The Design of Protocols for the Sustainable Harvest of the Non-Timber Boreal Forest Products *Acorus americanus* and *Vaccinium angustifolium*

by

Shaunna Marie Morgan

A thesis submitted to the Faculty of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Master of Science

Department of Botany

University of Manitoba

Winnipeg, Manitoba, Canada

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The Design of Protocols for the Sustainable Harvest of the Non-Timber Boreal Forest Products *Acorus americanus* and *Vaccinium angustifolium*

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Shaunna Marie Morgan

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of Master of Science

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ABSTRACT

Non-timber forest products (NTFP) are all biological materials, other than timber, which are removed from natural or managed forests for human use or consumption (Peters 1994, Broekhoven 1996). In recent decades, NTFP have been viewed as a means of conserving, managing and optimizing tropical forest ecosystems while still providing economic benefits to local residents (Wickens 1991, Hall and Bawa 1993, Salick *et al.* 1995, Velásquez Runk 1998). NTFP may provide similar opportunities and advantages to aboriginal Canadians living in the boreal forests of Canada. Therefore, protocols for establishing sustainable harvesting levels were designed and tested for two NTFP, *Acorus americanus* and *Vaccinium angustifolium*, in association with aboriginal communities of Manitoba and Ontario as a means of conserving, monitoring and optimizing boreal forest ecosystems.

This was the first study to examine the effects of various harvesting intensities on *V. angustifolium* and *A. americanus*. In accordance with expectations, *A. americanus* rhizome dry mass, shoot density and percent cover decreased as harvesting intensity increased. This was expected since the rhizome, the organ harvested for its medicinal values, is the primary means for propagation. Suggestions were made for modification to the monitoring protocols for *A. americanus* developed in this study. Monitoring different harvesting levels of *V. angustifolium* for two years produced unexpected results. This project is the first to examine effects of various harvesting levels on blueberry production. As harvesting intensity increased, mass, volume and berry density tended to decrease among harvested treatments. Interestingly, harvesting some (30%) or most (70%) of the berries may have had a stimulatory effect on berry density, resulting in an apparent increased yield compared with the control or the 100% harvesting intensity. Recommendations were also made to improve the monitoring protocols for *V. angustifolium* .

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CHAPTER 1 INTRODUCTION

1.1 Non-timber Forest Products

Interest in the commercial potential and traditional uses of non-timber forest plants and plant products has been increasing in recent years (Wickens 1991). Non-timber forest products (NTFP) are all biological materials, other than timber, which are removed from natural or managed forests for human use or consumption (Peters 1994, Broekhoven 1996). In recent decades, NTFP have been viewed as a means of conserving, managing and optimizing tropical forest ecosystems while still providing economic benefits to local residents (Wickens 1991, Hall and Bawa 1993, Salick *et al.* 1995, Velásquez Runk 1998). In tropical areas, many indigenous and rural people continue to rely on NTFP for subsistence and have started to harvest additional NTFP to supplement their incomes (Peters 1994, Broekhoven 1996, Mahapatra and Mitchell 1997, Velásquez Runk 1998). In Canada and the United States, many people are harvesting NTFP in boreal forests and temperate rain forests for similar purposes (Foster 1992, De Geus 1995, Schlosser and Blatner 1995, Liegel *et al.* 1998, Pilz *et al.* 1998, Love *et al.* 1998).

1.2 NTFP and Aboriginal communities across Canada

Canada has an abundant 417.6 million hectares of forested land, which constitutes 45% of the total area of Canada (Shilts 1999). An estimated 80% of Canada's aboriginal population lives within those forested areas (Shilts 1999). Owing to the lack of employment opportunities on Canadian Indian reserves, the unemployment rate for aboriginals living on reserves is 28.7% (Statistics Canada 1999a), in contrast with Canadian national rate of 8.1% (Statistics Canada 1999b). The revenue generated from NTFP has been increasing over the past few decades in tropical areas (Burman 1990,

Broekhoven 1996) and is also on the rise in North America (Molina *et al.* 1993). Therefore, NTFP may present a viable opportunity for economic development in the boreal forest regions of Canada where many aboriginal people suffer from high unemployment and low income levels. Central American communities currently harvesting NTFP are concerned with improving their quality of life by maximizing harvesting while minimizing its ecological effects, retaining control over their lands and resources, minimizing costs related to harvesting and sustaining their culture (Velásquez Runk 1998). Canadian aboriginal populations have similar concerns, thereby suggesting a good fit between aboriginal values and the use of NTFP.

1.3 Harvesting NTFP - Need for Studies

Presently, there are substantial gaps in our knowledge of the biology of NTFP and sustainable harvesting practices. Quantitative ecological analysis of the abundance, distribution, population dynamics, production and reproduction of NTFP are rare or nonexistent (Hall and Bawa 1993, Boot and Gullison 1995, Salick *et al.* 1995, Boot 1997, Johnston 1998, Velásquez Runk 1998). Such studies are fundamental for the accurate assessment of the potential sustainable harvest of NTFP (Hall and Bawa 1993, Boot and Gullison 1995). In addition to the lack of knowledge regarding the impact of harvesting NTFP from forest ecosystems, the relationship between harvesting intensity and impact is also largely unknown, even for NTFP with a long tradition of use, such as Brazil nuts (Boot and Gullison 1995).

Researchers have discussed methods and approaches to assess or develop sustainable extraction systems (Hall and Bawa 1993, Boot and Gullison 1995), but none has investigated the effects of differing harvesting levels in a natural system. Hall and Bawa (1993) suggested detailed biological investigations regarding the abundance and distribution of NTFP and investigations regarding the effects of a range of harvesting intensities on population dynamics as necessary. They also recognized the need for long

term monitoring in order to ascertain secondary harvesting effects in the ecosystem that might not be immediately evident. Boot and Gullison (1995) suggested that demographic models, which create a three dimensional forest based on species, age and location of trees, should be created and used to test the effects of harvesting at various intensities. These spatial, individual-based models may have the ability to predict the ecological maximum sustainable harvesting intensity (Boot and Gullison 1995). Modeling may be possible for some NTFP but it is unlikely to perform accurately for all plants or plant parts. Furthermore, the range of possible harvesting intensities tested should be investigated with respect to economic returns, and then the models should start testing at the minimum harvesting intensity that would be economically viable (Boot and Gullison 1995). The range of harvesting intensities would be bounded then by the economical minimum and the ecological maximum (Boot and Gullison 1995).

The elements affecting the relationship between harvesting intensity and effects on a forest are: (i) the number and strength of interactions between the NTFP and other species in the community, (ii) the relative abundance of the NTFP, (iii) the type of plant tissue harvested and (iv) the extraction method (Boot and Gullison 1995). However, the dynamic nature of forest systems increases the difficulty in deciding what level of impact on the ecosystem is acceptable (Boot and Gullison 1995).

1.4 Nonsustainable Harvesting of NTFP

The harvesting of any NTFP will produce a measurable effect on the structure and population dynamics of the target species (Peters 1994). Minimizing these effects is the goal of NTFP management activities (Peters 1994). The two key aspects important to the sustainable harvesting of NTFP are: (i) the harvesting intensity and (ii) the type of plant tissue harvested (Boot 1997). The harvesting of reproductive propagules, like seeds and fruits, is thought not to affect the parent plant, but only this plant's ability to establish seedlings (Peters 1994, Boot 1997). On the other hand, harvesting the rhizome, as in

ginseng (Lewis and Zenger 1982), or the shoot apical meristem of the palm tree (palm heart) (Broekhoven 1996) results in the destruction of reproductive adult plants in the population. Even so, conservation and development specialists frequently assume that the extraction of NTFP does not affect the ecosystem structure and function and/or is sustainable for the NTFP plant population (Velásquez Runk 1998).

1.5 Medicinal NTFP

Medicinal plants have received special attention in recent years and have always been of pharmaceutical interest as a source of new drugs. Medicinal NTFP often serve as prime examples of how NTFP have been harvested in a nonsustainable manner in the past. A high profile example is the case of taxol, a drug isolated from the bark of *Taxus brevifolia* (western yew tree). Taxol is regarded as one of the most important advances in cancer research in recent history (De Geus 1995). As a result of medicinal properties, the total volume of *Taxus* bark harvested in British Colombia almost tripled from 1991 to 1993, to approximately 35,000 kg dry mass (De Geus 1995).

The World Health Organization concluded that traditional medicines are necessary to meet the minimum health requirements of developing countries (Croom 1983). There has also been phenomenal growth in the herbal remedy market in Europe and America in the past decade. This is evident in the popular media which are littered with advertisements for *Ginkgo biloba*, *Echinacea* spp. and St. John's Wort (*Hypericum* spp.) as health supplements. Consequently, many medicinal plants are being harvested without any information on the effects of harvesting. The harvesting of American ginseng (*Panax quinquefolius*) for export to the Asian market is an example of what can happen when harvesting is conducted without regard for the sustainability of such actions. Once abundant in eastern North America, American ginseng is now considered threatened, rare, or endangered in various parts of its natural range due to the unsustainable harvesting of the rootstocks (Lewis and Zenger 1982). If politicians decide to advocate sustainable

harvesting systems, and the socioeconomic circumstances are favorable, researchers must be prepared to devise these systems (Boot and Gullison 1995) for all NTFP with economic potential.

1.6 What is Sustainable Harvesting?

There has been much debate over what constitutes sustainable harvesting. In the simplest terms, sustainable harvesting is the removal of products by humans at a rate that does not exceed the rate of regeneration (Hames 1987). Peters (1994) defined sustainable harvesting as 'harvesting of product that can continue indefinitely from a finite forest area with minor effects on the structure and dynamics of the NTFP plant population.' Hall and Bawa (1993) have a much stricter idea of sustainable harvest:

> "...extraction is considered sustainable if the harvest has no long term deleterious effect on the reproduction and regeneration of populations being harvested in comparison to equivalent non-harvested natural populations. Furthermore, sustainable harvest should have no discernible adverse effects on other species in the community, or on ecosystem structure and function." pg. 235

This definition is more complete as it includes the reproduction aspect of a population being harvested as well as ecosystem structure and function.

One of the main concerns behind conservation efforts is the preservation of biodiversity. Ensuring that the number of plants is large enough for sexual reproduction to occur, allows for greater genetic diversity within the population. Hall and Bawa's (1993) definition also includes the role the harvest species plays within the ecosystem, recognizing that the selected harvest species is not only an entity unto itself but is also part of a complex system. The removal of any plant or plant part in large quantities may have effects on the rest of the ecosystem and these effects must be considered.

However, Boot and Gullison (1995) felt that Hall and Bawa's (1993) stringent definition goes too far. They argued that it is unreasonable to require the harvesting of significant quantities of any forest product to cause no changes in the ecosystem. Boot and

Gullison (1995) asserted that it is difficult enough to find sustainable uses of NTFP without insisting that the harvesting of NTFP have absolutely no discernible effects. Furthermore, Boot and Gullison (1995) contended that NTFP must compete with other forms of land use and that we should be more flexible in our acceptance in changing the composition and relative abundance of species in managed forests. They suggested that a harvesting system should only be required to result in no loss of species and no irreversible changes in ecosystem processes. Peters (1994) stated that, if performed on a sustainable basis, the exploitation of NTFP renders a unique means by which to use the forest for revenue and still maintain most of the biological diversity and ecosystem functions such as soil fertility, prevention of soil erosion, water filtration for controlled runoff, carbon storage and climate regulation. Johnston (1998) pointed out that NTFP extraction may only be economically viable when the product is in high abundance, as may be the case with low diversity forests, such as the northern boreal forest which covers much of Canada.

1.7 NTFP Research in Canada

Across Canada, research into NTFP is still in its early stages and most of it has been concentrated on the market for these products. In particular, ample research has focused on mushrooms and other fungi in the states of the Pacific Northwest and British Columbia due to the lucrative Asian market (Anon 1990, FBM Consulting Ent. 1989, De Geus 1992). In Saskatchewan, a market analysis of NTFP has been carried out through the Prince Albert Model Forest. Recently, in Manitoba a small number of projects investigating NTFP has been completed. Dr. Robin Marles of Brandon University finished a project entitled 'Traditional Plant Products of Aboriginal People in the Northwest Region' helping First Nations people in Alberta, Saskatchewan and Manitoba to inventory NTFP, especially those of culinary or medicinal value. In the department of Botany at the University of Manitoba former graduate students Jennifer Barker (1997) and Candace

Turcotte (1997) each completed a thesis on the NTFP, *Vaccinium myrtilloides* (velvet leafed blueberry) and *Polygala senega* (Seneca snakeroot), respectively.

1.8 Need for NTFP monitoring program implementation

Aboriginal Canadians require more opportunities for economic ventures and are concerned with preserving their culture and conserving the ecosystem around them. Harvesting of NTFP is believed to be an excellent way to provide employment in forested regions and conserve forests. These reasons provided the impetus for the creation of monitoring protocols for the sustainable harvest of NTFP in the boreal forest region of Canada.

1.9 Study Objectives

The first objective of this study was to establish monitoring protocols for two boreal NTFP plant species using various harvesting intensities. This is the first time a study monitoring the effects of various harvesting intensities on NTFP has been performed. The monitoring protocols were designed to monitor plant productivity and detect changes due to harvesting intensity. The term plant productivity for this study does not mean the net primary productivity, or the rate at which the plants convert energy into plant tissue. The term productivity is loosely used to refer to the production of vegetative and reproductive units from one year to the next. The second objective was to include First Nations leaders and elders to guide us in the direction they were most interested in with respect to NTFP. Finally, the principal objective was to collect data from the monitoring protocols for two growing seasons, analyze the data to test the effects of the various harvesting intensities on the NTFP, and make recommendations for the refinement of the monitoring protocols.

1.10 Community (Reserve) Selection

The Department of Indian and Northern Affairs was contacted for a list of chiefs and associated reserves in Manitoba and Ontario. Letters of inquiry (Appendix I) were sent to 20 chiefs of reserves within a four hour driving radius of Winnipeg. A self-addressed, stamped envelope was enclosed with each letter and a reply form which asked them to respond either positively or negatively to the proposed study. After telephone conversations and initial meetings with the chiefs and the elders from some of the communities, two locations were chosen for field study: Sagkeeng First Nation (MB) and Ojibways of Onegaming (ON, Figure 1.1). These reserves were chosen because of the positive and enthusiastic attitudes of the chiefs, environmental officers and elders to the proposed study.

1.11 Study species selection

During the meeting with the Sagkeeng elders, many plant species were discussed as possible candidates for study. The criteria for species selection were:
i) plants with high frequency and abundance; ii) plants traditionally used by the community; iii) plants with potential market value . *Acorus americanus* (Figures 1.2 and 1.3) and *Vaccinium angustifolium* (Figure 1.4) were agreed upon as appropriate study species.

At meetings with the chief, environmental officer and elders at the Ojibway of Onegaming, many of the same species were discussed. For the purpose of consistency between studies, it was agreed that *A. americanus* and *V. angustifolium* would be appropriate study species for this location, as elders believed that both species were relatively frequent and abundant.

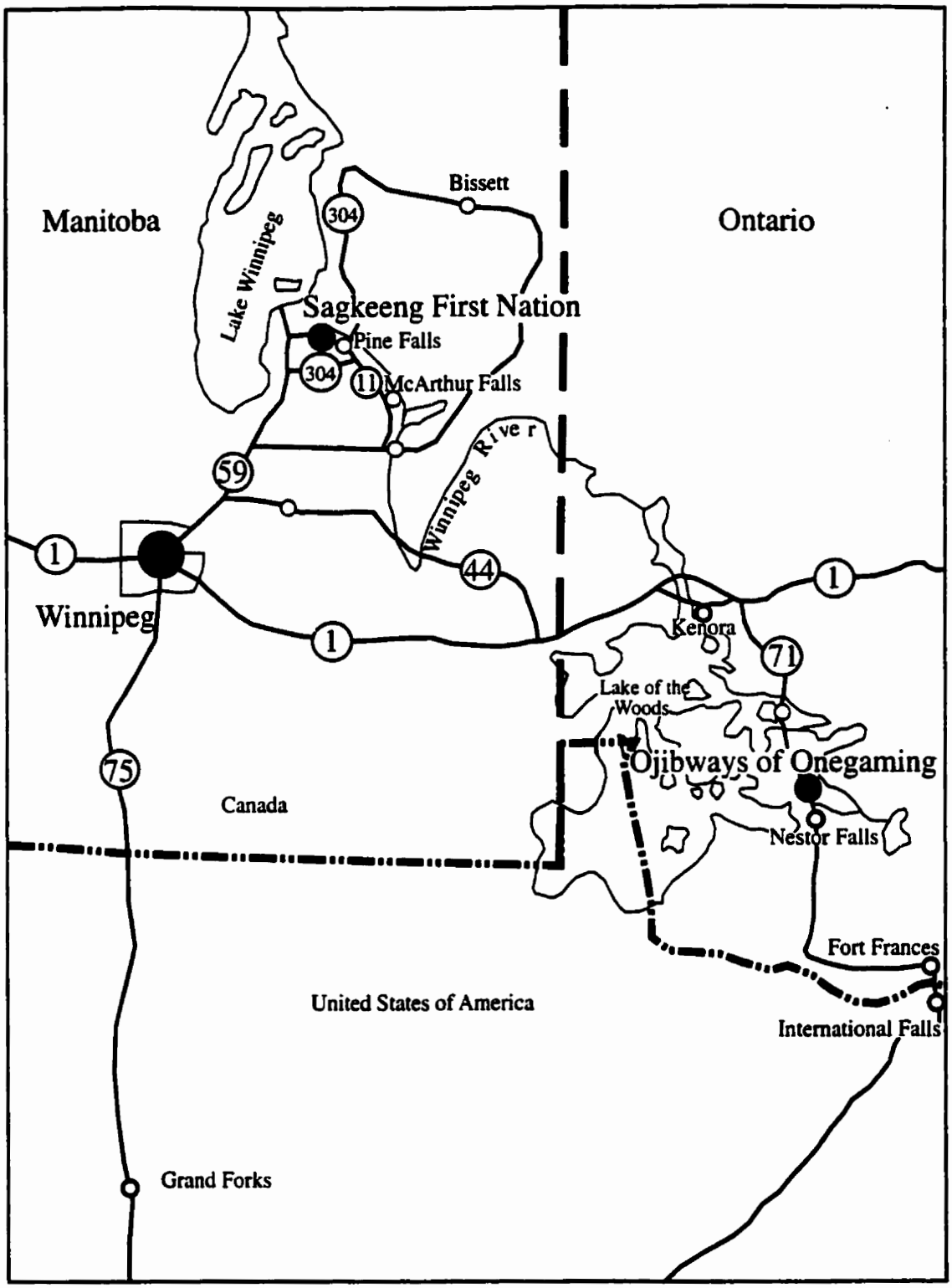

Figure 1.1 Map of eastern Manitoba and western Ontario showing the locations of Sagkeeng First Nation and Ojibways of Onegaming First Nation.

Figure 1.2 *Acorus americanus* (Sweet flag)

Figure 1.3 Uncleaned rhizome of *A. americanus*

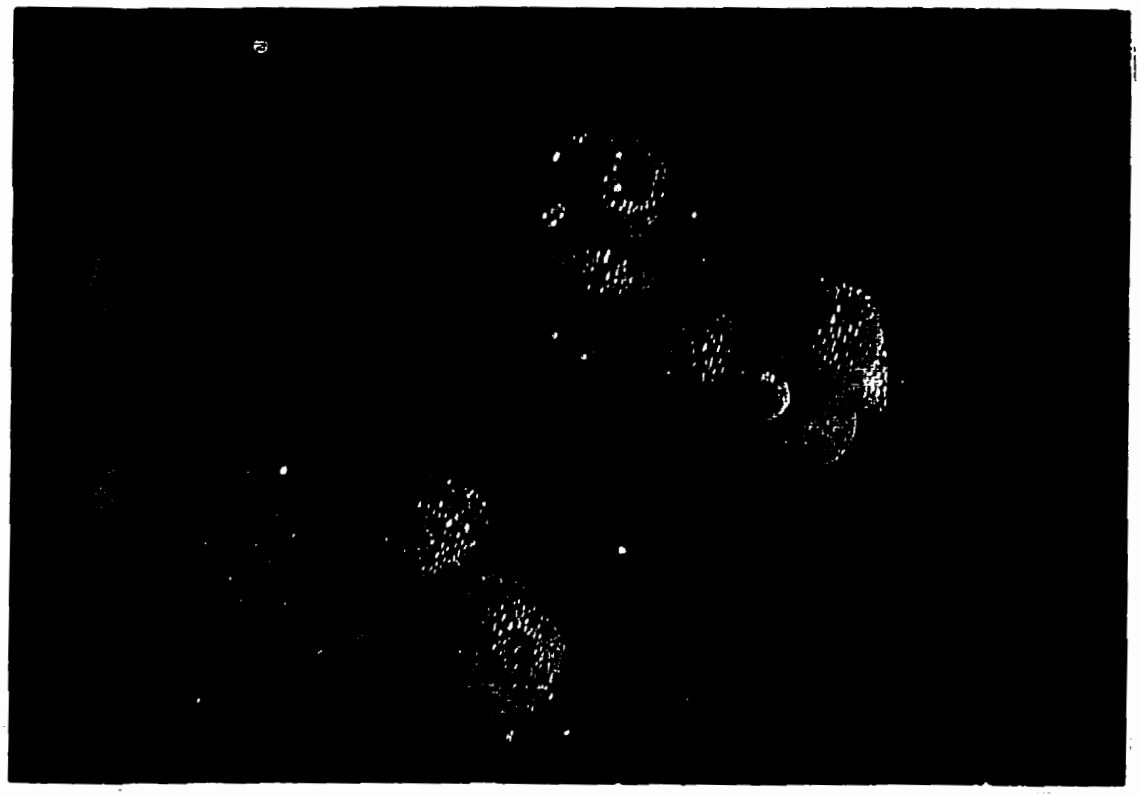

Figure 1.4 *Vaccinium angustifolium* (low bush blueberry).

