

METHODS

Sites

Source sites for the mesocosms consisted of a bog and a fen in the townships of Toivola and Alborn, respectively, in northeastern Minnesota (47°N, 92°W). The peat in the bog site is approximately 3.5 m deep with a basal date of 10,040 ± 70 years BP. The upper 60 cm is derived largely from *Sphagnum* moss, with increasing herbaceous remains below that point, and frequent woody inclusions throughout the profile. Porewater pH at Toivola is generally less than 4, with a mean H-corrected specific conductivity of about 1 uS cm⁻¹. The surface 0-25 cm of peat has a pH of 4.1, 42.2% carbon, 8.4% ash, and 73.7% rubbed fiber content on a dry-mass basis (Bridgham et al. 1998). Current vegetation is dominated by stunted (< 10-cm height), ericaceous shrubs (*Chamaedaphne calyculata* (L.) Moench., *Andromeda glaucophylla* Link., *Kalmia polifolia* Wang., *Vaccinium oxycoccos* L., *Ledum groenlandicum* Oeder.), mosses (*Sphagnum fuscum* (Schimp.) Klinggr., *S. capillifolium* (Ehrh.) Hedw., *S. magellanicum* Brid., *Polytrichum strictum* Brid.), and black spruce. We chose a large treeless area in the center of the bog that, based upon stratigraphic evidence, had burned approximately 100 years ago.

The fen is part of an extensive patterned fen system. It has approximately 4.4 m of sedge peat overlying about 2 m of unconsolidated aquatic (limnic) peat, with a basal age of 9730 ± 70 years BP. Water tables generally are above +3 to 4 cm in the flarks (pools). The monolith source sites were located mainly in flarks in order to minimize within-plot variability and maximize vegetation contrast with the bog. Porewater pH is about 5 and mean conductivity is 9.3 uS cm⁻¹. Porewater cation concentrations (Mg, Ca and Na) in samples of fen porewaters analyzed in 1995 were at least twice those seen in bog waters, although K was half as high as in the bog. The surface 0-25 cm of peat has a pH of 4.9, 38.6% carbon, 22.3% ash, and 29.2% rubbed fiber content on a dry-mass basis (Bridgham et al. 1998). To maximize the contrast with the bog, we chose low areas (flarks) that were dominated by graminoids (*Rhynchospora alba* (L.) Vahl, *R. fusca* (L.) Ait. f., *Carex limosa* L., *C. lasiocarpa* Ehrh., *C. livida* (Wahl.) Willd.) with minimal cover by mosses.

Experimental Design

We extracted intact peat monoliths from the two source sites and constructed a mesocosm facility to manipulate infrared inputs and water-table levels in a replicated experimental framework. This design also allowed measurement of plant community response and carbon, nutrient, and energy fluxes. With closely monitored water budgets, the mesocosms serve as lysimeters from which evapotranspiration and latent heat can be calculated. Although we augment atmospheric infrared inputs into the experimental plots, we do not control soil temperatures at some set point above ambient conditions. Therefore, in our experiment soil temperature is a dependent variable that can respond to internal ecosystem controls.

The construction of the mesocosm facility was begun in autumn 1993 at the University of Minnesota Fens Research Facility (FRF), approximately 70 km north of Duluth, MN. Twenty-seven intact cylindrical peat monoliths (2.1-m² surface area, 0.5 to 0.7-m depth) were removed each from the bog and fen, transported to the FRF, and placed in insulated plastic tanks of similar dimensions that had been sunken into a large field. The peat monoliths were removed with no surface disturbance to vegetation in late winter while frozen. Infrared radiation was augmented with overhead lamps set at none (ambient), ~ +40 W m⁻², and ~ +90 W m⁻² above ambient. Although these infrared loads are considerably above those predicted under a 2 x CO₂

atmosphere, soil temperature increases in the heated plots are approximately 1.6 to 4.1 °C above ambient (Bridgman et al. 1999), well within the range of temperature increases predicted by global climate models. Heating treatments and energy flux measurements continue on a year-round basis. Water-table levels in peatlands are typically measured relative to surface depressions or hollows. We designated a datum hollow in each mesocosm from which we initially set water-table levels to approximately +1, -10, and -20 cm relative its surface. Treatment combinations were replicated 3 times and randomly assigned within each ecosystem type, yielding a full-factorial experimental design (2 ecosystem types X 3 water-table treatments X 3 infrared-loading treatments X 3 replicates, N=54).

