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EFFECTS OF AERIAL APPLICATION OF THE HERBICIDE GLYPHOSATE ON FOREST ECOSYSTEMS: PART 3 EFFECTS ON VEGETATION AND UNGULATE BROWSE 1985 TO 1994

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Executive Summary

A program was initiated in the spring of 1985 to study the direct effects of aerial application of the herbicide glyphosate on target and non-target vegetation in the boreal forest region of southeastern Manitoba. During the last decade glyphosate has been used increasingly in silviculture practices in Manitoba and Canada.

Eleven study sites were monitored from 1985 to 1994 to assess the effects of various rates of glyphosate applications on the vegetation of forest ecosystems. Control (unsprayed) and treated (sprayed) sampling sites were established in two recently burned areas, a mature aspen stand, a forest plantation, and an area where an accidental spill of glyphosate had occurred in the past.

A separate study was established to specifically address the effects of glyphosate on available ungulate browse material. Data on the available browse from six forage species were collected from the control and treated burn and aspen stand areas.

Results from vegetation monitoring differed from site to site. The vegetation of one site in the treated aspen stand showed little evidence of adverse effects following glyphosate application when applied at a rate of 2.5 l/ha in 1985 and in 1986. This was likely due to poor weather conditions immediately following the application in 1985, and uneven application of the herbicide in 1986. A second site in the treated aspen stand, however, experienced a significant reduction in shrub and tree densities following the applications. This allowed greater light penetration to ground level, which resulted in the establishment of a distinct association of understorey species at the site. Results from the burn sites provide evidence which strongly suggests detrimental impacts from the 1985 and 1986 herbicide applications. The general effect of the 1985 and 1986 herbicide applications at one of the burn areas was to slow regeneration processes within the shrub and tree strata, and in doing so, allow the prolonged presence of early post-fire succession species in the understorey stratum. A single application of glyphosate at the other burn area in 1987 did not appear to directly affect the understorey stratum of the treated site, compared to that of its control site. However, immediate post-spray tissue samples collected in the shrub and tree strata of this site revealed high levels of glyphosate residue. This was reflected in a one-year post-spray decline in the shrub and tree populations at the treated site relative to its control site. Results from aerial photo interpretation and vegetation sampling at the forest plantation and accidental spill area indicate that the vegetation was heavily impacted by the glyphosate applications. Shrub and tree strata were eliminated following the herbicide applications, and have only begun to re-establish themselves within the last four to five years.

The available browse at the aspen stand and burn areas exhibited a decrease in density following the glyphosate applications relative to their respective control areas. By the 1992 and 1994 sampling periods (seven to nine years post-spray) the available browse in the sprayed aspen stand exhibited a trend of increasing density, but was still approximately 35% lower than that of the control by the end of the study. By the 1992 and 1994 sample periods the available browse in the sprayed burn area had regenerated to levels comparable to that of the unsprayed burn area.

The majority of the treated sites exhibited a response to herbicide applications. Generally the trees and shrubs were reduced, and the understorey herb layer was altered. Future monitoring of the sites, perhaps at four or five year intervals, is recommended in order to determine the long-term effects of glyphosate on the vegetation, and to determine the efficacy of the herbicide on the growth and maturation of conifer plantations.

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Abstract

A research program was initiated in the spring of 1985 to study the direct effects of aerial application of the herbicide glyphosate on target and non-target vegetation in the boreal forest region of southeastern Manitoba.

To study the effects of glyphosate on different vegetation types and at two application rates, five study areas were located north and northeast of Pine Falls, Manitoba. The study areas included: (i) aspen stands in the Sandy River area; (ii) a recently burned area located near the aspen stands; (iii) a second recently burned area located along the Trans Licence Road; (iv) a spruce plantation in a previously harvested area; and (v) an area which had received an accidental spill of glyphosate. A control site and a treated site, represented by the establishment of a 100 m^2 macroplot, were set up in each study area. The control sites were left undisturbed, while the treated sites received glyphosate applications.

Results from vegetation monitoring differed from site to site. The vegetation of the Treated Aspen (TA) site showed little evidence of adverse effects from the 1985 and 1986 herbicide applications. Reduction in the shrub and tree strata were very evident at the New Treated Aspen (NTA) site, which resulted in the establishment of a distinctly different compilation of understorey species than found at either the Control Aspen (CA) or TA sites. Results from the Burn sites provide evidence which strongly suggests detrimental impacts from the herbicide applications. The general effect of the herbicide at the Treated Burn (TB) site was to slow regeneration processes within the shrub and tree strata, and in doing so, allow the prolonged presence of early post-fire succession species in the understorey stratum. Application of glyphosate on the Treated Trans Licence (TTL) site did not appear to directly affect the understorey stratum. Immediate post-spray tissue samples collected in the shrub and tree strata of the TTL site revealed high levels of glyphosate residue. This was reflected in a one-year post-spray decline in the shrub and tree populations at the site relative to the Control Trans Licence (CTL) site. Results from aerial photo interpretation and vegetation sampling at the Timber Harvest and Accidental Spill sites indicate that the vegetation of the treated sites was greatly impacted by exposure to glyphosate. Shrub and tree strata were essentially eliminated following the herbicide applications, and have only recently begun to re-establish themselves at the sites.

The available browse at the aspen and burn areas at Sandy River exhibited a decrease in density following the glyphosate applications relative to their respective control sites. By the 1992 and 1994 sampling periods (seven to nine years post-spray) both sites showed strong evidence of browse regeneration.

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Résumé

Au printemps de 1985, on a mis en oeuvre un programme de recherche visant à étudier les effets directs de l'application aérienne de l'herbicide glyphosate sur divers genres de végétation dans la région forestière boréale du sud-est du Manitoba.

Afin d'étudier les effets du glyphosate sur divers genres de végétation et selon deux taux d'application, on a délimité cinq zones d'étude au nord et au nord-est de Pine Falls (Manitoba). Il s'agissait des zones suivantes : i) des peuplements de trembles dans la région de Sandy River; ii) une zone récemment brûlée, située près des peuplements de trembles; iii) une deuxième zone récemment brûlée, située le long du chemin Trans Licence; iv) une plantation d'épinettes dans une zone ayant antérieurement fait l'objet d'une récolte de bois; v) une zone ayant reçu un déversement accidentel de glyphosate. On a établi, pour chaque zone d'étude, un site de contrôle et un site de traitement, chacun étant représenté par un macroplaceau de 100 m^2. Les sites de contrôle n'ont fait l'objet d'aucune application d'herbicide tandis que les sites de traitement ont reçu des applications de glyphosate.

Les résultats varient selon les sites. La végétation du site de traitement de la zone des trembles (TT) affichait peu d'effets secondaires fâcheux résultant de l'herbicide appliqué en 1985 et en 1986. On a observé une réduction marquée des strates arborescentes et arbustives sur le site de nouveau traitement de la zone des trembles (NTT), qui s'est traduite par l'apparition d'espèces de sous-étage très différentes de celles trouvées tant sur le site de contrôle de la zone des trembles (CT) que sur le site TT. Les résultats observés sur les sites de la zone brulée suggèrent fortement que l'application d'herbicide a eu des effets nuisibles sur la végétation. Sur le site de traitement de la zone brûlée (TB), l'effet général de l'application d'herbicide a été la régénération lente des strates arbustives et arborescentes et, par conséquent, la présence prolongée d'espèces successives hâtives de post-incendie dans la strate de sous-étage. L'application de glyphosate sur le site de traitement de la zone Trans Licence (TTL) ne semble pas avoir modifié directement la strate de sous-étage. Les échantillons de tissu recueillis immédiatement après l'application dans les strates arbustives et arborescentes du site TTL indiquaient des niveaux élevés de résidus de glyphosate. Les résultats ont été confirmés par la réduction des populations d'arbrisseaux et d'arbres un an après l'application, comparativement aux populations sur le site de contrôle de la zone Trans Licence (CTL). Les résultats de l'interprétation des photos aériennes et de l'échantillonnage de la végétation des zones de récolte de bois et de déversement accidentel indiquent que la végétation des sites de traitement a subi des effets importants à la suite de son exposition au glyphosate. L'application d'herbicide a essentiellement éliminé les strates arbustives et arborescentes, qui n'ont commencé que récemment à se régénérer.

Comparativement aux sites de contrôle, les sites de traitement de la zone des trembles et de la zone brûlée dans la région de Sandy River ont affiché une diminution de la densité du brout après l'application de glyphosate. Les échantillons recueillis en 1992 et en 1994, soit de sept à neuf ans après l'application, indiquaient toutefois une régénération du brout.

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1. INTRODUCTION

Glyphosate or Roundup®* (N-(phosphonomethyl)glycine) was first described for use as a herbicide in 1971 (Baird *et al.* 1971). It is a post-emergent, non-selective, basipedal translocated herbicide that is quickly absorbed by photosynthesizing vegetation (Franz 1985). Glyphosate also binds rapidly to soil particles to become inert within seven to ten days following application (Duke 1988). Although the mode of action on plants is not fully understood (Franz 1985), glyphosate has been shown to affect certain enzymatic processes involved in aromatic amino acid biosynthesis (Jaworski 1972), and is suspected to adversely influence auxin production, the accumulation of chlorophyll in foliage, and photosynthesis and respiration processes (Cole 1985).

The chemical and physical properties of glyphosate (Goldsborough and Brown 1987) make it a preferred herbicide for use in certain agriculture and silviculture practices. Glyphosate (now distributed as Vision®* for forestry use) can be used in silvicultural practices as a site preparation tool prior to planting of conifer seedlings (Newton *et al.* 1984), or as a mechanism of weed control to release established seedlings from competing vegetation (Pitt *et al.* 1993, Wood and von Althen 1993). In the latter case, applications are usually conducted in the late summer, following bud formation and the onset of dormancy in conifers. At this time the herbicide is readily absorbed by ferns and angiosperms, which are still actively photosynthesizing, but is not absorbed by conifers (Franz 1985). The result is elimination of herb, shrub, and tree species which would otherwise compete with conifer seedlings for light, moisture, and nutrients (Malik and Vanden Born 1986). The forest industry has demonstrated that without the use of herbicides such as glyphosate, successful reforestation of timber harvested areas with conifer seedlings would be much more difficult and costly (pers. com. Peacock 1985).

Different species often exhibit different responses to glyphosate depending on their physiological sensitivity, morphology, and phenology at the time of application (Caseley and Coupland 1985). Annual weed species often exhibit a response to glyphosate application within two to four days, while signs of toxicity in perennials are often not apparent for seven to ten days post-spray (Sutton 1978). Sprankle *et al.* (1975) found that glyphosate absorption is quicker in non-woody plants, suggesting that many ferns, monocots, and herbaceous dicots are more rapidly affected than conifers and woody dicots. Torstensson (1985) and Sharma (1986) found that most plants show signs of toxicity within two to three weeks post-application. Malik and Vanden Born (1986) state that there can be up to a two-year lag

(*Roundup® and Vision® are registered trademarks of Monsanto Co., St. Louis, MO, 63167, USA.)

time between glyphosate application to control woody dicots and vegetation response depending on the species involved, the rate of application, and prevailing climatic conditions.

Meteorological conditions at the time of application are very important factors in the overall response of vegetation to glyphosate (Caseley and Coupland 1985). Rainfall occurring shortly after an application can remove glyphosate before it has been fully absorbed by the plant. The presence of moisture on leaves and stems from dew or high humidity may also induce run-off of the herbicide. Wind is also a factor in determining the success of glyphosate applications, particularly with fixed-wing aircraft applicators. Even a mild wind can cause the herbicide to drift to non-target areas and become more dispersed, and therefore less effective on the target vegetation. For best results, it is recommended that glyphosate be applied on days when conditions are clear and calm (Miller 1993).

The aerial application rate of glyphosate recommended by the manufacturer for silvicultural purposes is 3 to 6 l/ha (Monsanto Corp. 1984). Abitibi-Price (now the Pine Falls Paper Co.) conducted field trials with glyphosate in the southeastern Manitoba boreal forest region from 1979 to 1982. After testing various application rates, they opted to use an application rate of 2.5 l/ha on plantations within their harvest area. They found that a 2.5 l/ha application rate resulted in the die-back of 50 to 100% of the aspen trees and suckers in recently cleared areas, and from 65 to 100% of the mature aspen in NSR (non-sufficiently regenerated) areas (pers. com. Russel 1984). Freedman *et al.* (1993) found acceptable vegetation control in conifer plantations in Nova Scotia using an application rate of 3 l/ha. Pitt *et al.* (1993) found that application rates as low as 1.4 l/ha resulted in relatively high mortality on many target species in a hardwood forest in New Brunswick. They stress, however, that results were variable, and that the effective application of herbicides for use in silvicultural practices is often site and time specific.

Information concerning the effects of glyphosate use on Manitoba boreal forest ecosystems is lacking. Because of this lack of information, a study was established to examine the response of forest flora and fauna to glyphosate applications. The scope of the project included the monitoring of vascular plants, and the censusing of birds, ungulates, and small mammals at a number of sprayed and unsprayed sites north of the Powerview/Pine Falls area of southeastern Manitoba. Glyphosate deposition patterns in vegetation and soil were also monitored at the sites sprayed with herbicide. Initially, the study was conducted from 1985 to 1988 (inclusive), with further vegetation monitoring during the summer and fall of 1992 and 1994. The project was initiated by the Terrestrial Quality Management Section of Manitoba Environment under the terms of the Canada-Manitoba Forest Renewal Agreement (1985 to 1990) and the Canada-Manitoba Partnership Agreement in Forestry (1990 to 1995).

Two technical reports dealing with various aspects of the study have been published prior to this report. The first report (Henderson and Wotton 1987) served to introduce the project and described the methodology used in data collection. The second report (Henderson *et al.* 1988) summarized and discussed the vegetation, animal, and glyphosate deposition data collected from 1985 to 1988. The present report assesses the immediate and long-term response of vegetation to glyphosate application by using the vegetation and browse data collected during the 1985 to 1988 period, and incorporating data collected during the 1992 and 1994 sampling seasons to update the observations.

2 STUDY SITES

2.1 Study Region

The study region extends along the southern border of the Canadian Shield from the Winnipeg River north to the Sandy River area near Manigotogan in eastern Manitoba (Figure 1). The majority of the study region is Crown land, in which the forest resource is allocated under a Forest Management Licence Agreement to the Pine Falls Paper Company Ltd. (formerly Abitibi-Price, Inc.), which operates a pulp and paper (newsprint) mill in Pine Falls. The area is characterized by transitional deciduous-coniferous forest type vegetation, with mixed stands of *Picea glauca* (Moench) Voss (white spruce), *Pinus banksiana* Lamb. (jack pine), *Picea mariana* (Mill.) BSP. (black spruce), *Larix laricina* (DuRoi) K. Koch (tamarack), *Abies balsamea* (L.) Mill. (balsam fir), *Betula papyrifera* Marsh. (paper birch), *Populus tremuloides* Michx. (trembling aspen), and *Populus balsamifera* L. (balsam poplar). Bedrock geology of the area is mainly Precambrian granite and gneiss (Weir 1983). Some bedrock is exposed and some is overlain by a thin veil of glacial till. Luvisolic soils occur in the better drained portions of the landscape, and organic soils are present in moist depressions (Weir 1983).

Figures 2 and 3 present monthly temperature and precipitation data for the region during the course of the study. The area experiences short, cool summers and long, cold winters, with a high mean monthly temperature of 19 ^{0}C in July, and a mean monthly low of -18 ^{0}C in January (Weir 1983). There is no discernible dry season, although periods of lower than normal rainfall are not uncommon (deBlij 1981). Average annual precipitation in the study region ranges from 457 to 508 mm, with an average of 305 mm falling as rain from May to September (Weir 1983).

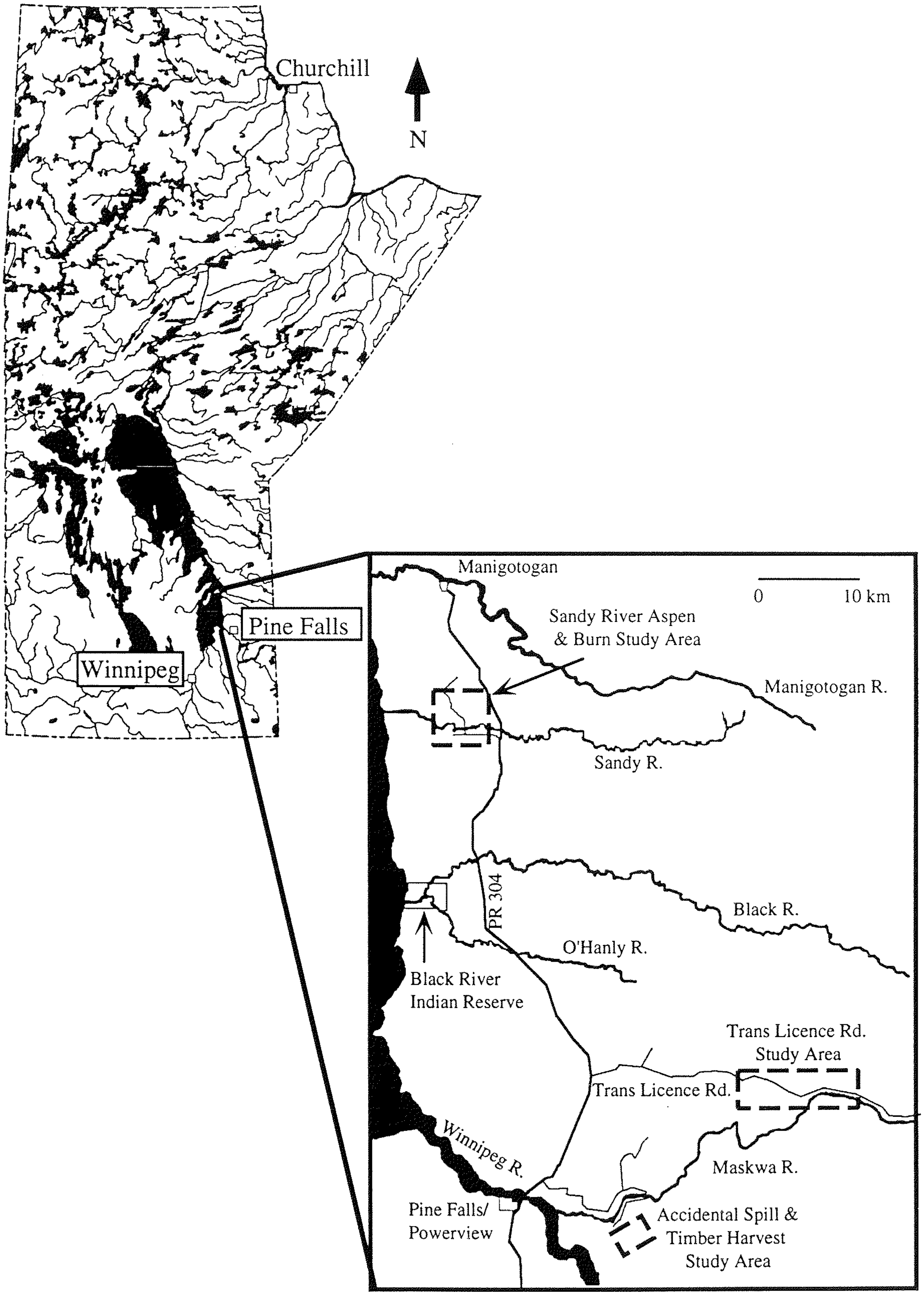

Fig. 1. Map of Manitoba with enlargement of the study region. Note location of the study areas in the enlarged map.

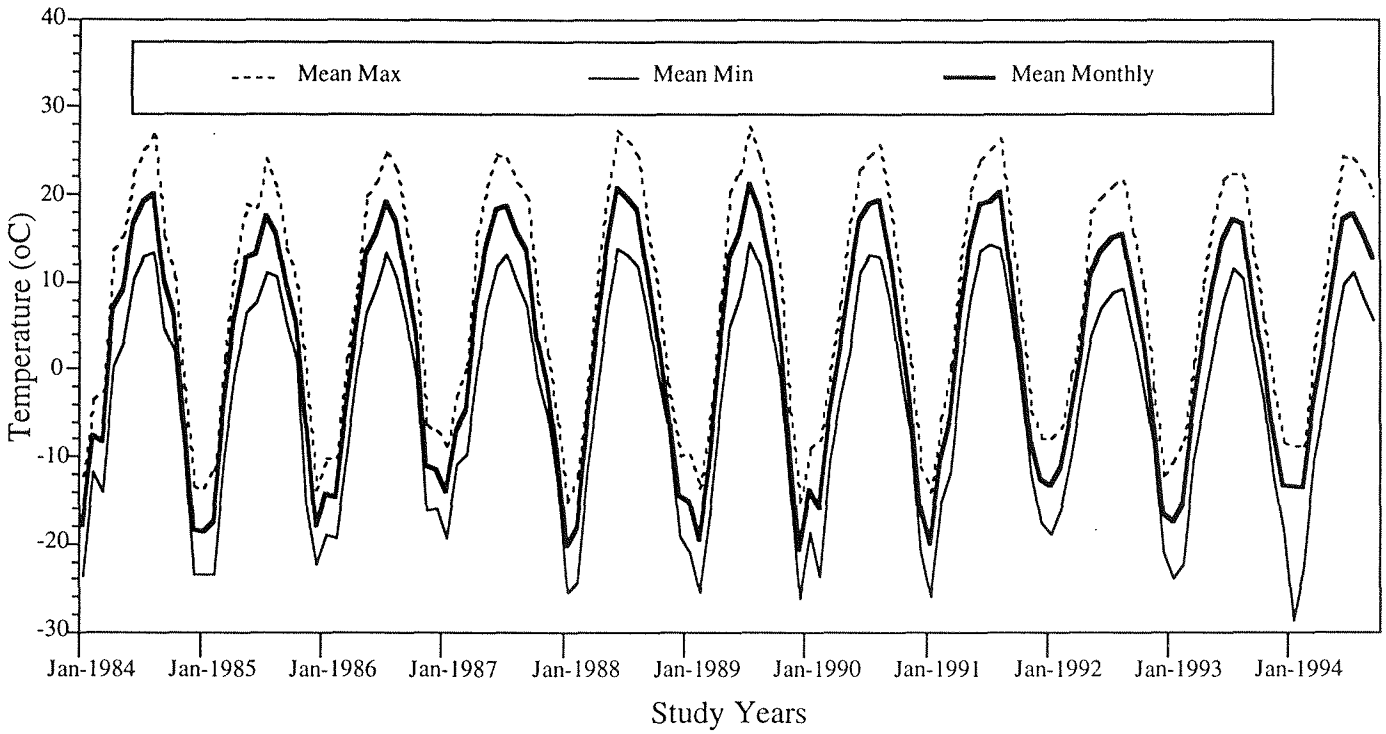

Fig. 2. Monthly mean temperature, with mean monthly highs and lows, recorded in the study region over the course of the study (Jan. 1984 - Oct. 1994). (Source: Environment Canada).

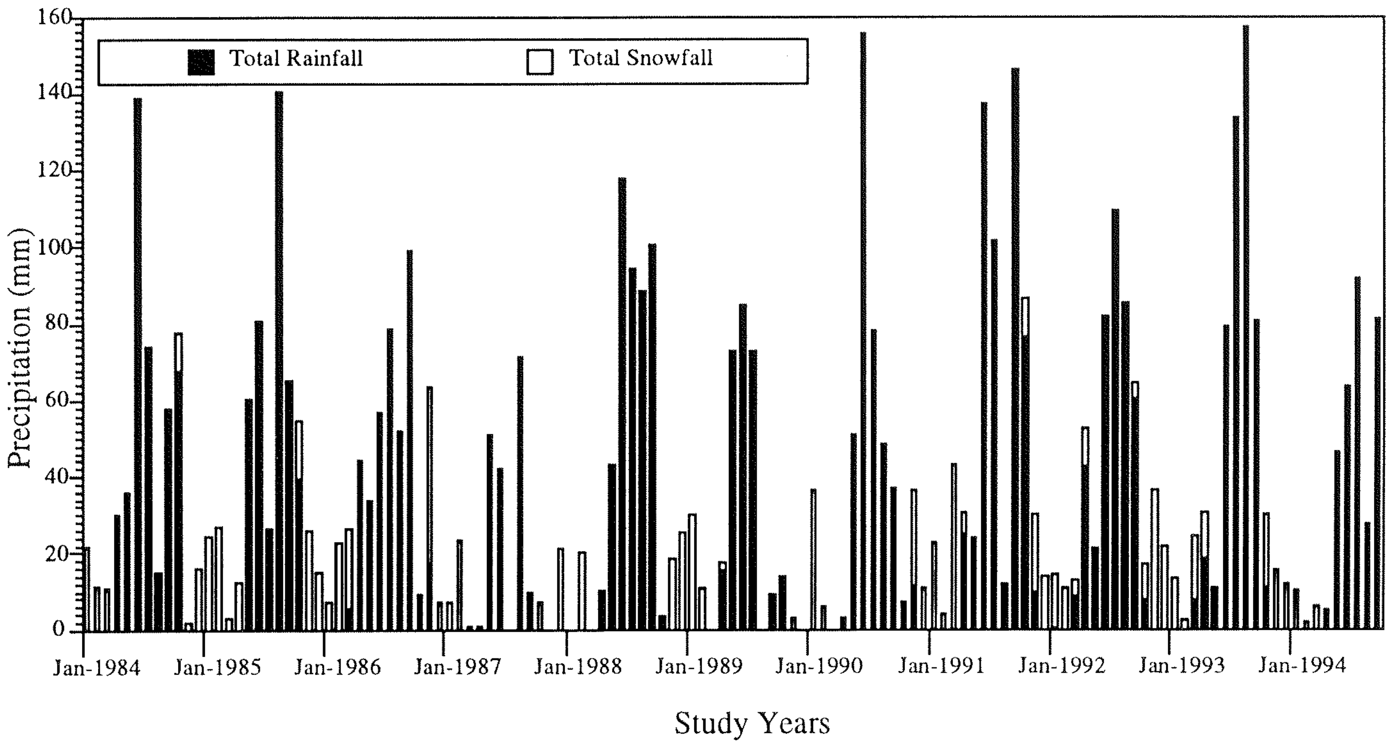

Fig. 3. Cumulative monthly precipitation (mm) in the study region over the course of the study (Jan. 1984 to Oct. 1994). Note that snowfall is expressed as precipitation (mm). To calculate total monthly accumulation of snowfall, multiply by a factor of 10. (Source: Environment Canada).

2.2 Study Site Descriptions

2.2.1 Introduction

Four sites were originally chosen for the study in 1985. Three new sites were added to the project in 1987, and four more sites were added in 1992, for a total of 11 sites in the overall study. The addition of sites in 1987 and 1992 served to incorporate a number of new forest types and silvicultural scenarios into the study. Table 1 summarizes the main characteristics of each study site. The sites are discussed in further detail in the remainder of this section.

2.2.2 Aspen and Burn Sites

The four initial sites of the study, designated as the Aspen and Burn sites, are located approximately 3.5 km west of Provincial Road 304, in the Sandy River area south of the town of Manigotogan (Figure 4). The Aspen sites included two relatively young forest stands of *Populus tremuloides*, one of which was designated as the Control Aspen (CA) site, and the other as the Treated Aspen (TA) site. The Burn sites consisted of two previously harvested areas that had been subjected to a burn in the summer of 1984, followed by shear blading and replanting (with *Picea glauca*) during the winter and summer of 1985. One of the sites was designated as the Control Burn (CB) site, while the other, which received the herbicide treatment, was designated as the Treated Burn (TB) site. The CA and the CB sites were located approximately 2 km northwest of the TA and TB sites (Figure 4).

The Aspen sites were chosen to be representative of typical not sufficiently regenerated (NSR) areas, which were being reforested by Abitibi-Price (Henderson and Wotton 1987). The sites consisted of mixed softwood/hardwood forest type vegetation dominated by *Populus tremuloides*. Other tree species found at the sites included *Abies balsamea* (L.) Mill. (balsam fir), *Larix laricina*, and *Betula papyrifera*. Shrub species included *Rosa acicularis* Lindl. (prickly rose), *Rubus idaeus* L. (raspberry), *Amelanchier alnifolia* Nutt. (saskatoon), *Prunus* spp. L. (cherry), *Viburnum trilobum* Marsh. (high-bush cranberry), and *Corylus cornuta* Marsh. (beaked hazelnut). Ground cover consisted mainly of mosses and vascular plants such as *Maianthemum canadense* Desf. (wild lily-of-the-valley), *Fragaria* spp. L. (strawberry), *Rubus pubescens* Raf. (dewberry), *Galium boreale* L. (northern bedstraw), *Aster ciliolatus* Lindl. (Lindley's aster), and various graminoids (grasses and sedges).

Table 1. Major characteristics of study sites. (Note the abbreviated study site names in parentheses.)

Study Site Areas	Location	Study Sites	Initial Sampling Year	Dominant Tree or Shrub Species in each Study Site	Forestry History
Sandy River Aspen sites	Sandy River area north of Pine Falls on Hwy 304	Control Aspen (CA)	1985	*Populus tremuloides*	All three aspen sites were previously logged areas that had naturally regenerated to aspen stands.
		Treated Aspen (TA)	1985	*P. tremuloides*	
		New Treated Aspen (NTA)	1987	*Rubus idaeus, Rosa acicularis*	
Sandy River Burn sites	Sandy River area north of Pine Falls on Hwy 304	Control Burn (CB)	1985	*Salix spp., P. tremuloides*	Both burn sites had been harvested in the past, and subjected to a burn in 1984. Shear-blading and replanting with spruce occurred in 1985.
		Treated Burn (TB)	1985	*Salix spp., P. tremuloides*	
Trans Licence Road sites	16 km and 26 km east of Hwy 304 on the Trans Licence Road	Control Trans Licence (CTL)	1987	*P. tremuloides*	Both Trans Licence Road sites were burned in 1983. The control site was shear-bladed and replanted with spruce in 1984-1985, while the treated site had naturally regenerated.
		Treated Trans Licence (TTL)	1987	*P. tremuloides*	
Timber Harvest and Accidental Spill sites	Maskwa River area 8 km east of Pine Falls	Control Timber Harvest (CTH)	1992	*P. tremuloides*	The timber harvest area was logged in the 1940's, and allowed to regenerate to a hardwood stand. In 1982 - 1983 it was shear-bladed and replanted with spruce. Glyphosate application was conducted over a portion of the area in 1984.
		Treated Timber Harvest (TTH)	1992	*Viburnum rafinesquianum, Prunus virginiana*	
		Control Accidental Spill (CAS)	1992	*P. tremuloides, Fraxinus pennsylvanica*	The accidental spill area was an undisturbed hardwood stand prior to the glyphosate spill in 1984.
		Treated Accidental Spill (TAS)	1992	*Salix spp.*	

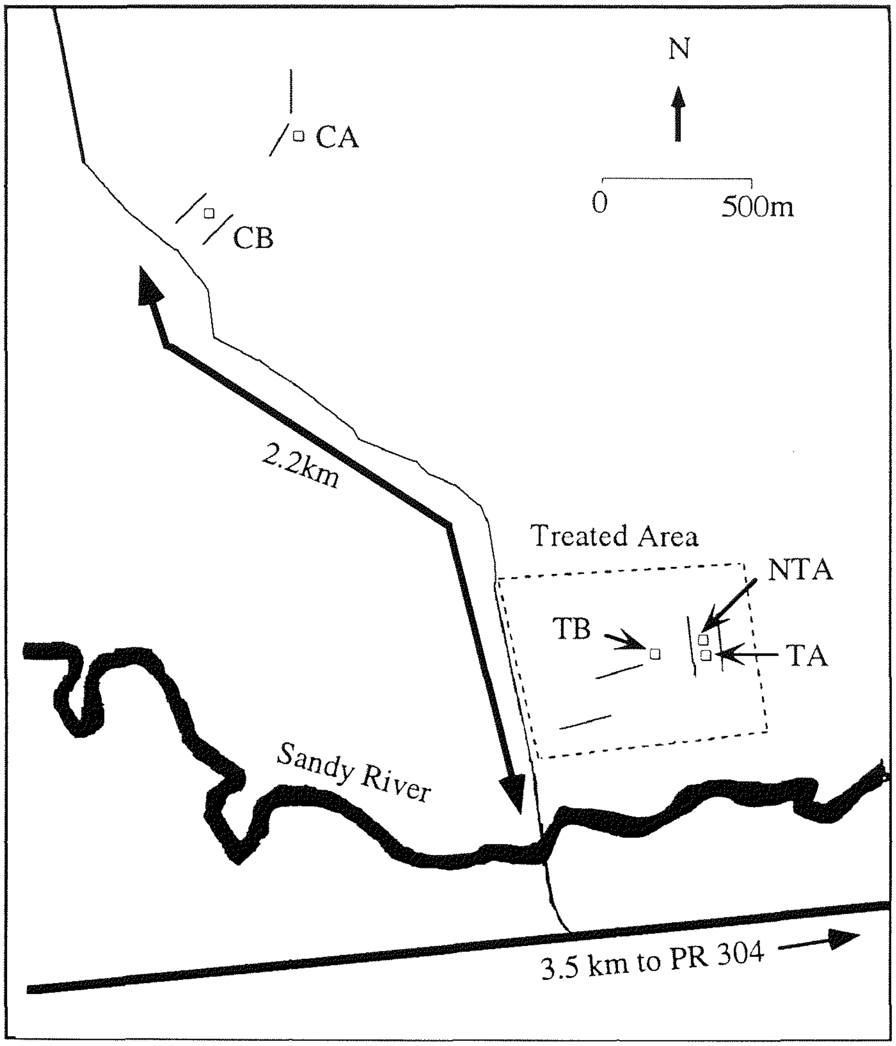

Fig. 4. Aspen (CA, TA, NTA) and Burn (CB, TB) study sites, north of Pine Falls near the Sandy River. Vegetation sample macroplots (□), and browse study transects (—) are shown.

In 1987, because of apparent poor kill by glyphosate at the original TA site, another treatment site, designated as the New Treated Aspen (NTA) site, was added to the study. This site was located 20 m northwest of the original TA site (Figure 4). It is likely the two sites shared similar vegetation characteristics prior to herbicide applications, because weather, drainage, and soil characteristics were similar.

The Burn sites, formerly occupied by stands of *Picea glauca* (Henderson and Wotton 1987), were characterized by scattered, remnant stands of *Picea glauca*, and clumps of *Salix* spp. L. (willow) and *Populus tremuloides*. Dominant shrub species at these sites included *Salix* spp., *Rosa acicularis,* and *Rubus idaeus*. The vascular plant ground cover consisted mainly of grass species, *Fragaria* spp., *Galium boreale*, *Aster ciliolatus*, and *Cirsium* spp. Mill. (thistles).

Soils at the Aspen and Burn sites were characterized by fibric and mesic peat material underlain by clayey, calcareous, lacustrine deposits, which overlie granitic bedrock (pers. com. Veldhuis 1986). Field observations indicated no substantial differences between the soils of the control and treated sites. Soils at the control sites belonged to the Malloy Series (clay)/Okno Complex (mesic peat)/Caddy Lake Series (clay), while the soils of the treated sites belong to the Malloy Series (clay)/Wanipigow River Series (clay)/Orok Complex (fibric peat) (pers. com. Veldhuis 1986).

2.2.3 Trans Licence Sites

The Trans Licence sites were added to the study in 1987. The sites included a Control Trans Licence (CTL) site, located approximately 16 km east of Provincial Road 304 along the Trans Licence Road, and a Treated Trans Licence (TTL) site located a further 10 km east of the control (Figure 5). Both sites had been burned in September 1983 and the CTL had been shear-bladed and replanted with *Picea glauca* in 1984 and 1985. Prior to herbicide treatment, the vegetation of the sites was dominated by young *Populus tremuloides*, *Pinus banksiana*, *Picea glauca*, *Amelanchier alnifolia*, *Salix* spp., *Crataegus* spp. L. (hawthorn), *Epilobium angustifolium* L. (fireweed), *Lathyrus* spp. L. (vetchling), and *Cirsium* spp.. The soil of the CTL and TTL sites was characterized by coarse, loamy to sandy glacial till overlying Precambrian bedrock. Outcroppings of bedrock were prevalent throughout the entire area. Thus, these sites differed appreciably from the Sandy River Aspen and Burn sites in both soil and vegetation characteristics, and were added to the study in order to increase the predictability of the results over a range of forest community types, and to examine the effects of a higher herbicide application rate.

