Vascular Plant Diversity in Burned and Unburned Alvar Woodland: More Evidence of the Importance of Disturbance to Biodiversity and Conservation

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Vascular plant biodiversity was compared in an unburned semi-open alvar woodland dominated by conifers and an equivalent woodland that had burned nine years previously and had developed into a long-lasting successional shrubland. The comparison, based on 30 quadrats 1 m² at each of two sites, revealed less than 25% similarity in the vegetation cover of the two sites. The successional alvar shrubland that developed following fire had twice as many species and more regionally rare species than the corresponding woodland site. The shrubland also had higher values for various biodiversity measures that take heterogeneity and evenness into account. These data provide additional evidence for the importance of fire and disturbance in the creation of successional habitat upon which biodiversity depends. A cautious use of fire in management of alvars is supported.

Key Words: vascular plant, alvar, biodiversity, rare species, disturbance, fire, succession, Simpson's Index, Shannon-Wiener function, Brillouin's Index, Smith and Wilson evenness, Ontario.

A number of articles have featured the beneficial effect of fire on rarer vascular plants and overall plant biodiversity on the Burnt Lands Alvar (Brunton 1986*; Catling and Brownell 1999; Catling et al. 2001, 2002; Catling and Sinclair 2002) and have suggested that the removal of biomass on a large scale may contribute significantly to the protection of biodiversity on alvars (e.g., Catling et al. 2001, 2002). These articles were based on studies within a year after a fire and 37 years after a fire. Here diversity of vascular plants is compared in two sites: (1) a semi-open woodland dominated by conifers and (2) successional shrubland resulting from a fire nine years previously that had replaced woodland corresponding to, and nearly adjacent to, the woodland at site 1. The description of these two habitats has additional importance since they have been utilized in comparisons (published elsewhere) of insect biodiversity based on sampling with pitfall traps and nets.

Methods and Materials

The study area

The woodland study site in West Carleton, City of Ottawa, ca. 4.6 km east-northeast of Almonte (Lanark County), Ontario, included 4 ha (approximately 10 acres) centred on 45.2569°N, −76.1437°W. The corresponding burned woodland study site 0.5 km to the southeast also included 4 ha, centred on 45.2507°N, −76.1337°W. Based on personal observation prior to the fire, examination of pre-fire aerial photographs, and determination of identity of burned trees, both of these study areas had been semi-open, mixed forest dominated by conifers until 23 June 1999, when a fire swept through 152 ha, including the southern study site. Both sites appeared to be similar in their vegetation throughout prior to the fire and both were of similar and unchanging elevation. At the time of the study, both sites were surrounded by similar vegetation for 100 m on all sides, the burned site by burned woodland and the unburned site by unburned woodland. At both sites, prior to the fire, the semi-open woodland was dominated by (in order of importance) *Thuja occidentalis, Picea glauca, Populus tremuloides, Abies balsamea,* and *Pinus strobus,* with an understory of mosses, including *Hylocomium splendens* and *Dicranum polysetum,* and occasional depauperate shrubs, including *Juniperus communis*. This is believed to be climax vegetation for these sites, since some trees are killed by drought leading to recolonization of the early successional tree species. The area has long been known to be particularly subject to fire, and it was named the Burnt Lands by settlers in 1870, at the time of the second most recent fire. For more information on this area, see White (1979), Brunton (1986*), and Catling et al. (2001, 2002).