Mesocosm Construction

The plastic tanks were insulated with 8 cm of sprayed urethane foam to reduce heat loss to the surrounding soil and buried in the ground. Perforated 1.25-cm diameter PVC pipe was placed along the bottom of the mesocosms and connected to an adjacent small "sump" bucket with an L-shaped PVC standpipe, the height of which set the water-table level in the adjoining mesocosm tank.

In the winter of 1993-94, a local contractor constructed access roads built on frozen peat into the source sites for heavy equipment access. We used a backhoe, a steel ring approximately the same dimensions as the mesocosm tanks, and a hydraulic-powered "clam-shell" apparatus to cut underneath the steel ring and extract the monolith. The peat monolith (weighing approximately 1.5 Mg, with intact vegetation and soil structure) was bundled and transported by trailer to the FRF. Straps were slid under each monolith, and it was carefully lowered with a forklift into its recipient tank.

Heating began on July 27, 1994 with infrared heat lamps (Kalgro Electronics Co., Bethlehem, PA). A 1.2-m long lamp was mounted approximately 130 cm above the mean surface height of each plot and left on continuously. Reflectors on the lamps distribute the infrared radiation evenly over the entire surface of the plot. We estimated ground-level IR inputs at a nominal 78 and 191 W m⁻² above background levels at half and full power, respectively, based on measurements with a THRDS-7 Total Hemispheric Radiometer (Radiation and Energy Balance Systems, Seattle, WA). Operationally, net IR inputs depended on many external factors, in particular windspeed, and in practice is about half of our nominal values (J. Chen, unpublished data). Cover characteristics also influence net IR inputs, with the result that the fen plots are, on average, 0.8 to 1° C warmer than the bog plots. Overall increases in mean growing-season soil temperature range from 1.6 to 4.1° C (Bridgman et al. 1999). Many of the mechanical controllers of the infrared lamps failed, and by 1996 many of the "half-heat" treatments were in fact receiving full heat. All the controllers were replaced with digital models early in 1998, enabling the restoration of our original settings.

Water-Table Control and Evapotranspiration Calculations

Water levels in each plot are maintained relative to a marked datum hollow in each plot using a PVC-pipe manostat. They were initially set to +1, -10 and -20 cm. As the surface grew upward due to vigorous moss growth in some of the bog plots, it became difficult to maintain the flooded (+1 cm) condition without overflowing the tanks. We also viewed this increase in elevation as a biotic feedback to our infrared and hydrology manipulations, and have let the

surface of the plots rise relative to the water table as a treatment response. In 1996 in the bog plots, the average water-table depths for the three hydrology treatments were at -11, -19, and -26 cm, whereas the fen plots remained relatively close to their original set values with treatment means of 0, -10, and -19 cm.

Water-table control of the mesocosms are maintained only during the growing season (~ May 15 – Oct. 15) to prevent ice damage to the PVC manostat assemblies. All mesocosms are allowed to fill and freeze during the remainder of the year. During the growing season, water is replenished by natural rainfall and, during dry periods, by measured additions of water pumped from a ditch draining a bog and transported in a 1900-L tank to the mesocosm facility for immediate use. The ditch water is similar to the bog porewater with respect to pH (4), although conductivity (9.6 uS cm^{-1}) is closer to that seen in the fen water. Nutrient (N and P) content, determined periodically, is comparable to that seen in bog porewater. We could find no readily available source of water with chemistry similar to the fen, so we use the bog ditch water for all mesocosms. The water tables is topped off at approximately weekly intervals via metered outlets to perforated standpipes in the center of each mesocosm, which allows rapid diffusion of added water directly into the peat profile. Excess water from the mesocosm tanks due to precipitation events is collected in the accompanying sump buckets, where its volume is determined before being pumped out. Rainfall is measured with a recording rain gauge.

Therefore, we have a complete input-output water budget in all mesocosms, with an approximately weekly time step. Evapotranspiration is estimated as:

$$ET = P + W_i - W_o,$$

where P equals precipitation inputs, W_i equals water put into the mesocosms to maintain water-table levels, and W_o equals water collected in the sump buckets after rain events.