CHAPTER 2 LITERATURE REVIEW

2.1 *Acorus americanus*

2.1.1 Taxonomy

At the present time, *Acorus* L. is considered to be the only genus in the family Acoraceae. Previously, this taxon was included as an aberrant genus in the family Araceae (Thompson 1995). Grayum (1987) removed *Acorus* from the Araceae and created the family Acoraceae using 16 specific lines of evidence. A thorough examination of the Araceae and Acoraceae families was completed by Thompson (1995). Since Grayum's (1987) paper, the family Acoraceae has become widely accepted (Cronquist 1988, Thorne 1992, Thompson 1995). Molecular evidence using the rbcL gene sequences also substantiates this concept (Duvall *et al.* 1993). Furthermore, genetic evidence (Duvall *et al.* 1993, Nickrent and Soltis 1995) suggests that *Acorus* is one of the oldest extant lineage of monocotyledons.

Taxonomic uncertainty has also been prevalent at the species level in the genus *Acorus*. Until recently, only one species, *A. calamus* L., was recognized by most North American floras (Hulten 1962, Locock 1987, Scoggan 1978). Packer and Ringius (1984) were the first to provide evidence that *A. americanus* (Rafinesque) Rafinesque is a species separate and distinct from *A. calamus*. Their findings were based on differences in ploidy, pollen stainability and fruiting capability between *A. calamus* and *A. americanus*. Thompson (1995) was the first to describe vegetative differences between *A. americanus* and *A. calamus* using leaf venation. *A. americanus* possesses several equally prominent veins compared with *A. calamus* that has one prominent midvein. Table 2.1 provides a summary of major differences between the two species.

Table 2.1 Summary of differences between *Acorus americanus* and *A. calamus* in North America (Thompson 1995).

	A. americanus	*A. calamus*
Leaf venation	Several ± equally prominent veins	One prominent midvein
Reproduction	Sexual and asexual	Asexual only - sterile in N. America
Fruiting	Regularly produces mature fruits	Never produces mature fruits
ß-asarone	Absent	Present
Geranylacetate	Present	Absent
Uromyces sparganii infections	Susceptible	Unknown - presently never observed
Pollen stainability (1% aniline blue disolved in lactophenol)	> 35.5%	0 - 3%
Ploidy	Diploid (2n=24)	Triploid (2n=36)
Native status	Native; possibly endemic to Great-Lakes region	Introduced

2.1.2 Description of *Acorus americanus*

(a) Raunkiaer life-form.

According to the Raunkiaer classification system, *A. americanus* is a geophyte, a plant that survives unfavorable conditions by means of an underground organ, such as a rhizome, with buds on this organ generating new aerial shoots when conditions are favorable (Allaby 1992). *A. americanus* is an aquatic to semi-aquatic perennial wetland herb with long, ensiform, equitant vegetative leaves, a solitary spadix that diverges from a fused peduncle and sympodial leaf; the upper sympodial leaf extends beyond the spadix, but is not a true spathe; reproduction is by seeds and rhizomes (Grayum 1987, Thompson 1995)

(b) Shoot morphology.

Small clusters of bright green leaves sprout from a shallow, compact network of rhizomes (Dykyjova 1980). Leaves are not differentiated into petiole and blade and possess several prominent veins running parallel the length of the leaf. Vegetative leaves range in length from 46 - 145 cm, averaging 94 cm; in width they range from 3 - 12 cm, averaging 7 cm (Thompson 1995). Sympodial leaves are usually about equal to or slightly longer than vegetative leaves. *A. americanus* is aptly called 'Sweet Flag' because the leaves have a distinctive, pleasantly sweet odor.

(c) Rhizome and Root morphology.

The extensive branching network of rhizomes that are positioned at the water-soil interphase, giving rise to numerous above ground shoots, is often mistaken as several plants (Bucher *et al.* 1996, Motley 1994, Thompson 1997). Many long white roots emerge

from the lower surface of the rhizome to anchor the plants to the substrate and also presumably function in nutrient absorption.

New, young rhizomes are produced over the summer period, and starch accumulates in the early summer in the old rhizomes (Bucher *et al.* 1996). The rhizome is the storage organ that allows the plant to survive the winter. New shoots are produced in the late fall and remain small and dormant until the spring when starch supplied by the rhizomes provides energy for rapid shoot growth. Dykyjova (1980) has shown that a cold period simulates winter, enabling normal sprouting of shoots and invigoration of *Acorus* plants in greenhouses. Plants exposed to a cold treatment had a greater leaf area, shoot dry mass, below ground dry mass, below/above ground ratio and total grams of carbon (Dykyjova 1980). Interestingly, rhizomes planted in soil and submerged in water produced new rhizomes and shoots without a cold treatment (personal observation). However, the shoots did not appear to grow vigorously. Dykyjova (1980) also observed a constant *Acorus* below ground ($g \cdot m^{-2}$)/above ground($g \cdot m^{-2}$) ratio from year to year because new shoots are produced on newly sprouting rhizomes and all along the length of old rhizomes as well. In a natural environment, Dykyjova (1980) observed R/S ratios of 1.85-1.96.

(d) Inflorescence.

The combination of sword-shaped leaves and solitary elongate inflorescence, a spadix borne about midway on the sympodial leaf, makes *A. americanus* uniquely identifiable among North American plants (Thompson 1997). Flowers of *A. americanus* are small (2 - 3 mm in diameter), perfect, densely aggregated on a spadix, trimerous, perigoniate with 6 light brown tepals (Grayum 1987, Thompson 1995, Thompson 1997). Dry berries, regularly produced by *A. americanus*, are obpyramidal, 4 - 6 mm in size and light brown to reddish in color. Fruits contain six to nine narrowly oblong to obovate seeds, 3 - 4 mm in length (Thompson 1995).

(e) Chromosome number.

A. americanus is a fertile diploid with a chromosome number of $2n = 24$ (Packer and Ringius 1984, Thompson 1995).

2.1.3 Geographic range

A. americanus is distributed in temperate to subtemperate regions from Newfoundland to British Columbia and from the Northwest Territories and Alaska to the northern United States (Motley 1994, Figure 2.1, Table 2.2). Recently, Evstatieva (1996) identified Mongolian specimens as *A. americanus* since the plants apparently lack ß-asarone (see Table 2.1) and are diploid. Further investigation is required to examine if the geographic range of *A. americanus* should be expanded to include Mongolia.

North American and European triploid *A. calamus* show genetic uniformity with regard to factors governing oil production, supporting the theory that European settlers introduced the plant to North America (Röst and Bos 1979). Further, the limited distribution of *A. calamus* in North America also supports the introduction theory (Packer and Ringius 1984, Thompson 1995). As all *Acorus* was originally thought to be *A. calamus*, it was therefore believed that all *Acorus* was introduced to North America from Europe (Packer and Ringius 1984, Thompson 1995). As two species of *Acorus* have now been recognized (Thompson 1995), we can now distinguish that one species was introduced and the other is native. *Acorus calamus* was introduced from Europe, probably before the end of the 17th century (Thompson 1995). *Acorus americanus* is considered to be native to North America. It is most commonly found from the Atlantic provinces to the Great Lakes region suggesting it may be endemic to those areas (Thompson 1995). Interestingly, the present geographical distribution of *A. americanus* and of aboriginal American people are very similar. This correlation, as well as reports of low genetic diversity, suggest that the current distribution of *A. americanus* was likely

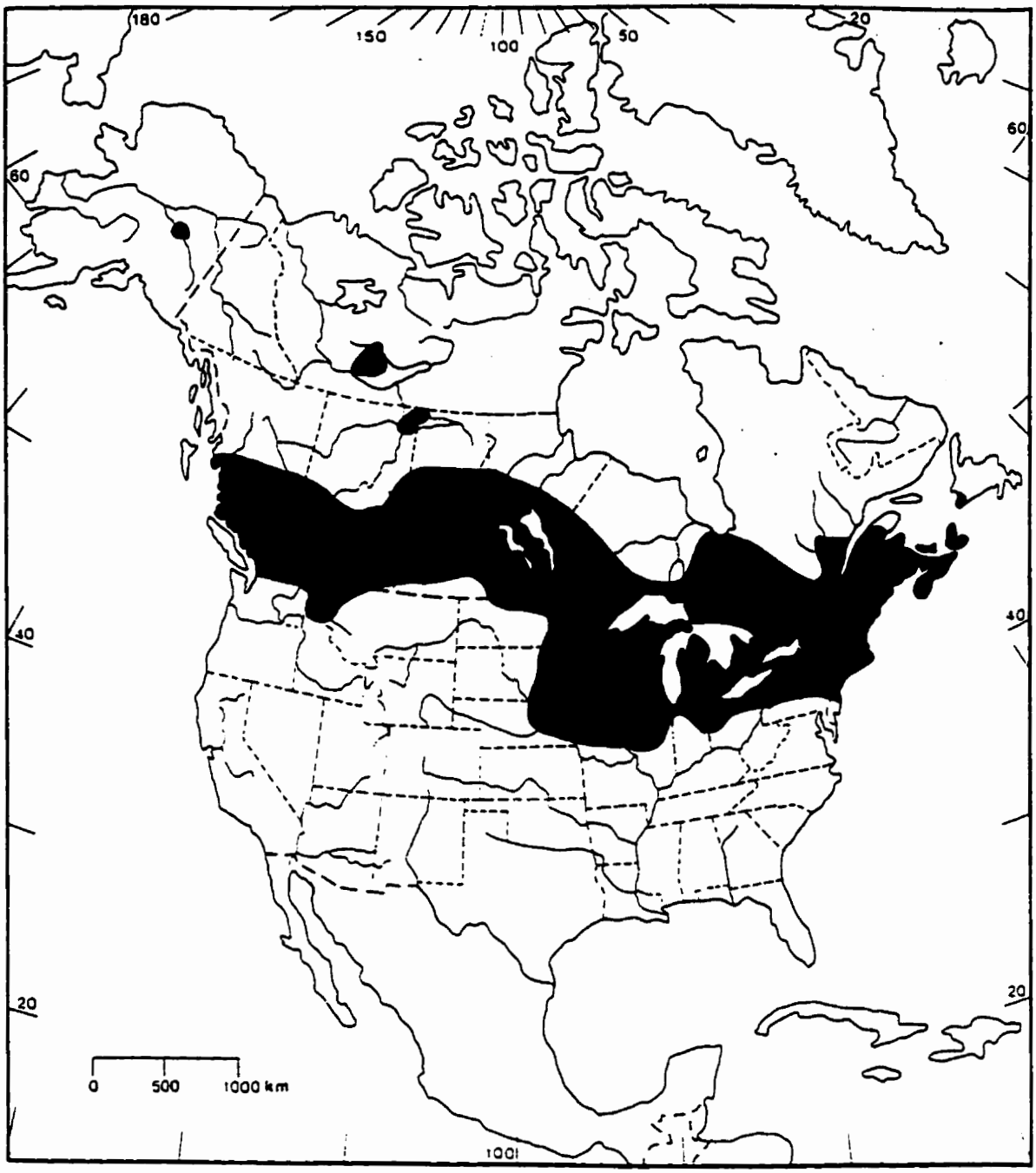

Figure 2.1 North American distribution of *Acorus americanus* (Packer and Ringius 1984, Thompson 1995, University of Manitoba (WIN) herbarium distribution map, 1999).

Table 2.2 Geographical distribution of *Acorus americanus* in North America. *Provinces and states with both *A. americanus* and *A. calamus* (Thompson 1995).

Canada	United States	
Alberta	Alaska	New Hampshire*
British Columbia	Connecticut*	New Jersey*
Manitoba	District of Columbia	New York*
New Brunswick*	Idaho	North Dakota
Newfoundland	Illinois*	Ohio*
Northwest Territories	Indiana*	Pennsylvania*
Nova Scotia*	Iowa*	Rhode Island*
Ontario*	Maine*	South Dakota*
Prince Edward Island	Massachusetts*	Vermont*
Quebec*	Michigan*	Virginia*
Saskatchewan	Minnesota*	Washington
	Montana	Wisconsin*
	Nebraska*	

determined by the trade, transportation and cultivation of *A. americanus* by aboriginal Americans (Thompson 1995). Indeed, Löve and Löve (1957) believe *A. americanus* has been a member of the North American flora since the early Tertiary, prior to the last glaciation, about 60 million years ago.

2.1.4 Physical Habitat

Acorus americanus is uncommon but widely distributed in littoral, wetland regions in Canada and the United States (Packer and Ringius 1984, Thompson 1995). It tends to have a very patchy distribution, with high abundance in certain localities (Shay 1996).

In a field experiment, Dykyjova (1980) showed that *Acorus* plants grown in hydroponic sand cultures in 25% - 300% range of undefined nutrient solutions achieved the greatest biomass in a 50% nutrient solution. Therefore, Dykyjova (1980) concluded that *Acorus* is adapted to nutrient poorer, sandy habitats. As Dykyjova (1980) did not identify the nutrient solution used it is difficult to determine if his conclusions are indeed correct.

2.1.5 Reproduction

Observed allele frequencies using isozyme electrophoresis among individuals in *A. americanus* populations suggest that this plant reproduces mainly vegetatively through rhizomes (Thompson 1995). Although seeds are regularly produced by *A. americanus*, it seems that large clonal populations are more common than individuals produced from seed. Alternatively, the allele frequencies could suggest that sexual recombination is limited as a result of inbreeding (Thompson 1995).

Due to the medicinal properties of *Acorus*, researchers (Harikrishnan *et al.* 1997) have investigated methods to increase the vegetative propagation of plants. Conventionally, each bud produces a single shoot thereby limiting the ability for mass

production of shoots. Harikrishnan *et al.* (1997) have developed tissue culture techniques using BAP (6-benzylaminopurine) and NAA (naphthaleneacetic acid) as growth regulators, on a MS (Murashige and Skoog) solid medium that induces multiplication of shoots to facilitate mass production of rhizomes.

2.1.6 Biochemistry

The medicinal value of *Acorus* rhizomes is believed to be in large part due to the chemical constituents of the essential oil. The main constituents of the essential oil of *A. calamus* leaves and rhizomes are asarone and ß-asarone (Thompson 1995). On the other hand, the main oil constituent of the essential oil of *A. americanus* leaves is geranylacetate, while *A. calamus* does not contain any geranylacetate(Röst and Bos 1979). Interestingly, the rhizomes of *A. americanus* do not contain any ß-asarone; the main constituents of the essential oil are shyobunones and other unknown compounds (Röst and Bos 1979). The concentration of chemical components varies within different plant parts and between plants (Röst and Bos 1979). Environmental factors likely play a major role in variations in the concentrations and composition of the essential oils (Evstatieva 1996). Studies investigating the pharmaceutical properties of *A. americanus* oil are reviewed by Locock (1987).

Acorus rhizomes have a rich mineral content. Essential nutrients such as N, P, and K accumulate in large quantities in *Acorus* leaves and rhizomes (Dykyjova 1980). Samudralwar and Garg (1996) report that the rhizome of *A. calamus* (tetraploid) is relatively rich in Fe and Br content, 355 and 20 µg/g dry mass, respectively. This may account for its reported medicinal value for restoring energy and vigor.

2.1.7 Ethnobotany

A. americanus has been used medicinally for hundreds, if not thousands of years in North America, Europe and Asia (Densmore 1974, Erichsen-Brown 1980, Kindscher 1992, Motley 1994, Thompson 1995). In Manitoba and Ontario, some of the aboriginal names used for *Acorus* are: (1) Cree: weekas, wee-kess (= muskrat root), pow-e-men-arctic (= fire root, bitter pepper root); and (2) Ojibway: wike, wiikenh, wika, wikén. A comprehensive list of common names for *Acorus* used by Native American groups has been completed by Thompson (1995). *Acorus* also has many common names world wide some of which are presented below:

beewort
bitter pepper root
calamus
cinnamon sedge
drug sweet flag
fire
flag root
gladdon
muskrat root
myrtle flag
myrtle grass
myrtle sedge
pepper root
pine root
rat roots
reed acorus
sweet calomel
sweet cane
sweet cinnamon
sweet flag
sweet flagroot
sweet grass
sweet root
sweet rush
sweet segg
water flag
yellow flag
(Motley 1994, Coon 1977).

According to legend, *Acorus* was first introduced to aboriginal people by the muskrat. The Penobscot (a northeastern Algonquian people who live south of the St. Lawrence River) use the muskrat root (*Acorus*) as a cure for cholera. It is believed that calamus is the food that makes the excrement of the muskrat 'meager' and will affect humans in a similar manner. This knowledge was imparted to the Penobscot shaman by the muskrat spirit during a dream at a time when his people were plagued by a sickness that was killing many people. In a vision, the muskrat spirit told the man where the *Acorus* was growing. The shaman awoke, acquired the muskrat root. He prepared the medicine and his people were cured of the illness that plagued them (Erichsen-Brown 1980).

The uses for *Acorus* in aboriginal culture are quite extensive. *Acorus*, as with all traditional medicinal plants, has spiritual significance and has been used in a religious way. For example, pieces of the rhizome tied to the clothing or blankets of children were

believed to keep night spirits at bay (Erichsen-Brown 1980). Additionally, Teton-Dakota warriors chewed the root and smudged it on their faces to prevent fear and excitement when going to battle (Erichsen-Brown 1980). Further, the Ojibway used the *Acorus* root tea on gill nets to aid in the catching of white fish by scenting the nets with a sweet smell (Erichsen-Brown 1980). Indeed, the Iroquois regarded *Acorus* as an important medicinal plant for improving one's singing voice for ceremonial purposes (Erichsen-Brown 1980).

Angier (1972) reported that the young flower stalks of fresh *Acorus* can serve as emergency food in the spring. However, most documented cases of the use of this herb are to relieve and/or heal several common sicknesses and ailments. It is for this reason that so much information has been written on the virtues of this herb. Indeed, Rafinesque listed *A. americanus* in his medical flora as one of the most promising candidates for medical study (Flannery 1998). Comprehensive ethnobotanical uses of *Acorus* by Native Americans and Europeans are found in Motley (1994) and Thompson (1995). Some selected uses are compiled in Table 2.3.

The traditional native medical system was tailored to the diseases and disorders of a people who sustained themselves entirely off the land. The focal point of this medical system was based on health maintenance and the prevention of disease. The basic requirements of the traditional daily life necessitated that they be in good health. Therefore, it was not an incidental matter when someone was sick. Any illness could have significant social impact by preoccupying and disrupting the ability of families and communities to cope (Marshall *et al.* 1989).

It was in the late 1800s that the Canadian government outlawed many forms of traditional native religious expression (Pettipas 1989). The medicine men and shamen were targeted by the Canadian government and Christian missionaries because they were recognized to have great political power over their associated groups (Zieba 1990).

Table 2.3. Selected traditional uses of *Acorus americanus*.