Description of the vegetation

In August 2008, 30 quadrats 1 m² were placed approx. 3 m apart along a transect through the centre of each site. One was placed directly over each of ten pitfall insect traps (at each site) and the other two were placed 2 m away. Thus there were 30 quadrats of 1 m² in each of the burned woodland and the unburned woodland. For each quadrat the percentage cover (represented by half of the surface area) of all plants to 1 m tall was estimated for each species of vascular plant, for bryophytes as a group, and for lichens as a group. The two sites were compared with regard to

FIGURE 1. Burned (left) and unburned (right) alvar woodland on the Burnt Lands Alvar in western Ottawa. On the left, fallen and dead standing trees are *Abies balsamea*, *Picea glauca, Pinus strobus,* and *Thuja occidentalis.* Regrowth on upper left is *Populus tremuloides,* and *Arctostaphylos uva-ursi* can be seen flowering in the foreground. In the right-hand photograph, the forest is dominated by *Abies balsamea*, *Picea glauca, Pinus banksiana, Pinus strobus, Populus tremuloides,* and *Thuja occidentalis*. Shrubs of *Juniperus communis* are present in the foreground. The photo on the left showing the area burned on 23 June 1999 was taken at 45.2507°N, −76.1437°W. The photo on the right was taken at 45.2569°N, −76.1437°W. (Photos: P. M. Catling, late May 2008)

the dominant species (frequency and cover) and biodiversity and to the value to pollinating insects. The plants were identified using Fernald (1950) and the online Flora of North America series (Flora of North America 1993-2009), and the names mostly follow the recent compilation of Kartesz and Meacham (1999). Vouchers of vascular plants are preserved in the National Collection of Agriculture and Agri-Food Canada in Ottawa (DAO), and vouchers of lichens and mosses are in the collection of the Canadian Museum of Nature (CAN).

Comparison and biodiversity measures

Sites were compared to determine the extent of distinctness, since sites that are more distinct would have higher biodiversity value. This aspect was evaluated with regard to the number of species in common and the percentage of the total cover provided by those common species (at both sites) compared to the combined cover of all species at both sites.

The two sites were also compared with respect to the presence of rare and restricted species. Regional rarity was determined by reference to the list of regionally rare species developed by Brunton (2005*).

The measures of biodiversity employed here for comparison were (1) total number of species and the frequency and cover of each species; (2) the reciprocal of Simpson's Index based on probability which weights common and dominant species; (3) the exponential form of the Shannon-Wiener function that is based on information theory and weights rare species more heavily; (4) Brillouin's Index, which employs numbers of individuals or, in this case, instances (i.e., frequency), and assumes no replacement; and (5) the Smith and Wilson evenness measure, which is sensitive to both rare and common species and is independent of species richness. These widely employed measures are all described by Krebs (1999); associated software was used for the computations (Krebs 2008*).

Results

The unburned site was a semi-open forest with dominant trees being (in order of importance) *Thuja occidentalis, Picea glauca, Populus tremuloides, Abies balsamea,* and *Pinus strobus.* The understory was dominated by *Carex eburnea* and bryophytes, mostly *Hylo-*

TABLE 1. Plant species with average cover and frequency values for plants less than 1 m tall in unburned semi-open alvar woodland. The tree cover was dominated by (in order of importance) *Thuja occidentalis, Picea glauca, Populus tremuloides, Abies balsamea,* and *Pinus strobus,* The species are arranged in descending order of average percentage cover value, then by frequency, then alphabetically. The data are based on 30 quadrats 1 m^2 at least 2 m apart sampling an area of 4 ha. Species marked with two asterisks (**) are regionally and/or provincially rare. Species marked with + are introduced.

