ITEX

a history of collaboration

Bob Hollister et al.

Latnjajaure, Sweden

Australian Alps, Australia

Kari

Bob

Greg

Phil

Ulf

21st -- Vancouver, Canada 2024
20th – Parma, Italy 2019
19th – Stirling, Scotland 2018
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4th -- Oulu, Finland 1992
3rd -- Boulder, Colorado, USA 1992
2nd -- Copenhagen, Denmark 1991
1st -- East Lansing, Michigan, USA 1990

ITEX officially Began in 1990 as the result of a meeting in Michigan led by Pat Webber

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ITEX Resolution

Webber and Walker 1991

Arctic and Alpine Research 23: 125

INTERNATIONAL TUNDRA EXPERIMENT (ITEX)

A workshop was held on 2–5 December 1990 at the Kellogg Biological Station, Michigan State University, U.S.A., to design an international tundra experiment to monitor response of vascular plant species in tundra regions to global climate change. The workshop was attended by 49 participants from 9 countries (Canada, Denmark, Finland, Iceland, Norway, Sweden, United Kingdom, United States, and USSR). It was sponsored and funded jointly by the U.S. National Science Foundation and the U.S. MAB (Man and the Biosphere) High-Latitude Ecosystems Directorate. The experiment is designed to be simple and inexpensive and may be conducted in conjunction with ongoing tundra research at existing sites. The proposed experiment will focus initially on vascular plant species, but future work may include other taxa, including animals.

The following resolution, outlining the workshop's findings and recommendations, was agreed upon by the participants for submission to their respective national organizations and scientific colleagues.

Resolution

As a result of deliberations and consensus achieved at a workshop to design an International Tundra Experiment (ITEX) on December 2–5, 1990, at the Kellogg Biological Station, Michigan State University, U.S.A., the participants from nine countries (Canada, Denmark, Finland, Great Britain, Iceland, Norway, Sweden, United States, USSR) have agreed to submit the following findings and recommendations to their respective organizations and scientific colleagues.

Taking into account

1. That the tundra regions represent an important component of the geosphere-biosphere, being a sensitive indicator of global change and contributing actively in the functioning of the global climate system;
2. That the understanding of the geophysical and ecological processes that occur in the tundra is an important objective of the international community concerned with global change, biodiversity, environmental protection, and sustainable development;
3. That recent acceleration of international interest and cooperation in arctic and alpine science has opened new possibilities for coordinated international research and analyses;

And recognizing

1. That carefully organized comparisons within and among tundra sites and over time will greatly increase understanding of the ecology of tundra species;
2. That coordinated observations and measurements of a few carefully selected arctic species populations occurring along circumpolar megatransects and environmental gradients are achievable;
3. That an experimental approach to a few selected manipulations of the environment is deemed desirable as a cost effective means to compare species responses to variables relevant to global change;
4. That international exchange of scientists, especially students, is highly desirable to enhance communication and training;

The participants therefore agree

That an initial set of selected tundra plant species, measurement protocols and manipulations have been specified for the ITEX experiments starting in 1991 as the result of this international meeting of experts. They, therefore, recommend

1. That the first ITEX experiment focuses on responses of vascular plant species;
2. That a set of abiotic observations and destructive and non-destructive measurements be carefully specified to determine phenological events, reproductive and vegetative effort, physiological responses, and genetic response to the manipulated and predominant environmentsl variables during the growing season and over a period of years;
3. That explicit protocols be developed for simple and relatively inexpensive manipulations of air temperature (such as by small greenhouses) and snow cover (as by snow fences) at participating sites;
4. That sets of selected individuals in field transplant gardens be subjected to a common garden (environmental) experiment and assessed in terms of genetic variation within each species population and its phenotypic response in order to evaluate probable adaptations to climate change;
5. That more complex or expensive experiments involving manipulations such as atmospheric CO_2, or soil temperature and reciprocal transplant gardens, fertilizer treatments, or even phytotron experiments may be desirable and practical for some sites;
6. That appropriate coordination of research, communication and synthesis of results be achieved by a small set of coordinators, and by convening of participating principal investigators for periodic assessment workshops, exchanges of scientists and students among sites will facilitate ITEX;
7. That development of an appropriate protocol for the exchange of ITEX data among participants is needed;
8. That funding for research is the responsibility of each participating country, and may utilize activities already underway, and including Biosphere Reserves, protected areas, and long-term ecological research areas; and
9. That future experiments focusing on other taxa and ecological parameters, including animals, are desirable, and contacts for ITEX established through the MAB Northern Sciences Network are encouraged.

The Unesco MAB Northern Sciences Network, the secretariat of which is located at the Arctic Centre, University of Lapland, Rovaniemi, Finland, has been proposed as the eventual coordinating body for ITEX.

Scientists interested in participating in ITEX should contact either of the interim coordinators for further information:

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Boulder, Colorado 80309-0450
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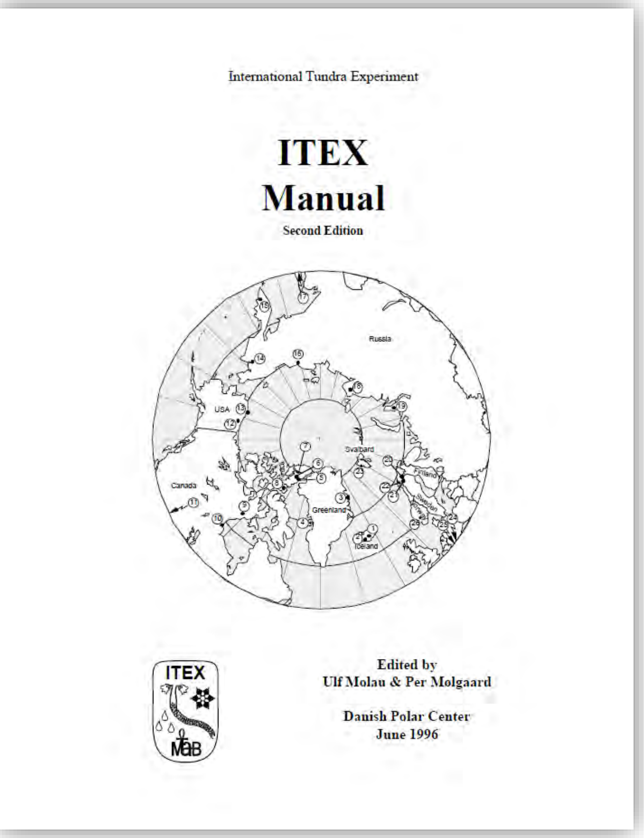
We agreed upon Common Protocols