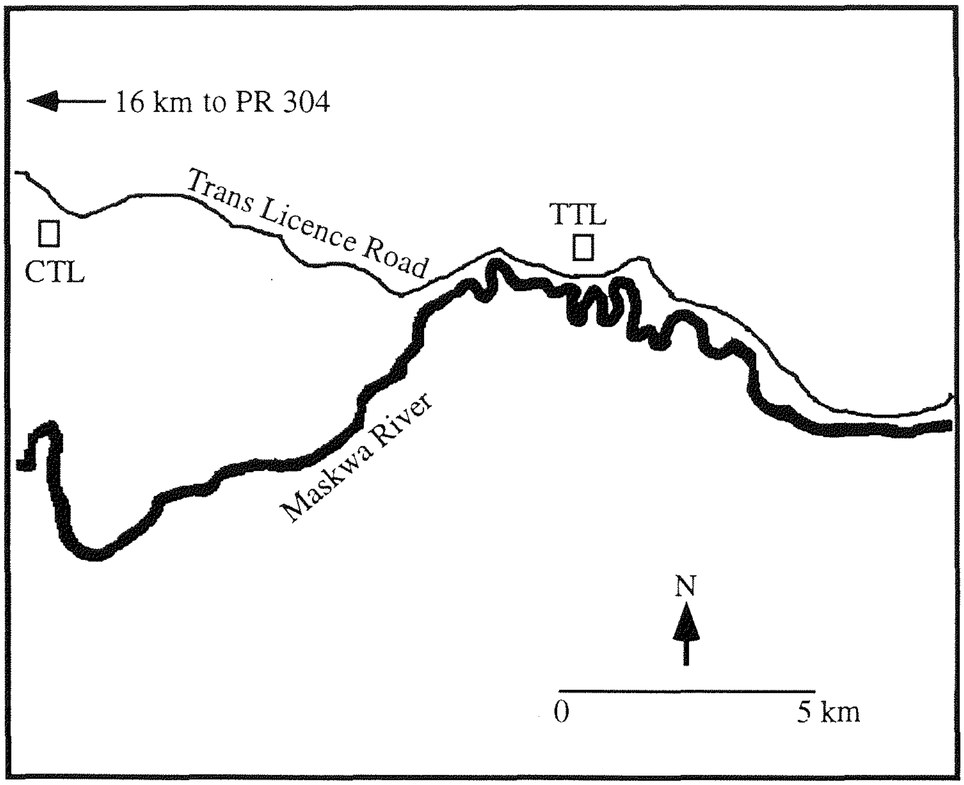

Fig. 5. Trans Licence (CTL, TTL) study sites, northeast of Pine Falls on the Trans Licence Road.

2.2.4 Timber Harvest and Accidental Spill Sites

The Timber Harvest and Accidental Spill sites were located 1 km east of the Maskwa River (Bear River), at a point approximately 3 km upstream from its convergence with the Winnipeg River (Figure 6).

The Timber Harvest sites, as the name implies, were located in an area that had been originally harvested in the early 1940's. By the early 1980's the area had regenerated to a *Populus tremuloides* stand. In the winter of 1982-1983 the area was shear-bladed in order to remove the hardwood species and allow replanting of *Picea glauca* seedlings. Replanting was conducted in the summer of 1983. In 1984 a portion of the replanted area was sprayed with glyphosate (2.5 l/ha), while the remainder of the area was left unsprayed. The Control Timber Harvest (CTH) site was located in the unsprayed area, while the Treated Timber Harvest (TTH) site was established in the sprayed area. Although the major perturbation activities took place at the sites prior to and including the summer of 1984, the vegetation of the sites was not studied until the summer of 1992. Aerial photographs taken in 1975 indicate that the vegetation across the entire timber harvest area was essentially homogeneous. At the time of sampling in 1992 the CTH site consisted of a relatively dense, young hardwood stand dominated by *Populus tremuloides*, with a shrub stratum and understorey dominated by *Rosa acicularis*, *Rubus idaeus*, *Rubus pubescens*, *Cirsium* spp., and graminoids. The TTH site, in 1992, supported dense populations of *Anemone canadense, Aster ciliolatus*, and *Fragaria* spp., with scattered, diminutive individuals of *Salix* spp., *Populus tremuloides*, and *Picea glauca.*

On August 7, 1984, while applying Roundup herbicide to the timber harvest area, the spray plane experienced an engine malfunction and had to jettison its remaining load of herbicide in an attempt to avoid a crash (pers. com. Russel 1984). The Roundup, with a concentration of 50 ml glyphosate (a.i) per litre of water, was deposited on a mature hardwood stand located 150 m northeast of the timber harvest area (Figure 6). As a result, all the vegetation within an area measuring approximately 40 m x 100 m, was killed (Phillips 1987). Treated and control sites were established in the summer of 1992 to address the long-term effects of the accidental spill on the vegetation of the area. The Control Accidental Spill (CAS) site was located adjacent to the western border of the accidental spill area, while the Treated Accidental Spill (TAS) site was located in the middle of the spill area. The sites appeared to be very different in regard to vegetation composition. However, pre-1984 aerial photographs show a uniform hardwood stand occupying the area, which indicates that the sites were likely very similar prior to the accidental spill. The CAS site supported a mature hardwood stand consisting of

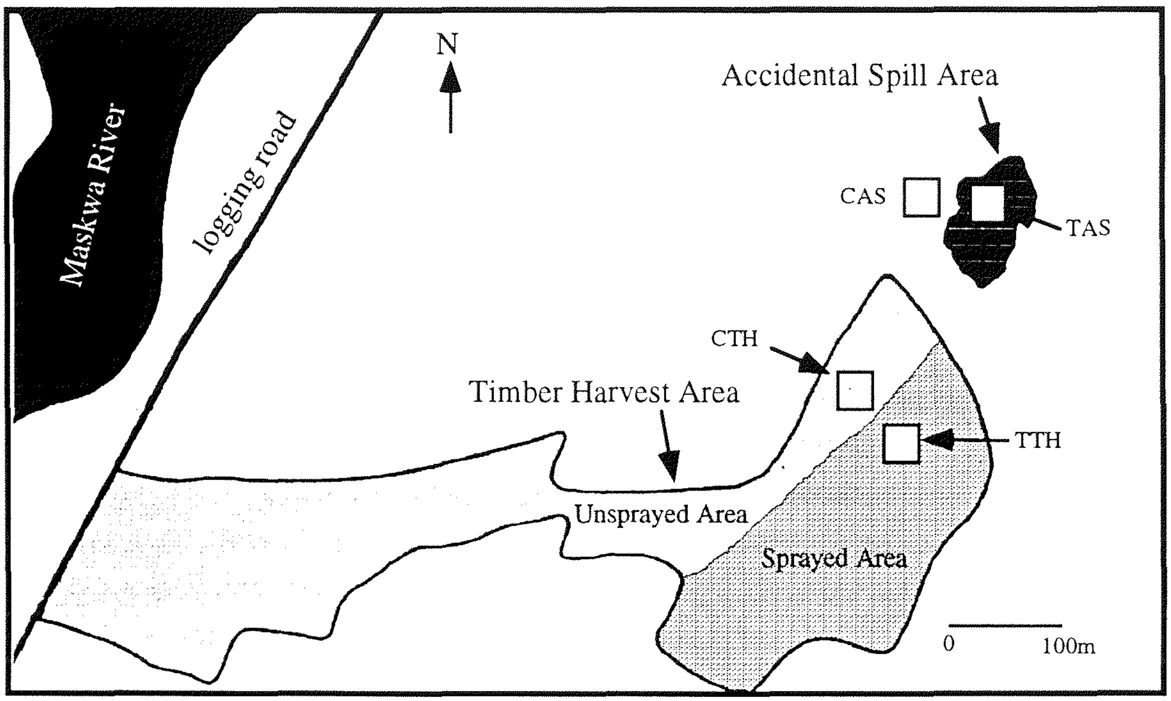

Fig. 6. Timber Harvest (CTH, TTH) and Accidental Spill (CAS, TAS) study sites, east of Pine Falls near the Maskwa River.

Populus tremuloides, *Ulmus americana* L. (American elm), *Fraxinus pennsylvanica* Marsh. (green ash), *Acer spicatum* Lam. (mountain maple), and a few *Picea glauca*. Shrub species at the CAS site included *Amelanchier alnifolia, Viburnum* spp., and *Prunus* sp., while herb layer species included *Maianthemum canadense, Rubus pubescens, Fragaria* spp., and sedges. The TAS site was characterized by no live trees, numerous clumps of *Salix* spp., and a dense undergrowth of grasses and sedges.

3. METHODS AND DATA ANALYSIS

3.1 Glyphosate Applications

The Sandy River TA and TB sites were first sprayed with glyphosate by fixed-wing aircraft on the evening of August 16, 1985. The application rate used was 2.5 l/ha. Rainfall occurred within six hours following the spray; which probably accounted for the fact that there was little or no effect on the vegetation (Caseley and Coupland 1985). The treated sites were resprayed at a rate of 2.5 l/ha on August 15, 1986. The second application was conducted in the early morning under clear sky and no wind; a light rainfall occurred in the afternoon.

Glyphosate application, via fixed-wing aircraft, at the TTL site was conducted in the early morning of August 18, 1987. The application rate used was 6.0 l/ha. Weather conditions were favourable with light wind, clear sky, and low humidity.

The TTH site received its glyphosate application on August 7, 1984. The rate of application was 2.5 l/ha. The application resulted in uniform vegetation kill within the target area. The accidental application of glyphosate on the TAS site was also on August 7, 1984, and has been discussed previously.

3.2 Vegetation Sampling

One permanent 10 m x 10 m macroplot was established in each of the CA, TA, CB, TB, CTL, and TTL sites to facilitate vegetation sampling and monitoring. Ten quadrats (1 m x 1 m) were randomly established within the larger macroplot at each site (see Figure 7). Prior to herbicide application the density and percent cover [based on a modified Braun-Blanquet Scale (Henderson and Wotton 1987)] of each vascular plant species within each quadrat were recorded (nomenclature follows Scoggan 1957). The same quadrats were sampled during each sampling period. All the trees and shrubs within each 10 m x 10 m macroplot were identified and tagged prior to herbicide applications. Diameter at breast height (DBH) (if available) was recorded for each tree. Maximum crown width or

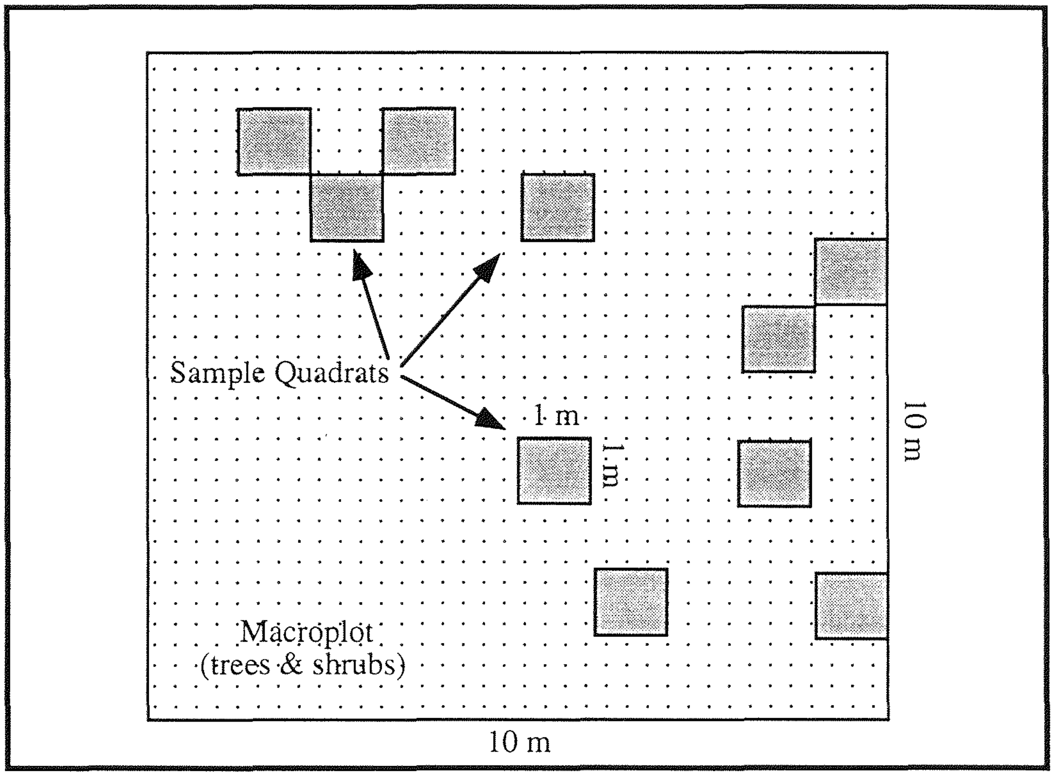

Fig. 7. Diagram illustrating the vegetation sampling design used at the Aspen, Burn, and Trans Licence study sites.

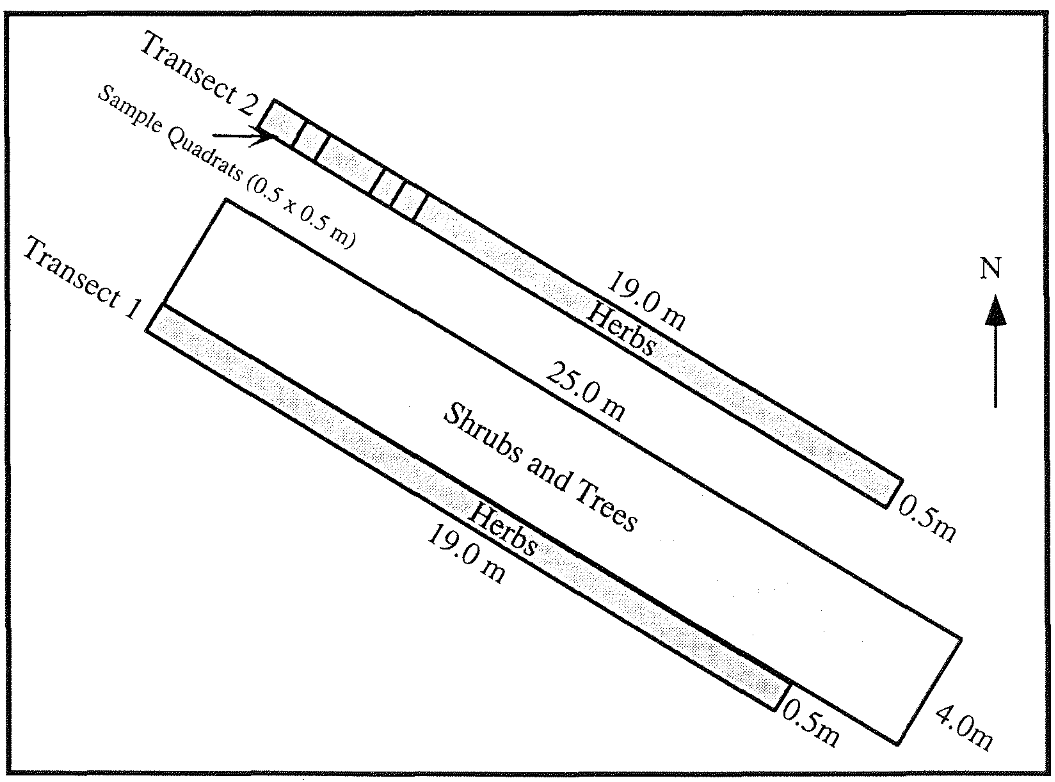

Fig. 8. Diagram illustrating the vegetation sampling design used at the Timber Harvest and Accidental Spill study sites.

spread, height of the tallest stem, and total number of stems, were recorded for each shrub individual. No height or diameter/crown measurements were taken on shrubs below 75 cm or trees below 1 m in height.

Permanent belt transects (0.5 m x 19 m) were used for annual monitoring of the vegetation at the Timber Harvest (CTH and TTH) and Accidental Spill (CAS and TAS) sites (see Figure 8). Twenty pairs of quadrats (each 0.5 m x 0.5 m) were placed along the transect at two meter intervals. Two parallel belt transects were established at each site. The distance between each transect varied from site to site, but was always greater than five meters. Quadrats were numbered 1 to 20 on the first transect (transect 1), and 21 to 40 on the second (transect 2). Transects were oriented in an east-west direction. The density and percent cover of each vascular plant species in each quadrat were recorded. To sample trees and shrubs, a rectangular macroplot measuring 4 m x 25 m was established adjacent to transect 1. All trees and shrubs present within the macroplot were identified, measured (as above), and tagged for future monitoring.

Differentiation between trees and shrubs is often subjective and to some degree arbitrary. For example, individuals of *Amelanchier alnifolia* often grow in clumps and do not reach a height greater than 2 to 3 m, and therefore, can be said to exhibit a shrub type of growth-form. However, individuals *can*, under ideal conditions, attain greater stature (Hosie 1979) and may then be referred to as trees. Thus, some species can exhibit both shrub and tree growth-forms, depending on their age and the prevailing environmental conditions. This can create difficulties in monitoring tree and shrub species development over time. A number of criteria were set, prior to sampling, in order to differentiate between trees and shrubs. An individual was considered a tree if it was single stemmed, greater than 100 cm in height prior to the herbicide applications, and was expected, under the environmental conditions present at each site, to exhibit indeterminate growth (Table 2). Those individuals arising from one or more stems, often forming a clump, and rarely attaining heights greater than 4 to 5 m, were classified as shrubs (Table 2). Any shrub stem under 75 cm in height was not included in shrub sampling of the macroplots.

Tagged trees and shrubs that had died during the study were subsequently omitted from further sampling. New recruits into the tree and shrub strata were included into the study when they met the height criteria.

Table 3 presents the vegetation sampling periods for the various study sites. Sample periods varied between sites and from year to year because of the addition of more sites after the commencement of the study in 1985.

Table 2. Categorization of tree and shrub species based on growth-form criteria.

Trees		Shrubs	
Genus/Species	Common	*Genus/Species*	Common Name
Abies balsamea	balsam fir	*Amelanchier alnifolia*	saskatoon
Acer negundo	Manitoba maple	*Cornus stolonifera*	red-osier dogwood
A. spicatum	mountain maple	*Corylus americana*	American hazelnut
Betula papyrifera	paper birch	*C. cornuta*	beaked hazelnut
Fraxinus pennsylvanica	green ash	*Crataegus* sp.	hawthorn
Picea glauca	white spruce	*Prunus pensylvanica*	pin cherry
P. mariana	black spruce	*P. virginiana*	choke cherry
Pinus banksiana	jack pine	*Rhamnus alnifolia*	buckthorn
Populus balsamifera	balsam poplar	*Ribes glandulosum*	skunk currant
P. tremuloides	trembling aspen	*R. oxyacanthoides*	gooseberry
Ulmus americana	American elm	*Rosa acicularis*	prickly rose
		Rubus idaeus	raspberry
		Salix spp.	willow
		Viburnum edule	low-bush cranberry
		V. rafinesquianum	downy arrow-wood
		V. trilobum	high-bush cranberry

Table 3. Vegetation sampling periods for each study site (1985 to 1994).

Vegetation Sample Period	Sites Sampled
July 1985	CA, TA, CB, and TB
September 1985	CA, TA, CB, and TB
July 1986	CA, TA, CB, and TB
July 1987	CA, TA, NTA, CB, TB, CTL, and TTL
July 1988	CA, TA, NTA, CB, TB, CTL, and TTL
July 1992	All Sites (including the new CTH, TTH, CAS, and TAS)
July 1994	All Sites

3.3 Browse Sampling

Little research has been conducted regarding the effects of glyphosate on ungulate [*Alces alces* L. (moose) and *Odocoileus virginianus* Zimmerman (white-tail deer)] forage material (Henderson and Wotton 1987). In 1985 a series of permanent sample plots were established in the sprayed and unsprayed aspen stands and burn areas at Sandy River in order to assess any impacts from aerial herbicide applications on six forage species. The six species monitored included: *Cornus stolonifera* Michx., *Rosa acicularis, Salix* spp., *Betula papyrifera, Populus tremuloides,* and *P. balsamifera* (Henderson and Wotton 1987). Two 200 m long transects were established within the vicinity of the vegetation sample macroplots (i.e. the Aspen and Burn study sites) (Figure 4). Twenty-five quadrats (2 m x 2 m) were located randomly along each transect, for a total of 50 quadrats per site. The number of live shoots (twigs) over 2.5 cm in length, and positioned on branches between 30 cm and 2.1 m above the ground on each forage species, were counted to provide estimates of available ungulate browse material. Sampling was conducted in mid-October of 1985 to 1988, 1992 and 1994.

3.4 Data Analysis

3.4.1 Vegetation Sampling

Calculations of species richness (number of taxa) and Brillouin diversity were carried out for each site based on the sample quadrat density (Bower and Zar 1984).

Correspondence analysis, with downweighting of rare species [CANOCO (ter Braak 1987-1992)], was used to illustrate and explore the vegetation changes at the control and treated sites of each forest type over the course of the study. Density values and total basal area of trees and total crown width of shrubs were calculated for each site.

The Brillouin index of species diversity was calculated because it combines the species richness (number of taxa) and evenness (density distribution of individuals per taxon) into a single measure (Tomkins and Grant 1977), thus allowing comparisons between sites and between sample periods. At each sampling period the species composition and number of individuals were recorded in the sample quadrats. Because the quadrats were fixed sample points and were repeatedly sampled over the course of the study, the Brillouin index is recommended (Tomkins and Grant 1977, Zar 1984). The index itself is an indication of "the amount of certainty that exists regarding the species of an individual selected at random from a population" (Pielou 1966). Thus, a site with a high diversity value suggests that the chance of randomly selecting individuals of the same taxon is lower than for a site with a relatively low diversity value. The Brillouin index is not strongly affected by the presence of rare species, but does indicate the degree of vegetation heterogeneity in a given community. Species diversity increases in a community as the number of species increases and as the species abundance becomes more even. High Brillouin diversity values suggest a corresponding high degree of heterogeneity in community species and populations, while low diversity values usually indicate dominance of a community by relatively few species.

Correspondence analysis on the species composition and density data collected from the quadrats at each site was conducted using CANOCO (ver. 3.11) (ter Braak 1987-1992) . This particular analysis was chosen for a number of reasons. First, it provides a graphical, two-dimensional presentation of the relationships among sample years for the control and treated sites. As well, the analysis illustrates the inter-relationships between species, and how closely each species relates to each sample year (Grieg-Smith 1983). Finally, correspondence analysis does not require the availability of environmental data (e.g. soil data), but instead arranges samples and species along a latent variable(s) gradient (ter Braak 1985). Thus, it is possible to first conduct the correspondence analysis, and then follow it by identification of the latent variable via comparison with observed, but non-quantified, variation in the sites (ter Braak and Prentice 1988). The resulting output from correspondence analysis, coupled with descriptive comparisons between sites and sample years should indicate how closely related the control and treated sites were before and after glyphosate applications.

Detrended correspondence analysis is often recommended as an alternative to correspondence analysis (Hill and Gauch 1980, Freedman *et al.* 1993), because of the so called 'horseshoe effect' inherent in correspondence analysis [the tendency for axes to exhibit a quadratic dependence on previous axes, causing arching and involution in the species and sample scores (Hill and Gauch 1980, Gauch 1982)]. However, detrended correspondence analysis has been shown to be more sensitive than correspondence analysis to sample replication (Gamito and Raffaelli 1992) and outlying or rare samples (Hill and Gauch 1980), and is subject to axes distortion by data exhibiting a high species turnover rate (Kenkel and Orloci 1986). More recently, it has been discovered that detrended correspondence analysis has difficulty distinguishing between arch effects caused by the correspondence analysis algorithm itself, and arch effects that are rooted in the natural variation of the data (Backeus 1993). Also, without care and thorough knowledge of the data set involved, selection of the proper detrending algorithm can be difficult (Gamito and Raffaelli 1992).

3.4.2 Browse Sampling

Total available browse was defined as the total number of twigs of each forage species estimated to be suitable for consumption by ungulates in the sample quadrats. Summary statistics were calculated for total available browse for each sampling period at each sample area. Data were log transformed to reduce heterogeneity of variances and then subjected to repeated measures ANOVA (Zar 1984, Wilkinson 1989) to determine if significant differences existed in total available browse between sampling periods within unsprayed and sprayed areas. Means were compared using the Tukey HSD multiple comparison test (Zar 1984).

4. RESULTS AND DISCUSSION

4.1 Glyphosate Deposition

Henderson *et al.* (1988) stated that the glyphosate applications on the TA and TB sites in 1985 had no observable effect on the vegetation in the sample plots. At the time of the application the foliage was wet and a heavy rainfall occurred about six hours following the application. Thus, the herbicide was likely washed off the plants before it could be absorbed. There was also a problem with the second application in 1986 in that the application was not uniform, with healthy strips of vegetation adjacent to areas exhibiting the expected plant mortality. Henderson *et al.* (1988) suggested that the latter application results may have been influenced by the interaction of numerous factors, including air temperature, light exposure, soil moisture, vegetation phenology, and the application technique used. Also, they surmised that since glyphosate is relatively slow-acting (Malik & Vanden Born 1986), observable effects on the vegetation may not have been apparent until the 1987, or possibly even the 1988 growing seasons.

No glyphosate residues were found in soil and vegetation samples collected prior to the herbicide application at the TA and TB sites (Henderson *et al.* 1988). However, residues were detected in samples collected immediately following the herbicide applications. The levels in the vegetation samples were far below those which may cause toxic effects if ingested by wildlife (Monsanto Corp. 1984). Levels in both vegetation and soil decreased rapidly, and were no longer detectable in samples collected 305 days post-spray. Samples collected from the control sites had no detectable pre- or post-spray glyphosate residues in vegetation and soil.

The application of the herbicide on the TTL site in 1987 resulted in non-uniform, patchy defoliation of vegetation. None of the immediate post-spray soil samples had glyphosate levels above the minimum detection limit of 1.0 µg/g. However, three days after the application the residue concentration in the organic surface layer of the soil ranged between 0.9 µg/g and 11.6 µg/g, with a mean of 4.08 ±1.97* µg/g. The mean concentration of glyphosate in the organic surface soil declined to 2.34 ±0.77* by 27 days post-spray, and to 1.06 ±0.27* µg/g by 305 days post-treatment. Glyphosate residue levels in soil samples from the 10 cm depth never exceeded 1.0 µg/g. Immediate post-spray sampling of vegetation at the site revealed relatively high levels of glyphosate residue in the shrub and tree canopies (range from 231.2 to 608.2 µg/g, and 190.6 to 318.0 µg/g respectively). Levels in the herbaceous or understorey layer were lower (165.1 to 188.6 µg/g) than those of the trees and shrubs, indicating that the trees and shrubs intercepted a greater amount of the herbicide. Residue concentrations declined rapidly with time following the three-day post-spray period; by 305 days post-spray, residue levels in vegetation samples were all below the detection limit.

Soil samples were collected at the TAS site 5 days, 79 days, and 304 days post-accident (Phillips 1987). The level of glyphosate in organic surface soil at the 5-day post-accident period was 4150 µg/g. This level decreased to 2750 µg/g by 79 days post-accident, and to 5.1 µg/g by 304 days post-accident. This rapid decline is likely due in part to redistribution of the residue in the soil through lateral movement and downward leaching (Phillips 1987). In spite of this lateral movement in the soil, and high concentrations of

*Values are means ± SE. n = 5

the herbicide detectable up wind of the spill (Phillips 1987), vegetation damage outside of the immediate spill area was not observed. No vegetation samples were collected for herbicide residue analysis at the spill site.

Soil and vegetation sampling at the TTH site was not undertaken. As mentioned previously, the spray application at the TTH site resulted in a uniform vegetation kill throughout the target area.

4.2 Vegetation Sampling

4.2.1 Introduction

Species composition, density, and estimates of percent cover data were obtained from each quadrat at each sample date. Since using estimates of percent cover as a measure of plant species productivity is subjective (Kennedy and Addison 1987), only species' density and composition data are presented, analyzed, and discussed in this report.

Field sampling indicated that the vascular plant species composition of the control and treated quadrats at the Aspen, Burn, and Trans Licence sites differed prior to the spray applications. In all three cases a number of the species found at the control sites (CA, CB, and CTL) were not present at their corresponding treated sites (TA, TB, TTL) and vice versa. Thus, based strictly on species composition, the control and treated sites were fairly dissimilar at the outset of the study. However, when comparing community structure between sites it is also important to address the number of different species and individuals per unit area within the sites (Tomkins and Grant 1977). The collective ecological interactions and environmental impacts of the occupying species may be similar between sites even though the particular species compositions of the sites are different. Two-sample *t* - tests (assuming unequal variances) were performed on the quadrat data collected from the CA, TA, CB, TB, CTL, and TTL sites in order to determine if the mean number of species per quadrat (or m^2) and the mean density of individuals per quadrat differed significantly (a = 0.05) between control and treated sites prior to herbicide applications. Tests were not conducted on the NTA site, nor on the Timber Harvest or Accidental Spill sites because pre-spray data were not available.

Statistical tests conducted on the July 1985 data (pre-spray) from the CA and TA sites indicated that the mean number of species per quadrat was significantly higher in the CA site than in the TA site (Table 4). However, the CA and TA sites did not differ significantly with regard to the mean density of individuals per quadrat. This indicated that the CA site was more heterogeneous in species composition than the TA site prior to the herbicide application. Tests conducted on the pre-spray CB site and TB site data indicated that prior to spraying the TB site was more heterogeneous with regard to species composition than the CB site. The mean number of species per quadrat in the TB was significantly higher than that of the CB site, while the mean number of individuals per quadrat between the two sites did not differ significantly. Results from the Trans Licence sites indicate that the TTL and CTL sites were significantly different in both mean number of species per quadrat and mean number of individuals per quadrat prior to the herbicide application. The CTL site had a significantly higher mean number of individuals per quadrat, while the TTL site had, on average, significantly more species per quadrat.

Table 4. *t* - test results indicating initial differences between control and treated study sites prior to glyphosate applications (n = 10) (a = 0.05).

Sites	Mean no. plant individuals/quadrat						p - value
	Control			Treated			
Aspen	177.0	±	12.4	187.4	±	24.1	0.7077
Burn	242.0	±	42.2	311.2	±	42.1	0.2627
Trans Licence	89.9	±	6.3	69.1	±	6.1	0.0299

Sites	Mean no. plant species/quadrat						p - value
	Control			Treated			
Aspen	17.4	±	0.64	12.6	±	0.97	0.0009
Burn	10.9	±	0.57	13.3	±	0.76	0.0223
Trans Licence	8.9	±	0.69	11.9	±	0.72	0.0008

4.2.2 Aspen Sites

The understorey vegetation of the CA, TA, and NTA sites was dominated by woody and non-woody dicots and grass species. Monocots, with the exception of grasses and *Maianthemum canadense*, were not common in the study quadrats. All three sites shared species in common, such as *Fragaria* spp., *Aster ciliolatus, Maianthemum canadense, Rosa acicularis,* and *Rubus idaeus*. The greatest number of species were found in the CA site, which fluctuated between 31 to 43 species depending on the sample period (Table 5). The TA site (Table 6) had a species compliment of 25 in September 1985, but by July 1994 it increased to 38 species. The number of species in the NTA site (Table 7) was relatively stable; ranging from 32 to 36 over the course of the study. The TA site tended to have the highest density of woody dicots; *Rubus idaeus, Rosa acicularis, Symphoricarpos albus* (L.) Blake (snowberry), and various species of *Ribes* were among the most common species. Although numerous species occurred in both the CA and TA sites, and the NTA site, the latter supported relatively high densities of *Lathyrus* spp., *Anemone canadensis* L. (Canada anemone), *Aquilegia canadensis* L. (wild columbine), *Solidago* spp. L. (goldenrod), and *Thalictrum* spp. L. (meadow-rue), all of which were not present or were scarce at the CA and TA sites.

During the pre-spray sample period in July 1985, the species richness and species diversity were appreciably higher in the CA site than in the TA site (Figure 9). Species richness and diversity in both the CA and TA sites decreased slightly from July to September in 1985. This decline was likely the result of natural senescence of certain species and individuals prior to the September sampling, and cannot be attributed to herbicide effects alone, as it occurred at both sites. Species diversity in the CA site increased gradually from September 1985 through to July 1988. The diversity level then remained constant for the remaining sample periods of the study. The TA site showed a slight increase in diversity from September 1985 to July 1986, followed by a relatively high increase from July 1986 to July 1987. This level of diversity was only slightly less than that of the control level, and was maintained throughout the rest of the study. Following the 1985 season, the species richness in the CA site increased steadily, peaking at 43 species in 1988. In the mean time, the species richness in the TA site, although higher than that of the 1985 sample periods, did not increase to the levels observed in the control. By the 1992 and 1994 sample periods, the species richness and species diversity of the CA and TA sites were comparable.

Pre-spray data is not available for the NTA site. The site was added to the study in 1987, one year following the last herbicide application in the area. Quadrat sampling of the site indicated that even though the species richness was generally lower than that of the CA and TA sites during the same sampling periods (1987 to 1994), the diversity of the site was considerably higher throughout the course of the study (Figure 9). This indicates that the NTA site was relatively heterogeneous, with no apparent dominance by any species (Freedman *et al.* 1993).

Table 5 . Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrats at the CA site. Values are means ± SE. (n = 10).

Species*	Jul-85	Sep-85	1986	1987	1988	1992	1994
Abi bal	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1
Act rub	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Ame aln	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.3	0.2 ± 0.2	0.3 ± 0.3	0.4 ± 0.4	0.9 ± 0.5
Aqu can	1.7 ± 0.7	1.7 ± 0.8	2.7 ± 0.9	1.5 ± 0.7	1.3 ± 0.5	0.7 ± 0.2	1.0 ± 0.4
Ara nud	5.0 ± 1.7	5.0 ± 1.8	7.5 ± 1.7	10.6 ± 2.4	12.0 ± 2.3	9.6 ± 1.6	9.8 ± 1.8
Asa can	0.0 ± 0.0	0.7 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ast cil	12.9 ± 3.8	12.9 ± 3.8	25.9 ± 6.6	32.8 ± 8.7	33.4 ± 7.5	4.5 ± 1.9	3.8 ± 1.6
Ath fil	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Bet pap	0.1 ± 0.1	0.0 ± 0.0	0.4 ± 0.4	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Chi umb	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Cir spp.	3.9 ± 1.2	3.9 ± 1.3	2.8 ± 0.4	1.5 ± 0.3	1.2 ± 0.3	0.1 ± 0.1	0.1 ± 0.1
Cor can	6.4 ± 2.1	6.4 ± 2.2	5.4 ± 1.8	9.7 ± 2.9	10.2 ± 3.4	5.4 ± 1.7	8.7 ± 2.5
Cor cor	0.3 ± 0.3	0.3 ± 0.3	0.8 ± 0.8	0.5 ± 0.5	0.7 ± 0.7	0.0 ± 0.0	0.0 ± 0.0
Epi ang	4.7 ± 1.0	4.7 ± 1.0	3.3 ± 0.9	3.7 ± 1.1	2.7 ± 0.8	0.4 ± 0.2	0.3 ± 0.3
Equ syl	5.8 ± 1.4	5.8 ± 1.5	5.4 ± 0.6	4.7 ± 0.7	1.3 ± 0.3	0.6 ± 0.3	2.5 ± 0.7
Fra spp.	28.4 ± 4.8	27.8 ± 5.2	18.6 ± 2.8	25.0 ± 3.4	30.7 ± 4.3	16.2 ± 2.1	21.3 ± 3.4
Gal bor	20.0 ± 3.5	20.0 ± 3.7	16.0 ± 3.8	21.2 ± 4.9	15.8 ± 3.0	2.7 ± 1.1	1.2 ± 0.4
Gal tri	0.4 ± 0.3	0.4 ± 0.3	0.1 ± 0.1	0.8 ± 0.4	1.3 ± 0.7	0.8 ± 0.4	0.0 ± 0.0
Geu spp.	0.6 ± 0.3	0.0 ± 0.0	1.3 ± 0.6	1.2 ± 0.5	1.5 ± 0.5	0.7 ± 0.4	0.6 ± 0.4
Gramineae	42.6 ± 10.7	73.9 ± 14.1	61.0 ± 14.4	1.0 ± 0.0	6.4 ± 2.8	2.6 ± 1.0	20.6 ± 6.0
Gym dry	2.5 ± 1.7	3.5 ± 2.3	3.2 ± 2.0	3.1 ± 2.0	1.8 ± 1.1	1.2 ± 1.1	1.5 ± 1.3
Hal def	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Lat spp.	1.5 ± 0.5	1.5 ± 0.5	2.4 ± 0.6	2.9 ± 0.7	3.0 ± 0.8	0.6 ± 0.3	0.2 ± 0.1
Mai can	9.7 ± 3.4	9.7 ± 3.6	8.3 ± 3.0	8.1 ± 2.3	15.5 ± 4.4	12.7 ± 2.9	16.5 ± 3.9
Mer pan	3.9 ± 1.2	3.9 ± 1.2	5.0 ± 2.4	4.0 ± 1.6	4.3 ± 1.7	0.5 ± 0.2	0.3 ± 0.1
Mit nud	7.0 ± 4.8	0.0 ± 0.0	14.2 ± 7.1	7.2 ± 4.1	5.0 ± 2.8	3.1 ± 1.6	4.2 ± 1.2
Pet pal	1.5 ± 0.7	1.5 ± 0.7	1.4 ± 0.7	0.9 ± 0.5	0.4 ± 0.2	0.5 ± 0.3	0.9 ± 0.5
Pop tre	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.3	0.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Pyr asa	0.0 ± 0.0	1.3 ± 0.6	0.0 ± 0.0	0.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Rha aln	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.6 ± 0.5	0.5 ± 0.4
Rib gla	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.5	1.1 ± 0.5	2.0 ± 0.9	1.3 ± 0.4	1.3 ± 0.5
Rib oxy	2.0 ± 0.7	2.0 ± 0.8	1.8 ± 0.7	2.4 ± 1.5	2.4 ± 0.9	0.5 ± 0.5	1.1 ± 0.5
Rib tri	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.3	1.9 ± 0.8	1.7 ± 0.7	2.4 ± 0.9
Ros aci	4.5 ± 0.9	4.5 ± 0.9	5.0 ± 1.1	6.0 ± 1.5	6.1 ± 1.0	6.6 ± 0.9	7.4 ± 1.0
Rub ida	3.6 ± 1.0	3.6 ± 1.0	2.9 ± 0.9	1.8 ± 0.5	3.2 ± 0.9	0.6 ± 0.2	0.7 ± 0.2
Rub pub	0.9 ± 0.5	1.2 ± 0.4	1.5 ± 0.9	1.4 ± 0.6	1.5 ± 0.9	2.5 ± 1.0	3.5 ± 1.1
Sol spp.	0.0 ± 0.0	1.4 ± 1.0	0.0 ± 0.0	0.4 ± 0.4	0.4 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Son arv	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5	3.2 ± 1.8	3.2 ± 1.6	0.2 ± 0.1	0.0 ± 0.0
Ste cil	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.5 ± 0.6	2.2 ± 0.8	1.7 ± 0.7	1.2 ± 0.6
Str ros	1.4 ± 0.9	1.4 ± 1.0	0.5 ± 0.5	0.7 ± 0.7	0.5 ± 0.5	0.5 ± 0.4	0.9 ± 0.6
Sym alb	1.5 ± 1.4	1.5 ± 1.5	1.5 ± 1.4	1.0 ± 0.8	2.1 ± 1.8	1.2 ± 1.0	1.5 ± 1.3
Tar off	1.1 ± 0.4	1.1 ± 0.4	2.1 ± 1.2	0.9 ± 0.4	0.9 ± 0.4	0.4 ± 0.2	0.8 ± 0.4
Tha spp.	0.2 ± 0.2	0.2 ± 0.2	0.6 ± 0.4	1.2 ± 1.0	0.9 ± 0.8	0.0 ± 0.0	0.0 ± 0.0
Tri bor	0.4 ± 0.4	0.0 ± 0.0	0.5 ± 0.5	1.3 ± 0.9	1.2 ± 0.6	2.2 ± 1.5	1.6 ± 1.2
Vib edu	0.5 ± 0.4	0.2 ± 0.1	2.3 ± 1.2	2.0 ± 1.2	2.4 ± 1.2	1.9 ± 1.0	2.4 ± 1.6
Vic spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0
Vio spp.	1.8 ± 0.6	0.0 ± 0.0	5.3 ± 1.4	5.8 ± 1.5	6.3 ± 1.6	1.2 ± 0.4	1.3 ± 0.6
Species Richness	33	31	38	41	43	37	36
Species Diversity	1.13	1.02	1.15	1.23	1.24	1.21	1.16

*For explanation of abbreviations see Appendix I.

