agroborealis

volume 35 number 2
winter 2003

Boreal Beverages

Cracking the Carbon Conundrum

Invasive Weeds Needs

School of Natural Resources and Agricultural Sciences
Agricultural and Forestry Experiment Station

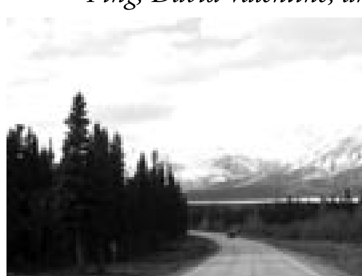
University of Alaska Fairbanks

contents:

Spotted knapweed blossom
—Photo by Michael Shephard, U.S. Forest Service, Anchorage

Stephen Sparrow staying out of the Delta wind.
—Photo by darleen masiak

About the cover: *Birch tree growing near Fairbanks, Alaska, on the West Ridge of the UAF campus near the SNRAS offices.*
—Photo by Deirdre Helfferich, winter 2003.



Heading down the open highway!
—Photo by Jeff Werner

letter from the dean and director:

Alaska covers a vast area that is unlike any other in the United States. To satisfy their needs, the state's people interact within physical features, living resources, and a complex geography. If Alaskans are to survive socially and economically, Alaska's resources must be properly managed and cared for by all of the state's people.

While Alaska's resources offer many opportunities, there are natural limitations to their use that must be recognized before natural development can sustain and enhance our economy at the local, regional, and statewide level over the long term. The School of Natural Resources and Agricultural Sciences and the Agricultural and Forestry Experiment Station are unique assets and sources of information for these resource-related efforts.

I am excited about this issue of *Agroborealis*. Natural resource management, agriculture, and forestry are intimately interrelated. Our faculty and staff are committed to this synergy, and this issue of the magazine illustrates their broad range of expertise. Natural resources management uses data and insights from many different fields of knowledge. Our research and teaching programs are an opportunity to be proactive about resource management, whether applied to natural ecosystems or managed systems that produce food, fiber, and physical products, or management objectives for human use.

In all of our programs and activities, we strive to provide information that is focused on issues important in the lives of Alaskans and to equip our graduates with the knowledge and perspectives to be efficient and effective resource managers. As always we welcome your comments.

My best wishes for the new year before us.

Carol E. Lewis

letter from the afes associate director:

This issue of *Agroborealis* highlights just a few of the Agricultural and Forestry Experiment Station research projects partially funded by the U.S. Department of Agriculture New Crop Opportunities. These projects address diverse products, from birch syrup and beverages to antioxidants in Alaska-grown vegetables and berries, to producing carbon credits in the boreal forest. Researchers at Fairbanks and Palmer are assessing the antioxidant potential of such plants as blueberries, lingonberries, currants, and a number of vegetable products. Antioxidants are well known for helping to prevent cell damage linked to age-related diseases in humans.

Potential new nontimber uses for birch, such as pharmaceuticals and cosmetics, are being investigated with the help of state-of-the-art high-pressure liquid chromatography at the Palmer soil and plant analysis laboratory. Forestry researchers are investigating many aspects of the biospheric carbon cycle for northern forest impacts on climate change, carbon sequestration, and interactions with fire. Among the outcomes of this research is the relatively new opportunity of marketing carbon credits. This is based on the concept that sequestering carbon in plants and soil keeps it out of the atmosphere as carbon dioxide, thus bestowing a marketable value in the form of carbon credits. The information produced by this research supports the development of new products and markets by the private sector.

G. Allen Mitchell

Agroborealis is published by the Agricultural and Forestry Experiment Station, University of Alaska Fairbanks. For more information about our research and education programs, please contact us at:

School of Natural Resources & Agricultural Sciences
P.O. Box 757140
Fairbanks, AK 99775-7140

Office of the Dean
(907) 474-7083
fysnras@uaf.edu

Student Information
(907) 474-5276

or visit our website:
http://www.uaf.edu/snras

Changes of address and requests for a free subscription or extra copies should be addressed to:

AFES Publications
P.O. Box 757200
Fairbanks, AK 99775-7200

fynrpub@uaf.edu

Agroborealis, Natural Resource News, and other publications are available in alternative formats. Please provide your e-mail address if you would like e-mail notification of online availability of our periodicals and other publications. You may download them from our website at:

http://www.uaf.edu/snras/afes/pubs/index.html

Agroborealis is produced by the AFES Publications Office.

ISSN: 0002-1822

Managing Editor
Deirdre Helfferich

Information Officer/Science Writer
Doreen L. Fitzgerald

Webmaster
Steve Peterson

To simplify terminology, we may use product or equipment trade names. We are not endorsing products or firms mentioned. Publication material may be reprinted provided no endorsement of a commercial product is stated or implied. Please credit the researchers involved, the University of Alaska Fairbanks, and the Agricultural and Forestry Experiment Station.

The University of Alaska Fairbanks is accredited by the Commission on Colleges of the Northwest Association of Schools and Colleges. UAF is an AA/EO employer and educational institution.

UAF UNIVERSITY OF ALASKA FAIRBANKS

Birch: white gold in the boreal forest

Deirdre Helfferich

Birch trees provide far more than beauty and shade. The root or twig is used to make birch beer, the sap can be condensed and used like maple syrup. The bark is used to make containers and art objects. Chemicals found in the bark are showing promise as industrial lubricants, fungicides, and in fighting diseases.

Birches are the most numerous deciduous trees in the boreal forest, and are proving to have a wide range of uses in addition to the traditional use of its wood. Birch is classed as a hardwood, known for its fine-grained white or reddish wood (depending on whether sapwood or heartwood is used). The wood is used for everything from flooring to cutting boards, bowls to chairs, decorative plywood to jewelry. Spalted birch has color or black introduced into specific grain lines, either artificially or naturally via disease or insect infestation. It and birch burls are prized for their decorative qualities, and are used in wood turning, jewelry, furniture, and cabinetry.

While the wood may be the best known of this tree's products, others also lend themselves to commercial application: sap (made into syrup, sugar, candy, wine, beer, soft drinks, vinegar, and other foods); leaves (made into tea and herbal supplements or used for extracts); and bark (made into such items as canoes, baskets, boxes, jewelry, sculptures, and used for dye and extracts such as birch tar and medicinals).

There are six forms of birch in Alaska: Paper or white birch (*Betula papyrifera* and two birches sometimes described as variants of *B. papyrifera: B. neoalaskana* or Alaska birch, and *B. kenaica* or Kenai birch); water birch, also known as red birch or black birch (*B. occidentalis*, also sometimes described as a white birch variant); dwarf birch *(B. nana)*; and bog or ground birch *(B. glandulosa)*. The latter two species are shrubs. Taxonomic battles are being waged in the scientific community over whether Alaska tree birches should be considered variations of the same species *(B. papyrifera)* or species in their own right.

Researchers at the School of Natural Resources and Agricultural Sciences are investigating birch in many ways: tree growth and climate change, bark harvest and use, sap production, twig water and sap rise, phytochemicals in birch, tree volume equations for determining such things as carbon sequestration, and recreational use impacts on lakeshore vegetation such as dwarf birch. Working with the Alaska Boreal Forest Council and the local school districts, present and former SNRAS students and faculty are helping local schoolchildren obtain scientific data on birch trees, such as the timing of their sap rise.

Birch leaves are used as a folk remedy. Researchers are examining the medicinal properties and chemical makeup of birch extracts.
—Photo by Paul Wray, Iowa State University, www.forestryimages.org

New industries are being developed in Alaska based on birch products, chief among them syrup manufacture and value-added birch bark and wood products. Other potential nontimber industries include pharmaceutical and cosmetics production. Birch bark is high in betulin and betulinic acid, phytochemicals which have a potential for pharmaceuticals that could be used to treat herpes, brain tumors, and melanomas. These may be found in higher percentages in Alaska trees than those of trees in the Lake States. (The University of Minnesota Duluth and the University of Alaska Fairbanks are comparing samples.) Birch oil is used for aromatherapy, leather oil, and in cosmetics such as shampoo and soap (particularly in Scandinavia). The leaves are used in herbal supplements and for medicinal tisanes (herbal tea). The commercial potential for birch is a tantalizing prospect: from its lumber to its chemical storehouse, sweet success may be on the horizon with Alaska's birch forests.

Alaska paper birch, such as these trees growing on the University of Alaska Fairbanks campus near the forest soils laboratory of SNRAS, may show tremendous variety in color. This small stand, for example, has trees with bark colored charcoal gray next to those that are golden orange next to still others that are brilliant white.
—Photo by Deirdre Helfferich, AFES Publications Office

A taxonomy of *Betula papyrifera*

Betula, from the Latin for birch
papyrifera, "paper-bearing," from the Greek, papyrus, "paper," and the Latin, fero, "to bear, carry, bring"
Common name: Paper birch, from the paper-like bark; White birch, from the white color of the bark
Also known as *Betula alaskana, Betula cordifolia, Betula neoalaskana*

Kingdom Plantae, the Plants
- Division Magnoliophyta, the Angiosperms (flowering plants)
  - Class Magnoliopsida, the Dicotyledons
    - Subclass Hamamelididae, witch hazels
      - Order Fagales, includes trees such as beeches, birches, etc.
        - Family Betulaceae, the Birches
          - Genus Betula, the Birches

Betula is a genetically plastic genus, often with variation continuous between species, and hybridization is common.

birch beverages

Birch sap straight from the tree is a traditional and refreshing spring tonic, tasting somewhat like mineral water. In Finland, Korea, Japan, and the Ukraine, birch sap is a valued drink. It is sold commerically in Scandinavia, Russia, and China, and is used as a traditional medicine. The sap can be drunk as is, or used instead of water to make other beverages, such as tea. Uncondensed sap has from about .5 to 2 percent sugar content, averaging around one percent and depending on the birch variety, location, and weather. Even though this may not seem like much, it is higher than many other tree species. Maples produce sap with about 2 to 2.5 percent sugar content. Unlike maple sap sugar, which has a very high proportion of sucrose, birch sap's sugar is about 42–54 percent fructose and 45 percent glucose, with a small amount of sucrose and trace amount of galactose.

Root Beer

A simple birch soda can be made by boiling down birch sap to about ten percent of its original volume and then using a soda siphon or an air pump to provide bubbles. Birch sap needs to be refrigerated to prevent spoilage.

Among the many products derived from birch sap is birch beer. This is in fact a carbonated beverage, like root beer, although alcoholic birch beer can also be made, usually a beer with birch syrup or extract (termed birch oil) added for flavoring.

Birch beer requires about fourteen percent sugar content. Traditional root beer recipes often included birch twigs or birch root, from sweet birch (*B. letula*, a species that does not grow in Alaska) for its wintergreen flavor. Birch flavoring in lieu of the twigs, or entire birch beer brewing kits, can be purchased at shops selling brewing supplies.

Many commercial birch root beers are available, and some of them use Alaska birch syrup. A producer in Vermont, for example, the Journey Food and Beverage Company, makes Borealis Birch Beer, using birch syrup from the Tanana Valley.

The Great Bear Brewing Company, a brewpub in Wasilla, Alaska, makes a root beer and a cream soda using birch syrup from local producers. The company uses birch syrup, granulated sugar (sucrose), flavorings, and then carbonates the drink without using yeast. They have been producing these soft drinks for about four or five years. According to one of the brewers at Great Bear Brewing, birch root beer makes great root beer floats.

Traditional root beer making required yeast. During the first stages of growth, the yeast produces carbon dioxide. When fermentation begins, alcohol is produced, and beer results.

Birch root beer recipe

Ingredients:
sweet birch twigs or birch oil (optional)
1 gallon honey
4 gallons birch sap
1 cake soft yeast
1 slice of bread, toasted (rye bread is recommended)

The traditional recipe calls for measuring four quarts of finely chopped twigs of sweet birch into the bottom of a five-gallon crock or carboy. (Where sweet birch is not available, sweet birch oil can be used, or no added birch flavoring.) In a large kettle, stir the honey into the birch sap and boil for ten to twelve minutes, then pour over the chopped twigs (or add flavoring). When cool, strain to remove the twigs and return to the crock.

Spread the cake of soft yeast on a slice of toasted bread and float on top of the beer. Cover with a cloth and let ferment until the cloudiness just starts to settle, a few days to about a week, depending on the temperature.

Bottle and cap tightly. Store in a dark place. (Capping at this stage prevents continued fermentation to alcohol, although even early on there may be some alcohol present.) It should stand in the bottles for about three months before using. If opened too soon, it will foam too much; the storage time allows it to become carbonated, as the carbon dioxide produced by the yeast slowly dissolves into the liquid.

—Photo by Deirdre Helfferich, AFES Publications Office

Beer

Haines Brewing Company makes an alcoholic birch beer every spring, Birch Boy Summer Ale. Paul Wheeler, brewmaster and owner, describes it as a lighter style of ale with a slight woody, birchy taste (like a popsicle stick). The flavor, he said, is subtle. Using premium syrup purchased from Birch Boy Products, Wheeler uses about a gallon of syrup to 140 gallons of brewery liquor (water), replacing some of the malted barley that he normally uses. He finds that the sugars in birch syrup are very fermentable, converting readily into alcohol and thus producting a dry ale, not a sweet one.

Resource management student Kimberley Maher (see also p. 10) and a friend tried making a home brew beer with birch sap and syrup. Instead of water, they used sap, and they replaced some of the malt with syrup, producing a birch ale. Below is their beer recipe.

Berley's Birch Brew

(recipe crafted by Steve Sheehy)

Ingredients:
5 gallons birch sap
1 lb crystal malt or other light malt,
lightly crushed, in mesh bag
6 lbs extra light malt extract
1 pint birch syrup

Bring to a boil; remove grain bag.

Add 2 oz hops (we used Cascade) and 1 oz finishing hops (for flavor) and boil five minutes. Cool to approximately 70° F. Funnel into carboy and pitch yeast. Allow to ferment for approximately two weeks; bottle.

Wine

Great Land Wines in Haines, Alaska, produces a birch sap wine, using sap from a local syrup producer, Birch Boy Products. The company, which started up in 1997, has produced two batches of birch wine. Co-owner Dave Menaker says he is still experimenting with the recipe, trying to get the right balance of sugars. In his first batch he used uncondensed tree sap, which made an acceptable wine, but didn't move as well as he'd hoped. The next batch of sap was condensed to ten percent sugar by Birch Boy, and the resultant wine had a distinctive woody to nutty taste. Menaker thinks that it might be worth trying sap with a higher concentration of sugar, perhaps forty percent.

Birch wine recipe

Recipes for winemaking vary, some calling for citric acid rather than lemon juice, corn syrup rather than grape concentrate, Campden tablets, raisins, and other ingredients. Times for fermentation and racking differ as well. A search on the web under "birch wine recipe" will reveal numerous variations on the theme below.

—Photo by Deirdre Helfferich, AFES Publications Office

1 gallon birch sap
2 lemons
2 oranges
1/2 cup strong tea
1/2 pint white grape concentrate
2 1/4 lb sugar
wine yeast
yeast nutrient

Peel oranges and lemons, discarding all white pith, and heat the peel in the sap at 120° F for 20 minutes. Add enough water and the tea to bring to one gallon. Pour into container with sugar and concentrate, and stir until sugar is dissolved. When it is cooled, add the fruit juice, yeast, and nutrient. Ferment to dryness and rack twice, then mature for six months before bottling. Some recipes suggest adding sugar to taste prior to bottling.

Birch Syrup Production in Alaska

Although birch sryup production is a more challenging process than maple syrup production, the potential for birch syrup has attracted commercial manufacturers to the industry: there are currently eight Alaska companies harvesting birch sap and producing birch syrup products. Alaska is on the cutting edge of birch syrup production, and most of the world's birch syrup is produced here. Alaska producers make about 1000 gallons of birch syrup a year. It is also produced in smaller quantities in Russia, Canada, and Scandinavia. Birch sap, condensed into syrup, is used for pancake syrup, candies, as an ingredient in sauces, dressings, and glazes, and as a flavoring in beer, wine, or soda pop.

The Alaska Birch Syrupmakers' Association (ABSA) is a group of seven manufacturers that was founded in the early 1990s by Marlene Cameron and three other birch syrup producers. Most of Alaska's birch syrup producers are members. The Alaska Science and Technology Foundation provided a grant to the association to promote birch syrup and its production, which helped get the group going. The current membership includes: the Alaska Boreal Forest Council (Fairbanks), Birchboy Birch Products (Haines), Birch Grove Birch Syrup (Eagle River), Chickaloon Birch Syrup (Chickaloon), Chugiak Mountain Birch Syrup, Kahiltna Birchworks (Wasilla), and Knik Birch Syrup Company (Wasilla).

Dulce Ben-East, of Kahiltna Birchworks, is the president of the association, which has produced guidelines for best practices for producing birch syrup (see facing page). The Food and Drug Administration has not yet created a legal definition for birch syrup, nor established grades of syrup, but the association has provided certification standards for birch syrup production, and is working toward independent certification by the state or another entity.

To receive ABSA certification, a birch syrup producer must be a member of the Alaska Birch Syrupmakers' Association and the syrup must be made from sap of Alaska birch trees (genus *Betula*); the producer also must adhere to the ABSA Best Practices and Department of Environmental Conservation and Food and Drug Administration regulations for equipment, facilities, and labeling; and the syrup must have a minimum 67 brix (percentage weight of sugar content), have no metallic or burnt flavors, and must be filtered and free of suspended solids. Syrup is evaluated according to color; flavor; specific gravity, or concentration of sugars and other nutrients; and viscosity.

Making syrup

There are several challenges in birch syrup production. While the process is similar to reduction of maple sap, the differences are important. The tapping window for birch is shorter than for maple, primarily due to climate: The quicker transition to warmer temperatures during Alaska springtimes means that wild yeasts and other organisms—and hence a bitter flavor—increase in the harvested sap sooner than for maples, which grow far to the south, where seasonal changes are slower. Another problem created by the short tapping season (approximately three weeks in southcentral Alaska, and as short as ten days in the Interior) is that by the time the sap begins flowing, air temperatures can be well above freezing. If the temperature is in the fifties or sixties before the sap run is over, the sap can easily spoil in the collection buckets. In maple country, the temperature change is more gradual, and so there is less risk of spoilage.

Birch sap is acidic, which means that the metal taps, buckets, or tanks used in maple sugaring will give the sap a metallic taste; thus, plastic or nylon equipment is preferred. Alaska birch trees have shorter lives than maples, living around 100 years, although 200-year-old stands have been found. They are susceptible to heart rot, and so care must be taken to sterilize equipment not only for the safety of the customer, but for the safety of the tree. According to Marlene Cameron, of Cameron's Birch Syrup and Confections, trunk and root pressure is not strong, so the pipeline or tubing method of sap collection that is used in large maple operations is not efficient for birch sap collection.

Because birch sap is normally only about one percent sugar, it takes about 80 to 100 gallons or more to make one gallon of syrup. In contrast, a gallon of maple syrup requires only about 40 or 50 gallons of sap. Whereas maple sap can simply be boiled down, this is time-consuming and expensive with birch sap. The first step in sap concentration is reverse osmosis. Approximately 70 percent of the water in the sap is removed using a reverse osmosis machine, which concentrates the sugars to about five percent. Then the sap is further concentrated using an evaporator, to approximately 60–70 percent sugar concentration. About 99 percent of the water in the sap is removed to make syrup. Low-heat, low-pressure extraction is used to avoid burning the syrup. Because of the high fructose content, birch syrup must be distilled at lower temperatures than maple syrup, or a scorched or off-flavor will result. (Fructose burns at a lower temperature than sucrose, the chief sugar in maple sap.) The ease with which the syrup can be scorched means that the sap can only be heated in a narrow temperature range, and greater care must be taken.