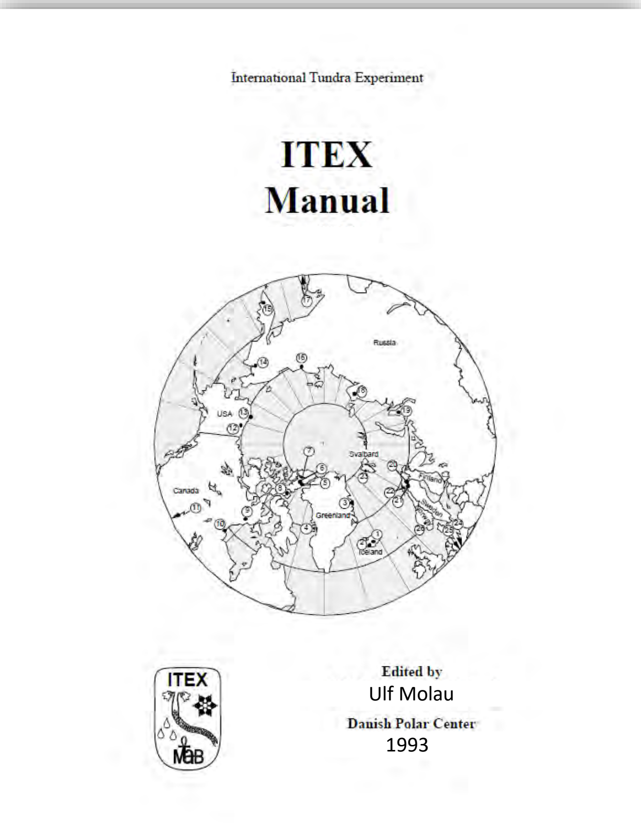
International Tundra Experiment

ITEX Manual

Second Edition

Edited by
Ulf Molau & Per Molgaard

Danish Polar Center
June 1996



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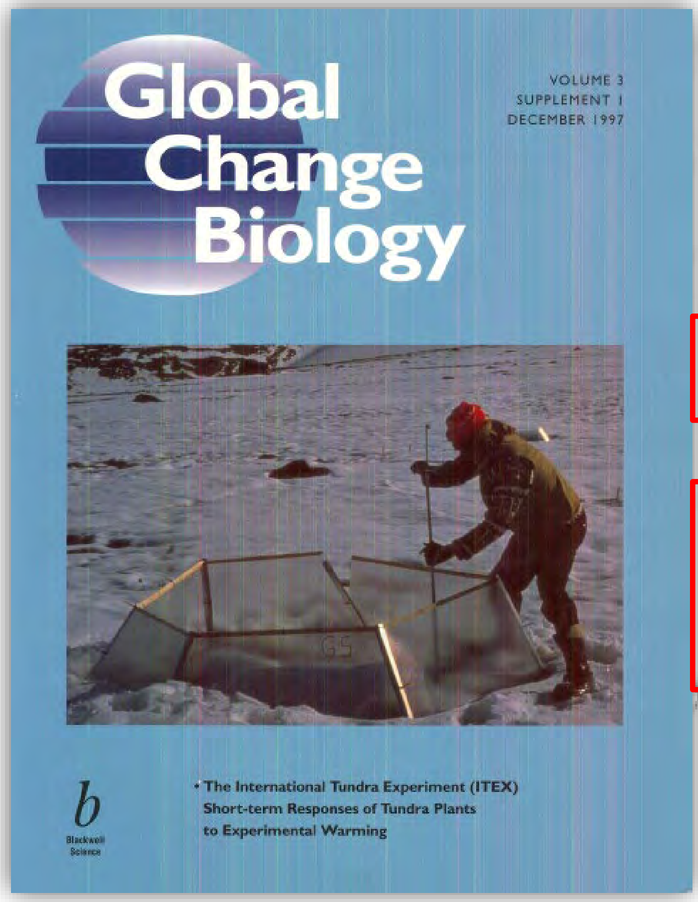

1 Overall Synthesis

15 cross site comparisons

Global Change Biology
Volume 3 Supplement 1, December 1997

Meetings 1994-5
Special Issue 1997
GCB 3(Suppl. 1)

ITEX

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Arft et al. 1999

Ecological Monographs 69(4):491-511

Meeting at NCEAS in December 1996


Ecological Monographs, 69(4), 1999, pp. 491–511

RESPONSES OF TUNDRA PLANTS TO EXPERIMENTAL WARMING: META-ANALYSIS OF THE INTERNATIONAL TUNDRA EXPERIMENT

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Abstract. The International Tundra Experiment (ITEX) is a collaborative, multisite experiment using a common temperature manipulation to examine variability in species response across climatic and geographic gradients of tundra ecosystems. ITEX was designed specifically to examine variability in arctic and alpine species response to increased temperature. We compiled from one to four years of experimental data from 13 different ITEX sites and used meta-analysis to analyze responses of plant phenology, growth, and reproduction to experimental warming. Results indicate that key phenological events such as leaf bud burst and flowering occurred earlier in warmed plots throughout the study period; however, there was little impact on growth cessation at the end of the season. Quantitative measures of vegetative growth were greatest in warmed plots in the early years of the experiment, whereas reproductive effort and success increased in later years. A shift away from vegetative growth and toward reproductive effort and success in the fourth treatment year suggests a shift from the initial response to a secondary response. The change in vegetative response may be due to depletion of stored plant reserves, whereas the lag in reproductive response may be due to the formation of flower buds one to several seasons prior to flowering. Both vegetative and reproductive responses varied among life-forms; herbaceous forms had stronger and more consistent vegetative growth responses than did woody forms. The greater responsiveness of the herbaceous forms may be attributed to their more flexible morphology and to their relatively greater proportion of stored plant reserves. Finally, warmer, low arctic sites produced the strongest growth responses, but colder sites produced a greater reproductive response. Greater resource investment in vegetative growth may be a conservative strategy in the Low Arctic, where there is more competition for light, nutrients, or water, and there may be little opportunity for successful germination or seedling development. In contrast, in the High Arctic, heavy investment in producing seed under a higher temperature scenario may provide an opportunity for species to colonize patches of unvegetated ground. The observed differential response to warming suggests that the primary forces driving the response vary across climatic zones, functional groups, and through time.

Key words: arctic tundra; experimental warming; global change; global warming; International Tundra Experiment; ITEX; meta-analysis; plant response patterns; spatiotemporal gradients; tundra plants.

