree than might be supposed (Table 2). For example, they are a major source of food for birds that migrate to the Arctic in summer to breed. Marked changes in the arctic insect fauna would thus influence organisms familiar farther south. Not all arctic species are known in taxonomic or ecological detail, but existing information allows predictions about the general habits of genera and families, suggesting the

TABLE 1. Number of named species of major groups of terrestrial arthropods reported from Canada and arctic regions (Danks, 1990)

	Number of named species			
Group	Canada	Arctic Canada and Alaska	Canadian Arctic Islands	Queen Elizabeth Islands
Arachnida (spiders)	1 256	112	30	18
Acari (mites)	1 915	261	120	77
Collembola (springtails)	295?	97	49	44
Insecta (insects)	29 976	1 468	462	242
Total named species[1]	33 672	1 943	661	381
Minimum species present[2]	—	2 237	858	553

[1]Including minor groups not listed.
[2]Including additional reported, unnamed taxa.

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TABLE 2. Summary of some trophic interactions between arthropods and other organisms (Danks, 1990)

Interaction			
Between	And	Notes	Examples
Arthropods	Vertebrates	Many saprophages depend on dung or carrion	Blow flies, some crane flies, midges, etc
		Some saphrophages scavenge in vertebrate nests or burrows	Some mites, etc.
		Ectoparasites attack birds and mammals	Characteristic biting flies, many ectoparasitic mites, fleas, lice, etc.
Arthropods	Plants	Several arthropod herbivores eat arctic plants	Butterflies, moths, sawflies, aphids, etc.
		Many arctic arthropods visit flowers, for nectar or pollen (and for basking or other activities)	Bumble bees, various flies; mosquitoes, butterflies, etc.
Arthropods	Arthropods	Parasitoids of insects such as sawflies and moths are numerous	Chiefly ichneumonids, but also chalcidoids, braconids, etc.
		Some mites are ectoparasitic on arthropods	Water mites
		A few nest parasites steal nest provisions or parasitize established nests of related species	The bumble bee *Bombus hyperboreus* Schönherr
		Many predators attack other arthropods	Diving beetles, several kinds of flies, and other insects. Small predatory mites and spiders are especially numerous
Arthropods	Microflora	Arthropods stimulate decomposition	Many mites, springtails
Vertebrates	Arthropods	Many arctic birds prey on arthropods, especially to feed the young; non-insectivorous adults also supplement their diet with insects	Large or abundant prey are most used (e.g., crane flies, some midges), but also springtails and other small arthropods
		Mammals and fish eat insects	
Invertebrates	Arthropods	Invertebrate parasites of arthropods are widely distributed in the Arctic	Microsporidians, mermithids, etc.

nature of the fauna and the way it is constrained in arctic environments. Such interpretations are exemplified by the general information shown in Figure 1.

CONCEPTS AND METHODS FOR LONG-TERM ASSESSMENTS

Composition Indexes

The fauna changes in distinctive ways from tropical or temperate to arctic regions in accordance with environmental factors related to latitude. Some powerful taxonomic trends can thereby be identified in broad terms at the ordinal level (e.g., Table 3), but also at the level of family (Table 4) and genus (Table 5). Some taxa increase proportionally and others decrease as climates become more severe or ameliorate. For example, the tables show that the order Diptera, the family Chironomidae among the Diptera and the genus *Spilogona* among the Muscidae are very well represented, whereas the order Coleoptera, the family Asilidae and the genus *Fannia* are much less well represented as arctic conditions become more severe. The relative representation of selected groups in the Arctic (which can be assessed by a relatively modest local faunal inventory) therefore provides a quantitative index of environmental severity that can be monitored to detect long-term changes.