Gas Fluxes

Ecosystem respiration (ER) is sampled at two to three-week intervals throughout the growing season, and was done throughout the winter of 1998-1999. Because we are able to seal off each mesocosm under the chambers described below, the CO_2 and CH_4 fluxes represent the sum of both soil and plant (dark) respiration for the entire mesocosm.

We made portable static chambers that fit over the mesocosms on half-dome frames of steel conduit and fiberglass tent poles. These frames are covered variously with layers of FEP film (Norton Performance Plastics Inc., Wayne NJ), metallized nylon-EVA (James River Co., Shreveport LA) (for gas and light impermeability), and a white cross-laminated polyethylene vapor-barrier material for protection of the inner layers of teflon or nylon film. The plastic film "tent" is sealed to the sides of the tank using a ratchet-type load strap over closed-cell foam weatherstripping. The reflective white cover also serves to keep the chambers cool, generally resulting in air temperature increases of less than 3°C during incubations. Soil temperature changes during the incubations are negligible. Small battery-operated fans are hung from the top of each dome to mix the chamber air. Approximate chamber volume is 1000 L, which was estimated as described below.

Using five chambers and total incubation times of about 40 min., we obtain flux measurements for all the mesocosms over a period of 2 days, usually between 9:00 and 16:00 hours. Following at least a 10 min. wait to allow for equilibration of chamber air, we withdraw a series of 3 duplicate samples at 15 to 20 min. intervals from septum ports in the sides of the chambers. We used 10-mL nylon gas syringes with caps to collect and store our samples. Gas

samples are usually run within 48 h, and flux rates are calculated based on the linear accumulation of CO₂ and CH₄. Linear estimates with R² values of less than 0.9 are not used (less than 5 percent of plots are unusable in any given sample period). Samples are analyzed for CO₂ on a Shimadzu GC 14-A equipped with a 2-m Porapak Q column and thermal conductivity detector (TCD) and for CH₄ on a Hewlett Packard 5890 equipped with a 2-m Porapak Q column and flame ionization detector (FID).

For each sampled mesocosm we record the water table measured within the manostat pipe, as well as the air and soil temperatures. We obtain estimates of chamber volume by injecting known amounts of SF₆, an inert gas, prior to the last sample of the incubation.

Net Ecosystem Production

During the 1996 growing season we constructed an open chamber system, using a Licor 6400 Photosynthesis System (Licor Inc., Lincoln NE), that allows for rapid measurement of whole-mesocosm net ecosystem production (NEP). It consists of a PVC frame approximately 1-m high that conformed to the shape of the mesocosm tank, covered with Propafilm CK (ICI Americas, Wilmington, DE), a clear, PVdC-coated polypropylene film, and plates of rigid Plexiglas at either (flat) end. On these we installed 10-cm diam. PVC closet flanges for air intake and exhaust. The intake port feeds into a perforated plastic baffle for even distribution of air. Two small fans mounted near the top of the chamber ensure mixing of the chamber air. The exhaust port is also baffled on the outside to prevent wind incursion. Air sampling inlets are installed in both the intake and exhaust flanges, and are connected to the paired infra-red CO₂ analyzers on the Licor via Bev-a-line (Licor Inc., Lincoln NE) tubing and a 12-V double-headed diaphragm sampling pump (Brailsford & Co. Inc., Rye NY). Type-E thermocouples installed in the intake and exhaust ducts allow for measurement of input and chamber air temperatures. The input air is pumped using a pair of 435 CFM 2-speed blowers (Grainger Inc., Plymouth MN) that draw air through a 3-m vertical pipe into a large plywood box that serves as a buffer volume. The height of the intake pipe and the buffer volume help minimize variability in the temperature and CO₂ concentrations of the air entering the chamber. The dual blowers provide a flow rate of roughly 2000 L min⁻¹, or two chamber volumes per minute, as measured by flow-transducer (TSI Inc., St Paul MN) in the intake pipe.