Species	Average % Cover	Frequency
Bryophytes (mostly *Pleurozium schreberi* and *Dicranum polysetum*	42.50	27
Carex eburnea Boott, Bristle-leaf Sedge	40.26	23
Carex richardsonii R. Br., Richardson's Sedge **	8.10	21
Symphoricarpos albus (L.) Blake, Common Snowberry	6.00	19
Arctostaphylos uva-ursi (L.) Spreng., Red Bearberry	4.53	13
Juniperus communis L. var. *depressa* Pursh, Common Juniper	3.70	5
Waldsteinia fragarioides (Michx.) Tratt. ssp. *fragarioides,* Appalachian Barren-Strawberry	2.03	10
Prunella vulgaris L., Common Selfheal	1.96	6
Oryzopsis asperifolia Michx., White-grain Mountain-Rice Grass	1.60	17
Symphyotrichum (*Aster*) *ciliolatum* (Lindl.) A. & D. Löve, Lindley's American-Aster	1.30	6
Abies balsamea (L.) P. Mill., Balsam Fir	1.06	6
lichens (unidentified)	1.00	3
Thuja occidentalis L., Eastern Arborvitae	0.90	6
Maianthemum canadense Desf., False Lily-of-the-Valley	0.66	6
Rosa acicularis Lindl. ssp. *sayi* (Schwein.) W. H. Lewis, Prickly Rose	0.63	8
Aquilegia canadensis L., Red Columbine	0.60	8
Fragaria viginiana Duchesne ssp. *virginiana*, Virginia Strawberry	0.46	7
Picea glauca (Moench) Voss, White Spruce	0.43	4
Danthonia spicata (L.) Beauv. *ex* Roemer & J. A. Schultes, Poverty Wild Oat Grass	0.33	6
Shepherdia canadensis (L.) Nutt., Russet Buffalo-Berry	0.26	3
Rhamnus cathartica L., European Buckthorn +	0.20	3
Frangula alnus P. Mill., Glossy False Buckthorn +	0.20	4
Toxicodendron (*Rhus*) *rydbergii,* (Small ex Rydb.) Greene, Western Poison Ivy	0.16	3
Cypripedium parviflorum Salisb. var. *pubescens* (Willd.) Knight, Lesser Yellow Lady's-Slipper	0.16	4
Solidago juncea Ait., Early Goldenrod	0.13	3
Hieracium piloselloides Vill., Tall Hawkweed +	0.13	2
Achillea millefolium L. var. *millefolium*, Common Yarrow	0.13	2
Linaria vulgaris P. Mill., Greater Toadflax +	0.10	3
Hypericum perforatum L., Common St. John's-Wort +	0.10	2
Clinopodium vulgare L., Wild Basil	0.10	2
Chimaphila umbellata (L.) W. Bart. ssp. *cisatlantica* (Blake) Hultén, Pipsissewa	0.10	4
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roemer var. *compacta* (Nielsen) McKay, Saskatoon **	0.10	3
Viola nephrophylla Greene, Northern Bog Violet	0.06	3
Packera (*Senecio*) *paupercula* (Michx.) A. & D. Löve, Balsam Groundsel	0.06	2
Epipactis helleborine (L.) Crantz, Helleborine +	0.06	2
Solidago nemoralis Ait. var. *nemoralis*, Gray Goldenrod	0.03	2
Populus tremuloides Michx., Quaking Aspen	0.03	2
Lonicera tatarica L., Common Honeysuckle +	0.03	2
Antennaria sp. (cf. *neglecta),* Pussytoes	0.03	2
Total	120.22	

[1]Mostly *Pleurozium schreberi* and *Dicranum polysetum*

comium splendens and *Dicranum polysetum* (Table 1). There was no obvious change in the vegetation following the fire in the adjacent area. Thirty-seven vascular plants were recorded in the understory, 30 of which were native. Only *Carex eburnea* and bryophytes were prominent. The total cover averaged 120.22 m^2 per quadrat. The seven introduced species represented 0.66% of the total cover.

All vegetation in the burned site, including trees, had been killed by the fire. Nine years after the fire, the burned area had developed into a long-lasting successional shrubland dominated by shrubs, such as *Prunus virginiana, Arctostaphylos uva-ursi, Amelanchier alnifolia* var. *compacta,* and *Symphoricarpos albus*, and herbs, such as *Danthonia spicata* and *Carex richardsonii* (Table 2). Seventy-four vascular plants were recorded in the burned site, 11 of which were introduced, leaving 63 native. The total cover averaged 167.59 m^2 per quadrat. The introduced species accounted for 4.56% of the total cover.