Table 6. Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrats at the TA site. Values are means ± SE. (n = 10).

Species*	Jul-85	Sep-85	1986	1987	1988	1992	1994
Ach mil	2.5 ± 1.6	2.5 ± 1.7	1.8 ± 1.1	1.6 ± 1.1	0.8 ± 0.8	0.0 ± 0.0	0.0 ± 0.0
Ame aln	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.7 ± 0.6	1.0 ± 0.7
Aqu can	0.3 ± 0.3	0.3 ± 0.3	1.0 ± 0.4	0.3 ± 0.2	0.9 ± 0.3	0.0 ± 0.0	0.1 ± 0.1
Ara nud	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.1
Ast cil	3.6 ± 1.4	0.0 ± 0.0	6.2 ± 2.3	10.1 ± 3.5	10.2 ± 3.0	15.7 ± 3.2	10.6 ± 2.6
Cir spp.	0.8 ± 0.4	0.8 ± 0.4	1.2 ± 0.4	0.6 ± 0.3	1.5 ± 0.6	0.9 ± 0.3	0.3 ± 0.1
Cor cor	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5	0.4 ± 0.4
Cor sto	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Die lon	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.4 ± 0.4	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Epi ang	0.8 ± 0.2	1.3 ± 0.6	1.0 ± 0.4	1.1 ± 0.4	1.3 ± 0.4	0.1 ± 0.1	0.2 ± 0.1
Equ syl	0.5 ± 0.3	0.5 ± 0.3	1.0 ± 0.3	0.8 ± 0.3	0.5 ± 0.2	0.0 ± 0.0	0.3 ± 0.2
Fra spp.	4.5 ± 2.7	4.5 ± 2.9	3.5 ± 1.7	4.6 ± 2.2	6.6 ± 2.9	6.5 ± 2.6	9.8 ± 2.6
Gal bor	19.0 ± 3.8	24.0 ± 4.5	18.6 ± 2.5	23.0 ± 3.3	19.9 ± 3.1	14.0 ± 2.1	12.1 ± 2.3
Gal tri	5.1 ± 4.7	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.3	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Geu spp.	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.6 ± 0.4	0.4 ± 0.2	0.2 ± 0.1	0.1 ± 0.1
Gramineae	116.3 ± 22.4	106.9 ± 22.4	96.3 ± 14.9	15.2 ± 3.7	10.1 ± 1.7	6.6 ± 0.0	17.6 ± 3.3
Lat spp.	0.1 ± 0.1	0.1 ± 0.1	0.8 ± 0.4	0.4 ± 0.2	0.4 ± 0.3	0.2 ± 0.1	0.1 ± 0.1
Lon dio	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5	0.1 ± 0.1	1.1 ± 1.0	0.0 ± 0.0	0.9 ± 0.9
Mai can	4.7 ± 1.4	4.7 ± 1.4	7.5 ± 1.7	12.9 ± 3.0	20.2 ± 3.6	31.4 ± 5.2	33.1 ± 4.9
Mer pan	1.9 ± 0.7	5.3 ± 1.9	1.7 ± 0.7	0.8 ± 0.4	1.1 ± 0.4	0.4 ± 0.2	0.4 ± 0.2
Mit nud	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Mon uni	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.5 ± 5.2	0.0 ± 0.0
Pet pal	1.7 ± 0.5	1.7 ± 0.5	2.4 ± 0.8	3.3 ± 1.0	2.9 ± 1.0	2.4 ± 0.7	1.7 ± 0.6
Pet sag	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Pic gla	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2
Pop tre	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.6	0.7 ± 0.6
Pre alb	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.2	0.3 ± 0.3	0.3 ± 0.1	0.4 ± 0.3
Pyr asa	1.8 ± 0.9	1.8 ± 0.9	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0
Rib lac	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Rib oxy	3.3 ± 1.7	3.3 ± 1.8	2.3 ± 1.3	2.9 ± 1.7	2.0 ± 1.2	0.8 ± 0.3	1.1 ± 0.6
Rib tri	0.5 ± 0.3	0.0 ± 0.0	0.8 ± 0.4	1.2 ± 0.7	1.2 ± 0.6	0.6 ± 0.3	0.3 ± 0.1
Ros aci	4.3 ± 1.4	4.3 ± 1.5	6.1 ± 1.1	6.4 ± 1.6	8.2 ± 1.8	7.1 ± 0.9	7.5 ± 1.1
Rub ida	7.3 ± 1.2	7.3 ± 1.6	5.9 ± 1.5	4.0 ± 0.8	4.9 ± 1.0	1.4 ± 0.6	2.1 ± 0.8
Rub pub	1.2 ± 0.4	1.2 ± 0.4	4.6 ± 1.8	10.4 ± 2.7	7.9 ± 2.3	4.0 ± 1.8	5.7 ± 1.6
Sal sp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.1 ± 0.1
Sol spp.	0.0 ± 0.0	0.3 ± 0.3	0.5 ± 0.5	0.7 ± 0.6	1.1 ± 0.8	1.8 ± 1.3	1.5 ± 1.3
Ste cil	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	0.3 ± 0.2	1.4 ± 0.8	0.3 ± 0.2
Str ros	2.0 ± 1.3	2.0 ± 1.4	3.2 ± 2.3	2.8 ± 2.0	4.6 ± 3.1	2.9 ± 1.8	3.2 ± 2.3
Sym alb	2.6 ± 0.7	2.6 ± 0.7	3.6 ± 1.3	4.1 ± 1.6	4.7 ± 1.9	4.6 ± 1.2	3.9 ± 1.0
Tar off	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.3 ± 0.2	0.3 ± 0.3	0.9 ± 0.7	0.2 ± 0.1
Tha spp.	1.3 ± 0.6	1.3 ± 0.6	0.1 ± 0.1	0.4 ± 0.4	0.1 ± 0.1	1.9 ± 0.8	2.5 ± 1.0
Tri bor	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Tri cer	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.1 ± 0.1	0.3 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
Vac ang	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Vib raf	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	1.8 ± 1.4	2.4 ± 1.4
Vic spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	0.2 ± 0.2
Vio spp.	0.9 ± 0.5	0.9 ± 0.5	3.6 ± 1.5	6.5 ± 2.9	7.7 ± 2.9	3.2 ± 1.3	4.3 ± 2.2
Species Richness	26	25	33	34	36	34	38
Species Diversity	0.71	0.70	0.82	1.15	1.17	1.12	1.09

*For explanation of abbreviations see Appendix I.

Table 7. Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrats at the NTA site. Values are means ± SE. (n = 10).

Species*	1987			1988			1992			1994		
Abi bal	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1	0.1	±	0.1
Ach mil	0.7	±	0.4	1.8	±	1.1	0.7	±	0.4	0.8	±	0.4
Act rub	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.6	±	0.4
Ane can	17.1	±	2.7	28.7	±	4.9	10.3	±	2.0	10.7	±	2.1
Aqu can	5.5	±	1.2	9.5	±	1.6	0.0	±	0.0	0.8	±	0.6
Ara nud	4.1	±	1.6	4.9	±	1.7	3.7	±	0.9	5.6	±	1.0
Ast cil	9.7	±	3.3	14.8	±	4.0	20.7	±	5.1	29.9	±	8.0
Cir spp.	0.4	±	0.3	0.5	±	0.5	5.1	±	1.5	7.2	±	1.2
Die lon	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1
Epi ang	1.0	±	0.6	1.3	±	0.7	1.4	±	0.6	1.9	±	0.8
Equ arv	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1	0.0	±	0.0
Equ syl	0.1	±	0.1	1.2	±	0.5	0.7	±	0.3	1.4	±	0.5
Fra spp.	14.7	±	2.9	35.3	±	6.0	12.5	±	1.7	18.2	±	4.2
Gal bor	11.6	±	1.7	16.1	±	2.4	9.8	±	1.6	6.7	±	1.2
Geu spp.	0.1	±	0.1	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0
Gramineae	26.0	±	2.0	32.9	±	3.6	27.3	±	2.0	92.4	±	16.8
Hal def	0.0	±	0.0	0.3	±	0.2	0.1	±	0.1	0.1	±	0.1
Lac lud	1.3	±	0.8	1.2	±	0.7	0.0	±	0.0	0.0	±	0.0
Lat spp.	19.9	±	2.3	2.9	±	0.5	10.8	±	1.6	6.2	±	1.5
Lon obl	0.9	±	0.9	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0
Mai can	1.4	±	0.4	4.6	±	1.9	3.6	±	1.4	2.4	±	0.5
Mer pan	0.6	±	0.3	0.8	±	0.6	0.4	±	0.2	1.1	±	0.5
Pet pal	0.4	±	0.4	0.3	±	0.3	0.1	±	0.1	0.0	±	0.0
Pop tre	0.1	±	0.1	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0
Pot nor	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1
Pyr asa	0.5	±	0.4	1.8	±	1.2	0.0	±	0.0	0.9	±	0.7
Ros aci	4.6	±	1.0	4.4	±	0.9	3.1	±	0.7	3.6	±	0.7
Rub ida	6.3	±	1.4	7.2	±	1.9	4.8	±	1.7	8.0	±	2.8
Rub pub	3.1	±	0.9	5.4	±	1.7	1.4	±	0.6	2.5	±	1.0
San mar	1.9	±	0.5	4.4	±	1.3	2.6	±	0.6	4.1	±	1.1
Smi ste	2.8	±	1.1	16.1	±	6.7	0.0	±	0.0	0.0	±	0.0
Sol spp.	3.1	±	2.2	3.1	±	2.0	7.0	±	5.8	8.9	±	6.3
Son arv	0.0	±	0.0	0.0	±	0.0	2.7	±	0.8	5.7	±	1.5
Sta pal	0.0	±	0.0	0.0	±	0.0	0.2	±	0.2	0.4	±	0.2
Ste cil	1.1	±	0.7	0.2	±	0.1	1.2	±	0.8	1.0	±	0.6
Str ros	0.0	±	0.0	0.0	±	0.0	3.9	±	1.3	10.2	±	4.9
Sym alb	3.6	±	1.0	6.0	±	1.4	2.2	±	0.8	2.4	±	0.8
Tar off	1.6	±	0.4	1.0	±	0.4	0.9	±	0.3	0.6	±	0.2
Tha spp.	0.0	±	0.0	0.0	±	0.0	4.9	±	1.2	6.3	±	2.0
Vac ang	0.2	±	0.1	0.3	±	0.2	0.0	±	0.0	0.0	±	0.0
Vib edu	0.2	±	0.2	0.4	±	0.4	0.0	±	0.0	0.0	±	0.0
Vib raf	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.6	±	0.6
Vib tri	0.0	±	0.0	0.0	±	0.0	0.2	±	0.2	0.1	±	0.1
Vic spp.	0.0	±	0.0	14.4	±	1.9	1.1	±	0.4	0.5	±	0.3
Vio spp.	7.3	±	1.1	8.5	±	2.3	4.7	±	1.8	6.4	±	3.1
Species Richness	32			33			32			36		
Species Diversity	1.59			1.66			1.63			1.50		

*For explanation of abbreviations see Appendix I.

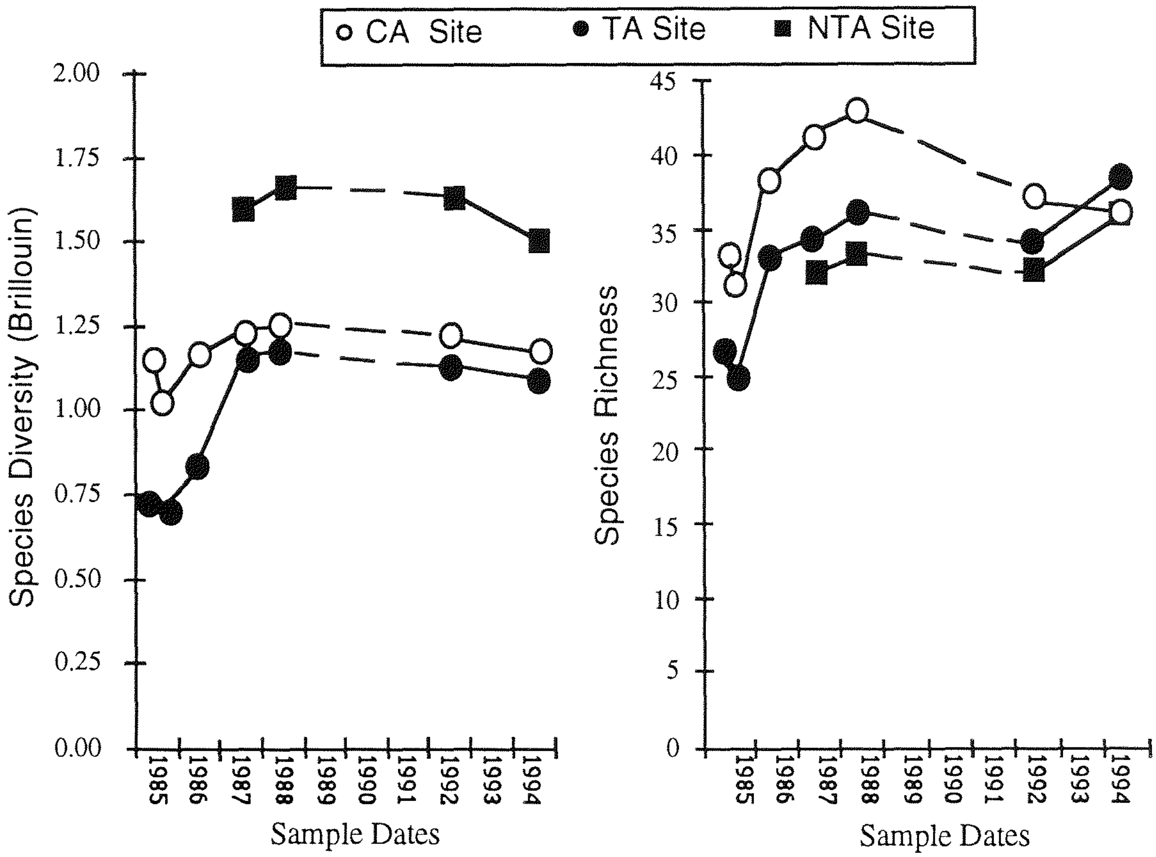

Fig. 9. Species diversity (Brillouin) and species richness of the CA, TA, and NTA sites at various sampling periods over the course of the study (1985 to 1994).

The increase in diversity and species richness in the TA site from 1986 to 1988 may be attributable in part to herbicide effects, as defoliation of trees probably allowed greater light penetration to understorey vegetation. However, as similar trends in diversity and richness were observed simultaneously in the CA site, it is likely the changes in vegetation were the result of shared environmental effects. The NTA site showed clear evidence of vegetation kill from the herbicide application in 1986. This site was located directly adjacent to the TA site, and although no pre-spray data exists for the site, it is likely that it shared very similar characteristics with the TA site prior to the herbicide applications. Assuming this, it follows that aerial glyphosate applications on aspen stands of this type leads to an increase in both species richness and density in the understorey vegetation, resulting in an overall increase in species diversity within one-year post-spray. This is an indirect effect resulting from the defoliation of the upper shrub and tree strata, which in turn leads to increased exposure to sunlight and decreased competition for soil nutrients in the understorey stratum.

Figure 10 shows the results of correspondence analysis conducted on the quadrat density data from the CA, TA, and NTA sites. The diagram illustrates the within and between site similarities at the various sample periods over the course of the study based on the species composition of the sites during sampling. Site sample years that appear close together share similar species composition and species densities. For example, the congregation of the CA site samples from 1987, 1988, 1992, and 1994 in the lower right of the diagram indicate that the species composition of the site did not change appreciably over the 1987 to 1994 period. The diagram also indicates which species characterized the understorey vegetation of the CA site over the 1987 to 1994 time frame. Species which share the same or similar coordinates in the diagram with a particular site sample year are indicative of a strong affinity of those species to that site and sample year. For example, the NTA site samples for 1987 and 1988, situated at the top of Figure 10, are in close proximity with *Lactuca ludoviciana* (Nutt.) Ridell, *Lonicera oblongifolia* (Goldie) Hook., *Smilacina stellata* (L.) Desf., *Vicia* spp. L., and *Anemone canadensis.* This configuration indicates that these species experienced their highest densities in the NTA site during the 1987 and 1988 sample years, and were found at greatly reduced densities, or were entirely absent, at the 1992 and 1994 sample years. None of the aforementioned species, with the exception of a few individuals of *Vicia* spp., were found at the TA or CA sites, and this is reflected in the ordination diagram. In general, "the probability of occurrence of a species tends to decrease with distance from its location in the ordination diagram" (ter Braak and Prentice 1988).

ter Braak and Prentice (1988) stated that in correspondence analysis ordination diagrams, the rarer species tend to occupy the edge of the diagram, while ubiquitous species are found mainly near the center (axes origin). They suggest omitting rare species from the data prior to conducting correspondence analysis. Rather than going to this extreme, in our analysis we incorporated downweighting of the rare species on the speculation that a rare occurrence of a particular species may be interpreted as the initial colonization or the possible extirpation of that species from the site, and thus, may be of intrinsic importance to the ecology of the site.

The axes of the correspondence analysis ordination and their eigenvalues provide an indication of the variance or structure in the data (Whittaker 1987, ter Braak 1987-1992). Axes generated by correspondence analysis represent directional trends in the data. Trends in data can then be inferred to be related to environmental gradients in the field. Each

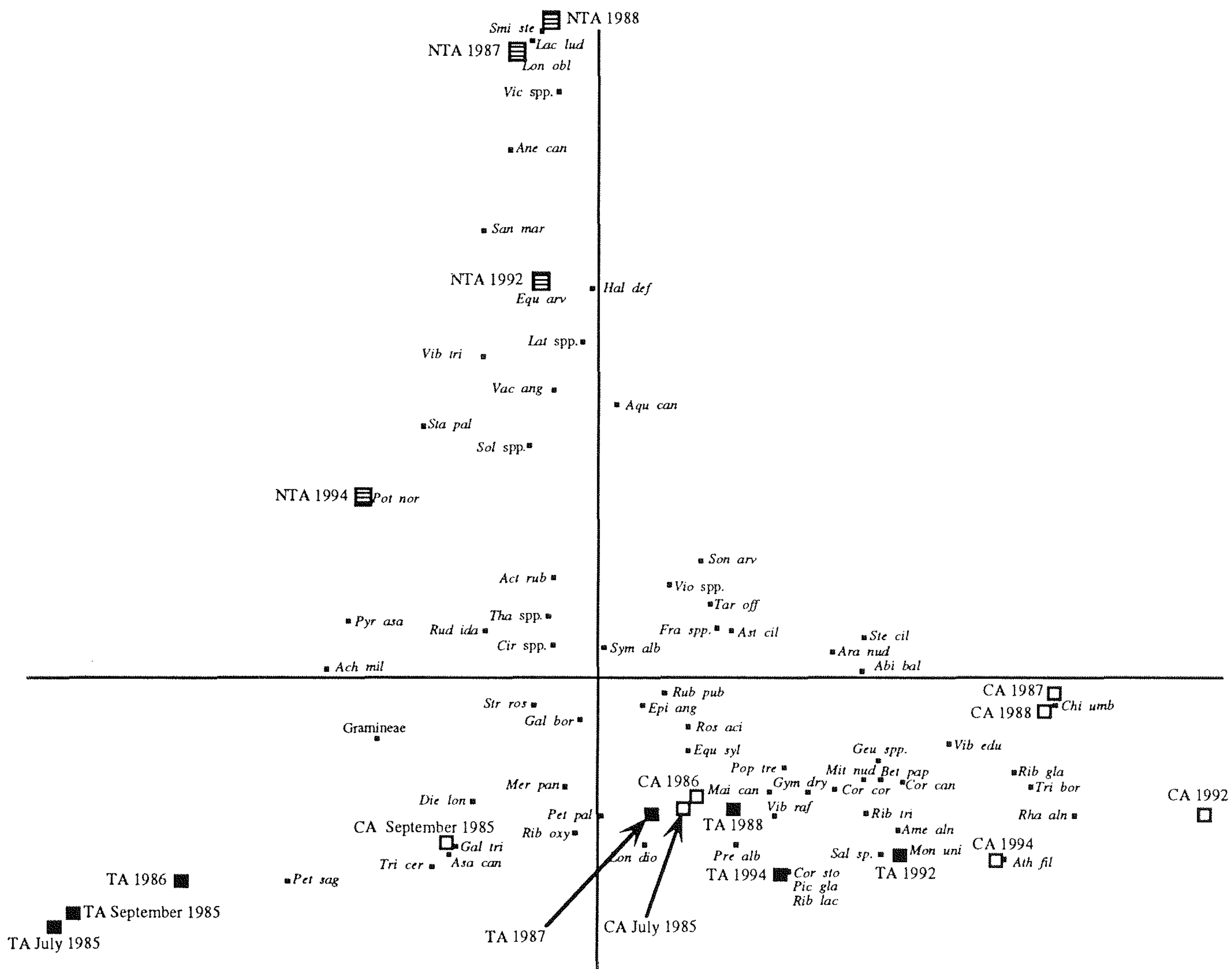

Fig. 10. Correspondence analysis of species and sample years from CA, TA, and NTA study sites. Species density data was collected from ten $1m^2$ quadrats during each sample period at each site. The sum of all eigenvalues is 0.909. The first axis (x) has an eigenvalue of 0.260, and accounts for 28.6% of the variance in the data. The second axis (y) has an eigenvalue of 0.214, which accounts for 23.5% of the variance in the data.

axis is assigned an eigenvalue which, in correspondence analysis, is defined as the "measure of separation of the species' distributions along the ordination axis" and is calculated as "the ratio of the dispersion of the species scores and that of the sample (site) scores" (ter Braak 1987-1992). The higher the eigenvalue of an axis, the more important the axis and subsequently the more influential the environmental gradient is in terms of vegetational changes and species' distributions.

In interpreting eigenvalues and the amount of variance in the data they represent, it is important to remember that the value is dependent on the number of variables (species) in the data. In ecological studies conducted over time, each species population usually varies temporally and spatially, and a large number of species (as in the case of the Aspen sites) will result in a large amount of overall variation in the data. Eigenvalues of axes can range between 0 to 1, with the sum of all eigenvalues of an analysis never exceeding 1. Eigenvalues are assigned to the axes in order of importance. That is, the first correspondence analysis axis (or x-axis) is considered to represent the major trend in the data and has the highest eigenvalue. The second axis (y-axis) represents the second strongest trend in the data and thus has a lower eigenvalue than the first. The eigenvalues continue to decrease for subsequent axes. Generally, the first two axes account for the majority of the variation in the data. However, when the data are highly variable, as in the quadrat data of the Aspen sites, the majority of the variation may be spread out over the first three or four axes. The first and second axes in the ordination of the Aspen sites had eigenvalues of 0.260 and 0.214, respectively. The total of all eigenvalues of the ordination was 0.9087. Thus, the first two axes only account for 52.1% $[((0.260 + 0.214) \div 0.9087) \times 100]$ of the total variation in the data. This indicates a weaker data structure and suggests that any trends in the vegetation composition and abundance at the Aspen sites were correspondingly weak. However, even an ordination that explains only a low proportion of the variation in the data can be informative. When dealing with ecological data, eigenvalues as low as 0.3 are quite common (ter Braak 1987-1992).

The correspondence analysis results for the Aspen sites illustrate that the TA and CA sites were quite dissimilar at the beginning of the study in 1985. The progression of TA and CA site sample periods along the first correspondence analysis axis (x-axis) in the diagram reflects a gradual change in vegetation composition and may represent natural succession at the two sites (Freedman *et al* 1993). Throughout the study the two sites shared many species in common. However, it was the differences in the relative abundance of individuals in each species and the presence/absence of less common taxa that distinguished the two sites from each other. The correspondence analysis diagram does not indicate any apparent effects on the TA site as a result of herbicide applications.

The NTA site shared several species in common with the CA and TA sites. However, species such as *Smilacina stellata*, *Vicia* spp., *Anemone canadensis*, *Aquilegia canadensis*, *Solidago* spp., *Sanicula marilandica* L. (snake root), and *Lathyrus* spp. were either exclusive to, or, at least, far more predominant in the NTA site than in the other sites. The correspondence analysis results reflect these differences by placing the NTA samples in a distinct grouping along the second correspondence analysis axis (y-axis); separate from the TA and CA sites. This second axis appears to represent the trend in vegetation composition and species population changes resulting from herbicide application and accounts for 23.5% of the variance in the vegetation data; only slightly less than the 28.6% accounted for by the first axis. Assuming the species composition in the NTA site was similar to that of the TA site before herbicide applications, and that the NTA site would have undergone similar successional changes, it then follows that the application of glyphosate caused the interruption or reversal of natural succession processes leading to the re-establishment of species from a prior seral stage. Furthermore, Figure 10 illustrates that at the end of the study the understorey vegetation of the NTA site was most closely ordinated with the TA and CA sites of 1985 to 1987. Thus, loss of species as a result of herbicide application appears to be only temporary, and provided that propagules are available, re-establishment of previously present species is likely.

Although the three Aspen sites had a number of shrub species in common, including *Rosa acicularis*, *Viburnum trilobum,* and *Rubus idaeus*, they did differ considerably over the course of the study in terms of population demographics (Figures 11 to 13). Throughout the study the shrub canopy in the CA site was dominated by *Rosa acicularis*. Relatively high stem densities and crown widths were also recorded for *Rubus idaeus*, *Amelanchier alnifolia*, and *Viburnum edule* (Michx.) Raf. (low-bush cranberry, mooseberry) at various sample dates. There was a general trend of decreasing total shrub stem density from 1985 to 1994 at the CA site. The data indicates that this was mainly due to a decline in density and crown width within *Rosa acicularis*. Alternatively, *Amelanchier alnifolia* and *Viburnum edule* registered increases in stem densities, mean stature, and total crown width over the same period. The decline of the *Rosa acicularis* population may be the result of unsuccessful competition with *Amelanchier alnifolia* and *Viburnum edule*, and reduced vigor brought about by ungulate browsing and trampling.

Viburnum rafinesquianum Schultes (downy arrow-wood) and *Rosa acicularis* co-dominated the shrub layer of the TA site for the first three sample years. By 1988, however, the stem density and total crown width of *Rosa acicularis* had declined

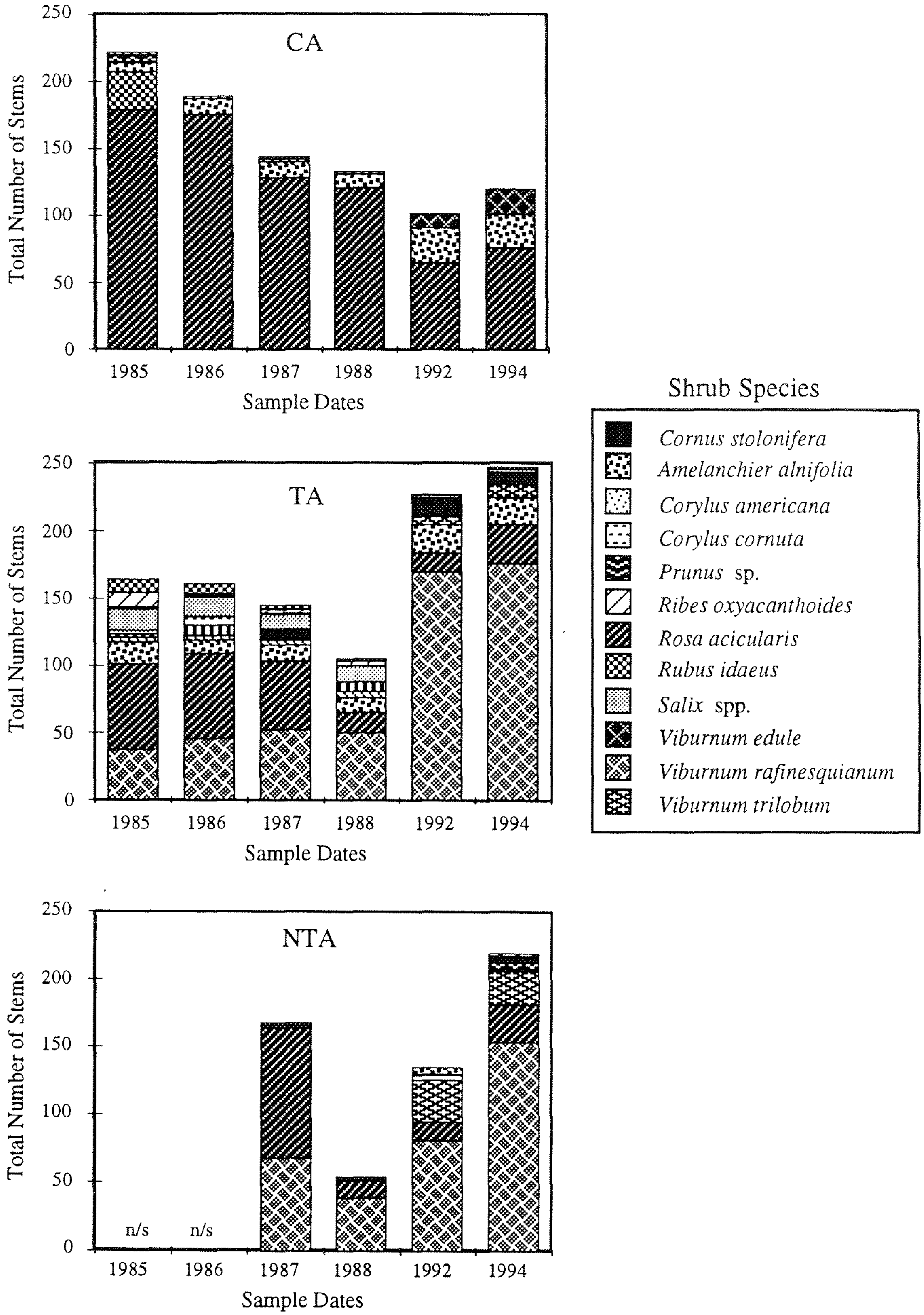

Fig. 11. Total number of stems of each shrub species recorded within the 100 m^2 macroplot at the CA, TA, and NTA study sites. Note no samples (n/s) were collected in the NTA study site in 1985 and 1986.

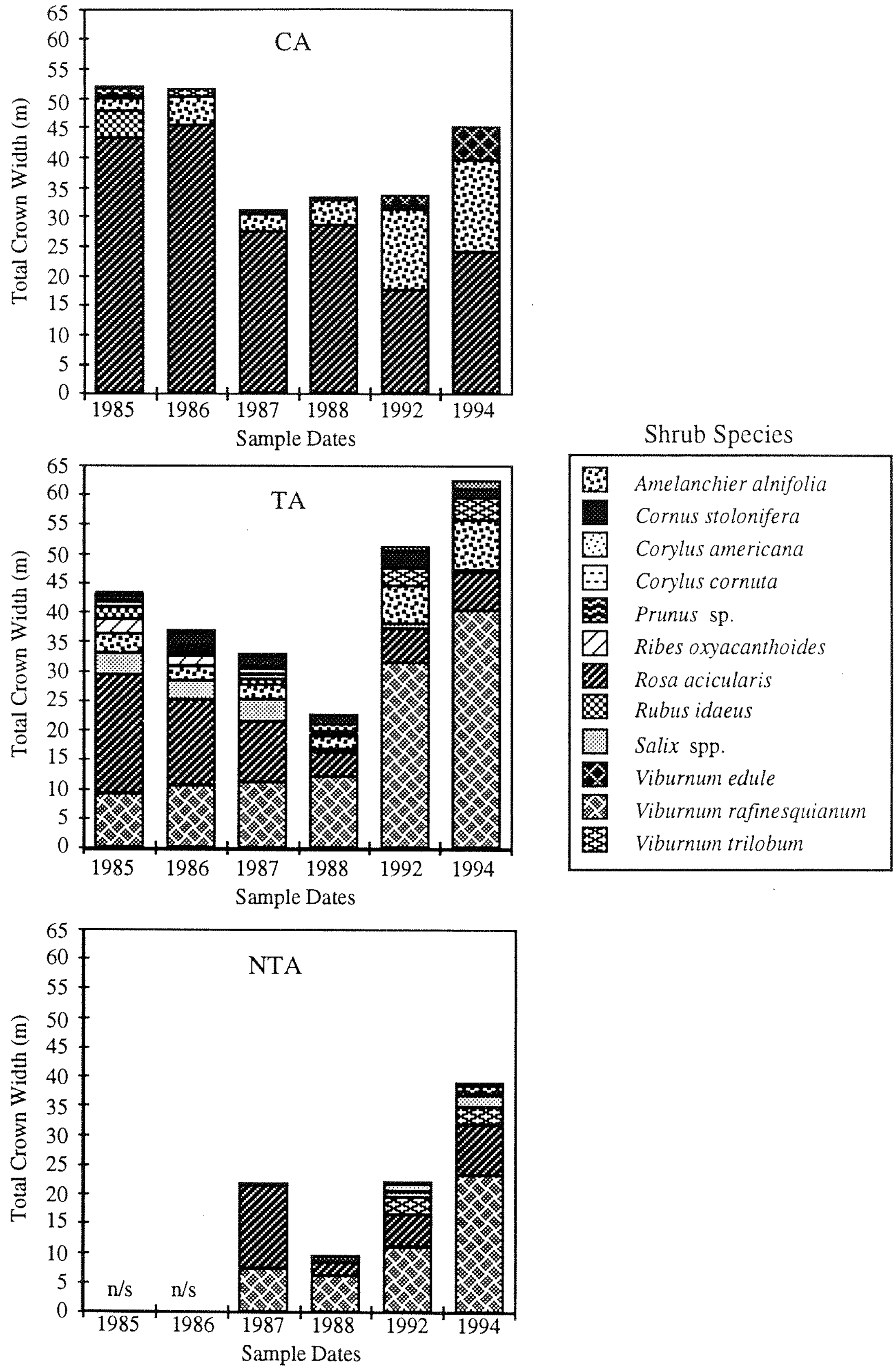

Fig. 12. Total maximum crown width (m) of shrub species recorded in the 100 m^2 macroplot at the CA, TA, and NTA study sites. Note no samples (n/s) were collected in the NTA study site in 1985 and 1986.