Because of these factors, birch syrup is almost five times as expensive to make as maple syrup, but its flavor is distinctive and marketable, particularly in the specialty gourmet food market, as Alaska's producers have demonstrated.

Alaska Birch Syrupmakers' Association

BEST PRACTICES For Producing High Quality Birch Syrup

Guidelines and Recommendations

A. Tree Tapping

1. Time to tap varies by location; usually first part of April
2. Tap holes: 1½–1¾" deep, slight upward angle, using a $^5/_{16}$–$^7/_{16}$" bit, depending on spout used
3. Location of hole: 2–4 feet high, to the side of previous holes
4. Tap healthy trees; 8" diameter at breast height or larger
5. Do not tap trees that have ever had pesticides sprayed on or around them.
6. Use one tap per tree.
7. Use plastic, nylon, or steel spouts, or tubing supplies commercially available through local syrup equipment suppliers.
8. Do not drive taps too deep—wood can split, causing leakage.
9. Sterilize taps before use.
10. Tap trees when the sap flow is continuous.
11. Tap trees only where access is good and equipment will not compromise ground cover. Minimize damage to trails during break-up.
12. Remove spouts at end of season; may spray hole with pure water. Cork tap holes upon removal with appropriate sized cork (available through local suppliers).

B. Sap Collection

1. Use equipment appropriate for trail conditions. On public lands follow regulations.
2. Use stainless or food grade plastic collection containers and storage tanks. Do not use containers previously containing toxic materials.
3. Use only food grade hose and lines or standard maple tubing (no garden hoses!).
4. Collect sap daily.
5. Clean collection tanks and pumps daily.
6. Discontinue collection when yeast appears on taps and sap turns cloudy. Once sap has begun to turn it should no longer be used for bottled pure birch syrup.

C. Sap Storage

1. Use FDA-approved food grade poly, stainless, or glass-lined tanks.
2. Process all sap daily in the order in which it was gathered. Keep stored sap below 42° F and out of direct sun.
3. Clean sap storage tanks daily.
4. Monitor sap brix (sugar content) with refractometer or hydrometer.
5. Filter all sap through 5-micron water filter.

D. Syrup Production—Reverse Osmosis (RO)—optional equipment

1. Follow manufacturer's instructions for operating and cleaning.
2. Keep RO-concentrated sap cool and out of direct sunlight. Process as soon as possible to prevent spoilage and yeast growth. Do not store concentrated sap.
3. Use FDA-approved storage tank for concentrated sap.
4. Use food grade lines, fittings, and valves on RO.
5. Never use chlorine bleach for cleaning tanks or lines—it will compromise RO membranes.

E. Syrup Production—Evaporator

1. Use standard or modified maple syrup evaporators (wood, oil, or gas-fired) with tig welded or lead-free soldered pans.
2. Run sap through hot and shallow, using consistent heat to establish proper gradient.
3. Clean evaporator daily, using standard pan cleaners available through local suppliers.
4. Rinse, Rinse, Rinse.
5. Filter sap back into cleaned pan.

F. Syrup Finishing

1. Evaporate syrup to minimum of 67 percent sugar (brix scale) by weight using a calibrated refractometer. Using a thermometer, syrup is reached at approximately 11° F above the boiling point of water (variable by barometric pressure).
2. Hand filter through approved rayon and felt filters OR, preferably, filter press (available from local suppliers).
3. For filter press use food grade filter aid (diatomaceous earth) matched to the filter papers used.
4. Heat syrup to a minimum of 180° F, and no higher than 190° F; immediately hot pack into approved non-metallic food grade container and seal, or bottle (see below).
5. Record date and/or batch number on container. Note quality: brix, flavor, color.
6. Cool all bottled or packed syrup as quickly as possible and store in a cool, dark place.
7. Bottle syrup between 180–190° F. Use only glass or food grade plastic containers and heat seal lids. Lay container on side for at least 10 seconds after bottling to sterilize lid.

Best Practices reproduced courtesy the Alaska Birch Syrupmakers' Association. For more information, contact Dulce Ben-East, Kahiltna Birchworks, 907.733.1309; Danny Humphries, Birch Boy Products, 907.767.5660; Trudy Carlson, Birch Grove Birch Syrup, 907.696.0893; Marlene Cameron, Cameron's Birch Syrup and Confections, 907.373.6275; Jim Garhart, Chickaloon Birch Syrup, 907.746.2828; or Charlene Monatague, Knik Birch Syrup, 907.373.2925.

Birch Growth and Sap

Sap content and flow

Kimberley Maher, a masters degree student at SNRAS, is conducting a study to assess sap production by birch in interior Alaska. The study, a United States Department of Agriculture New Crops II and III project, is quantifying sap flow (volume and timing), sap chemistry (cation presence and sugar concentrations and components), and the relationship of sap productivity to environmental factors such as temperature. Maher is checking for the presence of seventeen different cations (mineral ions with a positive charge), such as calcium, magnesium, and potassium. Among the cations for which she has tested is arsenic, which appears only in low amounts, meaning that birch apparently does not concentrate this poisonous element—good news for syrup producers. She is also looking at factors such as soil moisture around the trees and their position on a slope.

Maher's work is done on three south-facing transects within fifteen miles of Fairbanks, in Ester, Ballaine, and on Murphy Dome. The trees are tapped from prior to the start of sap flow, usually during the second half of April, in accordance with the Alaska Birch Syrupmakers Association's guidelines for best practices. Data is available for two transects in 2002 and 2003. In the Ballaine transect, the first area established for the study, three years' sap production data was gathered, beginning in 2001. The trees were tapped at three sites in each transect, according to the position on the slope (top, middle, or bottom). Sap is collected daily and measured for volume and sugar concentration. Sap samples are taken every three days, frozen, and then analyzed later for their cations and sugar concentrations (fructose, sucrose, glucose, and galactose).

The results to date show that sap production varies widely from site to site and between years, but that most stands produce best during cool, prolonged spring weather. The sugar content of the syrup does not appear to be highly affected by the weather, but the volume and flow are.

Tree growth and weather

Syrupmakers are concerned with maintaining and protecting their trees, and some of the research done by SNRAS is exploring how trees are affected by tapping. Glenn Juday, professor of forest ecology at SNRAS, and Valerie Barber, director of the Tree-Ring Laboratory, are examining the correlation between tree growth, sap production, and age, climate, or other factors in productive birch stands (see p. 33). Because sap represents stored reserves of energy that were manufactured the previous year, Juday and Barber suspect that there is probably a direct relationship between sap and ring growth. They have collected tree cores from ten trees (five tapped and five not tapped) at each of the nine stands in Kimberley Maher's study of birch sap production. One of the nine is the Pearl Creek site of the Alaska Boreal Forest Council's Tapping Into Spring project.

Juday and Barber's results so far show that birch stands in prime condition for sap production are generally in the range of sixty to one hundred years old, the same age range in which radial growth reaches a maximum. They also find that in certain years most birch across interior Alaska experienced major decreases in growth (1958, 1969–70, 1993) or increases in growth (1933–36, 1952–53). Decreases in radial growth in particular years are associated with strong drought (1957–58), widespread outbreaks of defoliating insects (1969–70), and stem breakage from heavy snow (fall 1992). Increases in particular years are generally associated with cool, moist weather.

Juday says that it is hard to find mature Interior birch that are sound enough for a solid core sample—a high proportion of trees are decayed in the center. Matanuska-Susitna valley birch, Juday and Barber have found, are generally bigger trees and show less decay than trees in the Fairbanks area.

Tree growth will need to be examined in many birch stands to confirm the relationship between type of site and level of production of sap or wood, according to Juday. But based on the limited sample so far, the more exposed (low elevation, south-facing slope) the site is, the stronger the tendency for birch growth to be limited by warm summers. These trees are negative responders to warmth. Birch on moister sites, such as shaded northeast-facing slopes or low-lying areas, generally are positive responders to warmth. These two opposite growth responses to climate may be of use to birch syrup producers. By tapping a mixed population of trees made up of both positive responders and negative responders, birch syrup producers might be able to avoid poor production even in extremely warm or cold years.

Tapping Into Spring

The Alaska Boreal Forest Council began educational programs in the mid-1990s in the schools to educate people about the boreal forest and to encourage them to think more broadly about its uses. In 1998, Sally Anderson, UAF biology student, and Dan Stein, of the council, helped set up Tapping Into Spring, a place-based sap-tapping educational program that has grown to become a complete curriculum in sustainability. Every year, pupils tap trees and take scientific measurements that make up part of a long-term ecological study. The boreal forest council and community volunteers make syrup using a small sugar shack (called the North Star Syrup Works) that was purchased in 2000 with grant money from the Alaska Science and Technology Foundation. They develop products (such as Boreal Bliss ice cream, made with wild lingonberries and birch syrup), and market them.

With their teachers and sometimes their parents, the schoolchildren measure sap volume and sugar content, take daily weather observations, and create ecological profiles of trees (girth at an average breast height of four feet, height of tree, tree spacing). The data collected has proved to be helpful in predicting when the sap will start running. Preliminary results show that three days in a row where the temperature is 50° F or higher prior to April 15 results in sap flow about a week later; after April 15, the sap flows three days later.

The program has continued to expand through the help of the AmeriCorps Vista program, and volunteers Sunna Fessler, Kimberley Maher, and others. Tapping Into Spring has expanded from one to eight area schools and is offered to homeschoolers and members of the community as well.

The boreal forest council created teacher training toolkits through an Environmental Education Grant, and began a training course in 2003 for teachers and others who wish to participate in Tapping Into Spring, working with the Fairbanks North Star Borough School District and in cooperation with the University of Alaska's education department. The trainees can receive professional development credit through the university. The course will be offered again in March 2004, pending paperwork approval. This 500-level course, according to the description, "uses the activity of tapping birch trees as a window into the ecology, economy, and historical uses of the boreal forest of interior Alaska," and is designed for K-12 teachers.

The council also offers backyard syrupmaking classes through the community schools program, and conducts an biannual forest use survey in the Tanana Valley watershed, a collaborative effort between state, university, and borough agencies to understand use patterns for diverse forest resources. Birch bark harvesting and sap tapping are among these uses; one discovery as a result of the survey is that birch bark use is more widespread than previously realized. The survey analysis is done by masters students at the UAF School of Management in cooperation with forest council staff.

Elena Sparrow of SNRAS and GLOBE provides equipment for weather data monitoring and helped to train members of the forest council to train teachers, pupils, and parents in use of the equipment and in taking measurements. Deb Wilkinson, who was a local teacher at Pearl Creek Elementary and now is a faculty member at the UAF School of Education, has been involved from the program's early years and was instrumental in developing the educational programs with the council. Shawn McGee, also at Pearl Creek, helped establish the sugar shack, which was originally located at the school but is now at the council's office in Fairbanks.

—Photo by Deirdre Helfferich, AFES Publications Office

For more information:

Alaska Birch Syrupmakers Association

Dulce Ben-East, president
800.380.7457 (toll free in Alaska)

Alaska Boreal Forest Council

www.akborealforest.org
P.O. Box 84530
Fairbanks, AK 99708-4530
907.457.8453; fax: 907.457.5185
abfc@mosquitonet.com

Birch Boy Products

www.birchboy.com
Daniel and Susan Humphries
P.O. Box 637
Haines, AK 99827
907.767.5660
birchboy@wytbear.com

Birch Grove Birch Syrup

www.birch-grove.com
Trudy and Bob Carlson
P.O. Box 771375
Eagle River, AK 99577
907-696-0893
sales@birch-grove.com

Chickaloon Birch Syrup

www.chickaloon.org/Forestry/BirchSyrup.html
Jim Garhart
907.746.2828
cvforest@chickaloon.org

Great Land Wines, Ltd.

www.greatlandwines.com
Dave and Jeanie Menaker
P.O. Box 1083
Haines AK 99827
907.766.2698; fax: 907.766.2094
dave&jeanie@greatlandwines.com

Haines Brewing Company

Paul Wheeler
P.O. Box 911
Haines, AK 99827
907.766.3823
hainesbrew@yahoo.com

Kahiltna Birchworks

www.alaskabirchsyrup.com
Dulce and Michael East
907.373.1309, 907.733.1309
quietlake@matnet.com

Knik Birch Syrup Company

www.knikbirchsyrup.com
Charlene Montague
P.O. Box 877372
Wasilla, AK 99687
907.373.2935; fax: 907.373.2936
kbsc@mtaonline.net

Further reading:

Alaska Boreal Forest Council:

Backyard Birch Syruping. The How-to-Tap Manual. Rev. March 2003.

Developed by Integrative Graduate Education and Research Traineeship program student Nancy Fresco during a summer internship for the ABFC:

Alaska Birch Tapping for Everyone. Advice for experimenters, educators, hobbyists, and entrepreneurs on what can be gained from tapping birch trees, what delicious treats you can make from your sap, and how to avoid frustration—whether you're tapping one tree or one thousand.

Cooking with Birch Syrup and Birch Sap. Hints, marketing advice, and tested-and-approved recipes.

Sap and Syrup Science: Experiments in biology, chemistry, and math based on the sweet science of birch tapping and sugaring.

Alaska Cooperative Extension Service, UAF:

Under the Canopy, July 1999. "Factors that influence sap flow in paper birch," and "Tapping Into Spring," by Bob Wheeler. The newsletter is available on line at: http://www.uaf.edu/coop-ext/forestry/canopy/canopyjul99.html

Alaska Science Forum

"Sap's Arising," by John Zasada, Institute of Northern Forestry, U.S. Forest Service, available on line at http://www.gi.alaska.edu/ScienceForum/ASF4/467.html.

American Cancer Society

For information on studies of betulinic acid's potential as a treatment for cancer, go to: www.cancer.org/docroot/eto/content/eto_5_3x_betulinic_acid.asp?sitearea=eto

Birch Boy Products:

www.birchboy.com/articles.html

The Alaskan Birch Syrup Producer's Manual, by Danny Humphries

Cameron Syrup and Confections:

"Establishing an Alaskan Birch Syrup Industry: Birch Syrup—It's the *Un*-maple!" by Marlene Cameron. Available on line in pdf format at http://ncrs.fs.fed.us/pubs/gtr/other/gtr-nc217/

Grant Station:

"Tapping Into Spring Offers Sweet Lesson in Forest Sustainability," by Linda Schockley. Available on line at www.grantstation.com/Public/News_Views_px/sp_archives/sp1100.asp

Invasive Plants in Alaska: assessment of research priorities

Japanese knotweed is an agressive invader in Southeast Alaska.
—Photo by Nanna Borchert, Sitka Conservation Society

Jeff Conn
Research Agronomist, USDA Agricultural Research Service, University of Alaska Fairbanks
Ruth Gronquist
Wildlife Biologist, USDI Bureau of Land Management, Fairbanks
Marta Mueller
Program Assistant, Cooperative Extension Service, University of Alaska Fairbanks

Research needs and priorities on the threat of invasive plants differ for various state and federal agencies in Alaska—so how can they be assessed and ranked? The authors describe the problem posed by invasive plants, and present the approach to this question and some of the findings of the Committee for Noxious and Invasive Plant Management. The committee ranked research in three main areas of infestation management (prevention, eradication or control, and restoration).

The annual economic loss caused by invasive plants in the United States is estimated to be over 34 billion dollars (Pimentel et al. 2000). Forty-two percent of the species listed as threatened or endangered are primarily at risk due to competition or predation caused by non-native species (Wilcove et al., 1998). The rapidly increasing problem of invading plants into range and wild lands was a primary reason behind President Clinton's issue of executive order 13112, which required all federal land management agencies to develop action plans for preventing and controlling invasive species. Federal research agencies have expanded research on invasive species to aid in management of this problem.

Though the severity of the invasive plant problem in Alaska is not as great as in other states, where invasives such as purple loosestrife, yellow star thistle, and European cheatgrass are rapidly degrading wetlands and grasslands, recent surveys for invasive plant species in Alaska have revealed that non-natives are increasing in number and could cause problems for Alaska agriculture and forestry and have negative effects on Alaska ecosystems. In southeast Alaska, garlic mustard has been found in Juneau. This species has been found to out-compete spring-flowering understory species in the eastern United States. White sweetclover has invaded the floodplains of the Stikine and Matanuska rivers. The recent discovery of extensive white sweetclover stands on the Nenana River suggest that the entire Yukon River drainage may be susceptible to invasion by this species. If white sweetclover is competing with other floodplain species such as willows, it may affect moose winter food availability and plant succession. Other non-native plants that appear to be increasing in Alaska include: Japanese knotweed, bird vetch, orange hawksbeard, narrow-leaf hawksbeard, Canada thistle, and perennial sowthistle.

Development of a ranking system for research needs

In June 2000 a group of concerned citizens and land managers met in Fairbanks at the invitation of the UAF Cooperative Extension Service to discuss how non-native plant invasions could be prevented and controlled in Alaska. The group decided that a statewide effort was needed, and formed the Committee for Noxious and Invasive Plant Management (CNIPM). The CNIPM strategic plan recognized that research was needed to determine the best methods for preventing and controlling invasive plants in Alaska (Hebert 2001). During the Third Alaska Noxious and Invasive Plant Management Workshop in November 2002, attendees were asked to list ideas for research needed to improve prevention and control of invasive plant infestations in Alaska. Over the course of the meeting, forty-two ideas were submitted. Meeting attendees voted on the importance of the various research ideas. A breakout session at the end of the meeting was devoted to consolidating similar research ideas and was used to recruit members to serve on a CNIPM research needs subcommittee. The role of the subcommittee was to prioritize the research ideas and propose how the research might be accomplished. Subcommittee members are state experts on prevention and control of invasive weeds in Alaska and come from a wide cross-section of Alaska resource management and research agencies. Several people were members of the public who had been active in combating invasive weeds.

The committee, which included the authors, met every two weeks from February 2003 to June 2003, and looked at five main considerations. These were: whether some of the research ideas were similar enough to be combined; if research ideas should be rated by how they relate to management objectives or particular aspects of competing weed invasions; how the ideas should be ranked; how priorities should be peer reviewed; and how best to explain the process and results to potential funding sources.

The original forty-two research ideas were reduced to twenty-four, because of duplication. Since invasive weeds are managed at three levels (prevention, eradication/control, restoration) the remaining research needs were classified into these functional groups.

While deciding how best to rank the research needs, we decided that various resource management agencies would probably rank them differently. For example, State of Alaska Department of Transportation and Public Facilities (ADOT&PF) would be interested in knowing which plant species could be used for revegetation without becoming invasive, while farmers may not. Thus, research ideas were ranked according to land use objective. The land use objectives were: agriculture, natural areas, transportation, and urban. Agriculture refers to crop production and grazing lands. Natural areas are relatively wild lands managed by federal, state, or local government, private interests, or Native Alaskan interests. These lands may be managed for timber and other commercial uses, recreation, or conservation values. Transportation refers to roads, trails, railroads and airports. Urban areas are disturbed lands associated with cities and villages.

We developed a matrix with land use objectives as columns and research needs grouped by management objectives as rows. The committee then gave the research needs a value of 0 (no need) to 5 (highest need) for each land use objective. A research need that was ranked of low priority for a particular land use objective does not necessarily mean that the research is not important, but that other research needs rank higher for that land use objective.

The scores for each research need were averaged across objectives to produce an average score for each research need. Research needs that had a high average score can be perceived as being important topics of research for all or most land use areas. This is not to say that research needs with a low average score are unimportant. It may be that answers to certain research topics are urgently needed, but for only one or a few resource management agencies.

The entire research needs subcommittee and then the entire CNIPM membership, through e-mail solicitation, reviewed the results of the ranking process.