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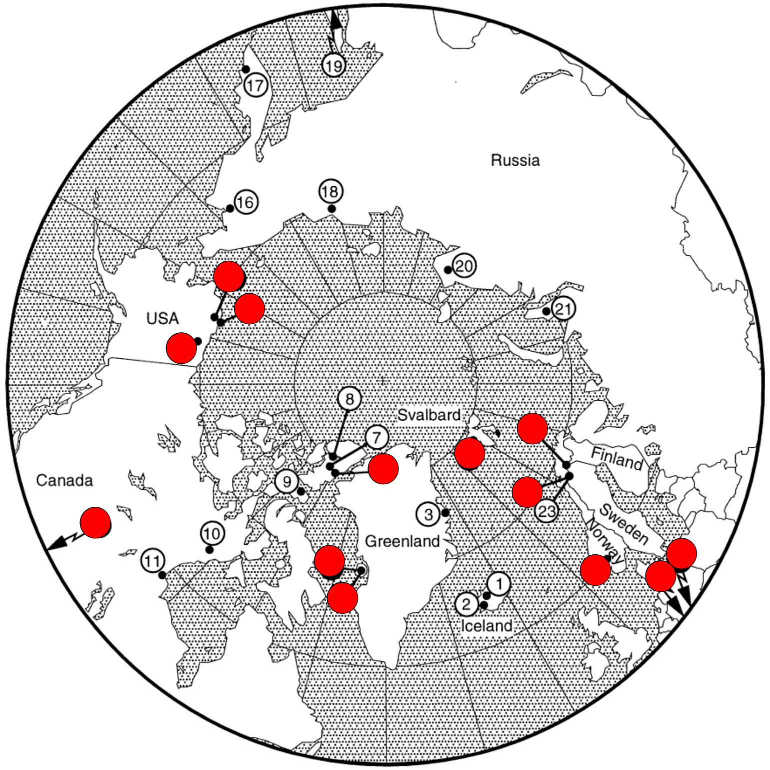

What do we do next?

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1st -- East Lansing, Michigan, USA 1990

Abisko Accord 2000

Witness the Arctic 8(2): 6

ITEX network re-affirms itself

ARCSS Program

ITEX Builds on First Decade, Renews Direction

The International Tundra Experiment (ITEX) held its tenth All-Scientists Workshop, *ITEX in the New Millennium*, in Abisko, Swedish Lapland in September 2000. Following progress reports and posters describing ten years of ITEX research, participants took the opportunity to assess the need and nature of continuing research directions. They addressed current issues including experimental methods, database management and data sharing, scaling up, and the relationship between ITEX and other international initiatives and funding.

The plenary coordination of these sessions, led by ITEX Chair Philip Wookey (University of Uppsala), resulted in the Abisko Accord (see box). This accord builds on the ITEX Resolution from the founding meeting of ITEX held in Michigan in December 1990 (*Arctic and Alpine Research* 23[1]:125). The new accord is seen as a blueprint and a platform for future developments in the program.

The Abisko workshop was organized by a committee chaired by Ulf Molau (Göteborg University) and hosted by Terry Callaghan, Director of the Abisko Scientific Research Station.

While at Abisko, the U.S. members of ITEX met with Program Officers Tom Pyle and Michael Ledbetter from the NSF Office of Polar Programs to discuss progress within NATEX (North American Tundra Experiment) and to stress the need for archiving and sharing of data. NATEX held an ITEX synthesis workshop on plant community change in Boulder, Colorado in February 2001. For more information, see www.lter.uaf.edu/~becru/ITEX_Workshop_Welcome.html.

The 11th meeting of ITEX is scheduled for 28 September–1 October 2001 at Finse in alpine Norway. Ørjan Totland (Agricultural University of Norway) will host the meeting. For more information, see www.nlh.no/ibn/itex2001.

For more information about ITEX, see the web sites at the Secretariat at the Danish Polar Center (www.dpc.dk/NSNITEX/Start.html) and Göteborg University (www.systbot. gu.se/research/ITEX/itex.html).

Abisko Accord

(25 September 2000)

Further to discussions at the 10th ITEX meeting in Abisko, Swedish Lapland, between 23-25 September 2000, the meeting participants hereby reaffirm our commitment to the continuation and further development of the International Tundra Experiment (ITEX).

We agree that:

- The original ITEX Resolution drafted at the Kellogg Biological Station, Michigan State University, USA, on 4 December 1990 remains valid.
- This Accord therefore supplements and extends (but does not replace) the 1990 Resolution.
- ITEX is a working, viable, and dynamic international program.
- We will regularly re-evaluate the methods and goals of ITEX relative to current research developments and, where necessary, respond by modifying our activities accordingly.
- The scope of ITEX includes the tundra biome in general; it is not, therefore, restricted to arctic tundra but rightfully incorporates alpine and Antarctic tundras (*inter alia* the connection between ITEX and Regional Sensitivity to Climate Change in Antarctic Terrestrial and Limnetic Ecosystems (RiSCC).

Key facets of ITEX after ten years include:

- the successful development and maintenance of an international network of research sites in the tundra biome;
- the continued use of common experiments and protocols to improve understanding of global change impacts upon biological processes in tundra ecosystems;
- the training and international exchange of young researchers (graduate and undergraduate);
- a continued focus upon biological responses to environment at the level of the species and functional group;
- increasing emphasis upon population and community dynamics and medium- to longer-term system responses to change;
- increasing emphasis upon meta-analytical techniques, development of databases, and ecological modelling; and
- initiation of advisory activities in relation to international monitoring networks and scientific agencies (such as Conservation of Arctic Flora and Fauna [CAFF] of the Arctic Council [see *Witness* Spring/Autumn 1999] and the Newsletter of the Global Change in Terrestrial Ecosystems Core Project of IGBP (International Geosphere-Biosphere Programme [GCTE News]).

We are committed to:

- retaining a flexible approach that allows for development of new research initiatives, but with a core of manipulation and monitoring activities at individual sites;
- exploring the relationship between species-specific responses to environmental change, and how these are modulated by community and site characteristics, and feedbacks on further change;
- evaluating ITEX investigations within the context of broader spatial scales, longer temporal scales, and higher trophic levels;
- exploring pragmatic approaches to long-term monitoring and measurement, designed to quantify and distinguish between (i) inter-annual variability in system state, and (ii) longer-term directional changes;
- development and implementation of an appropriate protocol for the exchange of ITEX data among participants and the broader community;
- development of thematic groups focused upon specific aspects of climate change impacts;
- development of procedures for sample collection, sharing and/or common analysis;
- regular meetings (yearly or biennial) with specific themes and progress reports;
- dissemination of data and research results to the broader community;
- development of a strong and active Steering Committee that will provide leadership and continuity and that will conduct business according to a set of by-laws.

ITEX Synthesis Community Change

Walker et al. 2006
PNAS 103(5): 1342-46

Meeting at UCAR in February 2001

Plant community responses to experimental warming across the tundra biome

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Edited by F. Stuart Chapin III, University of Alaska, Fairbanks, AK, and approved December 11, 2005 (received for review April 19, 2005)

Recent observations of changes in some tundra ecosystems appear to be responses to a warming climate. Several experimental studies have shown that tundra plants and ecosystems can respond strongly to environmental change, including warming; however, most studies were limited to a single location and were of short duration and based on a variety of experimental designs. In addition, comparisons among studies are difficult because a variety of techniques have been used to achieve experimental warming and different measurements have been used to assess responses. We used metaanalysis on plant community measurements from standardized warming experiments at 11 locations across the tundra biome involved in the International Tundra Experiment. The passive warming treatment increased plant-level air temperature by 1–3°C, which is in the range of predicted and observed warming for tundra regions. Responses were rapid and detected in whole plant communities after only two growing seasons. Overall, warming increased height and cover of deciduous shrubs and graminoids, decreased cover of mosses and lichens, and decreased species diversity and evenness. These results predict that warming will cause a decline in biodiversity across a wide variety of tundra, at least in the short term. They also provide rigorous experimental evidence that recently observed increases in shrub cover in many tundra regions are in response to climate warming. These changes have important implications for processes and interactions within tundra ecosystems and between tundra and the atmosphere.