• Abortion	The natives of Montana boiled the root of calamus in water and drank it to induce abortion (Weiner 1980).
• Antifatigue	The Cree chewed about one inch of calamus root that was about the thickness of a pencil (Crump 1967). It is considered a strong stimulant by the Cree and may be hallucinogenic (Lewis and Elvin-Lewis 1977).
• Asthma	The Cree boiled the root of calamus with the tips of spruce (*Picea* sp.) needles to yield a green syrup (Crump 1967).
• Bowel pain	The Cheyenne drank an infusion of the calamus root boiled in water to alleviate bowel pain (Vogel 1970).
• Burns	The boiled roots of calamus were directly applied to burns by the Meskwakis (Weiner 1980).
• Chest pains, lower back pain, neck pains, throat infection and whooping cough	The Cree used the root in a decoction to treat all of these ailments (Howarth and Keane 1995).
• Colds	The root stock was masticated, drunk in a decoction or used in a smoke treatment by Plains natives (Kindscher 1992). The Cree smoked the dried calamus root in a pipe to cure colds (Howarth and Keane 1995). The Chippewa drank a decoction of the root or snuffed up some of the dried root after it had been powdered (Erichsen-Brown 1980).
• Coughs	The dried roots of wild sarsaparilla (*Aralia nudicaulis*) were powdered and steeped with the roots of calamus to make a cough syrup used by the Penobscots (Vogel 1970).
• Diabetes	When the root stock was masticated regularly it reportedly cured the Dakota people of their diabetes (Kindscher 1992).
• Earache and toothache	A softened or chewed root was placed in the ear/tooth by the Cree (Howarth and Keane 1995).
• Flatulence	Natives of the Plains region used an infusion of the pounded root as a carminative (Vogel 1970).
• Headache	The Cree smoked the dried calamus root in a pipe to cure

	headaches (Howarth and Keane 1995).
• Hemorrhage	The Forest Potawatomi described this medicine as bitter as gall and caution that only a small piece of the calamus root was necessary for the following recipe: Chips from the heartwood from a four-inch piece of ironwood (*Ostrya virginiana*), arbor-vitae, calamus root, handful of the root bark of the common shining willow (*Salix lucida*),2 quarts water. The ingredients were placed in a pot and boiled until reduced to one pint. One tablespoon was ingested every hour until hemorrhaging stopped (Erichsen-Brown 1980).
• Indigestion	The following was a recipe to treat indigestion: 1 tsp. dried root, 1 cup boiling water. One to two cupfuls a day was to be drunk several sips at a time (Angier 1972).
• Joint and muscle pain, headache, rheumatism and swellings	The powdered roots of calamus, yellow pond lily (*Nuphar variegatum*) and cow parsnip (*Heracleum lanatum*) were combined and used by the Cree to treat this ailment (Howarth and Keane 1995).

Government thought it would be easier to dismantle the native societies and Westernize them by outlawing the religious ceremonies and oppressing the healers. Fortunately, many isolated communities in northern Canada did not have permanent settlements until the first half of the 20th century, thereby allowing traditional native medicines to exist in the absence of European medical systems.

By the 1940's or 1950's many of the northern communities received permanent nursing stations where they could receive contemporary medical services. These were well received by the aboriginals since traditional medicine could not battle tuberculosis and other foreign diseases resulting from European contact. With the establishment of permanent communities, Christian churches and conventional medical services, many of the traditional medical practices were ridiculed. However, traditional medicines continued to be used, but often in a covert fashion (Marshall *et al.* 1989).

Acorus has been described by historians as a panacea in native medicine due to its numerous medicinal uses (Locock 1987, Motley 1994, Thompson 1995). However, *Acorus* species have been used to treat very similar sicknesses and ailments across a variety of cultures (Motley 1994). This information, and the fact that *Acorus* continues to be used for similar ailments to the present day, implies that the medicinal constituents of *Acorus* species likely have some effectiveness in treating these ailments.

Presently, there appears to be a revival of traditional native medicines and ceremonies. With the arrival of self-government, old traditions are once again openly embraced by the native societies. Younger generations of natives and Euro-Canadians are being taught to respect the ancestral native culture. Younger generations of natives, blind to the negative attitudes their parents were subjected to by the church and government concerning their language, culture and religion, can more freely accept traditional medicines from the ever dwindling numbers of elders that still remember the remedies and ceremonies (Zieba 1990).

No information on the effects of harvesting *Acorus americanus* has been discovered. As herbal medicines increase in popularity, the commercialized harvesting of this plant may be inevitable. Teas containing *Acorus* are presently available in natural and health food stores. Furthermore, a pharmaceutical company interested in harvesting 6000 kg of *Acorus* rhizome, contacted the University of Manitoba Botany department for information on *Acorus* distribution in the province (Punter 1995). Evidently, the demand for this herbal medicine is present and with the rising interest in 'natural' medicines, the market is growing.

As the rhizome appears to be the primary means of reproduction for this plant and is the organ harvested for its medicinal value, we must be very careful in establishing harvesting guidelines so *Acorus* populations are not devastated. Although studies have established the correct nomenclature and basic biology of *A. americanus*, information on the effects of rhizome harvesting are lacking. In the interest of protecting this plant and other species that coexist in the fragile wetland habitats it occupies, it is imperative to

discern the effects before large scale harvesting occurs. In addition, the First Nation people must be included out of respect for the knowledge and healing they have shared and because they continue to rely on *A. americanus* for medicinal purposes.

2.2 *Vaccinium angustifolium*

2.2.1 Taxonomy

Vaccinium angustifolium is a member of the family Ericaceae, also known as the heath family. The Ericaceae is cosmopolitan in its distribution. Most members are found on acidic soils and are generally shrubs, sub-shrubs or woody perennial herbs, but some are considered trees and vines (Smith 1977).

The genus *Vaccinium* L. is represented by 10 sections and 26 species in North America (Vander Kloet 1988). *Vaccinium angustifolium* Ait. (Sweet Lowbush Blueberry) is a member of the section Cyanococcus. Members of the section Cyanococcus possess the following morphological characteristics: (a) current season twigs are warty in appearance; (b) develop floral and vegetative buds in the leaf axils; (c) buds are covered with more than five scales and floral buds are rotund and at least twice the size of vegetative buds; (d) flat-topped or round-topped inflorescences with the lower pedicels longer than the upper pedicels (corymb); (e) the pedicel is articulated with the calyx ; (f) the corolla resembles a small pitcher (urceolate) or bell; (g) the stamens do not project beyond the surrounding parts and do not possess a bristle-like appendage at the tip (awnless); (h) the berry is pseudo 10-loculed (Vander Kloet 1988).

Five of the nine species within the section Cyanococcus are diploid (2n = 24). Three of the remaining species are tetraploid (2n = 4*x* = 48), including *V. angustifolium*, and are likely hybrids originating from the 2n = 24. Finally, *V. corymbosum*, is a special

hybrid case that contains diploid, tetraploid and hexaploid lines (2n = 6x = 72) (Vander Kloet 1978, Vander Kloet 1988).

2.2.2 Description of *Vaccinium angustifolium*

(a) Raunkiaer life-form.

Vaccinium angustifolium is a chamaephyte as described by Raunkiaer's classification system. Futhermore it is a low, deciduous , perennial shrub with palatable blue fruits and reproduces by rhizomes and seeds.

(b) Shoot morphology.

Mature stems are woody, glabrous, ascending and on average 20 cm in height up to a maximum of 50 cm (Hall *et al.* 1979). Current season twigs are green or glaucous, angular, verrucose and glabrous to pubescent (Vander Kloet 1988). Large flower buds are borne terminally, whereas, vegetative buds are smaller, more lanceolate and borne proximally. Simple leaves are elliptical, glabrous, with a sharply serrate margin and have an alternate, spiral arrangement. New shoots or stems are produced from buds that occur on the woody rhizome (Barker and Collins 1963, Kender *et al.* 1964). Using leaf characteristics, *V. angustifolium* can be easily distinguished from *V. myrtilloides*, a close relative that often occupies the same habitat. *V. myrtilloides* has pubescent leaves with entire margins compared with serrated leaves of *V. angustifolium.* New shoots arise vegetatively from the woody rhizomes.

(c) Root morphology.

V. angustifolium produces a large tap root system (Hall 1957). Hall (1957) described tap roots with more growth layers than associated rhizomes, suggesting that the

root was older than the rhizome. Adventitious roots arise at several points from decumbent stems (Nams 1994).

(d) Inflorescence.

V. angustifolium flowers are borne in racemes. Typical flowers have five sepals, and five fused petals that form a bell-shaped corolla, 10 stamens fused to the corolla and five fused carpels forming an inferior ovary. The fruit is a berry with few to many seeds. Bell (1957) found an average of 13 perfect and 50 imperfect seeds per *V. angustifolium* berry. Interestingly, he also found larger berries have a much greater proportion of perfect seeds. However, Kushima and Austin (1979) found the number of perfect seeds and berry size in *V. ashei*, only correlate if the berry size is > 1.78 g, a condition frequently observed in cultivated varieties but rarely observed in wild populations. Furthermore, Vander Kloet (1983) observed that the number of perfect seeds is correlated with pollen viability especially when pollen viability is low.

(e) Chromosome number.

Vander Kloet (1988) reports the chromosome number of *V. angustifolium* as $2n = 48$. *V. angustifolium* is consistently a tetraploid (Vander Kloet 1978, Vander Kloet 1988). The tetraploid condition may be a result of the production of diploid (unreduced) gametes (Vander Kloet 1988). Diploid gametes may stem from irregular pairing of the chromosomes, resulting in the occasional occurrence of tetraploid or hexaploid plants (Vander Kloet 1988).

2.2.3 Geographic range

V. angustifolium is endemic to North America, extending from Labrador and Newfoundland, 57° N in Quebec, west to southern Manitoba and Minnesota, south to

northern Illinois, Pennsylvania and Delaware, and in the Appalachian mountains to Virginia and West Virginia, 37° N (Figure 2.2) (Vander Kloet 1978, Hall *et al.* 1979).

2.2.4 Physical Habitat

(a) Climatic conditions.

Vaccinium angustifolium, present in a vast portion of eastern North America, tolerates a broad range of climatic conditions (Hall *et al.* 1979). Climatic conditions are believed to influence berry production and seedling germination. Snow cover helps to mitigate winter temperatures in Canada and the United States for *V. angustifolium* and other chamaephytes (Hall *et al.* 1979). Floral buds are produced the autumn prior to flowering. For this reason, the winter climatic conditions preceding the summer play an important role in berry production. Insufficient snow accumulation may result in a loss of berries due to frost damage of the floral buds. In addition, relative humidity may be an important factor influencing fruit production (Hall *et al.* 1979). Seed germination is dependent on long periods of rain in the late summer or early fall (Hall *et al.* 1979).

(b) Edaphic conditions.

V. angustifolium grows and reproduces successfully by rhizomes on organic and mineral soils. Optimum growth is attained with adequate soil moisture and aeration at a low pH, although *V. angustifolium* is capable of tolerating a broad range of soil conditions (Hall *et al.* 1979). Optimum soil pH ranges from 4 to 5 (Hall *et al.* 1964). Soils containing a high percentage of stone or gravel are optimum for seedling emergence, growth and development (Hall *et al.* 1979).

Figure 2.2 North American distribution of *Vaccinium angustifolium* (Vander Kloet 1978, Vander Kloet 1988, University of Manitoba (WIN) herbarium distribution map, 1999).

(c) Nutrient and Water conditions.

The extensive rhizome system of this plant plays an important role in preventing soil erosion. When soil particles are washed into the rhizome-root-shoot network, new roots grow into the soil particles for mineral and nutrient absorption, thereby retaining the soil (Hall *et al.* 1979). *Vaccinium* species also have shallow roots that arise from the rhizomes. These roots are primarily located in the litter horizon and mainly function in nutrient absorption (Ingestad 1973). The extensive tap root system that may penetrate to depths greater than 1 m, allows for greater water absorption from subsoil moisture reserves (Hall 1957). This may account for the ability of *Vaccinium angustifolium* to grow on extremely poor soils while still producing a heavy crop of fruit (Hall 1957).

2.2.5 Plant Communities

Vaccinium angustifolium is an important component of the flora found in exposed headland vegetation, raised bogs, high moors, outcrops of the Canadian shield, and open to moderately shaded coniferous forests from the Atlantic provinces to Lake Winnipeg (Hall *et al.* 1979). *V. angustifolium* is most abundant in areas that have been disturbed through fire, clear-cut logging and infertile abandoned agricultural lands in the Maritimes (Hall *et al.* 1979, Vander Kloet 1988). Some species commonly occurring in association with *V. angustifolium* are: *V. myrtilloides* (Velvet-leaf blueberry), *Gaultheria procumbens* (Checkerberry), *Fragaria virginiana* (Wild strawberry) and *Maianthemum canadense* (Wild lily-of-the-valley) (Hall *et al.* 1979).

2.2.6 Growth and Development

(a) Morphology.

Radicles emerge from *Vaccinium angustifolium* seeds in 11-25 days. The cotyledons are oblong-elliptical and about 2 mm in length. The first true leaves are more elliptical than the mature leaves, making *V. angustifolium* seedlings difficult to identify. The seedling must reach a height of 7 - 10 cm before new leaves resemble those of a mature plant (Vander Kloet 1988). At this point, several new shoots may arise from the root crown in the axils of the cotyledons. These shoots will grow taller than the primary shoot which often becomes recurved (Vander Kloet 1988). Flowers and rhizomes seldom develop until four years post-germination (Hall *et al.* 1979). When rhizomes develop, they are capable of growing up to 10 cm or 50 cm a year on mineral and organic soil, respectively (Hall *et al.* 1979). Some clones of *V. angustifolium* have been found to have rhizomes 10 m long (Hall *et al.* 1979). This aggressive development of the rhizomes allows for lateral colonization of surrounding areas (Barker and Collins 1963). New shoots arise from the rhizome sporadically, either by conversion of the apical meristem or from a bud on the axis of the rhizome (Barker and Collins 1963). With periodic burning, berry production is highest the year after the burn (Barker and Collins 1963). Subsequent berry production is reduced because of increased vegetative growth and decreased flowering (Barker and Collins 1963).

(b) Physiology.

Leaf maturity, temperature, and CO_2 concentration affect photosynthetic rates (Forsyth and Hall 1965). The rate of photosynthesis was greatest early in the day when carbohydrate levels are depleted (Hall *et al.* 1966a). Hall *et al.* (1979) reported that differences in light/dark regimes result in changes in growth patterns. For example, 16 hours light and 8 hours dark per 24 hours at 18° C result in vigorous vegetative growth,

whereas, 12 hours of light and dark per 24 hours at 18°C induces floral bud formation. Hall and Ludwig (1961) showed that by the time equinoctial conditions are reached in nature, the accompanying temperatures limit the growth of the plant.

(c) Phenology.

Vaccinium angustifolium is deciduous and therefore overwinters in a leafless state. In the spring, flower buds swell when the air temperature exceeds 10° C for three to four days (Hall *et al.* 1979). Flowering starts about two weeks later and continues for about a month. Vegetative growth commences about a week after floral bud expansion and ceases in early July (Hall *et al.* 1979). Depending on the clone, leaf development precedes, occurs simultaneously with, or follows flowering (Hall *et al.* 1979). Leaves harden by mid-July, change color by late August, and fall by the end of October (Hall *et al.* 1979). Berries begin ripening in late July and may continue until mid to late August in southern Manitoba and Ontario. The flower primordia begin to grow after vegetative growth ceases and continue into the fall until temperatures regularly fall below 0° C (Hall *et al.* 1979). Some floral buds that develop too early in the summer may develop prematurely into flowers before the winter. However, these flowers do not mature to fruit because of the onset of winter.

2.2.7 Reproduction

(a) Floral biology.

Vaccinium angustifolium flowers are pollinated by insects. Stamens and stigmas are functional as soon as the flower opens fully. The receptivity of the stigma remains constant for four days; however, by the seventh day, it drops to 20% (Wood 1962). After fertilization, the corolla turns pink and rapidly degenerates. Researchers have shown that both male and female flowers range from highly infertile to highly fertile (Hall and Aalders

1961, Aalders and Hall 1963, Hall *et al.* 1966b). If a plant is highly infertile, flowers may be produced abundantly, but have little to no fruit set. Further, the fertility of clones appears to be constant from year to year (Hall *et al.* 1966b). The fertility of the *Vaccinium angustifolium* plants plays a major role in the variability of the fruit produced each year (Aalders and Hall 1963).

(b) Fruit set and berry development.

Hall and Aalders (1968) used experiments in growth chambers to show that warmer temperatures help to speed fruit maturity and ultimate berry size, but not to alter fruit set. Although *Vaccinium angustifolium* plants can set up to 100% of their blossoms with only native pollinators present in a natural setting, fruit set rarely exceeds 40% (Wood 1969). The best criterion for fruit maturity in *V. angustifolium* is the appearance of the blue color (Hall *et al.* 1972).

Berry production in *V. angustifolium* varies from very high yields to very low yields year to year. In long term studies, berry production exhibits the greatest fluctuations of all variables measured (Eaton 1994, Vander Kloet and Hill 1994). Although fluctuations in *V. angustifolium* berry yields are often attributed to climatic conditions, Hall *et al.* (1982) found no significant correlations between 27 years of cultivated berry yields and climatic conditions in Canada. Furthermore, no significant correlation was found between *V. corymbosum* berry production and precipitation or temperature in a natural setting (Vander Kloet and Cabilio 1996). However, the notion that berry productivity is dependent on climate may result from the necessity of adequate soil moisture for flower bud development and increasing berry mass (Benoit *et al.* 1984).

The long term effects of fertilizers and herbicides have been studied within the context of the blueberry industry. *Vaccinium angustifolium* reacts slowly to the applications of herbicide and fertilizer (Eaton 1994). Eaton (1994) indicated that, on average over a 12 year period, herbicides did increase fruit production, but not in every growing season.

Herbicide application produced a greater effect than fertilizer likely due to reduced competition for nitrogen resources.

(c) Seed production and dispersal.

Seedless berries are rarely produced by *V. angustifolium*, even in clones that are very productive (Hall *et al.* 1979). Seeds are dispersed via animal frugivores such as black bears and American robins. The seeds are passed through the gut and are passed out in the feces. Frequent non-development of ovules has been shown, suggesting that there is likely a low average number of viable seeds per ripe berry (Bell 1957).

Seed numbers per berry vary greatly from year to year and from location to location and are dependent on genetics and environmental conditions (Hall *et al.* 1979, Vander Kloet and Hill 1994). Warm, dry weather during the receptive period is most favorable for insect pollination and results in berries with more seeds (Hall *et al.* 1979). Relative to other shrubs, the quantity of *Vaccinium* seeds in the seed bank is disproportionately low (Vander Kloet and Hill 1994). For instance, *Kalmia angustifolia*, another ericaceous shrub, covered an area one sixteenth the area of *V. angustifolium*, yet *K. angustifolia* contributed approximately four times the amount of seed to the seed bank (Vander Kloet and Hill 1994). Vander Kloet and Hill (1994) have concluded that *Vaccinium* seeds are not pervading the soil column despite its abundance in the habitat for several reasons. Firstly, the avian dispersers may reduce seed viability. Crossland and Vander Kloet (1996) showed a 17% reduction in the germination of *V. angustifolium* seeds passed through the gastrointestinal tract of the American robin which may in part be due to bacterial and *Mucor* infection. Secondly, seeds may be destroyed between deposition on the soil surface and their incorporation into the soil column (Vander Kloet and Hill 1994). Thirdly, seeds may simply germinate (Vander Kloet and Hill 1994). Finally, seeds may be destroyed by microbial activity, such as fungal decomposition, within the soil column (Cippolini and Stiles 1992).

(d) Seed viability and germination.

Berries containing seeds can be stored dry (-23° C or -2° C) or frozen (-23° C) for up to 6 months with no reduction in seed viability (Aalders and Hall 1975). Ideal germination conditions are 21° C, under 16 hours of light per 24 hour period on a soil mix with a pH of 4.7 (Hall *et al.* 1979).

(e) Vegetative reproduction.

V. angustifolium reproduces asexually by rhizomes. Townsend *et al.* (1968) showed that rhizomes accumulate starch late in the fall and release carbohydrates to the developing plant late in the spring at the time of flower bud break. Asexual reproduction predominates when the rhizomes are severed or damaged by fire, shading, burrowing and/or frost action (Hall *et al.* 1979). On the other hand, sexual reproduction occurs when a gap in habitat is formed due to cultivation, flooding or tree fall (Hall *et al.* 1979).

2.2.8 Population Structure and Dynamics

Vaccinium angustifolium has a clumped distribution at the landscape level. This is likely due to animal dispersal of the seeds through their droppings (Hall *et al.* 1979). Hall *et al.* (1979) and Vander Kloet (1988) reported the occurrence of seedlings in a natural setting as rare, except under specific conditions (Vander Kloet 1976). Favorable conditions are considered to be: (i) a cool spring which delays berry dispersal; (ii) a wet August and September to prevent desiccation; (iii) a mild winter or good snow cover to prevent winter kill; (iv) a wet spring to promote seedling growth (Vander Kloet 1976). Clumps of seedlings may be established after seed dispersal. Nonetheless, seedling mortality has been shown to be >99%, even under partially controlled conditions (Vander Kloet 1976).

Due to the territorial nature of the animals that typically consume *V. angustifolium*, the long-distance dispersal of seeds is rare (Vander Kloet 1988). Even if berry ripening coincides with migration of vector birds, the berry pulp passes quickly through the bird (Vander Kloet 1988). In fact, Crossland and Vander Kloet (1996) found the bulk of *V. angustifolium* seeds to be defecated by the American robin within 35 minutes of feeding.

V. angustifolium colonies may grow quite old on stable habitats such as outcrops on the Canadian Shield (Hall *et al.* 1979). Clones may reach sizes > 10 m in diameter and ages > 150 years (Hall *et al.* 1979). Indeed, instances where the species composition and abundance on granitic outcrops of the Canadian Shield have remained quite stable over a 10 year observation period have been reported (Hall *et al.* 1979).