Infestation management priorities

Prevention

The most cost-effective strategy for combating noxious and invasive plants is to prevent the establishment of plant populations in the first place (National Invasive Species Council 2001). We ranked fifteen prevention research needs.

• Invasiveness Index by region

The Invasiveness Index is a ranking system that takes into consideration aspects of an invasive species' biology and history in other locations to estimate its potential to spread and create economic and ecological damage. Not all exotic species will be invasive, and use of the Invasiveness Index will allow scientists and managers to focus personnel and funds on addressing prevention and eradication or control of the most invasive species (Hiebert 1997). Due to the diverse climatic regimes in Alaska, which can influence species biology, we recognized that the invasiveness indexes would need to be performed separately for each Alaska ecoregion. Committee members thought that invasiveness indexing was very important (5) for all management objectives.

• Method and rate of spread

To design an effective prevention strategy, one needs to know how seeds or vegetative propagules of various species are brought into Alaska and disseminated, and how fast the infestation could be expected to spread. For example, if seed were found to spread from soil adhering to construction equipment, one strategy for preventing new infestations would be to wash equipment before it leaves an area where invasive species are found. If exotics are found to spread down rivers, efforts should be made to prevent the spread of these species along roads where they would intersect rivers. The relative importance of various routes of plant introduction is largely unknown. How frequently is plant seed introduced from vehicles driving through Canada versus through contaminated crop, horticulture, or revegetation seed? The answer to this question could be helpful in deciding whether stronger seed laws are required, or whether a vehicle washing station should be built at the Alaska-Canada border. This research need was also ranked high under most land use objectives (5). An exception was Agriculture (3), where agencies

Table 1. Invasive plant research needs ranked according to land use and infestation management objectives, with averages over land use objectives. Needs are ranked from no need, 0, to highest need, 5.

Research Need	Agricultural Areas	Natural Areas	Transportation	Urban Areas	Average
Prevention					
Invasiveness Index by region	5	5	5	5	5.0
Methods and rates of spread	3	5	5	5	4.5
Potential for new invasion from outside Alaska	3	4	4	5	4.0
Species biology of exotics (for use in ranking systems)	3	4	4	4	3.8
How exotics affect ecosystems (diversity, wildlife)	2	4	4	4	3.5
Costs of prevention versus control later	2	2	4	4	3.0
Invasions from horticulture (wildflowers, nursery containers, introductions)	1	3	1	4	2.3
Nitrogen-fixing legumes that are not invasive	4	0	2	2	2.0
History of introductions and distribution in Alaska	1	1	3	3	2.0
Use of remote sensing and GIS to map and predict invasions	1	2	2	1	1.5
Effects of fire on movement of exotics	0	3	0	0	0.8
Effects of nitrogen-fixing plants on facilitating exotics	0	1	2	0	0.8
Hybridization of native species with non-natives	0	1	0	1	0.5
Effects of global change on invasions	0	2	0	0	0.5
Most effective inventory methods	0	0	1	0	0.3
Eradication and Control					
Longevity of seed in soil	5	5	5	5	5.0
IPM approaches and best management practices	5	5	5	5	5.0
Effectiveness and cost of using herbicides	5	3	4	4	4.0
Persistence and fate of herbicides in soil and injury to later crops	4	4	4	4	4.0
Cost and effectiveness comparison for control methods	4	3	4	3	3.5
Non-chemical control methods (heat, mowing, tillage, digging, pulling)	4	2	4	1	2.8
Biological control methods	3	2	3	2	2.5
Restoration					
Methods for producing propagules of native plants for revegetation	5	5	5	4	4.8
Which plants can be used for revegetation without being invasive?	2	3	5	3	3.3

have a better idea of the methods and rates that agronomic weeds spread than do other resource management areas.

• Potential for new species from outside Alaska

Knowing which plants have the potential to be serious invaders would lead to improved regulation. Outbreaks may be prevented by banning seed of these species in revegetation mixes and from livestock feed shipped in from outside the state. This research need was ranked highly (4-5) under most resource management objectives.

• Species biology of exotics (for ranking)

Invasiveness indexing requires knowledge of plant species biology, including number of seeds produced, competitiveness, and growth potential (Hiebert 1997). This information is lacking for many species and the information that is known may be from other locations that are warmer than Alaska. Thus, for some species, species-specific information is needed to determine their invasiveness potential under Alaska conditions. This research need was ranked highly (3-4) as a need for all management objectives.

• How do exotics affect ecosystems (diversity, wildlife)?

In some cases invasive weeds have been shown to displace other plant species and decrease overall ecosystem diversity (Wilcove et al. 1998). If the displaced species are essential to wildlife, this can have a detrimental effect on other ecosystem components, as well as on subsistence and sporting activities. Subcommittee members ranked this as important research for natural areas, Urban, and Transportation (4), and less important for Agriculture (2) than other research needs.

• Costs of prevention versus control later

Prevention measures are usually inexpensive compared to the costs of an ongoing control effort or to the economic and ecological damage that may occur if an invasive weed becomes established (National Invasive Species Council 2001). Results of studies to examine the relative costs of prevention versus control could be used to help spur managers, regulators, and landowners to take preventative measures. Committee representatives ranked this important research for Transportation and Urban (4) and less important for Agriculture and Natural Areas (2). Agriculture representatives felt that this information is largely already known and appreciated. For Natural Areas, other research is currently more pressing.

• Invasions from horticulture (wildflowers, nursery containers, introductions)

Weeds can be imported in nursery containers and can be components of wildflower seed mixes. Also, gardeners have sought out exotic species from outside Alaska to add to their gardens. These species can occasionally become invasive. At this point we do not know how important these avenues are for importation of invasive species into Alaska, and what should be done to decrease this risk. It is suspected that the garlic mustard *(Allaria petiolata)* invasion that has recently occurred in Juneau was from seed brought in with a nursery container or from wildflower seed. Committee representatives ranked this as important research for Urban and Natural Areas (3-4) and not important, or that other needs were more pressing, for Transportation and Agriculture (1).

• Nitrogen-fixing legumes that are not invasive

Agronomists have experimented with nitrogen-fixing legumes to determine which are adapted to Alaska. These legumes could be used by farmers and in revegetation to enhance soil nitrogen levels without using expensive inorganic nitrogen fertilizers. Unfortunately, several legumes, such as sweet clover (Melilotus spp.) and bird vetch (Vicia cracca) have been found to be invasive in Alaska. Sweetclover has taken over the floodplain of the lower Stikine River and is spreading along the Matanuska and Nenana rivers and along the Dalton Highway north of the Yukon River bridge, while bird vetch has spread along roadsides and is colonizing urban areas. There is a need to determine which legumes that are adapted to Alaska can be grown for nitrogen enrichment without becoming invasive. Subcommittee members ranked this as important research for Agriculture (4), of moderate importance for Transportation and Urban (2), and not very important for Natural Areas (0).

• History of introductions and distribution in Alaska

Study of the historic methods of introduction and rate of spread of plant invaders already in Alaska could give important lessons learned that may help in designing strategies to prevent future invasions. Committee representatives determined that this research need was a moderate priority (3) for Transportation and Urban Areas and a low priority (1) for Agriculture and Natural Areas.

• Use of remote sensing/GIS to map and predict invasions

Locations of exotic species could be plotted and the rate of spread determined using GIS. Habitat information from remote sensing and climatic data could be used to make GIS layers to model potential sites for invasion and to estimate the potential for infestation. This research need was ranked fairly low by committee representatives (1-2). It was perceived that this was a very good tool that should be applied to Alaska, but that much of the research had already been done and could be transferred readily to Alaska as agencies complete inventories of invasive plants.

• Effects of fire on movement of exotics

In the Lower 48 States, populations of invasive plants have been found to increase dramatically in native ecosystems after fires. The newly burned areas provide areas to colonize without competition from established species. The burns also provide corridors for invasive species to spread through previously continuous or late-succession ecosystems. Invasive species can also cause an ecosystem to be more fire-prone (Vitousek et al. 1996). Committee members thought this research need was of moderately high priority (3) for Natural Areas but not important (0) for other management areas. At this point we have not seen that invasive species have been increasing in burned areas in Alaska.

• Effects of nitrogen-fixing plants on facilitating exotics

Invasion by nonindigenous plant species can be greater when soil nitrogen levels are elevated (Mountford et al. 1996). It is common to plant legumes for revegetation purposes to increase soil nitrogen, which may enhance growth and spread of invasive plants. Subcommittee members gave this research need moderate priority for Transportation (2) and a no-need (0) or a very low priority (1) for other management objectives.

• Hybridization of natives with non-native species

It is possible for closely related native species to hybridize with invading plant species, which could lower the fitness of native plants. Subcommittee members gave this research need a low score (0-1) for all management objectives.

• Effects of global change on invasions

The subcommittee members recognized that global change would likely affect the number of plant invasions and range extensions in Alaska, yet there is little that agencies can do. Committee members gave this a moderate need rating (2) for Natural Areas and no-need (0) for other management objectives.

• Most effective inventory methods

The committee members felt that effective inventory methods had already been established and were being used in Alaska.

Eradication and Control

If prevention measures have failed, the next step in invasive plant management is to try to eradicate new populations. If eradication is not feasible, then invasive species should be controlled to limit spread to new areas.

• Longevity of seed in soil

Since a species will continue to germinate and grow in an area as long as seed or other propagules remain viable in the soil, it is important to determine how long the seeds or propagules will remain viable. This period will define the length of time that control measures must be in place to totally prevent production of new seeds or propagules. Subcommittee members thought this was a high research priority (5) for all land use objectives.

• Integrated Pest Management approaches and best management practices

Integrated Pest Management (IPM) relies on a multidisciplinary approach using several control options to tackle pest management problems. Best management practices enable management agencies to more efficiently target invasive plant problems or manage projects so that the infestations do not spread. For example, best management practices involving control of soil movement by and on equipment could aid ADOT&PF to prevent spread of invasive plants that may occur at a road construction site with an existing infestation. This research need was also given the highest priority (5) for all areas.

• Effectiveness and cost of using herbicides

Herbicides can be very effective tools for controlling invasive plants. Research conducted to determine which herbicides and what rates are effective for killing specific invasive plants under Alaska conditions is needed. This research need was ranked highly (3-4) by committee members for all areas.

• Persistence and fate of herbicides in soil and injury to following crops

Herbicides can pose environmental problems by killing or injuring untargeted organisms. Herbicides can be slow to break down in cold Alaska soils and can injure crops that are planted in subsequent years (Conn et al. 1996). The possible detrimental effects of herbicides should be evaluated before using them as a control option. This was ranked as an important research need (4) for all land use objectives.

• Cost and effectiveness comparison for control methods

Managers need information on the effectiveness and costs of control alternatives to make good decisions about what methods to employ. Often there may be a short window in which eradication is possible. It may be more effective to pick the most effective control measure rather than the cheapest one. This was ranked as medium to high priority (3-4) for all areas.

• Nonchemical control methods (heat, mowing, grazing, tillage, digging, pulling)

Herbicides can negatively affect untargeted species. Also, it is often difficult to get permit approval for use of herbicides on public lands. Thus, there is a need for nonchemical methods to control invasive weeds. Subcommittee members thought this was an important

Japanese knotweed rhizomes can be transferred to new sites with soil removed in ditch cleaning operations.
—Photo by Michael Shephard, U.S. Forest Service, Anchorage

research need (4) for Transportation and Agriculture but gave it a low ranking (1-2) for Urban and Natural Areas.

• Biological control methods

There have been some spectacular success stories in keeping populations of invasive weeds under control through use of natural enemies such as insects and fungi. This research topic was ranked as having medium priority (2-3) for all management objectives. It was thought that most of the invasive plants in Alaska were cosmopolitan in distribution and did not lack their natural predators. Many of the success stories for biological control have involved introduction of a predator that is lacking in the new range of the invasive plant.

Restoration

Once an invasive plant species has been eradicated or mostly controlled, newly opened bare areas need to be replanted to prevent soil erosion and to discourage colonization by other undesirable species. The CNIPM annual workshop attendees recognized two research needs that could help improve restoration efforts.

• Methods for producing propagules and planting native plants for revegetation

It is desirable to use native species for revegetation whenever possible. Seed of invasive species can be introduced when non-native species or seed sources from outside Alaska are used for revegetation. Alaska's annual production of seed lots of native species is too low to meet the demands of restoration projects. Research is needed to determine the best agronomic practices for planting, growing, harvesting, and cleaning native species for seed production or for obtaining vegetative propagules. All of the subcommittee members ranked this research topic very highly (4-5) for all areas.

• Which plants can be used for revegetation without being invasive?

One requirement for plant species under consideration for use in the initial phases of a restoration program is that the species germinate and cover ground surfaces rapidly. This reduces the potential for soil erosion and eliminates empty space for undesirable plant species to invade. Rapid growth and colonization ability are also characteristics of invading species. It is possible that non-native plants used in the initial phases of revegetation could become invasive themselves, as was the case for kudzu (Pueraria montana) in the southeastern United States. Sweet clover (Melilotus spp.) and other legumes that have been used in revegetation mixes are showing that they can be invasive, as has been seen on the Stikine, Nenana, and Matanuska rivers. Subcommittee members gave this research need a moderate priority for Agriculture (2), and Natural Areas and Urban (3). For Transportation, this research topic ranked as a high priority (5) due to the amount of revegetation done and the proximity of roads to rivers and other natural areas that could be subject to invasions.

Since funding for research is always limited, we hope that the research priorities identified by CNIPM will provide administrators and legislators insight on the most important research needs for Alaska. Limited research funds can accomplish the most when agencies can develop common priorities and pool resources and effort. Research on ways to prevent further invasive weed introductions to Alaska will give the greatest benefit in the long run. Similar to oil spill response strategy, prevention is much more cost effective than cleanup.

Literature Cited

Conn, J.S., W.C. Koskinen, N.R. Werdin, and J.S. Graham. 1996. Persistence and leaching of metribuzin and metabolites in two subarctic soils. *J. Envir. Qual.* 25: 1048–1053.

Hebert, M. 2001. Strategic Plan for Noxious and Invasive Plants Management in Alaska. University of Alaska Fairbanks Cooperative Extension Service. Fairbanks, AK.

Hiebert, R.D. 1997. Prioritizing invasive plants and planning for management. Pages 195–212 in J.O. Luken and J.W. Thieret, editors. Assessment and management of plant invasions. Springer-Verlag, New York, New York, USA.

Mountford, J.O., K.H. Lakhani, and R.J. Holland. 1996. Reversion of grassland vegetation following the cessation of fertilizer application. *Journal of Vegetation Science* 7: 219–228.

National Invasive Species Council. 2001. Meeting the Invasive Species Challenge. A National Management Plan. Washington, D.C.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. *Bioscience* 50: 53–65.

Vitousek, P.M., C.M. D'Antonio, L.L. Loope, and R. Westerbrooks. 1996. Biological invasions as global environmental change. *American Scientis*t 84: 468–478.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Loses. 1998. Quantifying threats to imperiled species in the United States. *Bioscience* 48: 607–615.

Contributors on the development of research needs ranking:

Michele Hebert, Cooperative Extension Service, University of Alaska Fairbanks

Beth Shulz, Pacific Northwest Research Unit, USDA Forest Service

Phil Kaspari, Cooperative Extension Service, University of Alaska Fairbanks

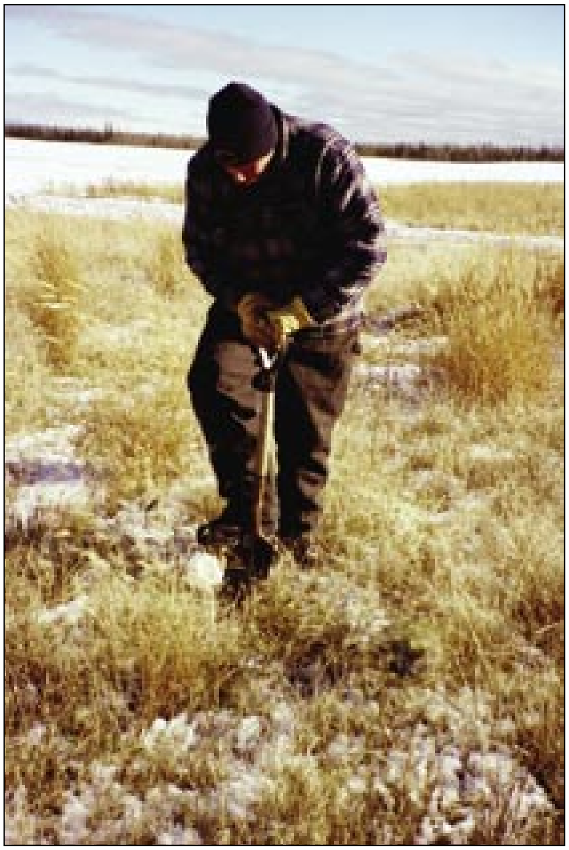
Clint Adler, Research and Technology Transfer, ADOT&PF

Michael Shephard, State and Private Forestry, USDA Forest Service

Kaleen Knodel, Homer Soil and Water Conservation District

Otto Kilcher, Homer Soil and Water Conservation District

Shirley Schollenberg, Homer Soil and Water Conservation District



Above: For Alaskans doing outdoor research, scenery is often a bonus, as in this view of snow-covered Granite Mountain, which was photographed from the field where the tillage sample plots are located.
Left: Jon McCabe digging soil samples in one of the no-till plots. All of the samples taken within the tillage study area will be analyzed for physical, chemical, and biological properties relating to the tillage treatment, straw management, and fertilizer rates.
Below: Whatever works—the probe is permanently attached to a vintage Vietnam-era army truck (which doesn't run). From left to right: Mingzhu Chang is steering, Steve Sparrow's shadow reveals the photographer, Bob VanVeldhuizen is by the probe, darleen masiak is prepared with a yardstick to measure the soil samples, and research associate Jon McCabe stands at the ready with paper bags for sample collection.

A Winter Delta Dig

Doreen Fitzgerald
photos by Stephen Sparrow

Neither rain, sleet, hail, or snow shall keep them from their appointed rounds—true for the postal service, and as well for researchers who collect data in the natural world. In early October, those working on the Delta Tillage Study and new agronomy professor Mingchu Zhang traveled from Fairbanks to mile 1408 Alaska Highway near Delta to collect samples related to summer experiments that are part of the long-term research project. This year was the twentieth anniversary of the study, which has the following objectives:

• Evaluate various tillage treatments: no tillage; minimum tillage (till once in the fall after harvest); chisel plow (once in the fall after harvest); and conventional tillage (disked twice, once in the spring before planting and once in the fall after harvest).

• Evaluate various straw treatments: no stubble or straw remaining (all baled and removed); stubble and straw remaining; only stubble remaining (all straw baled and removed).

• Evaluate various fertilizer treatments (based on varying nitrogen rates). The sources of nutrients are nitrogen (from urea 46-0-0 and ammonium phosphate 11-51-0), phosphorus (from ammonium phosphate 11-51-0), and potassium (from potassium chloride 0-0-50). The treatments are: 11-51-60, 51-51-60, 91-51-60, and 131-51-60.

The tillage study, in which barley is annually grown, is carried out on 6.5 acres within the original 40-acre Delta study site.

"Currently we have over 300 acres surrounding the original 40 acres at the Delta Junction Field Research Site," said research technician Bob Van Veldhuizen. "Current and planned research includes the tillage study, variety trials for small grains, oilseed, and legumes, forage yield and date of

Left: Bob Van Veldhuizen at the soil probe.

Above: Jon McCabe is on the tractor, which pulls the truck, and Steve Sparrow will steer the truck. Bob Van Veldhuizen operates the probe while Mingchu Zhang and darleen masiak wait for the sample to be extracted.