Limit Lines

The edge of a species range shows where conditions have changed such that the organism can no longer survive. The tree line, typically the edge of the range of white spruce, *Picea glauca* (Moench) Voss, is a well-known index of environmental change in northern North America. Species of insects likewise drop out as climates become harsher toward the north (Fig. 2). Some range limits coincide with the tree line or other marked environmental disjunctions (Danks, 1981, in press). Some limits appear to accord with summer isotherms. Other

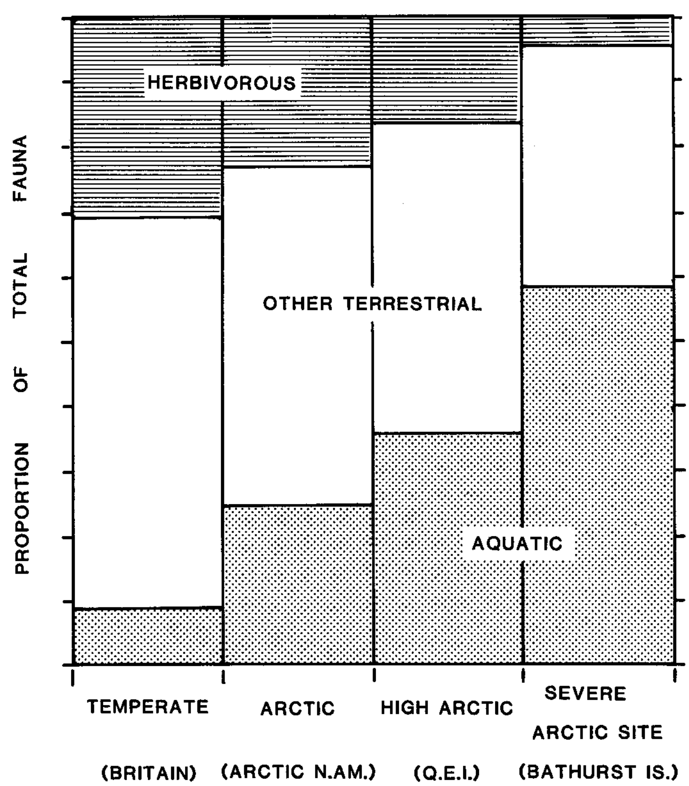

FIG. 1. Relative representation of terrestrial (herbivorous and non-herbivorous) and aquatic species of insects in a temperate area (Britain) and in arctic areas of increasing severity (arctic North America; the Queen Elizabeth Islands; Bathurst Island) (Danks, 1990).

species evidently respond to less easily assessed factors or to complex influences and do not coincide with clear disjunctions (Danks and Foottit, 1989).

Many insect species are relatively mobile and would be expected to colonize without delay currently unsuitable terrain that became suitable as conditions changed. Monitoring range limits for selected species (see also Marker Species below) would therefore indicate the rapidity of change. For example, species of several distinctive groups, such as solitary bees (Sakagami and Toda, 1986) and psyllids (Hodkinson, 1978), currently drop out at or near the tree line and might be instructive indicators.

Marker Species

Some conspicuous species that are well known taxonomically lend themselves to use as markers of abundance or range. Such species include butterflies, mosquitoes and bumble bees (Fig. 2d,e,f). For example, the 74 species of Canadian mosquitoes are well known (Wood *et al.*, 1979). About 16 species occur in the Arctic, and 3 species occur even in the High Arctic, 2 of them commonly. However, the northern species have to develop from egg to egg in a single year and do not persist in the coldest parts of the Canadian arctic archipelago. Even near the tree line, most species rely on incursions of warmer, modified air to allow necessary activities (Haufe, 1966). Butterflies rely on sunshine to raise body and habitat temperatures for flight (Kevan and Shorthouse, 1970) and likewise are not found in the coldest, cloudiest parts of the Arctic, the northwestern Queen Elizabeth Islands (e.g., Danks, in press). It might be possible to correlate the occurrence, and even the abundance, of some of these well-known and conspicuous species (dependent on temperatures for activity) with simple temperature measurements and to make predictions from general models of temperature change.