The successional habitat that developed following a fire in boreal semi-open alvar woodland is thought

TABLE 2. Average cover and frequency values for plants less than1 m tall in treeless burned alvar woodland 10 years after the fire. Tree cover was previously dominated by *Abies balsamea, Picea glauca, Pinus strobus, Populus tremuloides,* and *Thuja occidentalis*. The species are arranged in descending order of average percentage cover value, then by frequency, then alphabetically. The data are based on 30 quadrats 1 m^2 at least 2 m apart within an area of 4 ha. Species marked with two asterisks (**) are regionally and/or provincially rare. Species marked with + are introduced. Species marked +? are possibly introduced.

Species	Average % cover	Frequency
Danthonia spicata (L.) Beauv. ex Roemer & J. A. Schultes, Poverty Wild Oat Grass	28.26	32
Prunus virginiana L., Choke Cherry	22.43	14
Arctostaphylos uva-ursi (L.) Spreng., Red Bearberry	18.13	19
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roemer var. *compacta* (Nielsen) McKay, Saskatoon **	14.43	11
Carex richardsonii R. Br., Richardson's Sedge **	13.83	31
Symphoricarpos albus (L.) Blake, Common Snowberry	7.76	18
Rosa acicularis Lindl. ssp. *sayi* (Schwein.) W. H. Lewis, Prickly Rose	5.00	15
Populus tremuloides Michx., Quaking Aspen	5.00	6
Toxicidendron (*Rhus*) *rydbergii* (Small ex Rydb.) Greene, Western Poison Ivy	4.13	16
Cornus sericea (*stolonifera*) L. ssp. *sericea*, Redosier	3.63	8
Solidago nemoralis Ait. var. *nemoralis*, Gray Goldenrod	3.46	16
Symphyotrichum (*Aster*) *ciliolatum* (Lindl.) A. & D. Löve, Lindley's American-Aster	3.03	17
Oligoneuron album (*S. asteroides, ptarmicoides*) (Nutt.) Nesom, Prairie Flat-Top-Goldenrod	2.90	7
Packera (*Senecio*) *paupercula* (Michx.) A. & D. Löve, Balsam Groundsel	2.70	17
Fragaria virginiana Duchesne ssp. *virginiana*, Virginia Strawberry	2.43	15
Hypericum perforatum L., Common St. John's-Wort +	1.96	11
Carex eburnea Boott, Bristle-leaf Sedge	1.86	11
Poa compressa L., Flat-Stem Blue Grass +	1.86	6
Bryum sp., bryophyte	1.80	8
Muhlenbergia glomerata (Willd.) Trin., Spiked Muhly	1.73	9
Pinus banksiana Lamb., Jack Pine	1.66	3
Solidago juncea Ait., Early Goldenrod	1.36	12
Hieracium piloselloides Vill., Tall Hawkweed +	1.06	14
Campanula rotundifolia L., Bluebell	1.00	11
Astragalus neglectus (Torr. & Gray) Sheldon, Cooper's Milk-Vetch **	1.00	3
Carex umbellata Schkuhr ex Willd., Parasol Sedge	0.96	10
Echium vulgare L., Common Viper's-Bugloss +	0.96	5
Viola adunca Sm. var. *adunca*, Hook-Spur Violet **	0.76	8
Penstemon hirsutus (L.) Willd., Hairy Beardtongue	0.76	7
Dichanthelium acuminatum (Sw.) Gould & C. A. Clark var. *fasciculatum* (Torr.) Freckman, Tapered Rosette Grass	0.73	4
Aquilegia canadensis L., Red Columbine	0.63	6
Juniperus communis L. var. *depressa* Pursh, Common Juniper	0.60	5
Trifolium hybridum L., Alsike Clover +	0.56	8
Medicago lupulina L., Black Medick +	0.53	11
Rubus idaeus L. ssp. *strigosus* (Michx.) Focke, Common Red Raspberry	0.53	6
Anemone cylindrica Gray, Long-Head Thimbleweed	0.50	7
Apocynum cannabinum L., Indian-Hemp	0.50	3
Calystegia spithamea (L.) Pursh ssp. *spithamea*, Low False Bindweed **	0.46	7
Polygala senega L., Seneca-Snakeroot	0.43	5
Solidago canadensis L. var. *canadensis*, Canadian Goldenrod	0.40	4
Lilium philadelphicum L. var. *philadelphicum*, Wood Lily	0.40	4
Taraxacum officinale G. H. Weber ex Wiggers ssp. *officinale*, Common Dandelion +	0.33	6
Cypripedium parviflorum Salisb. var. *pubescens* (Willd.) Knight, Lesser Yellow Lady's-Slipper	0.33	5
Sisyrinchium montanum Greene var. *crebrum* Fern., Strict Blue-Eyed-Grass	0.33	3
Waldsteinia fragarioides (Michx.) Tratt. ssp. *fragarioides,* Appalachian Barren-Strawberry	0.26	4
Euthamia graminifolia (L.) Greene var. *graminifolia*, Flat-top Goldenrod	0.26	4
Bromus kalmii (Gray) Holub, Kalm's Brome **	0.26	4
Panicum flexile (Gattinger) Scribn., Wiry Panic Grass **	0.26	3
Erigeron philadelphicus L. var. *philadelphicus*, Philadelphia Fleabane	0.26	3
Elymus trachycaulus (Link) Gould ex Shinners ssp. *trachycaulus*, Slender Wild Rye	0.26	3
Rosa blanda Ait., Smooth Rose	0.23	5
Isanthus brachiatus (L.) B.S.P. (*Trichostema brachiatum*), False Pennyroyal	0.23	4
Tragopogon dubius Scop., Meadow Goat's-Beard +	0.23	3
Scutellaria parvula Michx. var. *parvula,* Small Skullcap	0.20	5
Sporobolus vaginiflorus (Torr. ex Gray) Wood var. *vaginiflorus*, Poverty Dropseed	0.20	4