The chambers develop a slight positive pressure, which minimized the risk of contamination by inward leakage or diffusion. For estimation of gross primary production (GPP), which required that the respiration component be added back in, we use respiration estimates derived from the regressions based on static-tent measurements. Light curves are generated by placing shade clothes over the chambers and measuring incoming photosynthetic active radiation (PAR). GPP is then calculated as a function of the amount of light captured by the green canopy (GIPAR), by multiplying PAR by the percentage of light intercepted in the canopy and a visual estimate of the percentage of the canopy that is composed of green, photosynthesizing vegetation.

Water Analyses

Porewater is collected monthly throughout each growing season by pumping samples through the manostat pipes in the sump buckets. This method ensures that we obtain an "integrated" water sample that represents the whole profile. Samples are collected at least 24 h after any additions of ditchwater, and never during precipitation events. Water samples are refrigerated and analyzed for pH within 24 h, then filtered using glass-fiber syringe filters.

Subsamples are subjected to persulfate digestion for total N (Owen and Axler 1991), and colorimetric analysis by autoanalyzer for NO_3^- -N and NH_4^- -N (Quickchem methods 12-107-04-1-A and 10-107-06-2-C respectively, Lachat Instruments, Mequon, WI) .

Dissolved nitrogen (N), phosphorus (P), and dissolved organic carbon (DOC) fluxes are estimated by the difference between incoming amounts in rainwater and bog ditch-water and amounts leached (in porewater outflow). Concentrations are multiplied by monthly water budgets to obtain estimates of monthly mass balances.

Aboveground Net Primary Production

Annual aboveground net primary production (ANPP) of bryophyte, herbaceous dicot and monocot (hereafter forb), graminoid, and shrub lifeforms between 1994 and 1997 was determined non-destructively for all dominant species present in the mesocosm plots. Summaries and detailed descriptions of methods are provided below. Generally, for each species, we developed predictive algorithms between measurements of various canopy components (i.e., shoots, flowers, fruits) and the oven-dry biomass of those components. Algorithms were based on data collected between 1994 and 1997 at both the bog and fen source sites and from portions of the mesocosm plots themselves, as appropriate. In particular, after each canopy component was measured, it was harvested, dried at 60°C to constant mass, and weighed. We then developed various algorithms (e.g., mean shoot or tiller mass, least-squares simple and multiple regressions) to predict annual aboveground biomass production from measurement data.

Non-destructive assessment of individual plant canopy components for each species was conducted for each mesocosm plot in each year. Because of the total number and size of the mesocosm plots, and the density of vegetation therein, we sampled most plant species from four 10-cm x 50-cm permanent subplots located within each quadrant of each plot. We used subplots for species with characteristically high densities or small individuals, and the entire plot for species with lower densities or larger individuals. ANPP was calculated for each species; these data were summed to determine ANPP within lifeform (bryophyte, forb, graminoid, and shrub) and total ANPP.

Graminoids and forbs

Summary:

Annual ANPP of graminoids and forbs was estimated based on mean shoot weights or canopy/biomass relationships of plants destructively sampled from bog and fen source sites between 1994 and 1996 and, for a subset of relatively common species, from a subset of the mesocosm plots in 1997. We calculated an estimate of annual ANPP for each taxa based on the product of mean forb shoot mass or mean graminoid tiller mass and the number of shoots or tillers within each plot or its subplots, as appropriate. Non-destructive counts and/or measurements of all graminoid and forb taxa in the plots or subplots were conducted in July and August of each year.

Detailed description:

Annual ANPP (g/m^2) of graminoids and forbs was estimated based on mean shoot

weights or canopy/biomass relationships of plants destructively sampled from bog and fen source sites between 1994 and 1996. In addition, mean shoot weights for relatively common species were determined from a subset of the mesocosm plots in 1997. For all graminoid and forb taxa, non-destructive counts and/or measurements of plants in the plots or subplots were conducted between June and August of each year, depending on the phenology of each species.

In particular, with the exception of two species, we determined reproductive and/or vegetative shoot mass of most forbs and tiller mass of most graminoids present in the mesocosms. We calculated annual ANPP for each taxon based on the product of tiller mass data and the number of shoots or tillers within each plot or its subplots, as appropriate.