TABLE 3. Relative representation of the insect fauna in different regions to show changes in the representation of selected orders (based on named species reported) (Danks, 1990)

Order	Percentage of the regional insect fauna in: World	North America	Arctic North America	Canadian Arctic Islands	Queen Elizabeth Islands
(Total no. of insect spp.)	(762 659)	(93 728)	(1468)	(462)	(242)
Orthoptera	4	1	0.4	0.2[1]	0.4[1]
Phthiraptera	0.4	0.4	4[2]	9[2]	14[2]
Hemiptera	7	12	4	4	3
Coleoptera	39	32	13	6	3
Diptera	16	19	50	53	61
Lepidoptera	15	12	11	12	10
Hymenoptera	14	19	13	11	10

[1]Adventitious.
[2]Based partly on host ranges.

TABLE 4. Relative arctic representation of selected larger families of Diptera, showing the percentage occurrence of each family relative to its occurrence in the fauna of Canada (and Alaska); and the percentage of the total, arctic and high arctic Diptera faunas contributed by each family (chiefly from information in Danks, 1979, 1981, 1990)

	Percentage of the total Canadian and Alaskan species of the family that occurs in:		Percentage of the regional Diptera fauna made up by the family in:		
Family[1]	Arctic	Queen Elizabeth Islands	Canada	Arctic	Queen Elizabeth Islands
Tipulidae	10	1	7	7	5
Culicidae	22	4	1	2	2
Simuliidae	24	0	2	4	0
Chironomidae	30	14	7	20	46
Stratiomyiidae	0	0	1	0	0
Tabanidae	3	0	2	<1	0
Asilidae	0	0	2	0	0
Empididae	6	2	4	3	3
Syrphidae	3	1	7	2	3
Ephydridae	6	1	2	1	1
Muscidae	30	4	7	22	14
Sarcophagidae	0	0	1	0	0
All other families	7	1	56	38	25
Total Diptera	10	2	100	100	100

[1]Numbers of species in each family are estimates, except for a few families, such as Culicidae, that are better studied, because in many groups the species are inadequately known.

Interspecific Ratios

Many arctic species are linked with other organisms (Table 2). It may therefore be possible to use interspecific ratios to indicate ecosystem structure and hence to reveal correlated or distorted responses to environmental change. The relative proportions of plants and of the insect herbivores that eat them change dramatically with climatic severity (Table 6), and a small climatic change would be expected to produce a large change in interspecific ratios as extreme sites become slightly more favourable. For example, the high arctic sites at Lake Hazen, Ellesmere Island (81°N, mean July temperature about 5.9°C) and Polar Bear Pass, Bathurst Island (76°N, mean July temperature below 5°C) (Corbet and Danks, 1974; Danks, 1980; Edlund and Alt, 1989) have plant species:insect herbivore species ratios of about 1.8:1 (unpubl. analysis) and 13:1 (Table 6) respectively, compared with ratios of less than 0.3:1 for temperate regions (Table 6). Similar comparisons might be possible for other associations when further detailed samples have been taken. Insect:parasitoid ratios might depend on host availability and host-finding abilities in the face of climatic constraints. Aquatic:terrestrial ratios (compare

TABLE 5. Relative arctic representation of selected genera of Muscidae, showing the percentage occurrence of each family relative to its occurrence in the fauna of Canada (and Alaska) and the percentage of the total, arctic and high arctic muscid faunas contributed by each genus (chiefly from information in Danks, 1979, 1981; Huckett, 1965a,b)

		Percentage of the total Canadian and Alaskan species of the genus that occurs in:		Percentage of the regional muscid fauna made up by the genus in:		
Genus (no. of Canadian spp.)		Arctic	Queen Elizabeth Islands	Canada	Arctic	Queen Elizabeth Islands
Coenosia	(64)	23	0	12	9	0
Eupogonomyia	(5)	100	60	1	3	15
Fannia	(72)	17	0	14	7	0
Helina	(40)	23	0	8	6	0
Hydrotaea	(22)	36	0	4	5	0
Phaonia	(49)	31	0	9	9	0
Spilogona	(128)	53	13	24	42	80
All other genera	(97)	21	1	28	19	5
Total Muscidae	(525)	31	4	100	100	100