Right: The collected soil samples are bagged, labeled, and taken back to the laboratory in Fairbanks. Each sample is labeled with location information (which treatment plot it came from and the depth at which the sample was taken). Here darleen masiak prepares to bag the deepest depth from a probe sample while Bob Van Veldhuizen holds the probe to keep the sample in until they are ready to place it in the sack.

cutting trials, research on feed grain grown for reindeer feeding trials, Conservation Reserve Program studies (long term grass effects), insect and weed competition research, exotic tree plantation and seed production studies, and research on windbreaks, soil erosion, and irrigation." Some of the planned studies will be carried out when funding and manpower is available.

Cooperating agencies for the research are the U.S. Department of Agriculture Agricultural Research Service, USDA Natural Resources Conservation Service, the Alaska Department of Natural Resources Division of Agriculture and Alaska Cooperative Extension Service.

Right and far right: agronomy professor Mingchu Zhang measures and slices a soil sample for each depth within the probe. Together, he and darleen masiak bag the sample.

Students Afield!

Natural Resources Management 290

Doreen Fitzgerald

Students at Bodenburg Butte near Palmer during the 2002 field trip. From left to right: Svein Harald Sonderland, Jørn Magne Foreland, Maggie Rogers, Andrea Facio, Tasmia Parker, and Matt Neville.

Doreen Fitzgerald
photos by Jeff Werner

The field course Resources Management Issues at High Latitudes, NRM 290, gives students a close-up look at specific natural resources in Alaska during a ten-day trip around the state, with stops and activities at significant resource locales. Last spring the field course participants traveled to the Kenai Peninsula and back to Fairbanks.

"It is one of the few, if not the only course, where students can meet in the field with professionals in many resource areas, many who are movers and shakers in their area of expertise," said David Valentine, professor of forest soils.

"I thought it was fun. It was interesting and I learned a lot more than I thought I would," said Tia Callison, a senior who took the field course in 2000.

For completing the ten-day trip and the associated coursework, students receive two credit hours. Grades are based on a daily trip journal that discusses the highlighted management issues, a discussion paper on one aspect of resource management covered during the trip, and an instructor evaluation of the student's participation and contributions.

All natural resource management majors are required to complete NRM 290, which is designed to provide a broad perspective on resource management issues and to enhance understanding of how resource management relates to environmental, social, and economic issues in the state. Accompanied by participating faculty, expeditors, and a staff assistant, they travel by bus or vans, stopping along the way to visit commercial and public enterprises based on natural resources.

"The course is an intensive educational experience," said Deb Segla, the staff member who coordinates the course and handles the logistics. "It is interesting to see students and professors interact with each other as they handle the demanding schedule, miles of travel, and sometimes spartan living conditions."

During their stops, students participate in on-site analyses of resource management needs, opportunities, and conflicts in various industries: agriculture, forestry, mining, seafood, petroleum, recreation and tourism. Because the course varies somewhat from year to year, it may be repeated with the instructor's permission. To help offset the cost of travel and board, students pay a materials fee of $175. The course is open to students of junior standing who have a three-point grade average. Faculty rotate responsibility for and participation in the class.

NRM 290 Itinerary

The field trips vary from year to year, but this itinerary for the 2003 class is typical. The trip ran from 12 May to 21 May.

Monday: Fairbanks to Delta Junction

Topics: bank stabilization and agricultural history, greenhoue management, sport fishing (Alaska Dept. of Fish and Game), creek management, dairy farming and management, wildlife and agriculture interactions, and agricultural research.

Stops: Rika's Roadhouse, Nickay's Greenhouse and Truck Farm, Clearwater River, Clear Creek Campground, Dennis Green and Son's pellet mill, Northern Lights Dairy, the Clearwater Watershed Project, the Dept. of Fish and Game bison range, and the AFES mile 1408 Delta Field Research Site.

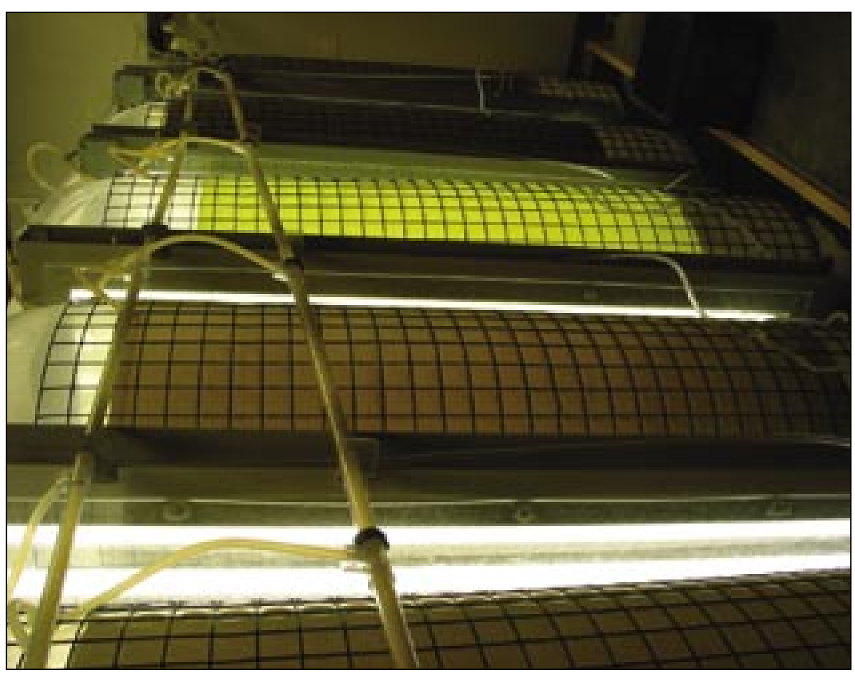
Tuesday: Delta Junction to Palmer

Topics: fire management, reclamation and conservation on military lands (Alaska Fire Service), climate and glaciers, geology, changing land use, wildlife viewing area, pipeline design and earthquake damage, the fish hatchery process, problems on the Gulkana River (BLM), and research protocol development.

Stops: Fort Greely, Black Rapids Glacier, Sheep Mountain (wild sheep viewing area), Trans-Alaska Pipeline at Denali fault pull-off, Gulkana River Hatchery, Glennallen BLM office, and UAF Matanuska Experiment Farm laboratory facilities.

Above: Cary deWit at Tom Williams' reindeer farm at Palmer during the 2002 field trip.

Top left: Plants in a commercial greenhouse at P & M Gardens.
Middle left: Glacier in Kenai Fjords seen from the ship during the 2003 tour.
Bottom left: Students lunching at the Alaska railroad's headquarters in Anchorage during the 2002 trip.
Below: Hatchery tanks seen on the tour of the Qutekchak Shellfish Hatchery, during the 2003 field trip.



WEDNESDAY: PALMER TO KENAI PENINSULA

Topics: a self-guided nature tour; visitor centers, early history of Russians in Alaska and Alaska economy, natural resource issues, and commercial fisheries issues.

Stops: Bird Point, Kenai Visitor Center, Russian Orthodox Church, Tesoro Refinery, and visit with set net fisherman.

THURSDAY: KENAI PENINSULA COMMUNITY COLLEGE TO HOMER

Topics: resource management issues (Alaska Dept. of Fish and Game), harbormaster viewpoint, charter boat captain (sport fishing industry) perspectives, the administration's new directions, learning center facility overview.

Stops: Clam Gulch, Deep Creek, Homer harbor and the ice plant, Katchemak Bay National Estuarine Research Reserve, and Kenai Peninsula Learning Center, Moose Pass.

FRIDAY: KENAI PENINSULA LEARNING CENTER AREA

Topics: state and private forestry (USDA Forest Service, Seward Ranger District), effects of recreational land use, birch bark beetle damage, forest management, moose habitat management, fish ladder visit, shellfish and fisheries management.

Right: Commercial fishing boats in Seward, Alaska, 2003.

Stops: Russian River Campground, Juneau Creek, Cooper Creek Campground, Quartz Creek Campground, visit to moose exclosures, Tern Lake, Qutekchak Shellfish Hatchery, Seward Fisheries, and Exit Glacier.

SATURDAY: LEARNING CENTER AT MOOSE PASS TO SEWARD

Topic: resource use for the tourism industry.

Stops: Kenai Fjords National Park boat tour, then travel to Birchwood Camp.

SUNDAY: BIRCHWOOD CAMP NEAR ANCHORAGE

Topics: commercial greenhouse operation, visit to trailhead (Dept. of Natural Resources state park ranger).

Stops: PM Gardens, Eagle River Campground and Flat Top Mountain trailhead, Eagle River Nature Center (or Thunderbird Falls).

MONDAY: ANCHORAGE DAY TRIP AND TRAVEL TO MEIER LAKE

Topics: Alaska Agricultural history, dairy operation, transportation, oil industry careers and issues, U.S. Bureau of Land Management (BLM) activities (panel of resource specialists), and turfgrass research.

Stops: Matanuska Maid Dairy, Alaska Railroad and Port of Anchorage, Ship Creek Park, British Petroleum Environmental Research Unit, BLM State Office, UAF Palmer Experiment Farm.

TUESDAY: MEIER LAKE TO DENALI PARK

Topics: Alaska soils, commercial organic farming (produce and beef), bison, elk, and muskox ranching, draft horses, and Denali Foundation research.

Stops: USDA Natural Resource Conservation Service, Arctic Organics farm, Wolverine Farms, Pitchfork Ranch, Windy Valley Farm, and Denali Park.

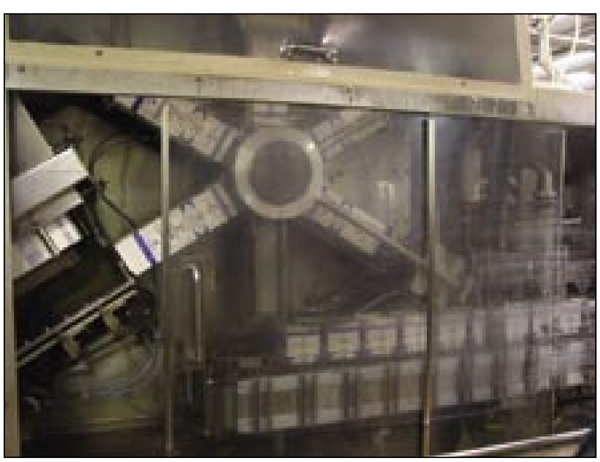
WEDNESDAY: DENALI PARK TO FAIRBANKS

Topics: national park visitor usage and coal mining.

Stops: Denali National Park headquarters and visitor center, Usibelli Coal Mine, and return to Fairbanks.

Above: tanks of milk at the Matanuska Maid dairy, seen during a tour of the dairy in 2002.

Right and far right: assembly line packaging of the milk.



Jobs for Credit!

Doreen Fitzgerald

College credit, work income, and experience with professional mentors are all part of the picture for students who enroll in NRM 300, Internship in Natural Resources Management. This supervised, pre-professional experience is open to students majoring or minoring in natural resources management.

"My internship has been fast-moving and intellectually challenging, said Maggie Rogers, a NRM student who's completing an internship as an information specialist with the Alaska Fire Service. "I'd never before had a responsible, interesting job in such a fun, welcoming environment," she said. "My days have been packed with different adventures—flying over fires, giving tours, getting involved with the stand conversion project, witnessing what's behind the scenes of Alaska firefighting, and talking with reporters and others. I'm learning how to work in a professional setting with people who really enjoy what they do and are very good at it."

Rogers said she was challenged from the start to use her own creativity and talents to bring up new ideas and projects. "As someone told me, 'AFS is a place where if you express the desire to do something, everyone tries to help you move forward, rather than trying to bring you down,'" she said. "Internships should give you an idea of what you are getting into, for better or for worse. They're a good introduction to the real working world, and may lead you in different directions than you ever planned. I know mine did." As part of her job, Rogers wrote the story about reducing fire risk that appears on page 14. For her, the internship was such a good fit it was extended until she graduates this December.

Students can take the course for one to three credits during the summer or fall and spring semesters. It can be repeated for a maximum of six credits. The prerequisites for the course include completion of NRM 101, junior standing with a minimum 3.0 grade point average, permission of the instructor, and an approved internship plan

During a summer 2003 internship at the Tetlin National Wildlife Refuge, student Ozie West, Jr. completed a plan for the Seaton Roadhouse area walking trails. Senior Heidi Lingenfelter has completed two internships with the Alaska Department of Natural Resources (DNR), one at the Public Information Center in Fairbanks, and one in the land sales division, where she did research on land parcel status for a state land disposal effort. "The people I worked with were really wonderful," she said, "and the work was interesting."

Since its inception in 1980, the DNR internship program has provided work experience to over 900 Alaska students, according to Lee McFarland of the agency's human resources department. "Internships offer unique opportunities to the DNR, students, educational institutions, and Alaska," he said. "The students gain academic and career development, while also accomplishing necessary work for DNR."

McFarland noted that along with the applied educational experience gained by the Alaska students, they are also exposed to the type of employment opportunities available in their prospective careers and to the most active fields of government and private industry in the state. In return, the DNR gains access to skilled students who need summer employment. "The program allows the DNR to participate in Alaska's educational system by encouraging and exposing students to career fields related to the agency," he said.

Eligibilty requirements at the DNR include Alaska residency, a minimum age sixteen, and good academic standing with a high school or college program. For summer jobs, the applicant must have been a full-time student in the immediately preceding spring semester and have proof of acceptance and admission for full-time studies in the upcoming fall semester.

Most internships with Alaska State Parks are done through the park volunteer program, although the Office of History and Archaeology hires a handful of interns through DNR internships. Contact the office of history and archaeology to inquire about any current openings.

Nonprofit agencies also are a source of internships. The Alaska Conservation Foundation provides a number of twelve-week paid internships that are open to undergraduate and graduate college students who want to work with organizations and agencies involved in environmental and resource management, habitat protection, advocacy, policy implementation, marine conservation, and conservation education. In 2004, fifteen internships will be awarded.

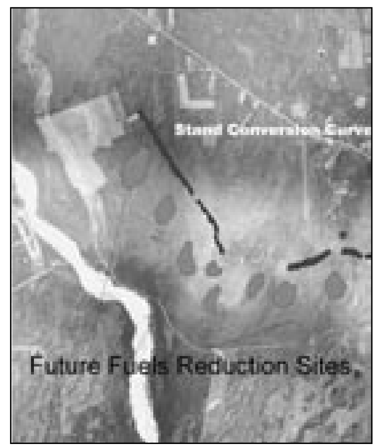
"For us, the Conservation Intern Program is an exciting initiative, one that offers excellent career development opportunities for college students, as well as important support to organizations, agencies, and other groups working to preserve wild and scenic Alaska," said the foundation's executive director, Deborah Williams. Internship descriptions and application materials can be found on the foundation's web site. These twelve-week work opportunities are with such entities as the Alaska Boreal Forest Council, Alaska Bird Observatory, Kachemak Heritage Land Trust, and many other conservation and environmental organizations.

McFarland can be contacted at the DNR Human Resources Office, 550 W. 7th. Ave., Suite 1240, Anchorage, AK 99501 (907-269-8668 or e-mail: Lee_McFarland@dnr.state.ak.us). The DNR program is described on the Internet at: dnr.state.ak.us/pic/intern.htm. The Alaska Conservation Foundation can be contacted at 907-276-1917 or e-mail: acfinfo@akcf.org. The foundation website is at akcf.org/grants/internship.htm.

The North Jarvis Stand Conversion Project

story & photos by Maggie Rogers

Above: Denali hotshot crew in the rain, leaving North Jarvis. The crews removed spruce from hardwood stands during phase one.



Right: Chart used in the planning phase, showing areas where the fuel load was to be reduced.

Prevention, preparedness, planning, and hazard fuel reduction are all components of a strategy to reduce the risk of wildland fires on military lands in Alaska. The BLM Alaska Fire Service (AFS) and U.S. Army-Alaska (USARAK) are using a four-step mitigation strategy to protect communities near military property. The North Jarvis Stand Conversion Project at the Donnelly Training Area (DTA), southeast of Delta Junction, is a good example of the partnership between USARAK and AFS.

Located in the Tanana Valley, the Delta Junction area has a rich fire history and has experienced many close calls from fires. Most of the land to the south of Delta Junction has previously burned, except the area surrounding the junction of Jarvis Creek and the Richardson Highway. It is only a matter of time until a fire will start in this mix of black spruce and hardwoods.

Recognizing the high fire danger in this area and the potential for wildfire encroachment into developed areas, two years ago AFS and USARAK personnel began to assess options for reducing the risk. The original plan was to use prescribed fire to reduce the fuel load and continuity. After critical analysis, AFS experts decided that although a prescribed burn would meet their objectives, the window of opportunity for safely conducting the burn would be too small and risk of the fire escaping too great.

The alternative eventually chosen was a five-year project that will mechanically convert a stand of black spruce to hardwoods. Although a hardwood stand will not necessarily stop a fire, it is less flammable than black spruce and creates a point at which an attack on the fire can be started. The area undergoing the stand conversion is about five miles long, 75–150 yards wide and was designed as a lazy curve to better blend with the surrounding landscape.

A three-phase process designed for the area includes both community involvement and ecosystem manipulation. Part of phase one involved hand-thinning by AFS hotshot and emergency firefighter crews and a USARAK fuels crew to remove the spruce component from existing hardwood stands and to thin out a pure spruce stand at one end of the project. This stage was completed in August 2003. Thirty-seven acres were thinned and more than 630 piles of brush were left to be burned in winter 2003 or 2004.

The conversion area is being treated as a test site. AFS and USARAK personnel will experiment with two different techniques, hydro-axing and shear-blading, to speed up the stand conversion process. This fall, the mechanical treatments

Area shear-bladed for moose habitat during phase three.

were applied to another forty acres to determine which method is the most effective and cost efficient. The treatment that best meets the criteria will dictate what happens along the rest of the curve. Seeds were collected during this phase to aid hardwood regeneration in areas that do not come back as readily as others.

Phase two involves participation from the surrounding community. AFS and USARAK will work with Alaska Division of Forestry and private homeowners to determine how this phase should be conducted. The goal is to encourage community fire preparedness by stressing homeowners' responsibilities in taking the initiative to prepare their houses and property for fire. Firewise, a national program for public education on fire readiness, will provide the suggested guidelines for homeowners.

Spruce brush piles in a thinned hardwood stand (birch).

During phase three, black spruce stands will be cleared in a series of polygons to break up the continuity of the fuels and reduce likelihood of high-intensity crown fires. A detailed assessment of wildland fire fuels will be conducted south of the project. Breaks in the homogenous black spruce stands will also improve wildlife habitat. In March 2003, a forty-acre polygon was shear-bladed using funds for the creation of moose habitat.

Once the three phases are completed, the project will require occasional maintenance. Hardwood regeneration is expected within the first two years. Spruce trees are predicted to come back after three to six years, except on areas of permafrost, where regeneration could take up to ten years. Any spruce growth will be removed every five years to maintain the hardwood component.

Specialists are involved in the many different aspects of the stand conversion process. Natural Resources Conservation Services soil scientists were consulted on how to accomplish the stand conversion. Project work is in cooperation with the Salcha Big Delta Soil and Water Conservation District. Archaeology crews have surveyed the five-mile site to identify any cultural resources. One site found to have stone flecks from tool-making was left untouched. Should other sites be found, the stand treatments will be shifted to other areas. USARAK Forester Dan Rees plans to conduct research on the conversion site throughout the course of the project. He will establish a minimum of three plots in each mechanical treatment area to measure tree and shrub composition and density, ground cover, percentage bare soil, duff depth, and permafrost depth.