TABLE 2. *(continued)*

Species	Average % cover	Frequency
Rhus aromatica Ait. var. *aromatica,* Fragrant Sumac	0.20	4
Rubus odoratus L. var. *odoratus,* Purple-Flowering Raspberry	0.20	3
Viola nephrophylla Greene, Northern Bog Violet	0.16	4
Rhus typhina L., Stag-Horn Sumac	0.13	4
Pteridium aquilinum (L.) Kuhn var. *latiusculum* (Desv.) Underwood *ex* Heller, Bracken Fern	0.13	4
Prunella vulgaris L. ssp. *vulgaris,* Common Selfheal	0.13	3
Diervilla lonicera P. Mill., Northern Bush-Honeysuckle	0.13	3
Potentilla norvegica L. ssp. *monspeliensis* (L.) Aschers. & Graebn., Norwegian Cinquefoil +?	0.13	1
Dichanthelium linearifolium (Scribn. & Nash) Gould, Slim-Leaf Rosette Grass	0.10	3
Arenaria serpyllifolia L., Thyme-Leaf Sandwort +	0.10	3
Eurybia (*Aster*) *macrophylla* (L.) Cass., Large-Leaf Wood-Aster	0.06	4
Arabis hirsuta (L.) Scop. var. *pycnocarpa* (M. Hopkins) Rollins, Hairy Rockcress **	0.06	4
Veronica peregrina L. ssp. *xalapensis* (Kunth) Pennell, Neckweed	0.06	3
Verbascum thapsus L., Great Mullein +	0.03	3
Silene antirrhina L., Sleepy Catchfly	0.03	3
Hedeoma hispida Pursh, Rough False Pennyroyal	0.03	3
Geranium bicknellii Britt., Northern Crane's-Bill	0.03	3
Clinopodium vulgare L., Wild Basil	0.03	3
Cirsium discolor (Muhl. ex Willd.) Spreng., Field Thistle **	0.03	3
Cirsium vulgare (Savi) Ten., Bull Thistle +	0.03	3
Agrostis hyemalis (Walt.) B.S.P., Winter Bent	0.03	3
Total	167.59	

to be relatively long-lasting, since trees were observed to be invading slowly nine years after the fire and their establishment would only be possible following successful competition with a well-established shrubland flora. In the woodland, young trees represented 2.01% of the total cover, but in the burned woodland, after nine years, young trees represented only 3.97%.