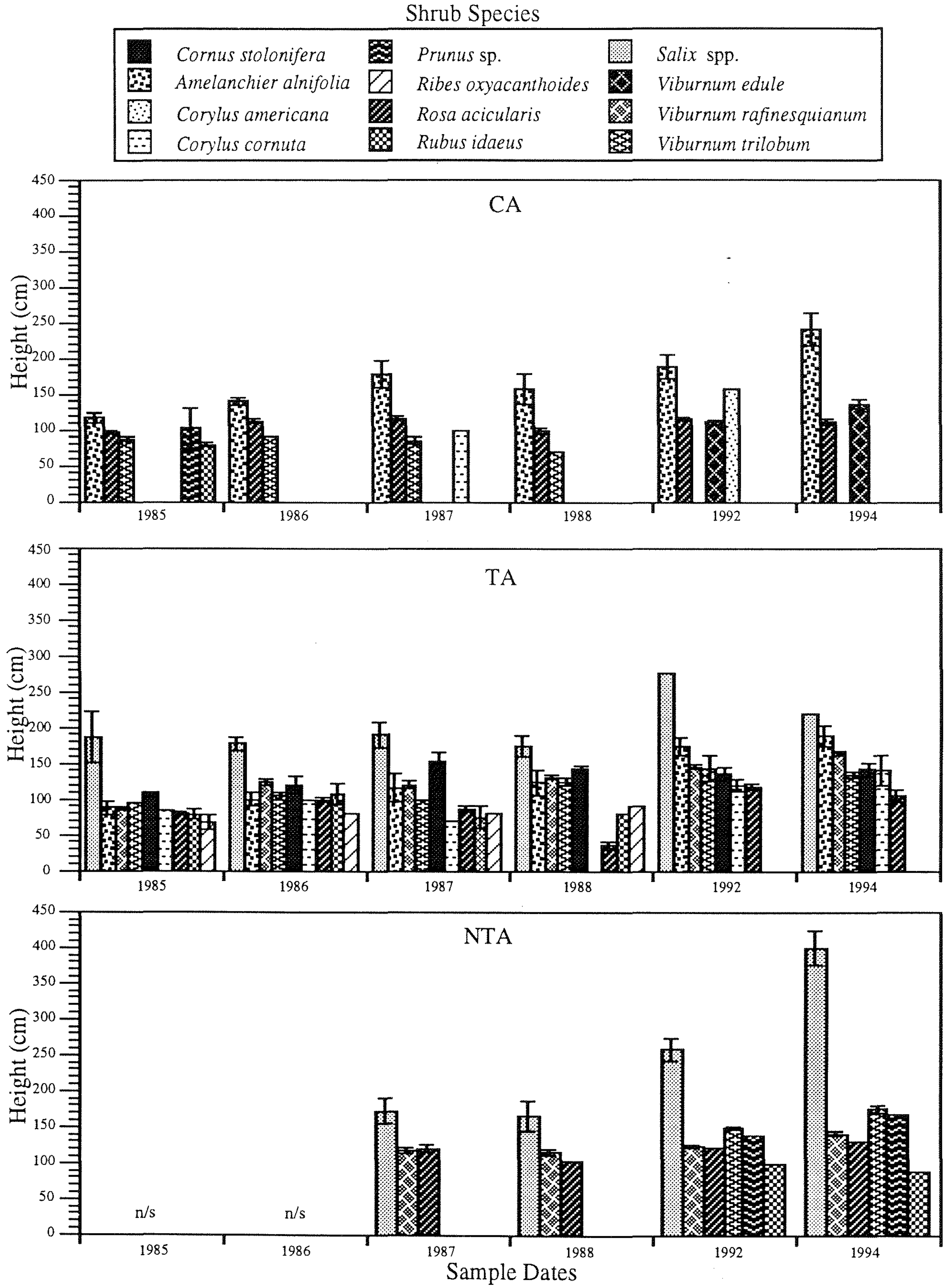

Fig. 13. Height (cm) of shrub species recorded within the 100 m^2 macroplot at the CA, TA, NTA study sites. Note no samples (n/s) were collected at the NTA study site in 1985 and 1986. Values are means ± SE.

considerably. *Viburnum rafinesquianum* clearly dominated the shrub canopy of the TA site during the 1992 and 1994 sample periods. As the stem density and total crown width declined in *Rosa acicularis,* so too did the mean height of the plants. Over the same period there was an increase in all three population parameters of *Viburnum rafinesquianum, Viburnum trilobum,* and *Amelanchier alnifolia.* As with the CA site, the shift in populations of the shrub species may have resulted from herbivory and interspecific competition. However, it is clear that the decline in *Rosa acicularis* in the TA site was more severe than in the CA site, and this may indicate an effect resulting from herbicide applications. Although the herbicide applications at the TA site were not uniform (Henderson *et al.* 1988) and data has shown that the effects on the understorey vegetation was negligible, a portion of the shrub/tree canopy in the sample macroplot did intercept some glyphosate (Henderson *et al.* 1988), which may have contributed to the decline in vigor of the *Rosa acicularis* population.

The NTA site experienced a decline in the shrub canopy from 1987 to 1988, followed by an increase in 1992 and 1994. As in the TA site, this pattern was characterized by a relatively large decrease in *Rosa acicularis* from 1987 to 1988, and a dramatic rise in *Viburnum rafinesquianum* and *Viburnum trilobum* in 1992 and 1994. The results suggest that *Rosa acicularis* may be more susceptible to glyphosate herbicide applications than *Viburnum rafinesquianum,* (which has somewhat leathery leaves suggestive of a relatively thick, less permeable cuticle) and that the decline of *Rosa acicularis* following the herbicide spray allowed for the proliferation of *Viburnum rafinesquianum* and the introduction of *Viburnum trilobum* at the site.

The CA and TA site tree strata were dominated by *Populus tremuloides* throughout the course of the study (Figure 14). Tree populations for both sites remained fairly constant (ca 70 individuals per site) for the first four years of the study, and then declined slightly by the 1992 and 1994 sampling periods. At the same time there was a steady increase in total basal area at each site, with the trees in the TA site consistently occupying a larger basal area than those at the CA site. The density and basal area data indicate that the trees in the CA site, although just as numerous, were generally smaller than those of the TA site. As well, the data indicate that herbicide applications did not have any detrimental effects on the growth of tree populations at the TA site.

Results of tree sampling at the NTA site reveal a considerable decline in density and total basal area following the herbicide applications of 1985 and 1986 (Figure 14). Once again, this assumes that the close proximity of the NTA site to the TA site would equate to similar pre-spray tree density and basal area measurements at both sites. As with the other

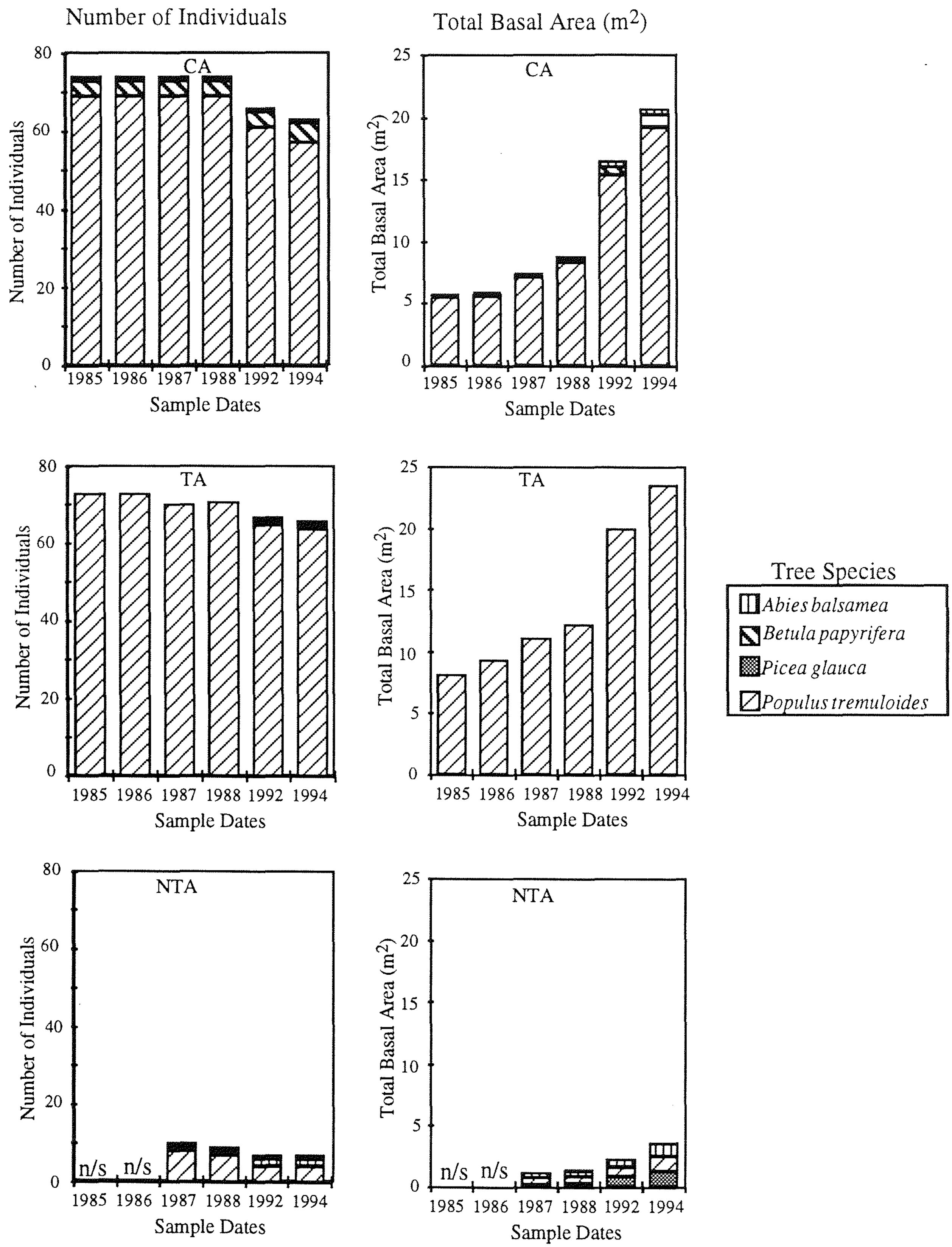

Fig. 14. Total number of individuals and total basal area (m^2) of tree species recorded in the 100 m^2 macroplot at the CA, TA, and NTA study sites. Note no samples (n/s) were collected in the NTA study site in 1985 and 1986.

Aspen sites, the data also suggests a trend of increasing size (i.e. basal area) of surviving individuals from 1987 through to 1994.

In summary, it appears that the two herbicide applications generally had little effect on the vegetation at the TA site when compared to the CA. There is some indication that the shrub stratum at the TA site may have been affected to a limited degree, however, this is not conclusive and may be due to other environmental parameters not addressed in this study. The NTA site exhibited clear evidence of vegetation kill as a result of herbicide applications. Based on the assumption that the NTA site and the TA site were similar in species composition and population structure prior to herbicide applications, it is evident that glyphosate is very successful in controlling shrub and tree strata vegetation when applied uniformly at a rate of 2.5 l/ha. The understorey layer or herb stratum of the NTA site was altered by the herbicide application. Initially, there was an influx of species which were rare or even absent at the other two Aspen sites. This contributed to the higher species diversity in the NTA site compared to the other Aspen sites. Gradually these populations began to decline and taxa characteristic of a later successional stage (i.e. species in common with the adjacent TA site) began to appear and increase in abundance. By the end of the study it was clear that the pre-spray herb stratum of the NTA site was becoming re-established through a succession of plant species.

4.2.3 Burn Sites

The understorey vegetation of the Burn sites consisted mainly of woody and non-woody perennial dicots and grass species. The density of grasses fluctuated considerably at each site over the course of the study. Generally, their greatest densities occurred during the 1985 and 1986 sample periods. The dominant dicots at the CB site included *Aster ciliolatus, Galium boreale, Cirsium* spp., *Fragaria* spp., *Lathyrus* spp., and *Rubus idaeus* (Table 8). *Viola* spp. L. (violet) was fairly common during the first sampling period, but appeared rare during the remaining years of the study. *Rubus idaeus* and *Galium boreale* were relatively common during the initial year of the study and then experienced a steady decline in density through to 1994. Meanwhile, *Aster ciliolatus, Rosa acicularis,* and *Rubus pubescens* tended to increase in density over the same period of time.

Commonly occurring dicots at the TB site included many species also found at the CB site, such as: *Aster ciliolatus, Cirsium* spp., *Fragaria* spp., *Galium boreale, Rubus idaeus,* and *Viola* spp. (Table 9). The density of *Viola* spp. was highest during the first few years of the study and then declined appreciably by the 1994 sampling period, while

Table 8 . Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrats at the CB site. Values are means ± SE. (n = 10).

Species	Jul-85	Sep-85	1986	1987	1988	1992	1994
Aqu can	0.8 ± 0.6	0.6 ± 0.6	3.3 ± 3.1	0.1 ± 0.1	0.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Ast cil	6.2 ± 4.2	6.2 ± 4.2	7.0 ± 3.9	15.0 ± 6.2	20.6 ± 10.2	24.7 ± 10.0	20.7 ± 7.4
Ast pun	0.1 ± 0.1	0.0 ± 0.0	1.3 ± 1.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Car spp.	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 2.5	2.1 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Che alb	0.5 ± 0.5	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Cir spp.	5.1 ± 1.5	4.9 ± 1.5	10.1 ± 3.6	8.5 ± 2.0	6.9 ± 1.4	3.7 ± 0.8	4.6 ± 1.2
Cor can	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Epi ang	1.2 ± 0.4	1.2 ± 0.4	1.0 ± 0.5	2.5 ± 2.1	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Equ syl	3.0 ± 1.0	3.0 ± 1.0	5.4 ± 2.0	0.1 ± 0.1	1.1 ± 0.5	1.6 ± 1.2	3.5 ± 0.7
Fra spp.	5.8 ± 3.2	5.8 ± 3.2	11.3 ± 2.9	8.6 ± 2.8	8.9 ± 2.8	6.0 ± 1.4	8.3 ± 2.3
Gal bor	63.8 ± 29.1	63.8 ± 29.1	76.0 ± 30.3	45.0 ± 15.4	44.2 ± 15.4	9.1 ± 2.9	7.9 ± 2.2
Geu spp.	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.3	0.5 ± 0.3	0.6 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Gramineae	103.1 ± 19.1	112.9 ± 17.9	151.0 ± 15.2	37.9 ± 8.9	40.3 ± 8.1	74.0 ± 16.2	124.3 ± 12.7
Hed spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Lat spp.	6.2 ± 1.8	5.7 ± 1.4	11.3 ± 5.1	6.6 ± 1.7	3.0 ± 0.8	7.6 ± 2.0	7.5 ± 1.4
Mai can	1.1 ± 1.1	1.1 ± 1.1	3.1 ± 1.9	3.0 ± 2.0	5.3 ± 3.4	5.7 ± 5.0	6.2 ± 2.4
Men arv	2.0 ± 1.1	2.0 ± 1.1	4.3 ± 1.5	4.6 ± 2.3	3.9 ± 1.4	0.0 ± 0.0	0.0 ± 0.0
Mer pan	2.0 ± 1.3	2.0 ± 1.3	0.4 ± 0.3	1.6 ± 1.5	1.4 ± 0.8	0.0 ± 0.0	0.4 ± 0.3
Pet pal	0.2 ± 0.2	0.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.2
Pol con	0.4 ± 0.2	0.3 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.3	0.2 ± 0.1
Pop tre	1.4 ± 0.8	1.4 ± 0.8	0.9 ± 0.5	1.0 ± 0.5	0.7 ± 0.3	0.4 ± 0.3	0.5 ± 0.3
Pyr ell	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ran spp.	0.2 ± 0.2	0.0 ± 0.0	0.3 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Rib oxy	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.1
Rib spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ros aci	2.0 ± 1.1	2.0 ± 1.1	2.2 ± 1.1	3.3 ± 1.5	3.5 ± 1.6	4.6 ± 1.8	5.6 ± 2.3
Rub ida	25.6 ± 4.6	25.6 ± 4.6	12.6 ± 2.9	12.5 ± 3.7	10.0 ± 3.4	4.2 ± 1.6	5.0 ± 1.4
Rub pub	0.0 ± 0.0	0.2 ± 0.1	1.4 ± 0.7	2.4 ± 0.9	6.2 ± 1.8	1.5 ± 0.8	5.2 ± 1.9
Sal spp.	2.7 ± 1.4	1.2 ± 0.9	2.9 ± 1.4	1.6 ± 0.8	1.7 ± 0.8	0.7 ± 0.4	0.3 ± 0.2
Sol spp.	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.4	0.2 ± 0.2	0.3 ± 0.2	0.0 ± 0.0	0.3 ± 0.3
Son arv	1.3 ± 0.8	1.5 ± 0.8	2.0 ± 0.6	5.7 ± 2.0	9.0 ± 2.8	3.9 ± 1.0	4.7 ± 1.3
Sta pal	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	1.0 ± 0.5
Ste cil	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 2.8	1.7 ± 1.7	0.8 ± 0.8
Tar off	0.6 ± 0.3	0.6 ± 0.3	1.6 ± 1.0	1.5 ± 0.8	2.0 ± 1.1	2.1 ± 1.0	0.0 ± 0.0
Tri bor	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Vic spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 1.0	2.5 ± 0.5	1.9 ± 0.7
Vio spp.	6.8 ± 3.9	5.7 ± 4.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.2
Species Richness	24	22	29	26	27	20	24
Species Diversity	0.78	0.73	0.77	0.92	1.02	0.83	0.73

*For explanation of abbreviations see Appendix I.

Table 9. Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrats at the TB site. Values are means ± SE. (n = 10).

Species	Jul-85	Sep-85	1986	1987	1988	1992	1994
Ach mil	7.1 ± 4.2	7.1 ± 4.2	3.1 ± 1.8	6.2 ± 3.2	15.1 ± 7.2	7.7 ± 3.4	5.6 ± 2.1
Ane can	6.6 ± 2.8	6.6 ± 2.8	6.2 ± 1.8	21.6 ± 6.2	41.5 ± 11.0	17.5 ± 4.2	7.3 ± 1.7
Aqu can	4.0 ± 2.0	4.0 ± 2.0	1.9 ± 0.9	2.1 ± 1.1	2.9 ± 1.2	1.5 ± 0.9	0.8 ± 0.4
Ara nud	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Asc spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Ast cil	7.8 ± 3.4	7.8 ± 3.4	13.1 ± 2.2	28.4 ± 4.1	38.0 ± 5.4	28.5 ± 6.0	30.5 ± 6.3
Ast pun	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ath fil	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Bet pap	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.4	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Bot vir	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Car spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.7
Cir spp.	7.9 ± 2.0	7.9 ± 2.0	7.0 ± 2.2	2.7 ± 0.8	2.9 ± 0.6	0.9 ± 0.3	2.9 ± 0.7
Com umb	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.4	0.2 ± 0.2	0.0 ± 0.0	2.1 ± 1.4	1.9 ± 1.3
Cor can	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.4	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0
Die lon	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Dry spi	0.4 ± 0.3	0.0 ± 0.0	0.4 ± 0.4	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0
Epi ang	10.6 ± 1.5	10.6 ± 1.5	13.3 ± 2.0	12.4 ± 2.3	6.9 ± 1.3	5.9 ± 1.6	7.0 ± 1.2
Equ syl	2.8 ± 1.4	2.8 ± 1.4	7.0 ± 3.4	5.0 ± 2.4	10.2 ± 4.2	3.7 ± 1.5	3.8 ± 1.6
Fra spp.	23.7 ± 4.5	23.7 ± 4.5	20.5 ± 5.1	20.8 ± 6.4	36.6 ± 11.4	22.6 ± 5.1	23.3 ± 5.8
Gal bor	13.4 ± 11.9	13.4 ± 11.9	6.3 ± 4.4	6.2 ± 5.4	3.8 ± 2.5	10.0 ± 4.8	8.2 ± 4.2
Gal tri	0.5 ± 0.3	0.5 ± 0.3	0.7 ± 0.3	0.3 ± 0.2	0.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Ger bic	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0
Geu spp.	1.9 ± 0.9	1.6 ± 0.8	7.4 ± 2.0	5.9 ± 2.7	7.2 ± 2.9	2.1 ± 1.2	1.2 ± 0.7
Gramineae	172.0 ± 42.5	152.7 ± 42.4	307.1 ± 28.6	50.9 ± 18.8	35.3 ± 8.6	41.2 ± 15.0	100.5 ± 20.7
Jun spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1
Lac hir	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Lat spp.	0.6 ± 0.3	0.6 ± 0.3	1.5 ± 0.5	3.4 ± 1.0	1.8 ± 0.8	2.4 ± 0.8	1.7 ± 0.5
Lin bor	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Mai can	0.9 ± 0.7	0.9 ± 0.7	1.6 ± 0.8	1.0 ± 0.5	8.5 ± 3.3	9.2 ± 3.6	8.1 ± 2.9
Men arv	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5	0.1 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Mer pan	3.2 ± 1.5	3.2 ± 1.5	2.8 ± 1.5	1.2 ± 0.7	1.8 ± 0.7	1.6 ± 1.1	1.0 ± 0.5
Mit nud	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.4	0.3 ± 0.3	0.3 ± 0.3	0.1 ± 0.1	0.0 ± 0.0
Pet pal	2.8 ± 1.3	2.8 ± 1.3	0.6 ± 0.2	1.0 ± 0.7	0.3 ± 0.2	0.7 ± 0.5	1.0 ± 0.8
Pet sag	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 1.1	0.0 ± 0.0	0.0 ± 0.0
Pet vit	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Pop tre	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Pot pen	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Pre alb	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0
Pyr ell	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.8	0.0 ± 0.0	0.0 ± 0.0
Rib oxy	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Rib tri	0.8 ± 0.6	0.8 ± 0.6	0.9 ± 0.5	0.0 ± 0.0	0.2 ± 0.2	0.1 ± 0.1	0.0 ± 0.0
Ros aci	0.9 ± 0.4	0.9 ± 0.4	1.2 ± 0.5	1.0 ± 0.4	0.8 ± 0.3	1.0 ± 0.4	1.2 ± 0.4
Rub ida	22.1 ± 3.3	22.1 ± 3.3	12.9 ± 2.2	6.8 ± 1.6	8.0 ± 1.7	4.4 ± 1.3	2.4 ± 0.8
Rub pub	0.2 ± 0.1	0.2 ± 0.1	1.5 ± 0.9	3.2 ± 1.5	5.0 ± 1.8	4.8 ± 2.0	8.3 ± 2.3
Sal spp.	2.4 ± 2.2	2.5 ± 2.2	2.5 ± 2.5	2.0 ± 2.0	0.9 ± 0.9	0.5 ± 0.4	0.7 ± 0.6
San mar	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	0.3 ± 0.3	0.9 ± 0.9	0.8 ± 0.8	1.6 ± 1.4
Smi ste	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.5	0.0 ± 0.0	0.3 ± 0.2	0.2 ± 0.2	0.0 ± 0.0
Sol spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.1	7.7 ± 2.6	2.8 ± 1.0
Son arv	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 1.6	6.9 ± 3.1	13.4 ± 5.2	0.0 ± 0.0	0.0 ± 0.0
Ste cil	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.7 ± 2.3	10.2 ± 3.4	6.9 ± 1.4	6.7 ± 1.5
Str ros	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.3
Tar off	0.4 ± 0.2	0.4 ± 0.2	0.4 ± 0.2	0.9 ± 0.5	1.2 ± 0.4	1.3 ± 0.5	1.0 ± 0.4
Tha spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Tri bor	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 1.1	0.2 ± 0.2	4.3 ± 3.1	0.5 ± 0.3	0.6 ± 0.5
Vac ang	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.9 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Vib tri	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Vic spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.5	3.4 ± 0.7	3.4 ± 0.5
Vio spp.	17.6 ± 4.0	16.9 ± 4.3	14.1 ± 2.6	33.7 ± 4.8	14.9 ± 2.9	4.4 ± 1.3	3.3 ± 0.8
Richness	27	25	38	34	41	35	34
Diversity	0.79	0.82	0.65	1.11	1.18	1.15	0.97

*For explanation of abbreviations see Appendix I

the density of *Aster ciliolatus* and *Rubus pubescens* increased from 1985 through to 1994. However, the stem density of *Rosa acicularis* in the TB site remained low and relatively static over the course of the study. The stem density of *Rubus idaeus* declined from one sample period to the next. Other species rare or absent at the CB site, but fairly common at the TB site included *Achillea millefolium* L. (yarrow), *Anemone canadensis,* and *Epilobium angustifolium.* The density of these species fluctuated slightly over the course of the study, but essentially remained static.

Non-graminoid monocots recorded at the Burn sites included *Maianthemum canadense, Smilacina stellata*, and *Streptopus roseus* Michx. (rose twisted stalk). *Maianthemum canadense* was found at both sites, while the latter two species occurred only at the TB site. *Maianthemum canadense* was relatively rare at the CB site during the 1985 sample period, but the density increased over the remainder of the study. A similar trend in *Maianthemum canadense* density was observed at the TB site; however, in this case the species did not exhibit an increase in density until the 1988 sample period.

Pteridophytes (ferns and fern allies) present at the Burn sites included *Equisetum sylvaticum* L. (wood horsetail), *Athyrium filix-femina* (L.) Roth (lady fern), *Botrychium virginianum* (L.) Swartz. (Virginia grape fern), and *Dryopteris spinulosa* (Muell.) Watt. (spinulose shield fern). *Equisetum sylvaticum* was fairly common at both sites throughout the entire study period, while the latter three species had relatively low densities in the TB site.

The understorey vegetation of the Burn sites was similar with regard to species diversity and species richness prior to, and immediately following, the 1985 herbicide applications (Figure 15). The species diversity at the CB site remained essentially unchanged from 1985 to 1986, as only a few relatively rare species were added, and these did not contribute to the overall species diversity index. The species diversity of the CB site increased through the 1987 and 1988 sample period. However, by the 1992 and 1994 sample periods the diversity of the site was in decline. Species richness at the CB site tended to fluctuate over the course of the study.

The species richness at the TB site increased dramatically in 1986; one year after the 1985 herbicide application. This was accompanied by a decrease in species diversity during the same period. This at first appears paradoxical; however, closer examination of the data reveals that the newly introduced species had relatively low densities, while the entire species compliment was dominated by six relatively high density species or species groups -- *Aster ciliolatus, Epilobium angustifolium, Fragaria* spp., *Rubus idaeus, Viola* spp., and grasses (Gramineae). Thus, the number of species increased one year following the 1985 spray, but at the same time the distribution of individuals among the species became more uneven, resulting in a decrease in overall species diversity. The species diversity of the TB site increased from a level of 0.65 in 1986 to 1.11 in 1987. Over the same period the species richness declined from 38 to 34. The increase in species diversity over this period was likely due to a decrease in the density of grasses (from 307.1 to 50. 9 individuals/m^2) and *Rubus idaeus* (from 12.9 to 6.8 individuals/m^2), and a simultaneous increase in the density of other species [examples include: *Aster ciliolatus, Anemone canadensis, Viola* spp., *Sonchus arvensis* L. (sow-thistle), and *Steironema ciliatum* (L.) Raf. (fringed loosestrife)], resulting in a more even distribution of individuals among the species aggregation. The species diversity and species richness at the TB site both appeared to peak in 1988, although no data are available for the 1989 to 1991 period. The diversity and richness then declined by the 1992 and 1994 sample periods.

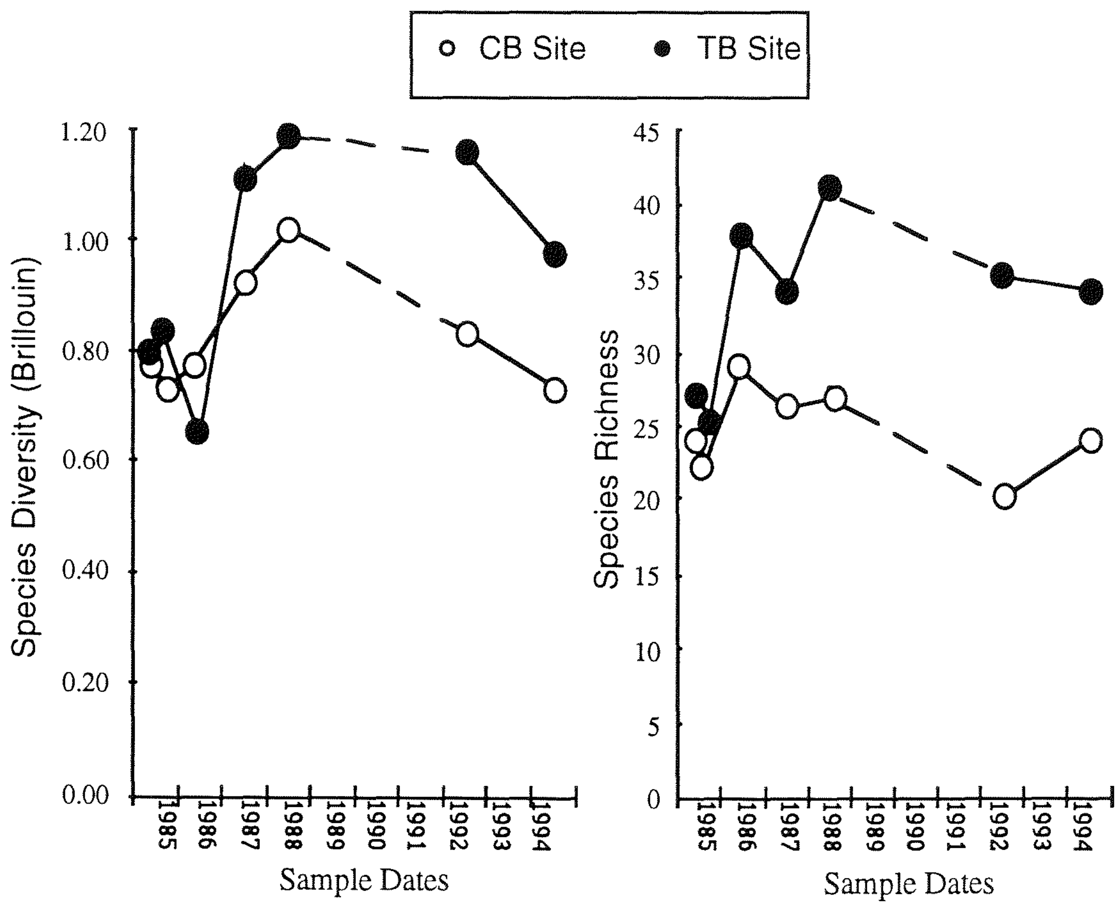

Fig. 15. Species diversity (Brillouin) and species richness of the CB and TB sites at various sampling periods over the course of the study (1985 to 1994).

Fluctuations in species diversity and richness indices at the CB site over the course of the study are reflective of the process of natural succession of vegetation following the 1984 forest fire in the area. There was a steady increase in species richness and diversity with the recolonization of the understorey layer of the site by plant species in 1985 and 1986. By 1987, the species richness of the site began to decline and the diversity continued to increase as the net recolonization by new species approached zero and the distribution of individuals among the species present became more even. By 1992 and 1994 the understorey vegetation became dominated by species more typical of aspen stands in the region. Over this latter half of the study there was a stabilizing of the species richness and a lowering of diversity. During this period the density of the majority of the species, and in particular initial recolonizers such as *Galium boreale, Epilobium angustifolium, Viola* spp., and *Rubus idaeus,* declined possibly because of increased competition from a more abundant shrub canopy.

The change in diversity and species richness in the TB site from 1986 through to 1988 can be attributed to post-fire natural succession processes. However, the time frame for recolonization at the TB site appeared prolonged when compared to that of the CB site. This apparent delay in successional development at the TB site may characterize the vegetation response to glyphosate impacts. The application of the herbicide in 1985 and 1986 is hypothesized to have acted as a disturbance factor, interfering with the normal vegetation succession.

Results from correspondence analysis conducted on the understorey vegetation density data indicate that there were temporal changes in the species composition and density at both Burn sites (Figure 16). Sample periods at the CB site form a cluster in the upper left quadrant of the diagram while those of the TB site are spread along the first axis. In the diagram the first axis (x-axis) accounts for 43.3% of the variation in the data and serves to separate pre-spray and post-spray sample years at the TB site. The second axis (y-axis) accounts for 23.5% of the variation in the data and may represent successional changes in the vegetation at each site. The relatively wide separation of the CB and TB sites from each other indicates that the two sites differed in species composition and density both before and after the herbicide applications. However, as shown previously in Figure 15, the two sites did have similar species richness and diversity values at the outset of the study. Clustering of the 1985 and 1986 sample periods at each site suggests that vegetation changes over this period were negligible. It follows that the 1985 herbicide application at the TB site had a minimal effect on the overall vegetation composition in 1986, although differences in diversity and species richness over the same period indicate that the establishment of some new species occurred. The 1987 to 1994 sample periods at the CB site show a trend of change along both the 1st and 2nd axis. This likely represents natural successional changes in vegetation composition following the 1984 fire. The CB sample periods are not as widely dispersed throughout the bi-plot as those of the TB site, indicating that although there were changes in species composition in the control site over the span of the study, these changes were more subtle than those at the treated site. In 1987 and 1988 the vegetation of the TB site exhibited a clear response to the previous years' herbicide applications. By eliminating much of the dense grass cover and recolonizing shrub species, the herbicide applications served to decrease interspecific competition among the understorey vegetation and allowed the proliferation of early seral species such as *Anemone canadensis* and *Achillea millefolium*, thus appearing to prolong the natural post-fire succession of plant species at the site.

Salix spp. dominated the shrub stratum of both Burn sites (Figure 17). In the case of the TB site, *Salix* spp. was the only shrub species present, while at the CB site it was accompanied by *Rosa acicularis* and *Prunus pensylvanica* L.F. (pin cherry). The total number of shrub stems increased sharply at both sites from 1985 to 1986. Following the 1985 - 1986 period, the trends in the growth of the shrub stratum of each site began to differ. The CB site had higher shrub stem densities and higher total maximum crown width values than in the TB site during corresponding sample periods. The highest number of stems for both sites were recorded in 1986, while the highest total maximum crown widths were recorded in 1994. Mean heights were also greatest in 1994 (Figure 18). Mean height measurements did not vary greatly between sites, and shrubs at both sites showed similar trends of increasing mean height over the course of the study.

The total number of shrub stems at the CB site showed a clear downward trend from 1986 to 1992, followed by a substantial increase in 1994. The 1986 to 1992 decline was due to a reduction in the number of *Salix* spp. stems. Stems of *Rosa acicularis* actually increased over this time period, and continued to increase into 1994. The maximum crown width (Figure 17) and mean height (Figure 18) of *Salix* spp. increased gradually over the course of the study. Thus, although the total number of stems of *Salix* spp. appeared to decline, the remaining stems continued to grow in size and stature. The total crown width of the shrub stratum at the CB site increased considerably from 1988 to 1992. Although part of this increase was due to growth of *Salix* spp., the major contributor was the increasing number and size of *Rosa acicularis* stems, and to a lesser extent, the emergence of a *Prunus pensylvanica* component.

The stem density of *Salix* spp. at the TB site decreased from 139 stems in 1986 to 80 stems in 1987; a decline of 42.5%. The stem numbers then remained relatively

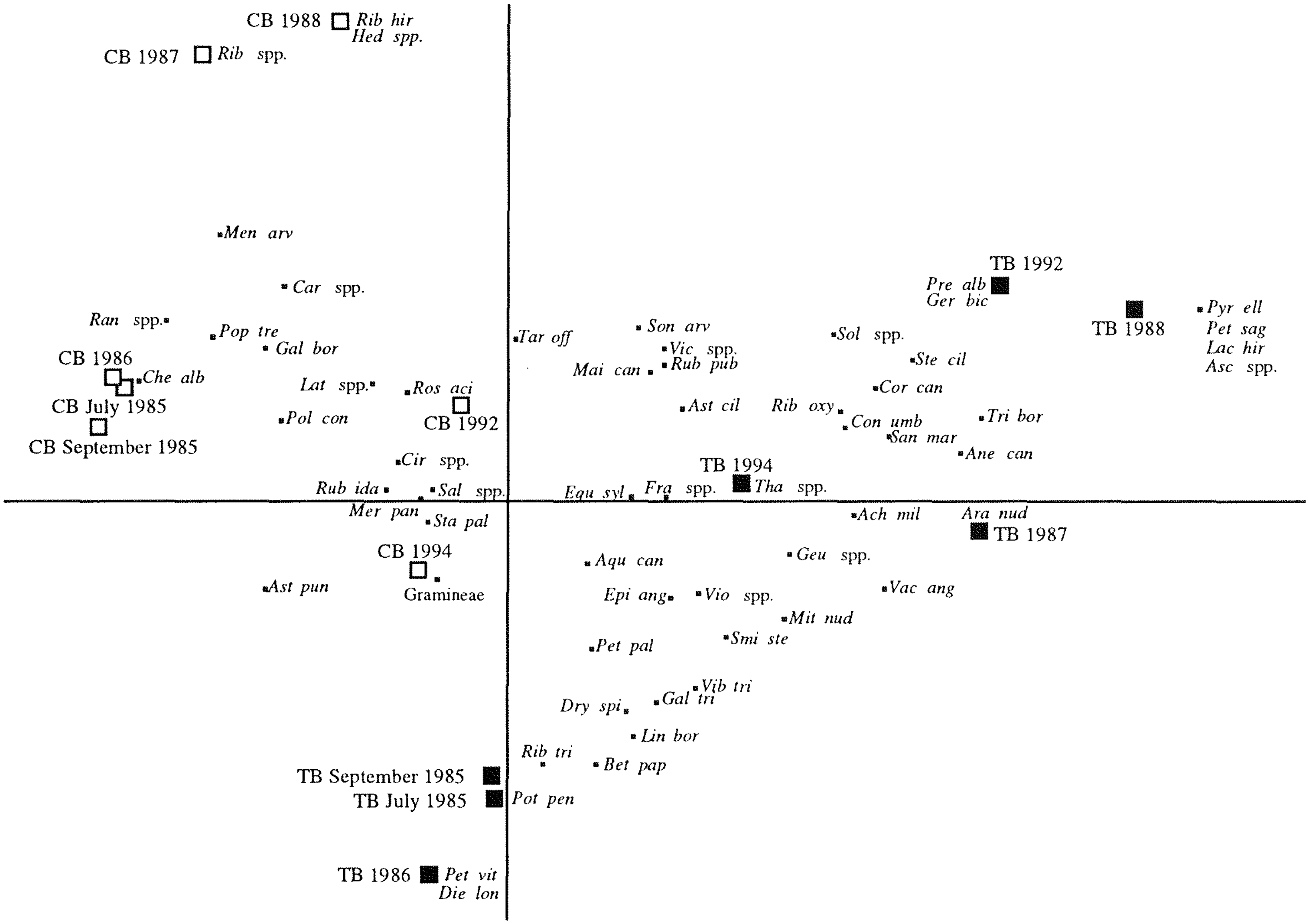

Fig. 16. Correspondence analysis of species and sample years from the CB and TB study sites. Species density data were collected from ten 1m^2 quadrats during each sample period at each site. The sum of all eigenvalues is 0.6098. The first axis (x) has an eigenvalue of 0.264, and accounts for 43.3% of the variance in the data. The second axis (y) has an eigenvalue of 0.143, which accounts for 23.5% of the variance in the data.