The North Jarvis Stand Conversion Project is one of several initiatives that AFS and USARAK are taking to prepare military lands for fire. As the urban-wildland interface continues to grow and as USARAK expands their mission, managers face the challenge of thinking ahead for fire readiness. AFS and USARAK's partnership has allowed them to move foreword in this challenge. Initially a large undertaking, the stand conversion could be an important factor in the Delta Junction area's future fire history.

Maggie Rogers is a senior in Natural Resources Management at UAF. She is completing an internship with the U.S. Bureau of Management Alaska Fire Service that she started during summer 2003. For more on SNRAS student internships, see page 13. Rogers can be contacted at the Alaska Fire Service Information Office, 907-356-5511, or by e-mail: maggie@infoinsights.com.

Piles of brush in a spruce stand.

Antioxidants in the North

While most of the berries picked in Alaska this summer went directly to the table, freezer, or into the jelly jar, some were set aside for science. They were collected for research on the antioxidant properties of wild and domesticated berries and vegetable crops in Alaska. Researchers Roseann Leiner, Rudy Candler, and Pat Holloway are conducting the study over a span of several years.

Antioxidants are chemicals that protect key cell components by neutralizing the damaging effects of free radicals, which are natural byproducts of cell metabolism. In chemical terms, free radicals are oxygen metabolites that have an uneven number of electrons. These reactive molecules seek to form new chemical bonds with other molecules, including DNA, RNA, proteins, and lipids (Prior and Cao 2000). As free radicals travel through cells, they disrupt the structure of other molecules. Antioxidant compounds can function as alternative targets for free radicals and prevent this disruption. The presence of more free radicals than antioxidants can cause cell damage that is linked to age-related diseases such as cancers. The presence of more antioxidants than free radicals can confer health benefits.

Using modern analytical instruments, the AFES study aims to identify antioxidant compounds in such Alaska plants as wild blueberries, lingonberries, and rosehips; cultivated strawberries, red and black currants, and raspberries; and cabbage, lettuce, mustard greens, and carrots. The project involves field cultivation at the AFES Fairbanks and Palmer farms, collection of wild berries throughout the state, and analysis at the Palmer Research Center laboratory.

Among compounds having antioxidant activity are vitamins C and E, and numerous members of the flavonoid family. Some previous studies have measured levels of specific flavonoids in plants, but since many compounds contribute to a plant's antioxidant capacity, another approach has been to measure the total antioxidant activity by determining oxygen radical absorbance capacity (ORAC) (Prior and others 1998, Wang and others 1997). A 1996 study by Wang and others reported that strawberries had the highest ORAC activity of twelve fruits tested. Cao and others (1996) reported that garlic had the highest ORAC activity of twenty-two vegetables tested, and that the activities of green and black teas was higher than any vegetable.

Recent studies of antioxidants in fruits and vegetables uses high-performance liquid chromatography (HPLC) to identify and quantify the electroactive compounds in food extracts (Guo and others 1997, Adamson and others 1999). Chromatography is a technique used to separate molecules based on how they adhere to or dissolve in various solids, liquids, and gases. HPLC is used for separating, identifying, purifying, and quantifying various compounds. For the AFES study, known antioxidant compounds were purchased and used for method development in 2001 and 2002. In the summer of 2002, numerous berry and leaf greens samples were collected and frozen until they could be extracted and analyzed. In early 2003, many of these were processed on the HPLC. Analyses on the HPLC of previously collected samples is ongoing.

Blueberry.
—Photo by Scott Bauer, USDA ARS, www.forestryimages.org

The AFES study will expand knowledge of human nutritional and antioxidant components of Alaska fruits and vegetables. Results could be used as a marketing tool to promote Alaska grown and harvested products. For example, if Alaska wild blueberries and lingonberries are highly antioxidant, opportunities in domestication and marketing of these as health food specialty products could increase. This project also will expand the capabilities of the Palmer Research Laboratory to provide local analysis of perishable samples whose chemistry may change in transit to more remote laboratories. The research is funded by a USDA special grant.

Cited References

Adamson, G.E., S.A. Lazarus, A.E. Mitchel, R.L. Prior, G. Cao, P.H. Jacobs, B.G. Kremers, J.F. Hammerstone, R.B. Rucker, K.A. Ritter, H.H. Schmitz. 1999. HPLC Method for the quantification of procyanidins in cocoa and chocolate samples and correlation to total antioxidant capacity. *J. Agric. Food Chem.* 47:4184–4188.

Cao, G., E. Sofic, R.L. Prior. 1996. Antioxidant capacity of tea and common vegetables. *J. Agric. Food Chem.* 44:3426–3431.

Guo, C., G. Cao, E. Sofic, R.L. Prior. 1997. High-Performance Liquid Chromatography coupled with coulometric array detection of electroactive components in fruits and vegetables: relationship to oxygen radical absorbance capacity. *J. Agric. Food Chem.* 45: 1787–1796.

Prior, R.L., G. Cao. 2000. Antioxidant phytochemicals in fruits and vegetables: diet and health implications. *HortSci.* 35:588–592.

Prior, R.L., G. Cao, A. Martin, E. Sofic, J. McEwen, C. O'Brien, N. Lischner, M. Ehlenfeldt, W. Kalt, G. Krewer, C.M. Mainland. 1998. Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species. *J. Agric. Food Chem.* 46:2686–2693

Wang, H., G. Cao, R.L. Prior. 1997. Oxygen radical absorbing capacity of anthocyanins. *J. Agric. Food Chem.* 45:304–309.

Wang, H., G. Cao, R.L. Prior. 1996. Total antioxidant capacity of fruits. *J. Agric. Food Chem.* 44:701–705.

Shapeshifter CARBON: a universal building block

Doreen Fitzgerald

Artificial heart valves, oil drills, soda pop, and roses share a common characteristic: each of them employs some form of the versatile element carbon (symbol C, atomic number 6, from the Latin word for charcoal, *carbo*).

As a simple element, carbon occurs as graphite, diamond, and fullerene. Pyrolytic carbon, which has a disordered graphite structure, is used in heart valves. Diamond, a crystallized form of pure carbon and the world's hardest natural substance, is widely employed in drilling and cutting tools. Carbonated beverages get their fizz from an infusion of carbon dioxide, a major performer in the carbon cycle and of current interest in climate warming because it functions in the atmosphere as a greenhouse gas. All living organisms, like the rose plant, contain carbon, which provides the framework for tissues, the elements of which are grouped around chains or rings made of carbon atoms. The human body is about eighteen percent carbon by weight.

Although carbon is not the most abundant element on Earth, the reactivity of the carbon atom allows it to link with other carbon atoms and other elements. It is known to form millions of compounds, more than the number formed by all the other elements combined. Several research projects at the school of Natural Resources and Agricultural Sciences are looking at the behavior of carbon compounds in northern ecosystems. Before discussing them, this article will look at some of the basic characteristics of carbon and the carbon cycle.

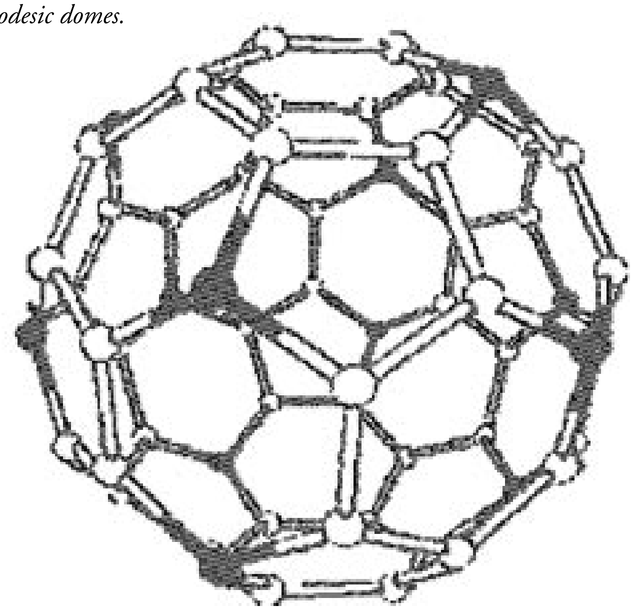
Diamond and graphite are deposited in widely scattered locations around the Earth. In 1985, fullerenes, clusters of carbon atoms, were discovered in a research laboratory among the byproducts of laser-vaporized graphite. Because their hollow spherical structure is similar to Buckminster Fuller's geodesic domes, they're called "buckyballs," as well as "fullerenes." Their unique structure, heat resistance, and electrical conductivity point to such possible uses as high-temperature lubricants, microfilters, more efficient semiconductors, and for manufacturing processes. Fullerenes also have been found in natural rock.

A diamond, no matter what the size, may be considered a single molecule of carbon atoms, each joined to four other carbons in regular tetrahedrons, or triangular prisms. Graphite consists of layers of carbon atoms joined in regular hexagons by strong bonds. The layers are held together by long-range, relatively weak attractive forces. The layers easily can slide over each other, which in part explains the lubricating property of graphite. Amorphous carbon is a form of graphite. It consists of microscopic crystals obtained by heating a carbon-rich material to 1,200–1,800°F in a limited amount of air so that incomplete combustion occurs. By this means coke is produced from coal, carbon black (lampblack or channel black) from natural gas or petroleum, charcoal from wood, bone char from bone and, from petroleum coke or coal, baked carbon, carbon arcs, or carbon electrodes.

The electrons in the outer shell of atoms can interact with each other to form chemical bonds. The exact nature of these bonding interactions mainly depends on the electronegativities of the individual atoms. Bonds between atoms with large differences in electronegativity tend to be ionic: the electrons are fully donated from one atom to another. Bonds between atoms with identical, or small differences in electronegativity tend to be covalent: the electrons are shared between the two atomic centers.

Because a carbon atom has four valence electrons and makes covalent bonds, it can form molecules that are long chains, such as hydrocarbons, carbohydrates, lipids, proteins,

"Buckyball," or fullerene, one of the natural molecular structures of carbon. This structure is similar to Buckminster Fuller's famous geodesic domes.



and DNA. It can make four single bonds with other atoms by sharing with each of those atoms one of its electrons and one of the other atoms' electrons. In a double bond, two pairs (four) electrons are shared between the two atoms involved. In this case, the carbon atom has only two other electrons available for bonding with any other atoms. For example, if a carbon atom is single bonded to another carbon atom, it could also bond to three hydrogens; if it is double bonded to another carbon, then it can only bond to two hydrogens.

Hydrocarbon molecules are one example of a carbon compound. Although they are not generally found in living organisms, they occur in fossil fuels, which used to be living organisms. These molecules consist of carbon and hydrogen. The type of hydrocarbon is determined by the number of carbon atoms in the molecules and whether the carbons are connected by double or single bonds bonds.

Some natural substances rich in carbon are common fuels (coal, petroleum, natural gas, oil shale), limestone, coral, oyster shells, marble, dolomite, and magnesite. Limestone, coral, and oyster shells are largely calcium carbonate. Marble, dolomite, and magnesite also contain calcium, magnesium, and carbon. Sugar, starch, and paper are compounds of carbon with hydrogen and oxygen. Proteins (hair, meat, and silk) contain carbon and other elements such as nitrogen, phosphorus, and sulfur. With oxygen and a metallic element, carbon forms many important carbonates, such as calcium carbonate (limestone) and sodium carbonate (soda). Certain active metals react with it to make industrially important carbides, such as silicon carbide (known as carborundum), calcium carbide, used for producing acetylene gas, and tungsten carbide, an extremely hard substance used for rock drills and metalworking tools. Coke is used as a fuel in the production of iron. Carbon electrodes are widely used in electrical apparatus. The "lead" of the ordinary pencil is graphite mixed with clay

Because of the many important and unique properties of carbon-based molecules, the field of organic chemistry is devoted exclusively to the study of these compounds, and new ones are regularly discovered or synthesized. Their synthesis starts from carbon compounds available in nature. The successful linking in the 1940s of carbon with silicon has led to the development of many new substances known collectively as silicones.

In green plants, carbon dioxide and water combine to form simple sugars (carbohydrates), using sunlight to fuel the process (photosynthesis). The energy from the sun is stored in the chemical bonds of the sugar molecule. Anabolism, the synthesis of complex compounds (fats, proteins, and nucleic acids) from simpler substances, involves use of the energy stored by photosynthesis. Catabolism is the release of stored energy by the oxidative destruction of organic compounds; water and carbon dioxide are two byproducts of catabolism. This continuing synthesis and degradation involving carbon dioxide is known as the biological carbon cycle.

Some of the most common carbon compounds:

carbon dioxide	(CO_2)
carbon monoxide	(CO)
carbon disulfide	(CS_2)
chloroform	($CHCL_3$)
carbon tetrachloride	(CCL_4)
methane	(CH_4)
ethylene	(C_2H_4)
acetylene	(C_2H_2)
benzene	(C_6H_6)
ethyl alcohol	(C_2H_5OH)
acetic acid	(CH_3COOH)

Further Reading

Isaac Asimov, *The World of Carbon* (rev. ed. 1966).

P.L. Walker, Jr., and P.A. Thrower, ed., *Chemistry and Physics of Carbon* (11 vols. 1966–74).

Sources for these carbon articles included:

Biology 104 course, David Fankhauser, professor of biology and chemistry, U.C. Clermont College, Batavia, Ohio: http://biology.clc.uc.edu/courses/bio104

Carbon Dioxide Information Analysis Center (CDIAC): cdiac.esd.ornl.gov/ (This organization includes the World Data Center for Atmospheric Trace Gases, the primary global-change data and information analysis center of the U.S. Department of Energy.)

Dendritics Gemscales Museum: dendritics.com

First Strike Diamonds, Inc.: http://www.first-strike-diamonds.com

Jefferson Lab, managed by the Southeastern Universities Research Association (SURA) for the U.S. Department of Energy. 12000 Jefferson Avenue, Newport News, VA 23606: www.jlab.org; Jefferson Lab Science Education: www.education.jlab.org.

How Much Carbon Where?

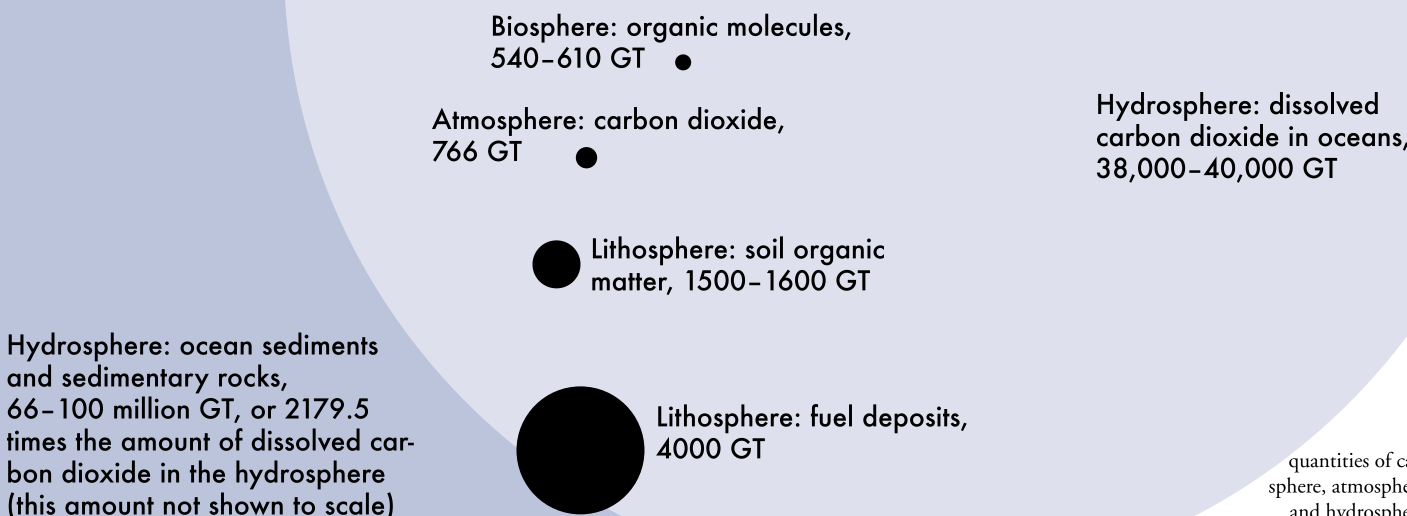
Carbon regularly cycles through the Earth system. The focus of carbon research at the School of Natural Resources and Agricultural Sciences is the acquisition of basic data about carbon in the biosphere at high latitudes, and how its interaction with the atmosphere is affected by changes in temperature and by disturbances such as wildfire. For the purposes of considering total carbon in the Earth environment, estimates are made in gigatons. One gigaton (GT) is equal to one billion metric tons (a metric ton equals 1,000 kilograms). Gigatons are also called pentagrams.

BIOSPHERE: The regions of Earth that support ecosystems collectively store carbon in the organic molecules in living and dead organisms. During the process of photosynthesis, plants convert carbon atoms from carbon dioxide gas in the atmosphere into sugars, which they need for growth. Terrestrial plants are estimated to store 540 to 610 GT of carbon, an amount similar to that of carbon presently in the atmosphere.

ATMOSPHERE: In the atmosphere, carbon is stored as carbon dioxide gas, one of the so-called greenhouse gases that are involved with the regulation of global temperatures. The amount of atmospheric carbon is estimated to be about 766 GT now, up from 578 GT in the year 1700. This increase, from preindustrial levels of 280 parts per million to present levels of over 365 ppm, is attributed to increased inputs of carbon dioxide into the atmosphere due to increased burning of fossil fuels after the industrial revolution.

LITHOSPHERE: In the solid part of the earth, carbon is stored as both organic and inorganic matter. Carbon exists as litter, organic matter, and humic substances (partially or wholly decayed vegetable matter) in soils. Inorganic carbon exists as fossil fuels (coal, oil, natural gas, oil shale) and sedimentary deposits (limestone, limestone dolomite, and chalk). From the interior lithosphere, the carbon dioxide released by volcanoes enters the lower lithosphere when carbon-rich sediments and sedimentary rocks are subducted and partially melted beneath tectonic boundary zones. Fuel deposits in the lithosphere account for about 4000 GT of the total carbon budget. Soil organic matter accounts for 1500 to 1600 GT.

HYDROSPHERE: Carbon enters the earth's waters (mostly ocean) by means of simple diffusion of carbon dioxide gas. Once dissolved in water, the carbon dioxide can remain as is or can be converted into carbonate or bicarbonate. Dissolved carbon dioxide in the oceans accounts for about 38,000 to 40,000 GT of carbon. Some forms of sea life biologically fix bicarbonate with calcium to produce calcium carbonate for producing shells and other body parts. When these organisms die, their shells and body parts sink to the ocean floor where they accumulate as carbonate-rich deposits. Eventually, these deposits are physically and chemically altered into sedimentary rocks. Ocean deposits are by far the biggest carbon sink; marine sediments and sedimentary rocks account for about 66,000,000 to 100,000,000 GT of carbon.