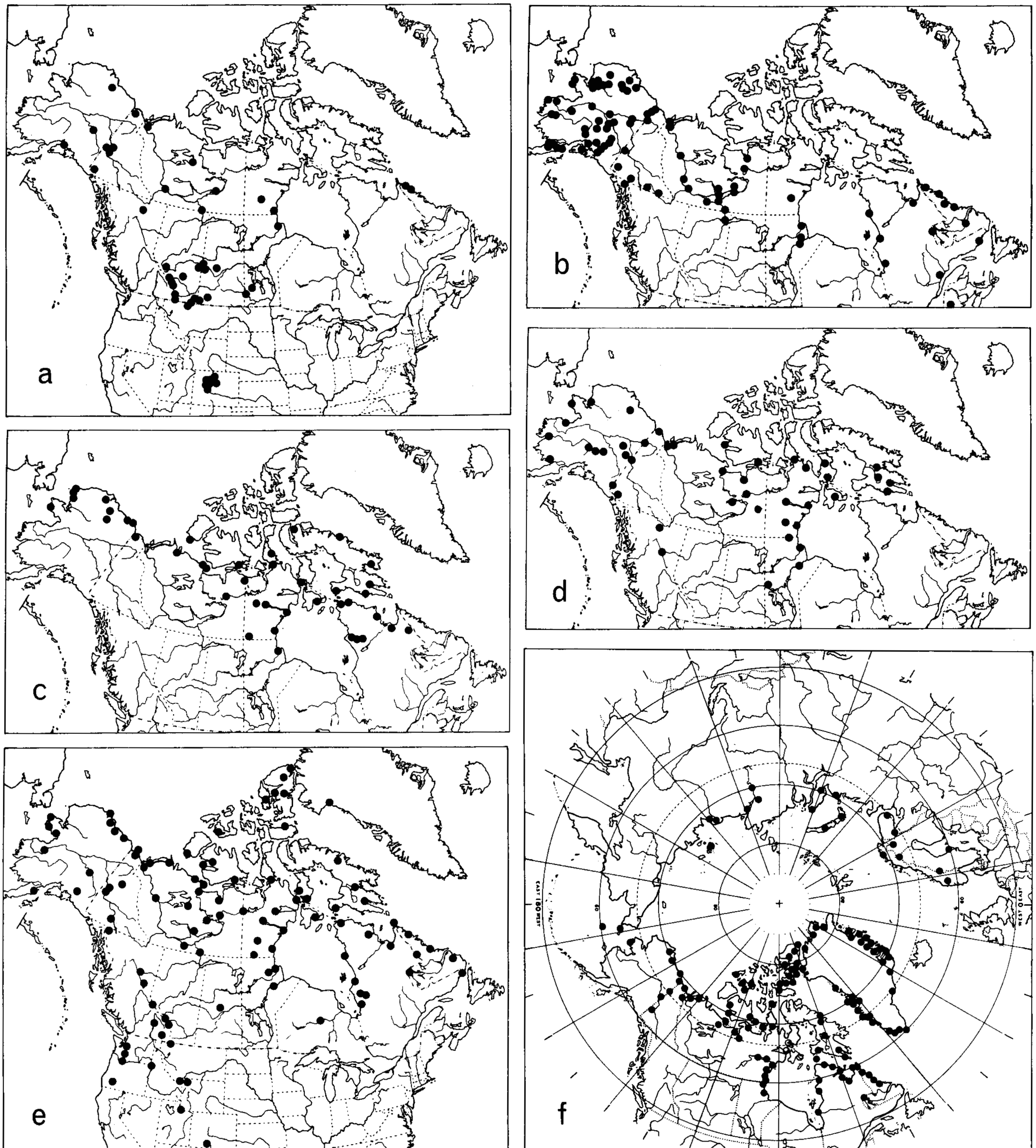

FIG. 2. Current northern ranges of selected species (from Danks, 1981) to show approximate northern limits. Note, for example, the absence of some species of the southern Arctic from areas farther north (a, b), the absence of some low arctic species from the High Arctic (c, d), and the absence from the northwestern Queen Elizabeth Islands of some high arctic species (e), even circumpolar species (f). a) Distribution of *Scopula* (formerly *Holarctias*) *sentinaria* (Geyer)(Geometridae). b) Distribution of *Vespula albida* (Sladen)(Vespidae). c) Distribution in North America of *Alopecosa hirtipes* Kulczynski (Lycosidae). d) Distribution in North America of *Erebia rossii* (Curtis)(Satyridae). e) Distribution in North America of *Aedes impiger* (Walker)(Culicidae). f) Distribution of *Bombus polaris* Curtis (Apidae).

TABLE 6. Relationships of the total number of insect species and the number of herbivore species only with the number of plant species in selected temperate, arctic and high arctic areas (after Danks, 1987a, in press)

Region	Insect species			No. of vascular plant species	Insect : plant ratios		
	Named spp.	Est. total spp.	Herbivores only, named spp.		Total insect species per plant species	Estimated total herbivore species per plant species	Estimated plant species per total herbivore species
Britain	21 871	23 600	6 750	2 080	11.3	3.5	0.3
Canada	29 976	54 629	8 990?	4 153	13.2	3.9?	0.3?
Arctic North America	1 408	3 100	335	600	5.2	1.2	0.8
Queen Elizabeth Islands	237	600	39	145	4.1	0.7	1.5
Bathurst Island	65	130	3	80	1.6	0.07	13

Fig. 1) reflect the fact that shallow waters are especially favourable habitats in the Arctic because they warm up rapidly by solar heating of the bottom, but cool down more slowly because of the high specific heat of water, and so integrate insolation and other factors with air temperatures.

Relationship Shifts