arctic and alpine ecosystems | biodiversity | climate change | vegetation change

Detecting biotic responses to a changing environment is essential for understanding the consequences of global climate change (1–4). Shifts in the composition and abundance of plant species will have important effects on ecosystem processes, including net primary production and nutrient cycling, and on organisms at all trophic levels (5). Vegetation changes are expected to be large in tundra regions (1, 4, 6) in response to predicted warming, although the variability in tundra vegetation at local and regional scales makes it difficult to predict these changes. Arctic regions have been warming since the mid-1800s (7), but the warming has accelerated in recent decades (1, 7, 8) and is expected to continue throughout this century (1, 4). Model projections show that the warming could result in the loss of as much as 40% of the current tundra area by the year 2100 as it is replaced by boreal forest (1). Observational studies have found that leaf-out is earlier (9) and shrub cover has increased in areas such as northern Alaska (10). Many observed biotic changes are consistent with expected responses to increasing temperature (11, 12); however, experimental warming provides a direct test of the effect of temperature on plant communities.

Over the past two decades, experimental studies have shown that tundra plants can respond strongly to environmental manipulations, including warming (e.g., refs. 13–16), and there have been a few syntheses of these studies (17–20). However, most of the previous studies were conducted at single sites for relatively short periods using methods unique to the study. The restricted geographic coverage, short duration, and variability in experimental design hinder the general conclusions from syntheses of these studies. These shortcomings were highlighted in the recent synthesis of responses of arctic terrestrial ecosystems to climate change completed for the Arctic Climate Impact Assessment (1), which recommended better coordination of research throughout the Arctic. Here, we report whole plant community results from standardized warming experiments conducted at 11 locations throughout the tundra biome (Fig. 1). The studies are part of the International Tundra Experiment (ITEX), which is a network of arctic and alpine sites throughout the world where experimental and observational studies have been established by using standardized protocols to measure responses of tundra plants and plant communities to increased temperature (16, 17, 21–28). The use of standardized protocols helps to ensure data are comparable among sites and increases the strength and reliability of conclusions based on analyses of the data. In a previous synthesis of short-term plant responses at ITEX sites (17), we found that graminoid and forb species showed the strongest growth responses to experimental warming, and these were greatest in the

Conflict of interest statement: No conflicts declared.

This paper was submitted directly (Track II) to the PNAS office.

Abbreviation: ITEX, International Tundra Experiment.

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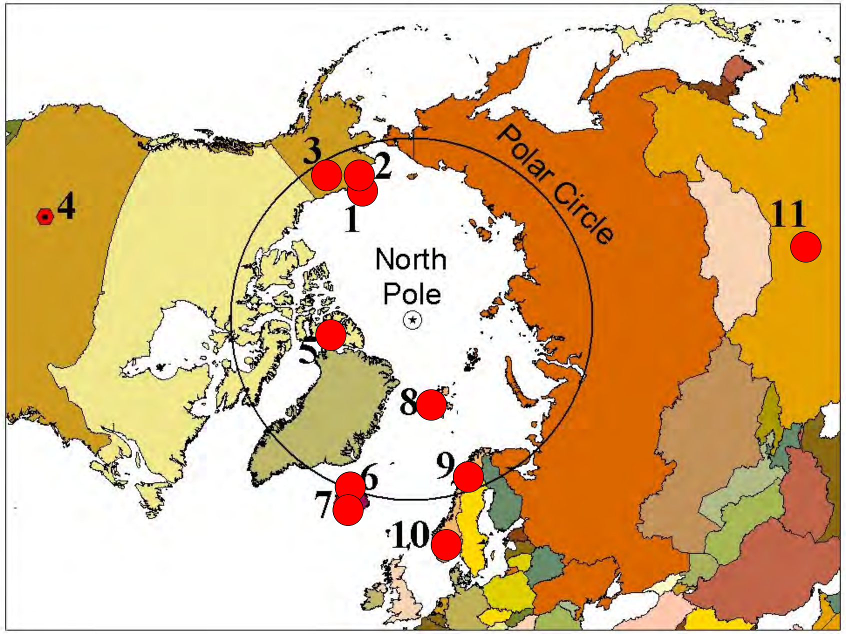

Ecological Monographs, 77(2), 2007, pp. 221–238

TUNDRA CO_2 FLUXES IN RESPONSE TO EXPERIMENTAL WARMING ACROSS LATITUDINAL AND MOISTURE GRADIENTS

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Abstract. Climate warming is expected to differentially affect CO_2 exchange of the diverse ecosystems in the Arctic. Quantifying responses of CO_2 exchange to warming in these ecosystems will require coordinated experimentation using standard temperature manipulations and measurements. Here, we used the International Tundra Experiment (ITEX) standard warming treatment to determine CO_2 flux responses to growing-season warming for ecosystems spanning natural temperature and moisture ranges across the Arctic biome. We used the four North American Arctic ITEX sites (Toolik Lake, Atqasuk, and Barrow [USA] and Alexandra Fiord [Canada]) that span 10° of latitude. At each site, we investigated the CO_2 responses to warming in both dry and wet or moist ecosystems. Net ecosystem CO_2 exchange (NEE), ecosystem respiration (ER), and gross ecosystem photosynthesis (GEP) were assessed using chamber techniques conducted over 24-h periods sampled regularly throughout the summers of two years at all sites.

At Toolik Lake, warming increased net CO_2 losses in both moist and dry ecosystems. In contrast, at Atqasuk and Barrow, warming increased net CO_2 uptake in wet ecosystems but increased losses from dry ecosystems. At Alexandra Fiord, warming improved net carbon uptake in the moist ecosystem in both years, but in the wet and dry ecosystems uptake increased in one year and decreased the other. Warming generally increased ER, with the largest increases in dry ecosystems. In wet ecosystems, high soil moisture limited increases in respiration relative to increases in photosynthesis. Warming generally increased GEP, with the notable exception of the Toolik Lake moist ecosystem, where warming unexpectedly decreased GEP >25%. Overall, the respiration response determined the effect of warming on ecosystem CO_2 balance. Our results provide the first multiple-site comparison of arctic tundra CO_2 flux responses to standard warming treatments across a large climate gradient. These results indicate that (1) dry tundra may be initially the most responsive ecosystems to climate warming by virtue of strong increases in ER, (2) moist and wet tundra responses are dampened by higher water tables and soil water contents, and (3) both GEP and ER are responsive to climate warming, but the magnitudes and directions are ecosystem-dependent.

Key words: carbon balance; climate warming; ecosystem respiration; High Arctic; International Tundra Experiment, ITEX; Low Arctic; net ecosystem exchange; soil moisture; tundra; water table.