2.2.9 Interaction with Other Species

(a) Competition.

In the Boreal Forest region east of Lake Winnipeg, *Vaccinium angustifolium* has many competitors on undisturbed, natural sites within its range of habitats (Hall *et al.* 1979). Within the forests where *Pinus banksiana* (Jack pine), *Picea glauca* (White spruce), *P. mariana* (Black spruce) and *Populus tremuloides* (Trembling aspen) are the dominant tree species, the understory generally include *Kalmia angustifolia*, *Ledum groenlandicum*, *Diervilla lonicera*, *V. myrtilloides*, *Cornus canadensis*, *Pteridium aquilinum*, *Clintonia borealis*, *Maianthemum canadense* and *Lycopodium* spp. which may compete with *V. angustifolium* for resources (Hall *et al.* 1979). In fact, in the Atlantic provinces, *Cornus canadensis* (bunchberry) is the principal competitor with *V. angustifolium* in the commercial blueberry industry (Yarborough and Bhowmik, 1993).

(b) Symbiosis.

The native pollinators of *Vaccinium angustifolium* in Canada are species in the Halictidae, Andrenidae, Bombidae , Anthophoridae, Colletidae and Xylocopidae (Hall *et al.* 1979). Mycorrhizal associations in *V. angustifolium* do occur (Hall *et al.* 1979). Fungi, such as *Pezizella ericaea* or *Clavaria* spp. infect the unsuberized portion of the root and increase the uptake up nitrogen and phosphorus, thereby improving the nutrient levels and growth rates of *Vaccinium* (Vander Kloet 1988). Powel and Bates (1981) inoculated several *V. corymbosum* varieties with a mycorrhizal fungus. Inoculated plants had an 11 - 92% increase over uninoculated plants in berry production (Powel and Bates 1981). Unfortunately, little research has been done in this area.

(c) Predation and parasitism.

The twigs and foliage of *Vaccinium angustifolium* are consumed by black bears(*Ursus americanus*), Eastern cottontail (*Sylvilagus floridanus*), and white-tailed deer (*Odocoileus virginianus*) (Hall *et al.* 1979). More commonly, the fruits of *V. angustifolium*, are consumed by many species of mammals and birds (Vander Kloet 1978, Hall *et al.* 1979). Grouse (Tetraonidae), willow ptarmigan (*Lagopus lagopus alleni* L.), robins (*Turdus migratorius* L.), bluebirds, thrushes (Turdidae, Muscicapidae), black bears, chipmunk (*Eutamias* spp.), red fox (*Vulpes vulpes* Desmarest), porcupine (*Erethizon dorsatum*) and raccoons and mice are just a few of the animals that make *V. angustifolium* part of their diet (Martin *et al.* 1951, Eaton 1957, Hall *et al.* 1979). In fact, large increases in bear mass coincide with fruit development and ripening in July and August (Moola *et al.* 1998). Furthermore, Moola *et al.* (1998) reported that Rogers (1976, 1987) found blueberry production to be critical to the growth and reproduction of black bears in northern Minnesota.

Insects feeding on *V. angustifolium* may cause substantial defoliation (Hall *et al.* 1972). Aalders *et al.* (1969) showed that defoliation early in the season under low light intensities significantly decreased fruit set. Many insects are considered blueberry pests; these include: blueberry maggot (*Rhagoletis mandax*), black army cutworm (*Actebia fennica*), chainspotted geometer (*Cingilia catenaria*), blueberry flea beetle (*Altica sylvia*), blueberry casebeetle (*Chamisus cribripennis*), blueberry thrips (*Frankliniella vaccinii* and *Catinathrips kainos*), blueberry tipworm (*Contarinia vaccinii*), sawflies (*Neopareophora litura, Pristiphora idiota* and *Pristiphora* sp.), red-striped fire worm (*Aroga trialbamaculella*) and stem galler (*Hemadas nubilipennis*) (Hall *et al.* 1979).

2.2.9 Response behavior

(a) Fire.

Vaccinium angustifolium rhizomes survive wild fires and controlled burning. Rhizomes sprout after fire to recolonize the burned area. After burn-pruning commercial stands every second year, rhizomes produce unbranched stems that have more flowers, and consequently more berries, on a per stem basis (Hall *et al.* 1979). *V. angustifolium* berry production may improve after burning as a result of the nutrients in the ash residue that remains on the soil surface (Smith and Hilton 1971). Eaton and MacPherson (1978) define yield for cranberry (*Vaccinium macrocarpon*) as mass of crop per unit area.

Cranberry, like *V. angustifolium*, exhibits highly variable yields in time and space (Eaton and MacPherson 1978). Two important morphological components of yield for cranberry are the number of flowering uprights per unit area and the number of flowers per unit area (Eaton and MacPherson 1978). Morphological components that did not contribute to the variability of yields in cranberry included berry size, fruit set and the number of flowers per flowering upright (Eaton and MacPherson 1978). Therefore, burning *V. angustifolium* may increase berry production due to its positive effect on stems per unit area and the number of flowers per unit area.

(b) Grazing.

Browsing by white-tailed deer (*Odocoileus virginianus*) removes the shoot tip and results in increased lateral branching (Hall *et al.* 1979).

2.2.10 Commercial harvesting

Vaccinium angustifolium is a commercially important crop species in eastern North America. For commercial purposes, a biennial production system is often imposed upon *V. angustifolium* by regular pruning, either by mowing or burning in the pruning year (Jordan and Eaton 1995). Pruning effectively eliminates older stems with reduced productivity, while stimulating the growth of new shoots with more floral buds (Moola *et al.* 1998). After being pruned, unbranched stems are produced from the rhizomes which remain unharmed from the pruning procedure because they are below ground level. No berries are produced in the pruning year as the floral buds are destroyed by the pruning process. However, floral buds, which will give rise to next year's crop, are produced on the unbranched stems in the fall of the pruning year. Jordan and Eaton (1995) showed the total number of flower buds on first crop stems equaled those on second crop stems. However, more flowers per bud were produced on first crop stems (Jordan and Eaton 1995). Therefore, the following spring, the first year crop stems produce more flowers than second year crop stems. Consequently, the most berries, on a per stem basis, are produced during the first cropping year (Black 1963, Hall *et al.* 1979, Jordan and Eaton 1995).

A possible explanation is that *V. angustifolium* production may be improved after burning as a result of the nutrient - ash residue that remains on the soil surface (Smith and Hilton 1971). Jordan and Eaton (1995) also suggested that fewer resources were available for reproductive growth in second crop stems compared with first crop stems based on experiments designed to investigate above ground biomass allocation of first and second

year crops. In general, older second crop stems allocated less total above ground biomass to reproductive organs when compared to younger first crop stems (Jordan and Eaton 1995).

Penney *et al.* (1997) completed a 24 year study on burn-pruning of a natural stand of *V. angustifolium* using 2, 3 and 4 year burning cycles. No other crop management practices were employed for the duration of the experiment. They showed burned areas have a larger mean annual crop yield than unburned areas. Furthermore, an overall linear decrease in berry production was established with the decreased frequency of burn-pruning, despite increased harvest years for the 3 and 4 year rotations compared with the 2 year burn cycle. They showed the number of flower buds·m^{-2} was reduced in second and third crops, which was contrary to that which Jordan and Eaton (1995) showed. Finally, Penney *et al.* (1997) showed that burn-pruning on a 2 year rotation did not significantly decrease crop yields over a 24 year period. This is supported by Bell (1953) who found burning or pruning of *V. angustifolium* had no effect on the growth cycle, the morphology of the growth maturation, or their sequences, other than delaying spring and summer growth by about two weeks. Penney *et al.* (1997) also addressed concerns about changes in the organic layer or total carbon content as a result of long term burning. Again, there were no significant differences in the depth of the surface organic layer or the total carbon content between unburned areas and any of the burning cycles, nor among burning cycles (Penney *et al.* 1997).

According to Black (1963), first year and second year burn-pruned plots provide a highly significant increase in fruit production over unpruned areas. Consequently, the sacrifice of a crop in the burn year is more than compensated for by the large yield increase (Black 1963). Black (1963) followed berry productivity in burn-pruned plots and unburned plots for nine seasons and found no deleterious effects, resulting from organic matter depletion of frequent burning, in the two year burn cycle. Interestingly, Black

(1963) also showed that high yields in unburned plots were normally succeeded by reduced yields the following year.

The economical costs and benefits of intensive agricultural management of a native stand of *Vaccinium angustifolium* and a similar sized cultivated stand using seedlings and clones have been analyzed by Blatt and O'Regan (1990). They found that the initial capital and start-up costs were much greater for the cultivated blueberry stand, as the stand had to be established. However, crop yields and investment returns were also greater in the cultivated stand. The internal rates of investment return, over a 20 year period averaged 10% higher for the cultivated stand versus the natural stand. However, if there was a greater demand for wild blueberries, resulting in a 40 - 45 cent price differential against the cultivated blueberries, the internal rates of return would be similar for both types of stands (Blatt and O'Regan 1990).

Wild blueberry (*Vaccinium* spp.) production in the boreal forest ecosystem has been a key link in the food chains of an assortment of animals and First Nations people for thousands of years. Within the past century, blueberries have also become an important concern to commercial blueberry growers and other casual berry harvesters in Canada (Moola *et al.* 1998). Due to the commercial nature of *Vaccinium*, many studies investigating berry production and techniques to improve production have occurred, especially in the Atlantic provinces where the Canadian blueberry industry is centered. Most of these studies have examined *Vaccinium* in an agricultural environment, where it has been extensively cultivated and intensive management programs have been implemented, using pruning and/or applications of fertilizers, herbicides and/or insecticides. Obviously, in this agricultural environment, resulting berry crop yields have been vastly increased from the berry yields one might likely encounter if harvesting berries from the natural boreal forest. Alternative practices would be necessary for harvesting in natural blueberry regions due to the impracticality and obvious danger of burning *Vaccinium* in a forest. Differing harvesting levels may provide this opportunity.

Natural stands of *V. angustifolium* in regions where it is indigenous and abundant have potential for commercial blueberry production (Smith *et al.* 1968). Very little research has been done in this field, although Vander Kloet (1988) mentioned that sizable harvests have been had in major blueberry production areas like, Michigan Minnesota, Wisconsin and West Virginia, from many local stands, with very little management. The primary objective of this study is to design and implement monitoring protocols which can detect the effects of harvesting blueberries from natural stands, at various harvesting intensities. It is a well known fact that agricultural blueberry crop yields significantly decrease in the second cropping year following burning. Within the blueberry industry, 100 % harvesting of the blueberries is always practiced.

The effects of harvesting less than 100% of the blueberries is senseless to the commercial growers whose primary goal is to maximize crop productivity. However, in the interest of natural habitat conservation, and in maintaining an ecological balance between *V. angustifolium* and all species intimately linked to it in the boreal forest, it is essential to understand the effects of alternate strategies for sustainable harvest of blueberries. Furthermore, such a practice could provide remote communities an economic opportunity to use natural blueberry stands.

CHAPTER 3 MATERIALS AND METHODS

3.1 Site Selection

Elders of each community guided investigators to traditionally harvested *Acorus* and *Vaccinium* sites. Sites were briefly inspected for suitability. Suitable sites i) had a high frequency and abundance of the study species; ii) were generally similar to previously established sites and iii) were geographically isolated from other human disturbance. In Manitoba, three *A. americanus* sites and four *V. angustifolium* sites were selected (Figures 3.1 and 3.2). The number of sites was based on the advice from the University of Manitoba Statistical advisory service after they reviewed some preliminary data. In Ontario, only one *A. americanus* site and three *V. angustifolium* sites were established (Figure 3.3). *A. americanus* sites in Manitoba were monodominant stands while the site in Ontario was vegetatively very different. This was visually apparent when sites were compared (Figures 3.4-3.7). The *V. angustifolium* stands all appeared to have similar vegetative characteristics.

3.2 Sampling design

The monitoring protocols, although designed for widely different plant species, were nonetheless very similar and followed a hierarchical design. Four harvesting intensities were decided upon: 0% harvesting (control), 30%, 70% and 100% harvesting. A minimum of three sites in each province for each species was necessary to provide replication. This requirement was not always met. As previously mentioned, three sites were not established for *A. americanus* in the Ontario locality. Within each site, three groups (blocks) of four similar $1m^2$ plots were established (Figure 3.8). Within each block, plots were spaced a minimum of 1m apart and were systematically selected based on the abundance and percent cover of the study species within the plot.

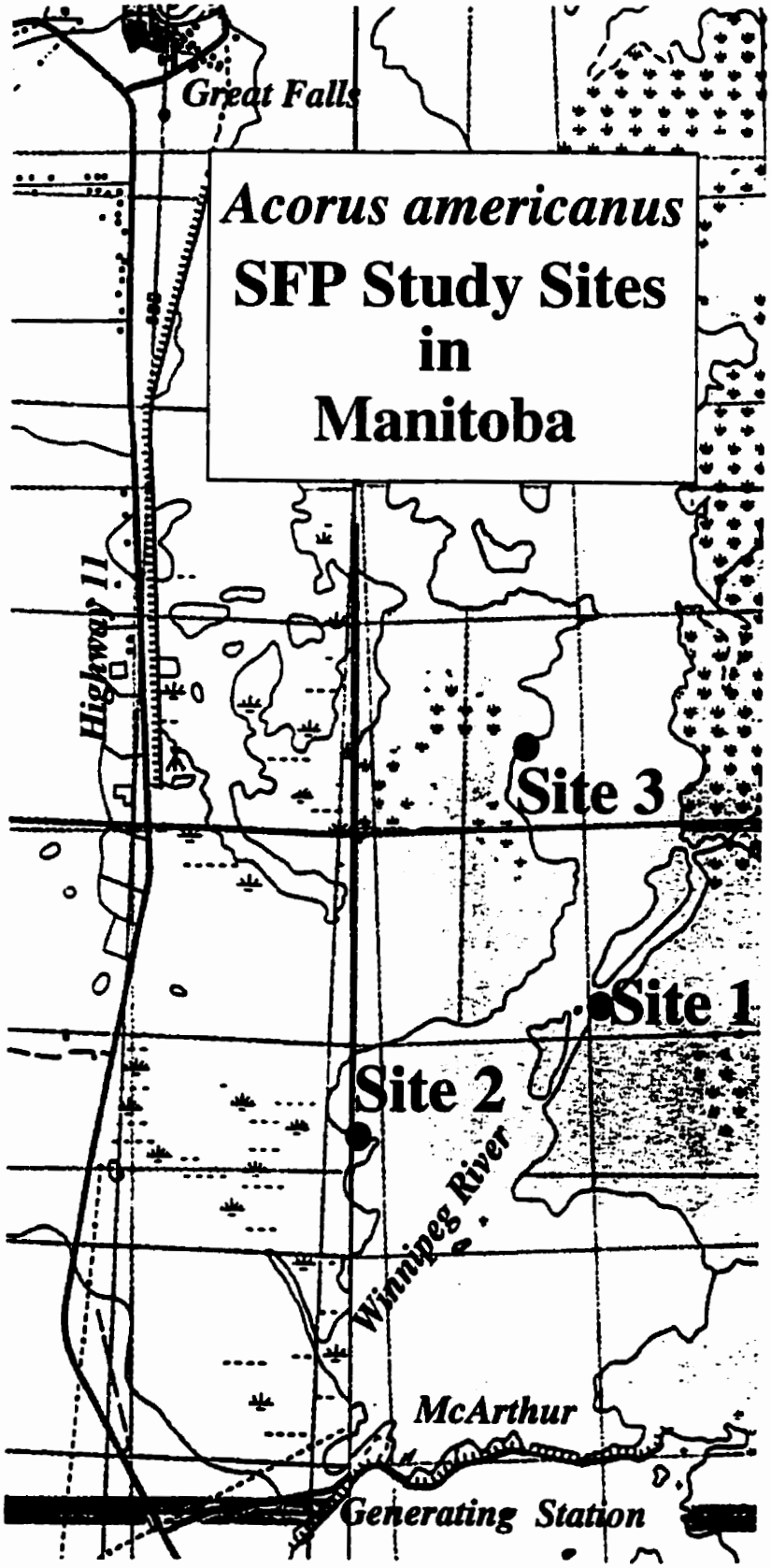

Figure 3.1 *A. americanus* NTFP Study Sites in Manitoba.

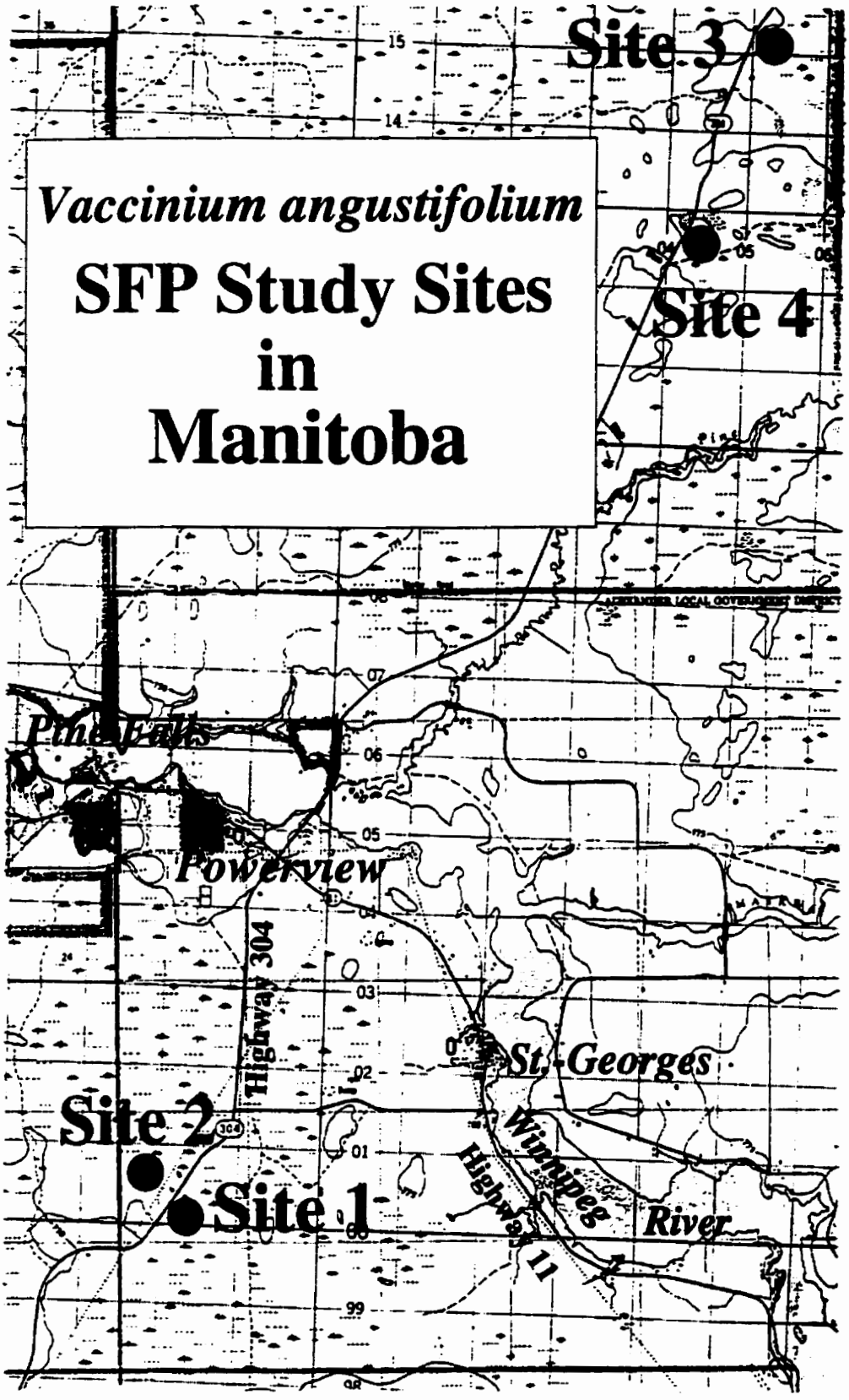

Figure 3.2 *V. angustifolium* NTFP Study Sites in Manitoba.