Because *Sarracenia purpurea* has leaves of greatly variable mass, we estimated its production based on relationships between leaf biomass and leaf length and mid-sagittal leaf orifice diameter. In particular, in 1994 we measured and then destructively harvested 15 leaves from *S. purpurea* plants at the fen source site, and used this information to develop the following relationship: $\ln(\text{mass of leaf in g}) = -10.39 + \ln(\text{length in mm})1.65 + \ln(\text{mid-sagittal orifice diameter in mm})0.63$; $R^2 = 0.92$, $P < 0.0001$). Because *S. purpurea* has relatively large flowers, we estimated production of flower mass based on a mean flower weight of 0.925 g determined for 20 flowers collected from the fen source site in 1996.

Tussocks of *Eriophorum spissum* were relatively large and clumped, so we estimated its production based on relationships between tussock biomass and tussock circumference, median height and visual estimates of percentage live (i.e., green) cover. In particular, in 1996 we collected aerial portions of twenty tussocks from the bog source site, and developed the following relationship: $\ln(\text{tussock mass in g}) = -7.15 + \ln(\text{tussock circumference in cm})1.20 + \ln(\text{tiller median height in cm})1.31 + \ln(\% \text{ green})0.44$; $R^2 = 0.91$, $P < 0.0001$).

To determine whether our water-table setting and infrared loading treatments affected values of tiller mass used to predict graminoid ANPP, in 1997 we destructively sampled 10-15 vegetative tillers (as subsamples) per plot for one species common to all bog plots (*Eriophorum spissum*) and three species common to all fen plots (*Carex lasiocarpa*, undifferentiated *Rhynchospora* spp., *Scheuchzeria palustris*). We used a fixed-effects ANOVA to determine main and interactive effects of water-table setting and infrared loading on tiller mass.

Tiller mass (0.025 g) did not differ between treatments for *E. spissum*. Although the ANPP algorithm of this species is based on tussock circumference, height, and percentage live cover, a consistent tiller mass across treatments suggests that canopy morphology of this species is relatively insensitive to the treatments applied. Accordingly, we used the least-squares multiple regression equation described above for data from all years and treatments.

Similarly, tiller mass (0.063 g) of undifferentiated *Rhynchospora* spp. (= *R. alba* + *R. fusca*) in 1997 did not differ between treatments. However, because this value was roughly half that of the mean mass of 40 *Rhynchospora* spp. tillers (0.125 g) collected from the fen source site in 1994, we incremented tiller mass of *Rhynchospora* spp. linearly between 1994 and 1997, and applied these values to all treatments; ANPP for 1994 through 1997 was calculated as the product of tiller mass and tiller count data for each year.

In contrast, tiller masses of *S. palustris* and *C. lasiocarpa* were affected by infrared loading, and water-table and infrared loading, respectively. Therefore, for these two species we incremented tiller mass linearly between the source site data collected in 1994 and each of the 9 treatment combinations in 1997. As for *Rhynchospora* spp., ANPP was calculated based on tiller mass and tiller count data for each year.

Shrubs

Summary:

Annual ANPP of dominant shrubs was estimated based on canopy/biomass relationships determined for plants destructively harvested from the bog source site in 1994, the fen source site in 1995, and the mesocosm plots in 1995 through 1997. We counted and measured shrubs within mesocosm plots or subplots in August or September of each year. Number and canopy dimensions of the largest dominant shrubs were collected from the entire 10-cm x 50-cm subplot. Because of time constraints, similar data for the smallest, most numerous shrubs were collected from one permanent 10-cm x 15-cm sub-subplot located at random within each subplot.

Detailed description:

Annual ANPP (g/m²) of dominant shrubs was estimated based on canopy/biomass relationships determined for plants destructively harvested from the bog source site in 1994, the fen source site in 1995, and the mesocosm plots in 1995 through 1997.

Specifically, in August of 1994 at the bog source site, we measured the lengths of new shoots, which were then clipped, dried, and weighed, for 20 individuals of *Chamaedaphne calyculata*, *Kalmia polifolia*, *Andromeda glaucophylla*, *Ledum groenlandicum*, and *Vaccinium oxycoccos*. In August of 1995, we collected similar data for *Vaccinium macrocarpon* from the fen source site. In 1995 through 1997, we collected similar data for subsets of shrubs within the bog plots to determine whether the water-table setting and infrared loading treatments affected stem length/mass relationships over time.