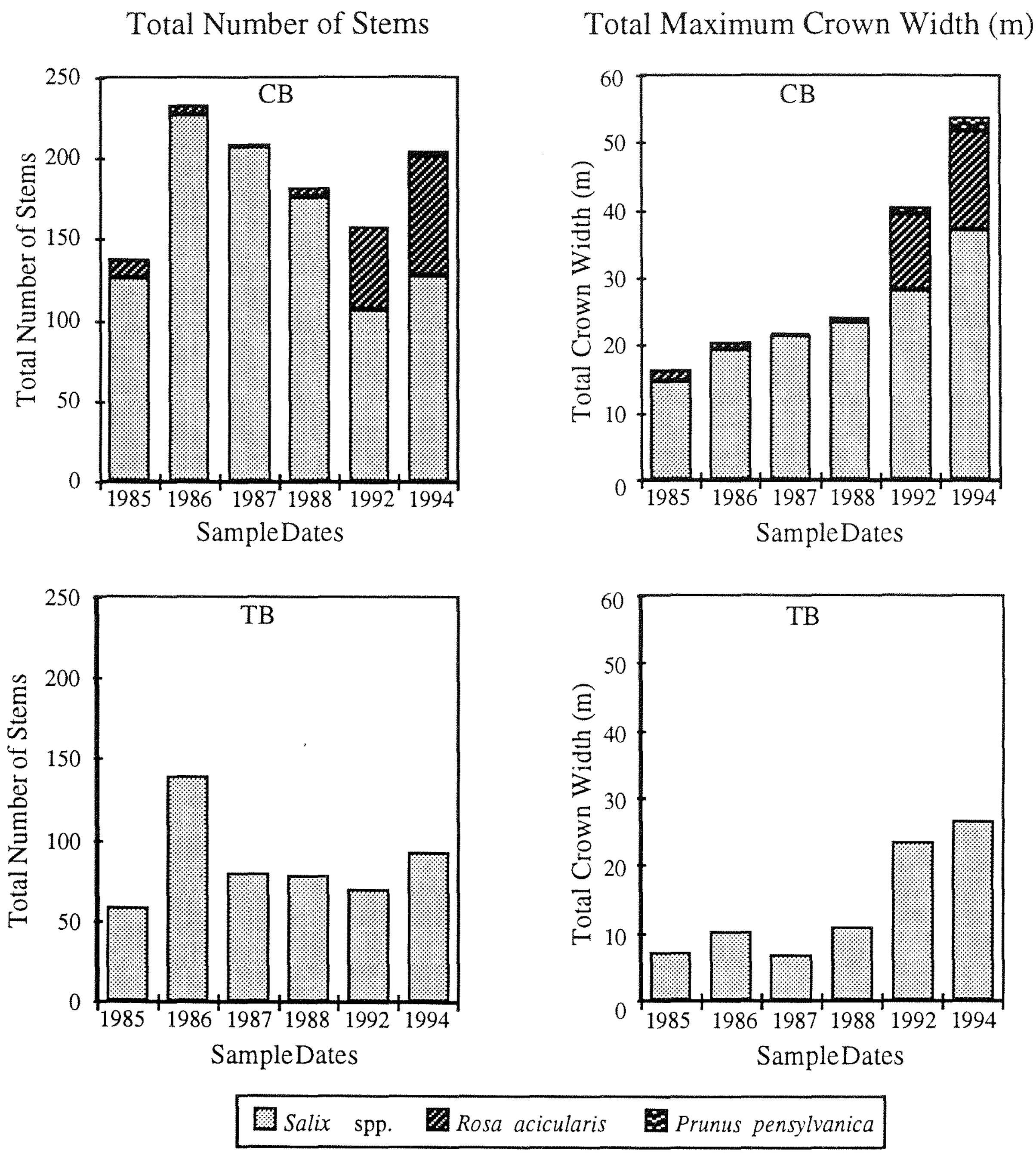

Fig. 17. Total number of stems and total maximum crown width (m) of each shrub species recorded within the 100 m^2 macroplot at the CB and TB study sites.

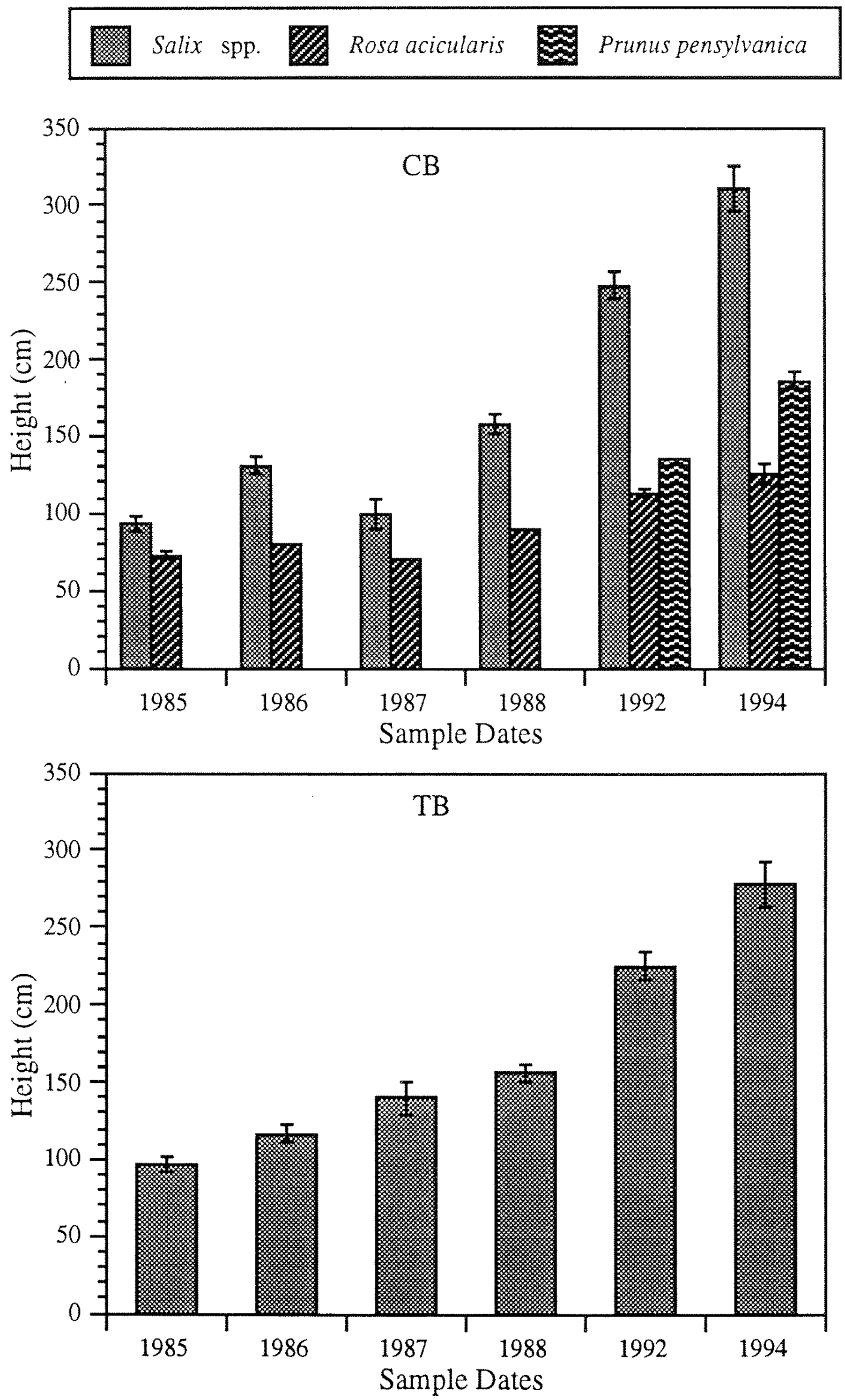

Fig. 18. Height (cm) of shrub species recorded within the 100 m^2 macroplot at the CB and TB study sites. Values are means ± SE.

constant through 1994. This decrease was far more severe than that recorded in the CB site over the same period. The total maximum crown width for *Salix* spp. in the TB site also declined from 1986 to 1987. The decline in stem numbers and total crown width indicates an overall decline in the sampled population during the 1987 sample period. In 1988, and through to 1994, the total maximum crown width of *Salix* spp. gradually increased. This, coupled with the steady increase in mean height of stems, suggests that surviving individuals in the sampled population tended to increase in size and stature over the latter years of the study.

Based on the results of shrub stratum sampling from both Burn sites it appears that *Salix* spp. was the initial recolonizing shrub after the 1984 burn. The results also suggest that the expansion of the *Salix* spp. numbers in terms of stem density was quite rapid for the first few years of site regeneration. CB site results indicate this expansion was followed by a decrease in stem density and increased growth of surviving stems. The trend of increasing mean stem height and total crown width over the course of the study appears to negate the possibility that browsing by ungulates was responsible for the decreasing trend in stem density. Rather, this decrease is likely the result of self-thinning in the *Salix* spp. population via intraspecific competition.

The 1992 sample period saw an influx of *Rosa acicularis* and the establishment of *Prunus pensylvanica* at the CB site. The initial expansion of the *Rosa acicularis* stem densities may have preceded the 1992 sample period, since no data were collected in the years between 1988 and 1992. The increase in the stem density and growth of *Rosa acicularis* at the CB site in 1992 suggest that this species is a secondary colonizer and its presence may represent the beginning of a second successional stage, in which the initial colonizer (i.e. *Salix* spp.) is gradually replaced. Further studies would be necessary to verify this theory.

Prior to 1987, the re-establishment of the shrub stratum at the TB site seemed to correspond well with developments at the CB site. The relatively high increase in stem density, and the modest increases in total maximum crown width and mean height from 1985 to 1986 suggest no effect from the 1985 herbicide application. However, the high stem mortality that occurred at the TB site from 1986 to 1987 does indicate a response to glyphosate. The effects of glyphosate applications have been known to have up to a two-year lag period (Malik and Vanden Born 1986). The reduction in *Salix* spp. stem density in 1987, and the failure of *Rosa acicularis* to become established in the shrub stratum at the TB site as it did in the CB site, may be attributable to the combined effects of the 1985 and 1986 herbicide applications.

Populus tremuloides was recorded at both the CB and TB sites. However, its density at the treated site was considerably less than at the control (Figure 19). *Betula papyrifera* was also present at the TB site. Twelve individuals of *Populus tremuloides* were recorded at the CB site in 1985. By the 1986 sample period this number had increased to 21 individuals. The density remained at this level during the 1987 and 1988 sample periods, and then increased to 77 and 79 individuals at the 1992 and 1994 sample periods, respectively. Total basal area at the CB site was not available for the 1985 to 1988 sample periods because all individuals were below breast height. By 1992 some individuals were high enough to allow the collection of DBH data and the calculation of total basal area for the site. In 1994 the total basal area at the CB site had more than doubled over that of 1992. The increase in density and total basal area indicates that the tree canopy was gradually being re-established at the CB site.

Nine *Populus tremuloides* and seven *Betula papyrifera* individuals were present at the TB site at the beginning of the study in 1985. By the 1986 sample period the *Betula papyrifera* individuals had died and the density of *Populus tremuloides* had decreased by three. In 1987 only two living *Populus tremuloides* remained at the site. The population increased to three individuals in 1988, and to ten individuals by the time of the 1992 sample period. As with the CB site, basal area measurements were not available at the TB site prior to the 1992 sample period. The decline in density of the tree species through the 1986 and 1987 sample periods, and their relatively slow recovery compared to the CB site, indicates that the 1985 and 1986 herbicide applications had a detrimental effect on subsequent growth and establishment of tree species at the TB site.

In summary, the results from sampling of the understorey, shrub, and tree strata at the CB site serves to illustrate the successional changes in vegetation composition, growth, and development following the 1984 forest fire. One year following the fire a number of early succession species such as *Rubus idaeus, Galium boreale, Viola* spp., *Salix* spp., and various graminoids became established. Within three or four seasons these species began to decrease in number, and secondary colonizers such as *Rosa acicularis, Aster ciliolatus, Maianthemum canadense,* and *Rubus pubescens* became established. This resulted in high species richness and diversity indices at the site. By the end of the sampling regime, the species diversity and richness were decreasing as the understorey species compliment became dominated by relatively few species, and the shrub and tree strata became more established.

Data from the tree, shrub, and understorey strata at the TB site suggest that the glyphosate applied in 1985 and 1986 caused vegetation moratlity. Generally, the herbicide

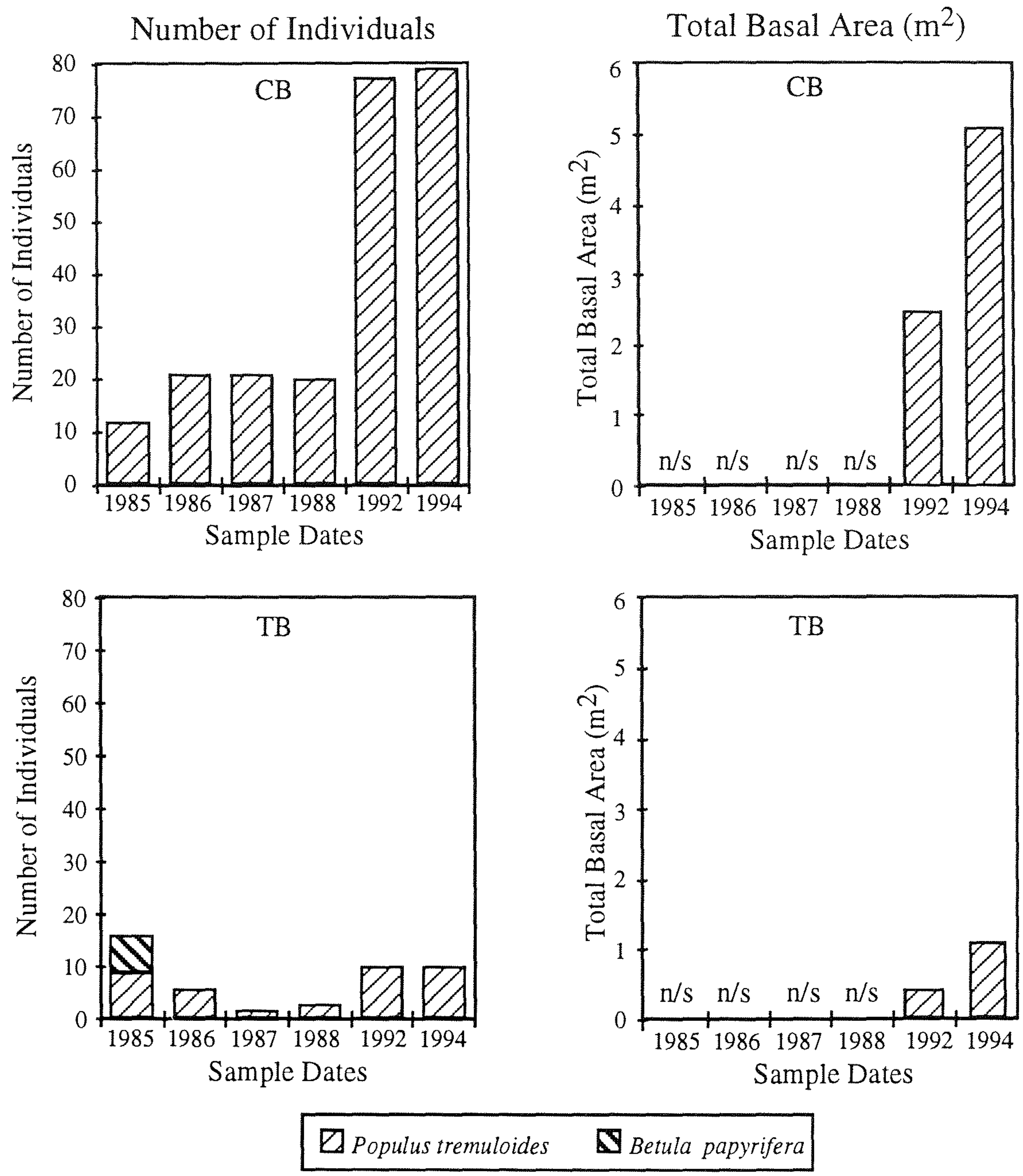

Fig. 19. Total number of individuals and total basal area (m^2) of tree species recorded in the 100 m^2 macroplot at the CB and TB study sites. Note there were no basal areas (n/s) sampled in 1985 to 1988 because the individuals were below breast height.

influenced the vegetation regeneration at the site by slowing the progress of tree and shrub strata re-establishment, and prolonging the presence of early succession understorey species such as *Epilobium angustifolium* and *Viola* spp. The disturbance brought about by the glyphosate applications also allowed the influx of a number of species not found in the CB site, which resulted in generally higher species diversity and species richness levels in the TB site.

4.2.4 Trans Licence Sites

The Trans Licence sites tended to support a relatively wide array of understorey species at fluctuating densities over the course of the study (Tables 10 and 11). Dicots, both herbaceous and woody, dominated the understorey vegetation of the sites. The more commonly occurring dicots at the CTL site included *Epilobium angustifolium, Rubus pubescens, Aster ciliolatus, Cornus canadensis* L. (bunchberry), and *Viola* spp., while *Epilobium angustifolium, Lathyrus* spp., *Vicia* spp., *Rubus idaeus, Sonchus arvensis*, and *Rubus pubescens* were the most common dicots at the TTL site.

Dicot species far out-numbered monocot, pteridophyte, and conifer species at both sites. Monocots that occurred at the CTL site included species of grasses, *Maianthemum canadense,* and *Clintonia borealis* (Ait.) Raf. (bluebead lily). Grasses were the only monocots recorded at the TTL site. The fern *Pteridium aquilinum* (L.) Kuhn (bracken fern) was found at both sites, but the club mosses *Lycopodium clavatum* L. and *Lycopodium obscurum* L., only occurred at the CTL site. The CTL site supported relatively small populations of *Pinus banksiana* and *Picea glauca* seedlings. *Pinus banksiana* seedlings were also present at the TTL site, but at very low densities.

Definite trends in species population changes were observed at both Trans Licence sites over the course of the study. At the CTL site *Aster ciliolatus, Maianthemum canadense, Cornus canadensis, Diervilla lonicera* Mill. (bush-honeysuckle), *Rubus pubescens, Apocynum androsaemifolium* L. (spreading dogbane), and grasses showed increasing densities, while the densities of both *Epilobium angustifolium* and *Viola* spp. were decreasing. The decreasing density of *Epilobium angustifolium* was also apparent at the TTL site. However, densities of *Epilobium angustifolium* at the TTL site were always higher than those recorded at the CTL site during the sample periods. This was particularly evident during the 1987 and 1988 sample periods when the density of *Epilobium angustifolium* was 49.0 and 35.2 individuals/m^2 respectively, while at the CTL site the densities were 38.6 and 22.3 individuals/m^2 over the same period. *Cirsium* spp. and *Viola* spp. also showed a gradual decrease in density over the study period. *Lathyrus* spp., *Vicia* spp., *Diervilla lonicera, Rubus idaeus, Rubus pubescens, Sonchus arvensis, Galium*

Table 10. Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrat at the CTL site. Values are means ± SE. (n = 10).

Species	1987			1988			1992			1994		
Apo and	1.1	±	1.0	0.6	±	0.5	1.8	±	1.1	3.0	±	1.7
Ara nud	0.4	±	0.2	0.2	±	0.2	0.3	±	0.2	0.7	±	0.4
Ara his	0.0	±	0.0	0.1	±	0.1	0.1	±	0.1	0.0	±	0.0
Ast cil	9.5	±	2.4	14.4	±	3.6	43.4	±	7.2	46.1	±	6.3
Ast sim	0.4	±	0.4	0.5	±	0.5	0.0	±	0.0	0.0	±	0.0
Cau tha	0.3	±	0.3	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0
Cir spp.	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1	0.1	±	0.1
Cli bor	0.4	±	0.4	0.7	±	0.7	0.7	±	0.7	1.4	±	1.4
Cor can	1.3	±	0.9	2.1	±	1.1	4.7	±	2.1	5.4	±	2.5
Cor cor	0.5	±	0.3	0.6	±	0.3	0.6	±	0.3	1.2	±	0.7
Die lon	1.0	±	0.4	1.2	±	0.5	2.2	±	0.8	5.5	±	1.7
Epi ang	28.6	±	3.9	22.3	±	2.2	9.2	±	1.1	7.8	±	1.1
Eri can	2.0	±	1.9	5.2	±	5.2	0.0	±	0.0	0.0	±	0.0
Fra spp.	0.8	±	0.6	0.7	±	0.6	1.3	±	0.6	1.3	±	0.6
Gal bor	0.3	±	0.3	0.5	±	0.5	0.6	±	0.6	0.8	±	0.8
Ger bic	2.2	±	0.7	0.3	±	0.2	0.0	±	0.0	0.1	±	0.1
Gramineae	0.0	±	0.0	0.2	±	0.2	0.6	±	0.3	10.6	±	4.2
Hal def	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1
Lat spp.	1.3	±	0.6	1.3	±	0.7	1.6	±	1.0	2.1	±	1.3
Lin bor	0.0	±	0.0	0.0	±	0.0	1.1	±	1.1	2.0	±	2.0
Lyc cla	0.0	±	0.0	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0
Lyc obs	0.7	±	0.6	0.4	±	0.4	1.0	±	0.7	0.8	±	0.6
Mai can	1.2	±	0.6	1.2	±	0.6	2.7	±	1.4	6.2	±	2.9
Pet pal	0.7	±	0.4	0.1	±	0.1	0.1	±	0.1	0.2	±	0.1
Pic gla	1.1	±	0.4	1.0	±	0.3	0.8	±	0.2	1.2	±	0.4
Pin ban	0.5	±	0.2	0.4	±	0.2	0.4	±	0.2	0.4	±	0.2
Pop tre	1.0	±	0.4	1.0	±	0.4	0.9	±	0.3	0.7	±	0.3
Pot tri	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1	0.0	±	0.0
Pte aqu	1.7	±	0.7	1.5	±	0.7	3.2	±	1.0	2.7	±	1.2
Ros aci	0.1	±	0.1	0.4	±	0.2	0.8	±	0.5	1.4	±	0.8
Rub ida	0.2	±	0.1	0.0	±	0.0	0.1	±	0.1	0.2	±	0.1
Rub pub	2.1	±	1.0	3.2	±	1.4	3.6	±	1.5	6.4	±	2.2
Sal spp.	1.2	±	0.6	1.7	±	0.8	0.6	±	0.3	0.7	±	0.3
Sol spp.	0.2	±	0.1	0.1	±	0.1	0.1	±	0.1	0.2	±	0.1
Tha spp.	0.5	±	0.4	0.3	±	0.3	0.0	±	0.0	0.0	±	0.0
Tri bor	0.1	±	0.1	0.1	±	0.1	0.4	±	0.4	0.4	±	0.4
Vac ang	1.6	±	0.7	0.2	±	0.1	0.7	±	0.4	0.4	±	0.3
Vac vit	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0
Vic spp.	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	1.0	±	0.5
Vio spp.	6.0	±	1.5	1.6	±	0.5	1.0	±	0.6	0.2	±	0.1
Species Richness		32			32			31			32	
Species Diversity		0.98			0.96			0.87			0.98	

*For explanation of abbreviations see Appendix I

Table 11. Density (individuals/m2) of vascular plant species recorded in 1m x 1m quadrats at the TTL site. Values are means ± SE. (n = 10).

Species	1987	1988	1992	1994
Ame aln	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.2
Apo and	0.5 ± 0.4	0.0 ± 0.0	1.0 ± 0.7	0.5 ± 0.2
Ara nud	0.6 ± 0.5	0.1 ± 0.1	0.2 ± 0.2	0.5 ± 0.3
Ast cil	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.3 ± 0.2
Car spp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Cir spp.	4.9 ± 1.1	3.9 ± 1.2	0.5 ± 0.2	1.3 ± 0.5
Cor can	1.8 ± 1.1	0.8 ± 0.6	3.0 ± 1.7	3.9 ± 2.1
Cor cor	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
Cor sto	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Die lon	1.6 ± 0.8	0.6 ± 0.4	1.3 ± 0.7	3.2 ± 0.9
Epi ang	49.0 ± 5.6	35.2 ± 5.0	11.5 ± 1.7	11.1 ± 1.9
Fra spp.	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.7 ± 0.7
Gal bor	0.0 ± 0.0	0.6 ± 0.6	2.3 ± 1.0	3.9 ± 1.3
Gau his	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Ger bic	0.7 ± 0.3	0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Gramineae	0.0 ± 0.0	0.0 ± 0.0	4.2 ± 2.1	39.1 ± 25.1
Hal def	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 1.3
Lac sp.	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0
Lat spp.	9.0 ± 1.6	13.2 ± 1.8	14.5 ± 3.7	10.8 ± 1.8
Med lup	2.1 ± 1.6	1.0 ± 0.6	0.4 ± 0.2	0.5 ± 0.3
Pet pal	0.4 ± 0.3	0.2 ± 0.2	0.1 ± 0.1	0.3 ± 0.3
Pin ban	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Pop tre	0.2 ± 0.2	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Pte aqu	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Ros aci	0.2 ± 0.1	0.2 ± 0.2	0.8 ± 0.4	1.2 ± 0.5
Rub ida	7.9 ± 2.4	9.4 ± 2.4	12.9 ± 1.8	16.8 ± 3.5
Rub pub	1.8 ± 1.3	1.7 ± 1.2	0.3 ± 0.3	5.0 ± 2.3
Sal spp.	0.2 ± 0.2	1.3 ± 1.3	0.4 ± 0.3	0.6 ± 0.5
Sol spp.	0.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2
Son arv	0.0 ± 0.0	0.9 ± 0.6	20.9 ± 5.1	15.3 ± 4.6
Tar off	1.8 ± 1.0	1.4 ± 0.9	1.3 ± 0.4	2.0 ± 0.4
Vac ang	0.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Vib raf	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Vic spp.	2.8 ± 0.9	2.9 ± 0.8	5.0 ± 0.9	3.9 ± 0.8
Vio spp.	3.5 ± 2.6	0.2 ± 0.2	1.2 ± 0.8	0.8 ± 0.4
Species Richness	22	24	25	29
Species Diversity	0.77	0.76	0.95	0.99

*For explanation of abbreviations see Appendix I

boreale, Taraxacum officinale Weber (dandelion), and grass species all increased in density at the TTL site over the course of the study.

Quadrat sampling results indicated that the species diversity and species richness of the understorey vegetation at the two Trans Licence sites differed both before the herbicide application in 1987 and one year post-spray in 1988 (Figure 20). The CTL site had the higher diversity index during 1987 and 1988. Its diversity declined in 1992 and then increased again in 1994 to levels equal to the 1987 sample period. Species richness at the CTL site remained essentially constant over the course of the study. A constant species richness accompanied by a fluctuating diversity index indicates changes in the relative densities of the species present, but no change in the overall number of species. The species diversity at the TTL site was considerably lower than at the CTL site over the first two sample periods. However, by the 1992 and 1994 periods the diversities had become approximately equal. The species richness at the TTL site was consistently lower than that of the control, but did increase from 22 to 29 over the course of the study.

The decrease in diversity at the CTL site from 1987 to 1992 could be attributed to a four-fold increase in *Aster ciliolatus* and a simultaneous decrease in the density of *Epilobium angustifolium* and *Viola* spp. This shift resulted in *Aster ciliolatus* becoming the dominant herbaceous species at the site in 1992. With the increase in densities of grasses, *Maianthemum canadense, Rubus pubescens*, and *Diervilla lonicera* in 1992, the distribution of individuals across the entire species compliment of the site became more even, resulting in an overall increase in the diversity index from the previous sample period. The constant species richness level over the course of the study at the CTL site is due to the introduction and subsequent loss of relatively uncommon species, which did not exert a large influence on the species diversity at the site.

The low species diversity encountered at the TTL site during the 1987 and 1988 periods is likely due to the dominance of *Epilobium angustifolium* in the understorey vegetation. After 1988, the density of *Epilobium angustifolium* began to decline while the density of species such as *Sonchus arvensis, Rubus idaeus, Lathyrus* spp., and *Vicia* spp. increased. This led to a more even distribution of individuals among the species and resulted in higher diversity values for 1992 and 1994. The increase in species richness in 1994 was due to the addition of new species and retention of 96% of the species compliment from the previous sample period. However, the new species were at very low densities (i.e. one or two individuals for the entire site) and thus did not affect the diversity index.

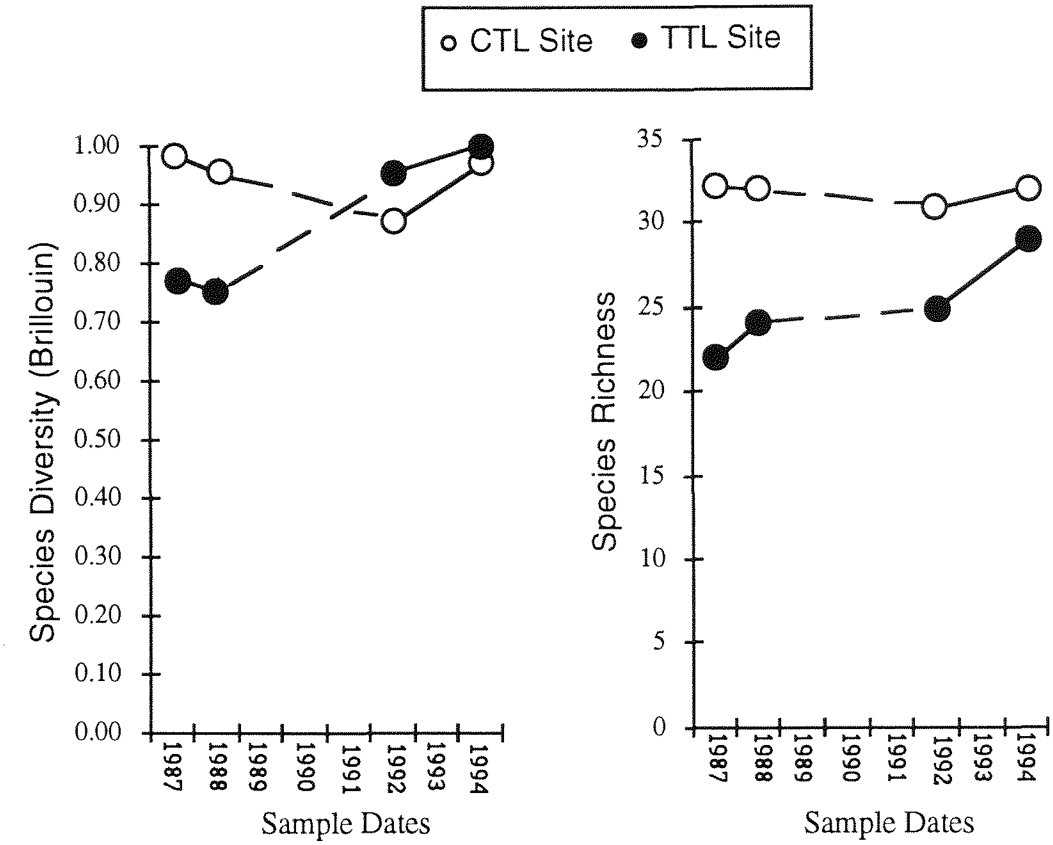

Fig. 20. Species diversity (Brillouin) and species richness of the CTL and TTL sites at various sampling periods over the course of the study (1987 to 1994).

The results of the correspondence analysis serve to illustrate the differences and similarities in understorey vegetation between the two Trans Licence sites (Figure 21). The first axis separates the two sites based on differences in species composition and density, while the second axis appears to separate the sample years within each site and represents post-fire successional changes in the vegetation of the sites.

The location of *Epilobium angustifolium* approximately midway between the sites on the upper part of the second axis clearly illustrates the close association of the species to both sites during the 1987 and 1988 sample periods. Its relatively greater distance from the 1992 and 1994 sample periods at both sites is reflective of a decrease in density at the sites during the later sample periods of the study. On the contrary, the positioning of the grasses between the 1994 CTL and TTL sites appears to have resulted from the fact that they were more prevalent at the sites later in the study.

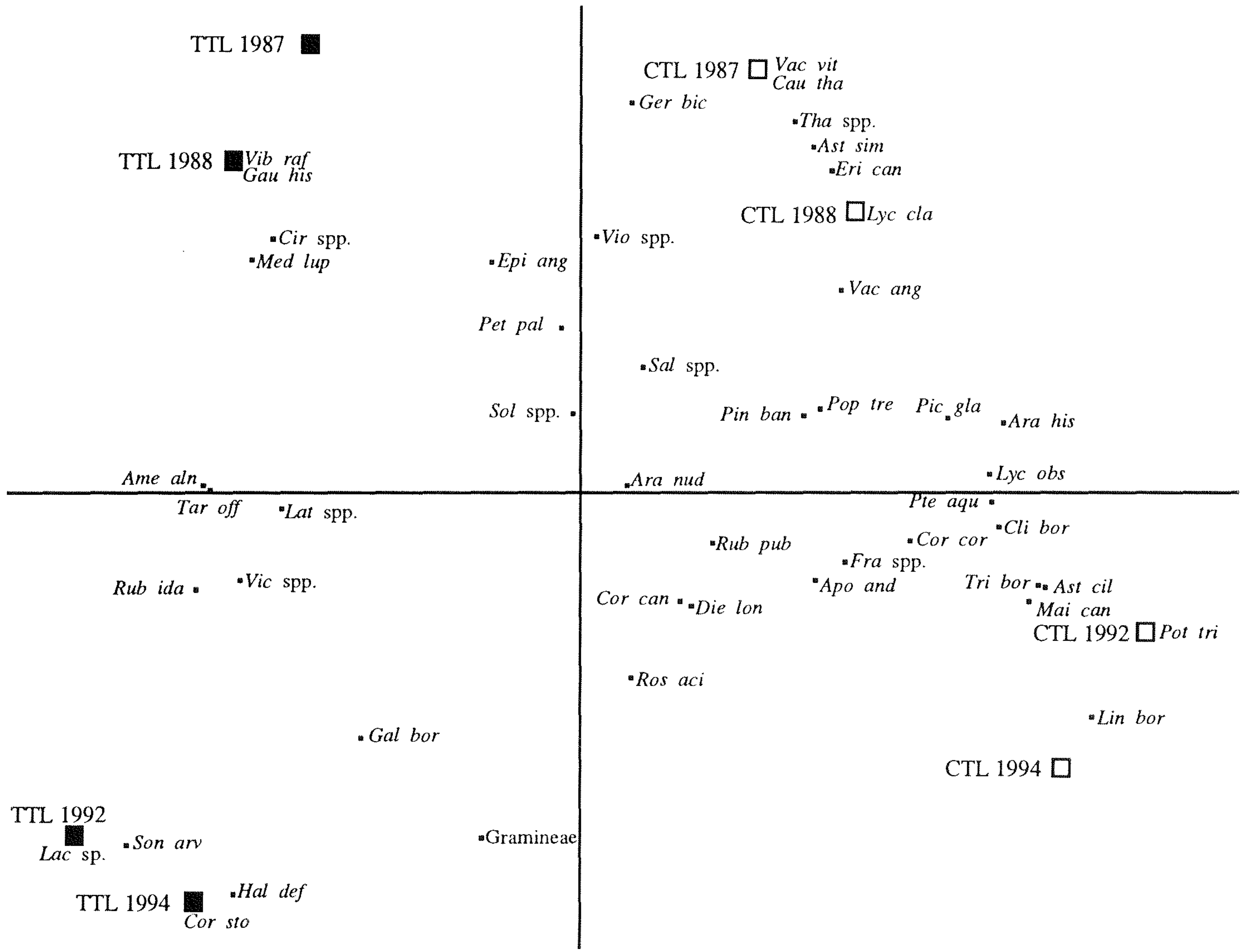

Fig. 21. Correspondence analysis of species and sample years from CTL and TTL study sites. Species density data were collected from ten $1m^2$ quadrats during each sample period. The sum of all eigenvalues is 1.063. The first axis (x) has an eigenvalue of 0.533, and accounts for 50.1% of the total variance in the data. The second axis (y) has an eigenvalue of 0.313, which accounts for 29.4% of the variance in the data.

