Studying Alvars in The Land Between

For: The Kawartha Heritage Conservancy
By: Derek Matheson
Date: April 27/07

Table of Contents

Introduction:

Through the Kawartha Heritage Conservancy (KHC) and in partnership with the Couchiching Conservancy (CC) I worked on a project entitled "The Land Between". The Land Between refers to a limestone plain corridor which is located between two distinct ecoregions (the Boreal Forest to the north and the St. Lawrence Lowlands to the south). This corridor is located approximately from Georgian Bay in the west to Kingston in the east (Fig. 1) (CC and KHC, 2006). The Land Between has a length of about 250 km, and an average north to south corridor width of 35 km (CC and KHC, 2006). Until recently this area has been overlooked as a distinct natural system.

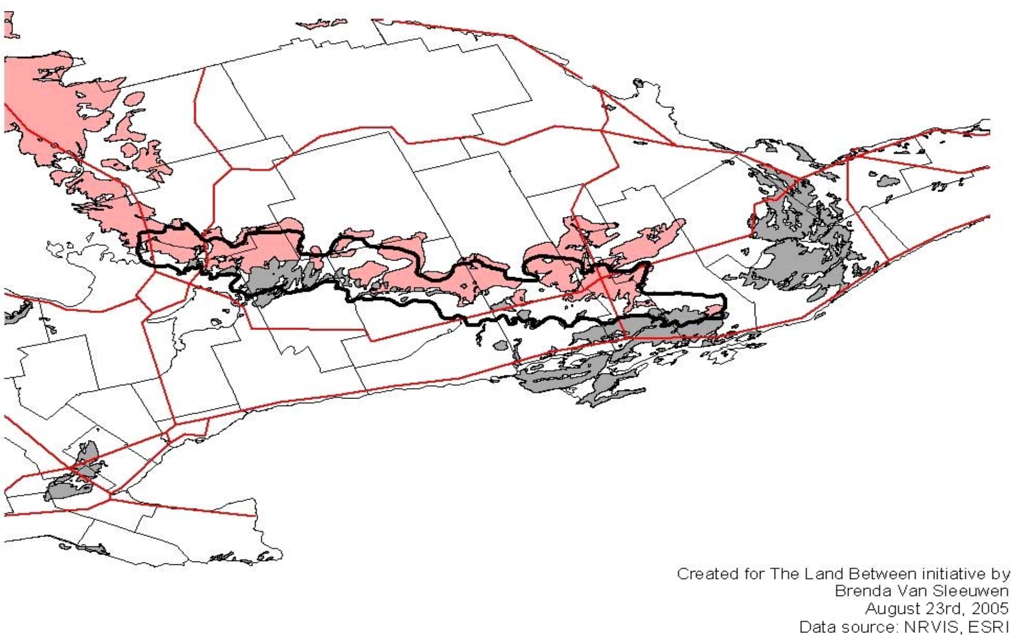

Fig. 1: The Land Between primary focus area (CC and KHC, 2006)

Since The Land Between has only recently been identified, there is much work to be done in inventorying, classifying and characterizing the abiotic and biotic features of the area.

By gathering this information and understanding the relationship between abiotic and biotic elements, the function of the whole system can be assessed. This will also allow for significant areas, species, and characteristics to be highlighted. From this understanding, relevant monitoring activities which help to identify changes and threats will be realized, and possible management implementations can be created.

The Land Between has a high degree of beta diversity due to its many interspersed habitats (including wetlands, lakes, streams, grasslands, forests, granite barrens and alvars) (CC and KHC, 2006). It is essentially a mosaic of habitats. For this project I have focused on the alvar habitat type. Alvars are rare communities that occur on thin discontinuous soil that is overtop beds of limestone or dolomite (Wisconsin Department of Natural Resources, 2005). Alvar characteristics include very shallow soils and exposed limestone pavements (National Heritage Information Centre, 2005). The soils present are alkaline limestone soils (Allaby, 1994).

The presence of shallow soils result in more direct chemical influences from the parent rock and also harsh moisture regimes (flash floods and drought), and thus presents unique vegetative communities. Having a shallow layer of soil creates other difficulties as well, particularly resulting in the habitat being susceptible to disruption. As a result of shallow soil, the communities contain sparse vegetation. This sparsity can also be maintained by a variety of factors including fire (National Heritage Information Centre, 2005). Such disturbances and stresses favour communities of herbaceous ground cover vegetation that can tolerate these conditions, and ultimately prevent the establishment of tree communities (National Heritage Information Centre, 2005). Both trees and bushes occur infrequently, and when they do they are severely stunted (Allaby, 1994). These areas characteristically have poor drainage, resulting in spring flooding and very hot, dry summer conditions (Allaby, 1994).

The main objective of this project was to collect information on alvars and activities occurring within them. This was broken down into four main objectives:

Objective 1- Identify indicator species. Further information would then be collected on their ranges and microhabitat requirements. The gathered information would then be arranged in a database.

Objective 2- Study the rock types and formations that are present in this area. Information would be gathered on their chemical properties and vegetative species associated with these rock types.

Objective 3- study the aggregate pit extraction in The Land Between. Information on aggregate operations would include number of sites, number of appeals for new sites, trends in numbers, and what is being extracted. Information would also be gathered on rehabilitation efforts, including seed mixtures.

Objective 4- Create a discussion on the trends of development and threats to alvar communities. This will include information gathered in the previously mentioned objectives.

Methods and Material:

This was a research-based project, requiring a variety of sources. Sources used included interviews (both in person and telephone), libraries, and websites.

Wasyl Bakowski was one of the people interviewed. Wasyl is a community ecologist for the Natural Heritage Information Centre. This interview took place in person at the Ministry of Natural Resources Office in Peterborough.

Ron Reid was another individual interviewed. Ron is the executive director of the Couchiching Conservancy, and one of the few alvar specialists in Ontario. This interview took place in person at the Kawartha Heritage Conservancy.

Paul Cutmore, Aggregate Officer for the Peterborough District for the Ministry of Natural Resources, was interviewed twice for this project. The first interview occured in person at the MNR office in Peterborough, and the second interview was over the phone.

Kevin Collins was interviewed in person at the same time as Paul. Kevin is a Geographic Information Systems/ Ecological Classification (GIS/ELC) Technician for the MNR.

Brian Hullingsworth was another individual interviewed. Brian is a Policy Officer and Planner for natural resources for the Aggregate and Petroleum Resources Section in Peterborough. I had two interviews with Brian, both over the phone.

Mark Browning was also interviewed for this project. Mark is a restoration and rehabilitation research biologist and a pit rehabilitation specialist for the MNR. The interview took place over the phone.

Colin Jones was a potential interviewee. Colin is a project biologist, and an insect specialist for the NHIC. Unfortunately I was unable to interview Colin as he was on sabbatical at the time.

During my meeting with Wasyl I was introduced to the NHIC library, one of the tools I used to complete my research on this project. In the library there was a large section on alvars, some including information from outside of Canada.

Another resource that I used was the Trent University library. This is where I began my research. I found that there was limited information on alvars, but it none the less remained a good starting point for my research.

The final source that I used for the project was the internet. This was a very helpful tool as it allowed me to search for journal articles, reports, and general information. Although most of the time only small amounts of information were collected at a site, it allowed me to pull my research together.

Results:

Characteristic Alvar Communities

While researching indicator species of alvars I encountered some difficulties, as I found that there was none yet identified. During the interviews with Ron Reid and Wasyl Bakowski, both indicated that that they were unaware of any alvar indicator species. It was found that many species have different associations with alvars, but not as indicator species. These associations include: species that are rare and occur in alvars; species found commonly in alvars but also other habitats; species common on some alvars but not others; and species which show affinities for alvar specific plants that do not occur across alvars (Alvar Working Group, 1999).

For these reasons, characteristic alvar communities were substituted for indicator species. In total there were 13 different types of alvar communities identified. These community types fell under three general categories- Open Alvar Grasslands and Pavements, Alvar Shrublands, and Alvar Savannas and Woodlands (Alvar Working Group, 1999).

In order for an alvar to be classified under one of the community types it must meet multiple criteria (Table 1). These criteria include diagnostic characteristics as well as the presence of certain flora. The diagnostic characteristics include information on trees, such as the amount of canopy cover present and in some cases include size requirements. Shrubs are also included with information on their cover, and in some cases size requirements also exist. The ground layer is also used as a diagnostic characteristic. What the ground layer is dominated by (bedrock and flora included) and the area covered are examined. Another important diagnostic characteristic is the soil. Soil characteristics such as type and depth are included. The rock formations below the soil are also listed in this section. Drainage properties and patterns are included under soil information as well. After a habitat has met the qualifying features of the diagnostic characteristics it must also meet certain floral requirements to be considered one of the characteristic alvar communities. Each community type has two classifications for plants. The dominate characteristic species classification is found for each community type. This refers to species which are characteristic of that type of alvar community, and also are dominant species in that community. The common characteristic species classification occurs for all community types but one. This classification refers to species which are characteristic of that type of alvar community, and are common species (but not dominate) in that community. The occasionally characteristic species classification occurs for only one community type. Occasionally characteristic species refer to species which are only characteristic of that community some of the time. For each of the plant species listed both the common and scientific names are given in alphabetical order (by common name).