By the same token, changes in the relationships among organisms would be expected as conditions change. For example, plant-pollinator relationships would be modified by changes in the composition of faunas and floras, the voltinism of insects and the growing or flowering seasons of plants. Diptera are the most abundant pollinators in the Arctic (e.g., Kevan, 1972; Danks, 1981, 1987a), and many flowers are insect pollinated there, although some plants that appear to be adapted for entomophily reproduce chiefly or entirely by vegetative means and apomictic seed production.

Pollination by Diptera is effective in the Arctic because few flowers are available simultaneously. Richer floras and the addition of other pollinators would be expected to change the dynamics of pollination. Despite the predominance of Diptera, some arctic flowers are pollinated by a reduced fauna of bees, notably *Pedicularis* species (pollinated chiefly by bumble bees). Some of the bee-*Pedicularis* relationships are relatively specific and so might show interesting responses to climatic change, especially in species, like those in the High Arctic, that rely entirely on insect pollination (Kevan, 1972, 1973). However, other *Pedicularis* species are partly or fully self-fertile (MacInnes, 1972).

Phenological Indicators

Insect life cycles are sensitive to developmental opportunities driven by climate, such as season length and mean summer temperature (Table 7). Some arctic insects, such as psyllids and mosquitoes, are constrained by life-cycle features to complete the life cycle within a season (MacLean, 1983; Corbet and Danks, 1973). Others regularly may take as many as 7 (Butler, 1982) or even 14 years (Kukal and Kevan, 1987).

Weather, and hence phenology, tends to vary greatly from one season to the next, and therefore long-term comparative studies will be required to quantify any shifts in voltinism or other measures. Nevertheless, mathematical analyses of trends over several years would be informative, using such indicators as the date on which seasonal emergence begins (*cf.* Danks and Byers, 1972, for *Spilogona* species; Danks and Oliver, 1972, for chironomid species), the seasonal duration of activity or reproduction (*cf.* Corbet and Danks, 1973, for mosquitoes), and the number of generations per year or years per generation.