Introduction

Climate warming in the Arctic is expected to strongly affect the carbon balance of tundra ecosystems, and some studies suggest that the carbon balance of these ecosystems is already changing (Oechel et al. 1993, 1995, 2000, ACIA 2005). Of great concern is that the very large stores of carbon present as peat in arctic ecosystems may be released as the Arctic warms and dries (Billings 1987, Oechel and Billings 1992, Shaver et al. 1992). However, the Arctic encompasses a wide range of tundra ecosystems with differing productivity that are arrayed along bioclimatic gradients (Webber 1974, Gilmanov and Oechel 1995). Furthermore, within a bioclimatic zone, different tundra ecosystems are positioned along topographic gradients in response to different soil moisture and nutrient regimes (Billings 1973, Bliss 2000). Ridgetops typically have low-growing dry vegetation dominated by dwarf shrubs and lichens,

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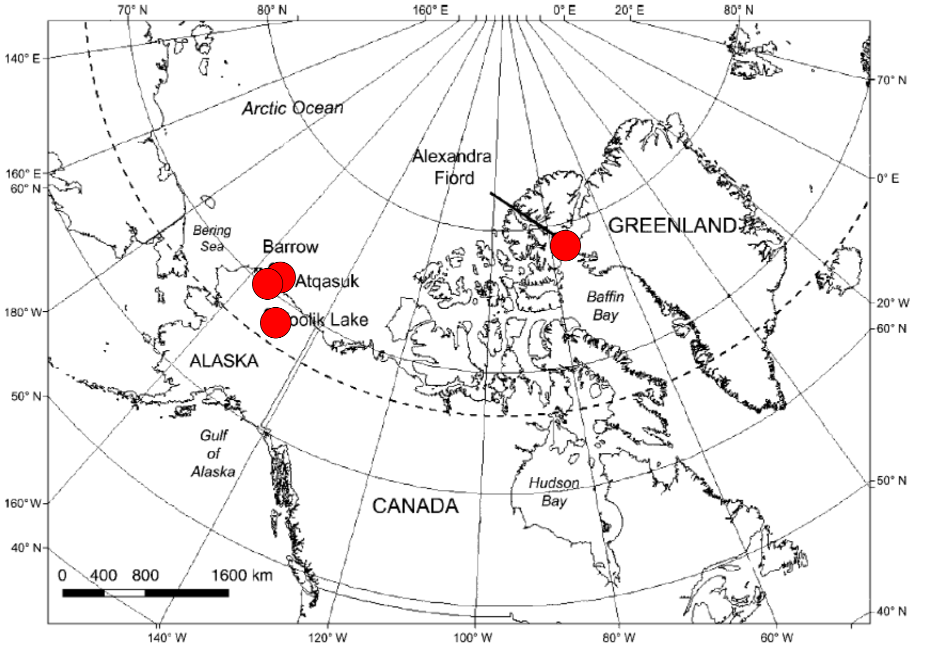
ITEX Synthesis
Carbon Flux

Oberbauer et al. 2007

Ecological Monographs 77(2): 221-238



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What do we do next?

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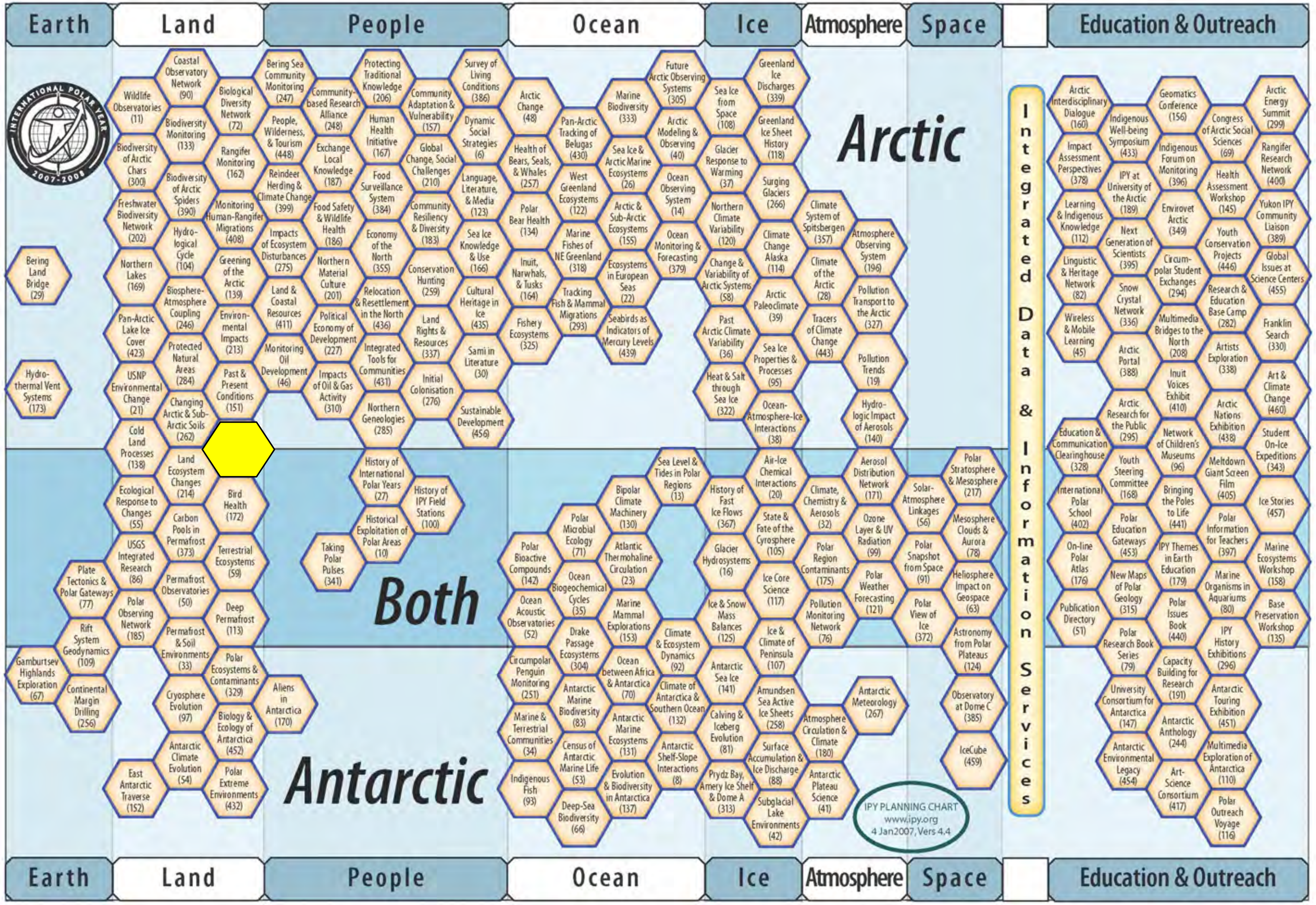