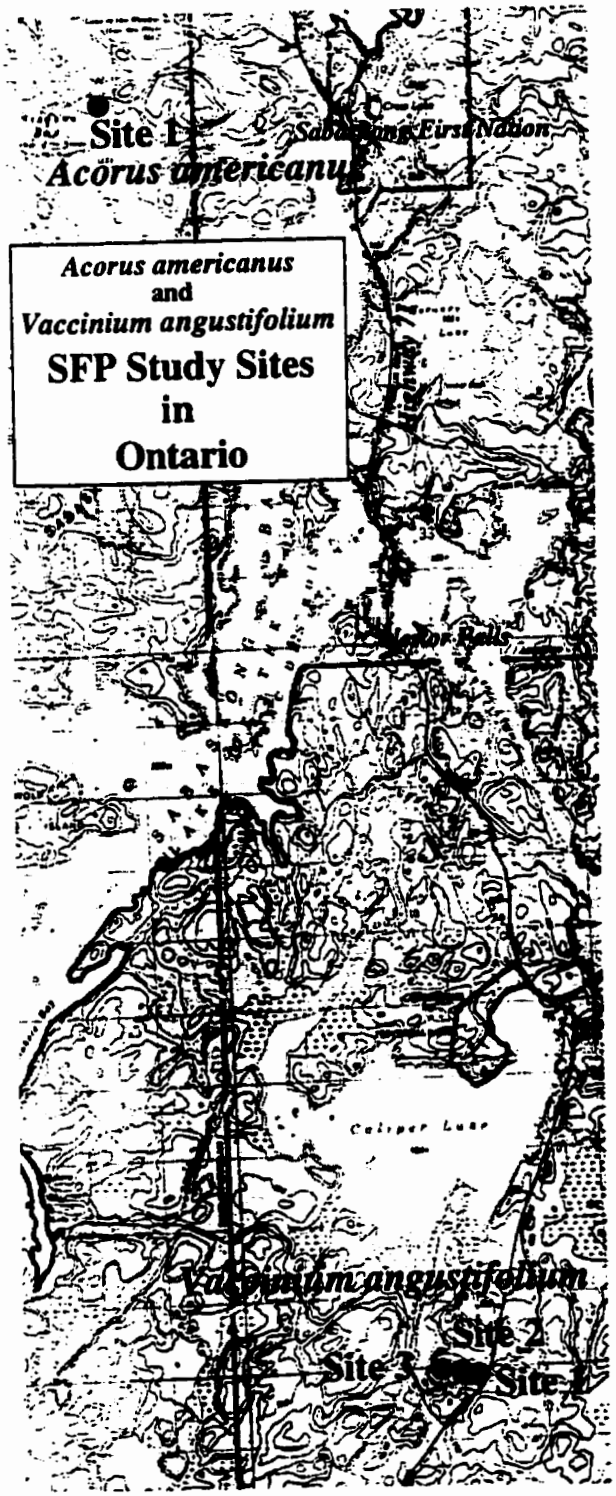

Figure 3.3 *A. americanus* and *V. angustifolium* NTFP Study Sites in Ontario. Sabaskong First Nation is the same as the Ojibways of Onegaming.

Figure 3.4 *A. americanus* Site 1 Manitoba.

Figure 3.5 *A. americanus* Site 2 in Manitoba.

Figure 3.6 *A. americanus* Site 3 in Manitoba.

Figure 3.7 *A. americanus* Site 1 in Ontario.

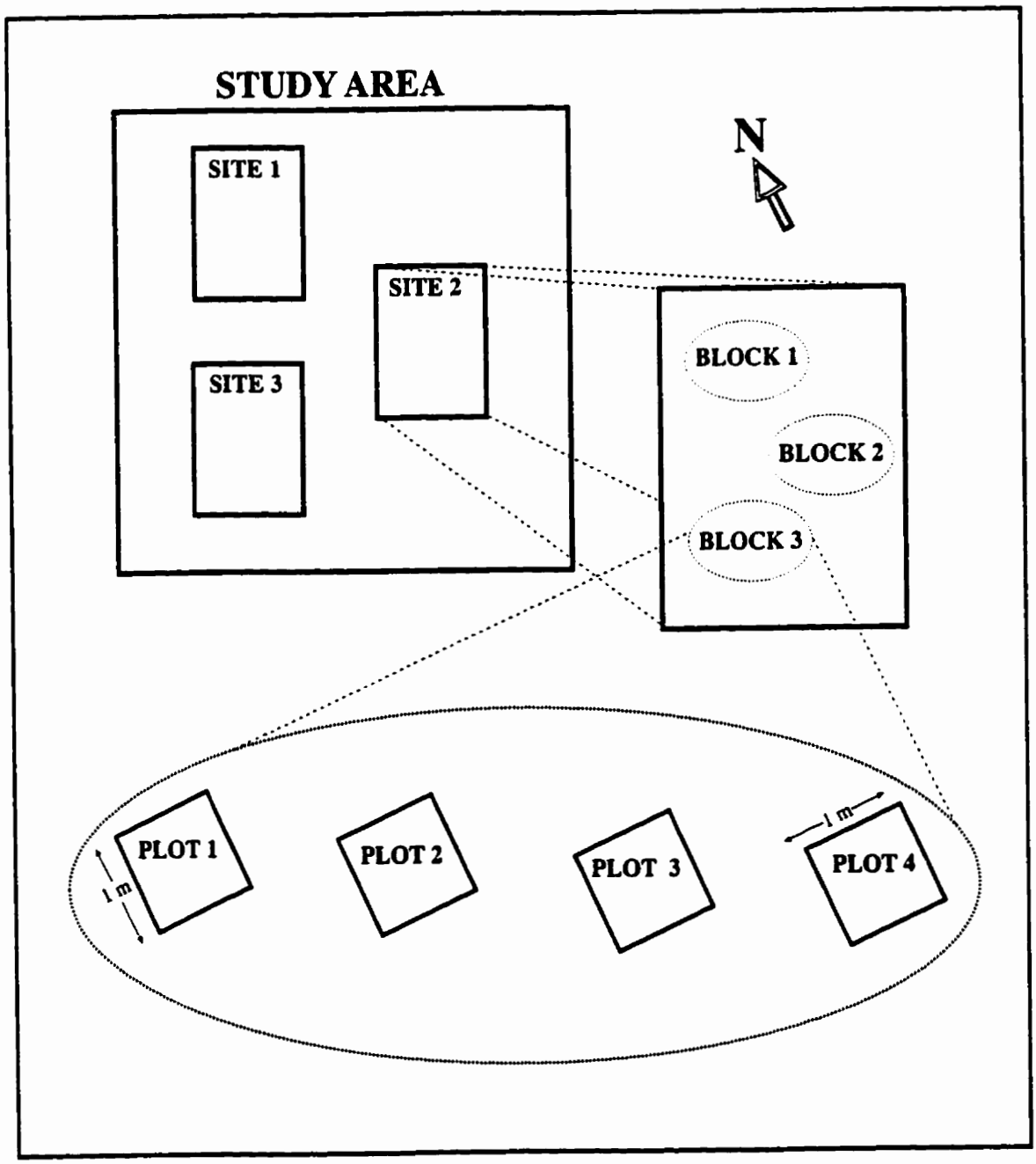

Figure 3.8 Illustration of the hierarchical sampling design at each location. Treatments were randomly assigned to the 1 m^2 plots in 1996 (Y1).

Within each block, treatments were randomly assigned to the plots. Treatments were replicated three times at each site.

A species list was created (Appendix II) by the collection of all species encountered in the sites at each location. Some of the species present at each location were not found within the study plots.

In 1997, members of Sagkeeng First Nation worked along side the primary researchers gathering the data in Manitoba. One training session was provided at the beginning of the data collection for each study species. Then Sagkeeng members were paired up with primary researchers as botany apprentices. In the beginning they observed and recorded data collection. After Sagkeeng members could identify common plant species they actively participated in the data collection. The harvesting methods were also demonstrated to Sagkeeng members and they participated in the harvesting of *Acorus* and *Vaccinium*. Furthermore, Sagkeeng members were instructed in plant collecting, plant identification, and plant mounting. These skills were taught with the hope that Sagkeeng members would be able to continue the monitoring protocols in the future.

3.2.1 *Acorus americanus*

(a) Field Equipment

Quadrats were marked with 1/2" PVC piping cut to 1m lengths and connected together with 1/2" copper elbows. This sturdy, yet lightweight and flexible construction allowed the quadrats to be assembled and disassembled quickly, to float on the water, and to be easily placed around the long, linear leaves of *A. americanus*.

(b) Plot selection

At each site in 1996, 1.5m lengths of construction reinforcing rod were driven into the ground on the shore for each block as permanent markers. The top of the rebar was spray painted fluorescent orange and trees or shrubs around the rebar were flagged

with orange flagging tape to facilitate finding the plots in the future. As plots were selected, the distance between the rebar and south-west corner of the plot was measured and the bearing of that line was taken using a Silva® ranger compass. At this point, blocks and plots were numbered, treatments were randomly assigned to the plots (Appendix III).

In Manitoba, the south-west corner of each plot was marked with a 1/2" acrylic rod spray painted orange at the top. In Ontario, the south-east corner of plots was marked. Acrylic rods were chosen because of their inert nature. However, because the durability of the rods in the riverine environment was inadequate, some rods were snapped and never recovered. In 1997, the cost of coating construction reinforcing rod with an inert substance was investigated and found prohibitively expensive. Therefore, acrylic rods were placed in all corners of every remaining plot in 1997 to increase the chances of relocating all plots in the future.

(c) Sampling

Sampling was performed in August 1996 and August - September 1997. The *A. americanus* shoot density, percent cover and rhizome dry mass were measured for all $1m^2$ plots to determine the effects of harvesting the rhizomes at various intensities. Individual shoots of *A. americanus* were counted in each plot. An individual shoot (ramet) was defined as one group of leaves emerging from a rhizome at the same point and apparently unattached to any other group of leaves (Figure 3.9). Those shoots that were rooted within or on the line that designated the edge of the plot were included within the study.

The percent cover of all species within the plot was estimated to the nearest 5%. If a species was present at less than 5% it was given a value of 1%.

(d) Harvesting

The number of *A. americanus* shoots to be harvested was calculated by multiplying the total number of shoots present in a plot by the assigned harvesting intensity (0%, 30%, 70%, or 100%, Figure 3.10-3.12). Shoots were harvested using a traditional

Figure 3.9 Individual shoots of *A. americanus* were counted. An individual shoot was defined as one group of leaves apparently emerging from a rhizome at the same point and apparently unattached to any other group of leaves.

method described by Evelyn Copnace, an elder from the Ojibways of Onegaming (Figure 3.13).

Shoots were removed by hand from the plot by grasping the leaf bases and pulling up to expose the rhizome. The rhizome was extracted by following the rhizome, breakingoff the roots along the rhizome. This traditional method was employed as no extraction methods were found in the literature. As much of the rhizome as possible for the calculated number of shoots was extracted from the plot using this method. However, if a rhizome broke, that was all of the rhizome for that shoot removed from the plot. Furthermore, if a rhizome grew toward the edge of a plot, the rhizome was deliberately broken or cut at the edge. The roots were numerous, long, spaghetti-like structures that grew perpendicular from the rhizome and anchored the rhizomes that grew at or just below the soil surface (Figure 3.14). Some rhizomes had more than one individual shoot

Figure 3.10 *A. americanus* 30% harvesting in Manitoba.

Figure 3.11 *A. americanus* 70% harvesting in Manitoba.

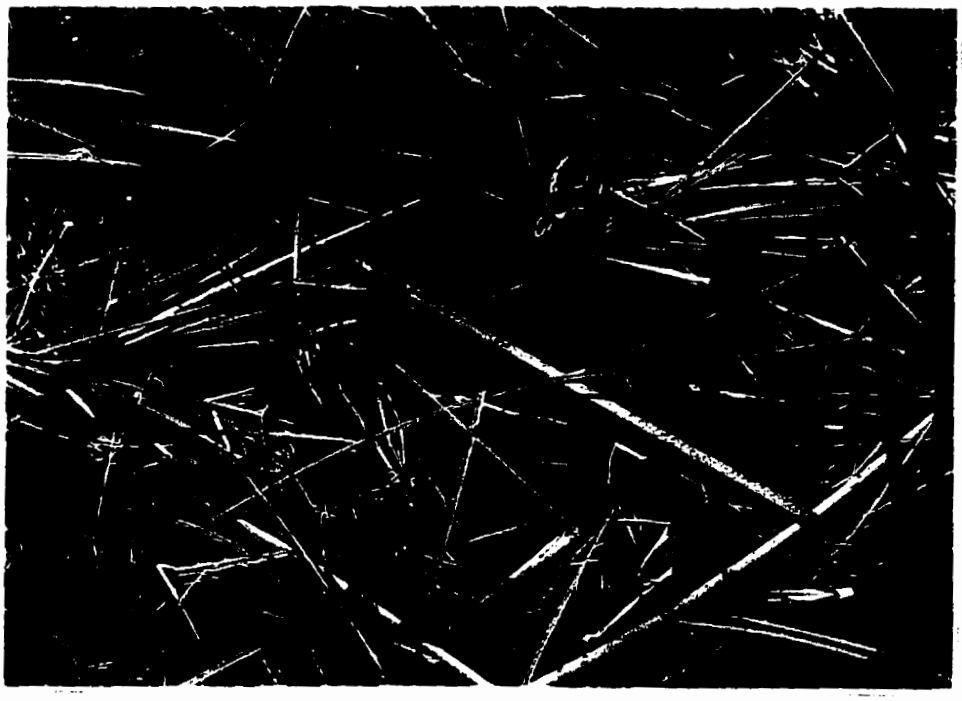

Figure 3.12 *A. americanus* 100% harvesting in Manitoba.

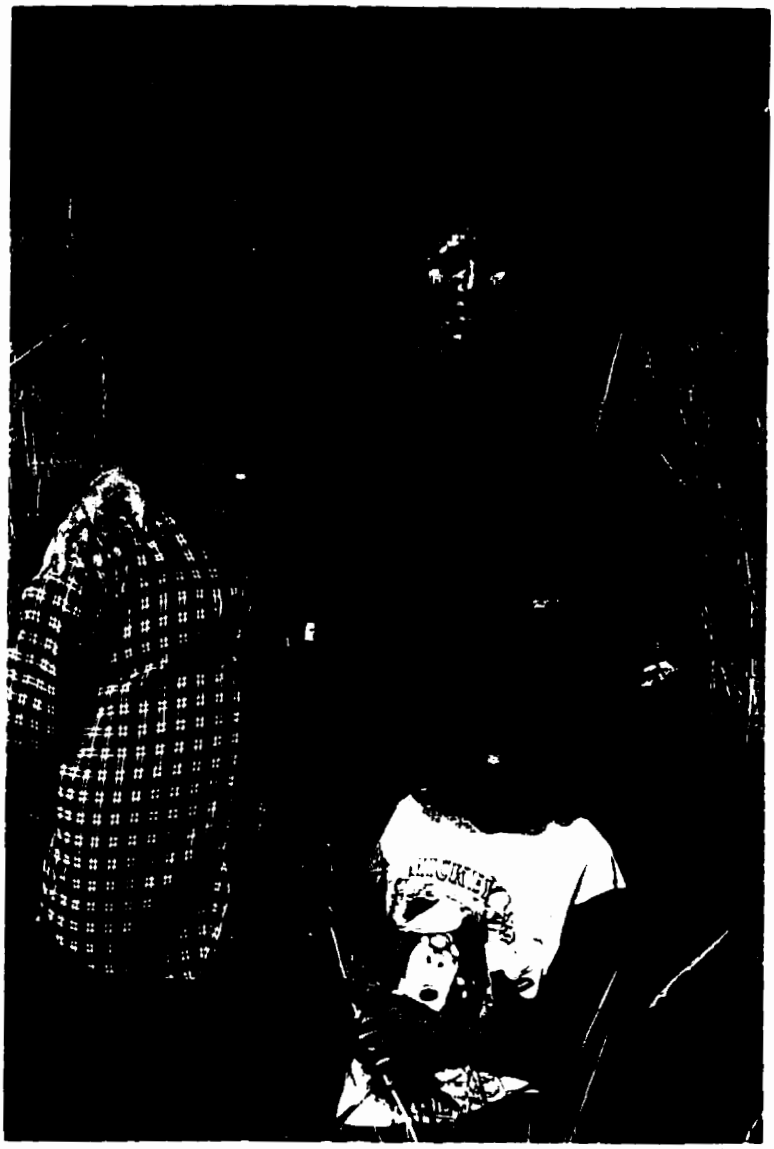

Figure 3.13 Evelyn Copnace, an elder from the Ojibway of Onegaming First Nation, with two of her granddaughters.

Figure 3.14 Crystal Henderson, in Manitoba, holding an *A. americanus* rhizome with associated shoot and roots still attached.

growing from them and when harvesting 30% or 70% these were counted as two or three individual shoots as the case may have been.

Finally, leaves and the majority of roots attached to rhizomes were cut and discarded at the plot. Rhizomes for each plot were collected in labeled plastic bags and taken to the lab for processing.

(e) Processing

Processing of *A. americanus* rhizomes involved the careful removal of root remnants from the rhizomes with razor blades (Figure 3.15 and 3.16), washing remaining soil from the rhizomes, placing the rhizomes in labeled paper bags and drying the tissue. All of the rhizomes were harvested in August. In 1996, the processing was done between the months of September and December. Therefore, some of the samples had to wait in the cold room for months before they were processed. In 1997, more people participated in the processing of the rhizomes, thereby decreasing from months to days the time rhizomes were stored in the cold room.

Rhizomes were dried in a Fisher Isotemp® Oven Model 501, at approximately 105°C, for 2-4 weeks until they reached a constant dry mass. Immediately upon removal from the drying oven, the dry mass per plot was measured to the nearest 0.000 g using a METTLER PM460 Delta Range® scale.

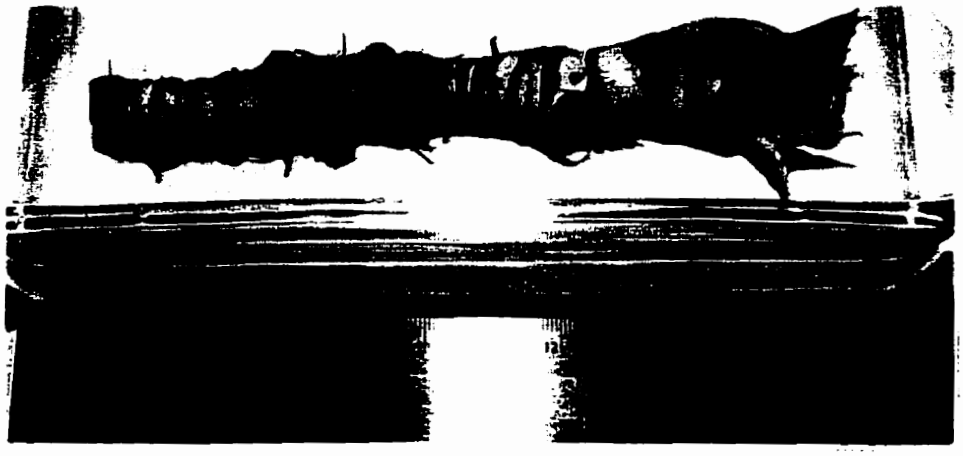

Figure 3.15 Cleaned *A. americanus* rhizome after processing, prior to drying.

Figure 3.16 Nahani Longpre and Crystal Henderson, of Sagkeeng First Nation, processing *A. americanus* rhizomes at the University of Manitoba in 1997.

(f) Shoot - Rhizome Correlation Study

The changes in *A. americanus* shoot density and percent cover were used to measure the effects of various rhizome harvesting intensities in the above ground portion of the plants. It was hypothesized that shoot density and rhizome dry mass might be correlated. If this were the case, then rhizome dry mass could be predicted by shoot density, thereby allowing for estimates of the rhizome dry mass of unharvested controls. For this reason, a second experiment was performed to test this correlation.

To assess the relationship between shoot and rhizome, smaller, $0.0625m^2$ (25 X 25 cm) quadrats were harvested at each site. These quadrats were situated more than 1m away from the $1m^2$ plots sampled to test harvesting intensity effects. Above ground shoots within the quadrat were counted and cut at the soil level. These shoots were collected, dried and massed separately for each quadrat. The below ground portion of the quadrat was sliced with a sharp shovel and the entire plug of soil, rhizomes and roots to a depth of approximately 20-30 cm was removed (Figure 3.17). The rhizomes are located at the soil surface to a depth of about 20 cm. The rhizomes were carefully removed from the soil, processed, dried and massed for each quadrat in the same manner and with the same equipment as previously described. A regression correlation analysis was performed on the Manitoba data for each year.

In 1996, nine samples were collected from Manitoba, i.e. three samples per site. Three samples were collected from Ontario. In 1997, 30 samples were collected in Manitoba, i.e. 10 samples per site. No samples were collected from Ontario in 1997 due to the dwindling frequency and abundance of *A. americanus* in the site.

Figure 3.17 Below ground portion of 0.0625 m^2 quadrat of *A. americanus* with the shoots cut off at the base

3.2.2 *Vaccinium angustifolium*

(a) Field Equipment

The same $1m^2$ quadrats that were used for the *A. americanus* sampling were used for *V. angustifolium*. However, cup hooks and wool were added to divide the quadrat into 16 equal subplots (Figure 3.18). HOMS Model 2 (1 kg X 10 g) and Model 100g (100 g X 1 g) instrument and laboratory spring scales were used to measure the fresh mass of the berries and a 250 ml measuring cup was used to measure the fresh volume of the berries. Mechanical counters were used in 1997 to facilitate the counting of berries and buds.