TABLE 7. Examples of arthropod species in which duration of the life cycle varies from region to region according to chiefly climatic features

Species	Range of life cycle duration (years)	Reference
Meta mengei (Blackwall) (Araneae)	1-2	Toft, 1983
Hypogastrura "tullbergi Schaffer" (Collembola)	0.2-5	Addison, 1977
Pteronarcys dorsata Say (Plecoptera)	1-4	Lechleitner and Kondratieff, 1983
Tipula carinifrons Holmgren (Diptera)	2-8	Chernov and Savchenko, 1965; Lantzov, 1982; MacLean, 1975

Techniques for making such assessments are available especially for aquatic insects.

Physiological Markers

Physiological traits such as cold-hardiness and dormancy respond readily to local selective pressures, so that regional populations differ significantly from one another. Changed conditions therefore would normally be followed by changed responses in local populations. The changes reflect either local adaptation (after an unknown period) or the invasion of individuals belonging to populations from less severe sites with responses characteristic of those sites.

Several locally selected traits can be used as physiological markers (Table 8). For example, many characteristics of insect diapause, including the cues used for control, and diapause intensity show very clear regional differences (Danks, 1987b). Similarly, levels of winter survival reflect local adaptation to cold and other seasonal elements. Measures of cold-hardiness, such as supercooling points or tolerance to freezing, differ in regions of different severity, even though different species in a region may use different strategies for cold-hardiness (Ring, 1981, 1983). In some populations, cold-hardiness parameters (such as cryoprotectant levels) change serially during the winter, chiefly in response to ambient temperatures (e.g., Baust and Nishino, 1991). Such changes appear to be more characteristic of populations farther south, in contrast to current high arctic sites where winters are continuously severe.

As in the case of the phenological characteristics of insect populations, variations from year to year in physiological responses governed by the weather in a given season mean that long-term studies will be required for effective use of these markers. However, because changes in microhabitat temperatures during mid-winter tend to be smaller in the Arctic than elsewhere, long-term patterns of cold-hardiness might be easier to establish and model there.

Key Sites

Several arctic areas are especially likely to yield information of value. For example, sites near the boundaries of existing ecological zones might best detect responses to the amelioration of climates in the Arctic and Subarctic (for example, Churchill, Manitoba, at the tree line; Tuktoyaktuk, north of the current tree line but with a favourable climate). At the other extreme, the most severe high arctic sites in the northwestern Queen Elizabeth Islands (e.g., Ellef Ringnes Island: McAlpine, 1965; Bathurst Island: Danks and Byers, 1972) might also respond rapidly to improved temperature conditions. Most of the arctic terrestrial biota lives in "arctic oases," where mesoclimatic and microclimatic conditions coincide to produce relatively rich and warm localities well supplied with water (Babb and Bliss, 1974; Fig. 3). Studies of selected oases would discover how robust these communities of organisms prove to be in the face of substantial environmental changes. Moreover, the floras of central Ellesmere Island and southern Melville Island appear already to be enriched relative to surrounding areas (Edlund, 1990).

Carefully choosing a few sites is valuable for logistic reasons too. Sites about which something is already known in detail would be especially profitable. Limiting the number of sites allows for long-term integration of activities and makes concerted efforts more visible. Siting them along north-south transects (*cf.* Royal Society of Canada, 1988) favours additional comparisons. For example, sites of this type for insects include, in the east, Lake Hazen and other oases on Ellesmere Island (e.g., Downes, 1964), Truelove Lowland, Devon Island (Bliss, 1977) and Baffin Island (substantial information on insects has been collected, although it requires collation: Danks, 1981:370), as well as sites in arctic and subarctic Quebec and Labrador. In the west, Melville Island (to a limited extent, see Mosquin and Martin, 1967), Banks Island (many collections made, although insect data have not been published extensively) and Tuktoyaktuk (with a relatively rich fauna close to the tree line), as well as subarctic and alpine sites in the Yukon territory and farther south, have been studied. Some sites likely to be of particular value are shown in Figure 4, and general information about them is summarized in Table 9.