ITEX Synthesis
Community Change II

Elmendorf et al. 2012
Ecology Letters 15(2): 164-175


ECOLOGY LETTERS

Ecology Letters, (2012) 15: 164–175 doi: 10.1111/j.1461-0248.2011.01716.x

REVIEW AND SYNTHESES

Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time

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Abstract

Understanding the sensitivity of tundra vegetation to climate warming is critical to forecasting future biodiversity and vegetation feedbacks to climate. *In situ* warming experiments accelerate climate change on a small scale to forecast responses of local plant communities. Limitations of this approach include the apparent site-specificity of results and uncertainty about the power of short-term studies to anticipate longer term change. We address these issues with a synthesis of 61 experimental warming studies, of up to 20 years duration, in tundra sites worldwide. The response of plant groups to warming often differed with ambient summer temperature, soil moisture and experimental duration. Shrubs increased with warming only where ambient temperature was high, whereas graminoids increased primarily in the coldest study sites. Linear increases in effect size over time were frequently observed. There was little indication of saturating or accelerating effects, as would be predicted if negative or positive vegetation feedbacks were common. These results indicate that tundra vegetation exhibits strong regional variation in response to warming, and that in vulnerable regions, cumulative effects of long-term warming on tundra vegetation – and associated ecosystem consequences – have the potential to be much greater than we have observed to date.

Keywords

Alpine, Arctic, climate warming, long-term experiment, meta-analysis, plants.

Ecology Letters (2012) 15: 164–175

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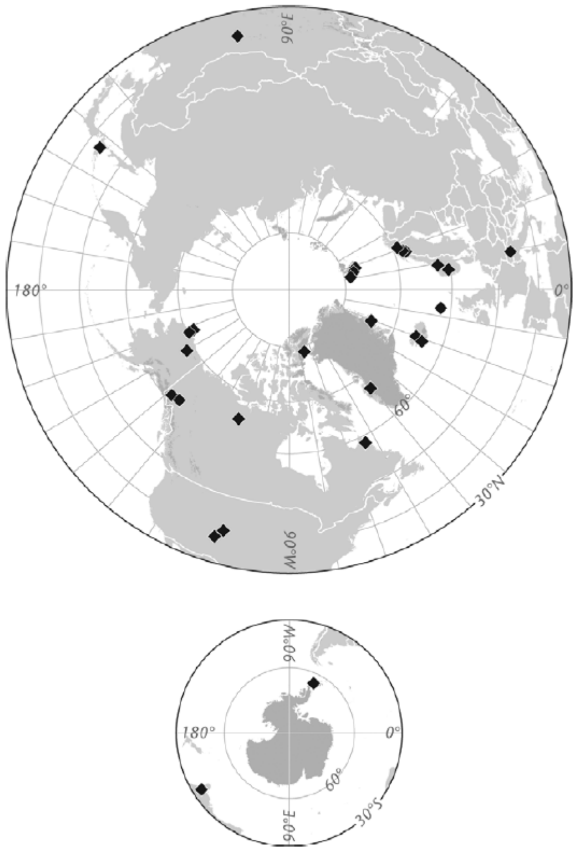

ITEX Synthesis
Community Change II
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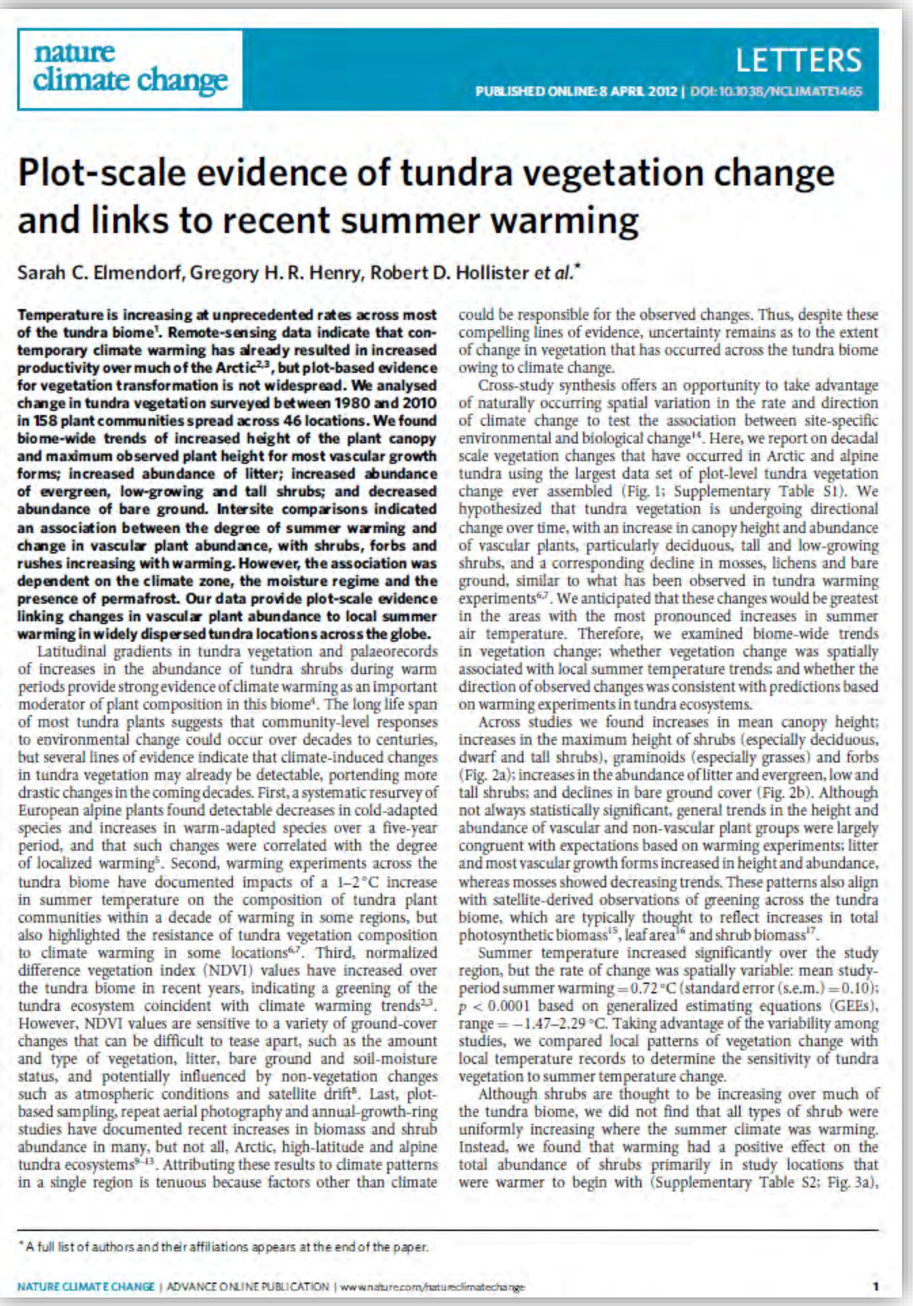
Elmendorf et al. 2012

Nature Climate Change 2(6): 453-457



nature climate change

LETTERS

PUBLISHED ONLINE: 8 APRIL 2012 | DOI: 10.1038/NCLIMATE1465

Plot-scale evidence of tundra vegetation change and links to recent summer warming