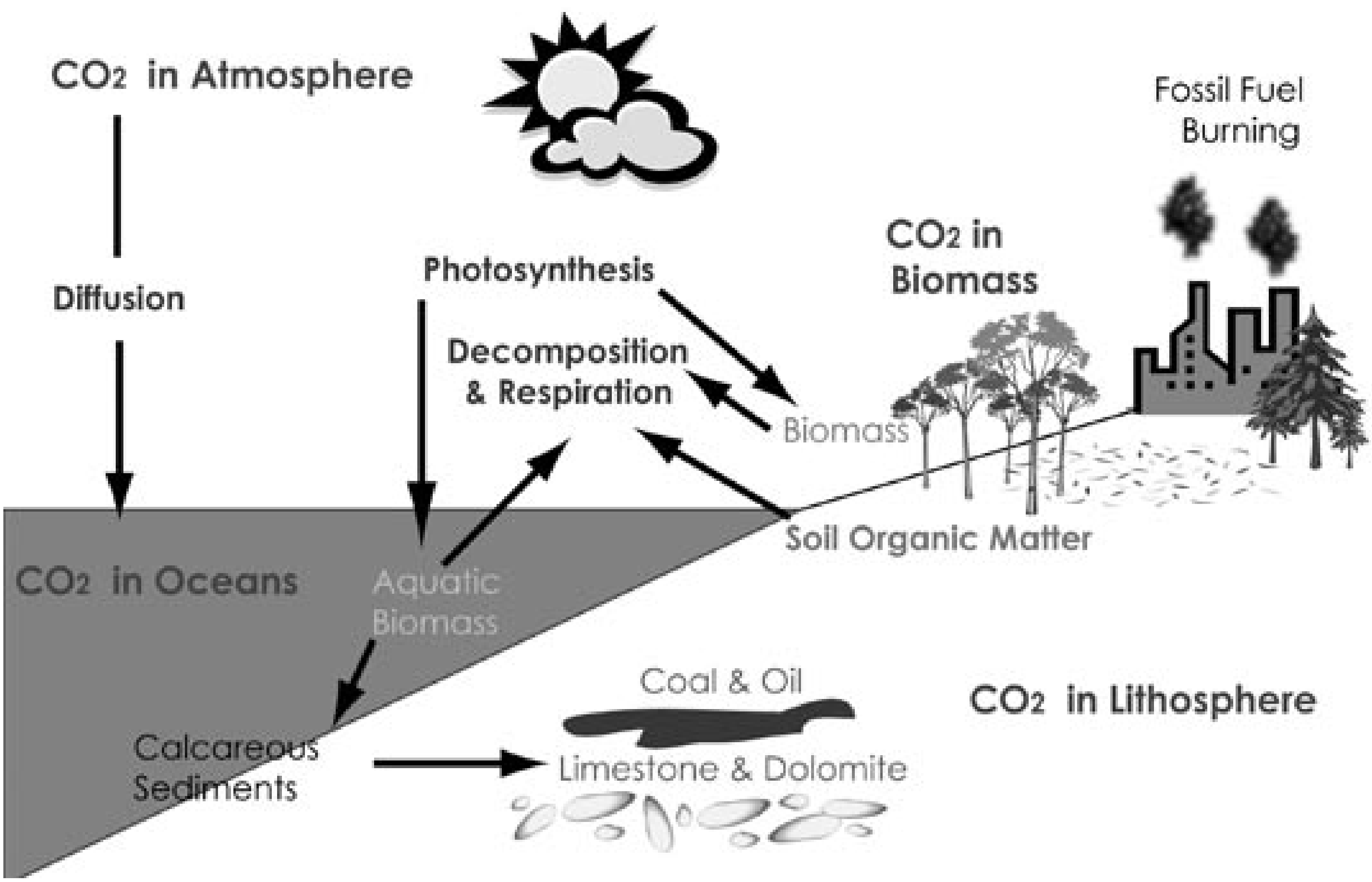
quantities of carbon in biosphere, atmosphere, lithosphere, and hydrosphere (dissolved carbon only) shown to scale

THE TERRESTRIAL CARBON CYCLE

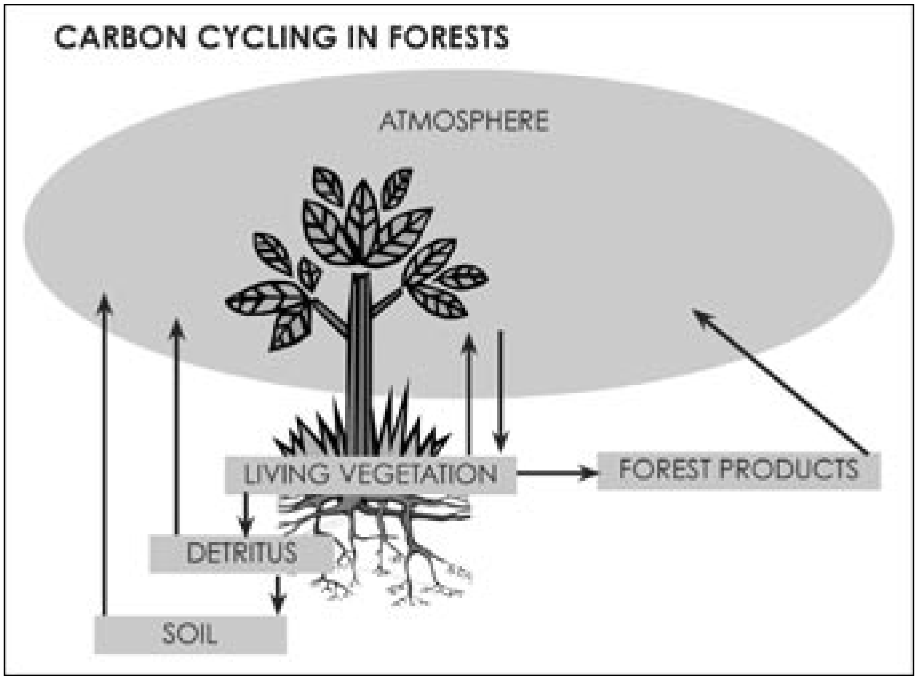
Carbon cycles through the lithosphere (solid earth), hydrosphere (oceans), biosphere (ecosystems), and atmosphere. Through photosynthesis, plants take up atmospheric carbon dioxide. A carbon atom stored as wood in a tree is converted to carbon dioxide when the wood burns. A plant, when eaten, becomes part of an animal's tissue. Animals return carbon dioxide to the air when they breath, and after death to the soil through decomposition. Through decomposition, the carbon atoms in soil may then be used by new plants or small microorganisms. Through soil respiration, carbon dioxide is again released into the atmosphere.

The processes that control these carbon exchanges between living organisms and the nonliving environment are collectively known as the carbon cycle. Research at SNRAS focuses on the terrestrial part of the cycle, which involves plants and soil and is discussed here. Carbon stored in the oceans as dissolved carbon dioxide, sediments, and sedimentary rock accounts by far for most of the carbon that exists in the Earth environment, but much of that carbon is sequestered. Carbon sequestration is the long-term storage of carbon in the terrestrial biosphere, underground, or in the oceans.

The natural equilibrium of the carbon cycle has in the last century been affected by the accelerating release of carbon dioxide through the burning of fossil fuels by humans. Since preindustrial times, the amount of carbon dioxide in the atmosphere has increased, in parts per million, from 280 to 365. This increase is of concern because carbon dioxide is the principal greenhouse gas and because the increase correlates with observed warming of temperatures around the world. The effects of this warming are expected to be most dramatic in the polar regions. Increased sequestration of carbon could reduce or slow the buildup of carbon dioxide concentration in the atmosphere. This could be accomplished by maintaining or enhancing natural processes or by developing new techniques to dispose of carbon.



Fixation and Photosynthesis



Most of the compounds that compose a living organism are made up mainly from carbon that's derived from free carbon dioxide in air, or water, in the case of an aquatic environment. As an organism's cells age and die, their materials return to the environment, and new cells are formed of newly incorporated substances. The process of incorporating inorganic molecules into the more complex molecules of living matter is called fixation.

Nearly all carbon dioxide fixation is accomplished by means of photosynthesis, in which green plants use energy from the sun, and water drawn into the plant through its roots, to form a simple sugar molecule ($C_6H_{12}O_6$). Sugars sometimes join together to form large starch molecules. Sugars and starches (carbohydrates) are used by green plants to build the other organic molecules that make up their cells, such as cellulose, fats, proteins, and nucleic acids, sometimes incorporating nitrogen as well. When carbohydrates are oxidized in cells, they release the energy stored in their chemical bonds, and some of that energy is also used by the cell to drive other reactions. During this process, oxygen gas is formed and released into the atmosphere.

Respiration

Although carbon enters terrestrial ecosystems primarily through a single process, photosynthesis, it can be returned through several processes collectively known as respiration. During respiration, oxygen from the atmosphere or water combines with portions of the carbohydrate molecule, producing carbon dioxide and water, the compounds from which the carbohydrate was originally formed. Energy for use by the cell is also released during respiration. Cellular respiration is similar to combustion in a vehicle engine. Cell mitochondria act as engines where sugar is burned for fuel. The exhaust is carbon dioxide and water, comparable to what it would be from a car that burned fuel perfectly.

Not all of the carbon atoms incorporated by the plant can be returned to the atmosphere by its own respiration. Some remain fixed in the organic materials that make up its cells. When the plant dies, its tissues are consumed by bacteria and other microorganisms, a process called decay. These microorganisms, which cannot make their own carbohydrates, break down the organic molecules of the plant and use them for their own cell-building and energy needs. Through their respiration, more of the carbon is returned to the atmosphere.

Animals cannot make their own carbohydrates either, so whether they feed on plants or on other animals, their matter and energy ultimately are derived from plants. The carbon-containing molecules that an animal gets from other organisms are reorganized to build its own cells or are oxidized for energy by respiration, releasing carbon dioxide and water. At death, the animal is decayed by microorganisms, resulting in the return of more carbon to the atmosphere.

Sometimes organic compounds other than carbohydrates, such as fats or proteins, are used as fuel. If a plant produces a seed that is then eaten by an animal, the carbon would enter a tissue cell and be chemically altered by an enzyme system that triggers cellular respiration. The carbohydrate reacts with oxygen to produce water, carbon dioxide, and energy. The carbon dioxide diffuses into the blood and moves to the lungs, where it is exhaled.

Carbon-containing molecules in wood (or other dry, slow-decaying organic materials) may be oxidized by burning, also producing carbon dioxide and water. Under conditions prevailing on earth at certain times, green plants have decayed only partially and have been transformed into fossil fuels—coal, peat, and oil. These materials are made of organic compounds formed by the plants; when burned, they too restore carbon dioxide to the atmosphere.

Under discussion and study today are ways in which carbon sequestration could be promoted to control the level of carbon dioxide in the atmosphere. There are many gaps in basic scientific knowledge about how ecosystems will behave if temperatures continue to increase in this century, which is predicted. Will the warming of frozen soils promote decomposition and cause the release of more carbon dioxide? Will increased carbon dioxide promote the growth of plants and forests, which could absorb more carbon dioxide? Will warming temperatures retard the growth of some forest species? Some research involves collecting basic data that can be used in conjunction with modeling—computer simulations of climate, plant growth, and other factors in the complex interactions of the carbon cycle.

Carbon Production in Alaska's Boreal Forest

The boreal forest, a circumpolar band that runs through much of Alaska, Canada, Russia, Scandinavia, and parts of northern Scotland, covers seventeen percent of the earth's land surface and accounts for about one third of the planet's total forest area. This extensive eco-region significantly affects Earth's water and carbon budgets, and the related process are now under study around the world. About fifteen percent of the boreal forest is in Alaska.

At the University of Alaska Fairbanks, a computer modeling study by forest sciences professor John Yarie and visiting scientist Sharon Billings developed estimates of net ecosystem production of carbon for Alaska's northern forest. The study produced an estimate of the forest's current standing biomass and carbon content; modeled the current dynamics of the forest carbon; and finally, estimated future carbon dynamics for a scenario in which the mean annual temperature has increased 5° centigrade (9° F).

"The main components of forest carbon dynamics are forest biomass, production, and decomposition of the forest floor and mineral soil organic matter," said Yarie. "The factors that control and change the dynamics of these components are related to climate, plant species, and the structure of the soil organic and mineral soil layers." Biomass is the dry weight of individual components of the ecosystem or, for total biomass, the dry weight of all components.

After creating an estimate of Alaska's forest biomass for each forest type, the study employed CENTURY, a general ecosystem computer model that can simulate nitrogen, carbon, phosphorus, and sulfur dynamics for forests, grasslands, crops, and savannas. It is a stand-growth model that includes belowground vegetation components (roots). The model was previously used for the boreal forest of Alaska in a study by Yarie, et al. (1994). It includes submodels for biophysical processes, plant production, and soil organic matter, and also can account for disturbances such as fire and logging.

"By combining the capabilities of CENTURY and our knowledge of the distribution of forest types and climate zones, we estimated a value for the net ecosystem production of carbon for the five major tree species in Alaska's boreal forest," Yarie said. The major ecosystem types, ranked from most prevalent to least, are black spruce, white spruce, birch, aspen, balsam poplar, and black cottonwood.

Whether an ecosystem is a source of atmospheric carbon or a sink where carbon is sequestered is determined by the relationship between production and decomposition. Climate warming could increase the number and size of trees, so that more carbon dioxide in the atmosphere would be converted to plant material and oxygen. A greater biomass of forest would also produce more material subject to decay. If climate warming promotes organic matter decomposition, this could increase soil respiration and the amount of carbon dioxide released to the atmosphere.

The study used inventory data from the U.S. Forest Service Inventory Analysis Unit to estimate the land area represented by the major overstory species at various age classes of trees. The CENTURY model was then used to develop an estimate of carbon dynamics throughout the age sequence of forest development for the major ecosystem types.

The maximum net primary production was estimated for various ecosystem types with a current climate scenario and a climate warming scenario. The model predicted that a 5° centigrade increase in the mean annual temperature, with no change in precipitation, would increase the net ecosystem production estimate of carbon for the taiga forest of Alaska by 16.95 teragrams (Tg) a year. A teragram equals one trillion grams.

Yarie's research background is in forest nutrient cycling and plant-soil relationships. He is also interested in applying site-specific knowledge to landscape level problems through the use of modeling and geographic information systems. He teaches forest ecology, theoretical ecology, and research methods, and directs the Forest Soils Laboratory. He can be reached by e-mail at: ffjay@uaf.edu

Reference

Yarie, J. and S. Billings. 2002. Carbon balance of the taiga forest within Alaska: present and future. *Canadian Journal of Forest Research*. 32: 757–767.

For more on the boreal forest, see the following websites:

Alaska Boreal Forest Council:
http://www.akborealforest.org/

Boreal Ecology Cooperative Research Unit:
http://www.becru.uaf.edu/default.htm

Bonanza Creek Long Term Ecological Research:
http://www.lter.uaf.edu/

Climate and Growth in the Boreal Forest


Photo by Glenn Juday

Doreen Fitzgerald with Valerie Barber

Studies correlating climate records and tree-growth in the boreal forest have important implications for predicting future growth and aboveground carbon storage under various climate scenarios. The Alaska boreal forest is one of the largest forest regions in the United States, is largely free of human disturbance, and has experienced a major climate warming since the 1970s. In work by Glenn Juday and Valerie Barber, hundreds of tree disks and cores were collected from black and white spruce and birch throughout interior Alaska to determine climate sensitivity, future growth scenarios under a warming climate, and potential for carbon credits and storage. Doctoral candidate Martin Wilmking has also collected over one thousand cores from treeline white spruce in the Brooks and Alaska ranges.

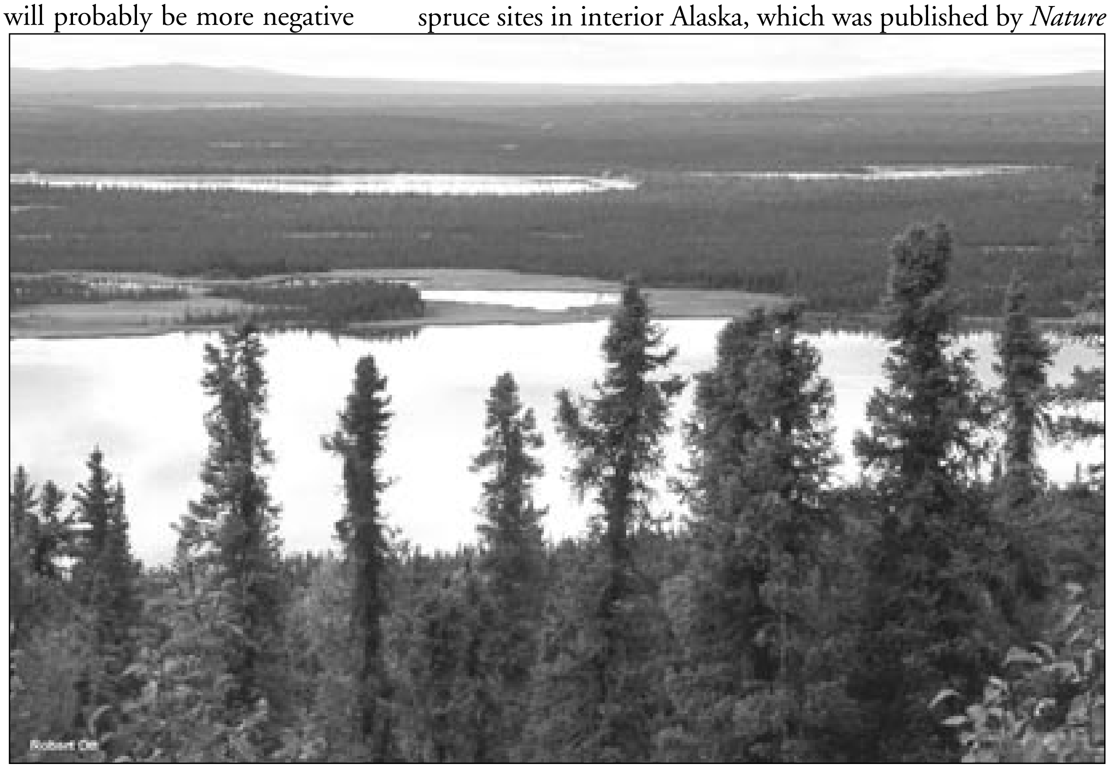
Most of the samples collected are five millimeter cores taken to the center of the tree at breast height or as low on the tree as feasible. Any disks collected were from trees that were being cut down for other purposes. A tree is typically not sacrificed to measure radial growth. The coring technique is nondestructive and doesn't hurt the tree.

Although boreal tree growth sometimes increases with climate warming and treeline is advancing in some regions, recent studies at the Bonanza Creek Long Term Ecological Research site (BNZ LTER) and elsewhere show that the effects of warming on the boreal forest will probably be more negative than positive. Ninety-five percent of the Alaska boreal forest consists of stands dominated by three tree species, black spruce (55%), white spruce (25%), and birch (14%). For all three species, at least some sites hold evidence of decreased radial growth from warming temperatures.

Interior upland white spruce trees are consistent in their negative growth response to warming summer temperature. Black spruce and birch show some mixed sensitivity. A negative growth response to temperature means that warmer temperatures produce less radial growth. A positive growth response to temperature means the warmer the temperature, the better the radial growth.

Different climate indices are developed for the different species and also for different sites. A climate index is created by running correlation analyses between average radial growth per year by site against monthly average temperatures. Sometimes more than one month is statistically correlated with growth, so an index must be made of those months. For example, interior Alaska white spruce show a strong negative correlation to summer (May–Aug) temperatures, so an index of summer temperature is created by averaging the mean monthly temperatures from May, June, July and August. This new average is a climate index for summer temperature. "We can create an index for each year of recorded climate date," said Barber, "and Fairbanks has one of the longest climate records, dating back to about 1904." Since many of the other interior Alaska recorded climate sites correlate well with Fairbanks climate data, the Fairbanks climate data is often the one of choice for sensitivity studies in Alaska.