The Open Alvar Grasslands and Pavements category (Table 1) contains five different characteristic alvar communities. The characteristic communities under this category include: tufted hairgrass wet alvar grasslands, little bluestem alvar grasslands, annual alvar pavement-grasslands, alvar nonvascular pavements, and poverty grass dry alvar grasslands (Alvar Working Group, 1999). The trees in this category form open canopies with less than 10 % cover. There are few shrubs present here, from under 25% to under 10 % cover (Alvar Working Group, 1999). In one community (little bluestem alvar grasslands) dwarf shrubs may have up to 50% cover (Alvar Working Group, 1999). The ground layer in general is dominated by grasses, and where pavements occur they are typically covered by mosses and lichens (Alvar Working Group, 1999). The soils are typically shallow (or very shallow if present with alvar nonvascular pavements) (Alvar Working Group, 1999).

All of the Open Alvar Grasslands and Pavements do not occur within the Land Between area. The tufted hairgrass wet alvar grasslands can be found in the Land Between area, located to the South-Eastern end as well as in the North-West (Fig. 2). Also located at the South-Eastern end and in the North-West are the little bluestem alvar grasslands (Fig. 3). The annual alvar pavement-grasslands can only be found at the South-East end of the Land Between (Fig. 4). There are no alvar nonvascular pavements found within the Land Between. Poverty grass dry alvar grasslands are present to the North-West (Fig. 5).

Table 1: Open Alvar Grasslands and Pavements (Alvar Working Group, 1999).

Community Type	Diagnostic Characteristics	Plant Type	Common Name	Scientific Name
Tufted hairgrass wet alvar grassland	**Open Canopy**: <10% tree cover	**Dominate Characteristic Species**		
	Few Shrubs: <10% shrub cover	herbs, grasses and sedges	Crawe's sedge	*Carex crawei*
	Ground Layer: dominated by		flat-stemmed spikerush	*Eleocharis compressa*
	grasses and sedges		prairie dropseed	*Sporobolus heterolepis*
	Soils: shallow organic soil usually		tufted hairgrass	*Deschampsia cespitosa*
	< 10 cm deep over flat limestone or			
	dolostone bedrock, soils often are wet	**Common Characteristic Species**		
	(saturated or flooded) during spring and	herbs, grasses and sedges	balsam ragwort	*Senecio pauperculus*
	fall and very dry during midsummer		false pennyroyal	*Trichostema brachiatum*
			sheathed rush grass	*Sporobolus vaginiflorus*
			small rush grass	*Sporobolus neglectus*
			wild chives	*Allium schoenoprasum*
Little bluestem alvar grassland	**Open Canopy**: <10% tree cover	**Dominate Characteristic Species**		
	Few Shrubs over 0.5 m tall: <25% shrub cover		little bluestem	*Schizachyrium scoparium*
	Dwarf Shrubs (<0.5m): maybe up to 50% cover but are mostly		northern singlespike sedge	*Carex scirpoidea*
	under a taller canopy of grasses or sedges		prairie dropseed	*Sporobolus heterolepis*
	Ground Layer: dominated by grasses and sedges with			
	< 50% of ground suface area exposed	**Common Characteristic Species**		
	Soils: shallow loam soil usually < 10 cm deep over		balsam ragwort	*Senecio pauperculus*
	flat limestone or dolostone bedrock, soils often are wet		Crawe's sedge	*Carex crawei*
	(saturated) during spring and fall and very dry during midsummer		creeping juniper	*Juniperus horizontalis*
			tufted hairgrass	*Deschampsia cespitosa*
Annual alvar pavement-grassland	**Open Canopy**: <10% tree cover	**Dominate Characteristic Species**		
	Few Shrubs: <25% shrub cover		false pennyroyal	*Trichostema brachiatum*
	Ground Layer: dominated by annual		Philadelphia panic grass	*Panicum philadelphicum*
	grasses and herbs or a mixture of mossy		sheathed rush grass	*Sporobolus vaginiflorus*
	pavement patches and grassy patches		small rush grass	*Sporobolus neglectus*
	Soils: shallow loam soil usually		wiry panic grass	*Panicum flexile*
	< 10 cm deep over flat limestone or			
	dolostone bedrock, soils often are wet	**Common Characteristic Species**		
	(saturated) during spring and		balsam ragwort	*Senecio pauperculus*
	fall and very dry during midsummer, over		Canada bluegrass	*Poa compressa*
	winter needle-ice formation occurs		Crawe's sedge	*Carex crawei*
	turning over small blocks of soil		poverty grass	*Danthonia spicata*
			upland white aster	*Solidago ptarmicoides*
Alvar nonvascular pavement	**Open Canopy**: <10% tree cover	**Dominate Characteristic Species**		
	Few Shrubs: <10% shrub cover	lichens and mosses	blackthread lichen	*Placynthium nigrum*
	Ground Layer: mostly exposed		cup lichen	*Cladonia pocillum*
	limestone or dolostone bedrock covered		twisted moss	*Tortella tortuosa*
	covered with mosses and lichens	very small herbs (< 15cm tall)	hairy beardtongue	*Penstemon hirsutus*
	Soils: mostly lacking or are restricted		false pennyroyal	*Trichostema brachiatum*
	to rock crevices (grikes). A very shallow		Norwegian cinquefoil	*Potentilla norvegica*
	layer (< 2 cm) may be present under a		Virginia saxifrage	*Saxifraga virginiensis*
	mossy mat			
		Common Characteristic Species		
		lichens and mosses	a variaety of *Tortella* species	
			silver skin lichen	*Dermatocarpon cf miniatum*
			tortula moss	*Tortula ruralis*
		very small herbs (< 15cm tall)	longleaf summer bluet	*Houstonia longifolia*
			Michaux's stitchwort	*Minuartia michauxii var. michauxii*
			Virginia strawberry	*Fragaria virginiana*
		taller herbs and low shrubs	gray goldenrod	*Solidago nemoralis*
			red columbine	*Aquilegia canadensis*
			riverbank grape	*Vitis riparia*
			snowberry	*Symphoricarpos albus*
			tall hawkweed	*Heracium piloselloides*
		trees and shrubs (sparse)	butternut	*Juglans cinerea*
			common juniper	*Juniperus communis*
			eastern red cedar	*Juniperus virginiana*
			eastern white cedar	*Thuja occidentalis*
			white birch	*Betula papyrifera*
			white pine	*Picea glauca*
Poverty grass dry alvar grassland	**Open Canopy**: <10% tree cover	**Dominate Characteristic Species**		
	Few Shrubs: <25% shrub cover		Canada bluegrass	*Poa compressa*
	Ground Layer: dominated by grasses, exposed pavement		poverty grass	*Danthonia spicata*
	patches may be covered with lichens and mosses			
	Soils: shallow loam that is well drained	**Occasionaly Characteristic Species**		
	over limestone or dolostone bedrock		little bluestem	*Schizachyrium scoparium*

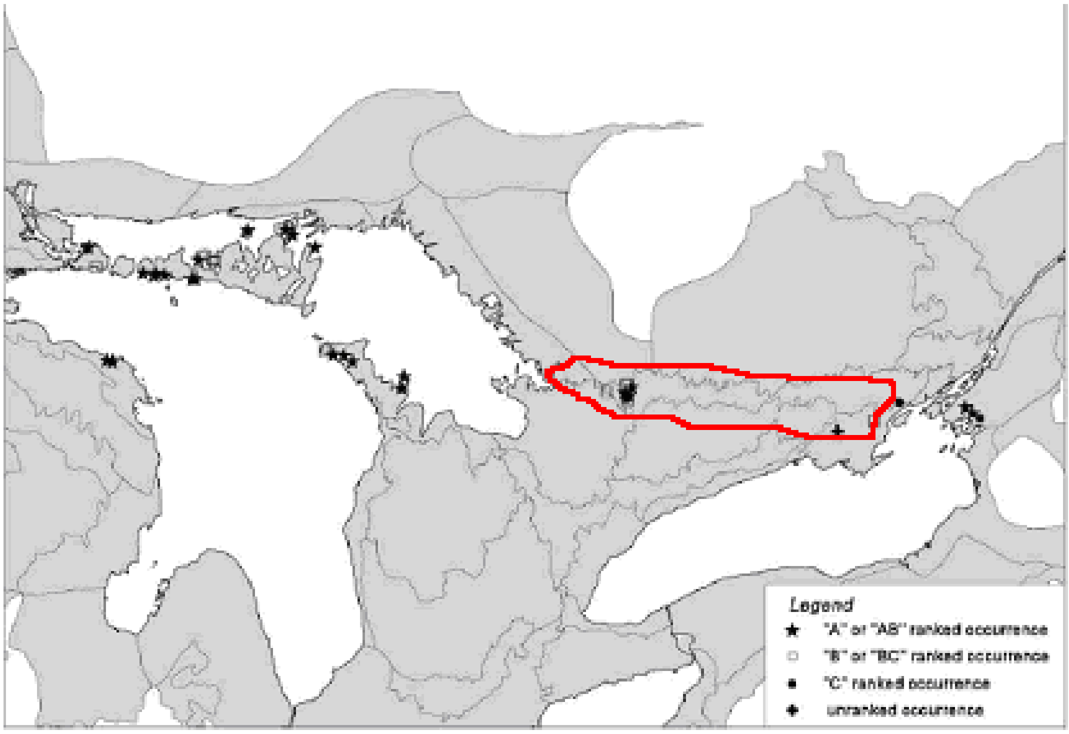

Fig. 2: Tufted hairgrass wet alvar grasslands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