Sarah C. Elmendorf, Gregory H. R. Henry, Robert D. Hollister *et al.**

Temperature is increasing at unprecedented rates across most of the tundra biome[1]. Remote-sensing data indicate that contemporary climate warming has already resulted in increased productivity over much of the Arctic[2,3], but plot-based evidence for vegetation transformation is not widespread. We analysed change in tundra vegetation surveyed between 1980 and 2010 in 158 plant communities spread across 46 locations. We found biome-wide trends of increased height of the plant canopy and maximum observed plant height for most vascular growth forms; increased abundance of litter; increased abundance of evergreen, low-growing and tall shrubs; and decreased abundance of bare ground. Intersite comparisons indicated an association between the degree of summer warming and change in vascular plant abundance, with shrubs, forbs and rushes increasing with warming. However, the association was dependent on the climate zone, the moisture regime and the presence of permafrost. Our data provide plot-scale evidence linking changes in vascular plant abundance to local summer warming in widely dispersed tundra locations across the globe.

Latitudinal gradients in tundra vegetation and palaeorecords of increases in the abundance of tundra shrubs during warm periods provide strong evidence of climate warming as an important moderator of plant composition in this biome[4]. The long life span of most tundra plants suggests that community-level responses to environmental change could occur over decades to centuries, but several lines of evidence indicate that climate-induced changes in tundra vegetation may already be detectable, portending more drastic changes in the coming decades. First, a systematic resurvey of European alpine plants found detectable decreases in cold-adapted species and increases in warm-adapted species over a five-year period, and that such changes were correlated with the degree of localized warming[5]. Second, warming experiments across the tundra biome have documented impacts of a 1–2 °C increase in summer temperature on the composition of tundra plant communities within a decade of warming in some regions, but also highlighted the resistance of tundra vegetation composition to climate warming in some locations[6,7]. Third, normalized difference vegetation index (NDVI) values have increased over the tundra biome in recent years, indicating a greening of the tundra ecosystem coincident with climate warming trends[2,3]. However, NDVI values are sensitive to a variety of ground-cover changes that can be difficult to tease apart, such as the amount and type of vegetation, litter, bare ground and soil-moisture status, and potentially influenced by non-vegetation changes such as atmospheric conditions and satellite drift[8]. Last, plot-based sampling, repeat aerial photography and annual-growth-ring studies have documented recent increases in biomass and shrub abundance in many, but not all, Arctic, high-latitude and alpine tundra ecosystems[9–13]. Attributing these results to climate patterns in a single region is tenuous because factors other than climate could be responsible for the observed changes. Thus, despite these compelling lines of evidence, uncertainty remains as to the extent of change in vegetation that has occurred across the tundra biome owing to climate change.

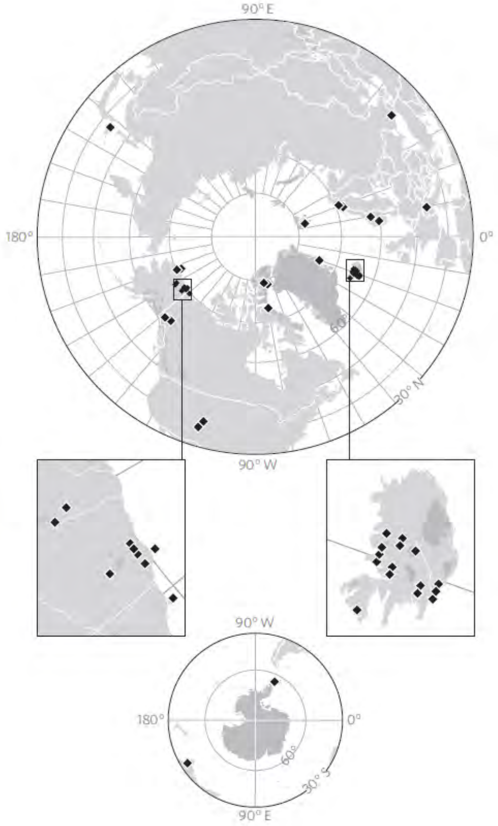
Cross-study synthesis offers an opportunity to take advantage of naturally occurring spatial variation in the rate and direction of climate change to test the association between site-specific environmental and biological change[14]. Here, we report on decadal scale vegetation changes that have occurred in Arctic and alpine tundra using the largest data set of plot-level tundra vegetation change ever assembled (Fig. 1; Supplementary Table S1). We hypothesized that tundra vegetation is undergoing directional change over time, with an increase in canopy height and abundance of vascular plants, particularly deciduous, tall and low-growing shrubs, and a corresponding decline in mosses, lichens and bare ground, similar to what has been observed in tundra warming experiments[6,7]. We anticipated that these changes would be greatest in the areas with the most pronounced increases in summer air temperature. Therefore, we examined biome-wide trends in vegetation change; whether vegetation change was spatially associated with local summer temperature trends; and whether the direction of observed changes was consistent with predictions based on warming experiments in tundra ecosystems.

Across studies we found increases in mean canopy height; increases in the maximum height of shrubs (especially deciduous, dwarf and tall shrubs), graminoids (especially grasses) and forbs (Fig. 2a); increases in the abundance of litter and evergreen, low and tall shrubs; and declines in bare ground cover (Fig. 2b). Although not always statistically significant, general trends in the height and abundance of vascular and non-vascular plant groups were largely congruent with expectations based on warming experiments; litter and most vascular growth forms increased in height and abundance, whereas mosses showed decreasing trends. These patterns also align with satellite-derived observations of greening across the tundra biome, which are typically thought to reflect increases in total photosynthetic biomass[15], leaf area[16] and shrub biomass[17].

Summer temperature increased significantly over the study region, but the rate of change was spatially variable: mean study-period summer warming = 0.72 °C (standard error (s.e.m.) = 0.10); $p < 0.0001$ based on generalized estimating equations (GEEs), range = −1.47–2.29 °C. Taking advantage of the variability among studies, we compared local patterns of vegetation change with local temperature records to determine the sensitivity of tundra vegetation to summer temperature change.

Although shrubs are thought to be increasing over much of the tundra biome, we did not find that all types of shrub were uniformly increasing where the summer climate was warming. Instead, we found that warming had a positive effect on the total abundance of shrubs primarily in study locations that were warmer to begin with (Supplementary Table S2; Fig. 3a),

*A full list of authors and their affiliations appears at the end of the paper.



ITEX Synthesis Phenology

Oberbauer et al. 2013

Phil Trans R Soc B 368(1624): 20120481

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Research

Cite this article: Oberbauer SF *et al.* 2013 Phenological response of tundra plants to background climate variation tested using the International Tundra Experiment. Phil Trans R Soc B 368: 20120481. http://dx.doi.org/10.1098/rstb.2012.0481

One contribution of 11 to a Theme Issue 'Long-term changes in Arctic tundra ecosystems'.