We focused our investigation of potential treatment effects on data collected in 1997, with the rationale that treatments should be most divergent after four growing seasons. In particular, in 1997 we destructively sampled 10-20 individuals (as subsamples) per plot of each of two shrub species common to all bog plots: *C. calyculata*--representative of shrubs with erect growth forms, and *V. oxycoccos*--representative of shrubs with prostrate growth forms. For each species, we determined least-squares regression coefficients (β) for allometric relationships between the natural log of the length (in mm) of each new shoot segment versus the natural log of the biomass (in mg) of that shoot segment (Whitaker and Marks 1975).

We then used a fixed-effects ANOVA to determine main and interactive effects of water-table and infrared loading treatments on β for each species. β did not differ between treatments for *C. calyculata* or *V. oxycoccos*.

In addition, to determine whether allometric relationships were changing over time, we compared β for 1994 and 1997 for these two species (Zar 1996). β did not differ between 1994 ($\beta \pm 1 \text{ SE} = 1.20 \pm 0.12$) and 1997 (1.21 ± 0.03) for *C. calyculata* ($P = 0.20$), but differed between 1994 (0.93 ± 0.13) and 1997 (0.99 ± 0.02) for *V. oxycoccos* ($P = 0.01$).

Therefore, for *C. calyculata* (and for other shrub species with similarly erect growth forms) we developed a single regression equation based on data pooled for all years. For *V. oxycoccos*, we incremented β and its intercept (α) linearly between 1994 and 1997, and applied these year-specific regression equations to data for each year. For *V. macrocarpon*, we applied the shoot length/mass relationship developed for the 1995 dataset to all years. In addition, for *V. oxycoccos*, we incorporated fruit mass into ANPP based on mean mass and counts of fruits.

We used the allometric relationships that we developed for *C. calyculata* to determine

ANPP for the following minor shrub species: *Salix* spp., *Populus* spp., *Betula glandulifera*, *Picea mariana*, *Larix laricina*, *Acer rubrum*, and *Vaccinium myrtilloides*.

We counted and measured shrubs within mesocosm plots or subplots in August and September of each year. Number and canopy dimensions of each shrub species were usually collected from the entire 10-cm x 50-cm subplot. Because of time constraints, when *C. calyculata*, *A. glaucophylla*, or *V. oxycoccus* were especially abundant, we sampled them within a permanent 10-cm x 15-cm sub-subplot located at random within each subplot. Estimates of annual aboveground production were determined for each species based on previously determined canopy/biomass relationships.

Bryophytes

Summary:

Bryophyte annual ANPP was estimated for bog plots only, and was based on basal cover, lineal shoot growth, and density of shoots and species-specific shoot mass/shoot length relationships for four dominant taxa destructively harvested from the bog source site in 1994 (Appendix 2). Bryophyte basal cover was estimated visually each year within ~110 round, 3-cm-diam. subplots within each plot. Lineal shoot growth was estimated using cranked-wires (Clymo 1970) placed within high, low, and intermediate microtopographic zones within each plot. Vertical height of bryophyte growth relative to the top of the cranked wire was measured monthly during the growing season in 1994 through 1997; monthly measurements were summed to obtain total lineal shoot growth within each microtopographic zone. Bryophyte annual ANPP was calculated for each species within each zone using mass/length relationships and shoot densities developed in 1994, zone-specific lineal growth, and species cover values within each zone. *Sphagnum fusca* and *S. capillifolium* were difficult to differentiate after 1994 because of organic staining from water applications, so were lumped into *Sphagnum Acutifolia* section for all analyses.

Detailed description:

Bryophyte annual ANPP (g/m²) was estimated for bog plots only, and was based on shoot density and species-specific shoot mass/shoot length relationships, basal cover, and lineal shoot growth. Shoot density and mass/length relationships were developed from samples collected at the bog source site in October, 1994, when we collected three 10-cm x 10-cm x 4-cm deep samples of *Polytrichum strictum*, *Sphagnum capillifolium*, *S. fuscum*, *S. magellanicum*, and *S. recurvum* from different mono-specific populations. Samples were stored frozen until they were processed. For each species-specific sample, we determined shoot density (#/dm²), and shoot mass/length relationships for individual shoots by clipping distal portions of each shoot to 1 cm for *Polytrichum strictum* or 2 cm excluding the capitula for *Sphagnum* spp., drying shoot segments at 60°C, weighing them to the nearest mg, and calculating shoot mass/shoot length ratios. *Sphagnum fusca* and *S. capillifolium* were difficult to differentiate after 1994 because of organic staining from water applications, so were lumped into *Sphagnum Acutifolia* section for all analyses.