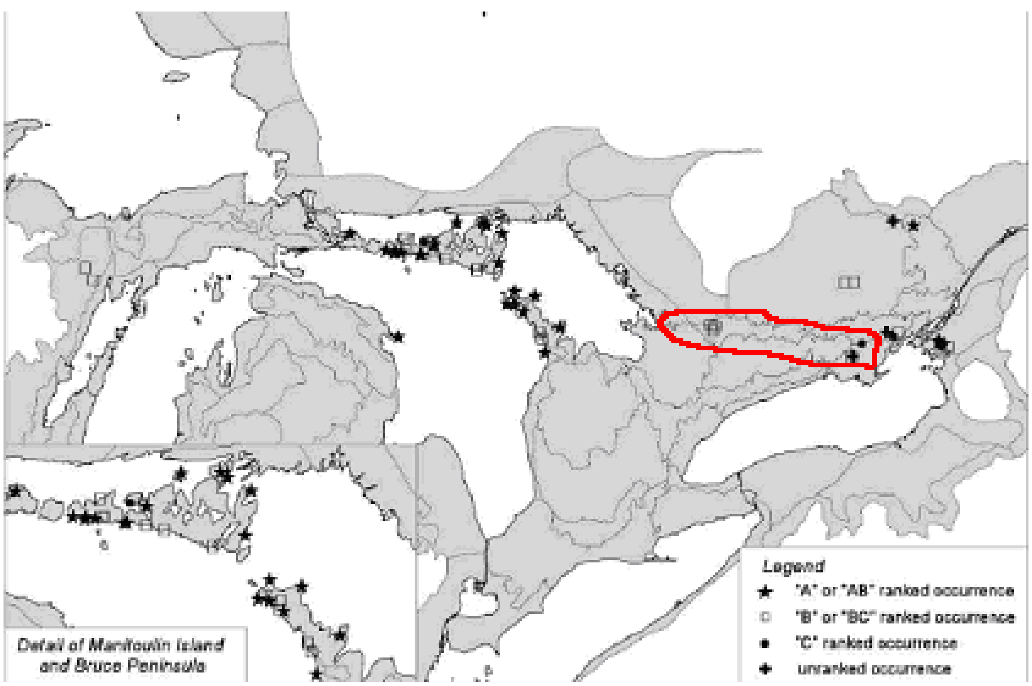

Fig. 3: Little bluestem alvar grasslands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

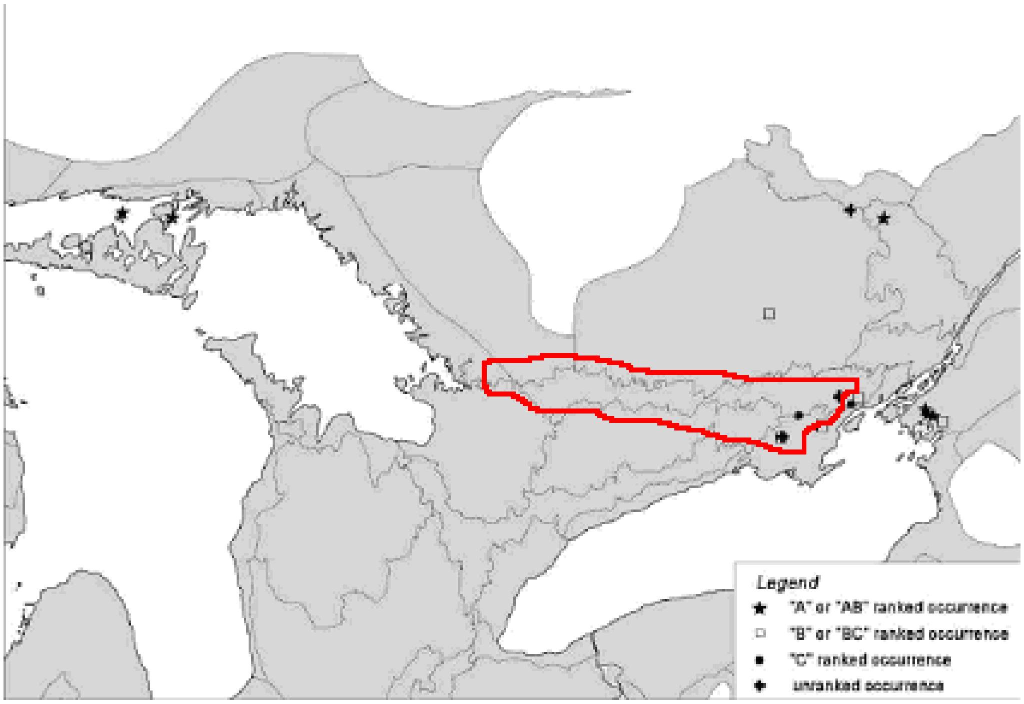

Fig. 4: Annual alvar pavement-grasslands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

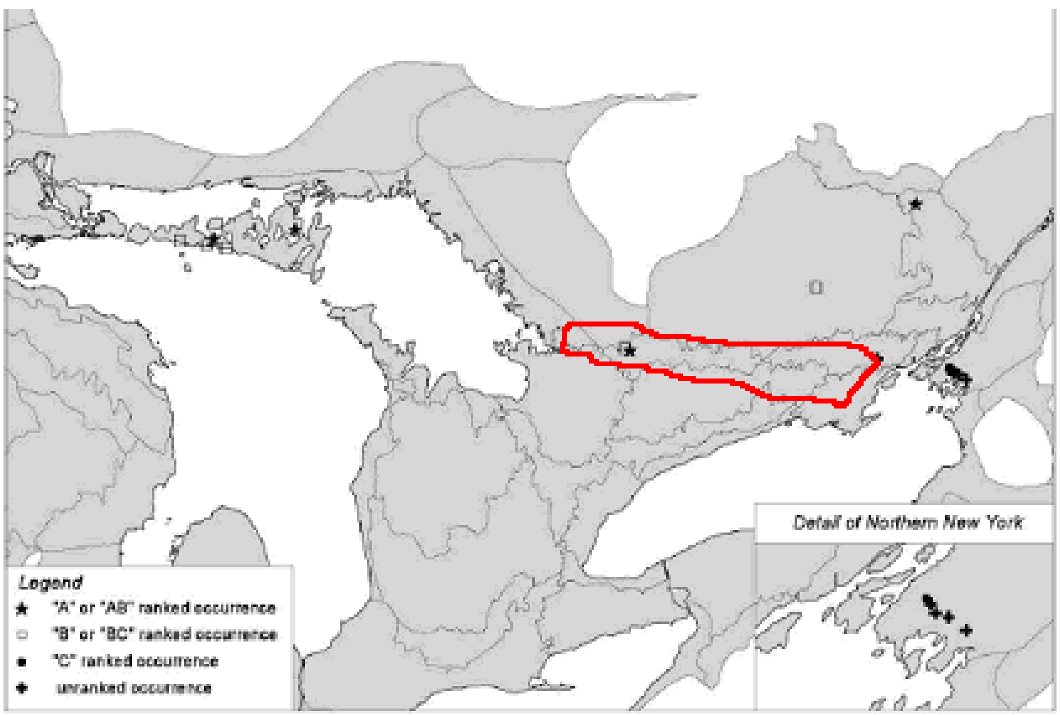

Fig. 5: Poverty grass dry alvar grasslands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

The Alvar Shrublands category (Table 2) contains three different characteristic alvar communities. These communities are: creeping juniper-shrubby cinquefoil alvar pavements, scrub conifer/dwarf lake iris alvar shrublands, and juniper alvar shrublands (Alvar Working Group, 1999). There are open canopies formed by trees (that are over 5 meters) which have less than 10% cover (Alvar Working Group, 1999). Typically shrubs and scrub trees together form more than 25% cover (Alvar Working Group, 1999). The ground cover for this category is variable depending on which community is being considered (Alvar Working Group, 1999). The ground cover is composed of herbs, which includes grasses and sedges, and may also include pavements (Alvar Working Group, 1999). The soils are shallow but typically deeper than soil found on the Open Alvar Grasslands and Pavements (Alvar Working Group, 1999).

The Land Between only supports two of the three Alvar Shrubland communities. Creeping juniper-shrubby cinquefoil alvar pavements can be found, and are located in the North-Western portion (Fig. 6). The other community which can be found in the Land Between is the juniper alvar shrublands. These communities are also found to the North-West (Fig. 7). The scrub conifer/dwarf lake iris alvar shrublands are not present within the Land Between.

Table 2: Alvar Shrublands (Alvar Working Group, 1999).