The two sites had only 16.33% of species in common, and these common species accounted for only 24.77% of the combined cover of both sites. Consequently, the vegetation was >75% different with respect to biomass. There were nine regionally rare species in the burned area with a cover value of 31.09%. Only two regionally rare species, with a cover value of 2.85% were present in the unburned woodland.

Not only were there almost twice as many species in the burned site as well as higher frequency and cover values, but the values for all biodiversity indices and an evenness measure were also higher for the burned area (Table 3). Introduced species contributed to overall biodiversity, but they were a minor component at both sites, resulting in only slightly higher values than for native species alone.

Discussion

The development of successional plant communities on alvar landscapes is likely to promote vascular plant biodiversity, which is often highest in mid-successional stages. The post-fire succession on alvars is unique and has high vascular plant biodiversity, so including fire, or an alternative biomass removal method, in the management plan for portions of an alvar landscape is appropriate, if not essential. With the decline of ecological processes such as natural fire, it is to be anticipated that certain kinds of successional communities will be lost. Without dedicated management of protected areas, there will be declines in biodiversity. However, taking into account the extent to which fires occurred on alvars (Jones and Reschke 2005), the occurrence of unique species in alvar woodlands (personal observation), and the susceptibility of some species to fire (Siemann et al. 1996), only portions of alvar landscapes should be burned at any particular time.

Important considerations for fire management include the following: (1) maximum successional changes occur in early stages (Catling et al. 1999, 2001, 2002); (2) succession proceeds at different rates in different places; (3) the pre-settlement fire return interval on Great Lakes alvar landscapes was at least 200–500 years (Jones and Reschke 2005); and (4) there may be little change in many alvar woodlands more than 100 years old due to the maintenance by drought of early successional forest dominated by conifers. These considerations suggest that an alvar landscape with maximum biodiversity would include alvar woodlands burned 10, 30, 60, 100, and 200 years previously. After 100 years of management, the first burned area may have returned to alvar woodland. Of course, there are many considerations, such as maintaining sufficiently large wooded areas for forest-nesting birds, and adjustments to speed up the burn cycle may be necessary during the management period. Although the management

TABLE 3. Biodiversity measures for all species/native species in burned and unburned alvar woodland.

Biodiversity measure	Alvar woodland	
	Burned	Unburned
Number of species	76/65	39/32
Total cover	167.59/159.94	120.22/119.4
Total frequency	553/540	254/236
Simpson Index reciprocal (cover)	12.51/11.44	4.04/3.98
Simpson Index reciprocal (frequency)	45.39/37.76	20.09/17.61
Shannon-Wiener function (cover)	4.43/4.23	2.77/2.71
Shannon-Wiener function (frequency)	5.87/5.62	4.77/4.52
Brillouin's Index (frequency)	5.52/5.28	4.41/4.20
Smith-Wilson evenness (cover)	0.21/0.20	0.18/0.17
Smith-Wilson evenness (frequency)	0.73/0.72	0.66/0.65

of alvars with fire is complex, failure to attempt it is failure to simulate a natural process that preserves biodiversity.

Future studies of biodiversity and its relation to succession on alvar landscapes are needed to determine the extent to which diversity of various animal groups corresponds to that for vascular plants. This would also help to improve the general understanding of the effectiveness of easily surveyed plants in predicting biodiversity of animals which has a number of constraints (Wolters et al. 2006).

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