A study on twenty different low elevation upland white spruce sites in interior Alaska, which was published by *Nature*



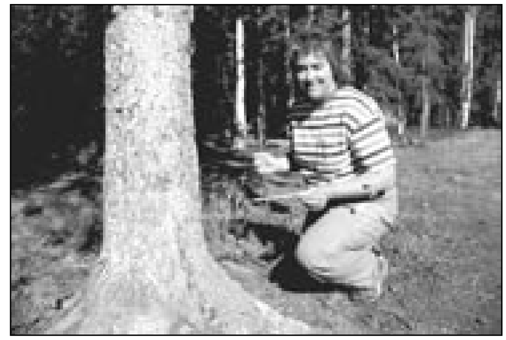
Black spruce forest. Climate warming could cause the demise of some black spruce stands in Alaska.
—Photo by Robert Ott

in June 2000, showed that all sites had a negative radial growth response to summer temperature. A regime shift occurred in the mid to late 1970s, where the summer climate in interior Alaska went from cool and moist to hot and dry. During the cool and moist period, the white spruce from these sites grew well. The warm and dry summers were particularly detrimental to the radial growth of white spruce.

A study conducted by Martin Wilmking shows that high elevation treeline white spruce show mixed sensitivities to climate. He found that approximately forty percent of the trees responded with negative radial growth to warmer summer temperatures, forty percent showed positive radial growth to warmer spring temperatures, and about twenty percent showed no sensitivity. This study has broad implications for predicting treeline advance, because it demonstrates that under a warming climate, some populations of treeline trees will grow markedly less, and perhaps not even be able to grow at all on some types of sites.

"The recent find that Alaska black spruce trees are highly sensitive to climate and have a number of different climate indices that optimize growth is surprising," Juday said. "It indicates that black spruce trees occupy sites with more varied environmental conditions than previously thought."

Growth of slope and ridge-top black spruce is negatively related to early and late summer temperatures at Fairbanks; the trees grow best in cool summers and least in warm summers. This indicates that climate warming of 2–4° C would probably result in the death of some black spruce populations in Alaska. Growth of valley bottom black spruce on permafrost is both positive to winter temperature and negative to early spring (April) temperature. Growth of black spruce on Tanana Valley surfaces near Fairbanks responds positively to midwinter temperatures. These populations will probably do well for a time under increased warming, but most black spruce trees are found on permafrost sites. With thawing permafrost, predictability of growth or survival of black spruce is unreliable.



Valerie Barber coring a white spruce.
—Photo by Doug Schneider

Karen Brewster coring a black spruce tree on an interior Alaska floodplain.
—Photo by Claire Alix

Preliminary studies of Alaska birch show that it too responds to climate depending on site. Birch, which is considerably more productive on average than black spruce, is the third most extensive forest type in Alaska, and birch-dominated stands make up about fourteen percent of the boreal forest. "Very little research about birch growth has been published, and practically none relating to how its growth is controlled by climate," Juday said.

Tree-ring samples were collected from about 174 Alaska birch trees at four sites in the Fairbanks area. There are several challenges to working with birch. Wood decay and rot is so common in mature Alaska birch that only one in four sampled trees produced useable cores. Because radial growth of Alaska birch is highly irregular, two to four radii per tree are needed to accurately measure annual growth. This means that at least two different cores from different sides of the tree must be taken and measured for an average, or if a disk is obtained, radial growth will be measured from bark to pith at two or three different points (sides) of the trunk and then averaged. Typical birch stands around Fairbanks have dates of origin in the 1930s. The Live Birch reference hectare at the BNZ LTER site contains birch with a measured date of origin at about 1810. In many birch trees, growth in certain years practically ceased (1877–78, 1921, and 1970 for example), producing rings that are difficult to distinguish.

Although measurement of birch tree-rings is much more difficult than either white or black spruce, previous experience with the spruces allowed staff at the SNRAS tree-ring laboratory to successfully identify and sequence tree-rings in the birch sample. Although different climate indices optimize growth according to site, summer temperatures appear to have the greatest effect. Radial growth of birch trees sampled from several south-facing slopes near Fairbanks indicates a high negative correlation with summer temperature: warmer temperatures induce reduced growth.

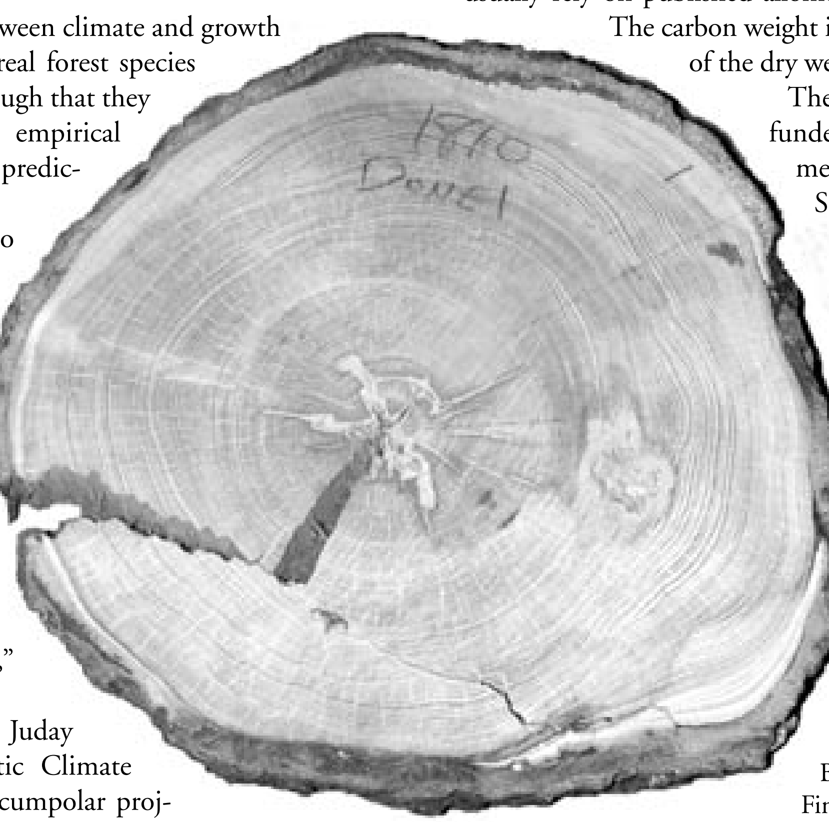
"In a sample of forty-seven birch from the two stands, radial growth was highly negatively correlated with May through August Fairbanks temperature," said Barber. "This suggests that recent summer warmth has reduced and future warming would reduce radial growth of this species." The growth of older birch on an east-facing slope in Bonanza Creek LTER showed a positive correlation with individual summer months over a three-year period, indicating that trees on this site will do better with warmer summer temperatures.

The relationships between climate and growth for these three major boreal forest species are statistically strong enough that they can be used to develop empirical equations and excellent predictive relationships.

"All sites sampled to date register some form of climate sensitivity in at least some trees. For most of the sites, we have observed statistically significant relationships between climate and tree growth, and these allow us to predict future growth under various climate scenarios," Barber said.

Participation by Juday and Barber in the Arctic Climate Impact Assessment, a circumpolar project, allowed them to obtain predicted monthly climate output data from five Global Climate Models up through the year 2099. The empirical relationships developed from the climate sensitivity studies and used in conjunction with these global climate models was used to predict annual radial growth of these three species. Results show that some populations of white and black spruce and birch would not survive at all, because their growth rates would actually approach zero within seventy to one hundred years.

The first generations of vegetation models assumed that warming would cause an increase in boreal forest grwoth. "Because our findings have broad implications for carbon uptake and aboveground carbon storage, it is important that dynamic vegetation models incorporate this new information," said Juday.



Section of a black spruce showing annual growth rings. The width of the rings shows the relative favorability of growing conditions.
—Photo by Valerie Barber

Boreal forests are a significant factor in world carbon uptake, and forest stands dominated by black spruce make up over half of Alaska's boreal forest cover. "Despite the generally small size and slow growth of individual black spruce, the total area they cover, and their total volume, make them an important species when looking at potential changes of carbon uptake in Alaska," Juday said.

The aboveground carbon biomass, which is the weight (Mg.ha or kg/m2) of the aboveground portion of the tree, is determined by oven drying the samples until a constant weight is reached. To do this accurately, there must be a consistent allometric relationship between plant dimensions (usually diameter at breast height (dbh) and/or height) and biomass for a given species or growth form. Barber and Juday usually rely on published allometric relationships by species. The carbon weight is typically about fifty percent of the dry weight.

The research discussed here was funded in part by the U.S. Department of Energy, the National Science Foundation's LTER program, and a USDA "New Crops Opportunities"grant from the Cooperative State Research Education and Extension Service. For more information, contact Glenn Juday (ffgpi@uaf.edu) or Valerie Barber (barber@ims.uaf.edu) at the School of Natural Resources and Agricultural Sciences.

References

Barber, V.A., G.P. Juday, and B.P. Finney. 2002. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Nature*. 405:668–673.

Barber, V.A., G.P. Juday, B.P. Finney, and M. Wilmking. In press. Reconstruction of summer termperatures in Interior Alaska from tree-ring proxies: Evidence for changing synoptic climate regimes. *Climatic Change*.

Juday, G., V. Varber, S. Rupp, J. Zasada, and M. Wilmking. 2003. A 200-year perspective of climate variability and the response of white spruce interior Alaska. In: *Climate Variability and Ecosystem Response at the Long-Term Ecological Sites*, Greenland D., Goodin, D., and Smith, R.C., eds. Oxford University Press, 2003. pp. 226–150.

Wilmking, Martin. 2003. The treeline ecotone in interior Alaska—from theory to planning and the ecology in between. Doctoral dissertation. School of Natural Resources and Agricultural Sciences, University of Alaska Fairbanks.

Areas of permafrost along the Innoko River.
—PHOTO COURTESY OF THE U.S. FISH AND WILDLIFE SERVICE

Soil: the Dark Laboratory

Soil, the dynamic, biologically active layer of Earth's continental surface, sustains life through its biogeochemical and hydrologic processes. In grade school, we all learned that decomposition in soil is necessary for recycling nutrients into forms available for plants—without it, dead things would pile up indefinitely. Decomposition also makes soil a major player in the global carbon cycle.

To understand how life in soil matters to the global carbon cycle, we first need to review respiration. All living things respire; that is, they metabolize energy-rich compounds and usually release carbon dioxide (CO_2) as a result. The source of those compounds determines whether the respiration is termed autotrophic, as in the case of plants making their own "food" during photosynthesis, or heterotrophic, as in the case of most other living things that rely on outside sources (ultimately plants) for theirs.

Autotrophic respiration occurs in living plants, both above ground and below ground through plant root systems. Heterotrophic respiration occurs through the consumption of live plant parts and the decomposition of dead plant residues. Both kinds of respiration occur in soils—autotrophic respiration from plant roots and heterotrophic respiration from soil animals and microorganisms, including decomposers.

The problem soil scientists face in understanding the role of soils in carbon balance is that while it is easy to measure total soil respiration (i.e., CO_2 emission), it is difficult to separate autotrophic from heterotrophic sources. And only the heterotrophic component affects carbon balance. The exact proportion each of these contribute to total ecosystem respiration varies a great deal from place to place, although the heterotrophic respiration resulting from decomposition is thought to make up roughly half of the total global carbon dioxide emitted by terrestrial ecosystems.

The general factors determining respiration are well understood. In living plant roots, autotrophic respiration is related to their overall productivity and how they allocate the photosynthate (sugars) produced by photosynthesis. Carbon dioxide release through decomposition (heterotrophic respiration) relates to factors that control microbial activity: temperature, moisture, and the type and amount of material subject to decay.

Largely unknown is exactly how these factors combine to affect soil respiration at a given point in time. This is due to the complexity of interactions in soil and the variability of organisms present, type of plants and their strategies, microenvironmental conditions, and such other factors such as site history, soil mineralogy, nutrient availability, and types of plant litter. Depending on these factors and climate, soil organic matter can be either a source of, or a sink for atmospheric CO_2. It is a sink if carbon inputs from plants exceed heterotrophic respiration, otherwise it is a source.

Current research by faculty and graduate students at the School of Natural Resources and Agricultural Sciences is aimed at closing some of these information gaps for high-latitude soils. Among the questions now being explored are how changes in disturbance regime and in climate affect carbon balance in black spruce stands. Of high interest in light of climate warming projections is how the north's perennially frozen soil, permafrost, will respond to warmer temperatures. Although twenty to twenty-five percent of Earth's land surface is underlain by permafrost, scientists are uncertain how warmer temperatures might affect it, or how thawing ground ice could affect everything from local ecology to regional climate. Could warmer, wetter weather, for example, increase vegetation growth, insulating the permafrost and keeping the near-surface ground layers frozen? Or, will melting permafrost cause these soils to release sequestered carbon into the atmosphere as carbon dioxide? Because permafrost may vary dramatically from region to region, scientists are studying its properties over large geographic areas. The studies covered in the following pages illustrate how researchers are tackling these questions and what they have found to date.

—Doreen Fitzgerald with David Valentine

Black Spruce and Soil Carbon Exchange

Trees are a major consumer of atmospheric carbon dioxide (CO_2). They store the carbon as organic matter in their tissues and also deposit carbon in the soil. This makes forests important repositories for the CO_2 coming from human fossil fuel burning. In Alaska, ecosystems with black spruce as the major trees species are the most common, followed by white spruce, birch, and mixed spruce stands.

Black spruce forests grow slower than other boreal forest types, but they end up storing more carbon because cold and wet soil conditions restrict the decomposition of organic matter. An important question is whether and how black spruce forest soils will alter their soil carbon balance (net carbon loss or gain) in a warmer climate. Although climate warming is expected to have the greatest effect at high latitudes, there are considerable information gaps related to how much carbon trees allocate below ground for roots, the rate microbes decompose organic matter, and what this all means for aboveground plant growth.

A study by doctoral candidate Jason Vogel and soil scientist David Valentine has provided some insight into the relationship between local climate and soil carbon balance. "Boreal black spruce and soil carbon exchange along an elevation gradient" is an ecosystem carbon cycling study that was conducted near Fairbanks, Alaska.

"The decomposition rate, or the rate microbes (microscopic soil organisms) turn organic matter back into CO_2 increases with temperature, so a warming climate is expected to accelerate soil carbon loss via soil respiration from cold boreal soils," said Vogel." "This should result in more carbon released into the atmosphere. But increased decomposition can also increase the nutrients available to plants and result in increased plant productivity. These factors could increase the storage of organic matter in plants and soil."

Vogel and Valentine looked at the relationship between decomposition and aboveground plant growth, total soil respiration, and the heterotrophic respiration that occurs during decomposition of organic material.

"We wanted to control for the effects of vegetation and look specifically at how soil environment affects decomposition and plant productivity, so we found sites that were similar in tree age, tree size, and number of trees," Vogel said. "Black spruce sites were selected for variation in slope orientation, elevation, and depth to permafrost, because these characteristics should create variability in soil temperature."

They hypothesized that as decomposition rates increase, both the ecosystem's aboveground uptake of CO_2 from plant photosynthesis, and the CO_2 loss from soil respiration (root respiration and microbial respiration from decomposing organic matter) will increase. In other words, warming will promote decomposition; as decomposition increases, the amount of CO_2 released from soil through respiration will increase, as will the uptake of carbon dioxide by plants. The result would be a balance between forest growth and decomposition with no net increase in the loss of carbon from the ecosystem.

To check this hypothesis, they looked at decomposition rates of black spruce needles and cellulose paper, and the heterotrophic respiration coming from areas where live roots had been eliminated (root exclusion). Soil respiration, or CO_2 release from the soil surface, was measured with a portable infrared gas analyzer both in and outside the root exclusion areas. The difference between areas was assumed to equal root respiration. Aboveground tree increment was measured by removing tree cores and measuring the tree ring width.

Faster decomposition correlated to greater heterotrophic respiration in the root exclusion areas and greater aboveground plant production. These two results suggest that ecosystems will not lose more carbon with warming, because decomposition is offset by plant production. However, contrary to their hypothesis, soil respiration (roots plus microbes) was greater where decomposition and heterotrophic respiration was the slowest. "We were initially surprised by the results, but realized that the plants were allocating less carbon to the root system, where decomposition was faster," Vogel said.

The researchers believe the black spruce allocates more carbon below ground when their growth is limited, either by low nutrient or moisture availability. "Greater allocation of carbon to roots probably indicates that spruce have to work harder at getting nutrients or moisture when the availability of these resources are limited," said Vogel, "and slower decomposition rate seems to be a good indicator of when black spruce puts more carbon below ground."

The researchers suggest that variability in aboveground growth might result from spruce shifting carbon allocation between above- and belowground plant parts when the environment changes. Shifting allocation seems to occur across the boreal forest. For example, they looked at other research in the North American boreal forest and found the amount of carbon cycling below ground changes drastically across a precipitation and evaporation gradient.

The observation that allocation shifts in response to environment changed their perspective on how climate change might influence carbon balance. Forests might remove the same amount of carbon from the atmosphere, but it ends up in a different place as a function of environment. However, the research points out that both temperature and moisture will be important to forest growth. "Research that manipulates soil moisture or temperature is necessary before we will know for sure how these forests will respond to climate change," Vogel concluded.

The research was funded by the UAF Center for Global Change and the Bonanza Creek Long Term Ecological Research program. For more information contact: Jason Vogel (ftjgv@uaf.edu) or David Valentine (ffdlv@uaf.edu)

Soil Respiration After Fire

Doreen Fitzgerald

Wildfire is a regular part of the summer season in Alaska, and unless it occurs in a protected area, it is allowed to burn unchecked. Frostfire, a project that in 1999 burned a carefully isolated experimental area, gave researchers the chance to study various conditions before, during, and after fire in the boreal forest.

Although the greatest proportion of the world's terrestrial carbon is found in wetlands, tundra, and alpine soils, the thick, mossy forest floor in boreal forests contains more carbon than temperate forests, tropical forests, or cultivated land. Most of this forest is in wilderness, and millions of acres worldwide burn annually. Knowing how this affects the release of carbon dioxide (CO_2) from the soil is an important part of the global carbon picture.

David Valentine, associate professor of forest soils, decided to use the Frostfire burn to find out how wildfire in interior Alaska affects respiration and the carbon balance (net gain or loss of carbon) of soils. He hypothesized that since warmer temperatures tend to accelerate soil respiration, the burned boreal forest soils would release more carbon dioxide than unburned ones. This is because fire removes the tree canopy and creates large blackened areas, so soils in burned areas absorb more sunlight. Fire also removes much of the insulating moss layer, allowing soils to warm more during summer months. Warmer soils are expected to increase activity of soil microorganisms and release more carbon dioxide (although root respiration would, of course, stop). This has proven to be the case when burned areas have been studied at lower latitudes. Valentine has discovered a different response in Alaska.

"Our measurements since the summer of 1999 have clearly shown a persistent and growing decline both in total and heterotrophic soil respiration in burned areas compared to control areas," he said. The research site is at the C4 watershed in the Caribou Poker Creeks Research Watershed.

For this research, soil respiration is being measured at three burned and three unburned black spruce sites. The basic approach to measuring soil respiration is to invert a chamber on the ground and measure the change in CO_2 concentration over time. In this case, the researchers used a portable infrared gas analyzer (IRGA) that Tim Quintal had customized to fit into a backpackable weatherproof box. Tim is the research technician for the SNRAS Forest Soils Laboratory.

Respiration measurements in the research watershed began in 1998, paused for the fire in July 1999, then resumed and have continued each summer. At the same time, Valentine's group has monitored soil temperature and moisture, soil gas concentrations, and the rate at which decomposition of a standardized substrate (birch tongue depressors) occurs.