Bryophyte basal cover was determined in July through August of 1995-1997 from subplots within each plot. Subplots were positioned using a removable sampling grid. The

sampling grid was constructed to form a 185-cm open square, with taut line strung from side to side at right angles to form a grid of ~110 intersecting points at a spacing of 12.5 cm. The grid was leveled at about 20 cm above the median surface elevation of each plot, and was held rigidly by supports bolted to the tank. When sampling, we lowered a plumb bob from each grid point down to the bryophyte surface, where we placed a round, 3-cm-diam. quadrat. The percentage cover for each bryophyte species within the quadrat was then estimated visually. To minimize edge effects, we did not sample quadrats within 15 cm of the plot edge.

Lineal shoot growth was estimated using the cranked-wire method, wherein stainless steel wires set vertically into the bryophyte surface act as dynamic datum points for measuring bryophyte shoot extension (Clymo 1970). Because bryophyte growth rates are often related to relative elevation or microtopography (Clymo 1970), we placed one to six cranked-wires within each of three microtopographic zones within each plot based on relative elevation: high, low, and intermediate.

Microtopographic zones were defined each year based on the vertical distance between the bryophyte surface and each of the ~110 points on the removable sampling grid. Specifically, in each year, we ranked the vertical distances for all (27 plots x ~110 points per plot =) ~2970 points, and then divided this dataset into three equal-sized subsets: the ~990 points with the greatest vertical distance between the bryophyte surface and the frame were defined as representing low microtopographic zones in their respective plots. Similarly, the ~990 points with the least vertical distance represented high microtopographic zones, and the remainder of the points represented intermediate microtopographic zones. Cranked-wires were assigned to a microtopographic zone based on their relative elevation. Because we did not start using the removable sampling frame until 1995, we applied the 1995 cranked wire designations to the 1994 dataset.

Vertical height of bryophyte growth relative to the top of the cranked wire was measured monthly during the growing season in 1994 through 1997; monthly measurements were summed to obtain total lineal shoot growth within each microtopographic zone. Bryophyte annual ANPP was calculated for each species within each zone using species-specific stem mass/length relationships and shoot densities developed in 1994, lineal growth estimates for that zone, and species cover values within each zone. Although bryophyte ANPP was affected by microtopographic zone (unpublished data), we analyzed bryophyte ANPP on a plot-wise basis for the purpose of this paper. And, although bryophyte stem length/mass relationships within the mesocosms may have changed with time or treatment, the destructive sampling of the bryophyte community that would be required to determine these effects precluded their assessment.

Belowground Net Primary Production

Belowground net primary production (BNPP) was estimated for the growing seasons of 1995 through 1997 using root in-growth cores. Cores were constructed of ca. 6-cm x 27-cm closed-bottom cylinders sewn from polyethylene netting (0.5-cm mesh) and filled with screened, homogenized peat collected from the bog and fen source sites. In early June of each year, immediately upon thawing of the soil, we placed three in-growth cores in each plot such that the top of each core was level with the surrounding peat surface. In September, the ingrowth cores were carefully excavated with a serrated knife and were replaced immediately with fresh cores. Each core was weighed and homogenized, and a subsample (200 to 400-g moist weight) was collected for root separation. This subsample was wet-sieved over a 40-mesh screen prior to

hand-separation of live roots over 1 cm long. Root biomass was oven-dried at 60°C to constant mass and weighed to the nearest mg.

Root production was calculated volumetrically (based on root mass, subsample volume, and intact core volume), and was expressed on an areal basis (g/m² to 27-cm depth). Because BNPP was not determined in 1994, total net primary productivity (TNPP = ANPP + BNPP) was calculated only for 1995, 1996, and 1997.

Plant Species Cover

Canopy cover of graminoids, forbs, and shrubs was estimated visually by species within each plot in August and September of each year at the estimated time of peak standing biomass. Bryophyte basal cover within the fen community was obscured by green standing biomass during the summer, so we estimated fen bryophyte cover in September after graminoids senesced. Bryophyte cover data were not collected from the fen community in 1996 because of a relatively early snowfall.