TABLE 8. Some regional trends in potential physiological markers (based on information reviewed in Danks, 1987b, and Lee and Denlinger, 1991)

Feature	Typical characteristic in less severe or southern sites
Diapause characteristics	
Occurrence of diapause	Less prevalent
Sensitive stage for diapause cues	Perhaps sensitive over a longer period and earlier in the life cycle
Diapause stage	Perhaps in a less cold-tolerant stage
Photoperiodic induction	Shorter photoperiods and larger number of short-day cycles required to induce diapause
Temperature effects	Colder temperatures required to induce winter diapause, higher temperatures more likely to avert it
Diapause intensity	Less intense (shorter under given conditions)
Cold-hardiness characteristics	
Level of winter survival	Variable, but usually higher within a species
Supercooling points	Usually higher
Freezing tolerance	Less prevalent
Cryoprotectant profiles	Uncertain, complex information, but generally lower levels and fewer different substances
Variations in cryoprotectant levels within or between seasons	Perhaps more variation

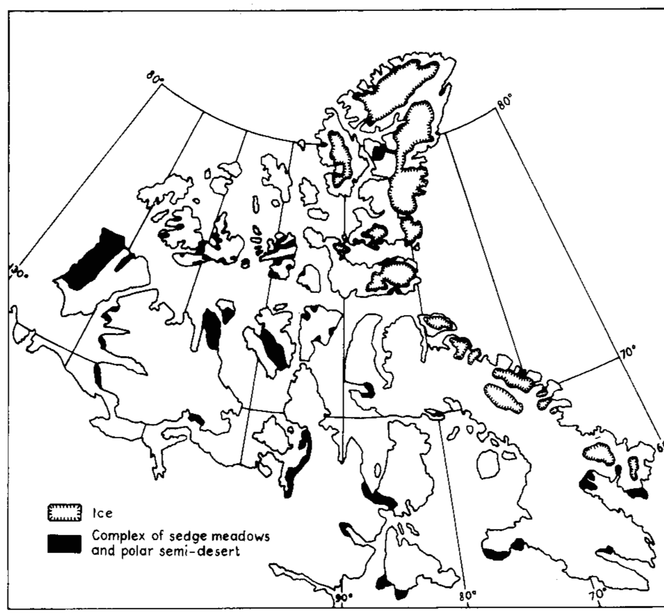

FIG. 3. Distribution of "arctic oases," richly vegetated sedge-moss meadows, in the Canadian Arctic (Danks, 1981, after Babb and Bliss, 1974).

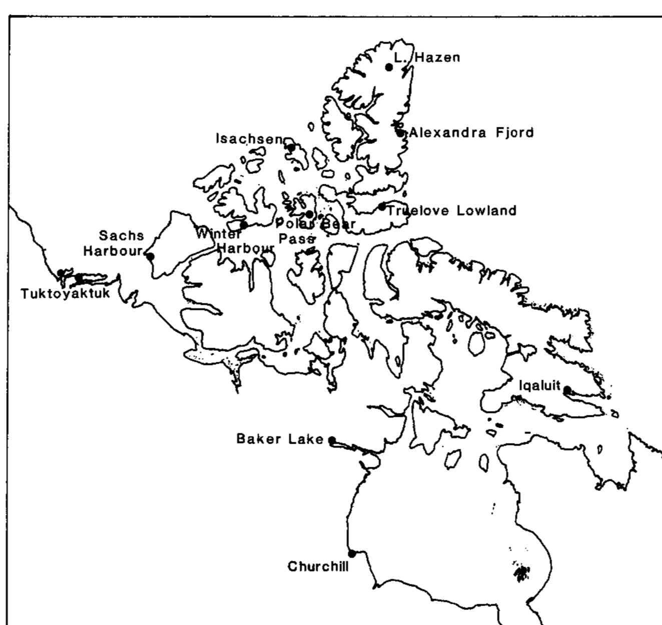

FIG. 4. Map of the North American Arctic to show selected field sites. For general information on these sites see Table 9.