Aerial view of a prescribed burn in a conifer-dominated forest.
—Photo by David P. Shorthouse, University of Alberta, www.forestryimages.org

The results of this study shed light on key dynamics governing carbon balance following fire, which is the major disturbance type in interior Alaska. The roots of trees killed by fire no longer respire CO_2, so Valentine expected an initial decline in soil respiration resulting from the loss of root respiration. In 2002 Valentine and his students began measurements to quantify the extent to which this loss of root respiration may account for the decrease in total soil respiration.

"Our results from 2002 indicate that root respiration accounts for most but not all of the decrease in soil respiration, suggesting that that fire also decreases the contribution of heterotrophic respiration (decomposition of organic matter) to total soil respiration," he said.

Fire and soil carbon bioavailability

Valentine is working with graduate student Sarah Masco on a study to understand whether fire-induced changes in organic matter quality in surface soils is consistent with the observed changes in heterotrophic respiration. At the Frostfire site, soil samples were obtained from the lower part of the organic surface horizon. Subsamples from each layer were incubated in the laboratory at three temperatures for six months. Respiration rates, total amounts of respired CO_2, and the temperature sensitivity of respiration rates were determined, then compared with chemical analyses of the soil organic matter.

The results showed that soil organic matter from burned sites respired slightly but significantly more slowly than soil organic matter from unburned control sites, especially early in the incubation period. Differences in respiration rate and temperature sensitivity did not correlate well with measured soil organic components. Burned soils had higher net nitrogen mineralization rates than unburned soils, possibly as a result of lower immobilization (microbial uptake of nitrogen) rates.

"This study points to a mechanism by which wildfire may reduce decomposition (heterotrophic production of CO_2) in boreal forests, thereby limiting post-fire release of carbon," Valentine said. "That mechanism is the lack of recent fresh carbon inputs into the soil surface horizon."

These two studies were supported by the National Science Foundation through the Frostfire project and the Bonanza Creek Long Term Ecological Research program.

Digging Up the Facts on Northern Soils

Doreen Fitzgerald
with Chien-Lu Ping

Ping and Michaelson sampling soils near Galbraith Lake, Alaska.
—Photo courtesy of Chien-Lu Ping

In the past, the amount of soil organic carbon in high-latitude soils was underestimated, as was the significance of a winter contribution of carbon dioxide (CO_2) to the atmosphere from alpine and artic regions. As a result of recent research, it is now understood that both factors have important implications for the assessment of the potential effects of climate warming. Under a continuous buildup of greenhouse gases in the atmosphere, general circulation models already predict climate warming that at high latitudes may be several times greater than the global average, and possibly more pronounced in the winter.

About one-third of Earth's soil organic carbon is locked in tundra and boreal soils because of cold temperatures, and past trace gas budgets have assumed that trace-gas exchange between soil and atmosphere stops when soil temperatures decrease to zero degrees centigrade. For this reason, the contribution of CO_2 from alpine and arctic regions in winter has not been considered important in calculations of global carbon balances. Now, recent National Science Foundation (NSF) C-Flux winter monitoring studies have identified large quantities of CO_2 efflux from arctic soils during the winter period. This previously overlooked contribution could amount to as much as sixty percent of the annual CO_2 efflux. To account for winter in carbon balance models and calculations, the need for information about quality, quantity, and distribution of soil organic carbon in the Arctic is now fully recognized.

At the Palmer Research Station of the Agricultural and Forestry Experiment Station, professor of soil sciences Chien-Lu Ping and research associate Gary Michaelson are participants in an effort to obtain this information, the Land-Atmosphere-Ice Interaction (LAII) program. LAII is a multidisciplinary, integrated research effort funded by the NSF and conducted under the auspices of the foundation's Office of Polar Programs, Arctic System Science (ARCSS) program. ARCSS is the only element of the U.S. Global Change Research Program specifically concerned with the arctic region.

Information crucial for evaluating potential climate warming effects includes: the quality and quantity of organic matter in these soils, rate of microbial decomposition at below-zero temperatures, and the mechanisms that control the rate of low-temperature microbial decomposition.

The LAII goal is improved understanding of the interactions among land, atmosphere, and ice in the functioning of the Arctic System, with emphasis on improving the predictability of likely responses of the Arctic System to global change. Because these interactions are broad and complex, the research program strongly emphasizes integrated research that brings together scientists from multiple disciplines, including biology, hydrology, ecology, climatology, paleoecology, and soil science.

Winter carbon flux study

From 1999–2003, the LAII-ATLAS (Arctic Transitions in the Land Atmosphere System) Winter C-flux study was conducted by NSF. It was designed to develop a sufficient understanding of winter carbon dynamics in arctic soils to effectively model the spatial dynamics of winter CO_2 fluxes, and how they will vary with altered climate. The work involves field measurements of CO_2 fluxes and environmental factors likely to control them, along with modeling and mechanistic studies.

The project's four main objectives are to quantify the magnitude and timing of winter CO_2 fluxes across a range of arctic tundra types; determine how winter respiration is controlled by the physical regime of the soils; evaluate how organic matter composition controls winter carbon cycling; and develop simple models of winter microbial activity. These objectives link the soil thermal and unfrozen water regimes to microbial activity and substrate use. The overarching goal is to develop the simplest possible models that can be driven by broad scale parameters, while retaining necessary mechanistic information to provide reliable estimates of carbon dynamics.

Earlier field investigations determined that arctic soils contain about twice as much of the terrestrial carbon pool as previously reported, and that the major portion occurs in the lower active layer and upper permafrost layer. The soil active layer is that portion of the soil that is subject to seasonal freeze and thaw, rather than perennially frozen. These results were published in the journal Arctic and Alpine Research. Recent research conducted by Ping, Michaelson, and colleagues from the University of California Santa Barbara and Colorado State University has demonstrated that in these soils, trace-gas exchange from microbial activity does not stop during winter, and that a positive feedback of some arctic ecosystems to climate warming may be due to the efflux of substantial amounts of soil carbon to the atmosphere.

Using eighty-eight arctic soils collected from twenty-eight sites spanning hundreds of miles, Michaelson and Ping completed a study under ATLAS that has answered some important questions. After determining the properties (quality and quantity of organic material) of their soil samples, they incubated them at low temperatures in the laboratory and measured carbon dioxide respiration. They found that respiration rates varied considerably, depending on a sample's organic carbon content, organic matter quality, and whether the experimental temperature was a few degrees above or below zero degrees centigrade (4º C and -2º C). When temperatures dipped below freezing, subsoils from the active layer and upper permafrost that contain large amounts of cryoturbated organic matter (mixed in by frost action) were found to maintain relatively high rates of CO_2 efflux compared to the organic surface soils.

"Our results suggest that relatively small changes in temperature will alter cold-season respiration throughout the soil active layer," Ping and Michaelson concluded. The research was published in the Journal of Geophysical Research.

Soils dataset

Ping, Michaelson, and Kimble reported in 2002 that for the first time, soils data (morphological, physical, and chemical) were available for sites across arctic and subarctic Alaska. The first soils dataset for arctic Alaska resulted from extensive field investigations, a cooperative research effort funded by the NSF, the U.S. Department of Agriculture (USDA) Hatch program and the USDA National Soil Survey Center. See "More Information" at the end of this article for data availability. This soils information is being used in the integrated research projects of NSF-LAII: C-Flux, ATLAS, Circumpolar Active Layer Monitoring (CALM) project, and the USDA Global Change Initiative projects that are examining arctic and subarctic terrestrial systems.

"These investigations were important in field-testing the newly adapted Gelisol order in Soil Taxonomy, in supporting ongoing soil survey projects in Alaska, in the development of the Circumpolar Soils Map and the North American Soil Carbon Map. The dataset is also important for climatic modeling efforts," Ping said.

Gelisols are soils of very cold climates that contain permafrost within two meters of the surface. They account for approximately thirteen percent of the earth's land surface area and are in the high-latitudes polar regions and localized areas on high mountains.

Soil organic carbon

Thus far, detailed and specific studies of soil organic carbon (SOC) stocks under the ARCSS-LAII programs indicate that arctic soils contain twice as much of the terrestrial carbon pool as previously reported. This newly accounted for SOC is significant, not only in magnitude, but also in its quality as it relates to arctic and global carbon cycles under changing climate.

Organic matter characterization study indicates that soil active layers contain relatively large amount of their carbon in fractions that are in an intermediate state of decomposition and are susceptible to further decomposition under warmer temperatures and changing moisture levels.

Large amounts and proportions of SOC stocks are found in both the active-layer and upper permafrost due to cryoturbation (soil mixing due to frost action). Because this large portion of soil organic carbon is not highly decomposed, it is susceptible to increased decomposition with warming winter and shoulder-season

Graduate student Paul Overdiun excavated permafrost soils with a jackhammer.
—Photo courtesy of Chien-Lu Ping

conditions such as those that are now being observed in arctic Alaska.

For the circumpolar Arctic, this research provides a basis for future work to link terrestrial carbon flux to soil carbon stocks and quality. ATLAS research thus far has laid the soils groundwork for such a link and provided data that is important to all facets of the project. It is now recognized that winter soil processes are the key to understanding whole-season carbon fluxes in the arctic system. This illuminates the need for further research on soil processes, soil carbon cycles, and their controls in the context of soil-landscape evolutionary processes.

Soils associated with frost boils in the Arctic

Ping and Michaelson are participating in another NSF multidisciplinary project titled "Biocomplexity of Frost Boil Ecosystems." Cooperating scientists are Donald (Skip) Walker of the UAF Institute of Arctic Biology, Vladimir Romanovsky, UAF Geophysical Institute, Charles Tarnocai of Agriculture and Agri-Food Canada, and others (see http://www.geobotany.uaf.edu/cryoturbation).

This project is looking at the role of frost boils in ecosystems ranging from the Canadian high Arctic to Alaska's north slope. Frost boils are formed by differential frost heave, and are unsorted circles of mineral soil commonly found in alpine and arctic regions. On the ground, the fresh soils form a circle or stripe that looks like a mud "boil" surrounded by tundra vegetation. Carbon sequestered in frost boils accounts for at least one-half of the total terrestrial carbon stored in arctic ecosystems, and has not been reported before this research. In early studies, frost boils were found more frequently in the land cover type moist nonacidic tundra (MNT) than the moist acidic tundra (MAT) of the Arctic Coastal Plain and the Arctic Foothills of Northern Alaska.

For this study, soils investigation sites were selected in association with the vegetation plots of the NSF Biocomplexity project. Complete morphological descriptions of the soils are being made to follow the USDA Soil Survey Manual. Soil samples from each horizon are sent to the UAF-SNRAS Palmer Plant and Soils Analysis Laboratory for detailed physiochemical and nutrient analysis and to the USDA Soil Survey Laboratory in Lincoln, Nebraska, for physical and chemical characterization using the USDA National Soil Survey laboratory standard procedures.

"Our preliminary results indicate that frost boils are actually widespread in both land cover types," Ping said. "On the surface, there appear to be more fresh frost boils in the MNT than MAT, but we found that more frost boils occur under the MAT, where they are masked by vegetation cover."

The active layer is deeper under the boil than under the area between the frost boils. In cross section, the frost boil is defined by a bowl shape indented into the top of the permafrost table. Although frost boils in the MAT are not as evident in surface vegetation patterns, they are still active, as indicated by chunks of cotton grass *(Eriophorum vaginatum)* found at various stages of decomposition and in the process of being frost-churned downward along the slopes of the "bowl" onto the top of the permafrost table.

"In the lower active layer and upper permafrost," said Ping, "a concentration of frost-churned organic matter mixed with gleyed mineral horizons occurs. Thus, the frost boil process can be regarded as a controlling factor for sequestering surface organic carbon into the upper permafrost." Frost boil processes and resulting soils are much more important than previously recognized for their role in the carbon-cycle of arctic ecosystems.

Biocomplexity of frost boil ecosystems: 2003 expedition

A major goal of the biocomplexity study is to help explain how frost boils and arctic vegetation will respond to climate change. The study team includes the previously mentioned Walker (project leader), Ping, Michaelson, Romanovsky, and Tarnocai, along with Martha Raynolds of the UAF Institute of Arctic Biology, Anja Kade of the UAF Biology Dept., Howard Epstein and Alexia Kelly of the University of Virginia Dept. of Environmental Sciences, William Gould and Grizelle Gonzalez from the International Institute of Tropical Forestry, USDA Forest Service (San Juan, Puerto Rico), and William Krantz of the University of Cincinnati Dept. of Chemical Engineering.

The team is interested in the self-organization processes involved in frost-boil formation and how the complex interactions between the elements involved in frost-boil formation (frost heave, vegetation, and soil properties) vary along the arctic bioclimate gradient.

Study sites are being established in each of five circumpolar arctic bioclimate subzones; Subzone A is the coldest and Subzone E is the warmest. In Alaska the study sites include Howe Island, West Dock, Deadhorse, Franklin Bluffs, Sagwon Hills, and Happy Valley.

In July 2003, the team began setting up its Canadian network at a site on Banks Island, near Green Cabin in Aulavik National Park and at Mould Bay, Prince Patrick Island. Most of the 2003 work was at Banks Island, which is in Bioclimate Subzone C, an area where the zonal vegetation consists of prostrate dwarf shrubs, sedges, and a few forbs, mosses, and lichens. The interdisciplinary project has five major components: (1) Climate and Permafrost, (2) Soils and Biogeochemical Cycling, (3) Vegetation, (4) Ecosystem Modeling, and (5) Education.

The team characterized the frost boils, vegetation, and soils within three 10-meter by 10-meter grids along a toposequence. The education component was an Arctic Field Ecology course offered through the University of Minnesota. Frost boils on zonal sites had similar morphology to those on Howe Island, and other Subzone C sites. The frost boils on zonal sites were of one to two meter diameter (30 frost boils/100 m2). The frost boils were nearly barren with only a few scattered grasses and forbs. The inter-boil areas had more continuous cover of vegetation consisting of a mountain avens *(Dryas integrifolia)* community. *Dryas integrifolia* is a dwarf shrub in the rose family. A strong thermal gradient existed between the barren boils and well-vegetated inner-boil areas, particularly in the wet site. The soils show strong mixing with abundant carbon in the active layer and in the top portion of the permafrost. Covering the inter-boil areas and extending into the boils themselves were small hummock features (20–50-cm diameter), caused by either thermal-contraction within the active layer or desiccation. In July the soils study group (Ping, Michaelson, and Tarnocai) characterized and sampled eight sites and collected seventy-five samples from Banks Island.

In August Ping organized another team to study soils associated with frost boils in arctic Alaska. It included Michaelson, John M. Kimble of USDA-NRCS National Soil Survey Center, Lynn Everett of Ohio State University, UAF forest management professor Edmond Packee, Norman Bliss of the U.S. Geological Survey, and resources management graduate students Carolyn Rosner and Patrick Borden. The group studied five sites and collected forty samples from arctic Alaska. These samples are being analyzed in the Palmer Research Center and also the USDA National Soil Survey Center Lab. Information from Alaska and Canada will be used to develop models of the interactions between frost-heave processes, vegetation and soil biogeochemical processes.

UAF team taking samples on the Arctic Coastal Plain, Alaska. Edmond Packee of SNRAS is at the far left.

—Photo courtesy Chien-Lu Ping

More Information

For more information, contact Chien-Lu Ping (pfclp@uaa.Alaska.edu) or Gary Michaelson (pngjm@uaa.alaska.edu) at the Agricultural and Forestry Experiment Station Palmer Research Center. Also see the following websites and references.

Alaska Geobotany Center (http://www.geobotany.uaf.edu)

NSF LAII (http://www.laii.uaf.edu/)

Cryosol Working Group of the International Union of Soil Science and the International Permafrost Association (http://igras.geonet.ru/cwg/).

The soils datasets are available through the National Snow and Ice Data Center (http://nsidc.org/data/arcss074.html) and also on the center's Ivotuk and Seward Peninsula CDs), the NSF Joint Office of Science Support (http://www.joss.ucar.edu/atlas/master_data_table.html), and through the USDA Natural Resource Conservation Service soils database (http://ssldata.nrcs.usda.gov/querypage.asp).

References

Ping, C.L., G.J. Michaelson, J.M. Kimble, Y.L. Shur, and D.A. Walker, 2002. Morphogenesis of soils associated with frost boils. Supplement, *Eos Transactions,* American Geophysical Union. 83(47):F259.

Michaelson, G.J., C.L. Ping, and D.A. Walker. 2002. Biogeochemistry of soils associated with cryptogamic crusts on frost boils. Supplement, *Eos Transactions,* American Geophysical Union. 83(47):F260.

Bliss, N.B., S.W. Waltman, and C.L. Ping. 2002. Sensitivity of soil carbon stock estimates to spatial patterns. Supplement, *Eos Transactions,* American Geophysical Union. 83(47):F206.

Michaelson, G.J., C.L. Ping, and J.M. Kimble. 1996. Carbon storage and distribution in tundra soils of arctic Alaska, U.S.A., *Arctic and Alpine Research,* 28:414–424.

Michaelson, G.J. and C.L. Ping. 2003. Soil organic carbon and CO^2 respiration at subzero temperature in soils of arctic Alaska. *Journal of Geophysical Research,* Vol. 108, (D2), 8164, doi:10.1029/2001JD000920.

Walker, D.A., G.J. Jia, H.E. Epstien, F.S. Chapin III, C. Copass, L.D. Hinzman, H. Maier, G.J. Michaelson, F. Nelson, C.L. Ping, M.K. Raynolds, V.E. Romanovsky, N. Shiklomanov and Y. Shur. (in review). Vegetation-soil-thaw depth relationships along a Low Arctic bioclimate gradient, Alaska: Synthesis of information from the ATLAS studies. *Permafrost and Periglacial Processes,* 14(2): 103–124.

Dai, X.Y., D. White, and C.L. Ping. 2002. Evaluation of soil organic matter composition and bioavailability by Pyrolysis-gas chromatography/mass spectrometry. *Journal of Anal. Appl. Pyrolysis.* 62:249–258.

Dai, X.Y., C.L. Ping, R. Candler, L. Haumaier and W. Zech. 2001. Characterization of Soil Organic Matter Fractions of Tundra Soils in Arctic Alaska by Carbon-13 Nuclear Magnetic Resonance Spectroscopy. *Soil Science Society of America Journal.* 65:87–93.

Ping, C.L., J.G. Bockheim, J.M. Kimble, G.J. Michaelson, and D.A. Walker. 1998. Characteristics of cryogenic soils along a latitudinal transect in arctic Alaska. *Journal of Geophysical Research,* 103(D22):28,917–28,928.

Ping, C.L., G.J. Michaelson, and J.M. Kimble. 1997. Carbon storage along a latitudinal transact in Alaska. *Nutrient Cycling in Agroecosystems,* 49:235–242.

Ping, C.L. G.J. Michaelson, J.M. Kimble, and L. Everett. 2002. Chap. 47. Soil organic carbon stores in Alaska. pp. 485–494. In: R. Lal, J.M. Kimble, and R. Follet (eds.) *Agricultural Practices and Policies of Carbon Sequestration in Soils.* CRC Press LLC.

Ping, C.L., G.J. Michaelson, X.Y. Dai, and R.J. Candler. 2001. Chap. 18. Characterization of Soil Organic Matter. pp. 273–283. In: R. Lal, J.M. Kimble, R.F. Follett and B. Stewart (eds.) *Assessment Methods for Soil Carbon.* Lewis Publishers.

School of Natural Resources
and Agricultural Sciences
University of Alaska Fairbanks
P.O. Box 7577200
Fairbanks, AK 99775-7200

Nonprofit
Organization
U.S. POSTAGE
PAID
Permit No. 2
Fairbanks, Alaska

White sweetclover, Melitolus alba, *is taking over islands in the Stikine River floodplain. It has also invaded the Matanuska and Nenana rivers.*
—photo by Michael Shephard, U.S. Forest Service, Anchorage