Community Type	Diagnostic Characteristics	Plant Type	Common Name	Scientific Name
Creeping juniper - shrubby cinquefoil alvar pavement				
	Open Canopy: <10% tree cover	**Dominate Characteristic Species**		
	Few Shrubs over 0.5 m tall: <10%		creeping juniper	*Juniperus horizontalis*
	cover		little bluestem	*Schizachyrium scoparium*
	Dwarf Shrubs (<0.5m): > 25% cover		northern singlespike sedge	*Carex scirpoidea*
	Ground Layer: Herbs, Grasses, and		Richardson's sedge	*Carex richardsonii*
	Sedges < 50% cover, exposed pavement		shrubby cinquefoil	*Pentaphylloides floribunda*
	patches are commonly covered by mosses			
	and lichens with < 50% ground cover	**Common Characteristic Species**		
	Soils: shallow loam usually < 10cm deep		balsam ragwort	*Senecio pauperculus*
	over limestone or dolostone bedrock which		eastern white cedar	*Thuja occidentalis*
	is often broken.		jack pine	*Pinus banksiana*
			lakeside daisy	*Hymenoxys herbacea*
			limestone calamint	*Calamintha arkansana*
			poverty grass	*Danthonia spicata*
			upland white aster	*Solidago ptarmicoides*
Scrub conifer / dwarf lake iris alvar shrubland				
	Open Canopy: <10% tree cover for trees	**Dominate Characteristic Species**		
	over 5 m	Scrub trees (2-5m)	balsam fir	*Abies balsamea*
	Shrubs: >25% cover including stunted		eastern white cedar	*Thuja occidentalis*
	(or scrub) trees		tamarack	*Larix laricina*
	Ground Layer: usually >50% cover from		white spruce	*Picea glauca*
	herbs (including grasses and sedges)	herbs, grasses and sedges	dwarf lake iris	*Iris lacustris*
	resulting in a dense lawn between and		ebony sedge	*Carex eburnea*
	underneath shrubs			
	Soil: shallow organic soil (usualy 20-30 cm)	**Common Characteristic Species**		
	over limestone or dolostone bedrock	short shrubs (0.5-2m)	alderleaf buckthorn	*Rhamnus alnifolia*
			buffalo-berry	*Shepherdia canadensis*
			bush honeysuckle	*Diervilla lonicera*
			chokecherry	*Prunus virginiana*
			common juniper	*Juniperus communis*
			red-osier dogwood	*Cornus sericea*
		herbs, grasses and sedges	bearberry	*Arctostaphylos uva-ursi*
			poverty grass	*Danthonia spicata*
			Richardson's sedge	*Carex richardsonii*
Juniper alvar shrubland				
	Open Canopy: <10% tree cover for trees	**Dominate Characteristic Species**		
	over 5 m	Scrub trees (2-5m) (these species	bur oak	*Quercus macrocarpa*
	Shrub cover: >25% cover including	may also occur in tree form)	eastern red cedar	*Juniperus virginiana*
	stunted (or scrub) trees		eastern white cedar	*Thuja occidentalis*
	Ground Layer: variable % cover of herbs	short shrubs (0.5-2m)	common juniper	*Juniperus communis*
	(including grasses and sedges) resulting in		downy arrow-wood	*Viburnum rafinesquianum*
	dry, grassy meadow between shrubs.		fragrant sumac	*Rhus aromatica*
	Small patches (<50% ground cover) of	herbs, grasses and sedges	poverty grass	*Danthonia spicata*
	exposed limestone bedrock pavement		upland white aster	*Solidago ptarmicoides*
	usually exist, with grikes presnet allowing			
	trees and shrubs to root	**Common Characteristic Species**		
	Soils: shallow loam or sandy loam (usually	trees	rock elm	*Ulmus thomasii*
	<30 cm deep) over limestone bedrock that		shagbark hickory	*Carya ovata*
	is well drained and usually very dry		white ash	*Fraxinus americana*
	midsummer	short shrubs (0.5-2m)	chokecherry	*Prunus virginiana*
			gray dogwood	*Cornus foemina spp. racemosa*
		dwarf shrubs (<0.5 m)	bearberry	*Arctostaphylos uva-ursi*
			snowberry	*Symphoricarpos albus*
		vines	poison ivy	*Toxicodendron radicans*
			riverbank grape	*Vitis riparia*
		herbs, grasses and sedges	a sedge species	*Carex umbellata*

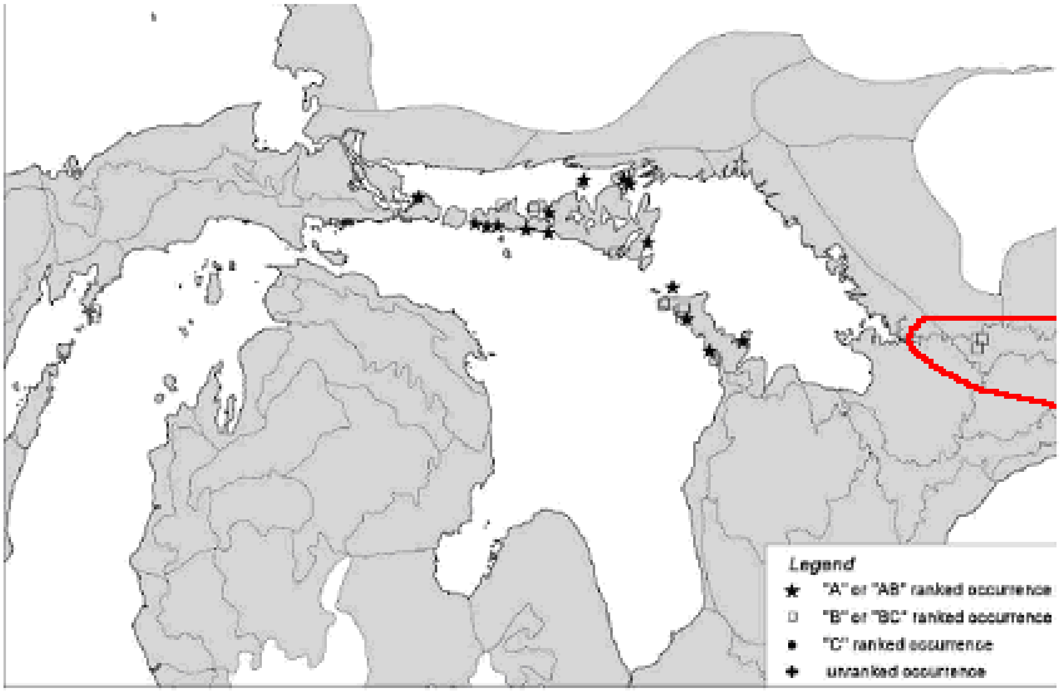

Fig. 6: Creeping juniper-shrubby cinquefoil alvar pavements distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

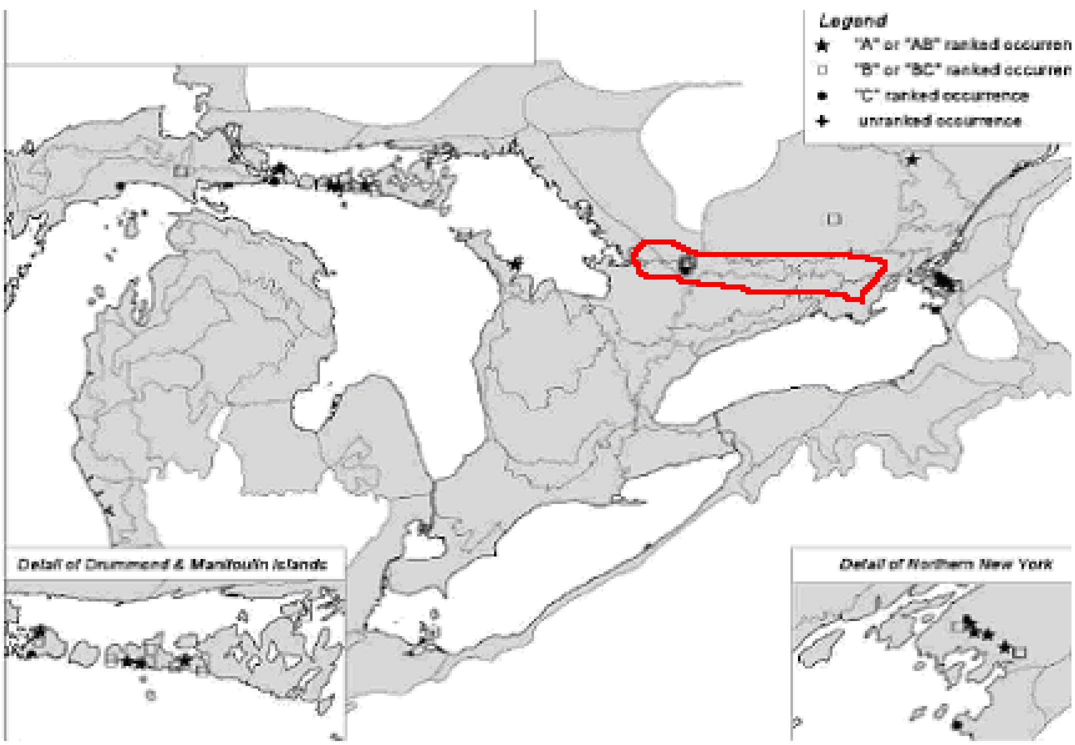

Fig. 7: Juniper alvar shrublands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

The Alvar Savannas and Woodlands category (Table 3) contains five different characteristic alvar communities. The five different communities are shagbark hickory/prickly ash alvar savannas, chinquapin oak/nodding onion alvar savannas, white-cedar – jack pine/shrubby cinquefoil alvar savannas, mixed conifer/common juniper alvar woodlands, and red cedar/early buttercup alvar woodlands (Alvar Working Group, 1999). In this category the trees reach over 5 meters tall and form a partial canopy with either 10-25% or 25-60% cover (Alvar Working Group, 1999). The shrubs found in these communities have variable cover, and may range from 2-55% cover (Alvar Working Group, 1999). Ground cover is comprised of herbs, grasses and sedges and had variable cover (Alvar Working Group, 1999). The ground cover either forms moist grassy meadows or is a mosaic with the limestone or dolostone (Alvar Working Group, 1999). The soil is a shallow loam that is typically deeper than the soil from the Open Alvar Grasslands and Pavements (Alvar Working Group, 1999).