During 1992 and 1994 *Sonchus arvensis* had a relatively high density at the TTL site, which accounts for the close proximity of the species to these two sample points in the diagram. This contrasts with the CTL site in 1992 and 1994, where *Maianthemum canadensis* and *Aster ciliolatus* were at their highest density levels. In fact, *Sonchus arvensis* was only found at the TTL site, and *Maianthemum canadense* was only recorded in the control. On the otherhand, *Aster ciliolatus* was common at the CTL site, and rare at the TTL site.

The understorey vegetation of the two sites was most similar in 1987 (four years after a forest fire had swept through the area). The application of the herbicide in mid-August 1987 did not affect the vegetation of that strata. Both sites followed the same general successional trend that is indicated by their distribution along the second axis. The distance between the 1987 and 1988 sample points at the TTL site is similar to that at the CTL site, indicating that neither site experienced a dramatic alteration in species composition from 1987 to 1988. Following the 1988 sample period the two sites became less similar over time. The data indicate that this change was likely due to the decrease in dominance of *Epilobium angustifolium* at both sites and the simultaneous increase in density of *Sonchus arvensis* and, to a lesser degree, *Rubus idaeus* at the TTL site, and *Maianthemum canadense* and *Aster ciliolatus* at the CTL site. By 1992 the two sites were very dissimilar. Based on the divergent trend from 1987 to 1992, it appears that the understorey species composition of the sites may have been quite similar immediately following the forest fire event in 1983, and through years of succession have since become increasingly dissimilar. The two sites began to converge slightly in 1994 (Figure 21). This was partly due to an increase in the density of grass species at both sites. Determination of the importance of this latter observation in the progress and direction of successional changes at the sites would require future field investigations.

Vegetation sampling revealed definite trends of increasing stem density and total maximum crown width within the shrub stratum of the CTL site over the course of the study (Figure 22). The total number of stems increased from 30 to 111, while the total maximum crown width rose from 400 cm to 3052 cm over the 1987 to 1994 period. The major shrub species found at the CTL site included *Corylus cornuta*, *Salix* spp., *Amelanchier alnifolia*, and *Rosa acicularis*. The density of the *Corylus cornuta* population was initially low, but increased during the 1988, 1992, and 1994 sample periods to become the most dense shrub species at the site. However, because the total maximum crown width and mean shrub height of *Corylus cornuta* were generally smaller than *Salix* spp. and *Amelanchier alnifolia* (Figure 23), *Corylus cornuta* did not appear to dominate the shrub stratum of the site.

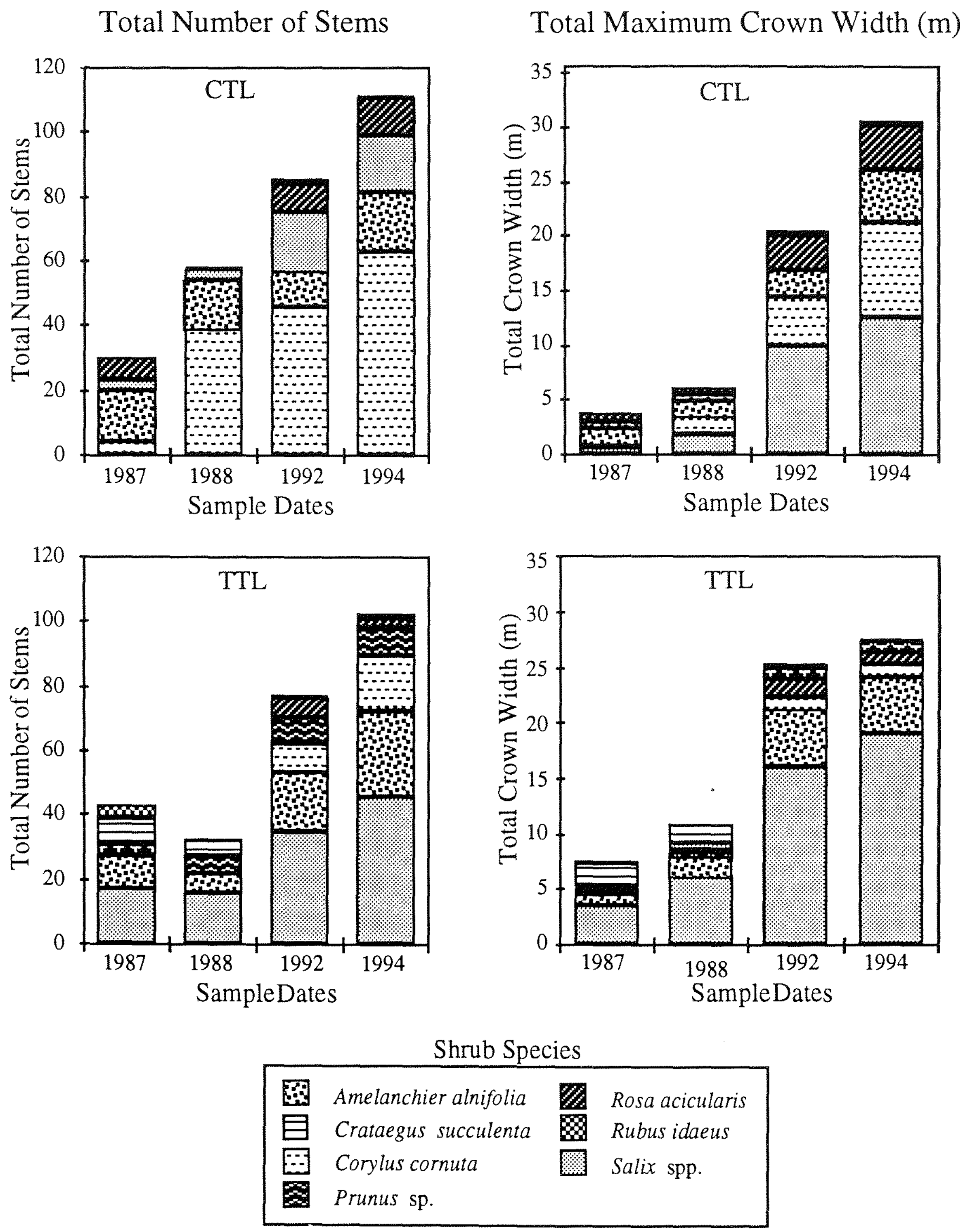

Fig. 22. Total number of stems and total maximum crown width (cm) of shrub species recorded in the 100 m^2 macroplot at the CTL and TTL study sites.

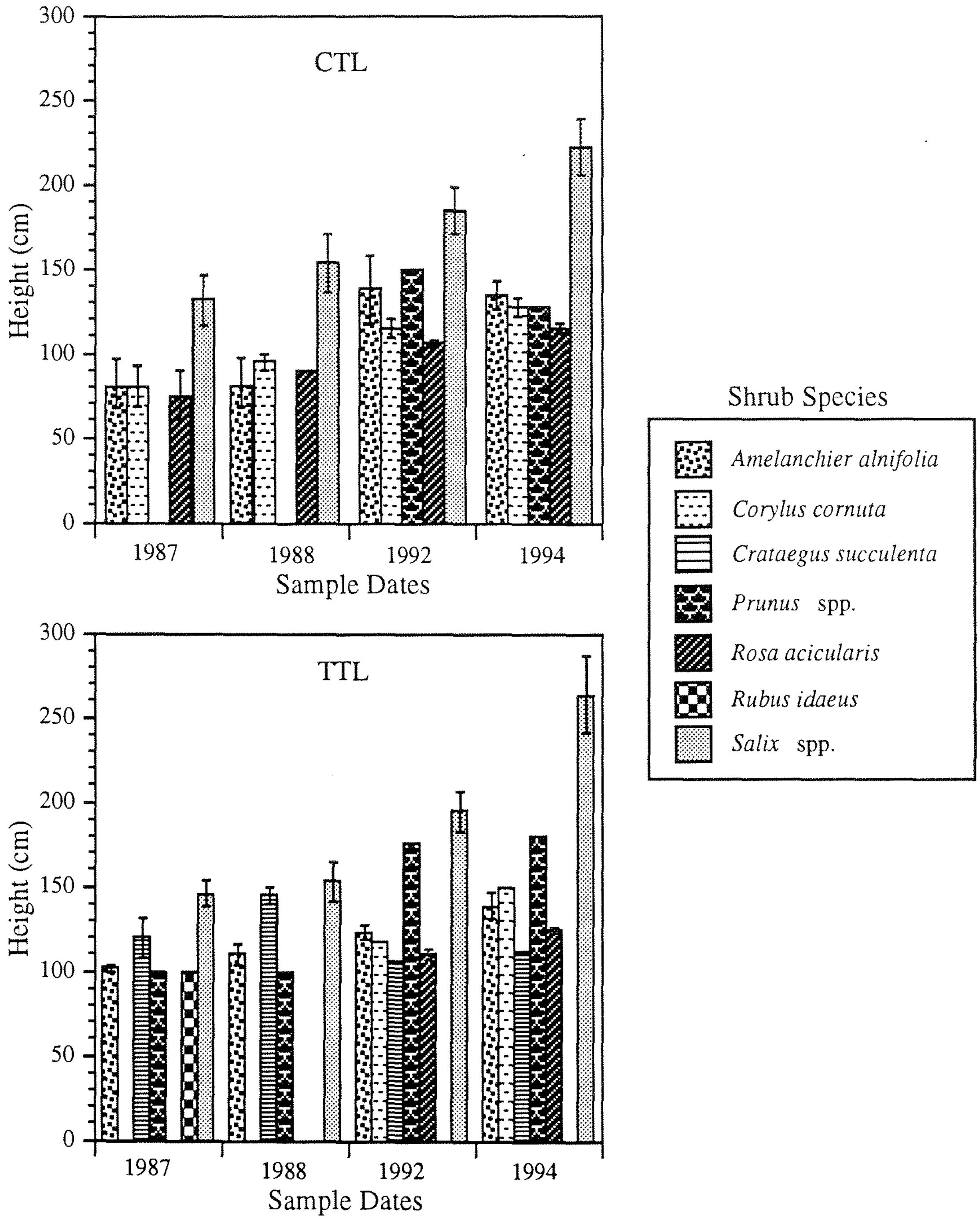

Fig. 23. Height (cm) of shrub species recorded within the 100 m^2 macroplot at the CTL and TTL study sites. Values are means ± SE.

Salix spp., *Amelanchier alnifolia, Prunus* sp., *Rosa acicularis,* and *Corylus cornuta* were the main shrub species found at the TTL site. Like the control site, shrubs at the TTL site increased in size over the course of the study (Figures 22 and 23). Unlike the control, *Salix* spp. and *Amelanchier alnifolia* dominated the shrub stratum of the TTL site, while the stem density and total maximum crown width of *Corylus cornuta* were considerably lower. Total stem density and crown width of the shrub layer at the site were similar to those of the control during corresponding sample periods except 1988. From 1987 to 1988 the total stem density at the TTL site decreased 28% (from 43 to 31 stems), while stem density increased 93% (from 30 to 58) at the CTL site over the same period. The decline at the TTL site and a corresponding increase at the CTL site is probably indicative of a herbicide effect on the shrub stratum at the former site. Leaf tissue samples of *Rosa acicularis* collected at the TTL site immediately following the herbicide application in 1987 contained glyphosate residue concentrations ranging from 231 μg/g to 608 μg/g, indicating that there was interception of herbicide by the shrub stratum. The herbicide application caused a decrease in the stem density of *Amelanchier alnifolia, Crataegus succulenta,* and *Rubus idaeus*. The effect on the *Salix* spp. population was to halt any further increase in stem density above the level recorded in 1987. *Prunus* spp. was the only shrub species which increased in stem density following the herbicide application at the TTL site. Shrub-size stems of *Rosa acicularis* and *Corylus cornuta* became established in the site following the 1988 sample period, during which time the *Crataegus succulenta* population declined to a single individual. Although the stem density data indicates a reduction in the overall shrub stem density due to the glyphosate application, the surviving members of the population continued to increase in size following the 1987 spray. By the 1992 and 1994 sample periods, the total stem density and maximum crown width measurements for the shrub stratum in the TTL site were comparable to those at the CTL site.

Populus tremuloides was the dominant tree species at both the Trans Licence sites (Figure 24). Individuals of *Picea glauca* and *Pinus banksiana* were also present at both sites, but at relatively lower densities. The density of *Populus tremuloides* at the CTL site experienced a 24% decline following the 1987 sample period. This decline may have resulted from a damaging wind storm which swept through the area of the Trans Licence sites during the late summer of 1987. This was evidenced by considerable deadfall at the CTL site in 1988, which was not observed the previous year. The densities of *Picea glauca* and *Pinus banksiana* remained unchanged at two and three individuals, respectively, over the 1987 to 1988 period. By 1992 the density of *Populus tremuloides* had increased to 136 individuals from the low of 84 individuals in 1988, and remained unchanged into 1994.

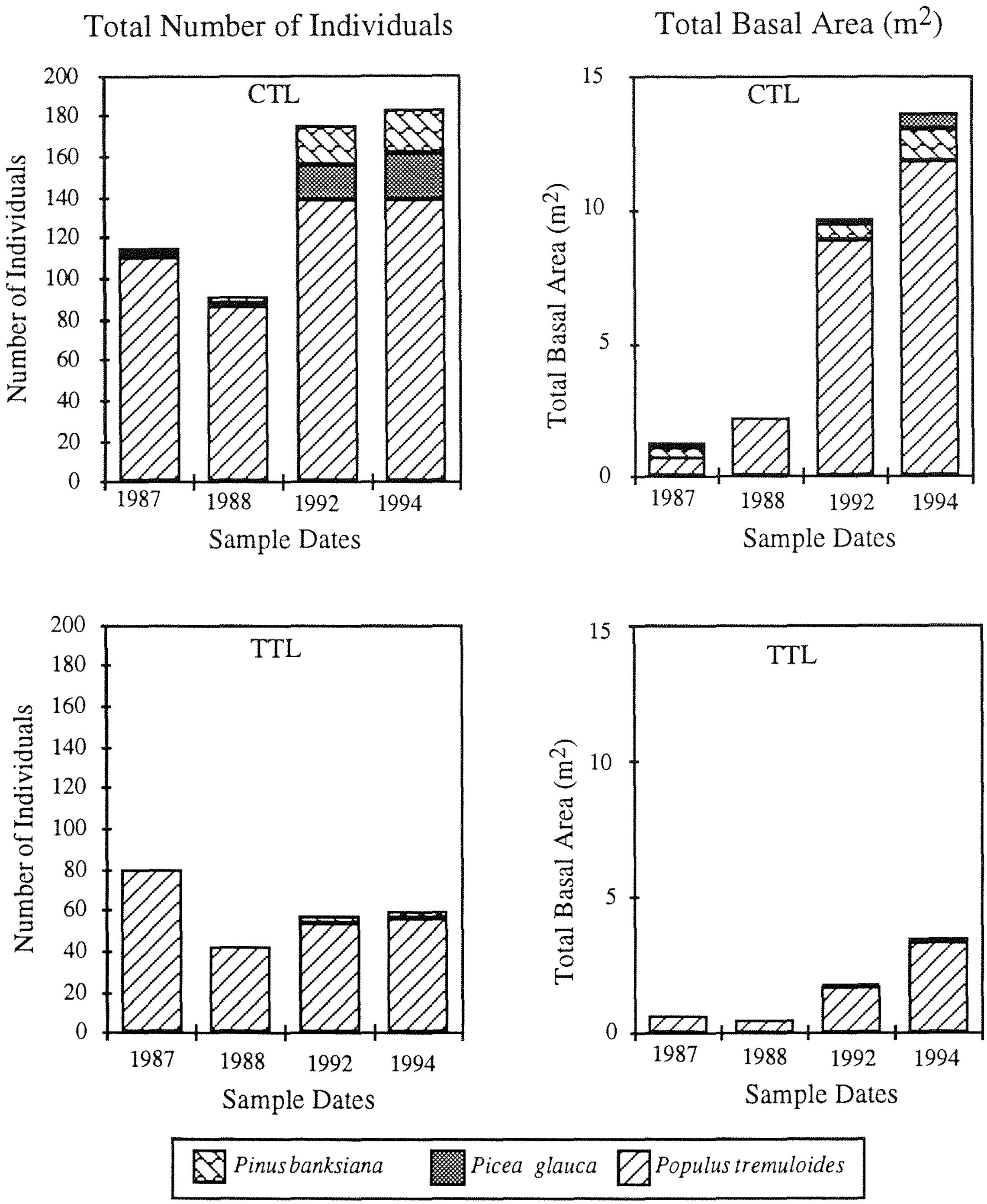

Fig. 24. Total number of individuals and total basal area (m^2) of tree species recorded in the 100 m^2 macroplot at the CTL and TTL study sites.

The densities of *Picea glauca* and *Pinus banksiana* at the CTL site also increased during the 1988 to 1992 period to 16 and 23 individuals, respectively. The 1994 sample period revealed that the number of *Picea glauca* had increased by an additional seven individuals, while that of *Pinus banksiana* remained unchanged from 1992 levels. Total basal measurements for the tree species were relatively low during the initial sampling in 1987, but increased through 1988, 1992, and 1994.

The TTL tree stratum consisted solely of *Populus tremuloides* for the first two sample periods (Figure 24). Total basal area measurements indicate that individuals were relatively small at that time. A few individuals of *Pinus banksiana* had become established by the 1992 and 1994 sample periods. The number of individuals and the total basal area of the tree stratum declined substantially from 1987 to 1988 at the CTL site, and by the end of the study the density of individuals still remained below the levels recorded in 1987. However, basal area measurements indicate that the surviving members were increasing in size over the course of the study. Herbicide interception by the tree stratum was evidenced by the presence of glyphosate residues at concentrations between 190 μg/g and 318 μg/g in leaf tissue of *Populus tremuloides*. Those concentrations were lower than those detected in the shrub layer, but higher than those found in the understorey herbaceous layer at the site. The presence of glyphosate in leaf tissue, the decline in density of individuals following the application, and the relatively slow recovery of the vegetation in post-spray years provide evidence that the 1987 herbicide application had a detrimental effect on the growth and post-fire succession of the tree stratum in the TTL site.

In summary, at the beginning of the study in 1987 the vegetation strata of the Trans Licence sites were still recovering from a forest fire that had swept through the area in September 1983. *Epilobium angustifolium* is a characteristic understorey species of early post-fire or post-disturbance succession (Vanha-Majamaa and Lahde 1991). This accounts for its high density at the two sites during the first two years of the study. The decline in density of *Epilobium angustifolium* at both sites in the latter years of the study, and concomitant increase in other species (*Aster ciliolatus, Maianthemum canadense, Rubus pubescens*, *Diervilla lonicera*, and grasses at the CTL site; and *Sonchus arvensis, Rubus idaeus, Lathyrus* spp., *Vicia* spp., and grasses at the TTL site) appear to have resulted from natural succession. It also appears that there may have been differences in soil characteristics and pre-fire species composition, and this, along with variability in survival of propagules following the fire, could have contributed to the differences in post-fire succession of the understorey vegetation between the two sites. The data do not indicate if the glyphosate applications in 1987 affected the understorey vegetation at the TTL site, but evidence for effects on the shrub and tree strata is apparent. Tissue samples of herbaceous species contained concentrations of glyphosate between 165 μg/g and 188 μg/g immediately following the application. Indications are that the shrub and tree strata, which had higher levels of residue, intercepted the majority of the herbicide before it could reach the ground level. As with the TB site results, the main effect of the herbicide on the shrub and tree layers at the TTL site was the interruption of the natural regeneration of those vegetation strata.

Successional progress also differed between the CTL site and the CB site. The temporal variation in species composition and growth parameters at the two sites represent natural post-fire regeneration through successional changes in vegetation. However, the fire event at the Burn sites occurred in 1984 and data collection was initiated in 1985, while the Trans Licence sites were burned in 1983 and data collection did not commence until 1987. Thus, four years of immediate post-fire data are not available from the CTL site. As well, the two control sites had different soil types, and it appears that their vegetation composition differed. The development of the tree stratum was also different between the CTL and the CB sites, which may account for differences in the successional development of the shrub and understorey strata at each site.

4.2.5 Timber Harvest Sites

The Timber Harvest sites occupy a portion of land along the Maskwa River that was harvested in the early 1940's. The entire area was shearbladed to remove regenerated hardwood species and replanted with *Picea glauca* seedlings during 1982-1983. A portion of the replanted area was sprayed with glyphosate (2.5 l/ha) in mid-August 1984, while the remainder of the area was left to regenerate naturally as a buffer near the river. The CTH site was located in the unsprayed area, while the TTH site was established in the sprayed area. Establishment of the sites for sampling purposes took place in the summer of 1992; eight years following the glyphosate application, and nine years after the shear-blading and replanting operation. Since no quantitative data are available regarding the vegetation status of either site prior to 1992, a series of aerial photographs were studied in an attempt to glean some information regarding the pre- and post-perturbation vegetation status of the sites. All photos were obtained from the Surveys and Mappings Branch of Manitoba Natural Resources, Winnipeg, Manitoba.

Figures 25 to 29 present a sequence of aerial photos of the timber harvest area taken in June 1927, June 1975, June 1983, May 1985, and June 1993, respectively. Each figure is a digitized reproduction of a portion of the original photo. The small river that appears in

Figures 26 to 29 is a tributary of the Little Bear Creek, which is, in turn, a tributary of the Maskwa River. Figure 25 presents an oblique view of the area northeast of the junction of the Maskwa River and the Winnipeg River. The photo was taken in 1927. Although the photograph does not provide a very clear picture of the future timber harvest area itself, it does provide clear indication that the whole area north of the Winnipeg River was virtually untouched by human activity at that point in time. Unfortunately, no aerial photos of the site immediately before or after harvesting in the early 1940's are available. However, aerial photos taken in 1948 (A11704-211) and 1958 (A15955-4) indicate ongoing regeneration of the logged area by hardwood species. These photos were not included as figures in this report because they were taken at a high altitude and the resulting resolution following digitization was poor. The entire timber harvest area consisted of a relatively dense stand of hardwoods, likely dominated by *Populus tremuloides* prior to shear-blading (Figure 26). The vegetation of the TTH and CTH sites were likely similar prior to shear-blading. A reproduction of the timber harvest area in June 1983, shortly after shear-blading and just prior to replanting, shows the shear-bladed area with its distinct windrows (Figure 27). The vegetation across the area where the CTH and TTH sites were located, appeared homogeneous. At that time the sites likely supported herbaceous species and a few scattered shrubs and small trees. In May 1985, one-year post-spray, regeneration of vegetation beyond the understorey herbaceous stratum is not apparent (Figure 28). Differences between the vegetation of the TTH and CTH sites were not discernible from the photo. *Populus tremuloides* regrowth in the unsprayed western and southern portion of the area was evident in the June 1993 photo (Figure 29).

Sampling in 1992 and 1994 revealed that the understorey vegetation of the CTH and TTH sites differed considerably (Table 12). There were a number of species that were unique to each site, and those species that were common to both sites often differed with regard to density. Relatively dense species that occurred at each of the sites were *Solidago* spp., *Thalictrum* spp., and *Equisetum arvense*. *Carex* spp., *Anemone canadensis, Aster ciliolatus, Cirsium arvensis, Fragaria* spp., *Lathyrus* spp., *Viola* spp., and *Vicia* spp., although found at both sites, were exceedingly more dense at the TTH site than at the CTH site. Meanwhile, *Maianthemum canadense, Rubus idaeus, Rubus pubescens, Athyrium filix-femina,* and grass species were more common at the CTH site than at the TTH site. Species that were unique to one site or the other tended to have low density values. Examples of such species included *Impatiens biflora* Walt. (touch-me-not, jewel-weed), *Galium triflorum* Michx. (sweet-scented bedstraw), and *Mitella nuda* L. (bishop's cap) at the CTH site, and *Epilobium angustifolium, Sanicula marilandica, Viburnum*

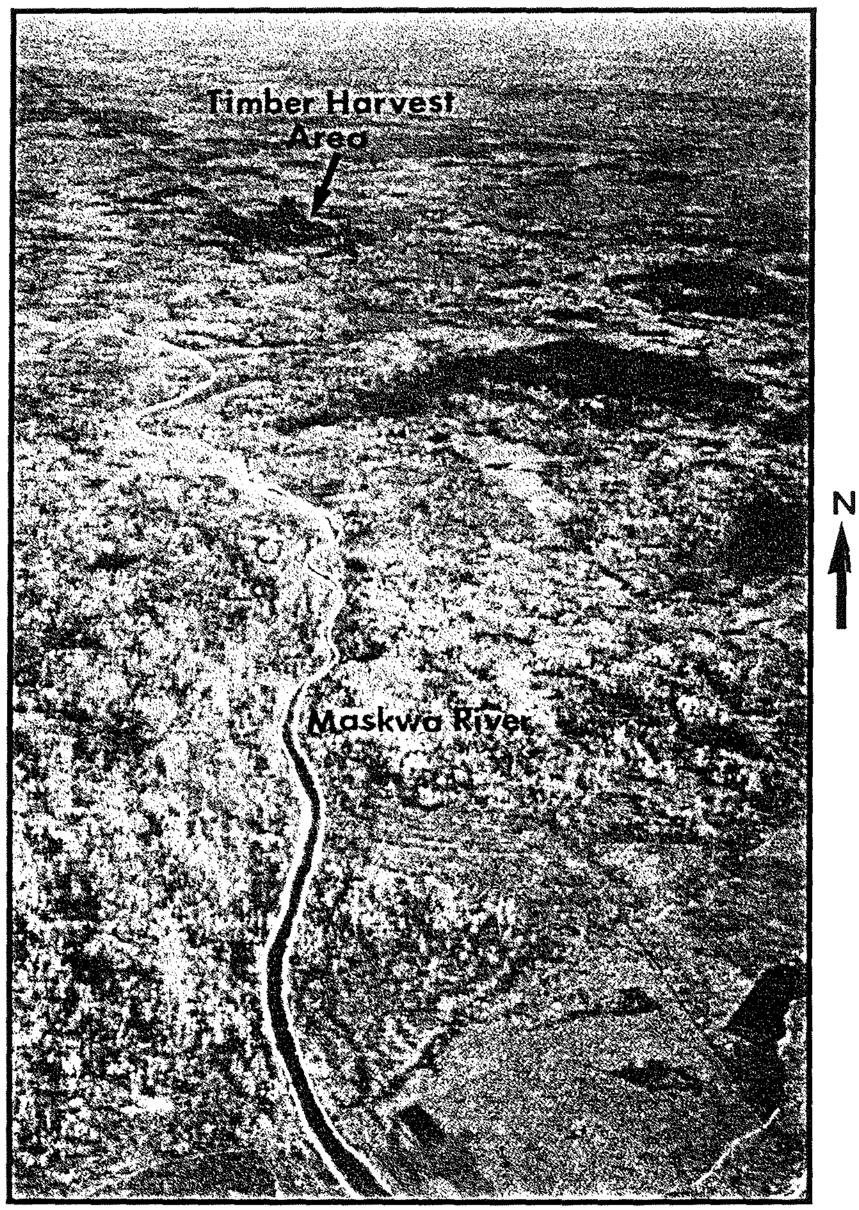

Fig. 25. Oblique aerial photo taken on June 1927, showing the Maskwa River and the timber harvest area prior to logging. (Source: Manitoba Natural Resources. Photo FA66-69).

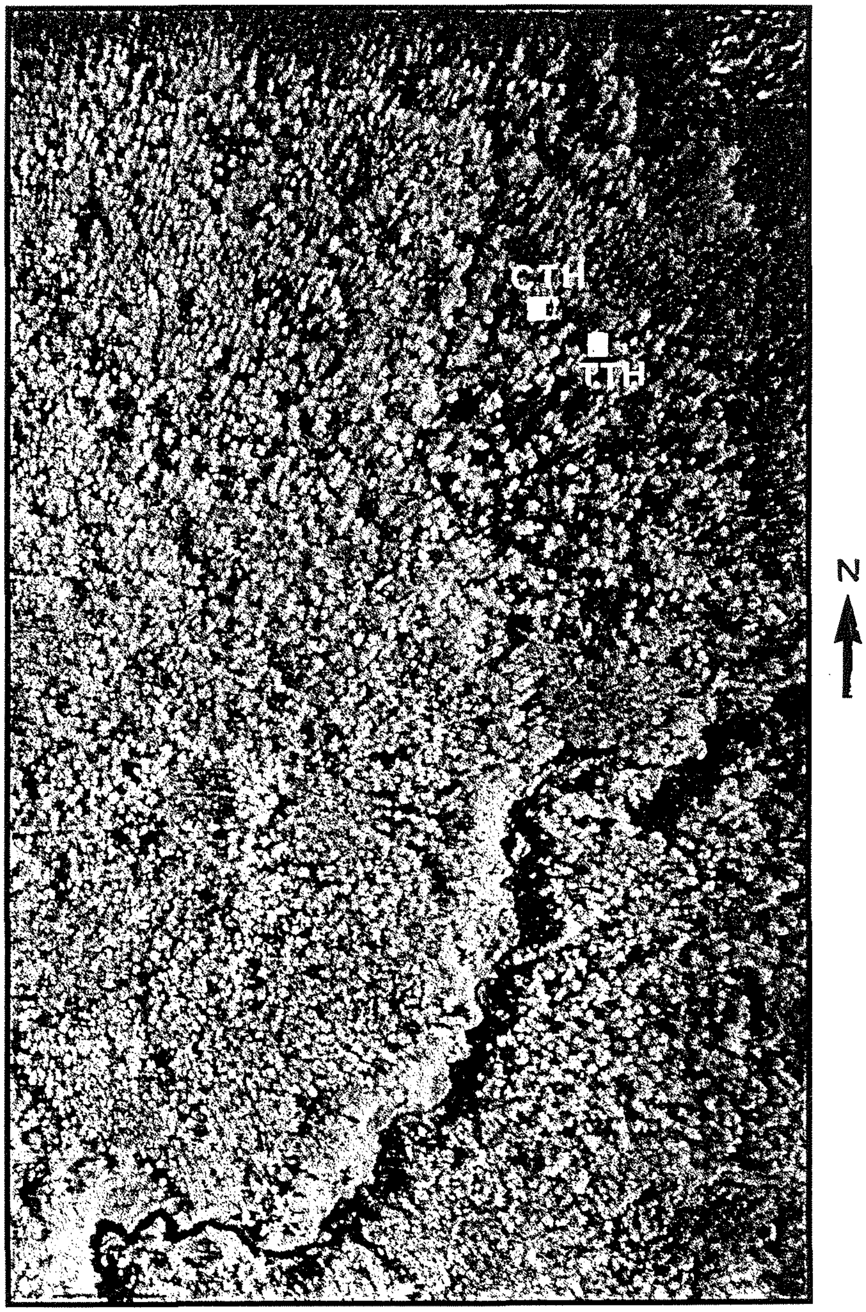

Fig. 26. Aerial photo taken on June 17, 1975, showing regeneration of the timber harvest area approximately 35 years after logging and 7 years before shear-blading. Note the future location of the CTH and TTH study sites which were established 17 years later in 1992. Scale is approximately 4800:1. (Source: Manitoba Natural Resources. Photo A24105-36).

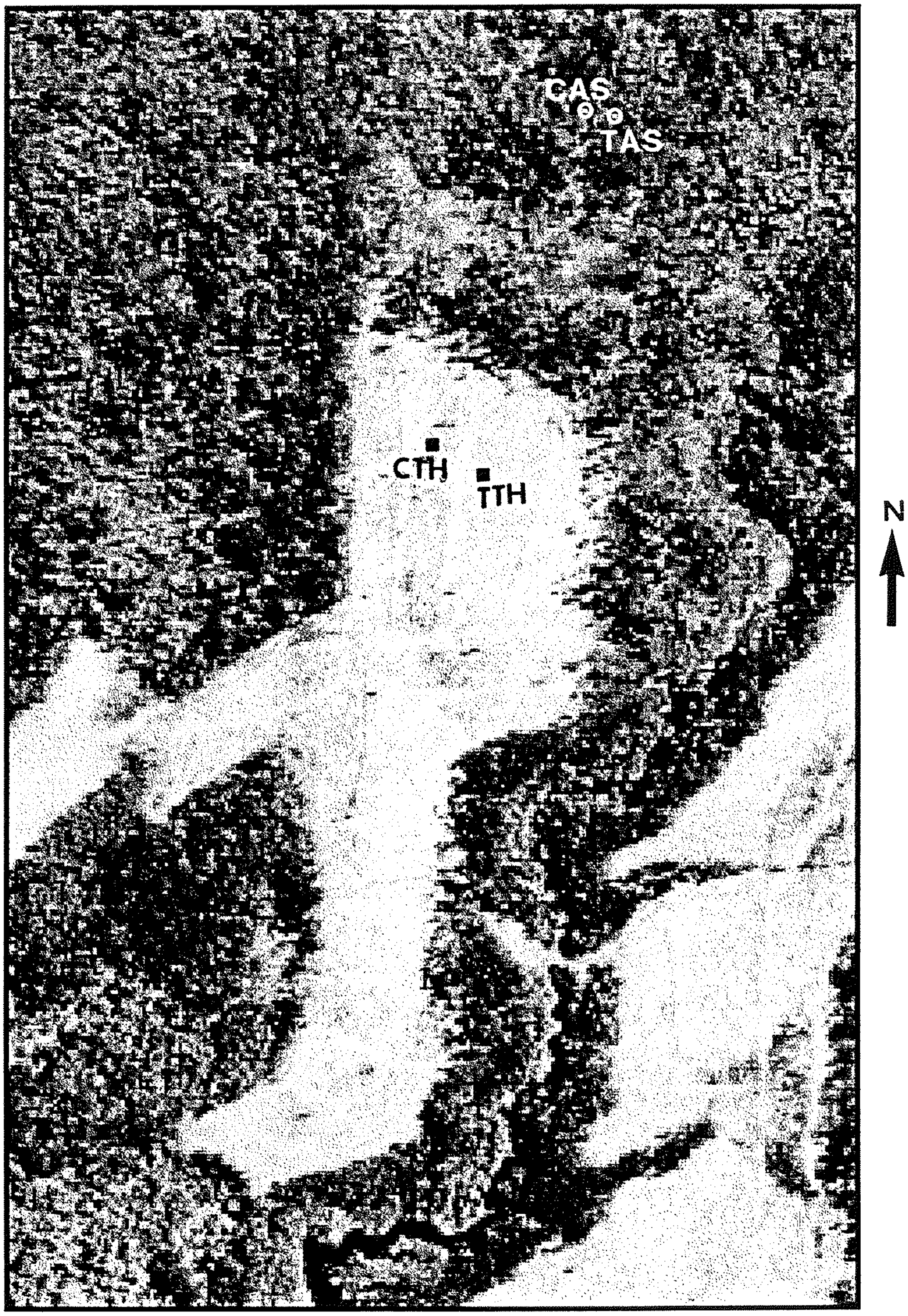

Fig. 27. Aerial photo taken on June 17, 1983, showing the timber harvest area shortly after shear-blading. Windrows of *Populus tremuloides* logs appear as white lines in the area. Note the future location of the CTH and TTH study sites, and the CAS and TAS study sites. Scale is approximately 4800:1. (Source: Manitoba Natural Resources. Photo A26267-53).

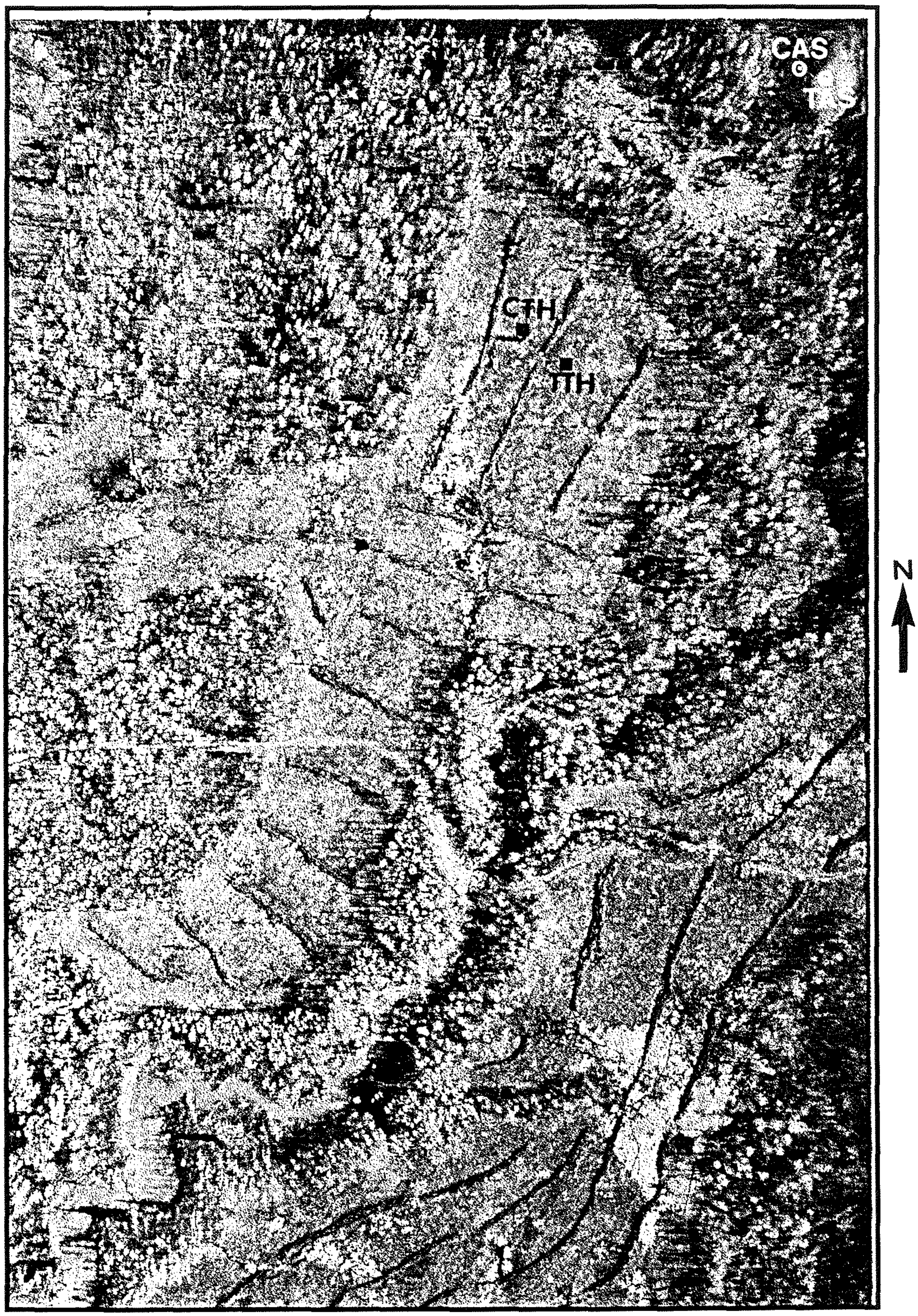

Fig. 28. Aerial photo taken on May 15, 1985, showing the timber harvest area following herbicide application and replanting with *Picea glauca*. Note the location of the CTH and TTH study sites, and the CAS and TAS study sites. Scale is approximately 4800:1. (Source: Manitoba Natural Resources. Photo MH85501402-17).