(b) Plot selection

V. angustifolium plots were established using the same procedure as was used for *A. americanus* plots. In 1996, four sites were established in Manitoba and three sites

in Ontario. The risk of disturbance by local blueberry harvesters at site 1 in Manitoba led to the establishment of site 4.

When possible all corners of the plots were marked with 1/4" acrylic rods with the tops spray painted orange. If the corner of the plot was situated on shield rock, an orange dot was spray painted on the rock.

(c) Sampling

In 1996 (Y1), sampling was performed between June and August in Manitoba and in August in Ontario. Berries were harvested between July 30 and August 1 in Manitoba and between August 6 -9 in Ontario. Most of the berries were ripe when harvested the first time in 1996. A second harvest was planned to retrieve remaining berries but upon investigation only three or four more berries per plot were found in the 100% harvesting intensity plots. As this amount of berries was less than 1 g, representing less than 0.004% of the total harvest, it was decided that one harvest would maximize efficiency and resources.

In 1997 (Y2), sampling occurred between June in Manitoba and July in Ontario. Berries were harvested the last week of August, when most of the berries were ripe in Manitoba and Ontario. Fall bud densities were collected in September in Manitoba and October in Ontario.

The densities of *V. angustifolium* shoots, buds, flowers, berries, and seedlings were counted before (Y1) and after (Y2) harvesting in four 0.0625m^2 subplots. Percent cover values for all species within the 1m^2 plots were also estimated and recorded.

The four subplots were situated in a 0.25m^2 corner of the plot. As the monitoring protocols were established to mimic the conditions that would be preferred by the blueberry harvester, the corners with the greatest percent cover of *V. angustifolium* and the most berries, were sampled. Due to the caespitose nature of many *V. angustifolium* shoots, white twist ties in Y1 and brightly colored clothespins in Y2 were used to mark each shoot initially. Once all shoots were identified and marked, all flowers and berries were counted.

Twist ties or clothespins were removed and counted to establish the number of shoots when scoring each shoot was completed. In 1997, the number of floral buds on each shoot was also counted preharvest and postharvest in the same way as the flowers and berries.

(d) Harvesting

In 1996, the 100% plots of each site were harvested first to calculate the fresh mass of berries to be harvested from the 30 and 70% plots. Fresh masses of the berries from the three 100% plots of each site were measured to the nearest gram using HOMS Model 2 (1 kg X 10 g) and Model 100g (100 g X 1 g) instrument and laboratory spring scales (Figures 3.18 and 3.19). Masses were averaged over the site. The grams of berries to be harvested was calculated by multiplying the average mass harvested for the 100% harvest plots by the harvesting intensity (either 70% or 30%). This value was further adjusted based on the difference between the average percent cover for the 100% plots and the plot to be harvested. For example,

Site/Block/Plot of 100% plots	mass (g)	percent cover
S2B1P4	101	60
S2B2P2	74	80
S2B3P3	70	70
average	82	70

S2B3P1 30% harvesting intensity and 60 percent cover

82g X 0.90 = 74g
74g X 0.30 = 22g 22g of berries were harvested.

S2B2P4 70% harvesting intensity and 85 percent cover

82g X 0.15 = 12g
82 + 12 = 94g
94g X 0.70 = 66g only 50g of berries were harvested as there did not appear to be 66g present.

Berries from the 70% and 30% harvesting intensities were hand picked evenly from plots. Mass to the nearest gram was measured and recorded in the field using spring scales. Occasionally, there were not enough berries within a plot to fulfill the calculated fresh mass of berries. At these times, estimates were implemented. Overall, this method

Figure 3.18 *V. angustifolium* 1m^2 plot before 100% berry harvesting.

Figure 3.19 *V. angustifolium* 1m^2 plot after 100% berry harvesting.

of harvesting the 70% and 30% levels was found to be imprecise because percent cover did not accurately reflect the quantity of berries within a plot. For example, two plots could have identical percent covers and when 100% of the berries were harvested the difference could be as much as 190g between the two.

Additionally, the volume of the berries was measured in cups. This value was then later converted to ml.

In 1997, the harvesting method was further refined. The number of berries was totaled for each $0.25m^2$ subplot. A "correction factor" was calculated for each plot based on the berry density of the plot to be harvested incorporating the berry density of the 100% plot. Again the 100% plots were harvested first, but the values were not averaged across the site. For example,

Harvesting intensity	Berry density ($0.25m^2$)	Mass of berries ($1m^2$)
S1B1P2 100%	447	50g
S1B1P1 70%	23	
S1B1P4 30%	110	

(23/447)0.70 = 0.036018 "correction factor"
50g(0.036018) = 1.8g 2g of berries were harvested in the 70% plot.
(110/447)0.30 = 0.073826 "correction factor"
50g(0.073826) = 3.7g 4g of berries were harvested in the 30% plot.

After each mass was estimated, the 70% and 30% plots were harvested to the estimated mass, while trying to pick berries as evenly as possible from the plot. Even though this method was more objective than the first harvesting method, it was difficult to apply in some cases. For example, some plots had high berry counts, but when they were harvested there were not enough berries to fill the estimated mass for harvesting. Sometimes this may have been due to microclimate conditions that did not favor berry development, disease or sickness that stopped berry development, and/or herbivory.

3.3 Analysis

Productivity values collected before (1996) and after (1997) harvesting indicated that sites in Manitoba and Ontario were floristically different for both study species. Therefore, means (± 1 SE) for shoot densities, rhizome dry mass, bud density, berry mass, berry volume, berry density, seedling density and percent cover of all species were calculated and presented in table form separately for each location. Based on the means calculated for these tables, histograms were produced to illustrate the increase or decrease in specific parameters from 1996 to 1997. As the histograms resulted from the subtraction of the 1996 mean from the 1997 mean (Y2 - Y1), therefore error bars were not applied. When necessary the sample size was reduced if no data were collected for a plot in 1997, therefore sample sizes (n) are variable.

A logarithmic transformation was performed on the original data [$X' = \log_{10}(X + 1)$]. Data were transformed to convert the distribution to a nearly symmetrical one so parametric, statistical tests could be performed (Krebs 1989). Student's Paired t-Tests were performed using Microsoft Excel 5.0a for Power Macintosh™ to test statistical significance of differences between Y1 and Y2 for each treatment. Significant differences ($p \leq 0.05$) were marked on the tables using an asterisk (*).

Linear regression analysis was performed using Microsoft Excel 5.0a for Power Macintosh™ on the data collected in the shoot-rhizome correlation study to return Pearson product moment correlation coefficients (R^2).

Analysis of Variance (ANOVA) was performed using Data Desk ® 4.1 Exploratory Data Analysis to test for differences between treatments on the $\log_{10}(x + 1)$ transformed original data. Least Significant Difference (LSD) post hoc tests were performed with Data Desk when the ANOVA had a significance of ≤ 0.05 identifying the probability of differences between pair-wise combinations of treatments. Significant differences ($p \leq 0.05$) were marked on tables using a lettering system. Treatments with the same letters are not significantly different. Box plots were also created using Data Desk and are included with the ANOVA and LSD post hoc tests in Appendix IV.

Considering the hierarchical sampling design a Nested ANOVA may have been an appropriate analysis to perform. It is recognized that had the data been subjected to the Nested ANOVA quite different results may have been obtained. However, because the sites and blocks were of unequal sizes it is believed that the ANOVA was more appropriate.

CHAPTER 4 RESULTS

4.1 *Acorus americanus*

4.1.1 Manitoba

(a) Shoot Density

As harvesting intensity increased shoot density decreased (Figure 4.1-A). Significantly more new shoots were produced within the control (0% harvesting intensity) in 1997 than 1996 (T-test, $p = 0.038$, $df = 7$). No significant differences between years were found for shoot density following 30%, 70% or 100% harvesting. However, the decrease from 61 shoots$\cdot m^{-2}$ to 35 shoots$\cdot m^{-2}$ (Table 4.1, T-test, $p = 0.068$) suggests that a negative effect following 100% harvesting is established. Significant differences between treatments were found (ANOVA, $p = 0.0098$, $n = 8$). Post hoc testing showed significant differences between the 100% harvesting intensity and all other treatments (LSD, 100% - 0, $p = 0.002$; 100% - 30%, $p = 0.008$; 100% - 70%, $p = 0.03$; Table 4.1).

(b) Rhizome Dry Mass

This trend is supported in the observations for rhizome dry mass (Figure 4.1-C), since no significant difference was observed following 30% or 70% harvesting, but the decrease observed after the 100% harvesting was nearly significant (T-test, $p = 0.058$, Table 4.1). Similarly, the differences observed between harvesting intensities narrowly missed significance (ANOVA, $p = 0.06$, $n = 8$).

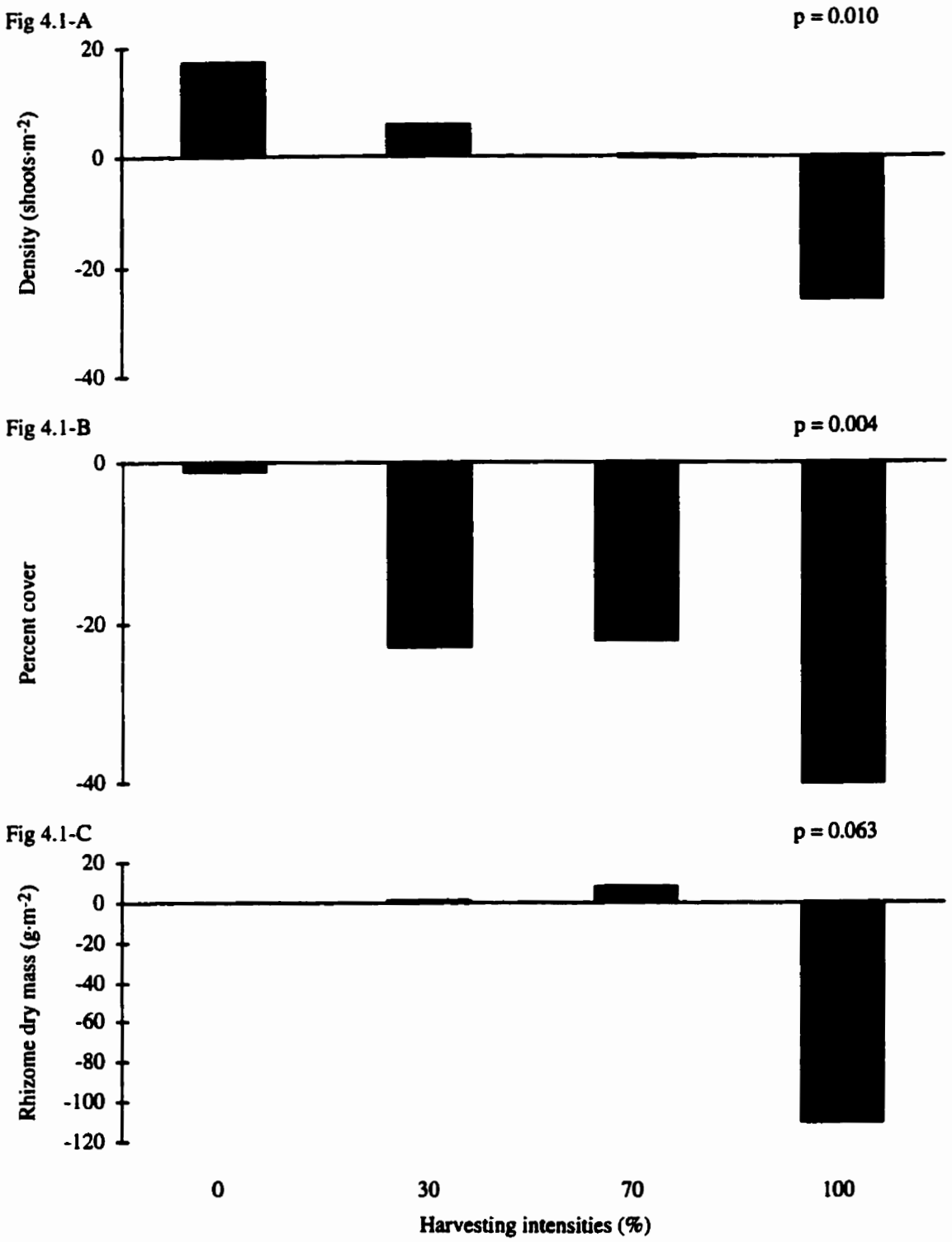

Figure 4.1. Change in *Acorus americanus* from 1996 (Y1) to 1997 (Y2) at various harvesting intensities in Manitoba. A) density (shoots·m^{-2}); B) percent cover (based on 1m^2 plots); rhizome dry mass (g·m^{-2}). No rhizome dry mass value exists for the 0% harvesting intensity as the rhizomes remained unharvested. P values are from ANOVAs.

Table 4.1. Change in *Acorus americanus* shoot density, percent cover, and rhizome dry mass in Manitoba in 1996 (Y1, n=9) and 1997 (Y2, n=8) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE).

Harvesting	Density (shoot·m^{-2})		Percent cover (1m^2)		Rhizome dry mass (g·m^{-2})	
intensities (%)	Y1	Y2	Y1	Y2	Y1	Y2
0	54 ± 21	71 ± 14*a	46 ± 12	45 ± 12a	—	—
30	59 ± 19	65 ± 19a	58 ± 21	35 ± 11*ab	56 ± 13	57 ± 13a
70	51 ± 20	51 ± 16a	49 ± 15	27 ± 8*b	88 ± 28	96 ± 46a
100	61 ± 26	35 ± 21b	58 ± 18	19 ± 9*bc	229 ± 102	119 ± 85a

* Indicates significant differences between years, $p \leq 0.05$.
Different letters indicate significant differences in the changes from Y1 to Y2 between treatments, $p \leq 0.05$

(c) Percent Cover

On the other hand, percent cover was significantly reduced in 1997 following all harvesting treatments, with the greatest reduction following 100% harvesting (T-test, $p = 0.004$, Figure 4.1-B). Significant differences between harvesting intensities were found (ANOVA, $p = 0.004$, $n = 8$). Post hoc tests showed significant differences between many of the treatments (LSD, 70% - 0, $p = 0.037$; 100% - 0, $p = 0.0004$; 100% - 30%, $p = 0.034$, Table 4.1) and some of the differences narrowly missed significance (LSD, 30% - 0, $p = 0.082$; 100% - 70%, $p = 0.077$).

(d) Rhizome - Shoot Correlation Study

No correlations were found between the shoot density and rhizome dry mass (Y1 $R^2 = 0.02$, Y2 $R^2 = 0.12$) or shoot density and shoot dry mass (Y1 $R^2 = 0.11$, Y2 $R^2 = 0.22$; Figure 4.2). A strong correlation between shoot density and rhizome dry mass would have allowed for estimates of the below ground productivity of the unharvested control. Consequently, as no correlation was observed no estimates of the below ground productivity of the control treatments could be made.

(e) Associated Plant Species

Contrary to expectations, harvesting intensity had little effect on associated plant species percent cover. Small sample size, and variability of percent cover and frequency, may be responsible since most associated plant species were present with very low percent covers relative to *A. americanus* (Table 4.2). Interestingly, *Carex* spp. significantly decreased in the control (T-test, $p = 0.013$) and 70% (T-test, $p = 0.02$) harvesting intensity.

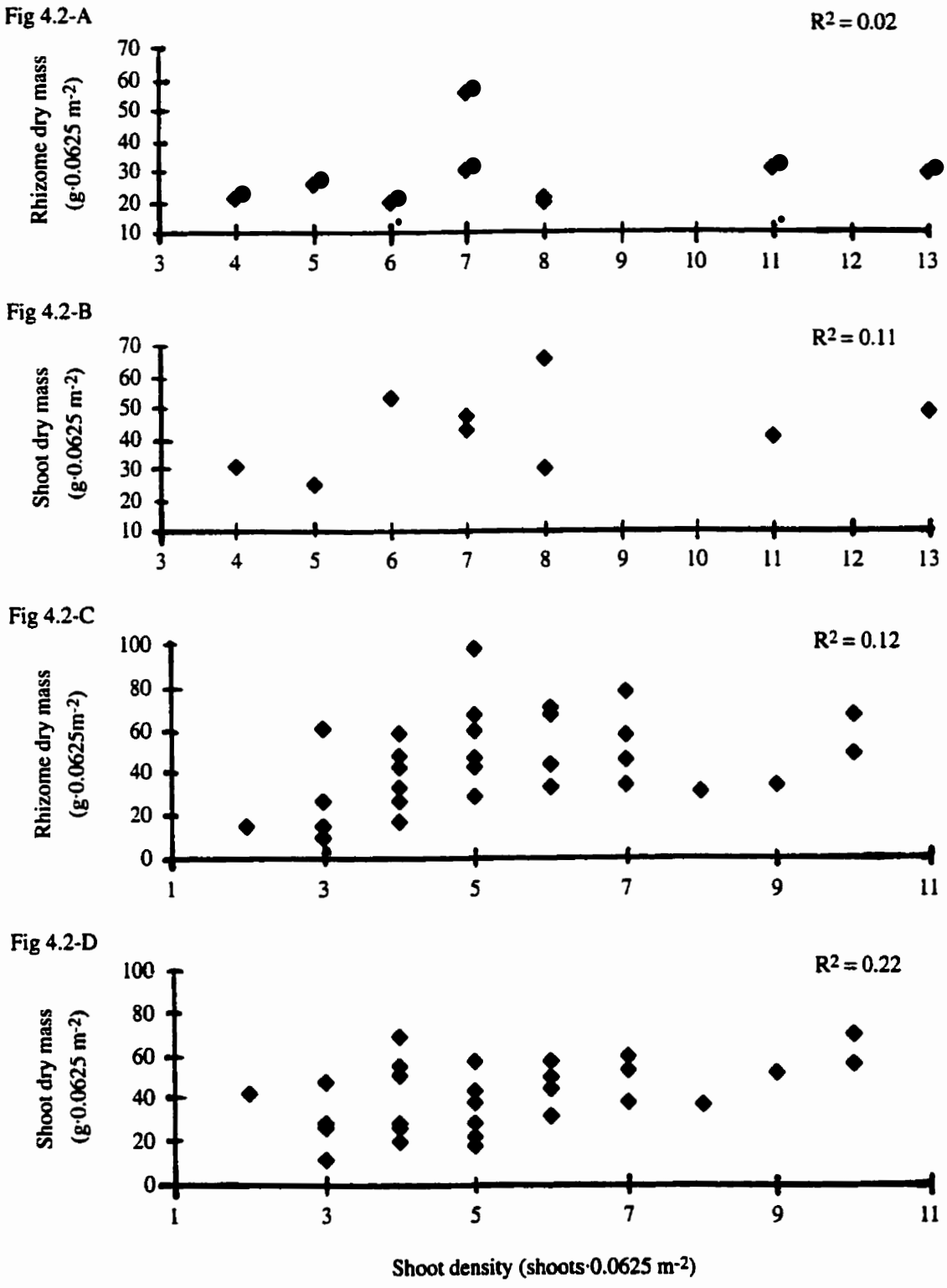

Figure 4.2. *Acorus americanus* rhizome (A and C) and shoot (B and D) dry masses (g·0.0625 m^{-2}) at various shoot densities within 0.0625 m^2 areas collected in Manitoba. A and B were collected in 1996 (Y1); n = 3 from three sites. C and D were collected in 1997 (Y2); n = 10 from three sites.

Table 4.2. Percent cover (based on $1m^2$ plots) of all species present in the *Acorus americanus* study sites in Manitoba in 1996 (Y1, n=9) and 1997 (Y2, n=8) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE). Dashes indicate absence from all plots.