There are only two of five community types present from the Alvar Savannas and Woodlands category within the Land Between. Both the shagbark hickory/prickly ash alvar savannas and the chinquapin oak/nodding onion alvar savannas are not present within the Land Between. The white-cedar – jack pine/shrubby cinquefoil alvar savanna type is also not found. Mixed conifer/common juniper alvar woodlands are present, and are located to the North-west (Fig. 8). Red cedar/early buttercup alvar woodlands are also present and can be found at the other end, to the South-East (Fig. 9).

It should be noted that not all alvar inventories have been complete. It is likely that there are still alvars that have not yet been identified.

Table 3: Alvar Savannas and Woodlands (Alvar Working Group, 1999).

Community Type	Diagnostic Characteristics	Plant Type	Common Name	Scientific Name
Shagbark hickory / Prickly ash alvar savanna	**Partial Canopy**: 10-25%tree cover for	**Dominate Characteristic Species**		
	trees > 5 m	tree	shagbark hickory	*Carya ovata*
	Shrubs: variable cover from 2-55%for	shrub	prickly ash	*Zanthoxylem americanum*
	shrubs from 0.5-5 m tall	herbs, grasses and sedges	Pennsylvania sedge	*Carex pensylvanica*
	Ground Layer: Herbs, Grasses, and		Philadelphia panic grass	*Panicum philadelphicum*
	Sedges have variable cover and produce a		poverty grass	*Danthonia spicata*
	dry grassy meadow between trees and			
	shrubs	**Common Characteristic Species**		
	Soils: shallow loam usually 10-20 cm deep	trees	bur oak	*Quercus macrocarpa*
	over dolostone bedrock, they are well		chinquapin oak	*Quercus muehlenbergii*
	drained and typically very dry during		rock elm	*Ulmus thomasii*
	midsummer		white ash	*Fraxinus americana*
		shrubs	buckthorn	*Rhamnus cathartica*
			chokecherry	*Prunus virginiana*
			gray dogwood	*Cornus foemina* spp. *racemosa*
			snowberry	*Symphoricarpos albus*
		herbs, grasses and sedges	Canada bluegrass	*Poa compressa*
		of grassy patches	gray goldenrod	*Solidago nemoralis*
			tall hawkweed	*Hieracium piloselloides*
		herbs, grasses and sedges	Bicknell's cranebill	*Geranium bicknellii*
		of pavement patches	false pennyroyal	*Trichostema brachiatum*
Chinquapin oak / nodding onion alvar savanna	**Partial Canopy**: 10-25%tree cover for	**Dominate Characteristic Species**		
	trees > 5 m	trees	blue ash	*Fraxinus quadrangulata*
	Shrubs: variable cover from 2-55%for		chinquapin oak	*Quercus muehlenbergii*
	shrubs from 0.5-5 m tall		swamp white oak	*Quercus bicolor*
	Ground Layer: Herbs, Grasses, and	shrubs	rough-leaved dogwood	*Cornus drummondii*
	Sedges have variable cover and produce a	herbs, grasses and sedges	Canada bluegrass	*Poa compressa*
	dry grassy meadow between trees and		nodding onion	*Allium cernuum*
	shrubs			
	Soil: shallow loam usualy about 10 cm	**Common Characteristic Species**		
	deep over limestone bedrock, seasonaly	trees	eastern red cedar	*Juniperus virginiana*
	flooded and usually very dry midsummer	shrubs	downy arrow-wood	*Viburnum rafinesquianum*
			fragrant sumac	*Rhus aromatica*
			prickly ash	*Zanthoxylem americanum*
			snowberry	*Symphoricarpos albus*
			staghorn sumac	*Rhus typhina*
		herbs, grasses and sedges	balsam ragwort	*Senecio pauperculus*
			false pennyroyal	*Trichostema brachiatum*
			troublesome sedge	*Carex molesta*
			wiry panic grass	*Panicum flexile*
White cedar - jack pine / shrubby cinquefoil alvar savanna	**Partial Canopy**: 10-25%tree cover for	**Dominate Characteristic Species**		
	trees > 5 m	trees	eastern white cedar	*Thuja occidentalis*
	Shrubs: variable cover		jack pine	*Pinus banksiana*
	Ground Layer: Herbs, Grasses, and	dwarf shrubs (<0.5 m)	creeping juniper	*Juniperus horizontalis*
	Sedges have variable cover and produce a		shrubby cinquefoil	*Pentaphylloides floribunda*
	moist grassy meadow between trees and	herbs, grasses and sedges	ebony sedge	*Carex eburnea*
	shrubs		limestone calamint	*Calamintha arkansana*
	Soils: shallow loam usually <30 cm deep		northern singlespike sedge	*Carex scirpoidea*
	over dolostone bedrock			
		Common Characteristic Species		
		trees	tamarack	*Larix laricina*
		herbs, grasses and sedges	little bluestem	*Schizachyrium scoparium*
			prairie dropseed	*Sporobolus heterolepis*
			Richardson's sedge	*Carex richardsonii*
Mixed conifer / common juniper alvar woodland	**Partial Canopy**: 25-60%tree cover for	**Dominate Characteristic Species**		
	trees > 5 m	trees	eastern white cedar	*Thuja occidentalis*
	Shrubs: variable cover		jack pine	*Pinus banksiana*
	Ground Layer: Herbs, Grasses, and		white pine	*Pinus strobus*
	Sedges have variable cover and are in a		white spruce	*Picea glauca*
	mosaic with limestone or dolostone	shrubs	common juniper	*Juniperus communis*
	bedrock pavement patches	herbs, grasses and sedges	ebony sedge	*Carex eburnea*
	Soils: shallow loam usually <30 cm deep		false pennyroyal	*Trichostema brachiatum*
		Common Characteristic Species		
		trees	balsam fir	*Abies balsamea*
		shrubs	bearberry	*Arctostaphylos uva-ursi*
			buffaloberry	*Shepherdia canadensis*
			creeping juniper	*Juniperus horizontalis*
		herbs, grasses and sedges	balsam ragwort	*Senecio pauperculus*
			Crawe's sedge	*Carex crawei*
			Richardson's sedge	*Carex richardsonii*
			sheathed rush grass	*Sporobolus vaginiflorus*
		mosses and lichens	common grimmia	*Schistidium* spp.
			dog lichen	*Peltigera canina*
			reindeer 'moss'	*Cladina rangiferina*
			rock surface algae	*Gloeocapsa alpina*
			twisted moss	*Tortella* spp.
Red cedar / early buttercup alvar woodland	**Partial Canopy**: 25-60%tree cover for	**Dominate Characteristic Species**		
	trees > 5 m	trees	red cedar	*Juniperus virginiana*
	Shrubs: variable cover	herbs, grasses and sedges	early buttercup	*Ranunculus fascicularis*
	Ground Layer: Herbs, Grasses, and		poverty grass	*Danthonia spicata*
	Sedges have variable cover and are in a			
	mosaic with limestone or dolostone	**Common Characteristic Species**		
	bedrock pavement patches	trees	eastern white cedar	*Thuja occidentalis*
	Soils: shallow loam usually <20 cm deep	herbs, grasses and sedges	Canada bluegrass	*Poa compressa*
			Philadelphia panic grass	*Panicum philadelphicum*
			sheathed rush grass	*Sporobolus vaginiflorus*
			upland white aster	*Solidago ptarmicoides*
			wiry panic grass	*Panicum flexile*
		mosses and lichens	twisted moss	*Tortella* spp.

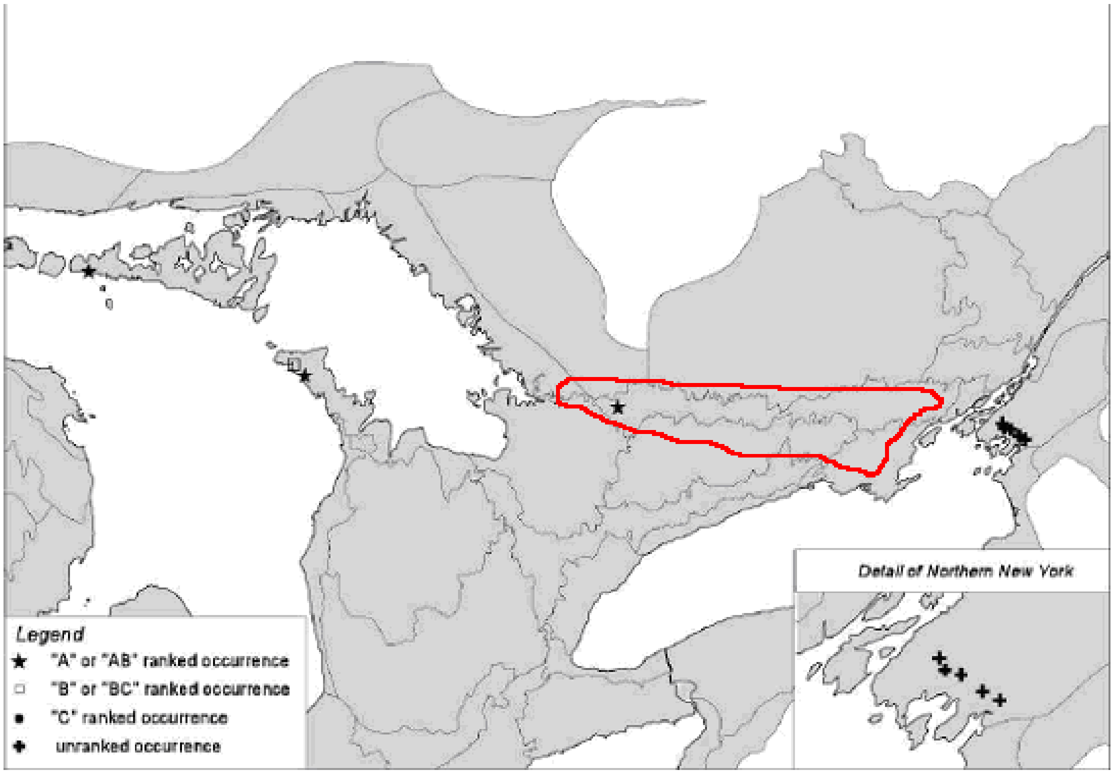

Fig. 8: Mixed conifer/common juniper alvar woodlands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