Subject Areas:
plant science, ecology

Keywords:
growth form, season length, snowmelt, thaw degree days

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Electronic supplementary material is available at http://dx.doi.org/10.1098/rstb.2012.0481 or via http://rstb.royalsocietypublishing.org.

Royal Society Publishing

Phenological response of tundra plants to background climate variation tested using the International Tundra Experiment

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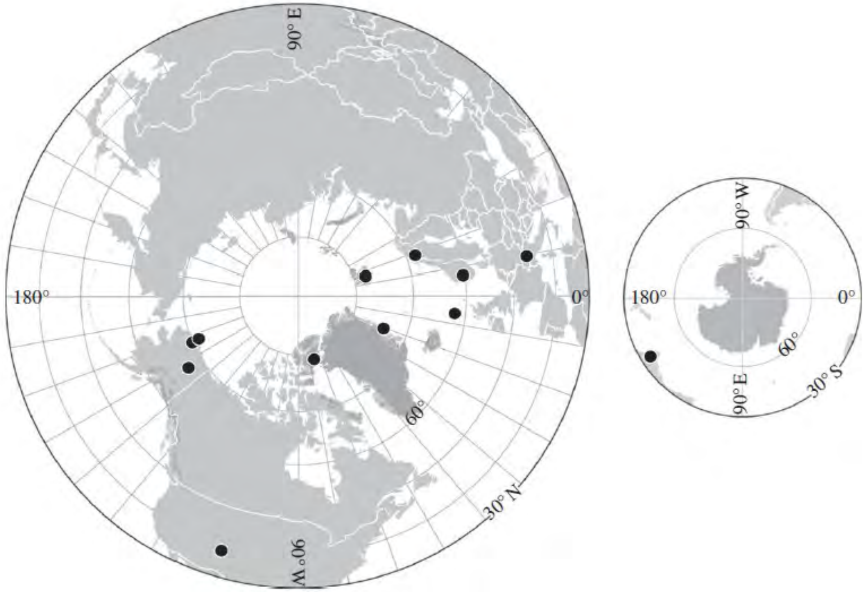
The rapidly warming temperatures in high-latitude and alpine regions have the potential to alter the phenology of Arctic and alpine plants, affecting processes ranging from food webs to ecosystem trace gas fluxes. The International Tundra Experiment (ITEX) was initiated in 1990 to evaluate the effects of expected rapid changes in temperature on tundra plant phenology, growth and community changes using experimental warming. Here, we used the ITEX control data to test the phenological responses to background temperature variation across sites spanning latitudinal and moisture gradients. The dataset overall did not show an advance in phenology; instead, temperature variability during the years sampled and an absence of warming at some sites resulted in mixed responses. Phenological transitions of high Arctic plants clearly occurred at lower heat sum thresholds than those of low Arctic and alpine plants. However, sensitivity to temperature change was similar among plants from the different climate zones. Plants of different communities and growth forms differed for some phenological responses. Heat sums associated with flowering and greening appear to have increased over time. These results point to a complex suite of changes in plant communities and ecosystem function in high latitudes and elevations as the climate warms.

1. Introduction

As Arctic and alpine regions warm in response to climate change, the growing season for plants is expected to increase from earlier snowmelt in the spring, later snow accumulation in the autumn, or both [1–4]. These climatic zones will also experience higher temperatures during the growing season, although most of the warming for high latitudes and high elevations is projected for the



Global Change Biology

Global Change Biology (2017) 23, 2660–2671, doi: 10.1111/gcb.13619

Greater temperature sensitivity of plant phenology at colder sites: implications for convergence across northern latitudes

2017

Global Change Biology

Global Change Biology (2017) 23, 2660–2671, doi: 10.1111/gcb.13619

Greater temperature sensitivity of plant phenology at colder sites: implications for convergence across northern latitudes

2017

2018

ARTICLE

https://doi.org/10.1038/s41586-018-0563-7

Plant functional trait change across a warming tundra biome

Global Change Biology

Global Change Biology (2017) 23, 2660–2671, doi: 10.1111/gcb.13619

2017

Greater temperature sensitivity of plant phenology at colder sites: implications for convergence across northern latitudes

2018

ARTICLE

https://doi.org/10.1038/s41586-018-0563-7

Plant functional trait change across a warming tundra biome

nature ecology & evolution

ARTICLES

https://doi.org/10.1038/s41559-018-0745-6

2019

Warming shortens flowering seasons of tundra plant communities

Global Change Biology
Global Change Biology (2017) 23, 2660–2671, doi: 10.1111/gcb.13619

2017

Greater temperature sensitivity of plant phenology at colder sites: implications for convergence across northern latitudes

ARTICLE
https://doi.org/10.1038/s41586-018-0563-7

2018

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nature ecology & evolution
ARTICLES
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2019

Warming shortens flowering seasons of tundra plant communities

Received: 20 September 2017 | Revised: 24 May 2018 | Accepted: 29 May 2018
DOI: 10.1111/geb.12783

2019

RESEARCH PAPER
WILEY Global Ecology and Biogeography A Journal of Macroecology

Traditional plant functional groups explain variation in economic but not size-related traits across the tundra biome

ARTICLE

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https://doi.org/10.1038/s41467-021-23841-2

OPEN

Experimental warming differentially affects vegetative and reproductive phenology of tundra plants

2021

ARTICLE

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https://doi.org/10.1038/s41467-021-23841-2 OPEN

Experimental warming differentially affects vegetative and reproductive phenology of tundra plants

2021

2022

ARTICLE

https://doi.org/10.1038/s41467-021-23841-2 OPEN

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Experimental warming differentially affects vegetative and reproductive phenology of tundra plants

2021

2022

2023

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Article

https://doi.org/10.1038/s41467-023-39573-4

Plant traits poorly predict winner and loser shrub species in a warming tundra biome

International Tundra Experiment (ITEX) Network

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ITEX Network

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ITEX   Terrestrial Ecosystems   Global Change Biology   Tundra   Climate Change Impacts

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Ongoing and planned synthesis activities using the ITEX network or ITEX data sets are:

Linking root traits with above ground phenology (Elise Gallois)
Mycorrhiza (Kevin Van Sundert)
Arctic plant diversity dynamics (Mariana García Criado)
Arctic vascular plant functional diversity (Joseph Everest)
Arctic vascular plant phylogenetic diversity (Ruud Scharn)
Coexistence theory (Yanhao Feng)
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Plant Community Synthesis (Robert Björk & Ruud Scharn)
Tundra Trait Team (Anne Bjorkman)
Phenology (Christian Rixen, Janet Prevéy, Zoe Panchen, Sarah Elmendorf, Courtney Collins & Geerte de Jong).
Below Ground Processes (Juha Alatalo & Sara Hallin)
Herbivore Activity (Isabel Barrio & Inga Svala Jónsdóttir)
sTundra (Isla Myers-Smith, Anne Bjorkman, & Sarah Elmendorf)
Eriophorum vaginatum material (Ned Fetcher)
Common Garden (Greg Henry, Anne Bjorkman, & Esther Frei)