	Harvesting intensities							
	0%		30%		70%		100%	
Plant species	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Acorus americanus	45.6 ± 12.4	45.0 ± 11.6	57.8 ± 20.5	35.0 ± 10.7	48.9 ± 15.2	26.9 ± 7.5	57.8 ± 18.4	20.6 ± 8.2
Butomus umbellatus	0.1 ± 0.3	—	—	—	—	—	—	—
Carex sp.	8.0 ± 7.3	2.4 ± 2.5*	7.0 ± 10.6	2.6 ± 4.2	9.0 ± 11.6	0.9 ± 1.6*	4.7 ± 6.7	1.9 ± 3.4
Cicuta bulbifera	0.2 ± 0.4	0.2 ± 0.4	0.1 ± 0.3	0.1 ± 0.3	0.4 ± 0.5	0.1 ± 0.3	0.3 ± 0.5	0.1 ± 0.3
Cicuta maculata	2.1 ± 2.2	1.4 ± 3.2	1.1 ± 2.2	0.4 ± 0.5	0.7 ± 0.5	—	4.8 ± 11.4	0.1 ± 0.3
Eleocharis palustris	0.6 ± 1.7	0.1 ± 0.3	—	—	0.7 ± 1.7	—	1.1 ± 2.2	0.1 ± 0.3
Equisetum sp.	0.1 ± 0.3	—	—	—	—	—	0.6 ± 1.7	—
Potentilla palustris	0.1 ± 0.3	0.6 ± 1.7	1.1 ± 3.3	1.1 ± 3.3	—	0.1 ± 0.3	1.1 ± 3.3	1.7 ± 5.0
Sagittaria cuneata	0.6 ± 1.7	0.7 ± 1.7	0.9 ± 1.6	0.3 ± 0.5	1.3 ± 3.3	0.2 ± 0.4	1.0 ± 1.6	0.3 ± 0.5
Sagittaria rigida	0.4 ± 0.5	0.8 ± 1.7	1.0 ± 1.6	0.8 ± 1.6	0.3 ± 0.5	0.8 ± 1.6	1.3 ± 3.3	0.7 ± 1.7
Scirpus cyperinus	—	0.1 ± 0.3	—	—	—	—	—	0.1 ± 0.3
Sparganium eurycarpum	0.2 ± 0.4	0.3 ± 0.5	0.2 ± 0.4	0.2 ± 0.4	0.1 ± 3.3	—	—	0.3 ± 0.5
Typha latifolia	0.7 ± 1.7	0.7 ± 1.7	0.6 ± 1.7	0.8 ± 1.6	0.1 ± 0.3	—	0.2 ± 0.4	0.2 ± 0.4
Zizania aquatica	0.1 ± 0.3	0.2 ± 0.4	0.2 ± 0.4	0.1 ± 0.3	0.7 ± 1.7	0.3 ± 0.5	0.2 ± 0.4	1.2 ± 2.2
Unidentified grass	0.1 ± 0.3	0.1 ± 0.3	0.7 ± 1.7	0.6 ± 1.7	0.3 ± 0.5	—	—	—

* $p < 0.05$

A slight decrease in species richness was observed as *Butomus umbellatus* and *Equisetum* sp. were not present in Y2, while *Scirpus cyperinus* appeared in Y2. In total, 15 plant species were observed in Manitoba representing 10 plant families (Appendix II).

4.1.2 Ontario

Due to the extremely small sample taken in Ontario (n=3 in Y1, n=2 in Y2), no significant effects were observed as a result of harvesting *A. americanus* between years (Table 4.3). However, significant differences between treatments were found within the shoot densities (ANOVA, $p = 0.0345$, $n = 2$; LSD, 100% - 0, $p = 0.015$; 100% - 30%, $p = 0.011$; 100% - 70%, $p = 0.033$). The 30%, 70% and control treatments increased in shoot density while the 100% harvesting intensity decreased (Figure 4.3-A). All treatments decreased in percent cover in Y2 (Figure 4.3-B) and no significant differences were found between treatments (ANOVA, $p = 0.6742$, $n = 2$). Additionally, 70% and 100% harvesting intensities showed a decrease in rhizome dry mass, while 30% harvesting showed a slight increase (Figure 4.3-C) however, no significant differences were found (ANOVA, $p = 0.8996$, $n = 2$).

As in Manitoba, harvesting intensity had no significant effects on the percent cover of associated plant species sampled due to the small sample size and high variability (Table 4.4). However, associated plant species, such as *Polygonum coccineum* had greater percentage cover relative to the Manitoba sites.

The *A. americanus* site in Ontario also showed an increase of species richness from 7 species representing five families in Y1 to 13 species representing nine families in Y2 (Table 4.4). Specifically, *Bidens cernua*, *Calamagrostis canadensis*, *Cicuta bulbifera*, *Galium boreale*, *Polygonum amphibium*, *P. lapathifolium*, *Sagittaria rigida* and *Sparganium eurycarpum* were the new species present in Y2 (Table 4.4).

Table 4.3. *Acorus americanus* shoot density, percent cover, and rhizome dry mass in Ontario in 1996 (Y1, n=3) and 1997 (Y2, n=2) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE).

Harvesting	Density (shoots·m^{-2})		Percent cover (1m^2)		Rhizome dry mass (g·m^{-2})	
intensities (%)	Y1	Y2	Y1	Y2	Y1	Y2
0	31 ± 10	36 ± 15a	37 ± 20	23 ± 4a	—	—
30	27 ± 8	33 ± 9a	38 ± 20	13 ± 4a	25 ± 13	26 ± 1a
70	24 ± 6	25 ± 0a	27 ± 6	10 ± 7a	60 ± 21	40 ± 5a
100	24 ± 11	18 ± 6b	30 ± 20	8 ± 4a	60 ±42	48 ± 31a

Different letters indicate significant differences in the changes from Y1 to Y2 between treatments, $p \leq 0.05$

Fig 4.3-A

p = 0.034

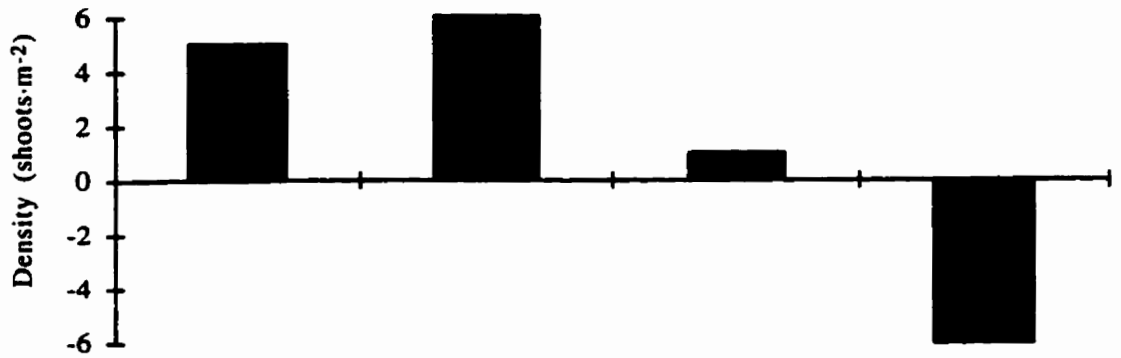

Fig 4.3-B

p = 0.674

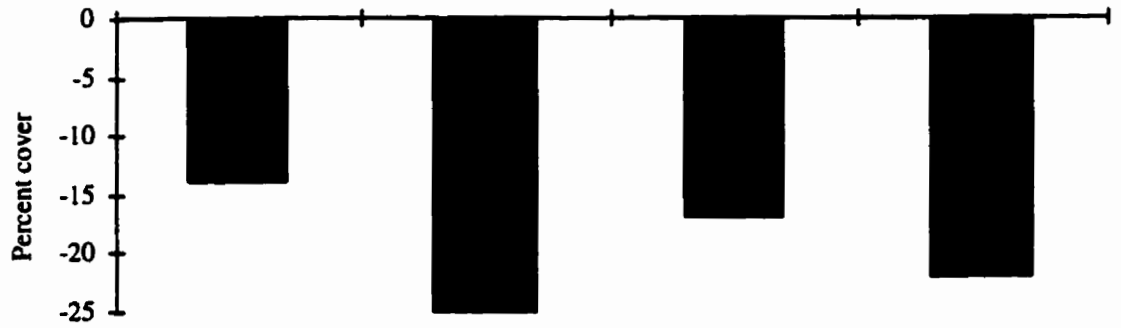

Fig 4.3-C

p = 0.900

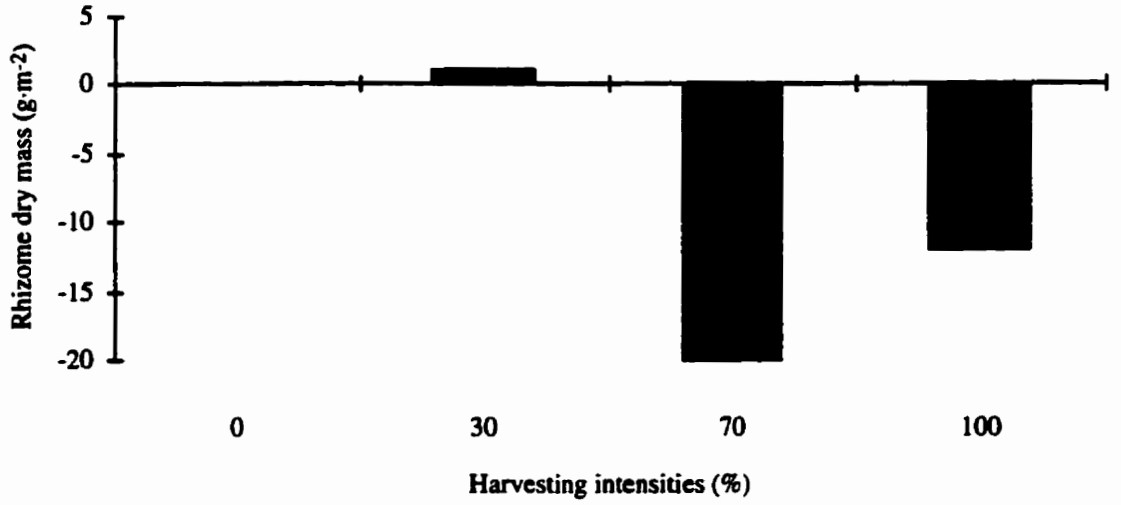

Figure 4.3. Change in Acorus americanus from 1996 (Y1) to 1997 (Y2) at various harvesting intensities in Ontario. A) Density (shoots·m^{-2}); B) percent cover (based on 1m^2 plots); C) rhizome dry mass (g·m^{-2}). No rhizome dry mass value exists for the 0% harvest intensity because the rhizomes remained unharvested. P values are from ANOVAs.

Table 4.4. Percent cover of all species present in the *Acorus americanus* study site in Ontario in 1996 (Y1, n=3) and 1997 (Y2, n=2) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE). Dashes indicate absence from all plots.

	Harvesting intensities							
	0%		30%		70%		100%	
Plant species	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
Acorus americanus	36.7 ± 20.2	22.5 ± 3.5	38.3 ± 20.2	12.5 ± 3.5	26.6± 5.8	10.0 ± 7.1	30.0 ± 20.0	7.5 ± 3.5
Bidens cernua	—	5.0 ± 0	—	5.0 ± 7.1	—	3.0 ± 2.8	—	3.0 ± 2.8
Calamagrostis canadensis	—	7.5 ± 3.5	—	—	—	0.5 ± 0.7	—	10.0 ± 14.1
Carex sp.	15.0 ± 13.2	22.5 ± 3.5	33.3 ± 5.8	10.0 ± 7.1	21.7 ± 7.6	12.5 ± 10.6	21.7 ± 16.1	15.0 ± 7.1
Cicuta bulbifera	—	1.0 ± 0	—	1.0 ± 0	—	1.0 ± 0	—	1.0 ± 0
Galium boreale	—	1.0 ± 0	—	0.5 ± 0.7	—	0.5 ± 0.7	—	—
Polygonum amphibium	—	3.0 ± 2.8	—	7.5 ± 3.5	—	10.5 ± 13.4	—	3.0 ± 2.8
Polygonum coccineum	5.0 ± 8.7	5.5 ± 6.4	7.0 ± 5.2	1.0 ± 0	7.0 ± 11.3	13.0 ± 17.0	5.3 ± 8.4	3.0 ± 2.8
Polygonum lapathifolium	—	0.5 ± 0.7	—	—	—	0.5 ± 0.7	—	—
Potentilla palustris	0.3 ± 0.6	2.5 ± 3.5	2.0 ± 2.6	0.5 ± 0.7	0.3 ± 0.6	2.5 ± 3.5	1.7 ± 2.9	5.0 ± 7.1
Sagittaria rigida	—	—	0.3 ± 0.6	—	—	—	—	—
Scirpus cyperinus	—	—	—	—	0.3 ± 0.6	0.5 ± 0.7	—	—
Sparganium eurycarpum	—	0.5 ± 0.7	—	5.5 ± 6.4	—	—	—	0.5 ± 0.7
Unidentified grass	0.7 ± 0.6	—	1.7 ± 2.9	—	0.7 ± 0.6	—	1.0 ± 0	—

4.2 *Vaccinium angustifolium*

4.2.1 Manitoba

(a) Percent Cover, Mass, and Volume

All treatments showed some decrease in Y2 for percent cover, berry mass and berry volume of *V. angustifolium*. Interestingly, as harvesting intensity increased, the decrease in the percent cover was relatively smaller (Figure 4.4-A). The control had the largest and only significant reduction in mean percent cover from 60% in Y1 to 50% in Y2 (T-test, $p = 0.04$, $df = 10$, Table 4.5). The decreases in percent cover following 30% and 70% harvesting were similar, although not significant, and intermediate to the decreases observed in the control and 100% harvesting, respectively. No significant differences in percent cover were found between treatments (ANOVA, $p = 0.5784$, $n = 11$).

The inverse trend was observed in the mass and volume of the fresh berries; as the harvesting intensity increased the negative effect became greater (Figure 4.4-B and 4.4-C). However, no significant differences were found between treatments for either the mass or volume (ANOVA, $p = 0.3159$, $p = 0.2013$, respectively, $n = 11$). The 30% harvesting intensity caused no significant change in the mean mass or mean volume in Y2. The 70% treatment had a relatively moderate negative effect. There was a significant mean decrease of 40 ml in the volume of fresh berries resulting from 70% harvesting (T-test, $p = 0.038$, $df = 11$, Table 4.5). The greatest mean change for mass and volume of fresh berries was observed in the 100% harvesting intensity. Mean mass of fresh berries decreased significantly from 121g in Y1 to 72g in Y2 (T-test, $p = 0.022$, $df = 10$). Mean volume of fresh berries was also significantly decreased from 237 ml in Y1 to 128 ml in Y2 (T-test, $p = 0.001$, $df = 10$).

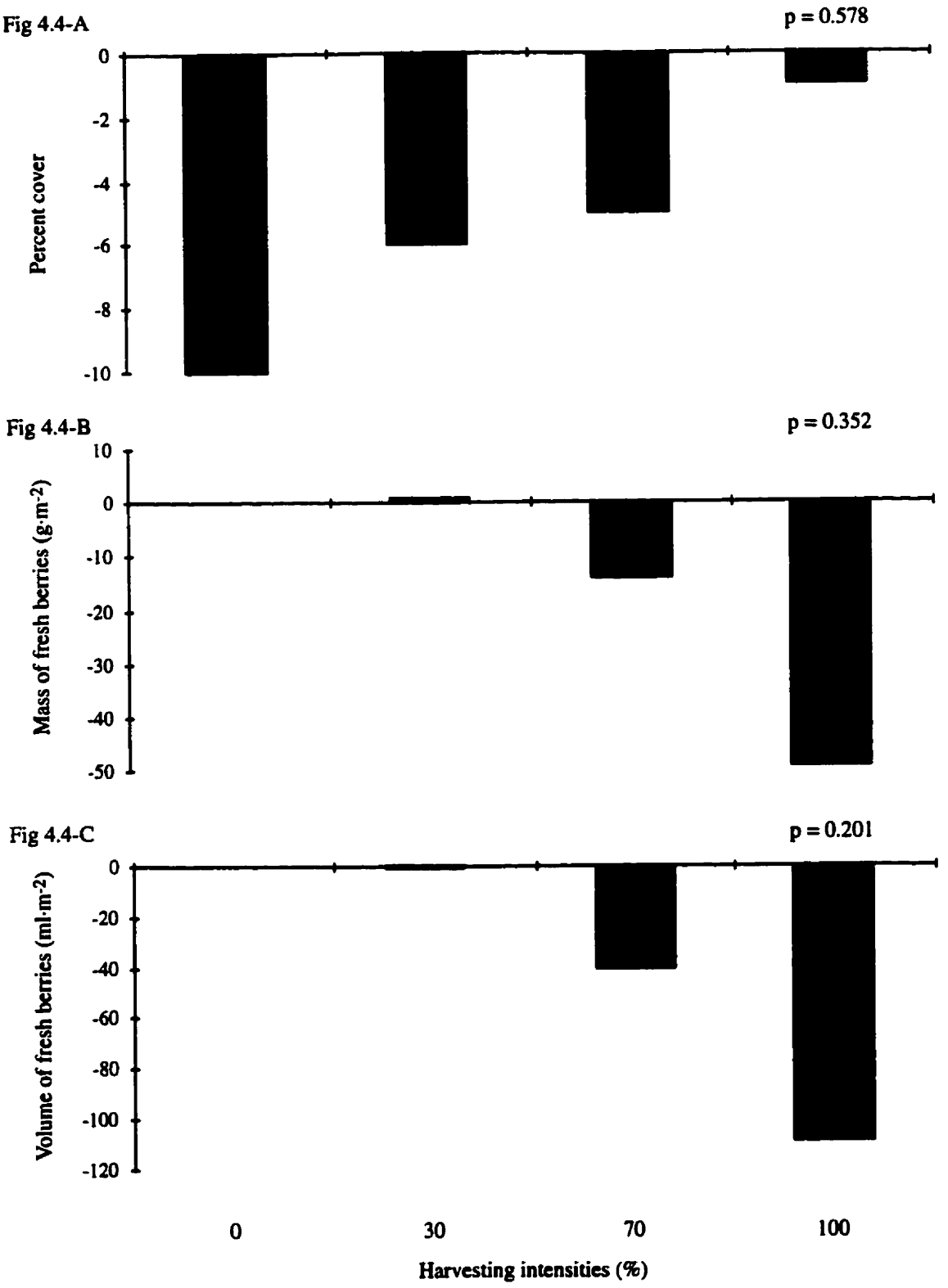

Figure 4.4. Change in *Vaccinium angustifolium* from 1996 (Y1) to 1997 (Y2) at various harvesting intensities in Manitoba. A) Percent cover (based on $1m^2$ plots); B) Mass of fresh berries ($g \cdot m^{-2}$); C) Volume of fresh berries ($ml \cdot m^{-2}$). 0 and 100% harvesting intensities n = 11. 30 and 70 % harvesting intensities n = 12. P values are from ANOVAs.

Table 4.5. *Vaccinium angustifolium* percent cover, fresh mass of berries (g) and fresh volume of berries (ml) in 1 m^2 plots in Manitoba in 1996 (Y1) and 1997 (Y2) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE); n = 11 for 0% and 100% harvesting intensities and n = 12 for 30% and 70% harvesting intensities.

Harvesting	Percent cover		Fresh mass of berries (g)		Fresh volume of berries (ml)	
intensities (%)	Y1	Y2	Y1	Y2	Y1	Y2
0	60 ± 17	50 ± 20*a	—	—	—	—
30	64 ± 15	58 ± 25a	24 ± 17	25 ± 17a	49 ± 32	49 ± 33a
70	65 ± 20	60 ± 21a	70 ± 63	56 ± 70a	139 ± 110	99 ± 106*a
100	60 ± 11	59 ± 18a	121 ± 110	72 ± 95*a	237 ± 170	128 ± 168*a

* Indicates significant differences between years, $p \leq 0.05$.
Different letters indicate significant differences in the changes from Y1 to Y2 between treatments, $p \leq 0.05$

(b) Shoot Density

Few significant changes were observed in the parameters measured on the *V. angustifolium* shrubs within the $0.25m^2$ sub-plots. The three harvesting treatments appeared to produce more shoots than the control (Figure 4.5-A). However, no significant differences were found between treatments (ANOVA, $p = 0.1739$, $n = 11$). No significant changes were observed in the control or 70% harvesting between years. Significant increases of shoot density were observed following 30% harvesting between years (T-test, $p = 0.042$, $df = 11$) increasing by 9 shoots (Table 4.6). Following 100% harvesting, a significant increase of mean shoot density was observed between years (T-test, $p = 0.014$, $df = 10$).

(c) Bud Density

Increases in bud density were observed at all harvesting intensities. No significant differences were found at the 0, 30% and 70% harvesting intensities between years. A significant increase from a mean of 112 buds to 162 buds was observed following 100% harvesting (T-test, $p = 0.009$, $df = 10$). No significant differences were found between treatments (ANOVA, $p = 0.5391$, $n = 11$).