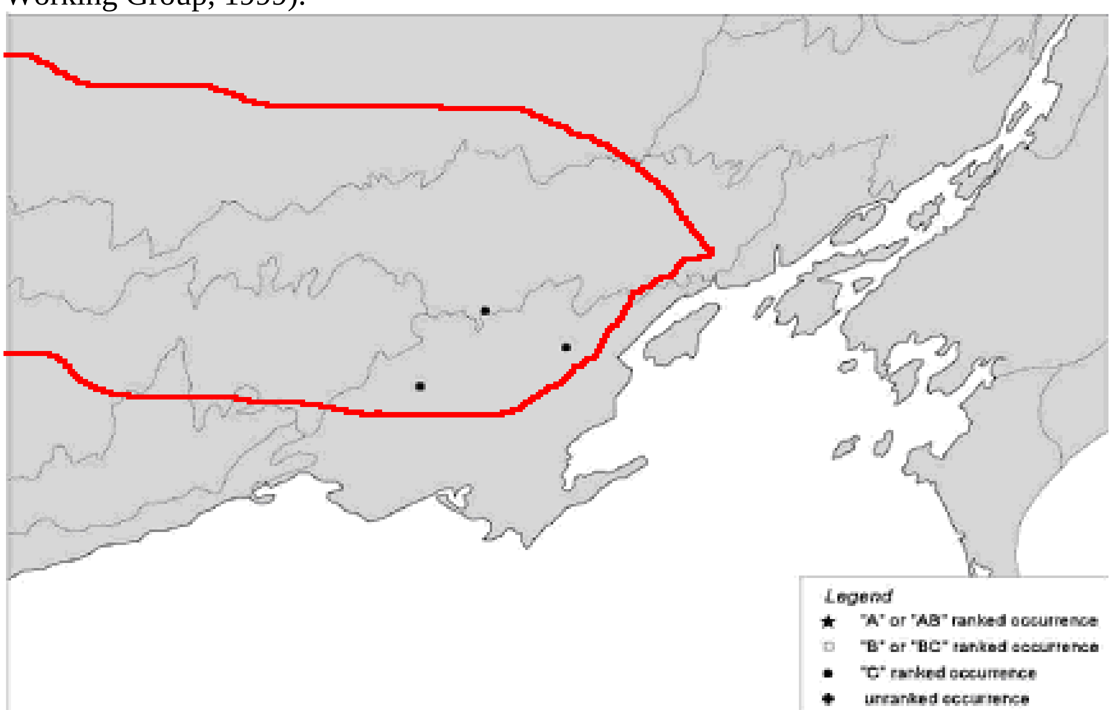

Fig. 9: Red cedar/early buttercup alvar woodlands distribution, the red outline represents the Land Between area as an estimate and is not geographically exact (Alvar Working Group, 1999).

Rock Types and Formation

It was found that for the underlying limestone formations found at these alvars, there are two different formations present. These two different types can be differentiated from each other by their "quality", which is a result of their different characteristics (Hullingsworth, 2006). The different types of limestone are found in layers at different depths (Hullingsworth, 2006). The first layer is known as the Bobcaygeon Formation, and the next "lift down" is the Guelph Formation (Hullingsworth, 2006). The upper layer (the Bobcaygeon Formation) is regarded as being a lesser quality for production purposes (such as cement and steel) and the lower layer (the Guelph Formation) is of a higher quality for production (Hullingsworth, 2006). This results in the Guelph Formation being more desired for extraction for use in cement and steel (Hullingsworth, 2006). This formation is of a higher quality because it is a source of high-purity dolomite and calcined materials used for production (Sangster *et al.*, 2006).

The Guelph Formation is the youngest unit of the Middle Siluran sequence (Singer *et al.*, 2003). This formation is very variable in thickness, and ranges from 4.0 to 100.0 meters thick (Singer *et al.*, 2003). The Guelph Formation is composed of a dolomite or dolomitic limestone (see Fig. 10) (Hubbard, 1895). This dolomite or dolomitic limestone is very fine-grained and is very light in colour (the powder is practically white) (Hubbard, 1895). It has been described as finely crystalline and sugary-textured (Planning and Engineering Initiatives Limited, 2002). The dolostone has occasional shale laminae and vugs (Planning and Engineering Initiatives Limited, 2002). Vugs are visible pores or macro-cavities which are interconnected and can allow for water and gas movement (Cunningham *et al.*, 2004). The limestone which is found here is very pure (Emery, 2004). It is so pure in some locations that drilled core samples show that the dolomite is virtually 100% (Sangster *et al.*, 2006). Since it is a very pure limestone it may be used for metallurgical purposes and for chemical lime (Emery, 2004).

Assessments have shown that there are magnesium values of 21.8% MgO in this formation (Sangster *et al.*, 2006). These same assessments have also shown impurities of SiO_2, Fe_2O_3 and Al_2O_3 being only 0.03% on average (Sangster *et al.*, 2006). The Ontario Geological Survey has confirmed the regional geochemistry consistency after analysis of more than 500 samples (Ministry of Northern Development and Mines, 2006). The results revealed an average magnesium weight percent of 21.4%, and average calcium values of 30.2% (Ministry of Northern Development and Mines, 2006). The Ontario Geological Survey also showed that the impurity values are consistently low (Ministry of Northern Development and Mines, 2006).

Fig. 10: Exposed dolostone outcrop of the Guelph Formation along Speed River (Planning and Engineering Initiatives Limited, 2002)

The Bobcaygeon Formation is part of the Middle Ordovician limestone sequence, along with the Lindsay Formation and Verulam Formations (located above it), and the Gull River Formation (located below it) (Ontario Power Generation, 2005). The formation ranges in thickness from about 7 to 87 meters (Environmental Monitoring and reporting Branch, 2001). This formation can be differentiated from the above formations by its noticeably less argillaceous and more crystalline calcarenitic limestone (Ontario Power Generation, 2005). The Bobcaygeon Formation is composed of fine to medium gained, thinly to medium bedded, crystalline limestone (Ontario Power Generation, 2005). There are low levels of shale present, resulting in the limestone being shaly to crystalline (Ontario Power Generation, 2005).

Alkaline pore solutions in concrete react with some forms of aggregates to cause deleterious effects (Rogers *et al.*, 2000). The alkaline pore solutions in concrete react with all natural rocks, but to much different extents (Rogers *et al.*, 2000). When deleterious, the reaction that takes places results in expansion, eventually causing cracking and deterioration of the concrete (Rogers *et al.*, 2000). This type of reaction can occur with limestone from the Bobcaygeon formation, resulting in it being of a lesser production value (Hullingsworth, 2006). The term used for this reaction is called alkali-aggregate reactions (Rogers *et al.*, 2000). In Ontario there are two different types of these reactions- alkali-carbonate rock reactions and alkali-silica reactions (Rogers *et al.*, 2000). A map of the geographic distribution of potentially alkali-reactive aggregates in Ontario is shown in Fig. 11. In order for these reactions to be deleterious there are certain requirements. The first is that a particular amount of reactive agent be present in the aggregate (Rogers *et al.*, 2000). Secondly, that there is a high concentration of hydroxyl ions in the concrete pore solution (Rogers *et al.*, 2000). The third and final requirement is a moist environment (Rogers *et al.*, 2000).

Some rocks that contain silica may be alkali-silica reactive (Ministry of Transportation, 2005). Cherty limestone in Ontario is one type of rock which has been found to be susceptible to alkali-silica reactions (Ministry of Transportation, 2005). This type of rock can be found in the Bobcaygeon Formation (Ministry of Transportation, 2005). The beds are not all reactive, and reactive beds have certain characteristics. The presence of small amounts (3% or less) of visible black chert, microscopic chalcedony, and a silica content of 5-10% are characteristic of reactive beds (Rogers *et al.*, 2000). Normally silica is an insoluble material, but in the presence of an alkaline solution its solubility is increased significantly (Rogers *et al.*, 2000). Under the proper alkali conditions, the silica in aggregates is dissolved and forms an expansive alkali-silica gel (Rogers *et al.*, 2000). This gel then uptakes water, creating swelling that results in expansion and cracking of the concrete (Rogers *et al.* 2000).