Fig. 29. Aerial photo taken in June 1993 showing the timber harvest area nine years after the herbicide application and replanting. Note the location of the CTH and TTH study sites, and the CAS and TAS study sites established the previous year. Scale is approximately 4800:1. (Source: Manitoba Natural Resources. Photo MH93501407-25).

Table 12. Density (individuals/m2) of vascular plant species recorded in 50 cm x 50 cm quadrats at the CTH and TTH sites. Values are means ± S.E. (n = 40).

Species	Control Site						Treated Site					
	1992			1994			1992			1994		
Ace spi	0.1	±	0.1	0	±	0	0.0	±	0.0	0	±	0
Ach mil	0.4	±	0.2	0.7	±	0.4	0.2	±	0.1	0.5	±	0.4
Act rub	0.1	±	0.1	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0
Ane can	2.2	±	0.8	0.3	±	0.3	35.9	±	6.6	53.7	±	8.5
Ane qui	1.3	±	0.9	1.5	±	0.9	5.7	±	2.1	5.9	±	2.9
Asa can	0.4	±	0.2	0.9	±	0.6	0.0	±	0.0	0.1	±	0.1
Ast cil	1.5	±	0.6	8.1	±	1.7	29.4	±	3.4	82.8	±	8.5
Ath fil	4.3	±	0.8	6.6	±	1.5	0.3	±	0.2	0.9	±	0.4
Car spp.	7.6	±	3.0	29.3	±	10.0	11.5	±	4.1	180.5	±	37.8
Cir arv	5.6	±	0.9	8.5	±	1.1	11.5	±	1.3	18.2	±	1.6
Cor cor	0.4	±	0.3	1.2	±	1.2	0.0	±	0.0	0.0	±	0.0
Epi ang	0.0	±	0.0	0.0	±	0.0	1.0	±	0.4	0.9	±	0.4
Equ arv	5.8	±	1.6	6.0	±	1.7	4.8	±	1.0	6.5	±	1.2
Equ syl	0.4	±	0.2	0.1	±	0.1	0.3	±	0.3	0.0	±	0.0
Fra spp.	16.6	±	4.1	18.1	±	5.9	76.2	±	6.8	134.6	±	11.0
Gal bor	2.9	±	1.2	3.0	±	1.4	9.1	±	2.4	15.2	±	3.1
Gal tri	0.4	±	0.4	1.0	±	0.5	0.0	±	0.0	0.0	±	0.0
Geu spp.	0.6	±	0.3	0.6	±	0.3	3.4	±	0.7	5.0	±	1.2
Gramineae	115.0	±	25.2	278.0	±	32.9	11.9	±	3.8	50.8	±	8.3
Her lan	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1
Imp bif	5.9	±	2.6	2.0	±	1.1	0.0	±	0.0	0.0	±	0.0
Jun sp.	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1
Lat spp.	0.3	±	0.3	0.1	±	0.1	4.0	±	0.6	6.8	±	1.2
Mai can	9.4	±	2.3	7.3	±	2.8	4.0	±	1.2	3.5	±	0.8
Mit nud	2.4	±	1.6	1.2	±	0.8	0.0	±	0.0	0.0	±	0.0
Pic gla	0.2	±	0.1	0.2	±	0.1	0.3	±	0.2	0.3	±	0.2
Pop tre	0.1	±	0.1	0.4	±	0.2	0.0	±	0.0	0.0	±	0.0
Pre alb	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0
Pru vir	0.2	±	0.2	0.2	±	0.2	0.0	±	0.0	0.0	±	0.0
Ran sp.	0.0	±	0.0	0.2	±	0.2	0.0	±	0.0	0.0	±	0.0
Rib gla	0.6	±	0.4	0.0	±	0.0	0.6	±	0.3	1.2	±	0.5
Rib oxy	0.2	±	0.1	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0
Rib tri	0.0	±	0.0	0.8	±	0.4	0.0	±	0.0	0.0	±	0.0
Ros aci	0.4	±	0.2	0.3	±	0.2	0.1	±	0.1	0.1	±	0.1
Rub ida	16.6	±	2.9	3.9	±	1.0	6.0	±	0.9	1.9	±	0.6
Rub pub	0.0	±	0.0	14.5	±	3.2	0.2	±	0.2	4.5	±	0.8
San mar	0.0	±	0.0	0.0	±	0.0	0.1	±	0.1	1.4	±	0.7
Smi ste	0.1	±	0.1	0.0	±	0.0	3.2	±	1.6	0.1	±	0.1
Sol spp.	7.7	±	1.9	9.7	±	2.0	5.1	±	1.4	8.8	±	2.3
Son arv	1.1	±	0.4	2.7	±	1.1	2.8	±	1.1	2.6	±	1.1
Sta pal	0.4	±	0.2	0.4	±	0.2	0.1	±	0.1	0.0	±	0.0
Ste cil	0.0	±	0.0	0.0	±	0.0	1.4	±	0.8	3.2	±	1.5
Ste lon	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.2	±	0.2
Str ros	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.7	±	0.3
Tar off	0.2	±	0.2	1.2	±	0.5	1.2	±	0.4	1.1	±	0.4
Tha spp.	5.1	±	1.4	6.2	±	1.7	4.7	±	1.4	6.5	±	1.5
Tri bor	0.0	±	0.0	0.0	±	0.0	0.3	±	0.2	0.5	±	0.5
Tri cer	0.4	±	0.2	0.0	±	0.0	0.3	±	0.2	0.0	±	0.0
Urt dio	0.0	±	0.0	0.0	±	0.0	0.0	±	0.0	0.4	±	0.3
Vib raf	0.0	±	0.0	0.0	±	0.0	0.6	±	0.3	1.1	±	0.7
Vib tri	0.2	±	0.1	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0
Vic spp.	0.2	±	0.1	0.2	±	0.1	10.0	±	1.8	6.5	±	1.2
Vio spp.	0.3	±	0.2	0.3	±	0.2	3.1	±	0.8	6.8	±	1.8
Species Richness		40			37			34			37	
Species Diversity		0.75			0.66			1.07			0.95	

*For explanation of abbreviations see Appendix I

rafinesquianum, and *Steironema ciliatum,* at the TTH site. Ten woody dicot species were found in the CTH site, while only five occurred in the TTH site.

The density of the more common species at the CTH site remained fairly constant from 1992 to 1994. Some exceptions to this include grasses and sedges, which increased by 160% and 320% respectively from 1992 to 1994. As well, the density of *Rubus idaeus* declined from 16.6 ±2.9 to 3.9 ±1.0 individuals /m^2, and the density of *Rubus pubescens* increased from 0 to 14.5 ±3.2 individuals /m^2 between 1992 and 1994. The density of most species at the TTH site increased from 1992 to 1994. Some notable examples include *Carex* spp., grasses, *Anemone canadensis, Aster ciliolatus,* and *Fragaria* spp. As with the CTH site, the density of *Rubus idaeus* decreased, and that of *Rubus pubescens* increased at the TTH site over the sample periods. Thus, the plant population at the unsprayed site appeared to be somewhat more stable than that of the sprayed site.

Species richness and species diversity at the CTH site were higher in 1992 than 1994 (Table 12). At the TTH site the species richness was highest during the 1994 sample period, while diversity was highest during the 1992 sample period. The TTH site had a higher species diversity than the CTH site over both sample periods. The CTH site tended to be heavily dominated by grasses, while the number of individuals at the TTH site was distributed more evenly among the species. This resulted in a higher diversity index for the TTH site, even though the species richness of the site did not exceed that of the control. The high increase in the density of graminoid species relative to the changes in density of other species present accounts for the decrease in species diversity recorded at both sites over the 1992 to 1994 period.

The results from correspondence analysis of the quadrat data clearly illustrate the dissimilarity between the Timber Harvest sites based on species composition and density of the understorey vegetation (Figure 30). The first axis of the bi-plot accounts for 76.4% of the total variation in the data and serves to separate the CTH site from the TTH site, and indicates a high degree of dissimilarity between sites based on species composition. The second axis, which accounts for 16.4% of the variation, separates the sample years of each site and represents post-spray successional changes in vegetation.

Species with highest densities at the CTH site are located on the right side of the diagram, while those with higher densities at the TTH site occur on the left side of the diagram. Species occurring at both sites at similar densities are clustered near the axes origin. Separation of the two sampling years at the CTH site was mainly due to temporal fluctuations in the populations of *Impatiens biflora, Rubus pubescens, Rubus idaeus,*

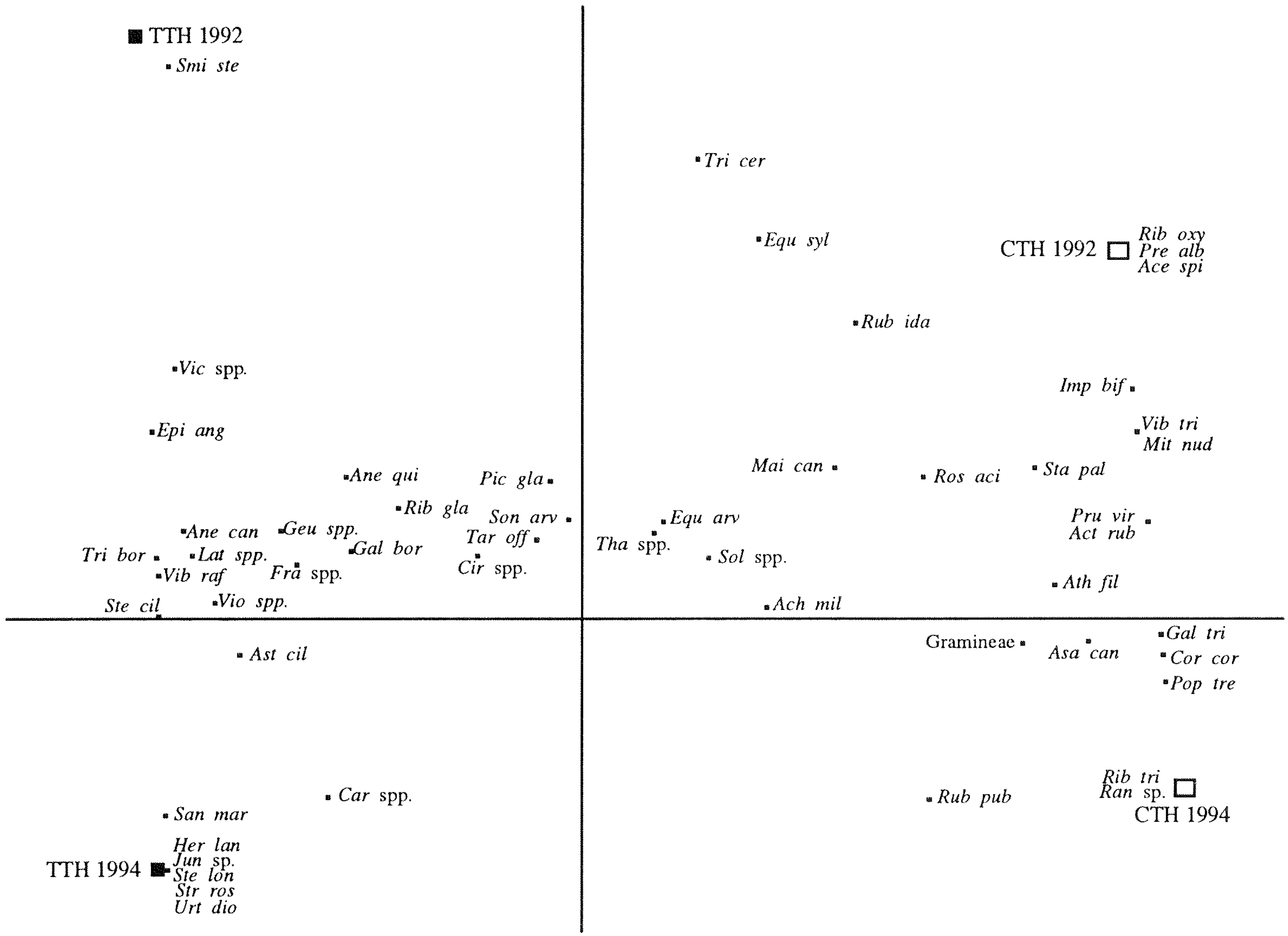

Fig. 30. Correspondence analysis of species and sample years from CTH and TTH study sites. Species density data were collected from 40 $0.25m^2$ quadrats during each sample period. The sum of all eigenvalues is 0.649. The first axis (x) has an eigenvalue of 0.495, and accounts for 76.4% of the total variance in the data. The second axis (y) has an eigenvalue of 0.107, which accounts for 16.4% of the variance in the data.

and grass species. *Impatiens biflora* and *Rubus idaeus* had their highest densities in 1992, while the graminoids and *Rubus pubescens* were more prevalent during the 1994 sample period. At the TTH site, the higher densities of *Carex* spp. and *Aster ciliolatus* recorded during the 1994 sample period acted to separate the two sample years.

The shrub stratum of the CTH site consisted of four species: *Amelanchier alnifolia, Corylus cornuta, Salix* spp., and *Prunus virginiana* L. (choke cherry). The shrub stratum of the TTH site consisted of *Prunus virginiana, Salix* spp., and *Viburnum rafinesquianum.* The overall shrub numbers of the TTH site were considerably higher than that of the control (Figure 31). Stem numbers for each species fluctuated from sample year to sample year at each site. The total number of stems remained almost equal at the CTH site from 1992 to 1994 (9 and 10 stems respectively), but decreased from 56 to 43 stems at the TTH site. The decline at the TTH site was mainly due to a 50% reduction in the stem density of *Viburnum rafinesquianum.* This large decline was countered, in part, by an accompanying increase in *Rosa acicularis*, so that the overall decline in shrub stem density from 1992 to 1994 was 23%.

Total maximum crown width of the shrub stratum of the CTH site declined from 1992 to 1994 (Figure 31). This decline was due to decreases in the *Salix* spp. and *Amelanchier alnifolia* stem densities. Mean height of shrub stratum species at the CTH site did not change from 1992 to 1994, indicating that overall growth of shrubs was static. This was likely due to shading from the tree canopy at the site.

The increase in height and total maximum crown width in the shrub stratum at the TTH site indicated that stems of *Salix* spp. and *Viburnum rafinesquianum,* although declining in density, were generally increasing in size and stature during the 1992 to 1994 period. Stems of *Prunus virginiana* increased in both size and density over the same period. The decline in the number of stems of *Salix* spp. and *Viburnum rafinesquianum* at the TTH site may have been the result of self-thinning in the population, interspecific competition, or possibly browsing by ungulates.

Populus tremuloides and *Picea glauca* composed the tree stratum at the CTH site, while *Picea glauca* was the only tree species found at the corresponding TTH site (Figure 32). *Populus tremuloides* clearly dominated the CTH site during both sample years. Basal area measurements indicate that although the *Populus tremuloides* population density declined slightly from 1992 to 1994, the size of the remaining individuals continued to increase. The *Picea glauca* population at both sites consisted of individuals that had been planted following the shear-blading of the area in the early 1980's. The density and basal area of this species was low at both sites, indicating the degree to which its growth and

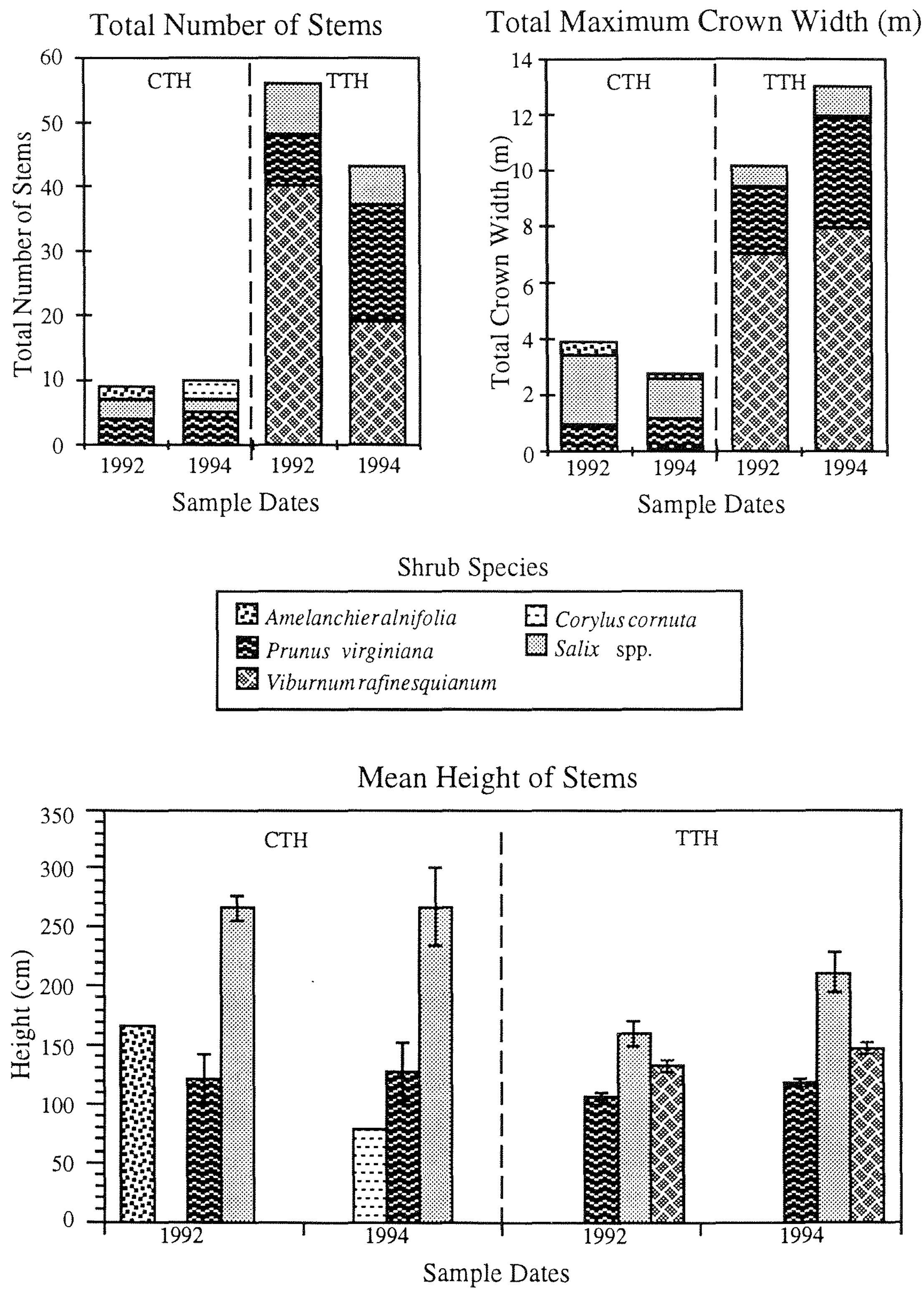

Fig. 31. Total number of stem, total maximum crown width (m), and mean height (cm ± SE) of shrub species recorded in the 100 m^2 macroplot at the CTH and TTH study sites.

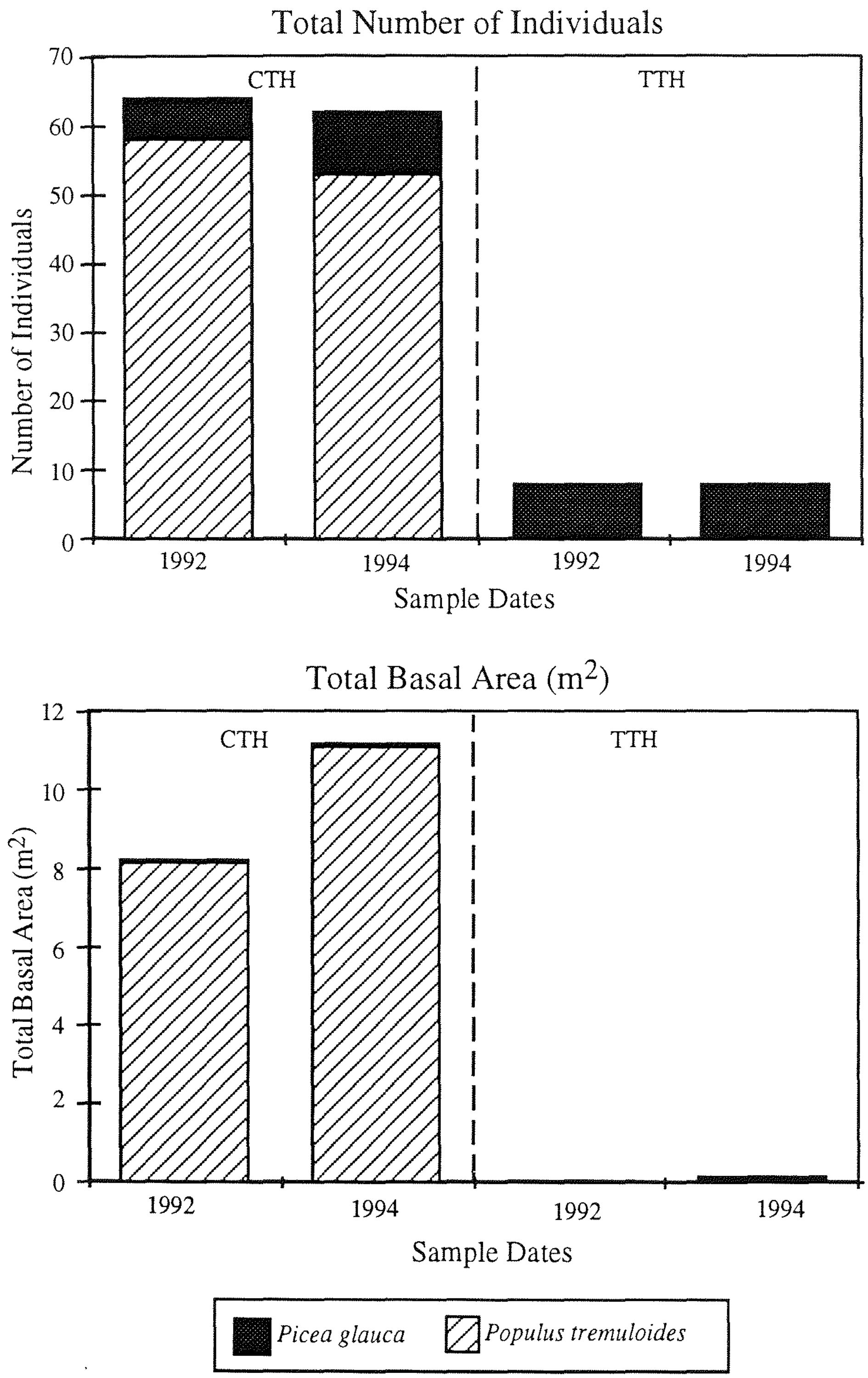

Fig. 32. Total number of individuals and total basal area (m^2) of tree species recorded in the 100 m^2 macroplot at the CTH and TTH study sites.

development rate lagged behind that of *Populus tremuloides*. No tree-sized individuals of *Populus tremuloides* were present in the TTH site, presumably because the herbicide application had killed any propagules which may have been present following the shear-blading.

To summarize, sampling of the understorey, shrub, and tree strata at sites established in the sprayed (TTH) and unsprayed (CTH) sections of the timber harvested area provided an assessment of the effects and efficacy of glyphosate application. The vegetation of the two sites differed considerably during both sample years. The understorey of the CTH site was dominated by relatively shade-tolerant graminoids, with perennial herbs and shrubs occupying small areas that corresponded with gaps in the tree canopy. Domination of the understorey vegetation by a single taxon was less apparent at the TTH site. At this site, the majority of individuals in the understorey vegetation were distributed among six major taxa, resulting in a higher diversity index for the TTH site than the CTH site. Ten different woody dicot species occurred in the understorey stratum of the CTH site. However, due to shading by the tree canopy, few individuals of these species attained heights above 75 cm. This is reflected in the relatively low shrub stem density and crown widths recorded. Stem density at the TTH site was four to five times that of the control during the period sampled. Maximum crown width was also consistently higher in the TTH site than in the CTH site. Sampling of the tree stratum at the CTH site revealed a relatively healthy population of *Populus tremuloides* which dominated the planted *Picea glauca* individuals.

The glyphosate application effectively halted the natural regeneration of *Populus tremuloides* in the sprayed area. This facilitated maximum light penetration to the understorey and shrub layers which allowed the establishment of a dense and diverse collection of herbaceous and woody plants in the area, and confirms the effectiveness of glyphosate in reducing interspecific competition for resources. Wood and von Althen (1993) state that the underlying purpose for the silvicultural use of glyphosate is to reduce competition between economically valued timber species and non-valued species by eradicating the non-valued species. Assessment of the growth of *Picea glauca* seedlings (i.e. the valued species) at the sprayed and unsprayed Timber Harvest sites indicated that the growth rate at the sprayed site (TTH site) was only slightly higher than at the unsprayed site(CTH site). Wood and Dominy (1988) suggest that the interpretation and evaluation of the efficacy of mechanical and chemical site preparation in *Picea glauca* plantations requires long-term measurements over 15 to 20 years following the implementation of the technique. Periodic vegetation monitoring of the sites in the future should reveal whether herbicide applications result in significant increases in *Picea glauca* productivity over the long term.

4.2.6 Accidental Spill Sites

The accidental spill of glyphosate occurred in 1984 over a relatively confined area approximately 150 m northeast of the timber harvest area. Prior to the accidental spill the vegetation of the area appeared to consist of an undisturbed low density stand of predominantly hardwood tree species (Figure 27). The spill area is represented quite distinctly as a clearing in the upper right of the aerial photographs taken in 1985 and 1993 (Figures 28 and 29, respectively). To assess the effects of the glyphosate spill on the vegetation, a sample site was established in the area affected (TAS site), and a control site (CAS site) was located adjacent to the area in an undisturbed mixed hardwood stand. Because of their close proximity, it has been assumed that the two sample sites were similar in species composition prior to the accidental spill (Figure 27). This assumption is reinforced by the presence of dead individuals (standing and fallen) of *Populus tremuloides* and *Fraxinus pennsylvanica* in the spill area.

The vegetation of the Accidental Spill sites was first sampled in detail in 1992 and again in 1994. Sampling of the various vegetation strata revealed that the CAS and TAS sites differed with regard to species composition, richness, and diversity (Table 13). The overall density of individuals was two to three times higher in the TAS site than in the CAS site. This was due mainly to the high number of grasses in the TAS as opposed to a relatively low number in the CAS.

The understorey of the CAS site was characterized by a highly diverse collection of dicots, over a third of which were woody perennials. Monocots at the site included various graminoids, *Maianthemum canadense, Smilacina stellata, Streptopus roseus,* and *Trillium cernuum* L. (nodding trillium). Ferns and fern allies included *Athyrium filix-femina* and *Equisetum arvense*. Over the two sampling periods *Carex spp., Equisetum arvense, Maianthemum canadense, Fragaria* spp., *Rubus pubescens, Trientalis borealis* Raf. (starflower), and seedlings of *Ulmus americana* and *Fraxinus pennsylvanica* were the most commonly encountered species in the understorey of the CAS site.

The TAS site also supported a variety of dicots, monocots, and pteridophytes; however, the richness and diversity of the vegetation at this site was considerably less than that of the control. Only six woody dicot species occurred in the understorey of the TAS site, compared with 19 at the CAS site. A large proportion of the herbaceous species at the TAS site were plants with close ecological affinities to moist or saturated soil conditions.

Table 13. Density (individuals/m2) of vascular plant species recorded in 50 cm x 50 cm quadrats at the CAS and TAS sites. Values are means ± S.E. (n = 40).

Species	Control Site		Treated Site	
	1992	1994	1992	1994
Ace spi	0.3 ± 0.3	5.1 ± 1.4	0.0 ± 0.0	0.0 ± 0.0
Ame aln	0.6 ± 0.3	0.8 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Ane qui	1.7 ± 0.7	3.3 ± 1.3	0.0 ± 0.0	0.0 ± 0.0
Ara nud	2.1 ± 0.5	1.0 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Asa can	2.3 ± 0.5	1.8 ± 0.5	0.0 ± 0.0	0.0 ± 0.0
Ast cil	0.3 ± 0.2	0.2 ± 0.2	0.4 ± 0.3	1.1 ± 0.8
Ast pun	0.3 ± 0.3	0.5 ± 0.4	18.8 ± 5.8	24.6 ± 8.7
Ath fil	1.1 ± 0.6	1.5 ± 0.7	1.2 ± 0.6	1.3 ± 0.6
Cal pal	0.0 ± 0.0	0.0 ± 0.0	4.7 ± 1.3	4.0 ± 1.0
Car spp.	9.9 ± 2.0	64.4 ± 11.5	24.1 ± 5.2	60.8 ± 14.6
Cir alp	1.4 ± 0.6	2.1 ± 1.3	0.0 ± 0.0	0.0 ± 0.0
Cir spp.	0.0 ± 0.0	0.0 ± 0.0	3.6 ± 0.8	2.8 ± 0.9
Cor ame	0.5 ± 0.3	0.4 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Cor cor	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Cor sto	1.4 ± 0.5	1.7 ± 0.7	0.0 ± 0.0	0.0 ± 0.0
Epi ang	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 0.9	5.2 ± 1.7
Equ arv	13.4 ± 2.7	30.5 ± 5.1	19.2 ± 2.4	5.9 ± 1.4
Fra pen	0.0 ± 0.0	8.9 ± 1.1	0.0 ± 0.0	0.2 ± 0.1
Fra spp.	4.3 ± 1.2	4.7 ± 1.0	0.0 ± 0.0	0.0 ± 0.0
Gal bor	1.4 ± 0.5	2.4 ± 1.0	1.2 ± 0.5	2.5 ± 0.7
Geu spp.	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1
Gramineae	2.6 ± 0.8	3.5 ± 2.1	143.1 ± 26.7	270.0 ± 32.6
Imp bif	0.0 ± 0.0	0.9 ± 0.3	18.8 ± 3.8	8.1 ± 2.1
Lon spp.	0.4 ± 0.3	0.6 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Lyc spp.	0.0 ± 0.0	0.0 ± 0.0	4.3 ± 1.8	8.1 ± 2.9
Lys thy	3.1 ± 1.0	3.6 ± 0.9	0.0 ± 0.0	1.4 ± 0.8
Mai can	8.2 ± 1.9	10.6 ± 2.2	1.3 ± 0.5	1.0 ± 0.5
Mel lin	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Men arv	0.1 ± 0.1	0.4 ± 0.2	10.0 ± 1.8	14.7 ± 2.5
Mit nud	6.1 ± 1.2	20.9 ± 4.0	0.0 ± 0.0	0.0 ± 0.0
Pet pal	0.6 ± 0.3	1.0 ± 0.5	0.0 ± 0.0	0.0 ± 0.0
Pop tre	1.0 ± 0.4	0.8 ± 0.4	0.0 ± 0.0	0.0 ± 0.0
Pre alb	0.0 ± 0.0	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Pru vir	0.5 ± 0.3	0.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Ran sp.	0.2 ± 0.1	0.4 ± 0.4	0.0 ± 0.0	0.2 ± 0.1
Rha aln	0.9 ± 0.3	0.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Rib gla	1.3 ± 0.6	0.7 ± 0.4	0.3 ± 0.2	0.5 ± 0.3
Rib oxy	1.1 ± 0.5	1.7 ± 0.6	0.0 ± 0.0	0.5 ± 0.3
Rib tri	0.8 ± 0.3	1.4 ± 0.5	0.2 ± 0.2	0.0 ± 0.0
Ros aci	3.9 ± 2.6	1.6 ± 0.5	0.0 ± 0.0	0.0 ± 0.0
Rub ida	0.1 ± 0.1	0.1 ± 0.1	7.3 ± 2.2	5.8 ± 1.8
Rub pub	7.7 ± 1.1	12.1 ± 1.6	0.0 ± 0.0	0.0 ± 0.0
Sal spp.	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.7 ± 0.4
San mar	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Scu lat	0.0 ± 0.0	0.0 ± 0.0	2.9 ± 0.8	3.5 ± 1.4
Smi ste	1.9 ± 0.5	1.5 ± 0.5	0.5 ± 0.3	0.1 ± 0.1
Sol spp.	0.2 ± 0.1	0.2 ± 0.2	0.3 ± 0.2	1.3 ± 0.7
Son sp.	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 1.2	0.9 ± 0.4
Sta pal	0.5 ± 0.3	0.2 ± 0.1	1.4 ± 0.5	2.4 ± 0.7
Ste lon	0.0 ± 0.0	0.2 ± 0.1	1.4 ± 0.7	0.8 ± 0.3
Str ros	0.1 ± 0.1	0.2 ± 0.2	0.2 ± 0.1	0.2 ± 0.1
Sym alb	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Tar off	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1
Tha spp.	0.5 ± 0.2	0.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.1
Tri bor	3.3 ± 1.1	4.3 ± 1.3	0.0 ± 0.0	0.0 ± 0.0
Tri cer	0.1 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Ulm ame	0.3 ± 0.2	7.9 ± 1.1	0.0 ± 0.0	0.0 ± 0.0
Vib raf	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
Vib tri	1.1 ± 0.4	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Vio spp.	0.3 ± 0.2	0.9 ± 0.3	0.9 ± 0.4	2.9 ± 1.1
Species Richness	47	49	28	32
Species Diversity	1.03	1.12	0.80	0.66

*For explanation of abbreviations see Appendix I

Many of these species had higher densities in the TAS site, but were absent or had only low densities in the CAS site. Examples of such species include *Mentha arvensis* L. (field mint), *Caltha palustris* L. (marsh marigold), *Lycopus* spp. L. (water-horehound), *Impatiens biflora*, *Scutellaria lateriflora* L. (blue skullcap), *Stachys palustris* L. (marsh hedge-nettle), and *Stellaria longifolia* Muhl. (long-leaved stitchwort). The *Carex* spp. found at the TAS site, although not identifiable to species, tended to be wide-leaved and robust, which is characteristic of sedge species found in wetland habitats. Separation of the Gramineae of both sites into species was difficult because of a general absence of flowering and fruiting structures. However, some wetland genera such as *Glyceria* R. Br. (manna grass) and *Calamagrostis* Adans (reed grass) were evident at the TAS site, while specimens of *Poa* L. (bluegrass) were found at the control. The density of graminoids at the TAS site was much higher than that of the CAS site. In fact, graminoids were by far the most densely occurring plants in the understorey of the TAS site itself, and this high relative density resulted in low diversity values for the site (Table 13).

Correspondence analysis of the understorey density data illustrates the dissimilarity between the two Accidental Spill sites (Figure 33). The first axis of the bi-plot serves to separate the TAS site from the undisturbed CAS. The axis accounts for 81.1% of the total variation in the data, thus emphasizing that there were marked differences between the vegetation of the two sites. The second axis represents 13.8% of the variation in the data and separates the sample years of each site. The close proximity of the sample periods at the TAS site and their wide separation at the CAS site indicate that fluctuations in species' densities were less influential on the overall vegetation composition of the TAS site than at the CAS site. It follows that successional changes in vegetation at the TAS site appear to be more static than the control. However, the low percentage of variation accounted for by the second axis indicates that the understorey vegetation of *neither* site varied a great deal from sample year to sample year. Some of the more dense species at the CAS increased from 1992 to 1994; however, the majority of species appeared to fluctuate only slightly between sample periods.