Bryophyte basal cover within bog plots was determined in July through August of 1995-1997 from subplots within each plot. Subplots were positioned using a removable sampling grid. The sampling grid was constructed to form a 185-cm open square, with taut line strung from side to side at right angles to form a grid of ~110 intersecting points at a spacing of 12.5 cm. The grid was leveled at about 20 cm above the median surface elevation of each plot, and was held rigidly by supports bolted to the tank. When sampling, we lowered a plumb bob from each grid point down to the bryophyte surface, where we placed a round, 3-cm-diam. quadrat. The percentage cover for each bryophyte species within the quadrat was then estimated visually. To minimize edge effects, we did not sample quadrats within 15 cm of the plot edge. Plot-level bryophyte species cover was calculated as the mean of the ~110 cover estimates.

Peat Accretion

Each summer we measure the distance between the surface of the bryophyte surface in the bogs or the peat surface in the fens and a taut string grid attached to a rigid steel frame. The frame has three legs, two of which are screwed to the rim of the plastic tanks in precise locations. Two of the legs function as extendable jacks. The distance from the frame to the tank was established in the first year of sampling. Each subsequent year the frame is positioned at that same distance. In June fen mesocosms are measured at 20 permanent locations in each plot. Bog mesocosms are measured in July or August with approximately 110 permanent locations in each plot. The measurements are recorded with millimeter precision.

Peat volumes are calculated by subtracting the average distance from the string grid to the mesocosm surface from the average distance from the frame to the tank rim. Volume changes from year to year are derived from comparing each year's calculated volume. Each millimeter of change in surface level is equivalent to 2.13 liters of volume change.

Energy Budgets

Photosynthetic radiative radiation (PAR) and net radiation budgets are measured in several different ways, depending on the application. Incoming PAR is continuously monitored at the site with a quantum sensor and logged onto a computer, with values averaged over 5 min

intervals on gas sampling days, and otherwise at 30 min intervals. PAR is also measured simultaneously with net ecosystem production in flow-through tent measurements using a gASP sensor that is part of the LiCor 6400.

A Radiation and Energy Balance System (REBS), Inc. net radiometer and quantum sensor are mounted 13.3 cm above each plot to measure net radiation input (R_n) and PAR. The height of 13.3 cm for the net radiometer was determined based on information provided by REBS to give a view factor of 0.90 (i.e., 90% of reflectance will come from the vegetation inside the container). Five soil heat flux plates (HFT3, Campbell Scientific, Inc., CSI) are used to measure the heat flux into the soil at 5-cm depth (G), sensible heat loss underneath the container (G_v), and horizontal sensible heat loss (G_h) at depths of 5, 25, and 45 cm. Soil temperatures are measured at 5, 15, 30, 45, and 60-cm depths using electronically insulated thermocouples. Two 60-cm stainless steel rods are vertically inserted into the soil at 10-cm spacing and connected with a Time-Domain Reflectometry (TDR) unit to monitor soil moisture.

A CR10 micrologger (CSI) and two AM416 multiplexers are used in six adjacent containers to sample all of the above variables every 10 sec and then store 30-min averages in a SM716 storage module. A combination of CR10 and SM 716 memory allows us to store data for 20 days before they are retrieved using a laptop computer. All 54 pairs of stainless steel rods for soil moisture measurements are connected with a central TDR system that is connected with a CR10 datalogger and SM716 storage module. Measurements are taken every hour since moisture changes very slowly in our system.

An independent weather station monitors local microclimatic conditions, including temperature and moisture in the soil surrounding the mesocosms. Variables monitored at the station include air temperature, relative humidity, wind speed and direction, incoming short-wave radiation, precipitation at 2 m above the ground, soil temperatures at 0, 5, 15, 30, 45, and 60 cm in the soil, soil moisture at 5 and 30 cm, and heat flux at 5 cm in the soil. Data collected at the weather station is used as a long-term database for microclimatic change at the study site and as independent variables to empirically fill gaps for any missing data points in the plots. Due to the large number of variables, a 21X micrologger with 16 single-ended channels and 4 pulse output is used for the station.