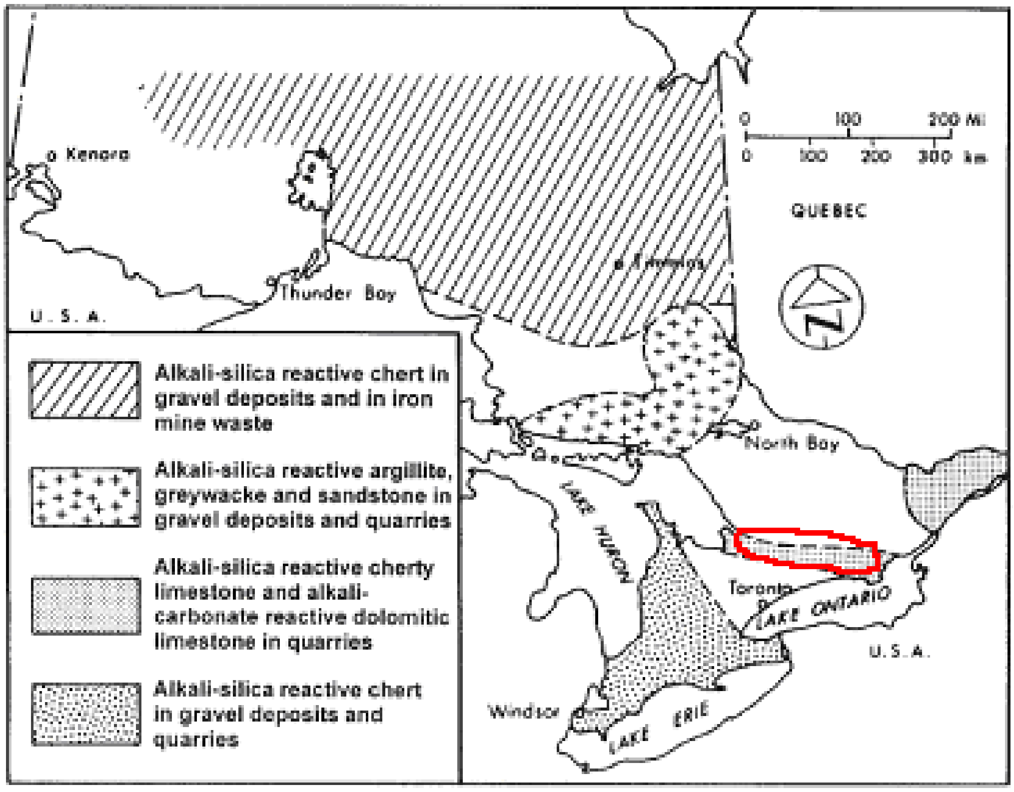

Fig. 11: Geographic distribution of potential alkali-reactive aggregates in Ontario. The red outline represents an estimate of the Land Between area and is not geographically exact (Rogers *et al.*, 2000).

Alvar Plant Dependencies

It was found that there are no identified plant dependencies on particular chemical or physical alvar characteristics (Reid, 2007). In fact, there are discussions on what properties cause the formation of alvars, physical or chemical (Reid, 2007). Of all of the potentially suitable land for alvar habitats, alvars only occur on about 10% of these sites. This suggests that there is an unknown parameter that has not yet been discovered. Ron Reid has a personal hypothesis on a possibility of why alvars only occur at some sites. This is based on wave washing of bedrock in post-glacial times. Remnant species that survived to the post-glacial period would have established themselves where possible (Reid, 2007). Eventually through successional changes trees would have taken over where ever they could have. The unique conditions on alvars, which could have been caused by post-glacial wave washing of bedrock, did not allow for successful establishment of trees. This would have allowed for other plant species to inhabit the area.

Along some river shores narrow bands of alvar vegetation have established because of spring flooding (National Heritage Information Centre, 2005). These establishments are also influenced by the pH of the substrate, and by the steepness of the shoreline. At these sites there has been ice scouring along the river shores. So the establishment and maintenance of alvar vegetation on these river shores is particularly associated with spring flooding and ice scours along the banks.

There could be chemical dependencies present which have not been well documented or realized to date. The second most abundant element in soil is silicon (Hodson *et al*., 2005). It is also one of the most abundant mineral elements found in plant tissues as well (Hodson *et al*., 2005). As was previously mentioned, silica is a rather insoluble material, but in the presence of an alkaline solution its solubility is increased significantly (Rogers *et al.*, 2000). Under the proper alkali conditions, the silica in aggregates is dissolved and forms an expansive alkali-silica gel (Rogers *et al.*, 2000). The most common form of silica found in plants is in the form of a silica gel (Lewin and Reimann, 1969). In many plant species this silica gel is deposited in the epidermal cells and cell walls (Lewin and Reimann, 1969). Plants use silicon for structural support, and it also increases tolerance to disease, drought, and metal toxicity (Hodson *et al*., 2005). When there is an increased amount of silicon present it can further improve structural integrity, tolerance to disease, drought and metal toxicities (Hodson *et al*., 2005).

Since there have been no identified chemical dependencies linking plants to alvars, there is a lack of studies available to support the possible relationship between alvars and silicon. However, there are other studies completed on non-alvar sites which could support this relationship. A study was conducted on the application affects of silicon on sorghum. It was found that under dry conditions the sorghum with the application had a lower shoot to root ratio (Hattori *et al*., 2005). This altered ratio indicates increased root growth and maintenance of the photosynthetic rate and stomatal conductance at a higher level than the plants that did not have the silicon application (Hattori *et al*., 2005). It was found that the sorghum with the application could extract more water from dry soils, showing improved drought tolerance (Hattori *et al*., 2005). This is a characteristic that would aid a plant in surviving in an alvar habitat.

Conversely, in another study conducted on rice plants it was found that a symptom of silicon deficiency is an increase in the rate of transpiration (Lewin and Reimann, 1969). The rate of transpiration was increased by about 30% for silicon deficient plants when compared to the controls (Lewin and Reimann, 1969). It was predicted that the rate of transpiration was affected by the amount of silica gel associated with cellulose in the epidermal cells and cell walls. So with increased amounts of silica gel being present, and forming a thickened layer, water loss would decrease (Lewin and Reimann, 1969). It was found that the largest amounts of solid silica were deposited in plants where the greatest water loss would occur (Handreck and Jones, 1968). If the relationship between alvars and silicon did exist then alvar plants would not experience this increased rate of transpiration, as silicon could be readily available to them in some areas (due to alkalinity). This could be an important factor in determining where alvars form.

Aggregate Operations

Within The Land Between there are approximately 4946 active pits and quarries (Gutowsky *et al*, 2004). From these 4946 active quarries present, there are about 120 which are active upon the limestone layer (Gutowsky *et al*, 2004). In the Peterborough area alone there is approximately one new application for limestone extraction every three months (Cutmore, 2007). In the Land Between area there is approximately one new application for limestone extraction each month (Cutmore, 2007). In terms of trends for extractions, there is an apparent increase in the number of applications each year (Cutmore, 2007). This increasing trend in limestone extractions has especially been noted over the last three years (Cutmore, 2007). Based on projections, it has been predicted that the market for high-purity limestone and dolostone will grow in the near coming future (Sangster *et al.*, 2006). This is predicted to be particularly true for steel manufacturing, environmental, chemical, and filler uses (Sangster *et al.*, 2006). Carbonate rocks extracted are used for many industrial purposes including lime, chemical and metallurgical stone, environmental applications, fillers, cement and construction aggregates (Sangster *et al.*, 2006, Ministry of Northern Development and Mines, 2006). Which carbonate rocks are extracted and what they are used for depends on many different factors. These factors include chemical composition, market demand, transportation options, and location relevant to markets (Sangster *et al.*, 2006). The Bobcaygeon and Guelph Formations are among the most quarried formations for crushed stone aggregate (Sangster *et al.*, 2006). The majority of the quarried material is shipped to major urban centres that are local to the area (Sangster *et al.*, 2006). As stated before, the Guelph formation is more pure and sought after for this reason. The purity of the formation means that alkali-aggregate reactions do not cause deleterious effects to concrete and steel (Hullingsworth, 2006). Since the products produced will last longer, and do not require as much maintenance, it makes the aggregate extractions from the Guelph Formation much more desirable (Hullingsworth, 2006). This results in higher extraction rates from the Guelph Formation.

Aggregate Rehabilitation

Rehabilitation efforts are put in place after a limestone quarry has been closed for extraction. In some cases seed mixtures are used to start the vegetative rehabilitation process (Browning, 2007). Seed mixtures are used on the slope and floor, when they are not below the water level (Browning, 2007). In some situations only tree species are used because they will do much better in the absence of competition from grass species (Browning, 2007).

There are a couple of standard seed mixtures which are used for this process (Browning, 2007). An attempt is made to try and keep these seed mixtures containing native species, but there are obstacles surrounding these efforts (Browning, 2007). These seed mixtures typically consist of prairie species, alvar species, and species which are native to the area but that are not necessarily native to alvars (Browning, 2007). Examples of the species which are native to the area but not to alvars include sand drop seed and poverty oats (Browning, 2007). The party that is paying for the rehabilitation has the option to request a customized seed mixture. Typically there are requests for the use of native seed mixtures if they are available. Unfortunately seeds for native alvar species are not available in sufficient quantities to meet these requests at present. Instead the most commonly used seed mixes include some tall grass prairie species from out west. This is because they are cheap and readily available.