TABLE 9. Summary of some general information about selected arctic sites

Site	Latitude (°N)	Longitude (°W)	Long-term mean July screen air temperature (°C)[1]	Vegetation zone	Notes	Current status	Sample references[2]
1. Lake Hazen, Ellesmere Island	81°49′	71°18′	5.9?	High arctic, enriched	Lowland oasis	National park	Powell, 1961; Savile, 1964; Soper and Powell, 1983
2. Alexandra Fjord, Ellesmere Island	78°53′	75°55′	4.2?	High arctic	Lowland oasis	Field station	Svoboda and Freedman, in press
3. Truelove Lowland, Devon Island	75°33′	84°40′	4.3?	High arctic	Lowland oasis	Field camp	Bliss, 1977
4. Iqaluit, Baffin Island [Frobisher Bay]	63°45′	68°33′	7.6	Low arctic	Various habitats, including richer ones	Settlement, research facilities	compare Polunin, 1948
5. Isachsen, Ellef Ringnes Island	78°47′	103°32′	3.2	High arctic, impoverished	Barrens, other habitats	Weather station	Savile, 1961
6. Polar Bear Pass, Bathurst Island	75°43′	98°23′	5.0?	High arctic	Lowland oasis	Field station (Canadian Museum of Nature); National Wildlife Area	Sheard and Geale, 1983a, b
7. Baker Lake, N.W.T.	64°10′	95°30′	11.0	Low arctic	Especially heath, low shrub tundra, wet sedge meadows	Settlement	Krebs, 1964; compare Zoltai and Johnson, 1978
8. Churchill, Manitoba	58°45′	94°04′	11.8	Tree line	Arctic-boreal transition	Settlement, research facilities	McClure, 1943
9. Winter Harbour, Melville Island	74°46′	110°32′	4.5?	High arctic, enriched	Barrens, local sedge meadows	National historic site	Edlund, in press, a
10. Sachs Harbour, Banks Island	71°59′	125°15′	5.9	Low arctic		Former weather station	Edlund, in press, b
11. Tuktoyaktuk, N.W.T.	69°26′	132°56′	10.6	Low arctic, near tree line	Western coastal tundra	Settlement, research facilities	Ritchie, 1984

[1]Temperatures are approximate for some sites (marked "?"), based on records of varying interval and reliability (sources: Atmospheric Environment Service, 1982; Edlund and Alt, 1989; and others).
[2]For additional general information on vegetation, see especially Polunin (1948) for the Eastern Arctic, Ritchie (1984) for the western mainland, and Edlund (1990 and papers cited there) for zonal analysis.

CONCLUSIONS

This paper suggests ways to establish the entomological components of a biological monitoring program; certain general procedures and specific measures would be expected to yield information of particular value in monitoring and interpreting environmental change. These procedures will require detailed faunal studies in key locations, which in turn support attempts to establish quantifiable taxonomic, distributional, ecological and physiological indexes that can be used to test expectations and to compare different sites. A long-term commitment to such detailed studies will be required to profit fully from them.

Although it is not yet feasible to specify the modes by which data can be modelled in detail, measurements of the physical environment for comparison with these indexes logically would emphasize temperatures. However, in addition to standard air temperatures, temperatures in the major microhabitats of arctic insects, shallow water bodies and the soil surface, must be monitored. Among standard meteorological data collected at the same time, assessments of cloud cover (or hours of sunshine) will be needed in particular to analyze the impact of long-term changes, because insolation greatly modifies temperatures in the microsites inhabited by arthropods.

Comparisons of ratios and other derived statistics (such as those introduced in this paper) are likely to prove much more informative for assessing change than the sort of information on insects typically collected in the Arctic: raw numbers of species, chiefly anecdotal observations, and in-depth information addressing very restricted questions. Such quantification allows the enormous and instructive diversity of arctic insects to be used to full advantage and at the same time emphasizes the importance of these organisms in arctic systems.

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