The shrub stratum of the CAS site was more diverse than that of the TAS site (Figure 34). The shrub stratum of the CAS supported eight species, with no one species dominating the others. The TAS site was clearly dominated by *Salix* spp., but also supported members of *Ribes* spp., *Cornus stolonifera,* and *Rubus idaeus.* The overall population parameters of the shrub stratum did not change appreciably between sample periods at either site. However, in the CAS site *Prunus virginiana, Cornus stolonifera,* and *Amelanchier alnifolia* decreased slightly in stem density and total maximum crown width from 1992 to 1994. *Viburnum rafinesquianum* and *Rosa acicularis* at the control

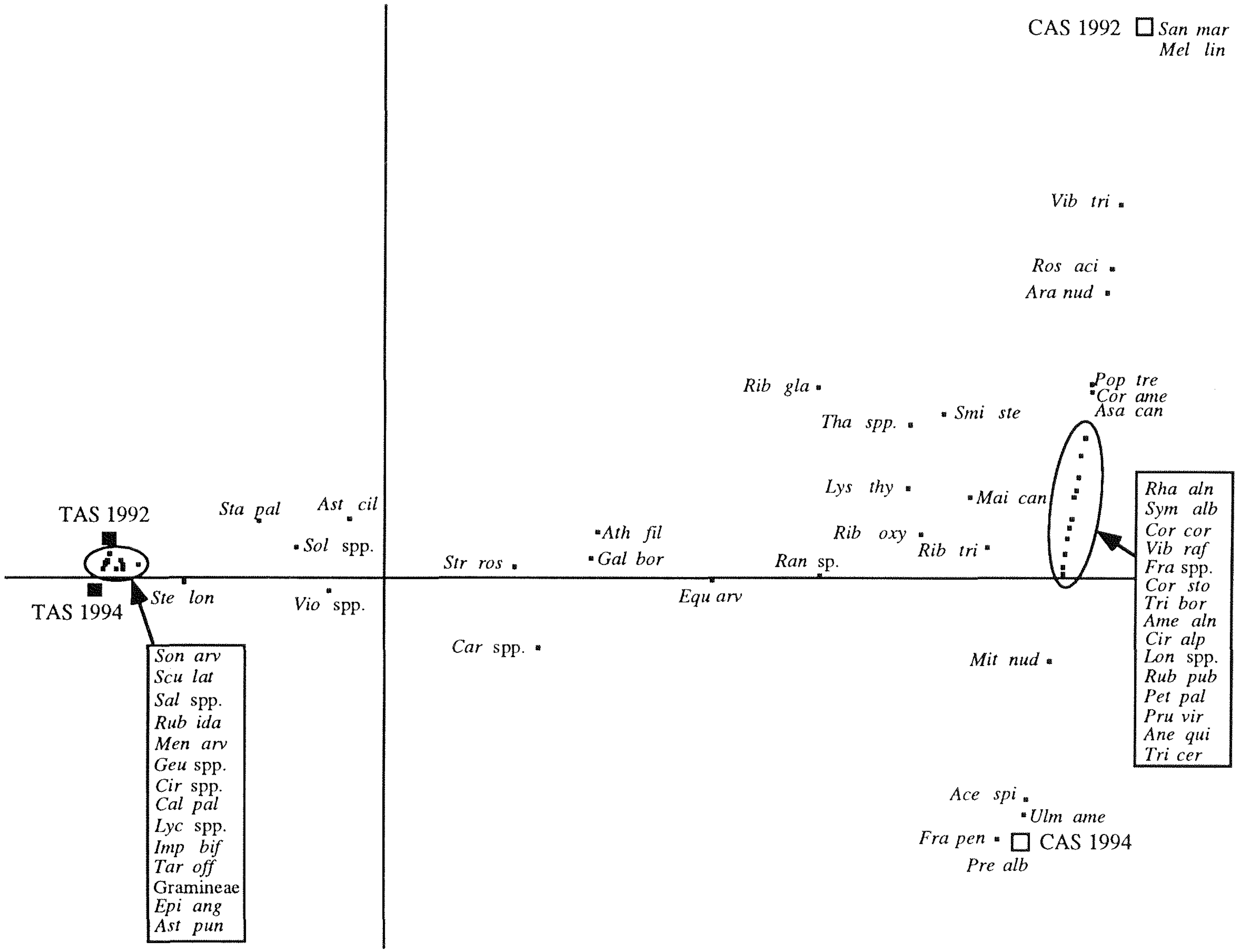

Fig. 33. Correspondence analysis of species and sample years from CAS and TAS study sites. Species density data were collected from 40 0.25m^2 quadrats during each sample period. The sum of all eigenvalues is 0.794. The first axis (x) has an eigenvalue of 0.644, and accounts for 81.1% of the total variance in the data. The second axis (y) has an eigenvalue of 0.110, which accounts for 13.8% of the variance in the data.

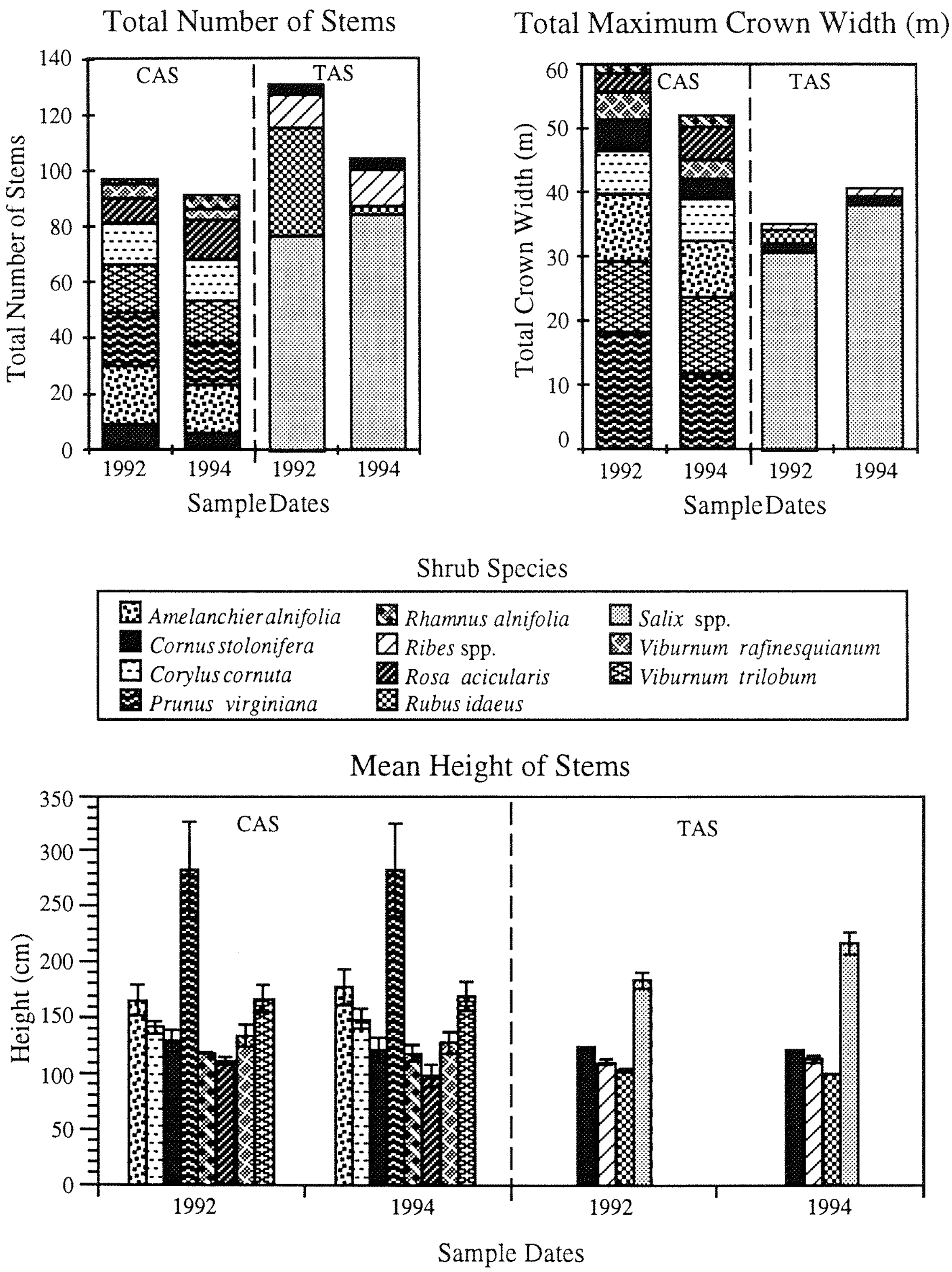

Fig. 34. Total number of stem, total maximum crown width (m), and mean height (cm ± SE) of shrub species recorded in the 100 m^2 macroplot at the CAS and TAS study sites.

both fluctuated slightly in these population parameters over the same period. At the TAS site the population of *Salix* spp. increased slightly from 1992 to 1994, while the population of *Rubus idaeus* almost disappeared over the same period of time. The relatively high density and mean height of stems in the shrub stratum at the TAS site indicates recovery of the stratum following the accidental spill event. However, the presence of shade intolerant species such as *Rubus idaeus* and the domination of the site by *Salix* spp. contrasts sharply with the more diverse and mature shrub stratum of the CAS site. The shrub species of the TAS site indicate an immature successional stage in the natural regeneration of the vegetation at the site. The slight fluctuation in species populations at both sites may be the result of grazing by ungulates, which may have increased with the re-establishment of early successional stages following the accidental spill.

Populus spp. and *Fraxinus pennsylvanica* dominated the tree stratum of the CAS site (Figure 35). *Ulmus americana, Acer negundo* L. (Manitoba maple), *Acer spicatum,* and *Picea glauca* were also present. Although *Acer spicatum* was the most dense tree species in the control, its total basal area was quite low in comparison to the other species. In general, high total basal area is directly correlated with high percentage cover by the tree stratum. It follows that most of the shrub and ground cover or understorey vegetation at the control consisted of moderately shade tolerant species, and tended to occur under openings in the overhead tree stratum. No post-spill regeneration of the tree stratum had taken place in the TAS site by the time of the 1994 sampling.

Based on the aerial photographs, the Accidental Spill sites appeared to have similar species compositions prior to the accidental spill. The spill resulted in the defoliation of the area where the herbicide contacted the foliage. Over time the spill area has become revegetated, but still remains distinctly different from the surrounding undisturbed area. The lack of a tree canopy would greatly reduce water transpiration rates, and thus may have contributed to locally waterlogged soils in the spill area. At present, many of the understorey species in the spill area are characteristic of wetland communities. Such species did not occur in the corresponding CAS site, even though both sites had relatively damp soil conditions. The immature shrub stratum and the lack of a tree stratum may have allowed the establishment and growth of wetland species at the TAS site, resulting in the development of a wet meadow or fen type of community. The dense shrub and tree strata of the control appears to have prohibited the proliferation of such species at that site.

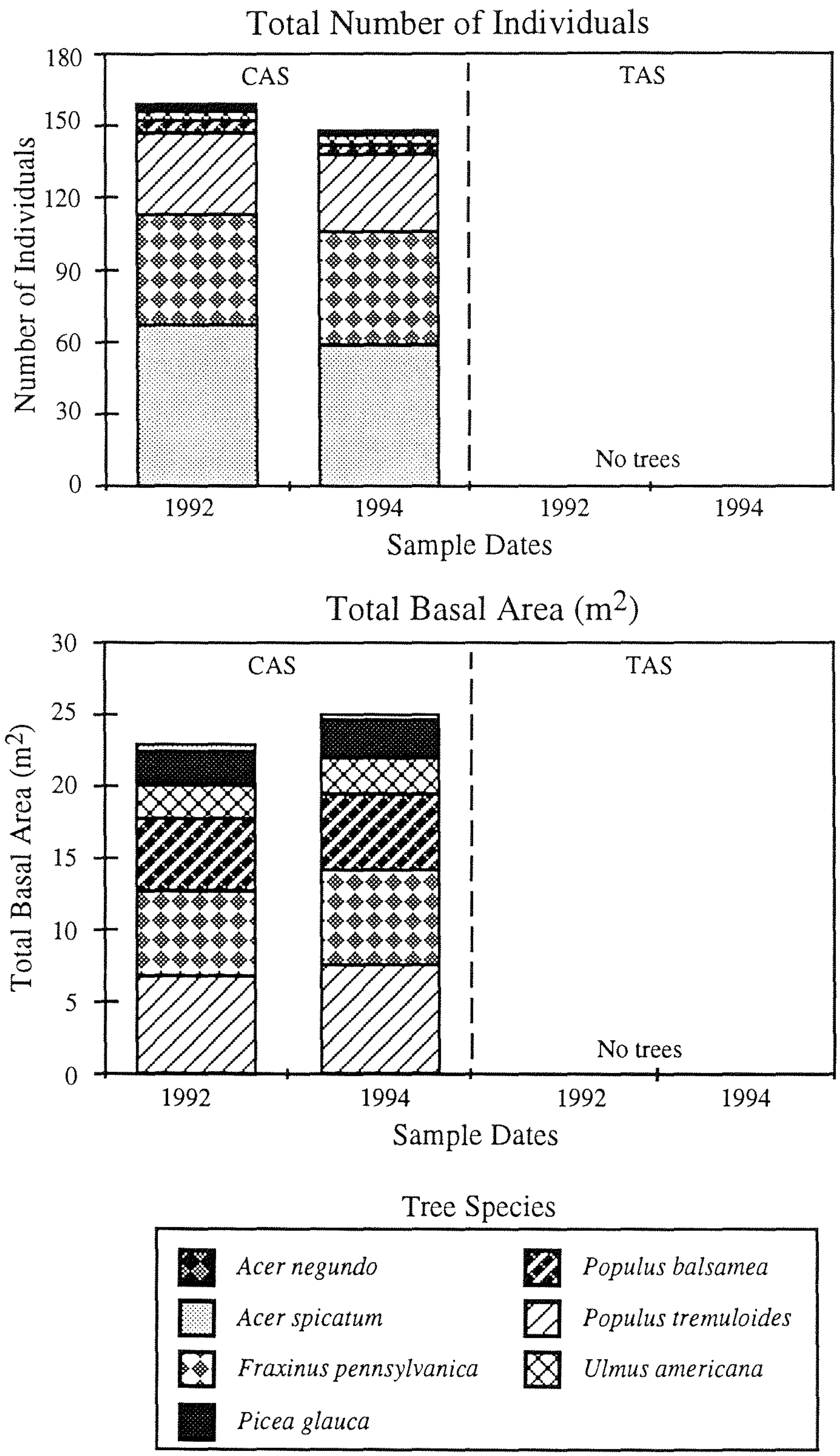

Fig. 35. Total number of individuals and total basal area (m^2) of tree species recorded in the 100 m^2 macroplot at the CAS and TAS study sites.

4.3 Browse Study

Figure 36 presents the mean density (number of specimens/m^2) of each browse species examined, as well as the mean density of the total available browse recorded along the transects at the control (unsprayed) and treated (sprayed) aspen stands at Sandy River. The total available browse at the control remained relatively constant with significant ($\alpha = 0.05$) declines evident in 1986 and 1994. *Salix* spp. dominated the browse of the unsprayed stand. *Populus tremuloides* and *Betula papyrifera* were also dense in some, but not all, of the sample years. *Rosa acicularis* and *Populus balsamifera* were uncommon, and *Cornus stolonifera* was entirely absent, except for a single specimen in 1992.

Results from ANOVA and Tukey tests indicate there was no significant difference ($\alpha = 0.05$) in total available browse at the sprayed aspen stand from 1985 to 1987. However, there was a significant decline in the 1988 total available browse. The total available browse in the 1992 and 1994 sample periods remained statistically the same as in 1988. *Populus tremuloides* was the dominant species in the treated stand during the 1985 to 1987 period. In 1988 it declined considerably, and the browse was then dominated by *Salix* spp. for the balance of the study. *Cornus stolonifera, Betula papyrifera, Populus balsamifera,* and *Rosa acicularis* were all present at the treated stand, but densities were relatively low.

Declines in total available browse at the unsprayed aspen stand in 1994 and at the sprayed aspen stand from 1988 to 1994 may have been partially due to increasing tree height. As tree height increased, the lower branches died, resulting in a decline in available material for ungulates within the measured browse zone. This was especially evident with *Populus tremuloides.* However, the decrease in browse density at the treated stand from 1987 to 1988 was characterized by an overall decline in each browse species examined. A similar decline was not observed at the control during the same sample period, which suggests that the decrease in density at the treated stand was a response to glyphosate applications. The glyphosate applications at the treated stand were conducted in 1985 and 1986. However, because the full effect of glyphosate on woody species may take up to two years (Malik and Vanden Born 1986), the vegetation response may not have been evident until the 1988 sample date.

Results from browse sampling at the control burn area showed an increase in density of available browse over the duration of the study (Figure 37). The 1984 fire likely greatly reduced or eliminated much of the vegetation in the area. Since the trees were destroyed by fire, the shrub stratum would have been able to develop with reduced competition, resulting in an overall trend of increase in total available ungulate browse

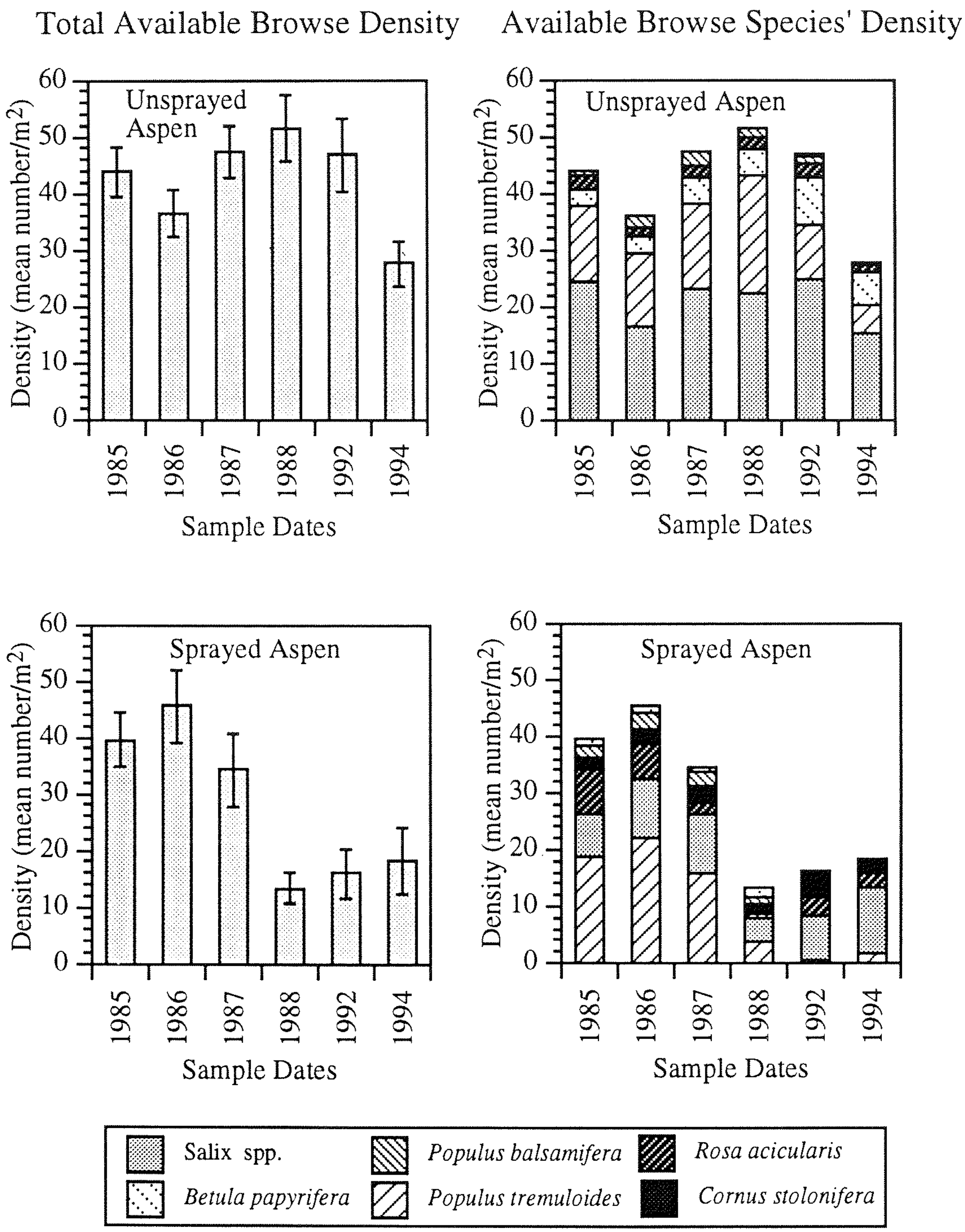

Fig. 36. Mean density of total available browse (number/$m^2 \pm$ SE) and available browse species (number/m^2) at the unsprayed and sprayed aspen areas.

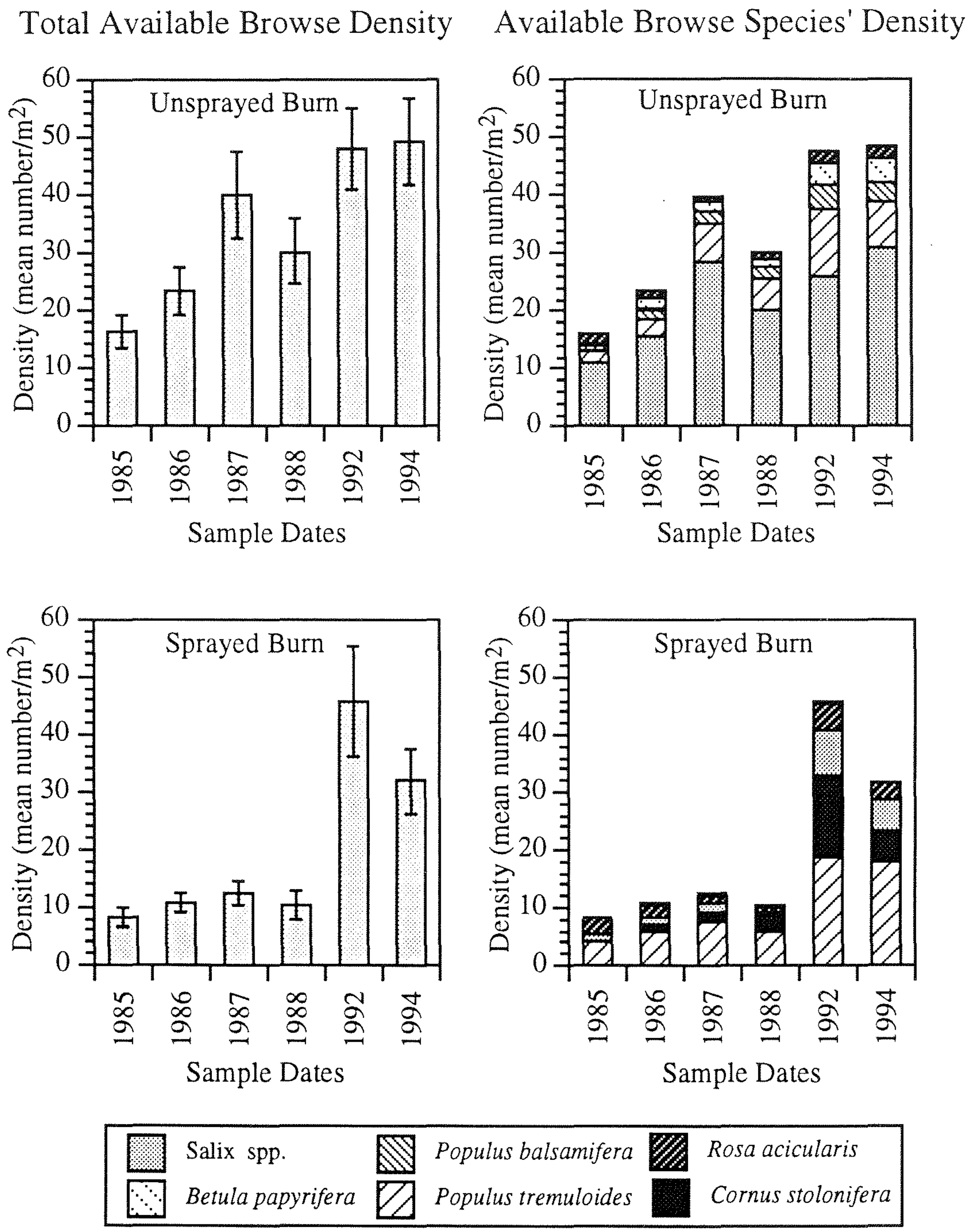

Fig. 37. Mean density of total available browse (number/$m^2 \pm$ SE) and available browse species (number/m^2) at the unsprayed and sprayed burn areas.

(Bangs *et al.* 1985). The dominant browse species at the control burn area was *Salix* spp., which was also the dominant species during post-fire regeneration of the shrub stratum at the CB site macroplot (see Section 4.2.3).

The relative densities of the six browse species differed between the control and treated burn areas. As mentioned, *Salix* spp. was the dominant browse species at the control, followed by *Populus tremuloides*, *Populus balsamifera, Betula papyrifera,* and finally, *Rosa acicularis*. No *Cornus stolonifera* was recorded at the control area. The treated burn browse was dominated by *Populus tremuloides*, with *Cornus stolonifera* becoming a major constituent during the last two sample periods. Small-scale variations in environmental factors and differences in propagule composition within the burn area were likely responsible for the differences in browse species composition between the control and its corresponding treated area.

Comparison of results between the treated burn area and the control burn area show strong evidence of glyphosate effects on the availability of browse species (Figure 37). Unlike the control, the treated burn area showed no significant increases in density of available browse from 1985 to 1988. However, by 1992 the density at the treated area had recovered to levels similar to those recorded in the control area. The effect of the 1985 and 1986 herbicide applications was to delay the recovery of browse species after the initial recolonization following the fire.

5. SUMMARY AND CONCLUSIONS

Comparison of vegetation sampling results from the study sites indicated that control of competing shrub and tree species with glyphosate was successful. However, the level of efficacy of the applications varied from site to site.

In the TA site there was some herbicide effect within the shrub stratum, particularly within the *Rosa acicularis* population, but no apparent effects on the herbaceous understorey or the tree stratum. A period of rainfall six hours following the 1985 application, and a non-uniform 1986 application (Henderson and Wotton 1988) were likely responsible for the poor vegetation kill in the TA site. Non-uniform herbicide applications are not rare in silvicultural practices and often result from rapid changes in weather conditions, difficulties in precise guidance of the applicator, and variations in the height of flight paths owing to the presence of residual trees or snags in some spray areas (Kennedy and Jordan 1985, Freedman *et al.* 1993). Santillo *et al.* (1989) estimated that in typical herbicide applications up to 10% of designated spray areas do not receive an effective dose of herbicide. However, this can prove beneficial in the long-term, as these pockets of undisturbed vegetation later contribute to the species diversity and species richness of the clearcut area as it regenerates (Freedman *et al.* 1993).

The tree and shrub strata of the TTL site exhibited a response to the 1987 glyphosate application. The understorey herbaceous layer, however, did not show any clear signs of herbicide influence. Foliage tissue samples indicate that the majority of the glyphosate was intercepted by the tree and shrub layers presumably before it could reach the herbaceous understorey layer. Lund-Hoie (1985) and Lautenschlager (1993) state that this phenomenon is not rare in silvicultural practices and this often leads to increased growth and diversity in the ground vegetation because of reduced competition from taller strata (Freedman *et al.* 1993). Increased growth in the understorey layer is not necessarily a concern for foresters. Due to differences in phenology between herbs and conifers, and the relatively low growth-form of most herbs, competition between conifers and herbs is not considered a significant problem in silvicultural practices (Gratkowski 1967).

The NTA site, the TB site, the TTH site, and the TAS site all showed clear evidence of vegetation control from glyphosate applications. The tree and shrub strata of the NTA site and the TAS site were killed, while regeneration of these same strata in the TB and TTH sites was greatly reduced as a result of the glyphosate applications. There was no evidence that glyphosate applied at a rate of 6.0 l/ha (Trans Licence sites) was more effective at controlling vegetation than when applied at a rate of 2.5 l/ha (Aspen, Burn, and Timber Harvest sites). In fact, the data from the Timber Harvest sites indicated that when applied properly, an application rate of 2.5 l/ha is quite adequate for long-term hardwood shrub and tree control. The species composition, diversity, and demographics of the understorey ground cover of each treated site were altered in comparison to their corresponding control site. The overall effect of the glyphosate was to return the vegetation of the treated sites back to earlier successional stages. It should be emphasized that species were not permanently lost by this action, and the direction of succession was not altered; but rather it was set back. Similar conclusions were reached in studies by Lund-Hoie (1975), Wendell and Kochenderfer (1982), Wagner (1984), and Freedman *et al.* (1993). According to Freedman *et al.* (1993) post-spray activities at such sites include rapid and progressive recovery of the vegetation due to growth and propagation of surviving individuals and perennating organs, increased recruitment from the *in situ* seed bank, and increased chance for establishment of plants originating from outside the effected area. This often results in initial increases in species diversity, but not necessarily species richness. All of these changes were the direct result of decreased competition within the sprayed area.

At the Sandy River treated aspen stand and treated burn area there was a decrease in available browse as a result of the 1985 and 1986 glyphosate applications. The available browse in the treated burn area did not increase significantly from 1985 to 1988, while the control burn area increased over the same period. The trend towards increasing browse in the latter is likely the result of post-fire succession and regeneration of the shrub stratum in the burn area. Studies have shown that effective applications of glyphosate have the potential of reducing browse resources for up to four years, and the reduction can be sufficient to cause moose to choose to feed elsewhere (Lautenschlager 1993). Connor and McMillan (1988) found that available moose browse on control plots was four times greater than on glyphosate-treated areas 21 months after the application. However, glyphosate applications, by reducing the tree stratum, can favour increased development of the shrub stratum. Regeneration of available browse was apparent at both sprayed areas in the latter years of the study. Regenerated areas are often favored by ungulates because of the diversity of browse species available and the increased ease of access to the areas (Kennedy and Jordan 1985, Newton *et al.* 1989).

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Appendix I : List of plant species abbreviations and corresponding scientific and common names for all study sites. (Nomenclature follows Scoggan 1957).

Abbreviation	Species	Common name	Abbreviation	Species	Common name
Abi bal	*Abies balsamea*	balsam fir	*Lyc spp.*	*Lycopus spp.*	water-horehound
Ace spi	*Acer spicatum*	mountain maple	*Lys thy*	*Lysimachia thyrsiflora*	tufted loosestrife
Ach mil	*Achillea millefolium*	yarrow	*Mai can*	*Maianthemum canadense*	wild lily-of-the-valley
Act rub	*Actaea rubra*	baneberry	*Med lup*	*Medicago lupulina*	black medick
Ame aln	*Amelanchier alnifolia*	saskatoon	*Mel lin*	*Melampyrum lineare*	cow-wheat
Ane can	*Anemone canadensis*	Canada anemone	*Men arv*	*Mentha arvensis*	wild mint
Ane qui	*Anemone quinquefolia*	wood anemone	*Mer pan*	*Mertensia paniculata*	tall lungwort
Apo and	*Apocynum androsaemifolium*	spreading dogbane	*Mit nud*	*Mitella nuda*	bishop's-cap
Aqu can	*Aquilegia canadensis*	wild columbine	*Mon uni*	*Monotropa uniflora*	Indian-pipe
Ara his	*Aralia hispida*	bristly sarsaparilla	*Pet pal*	*Petasites palmatus*	palmate-leaved colt's-foot
Ara nud	*Aralia nudicaulis*	wild sarsaparilla	*Pet sag*	*Petasites sagittatus*	arrow-leaved colt's-foot
Asa can	*Asarum canadense*	wild ginger	*Pet vit*	*Petasites vitifolius*	vine-leaved colt's-foot
Asc sp.	*Asclepias sp.*	milkweed	*Pic gla*	*Picea glauca*	white spruce
Ast cil	*Aster ciliolatus*	Lindley's aster	*Pin ban*	*Pinus banksiana*	jack pine
Ast pun	*Aster puniceus*	purple-stemmed aster	*Pol con*	*Polygonum convolvulus*	wild buckwheat
Ast sim	*Aster simplex*	tall white aster	*Pop tre*	*Populus tremuloides*	trembling aspen
Ath fil	*Athyrium filix-femina*	lady fern	*Pot nor*	*Potentilla norvegica*	rough cinquefoil
Bet pap	*Betula papyrifera*	paper birch	*Pot pen*	*Potentilla pensylvanica*	prairie cinquefoil
Bot vir	*Botrychium virginianum*	Virginia grape fern	*Pot tri*	*Potentilla tridentata*	three-toothed cinquefoil
Cal pal	*Caltha palustris*	marsh marigold	*Pre alb*	*Prenanthes alba*	white lettuce
Car spp.	*Carex spp.*	sedge	*Pru pen*	*Prunus pensylvanica*	pin-cherry
Cau tha	*Caulophyllum thalictroides*	blue cohosh	*Pru vir*	*Prunus virginiana*	choke cherry
Che alb	*Chenopodium album*	lamb's-quarters	*Pte aqu*	*Pteridium aquilinum*	bracken fern
Chi umb	*Chimaphila umbellata*	pipsissewa	*Pyr asa*	*Pyrola asarifolia*	pink wintergreen
Cir alp	*Circaea alpina*	enchanter's nightshade	*Pyr ell*	*Pyrola elliptica*	common shinleaf
Cir spp.	*Cirsium spp.*	thistle	*Ran spp.*	*Ranunculus spp.*	buttercup
Cli bor	*Clintonia borealis*	bluebead lily	*Rha aln*	*Rhamnus alnifolia*	alder-leaved buckthorn
Com umb	*Comandra umbellata*	comandra	*Rib gla*	*Ribes glandulosum*	skunkberry
Cor can	*Cornus canadensis*	bunchberry	*Rib hir*	*Ribes hirtellum*	low wild gooseberry
Cor ame	*Corylus americana*	American hazel	*Rib lac*	*Ribes lacustre*	swamp gooseberry
Cor cor	*Corylus cornuta*	beaked hazel	*Rib oxy*	*Ribes oxyacanthoides*	northern gooseberry
Cor sto	*Cornus stolonifera*	red-osier dogwood	*Rib tri*	*Ribes triste*	red currant
Die lon	*Diervilla lonicera*	bush-honeysuckle	*Rib spp.*	*Ribes spp.*	currant
Dry spi	*Dryopteris spinulosa*	spinulose shield fern	*Ros aci*	*Rosa acicularis*	prickly rose
Epi ang	*Epilobium angustifolium*	fireweed	*Rub ida*	*Rubus idaeus*	wild red raspberry
Equ arv	*Equisetum arvense*	field horsetail	*Rub pub*	*Rubus pubescens*	dewberry
Equ syl	*Equisetum sylvaticum*	wood horsetail	*Sal spp.*	*Salix spp.*	willow
Eri can	*Erigeron canadensis*	Canada fleabane	*San mar*	*Sanicula marilandica*	snakeroot
Fra pen	*Fraxinus pennsylvanica*	green ash	*Scu lat*	*Scutellaria lateriflora*	blue skullcap
Fra spp.	*Fragaria spp.*	strawberry	*Smi ste*	*Smilacina stellata*	false solomon's-seal
Gal bor	*Galium boreale*	northern bedstraw	*Sol spp.*	*Solidago spp.*	goldenrod
Gal tri	*Galium triflorum*	sweet-scented bedstraw	*Son arv*	*Sonchus arvensis*	field sow-thistle
Gau his	*Gaultheria hispidula*	creeping snowberry	*Son spp.*	*Sonchus spp.*	sow-thistle
Ger bic	*Geranium bicknellii*	Bicknell's geranium	*Sta pal*	*Stachys palustris*	marsh hedge-nettle
Geu spp.	*Geum spp.*	avens	*Ste cil*	*Steironema ciliatum*	fringed loosestrife
Gramineae	*Gramineae*	grass	*Ste lon*	*Stellaria longifolia*	long-leaved stitchwort
Gym dry	*Gymnocarpium dryopteris*	oak fern	*Str ros*	*Streptopus roseus*	rose twistedstalk
Hal def	*Halenia deflexa*	spurred gentian	*Sym alb*	*Symphoricarpos albus*	snowberry
Hed sp.	*Hedysarum sp.*	hedysarum	*Tar off*	*Taraxacum officinale*	dandelion
Her lan	*Heracleum lanatum*	cow-parsnip	*Tha spp.*	*Thalictrum spp.*	meadow-rue
Imp bif	*Impatiens biflora*	jewelweed	*Tri bor*	*Trientalis borealis*	northern starflower
Jun spp.	*Juncus spp.*	rush	*Tri cer*	*Trillium cernuum*	nodding trillium
Lac lud	*Lactuca ludoviciana*	western lettuce	*Ulm ame*	*Ulmus americana*	American elm
Lac sp.	*Lactuca sp.*	lettuce	*Urt dio*	*Urtica dioica*	stinging nettle
Lat spp.	*Lathyrus spp.*	vetchling	*Vac ang*	*Vaccinium angustifolium*	blueberry
Lin bor	*Linnaea borealis*	twinflower	*Vac vit*	*Vaccinium vitis-idaea*	dry-ground cranberry
Lon dio	*Lonicera dioica*	twining honeysuckle	*Vib edu*	*Viburnum edule*	low bush cranberry
Lon obl	*Lonicera oblongifolia*	swamp fly honeysuckle	*Vib raf*	*Viburnum rafinesquianum*	downy arrowwood
Lon spp.	*Lonicera spp.*	honeysuckle	*Vib tri*	*Viburnum trilobum*	high bush cranberry
Lyc cla	*Lycopodium clavatum*	running club-moss	*Vic spp.*	*Vicia spp.*	vetch
Lyc obs	*Lycopodium obscurum*	ground-pine	*Vio spp.*	*Viola spp.*	violet