In other cases rehabilitation is left to nature. In these cases natural succession is allowed to take place, re-vegetating the area with local species. This approach may be best in some cases to attain a higher diversity of species. There are examples of the natural succession approach which have worked very well in re-vegetating the abandoned quarries. The key to success when using natural succession is creating the proper physical conditions (Browning, 2007). When the proper physical conditions are put in place, no seed mixtures are required as natural succession is put to work.

Discussion:

Further research on alvars needs to be completed to identify indicator species. The identification of alvar indices would be especially important. If such events were to occur, the health of alvars could be followed much closer. The information collected on characteristic alvar communities can be used as a conservation tool. By going into the field and completing surveys, boundaries of these communities could be mapped. When a specific alvar community had its boundaries mapped, this could be used as a monitoring tool. Successive surveys could then be compared to the ones previously completed. This would provide information on range retractions/expansions, as well as the general community structure. The occurrence of habitat degradation or alteration would be easily identified, and conservation initiatives could be implemented.

Research is also required in identifying why alvars only occur on about 10% of the sites that appear to be able to support alvars. The discovery of some form of plant dependency to an alvar characteristic is of the utmost importance. This would create a much deeper understanding of how alvars function. One possibility of a chemical dependency could exist with silicon. This could be because of the fact that silicon has been shown to increase the tolerance of drought. It is possible that some alvar plants have adapted to the use of silicon for drought tolerance to help them survive in these harsh environments. The fact that increased amounts lead to increased tolerance supports this theory. This is because it is normally insoluble, but its solubility is greatly increased with alkaline solutions. The Bobcaygeon Formation is known for its alkali-aggregate reactions, possibly resulting in increased silicon availability for plants. Another line of evidence to support this theory can be seen between dry and wet cycles. During the wet years trees move further onto alvar habitat (Reid, 2007). When the year is drier, the trees will also retract back out of or away from the alvar habitat (Reid, 2007). This suggests that water is an important limiting factor in alvars. Since the alvar species are able to reside there even through drought, it is possible that silicon uptake is at least partially responsible. The largest threat to alvar communities are quarries (Reid, 2007). The current trend of increasing limestone and dolostone extraction means further threats to alvar communities. Since the Guelph Formation is sought after to a higher degree, this also imposes further threats. This is a result of the Guelph Formation being located at a greater depth. Some pits occur below the water table, and the water bodies and groundwater aquifers in The Land Between are for the most part all interconnected. These sites are very vulnerable to environmental disturbance for this reason (Cutmore, 2006). Deeper extractions also results in further surface disturbance, as it requires more traffic for the transport of more material.

The creation of new quarries also means more roads to access the site. This creates further threats beyond those caused by extractions- the roads to these quarries provide access to alvars for recreational purposes. The ruts left behind from recreational vehicles can cause problems, as they create a miniature ditch which collects water (Reid, 2007). This then provides a narrow corridor for invasive species because of the pooled water (Reid, 2007). Previously the invasive species may not have been able to colonize because of a lack of water, but this small physical change may allow them to.

The lack of availability of native seeds for seed mix rehabilitation further harms alvars. This leads to the use of western tall grass prairie seeds opposed to native seeds. The fact that these seeds are cheap and available poses a problem for alvars, as it only increases the likelihood of their use. The western seeds do not have the same genotypes as local varieties (Browning, 2007). This results in native alvar species having to compete with new genetic variants (Browning, 2007). The introduction of new genes could also lead to the native species' gene pool being diluted after the two species have interbred.

In order for seed mixtures to be effective, and not harmful, there needs to be access to readily available native alvar species. The key to achieving this is to generate more interest for better seed sources (Browning, 2007). This is a goal that is in working process, but further interest needs to still be developed (Browning, 2007).

New standard seed mixes for alvar rehabilitation need to be introduced so that alvars are not further degraded. Since there are a variety of characteristic alvar communities, one standard alvar seed mixture may not be sufficient. Alvars should be assessed pre-disturbance to determine which community type they fall under. This way a seed mix could be applied post-disturbance which would include the characteristic species of that habitat type which were previous displayed in Tables 1, 2, and 3. If it is not possible to complete a pre-disturbance assessment, then a post-disturbance assessment could still be completed to predict the characteristic community that is/was present.

The Land Between also acts as a range boundary for many species from adjoining ecozones and so it is presumed that it may provide key areas of refuge with increasing affects of climate change (CC and KHC, 2006). It is believed that global warming may actually benefit alvars, as these hardy communities are adapted to dry conditions (Reid, 2007). These are further reasons why the conservation of alvar communities is important.

The Land Between represents an important region that requires conservation because of the threats being imposed on it. Most alvars in Ontario are found here. Further information is required on how alvars function to properly conserve them. Once we understand how they function, we will be able to identify where conservation priorities lay. The faster this is achieved, the better the chance of guarding against loss and damage to a rare and globally unique habitat.

References

Allaby, M. 1994. The Concise Oxford Dictionary of Ecology. Oxford University Press, Oxford, England.

Alvar Working Group. 1999. Conserving Great Lakes Alvars; Final Technical Report of the International Alvar Conservation Initiative. The Nature Conservancy, Chicago.

Browning, Mark. Phone Interview. 2007.

Couchiching Conservancy and Kawartha Heritage Conservancy. 2006. The Land Between Collaborative: Phase I Technical Report.

Cunningham, Kevin J., Janine I. Carlson, and Neil F. Hurley. 2004. New method for quantification of vuggy porosity from digital optical borehole images as applied to the karstic Pleistocene limestone of the Biscayne aquifer, southeastern Florida. Journal of applied Geophysics **55** (1-2):77-90.

Cutmore, Paul. Personal Interview. 2006.

Cutmore, Paul. Phone Interview. 2007.

Emery, John. 2004. Geological Investigation: Proposed Dolostone Quarry, Part of Lot 1 and All of Lots 2 and 3, Concession 11 Geographic Township of East Flamborough City of Hamilton. John Emery Geotechnical Engineering Limited, Consulting Engineers, Toronto Ontario. JEGEL 103191; p. 1-110.

Environmental Monitoring and Reporting Branch. 2001. A Groundwater Monitoring Network And Partnership for Ontario: Suggested groundwater monitoring networks for ten basins in southern Ontario. Ministry of the Environment, Toronto Ontario. Pages 141-151.

Gutowsky, L., J. Reeder, L. Sherman. 2004. Credit for Product Final Draft Report, Kawartha Heritage Conservancy: The Land Between.

Handreck, K.A., and L.H.P. Jones. 1968. Studies of silica in the oat plant. Plant and Soil **29**(3): 449-459.

Hattori, Taiichiro, Shinobu Inanaga, Hideki Araki, Ping An, Shigenori Morita, Miroslava Luxová, Alexander Lux. 2005. Application of silicon enhanced drought tolerance in *Sorghum bicolor*. Physiologia Plantarum **123**(4): 459–466.

Hodson, M.J., P.J. White, A. Mead, and M.R. Broadley. 2005. Phylogenetic Variaition in the Silicon Composition of Plants. Annals of Botany **96**(6): 1027-1046.

Hubbard, Lucius L. 1895. Geological Report on the Lower Peninsula of Michigan with Reference to Deep Borings. Geological Survey of Michigan, Michigan.

Hullingsworth, Brian. Phone Interview. 2006.

Lewin, J., and B.E.F. Reimann. 1969. Silicon and Plant Growth. Annual Review of Plant Physiology 20: 289-304.

Ministry of Northern Development and Mines. 2006. Southwestern Ontario Monthly Activity Summary, October 2005. Queens Printer, Ontario.

Ministry of Transportation. 2005. Material Specification for Aggregates – Concrete. Government of Ontario, Canada, Queens Printer for Ontario.

National Heritage Information Centre, 2005. Riverine Alvars and Prairies in Southern Ontario. Science and Inofrmation Newsletter **10**(1): 5-8.

Ontario Power Generation. 2005. Deep Geological Repository for Low and Intermediate Level Radioactive Wastes. Report Number: 00216-REP-07722.07-00001. Pages 1-163.

Planning and Engineering Initiatives Limited. 2002. Forbes Creek Subwatershed Study, Summary Report Section 2. The Corporation of the City of Cambridge. Pages 1-99.

Reid, Ron. Personal Interview. February 15, 2007.

Rogers, Chris, P.E. Grattan-Bellew, R. Doug Hooton, J. Ryell, and M.D.A. Thomas. 2000. Alkali-aggregate reactions in Ontario. Can. J. Civ. Eng./Rev. can. génie civ. 27(2): 246-260.

Sangster, P.J., D.A. Laidlaw, V.C. Papertzian, K.G. Steele, C.R. Lee, M. Barua, and T.R. Carter. 2006. Report of Activities 2005, Resident Geologist Program, Southern Ontario Regional Resident Geologist Report: Southeastern and Southwestern Ontario Districts, Mines and Minerals Information Centre, and Petroleum Resources Centre; Ontario Geological Survey, Open File Report 6186, 77; p:1-92.

Singer, S.N., C.K. Cheng, and M.G. Scafe. 2003. The Hydrogeology of Southern Ontario; Second Edition. Environmental Monitoring and Reporting Branch, Ministry of the Environment Toronto Ontario. Pages 1-213.

Wisconsin Department of Natural Resources. 2005. Niagara Escarpment Report – Glossary. http://www.dnr.state.wi.us/org/land/er/publications/niagara/Glossary.asp