(d) Berry Density

No significant change was observed in the control for berry densities between years. Similar mean increases of 84 berries and 83 berries, respectively, from Y1 to Y2 were observed following 30% and 70% harvesting (Figure 4.5, Table 4.6). A mean decrease of 82 berries was observed following 100% harvesting

Fig. 4.5-A

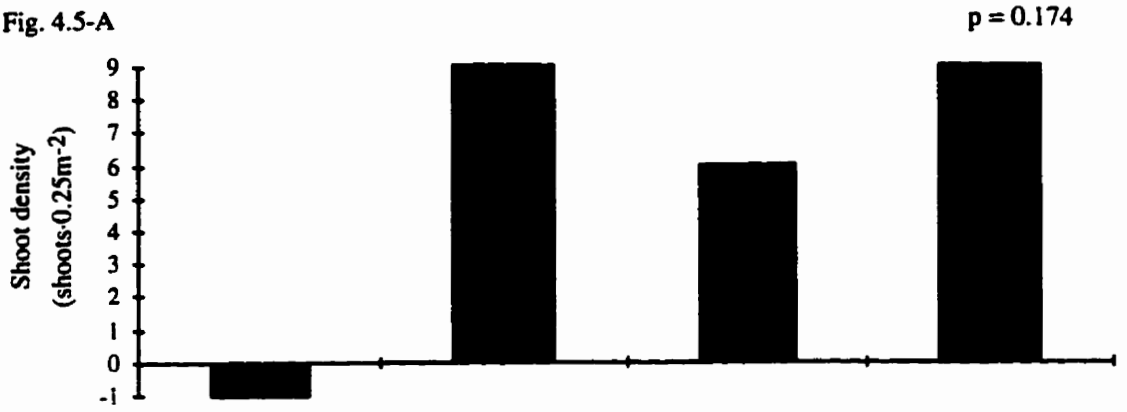

Fig. 4.5-B

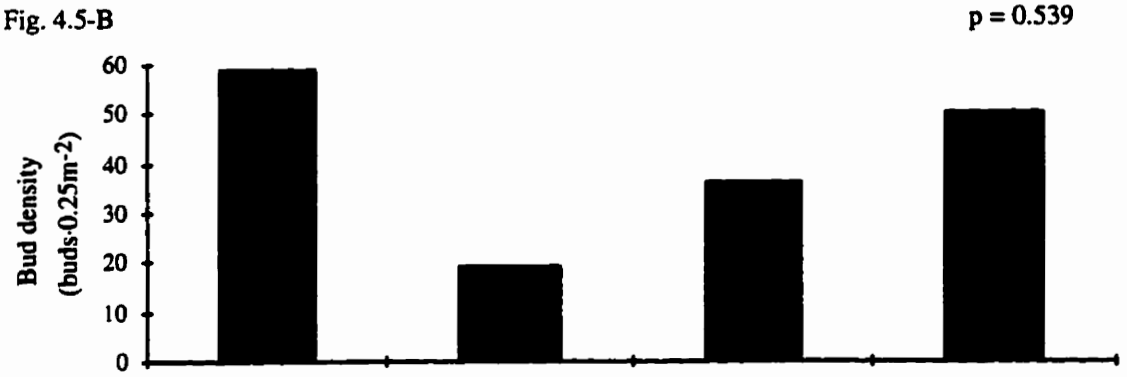

Fig. 4.5-C

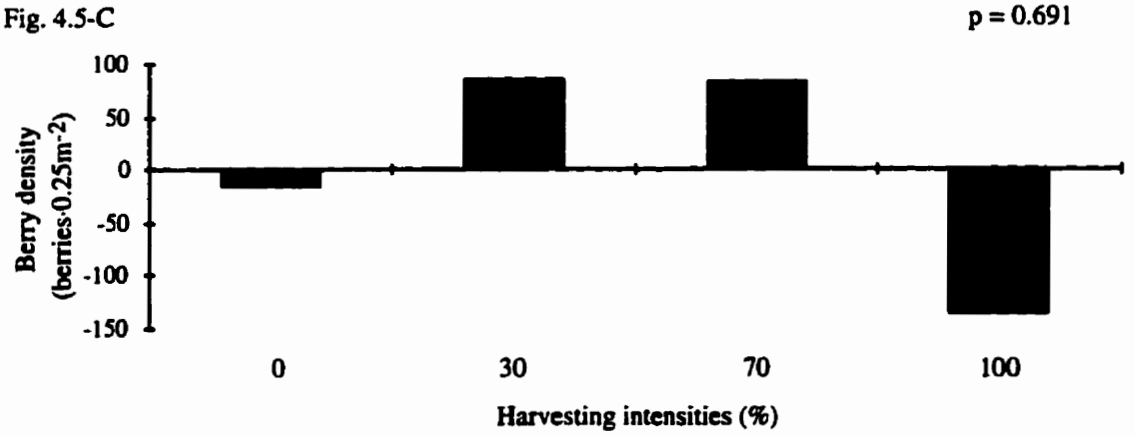

Figure 4.5. Change in *Vaccinium angustifolium* from 1996 (Y1) to 1997 (Y2) at various harvesting intensities in Manitoba. A) Shoot density (shoots·0.25 m^{-2}); B) Bud density (buds·0.25 m^{-2}); C) Berry density (berries·0.25 m^{-2}). 0 and 100 % harvesting intensities n =11. 30 and 70 % harvesting intensities n = 12. P values are from ANOVAs.

Table 4.6. *Vaccinium angustifolium* : densities of shoots, buds and berries in 0.25 m^2 in Manitoba in 1996 (Y1) and 1997 (Y2) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE). n= 11 for 0% and 100% harvesting intensities and n=12 for 30% and 70% harvesting intensities. Values were not converted to a standard 1 m^2 due to non-random sampling within the 1 m^2 quadrats.

	Shoot density (no.·0.25m^{-2})			Bud density[†] (no.·0.25m^{-2})		Berry density (no.·0.25m^{-2})	
Harvesting intensities (%)	Y1	Y2 - S	Y2 - F	Y2 - S	Y2 - F	Y1	Y2
0	37 ± 10	36 ± 13a	57 ± 13	142 ± 77	201 ± 96a	336 ± 320	320 ± 209a
30	37 ± 11	46 ± 13*a	60 ± 22	130 ± 95	149 ± 101a	213 ± 125	297 ± 223a
70	37 ± 16	43 ± 14a	54 ± 16	149 ± 97	185 ± 134a	312 ± 263	395 ± 292a
100	35 ± 10	44 ± 9*a	54 ± 14	112 ± 91	162 ± 98*a	393 ± 479	258 ± 311a

[†] Bud density data collected in the summer (S) before harvesting and fall (F) after harvesting in 1997 (Y2)

* Indicates significant differences between years, $p \leq 0.05$.

Different letters indicate significant differences in the changes from Y1 to Y2 between treatments, $p \leq 0.05$

although this was not significant. Extreme variability in berry densities occurred in all treatments (Table 4.6). No significant differences were found between treatments (ANOVA, $p = 0.6911$, $n = 11$).

(e) Associated Plant Species

Within the study sites in Manitoba, 73 species of plants were identified representing 34 families (Appendix II). Six species were present in Y1 that were not present in Y2 while 13 species were present in Y2 that were not present in Y1 (Table 4.7).

Very few changes in the percent cover from Y1 to Y2 were found to be significant (Table 4.8). *Cladonia* spp. were found in more plots in Y2 than in Y1, thereby significantly increasing the mean percent cover in the 30% and 70 % harvesting intensities (T-test, $p = 0.039$, $p = 0.017$, $df = 11$, respectively). *Diervilla lonicera* increased significantly from a mean percent cover of 0.83% to 2.58% (T- test, $p = 0.021$, $df = 11$) following 30% harvesting of the *V. angustifolium*. *Oryzopsis pungens* was the only plant to show a significant decrease in the 100% harvesting intensity from a mean percent cover of 1.75% to 0.75% (T-test, $p = 0.052$, $df = 11$).

Table 4.7. Plant species present or absent from the Manitoba sites sampled for the harvesting of *Vaccinium angustifolium* . A) List of plant species present in 1996 (Y1) and absent in 1997 (Y2). B) List of plant species absent in 1996 (Y1) and present in 1997 (Y2).

A)	Plant species	B)	Plant species
	Agropyron repens		*Abies balsamea*
	Agrostis hyemalis		*Carex* spp.
	Anaphalis margaritacea		*Epilobium palustre*
	Anemone canadensis		*Gaultheria procumbens*
	Muhlenbergia racemosa		*Luzula* sp.
	Phleum pratense		*Lycopodium complanatum*
			Lygodesmia juncea
			Melampyrum lineare
			Polypodium virginianum
			Sanicula marilandica
			Solidago sp.
			Trientalis borealis
			Viola sp.

Table 4.8. Percent cover of selected species present in the *Vaccinium angustifolium* study sites in Manitoba in 1996 (Y1, n=16) and 1997 (Y2, n=12) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE). Dashes indicate absence from all plots.

	0% harvest				30% harvest				70% harvest				100% harvest			
Species	Y1		Y2		Y1		Y2		Y1		Y2		Y1		Y2	
Achillea millefolium	0.08	0.3	0.17	0.4	0.17	0.4	0.17	0.4	0.17	0.40	0.25	0.5	0.08	0.3	0.25	0.5
Cladonia spp.	—	—	0.17	0.4	0.17	0.4	0.50	0.5	—	—	0.42	0.5	0.08	0.3	0.42	0.5
Comandra umbellata	0.42	1.4	0.17	0.4	0.42	1.4	0.17	0.4	0.08	0.3	0.08	0.3	—	—	—	—
Danthonia spicata	2.17	5.8	0.25	0.5	0.08	0.3	1.83	5.7	0.58	1.4	0.25	0.5	0.42	1.4	0.08	0.3
Dicranum sp.	0.08	0.3	0.67	1.4	0.08	0.3	1.00	2.9	0.50	1.4	1.00	2.9	0.50	1.4	0.50	1.4
Diervilla lonicera	2.17	4.5	1.75	3.2	0.83	1.4	2.58	2.5	1.67	3.3	0.58	1.4	3.33	4.4	3.75	3.8
Epilobium angustifolium	—	—	—	—	0.58	1.4	0.58	1.4	0.58	1.4	0.33	0.5	0.17	0.4	0.50	1.4
Epilobium palustre	—	—	0.42	0.5	—	—	0.17	0.4	—	—	0.17	0.4	—	—	0.17	0.4
Fragaria virginiana	1.50	3.0	1.83	2.4	1.50	2.2	0.50	1.4	2.00	3.8	1.25	1.8	0.75	0.5	1.50	2.2
Galium boreale	—	—	—	—	—	—	—	—	—	—	—	—	0.08	0.3	0.42	1.4
Gaultheria procumbens	—	—	—	—	—	—	0.42	1.4	—	—	—	—	—	—	—	—
Hieracium scabriusculum	0.17	0.4	0.17	0.4	0.17	0.4	0.25	0.5	0.17	0.4	0.33	0.5	0.25	0.5	0.08	0.3
Lactuca canadensis	—	—	0.08	0.3	0.08	0.3	—	—	0.08	0.3	—	—	0.08	0.3	—	—
Lathyrus ochroleucus	0.50	1.4	0.75	1.4	0.92	1.9	1.00	1.9	1.08	1.9	0.75	1.4	0.33	0.5	1.00	1.9
Lathyrus venosus	0.83	1.9	0.83	2.9	0.58	1.4	1.00	1.9	0.50	1.4	0.08	0.3	0.17	0.4	0.58	1.4
Luzula sp.	—	—	0.25	0.5	—	—	0.17	0.4	—	—	0.08	0.3	—	—	0.08	0.3
Lycopodium complanatum	—	—	0.17	0.4	—	—	—	—	—	—	—	—	—	—	—	—
Lygodesmia juncea	—	—	—	—	—	—	—	—	—	—	0.08	0.3	—	—	—	—
Maianthemum canadense	5.75	5.9	4.83	5.6	3.67	4.2	4.92	4.7	2.58	2.2	3.25	2.2	6.50	6.9	4.83	4.7

Species	0% harvest				30% harvest				70% harvest				100% harvest			
	Y1		Y2		Y1		Y2		Y1		Y2		Y1		Y2	
Melampyrum lineare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.83	2.9
Muhlenbergia racemosa	0.08	0.3	—	—	—	—	—	—	—	—	—	—	0.08	0.3	—	—
Oryzopsis asperifolia	1.00	1.9	0.67	1.4	0.17	0.4	1.58	4.3	0.58	1.4	1.75	2.4	0.50	1.4	1.33	1.8
Oryzopsis pungens	0.75	1.4	0.50	0.5	0.67	0.5	0.50	0.5	0.50	0.5	0.33	0.5	1.75	2.0	0.75	1.4
Phleum pratense	—	—	—	—	—	—	—	—	—	—	—	—	0.08	0.3	—	—
Picea glauca	—	—	—	—	0.08	0.3	0.42	1.4	—	—	—	—	0.42	1.4	0.42	1.4
Pinus banksiana	—	—	—	—	0.08	0.3	5.00	14.5	—	—	4.17	14.4	—	—	—	—
Pleurozium schreberi	3.08	8.6	3.92	6.0	1.17	2.8	1.42	2.2	1.75	4.4	1.75	2.9	0.92	1.9	2.83	6.1
Poa sp.	—	—	0.17	0.4	—	—	—	—	—	—	0.17	0.4	0.83	2.9	0.17	0.4
Polypodium virginianum	—	—	0.08	0.3	—	—	—	—	—	—	—	—	—	—	—	—
Polytrichum commune	—	—	0.08	0.3	—	—	0.08	0.3	0.08	0.3	—	—	0.08	0.3	—	—
Polytrichum juniperinum	1.58	3.0	3.08	5.6	2.33	4.9	1.58	2.1	0.92	1.4	2.17	4.3	9.42	27.0	1.42	1.7
Populus tremuloides	0.42	1.4	0.17	0.4	0.83	2.9	4.58	14.4	0.17	0.4	2.17	7.2	0.42	1.4	0.42	1.4
Potentilla tridentata	0.08	0.3	—	—	0.50	1.4	0.25	0.5	0.17	0.4	0.08	0.3	0.17	0.4	0.08	0.3
Prunus pensylvanica	—	—	—	—	0.08	0.3	2.08	7.2	0.83	2.9	0.42	1.4	0.42	1.4	—	—
Prunus virginiana	—	—	—	—	0.08	0.3	0.42	1.4	—	—	—	—	—	—	—	—
Pteridium aquilinum	0.08	0.3	0.42	1.4	—	—	—	—	—	—	—	—	—	—	—	—
Rhus glabra	0.83	2.9	0.42	1.4	0.17	0.4	0.08	0.3	0.50	1.4	0.83	2.9	0.25	0.5	0.17	0.4
Rosa acicularis	0.50	1.4	0.25	0.5	—	—	—	—	1.25	4.3	0.42	1.4	0.50	1.4	0.17	0.4
Rubus idaeus	—	—	—	—	0.08	0.3	0.08	0.3	—	—	—	—	0.08	0.3	0.08	0.3
Salix spp.	0.08	0.3	0.50	1.4	0.83	2.9	—	—	0.42	1.4	0.42	1.4	—	—	—	—

Plant species	0% harvest				30% harvest				70% harvest				100% harvest			
	Y1		Y2		Y1		Y2		Y1		Y2		Y1		Y2	
Sanicula marilandica	—	—	0.17	0.4	—	—	0.08	0.3	—	—	—	—	—	—	—	—
Schizachne purpurascens	0.58	1.4	1.42	2.2	0.92	1.9	1.00	2.9	0.17	0.4	0.75	1.4	0.92	1.9	0.67	1.4
Solidago hispida	0.08	0.3	0.25	0.5	0.17	0.4	0.25	0.5	1.00	1.9	—	—	0.17	0.4	0.25	0.5
Solidago sp.	—	—	0.42	1.4	—	—	—	—	—	—	—	—	—	—	—	—
Sphagnum sp.	0.42	1.4	—	—	—	—	—	—	—	—	0.08	0.3	0.08	0.3	0.08	0.3
Spiraea alba	2.58	5.8	1.75	3.2	0.25	0.5	0.58	1.4	1.25	4.3	0.67	1.4	2.17	5.0	0.83	2.9
Symphoricarpos albus	0.50	1.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Taraxacum officinale	0.08	0.3	0.08	0.3	0.08	0.3	—	—	0.08	0.3	—	—	—	—	—	—
Trientalis borealis	—	—	—	—	—	—	0.08	0.3	—	—	—	—	—	—	—	—
Trifolium hybridum	—	—	0.08	0.3	—	—	—	—	0.08	0.3	0.08	0.3	0.42	1.4	0.42	1.4
Umbilicaria sp.	—	—	0.08	0.3	0.42	1.4	0.08	0.3	—	—	0.83	1.9	0.08	0.3	0.50	1.4
unidentified grasses	—	—	0.17	0.4	—	—	—	—	—	—	—	—	0.08	0.3	0.17	0.4
unidentified mosses	0.42	1.4	0.17	0.4	0.08	0.3	0.42	0.5	0.08	0.3	0.33	0.5	0.08	0.3	0.33	0.5
*Vaccinium** spp.	59.75	17.0	49.58	19.6	63.75	15.2	58.33	24.5	64.75	19.6	60.00	21.2	60.00	11.0	59.00	18.0
Vicia americana	1.08	1.9	1.17	1.9	0.75	1.4	0.33	0.5	0.92	1.4	0.92	1.4	0.42	0.5	0.50	0.5
Viola adunca	0.17	0.4	0.25	0.5	0.33	0.5	0.17	0.4	0.17	0.4	0.25	0.5	0.25	0.5	0.08	0.3
Viola sp.	—	—	0.08	0.3	—	—	0.17	0.4	—	—	0.08	0.3	—	—	0.17	0.4

* Both *Vaccinium angustifolium* and *V. myrtillodies* present.

4.2.2 Ontario

(a) Percent Cover, Mass, and Volume

In Ontario, unlike Manitoba, no trends or significant changes between years were observed in the mean percent cover of *V. angustifolium* (Figure 4.6-A). The mean changes from Y1 to Y2 for the 0, 30% and 100% harvesting intensities were less than a 2% increase or decrease. The greatest decrease of 7% occurred after 70% harvesting. Between treatments, no significant differences were found (ANOVA, $p = 0.7995$, $n = 9$).

Although changes in the mass and volume of fresh berries between years were insignificant, trends similar to those in Manitoba were observed (Figures 4.6-B and 4.6-C). A small increase in the 30% harvesting intensity was observed, with a 6 g increase in the fresh mass and 13 ml increase in the fresh volume (Table 4.9). A slight decrease of 7g of fresh mass and 3 ml of fresh volume were observed in the 70% treatment. The greatest change between years was observed in the 100% harvesting intensity, where mass decreased by 31 g and the volume by 41 ml. No significant differences between treatments were found for the mass or volume of fresh berries (ANOVA, $p = 0.1450$ and $p = 0.3889$, respectively, $n = 9$)

(b) Shoot Density

All treatments showed significant increases in shoot density between years. As harvesting intensity increased, the mean change in shoot density decreased (Figure 4.7-A). The greatest mean increase of 28 shoots (T-test, $p = 0.001$, $df = 8$) was observed in the control (Table 4.10). The 30% harvesting intensity increased by 14 shoots (T-test, $p = 0.009$, $df = 8$), the 70% harvesting intensity increased by 11 shoots in Y2 (T-test, $p = 0.003$, $df = 8$), and the 100% had the smallest increase of 10 shoots (T-test, $p = 0.005$, df

Fig 4.6-A

p = 0.800

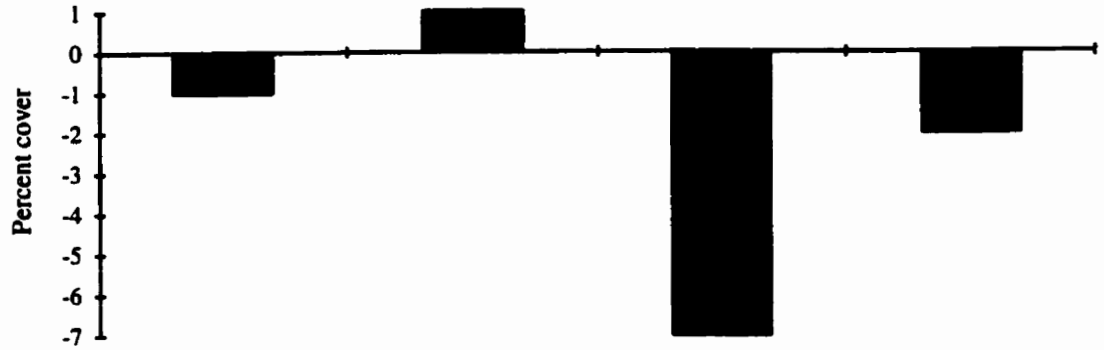

Fig 4.6-B

p = 0.145

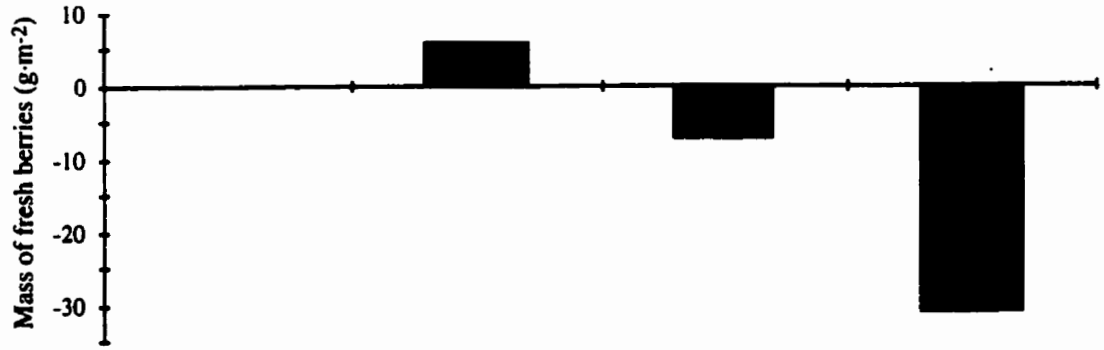

Fig 4.6-C

p = 0.390

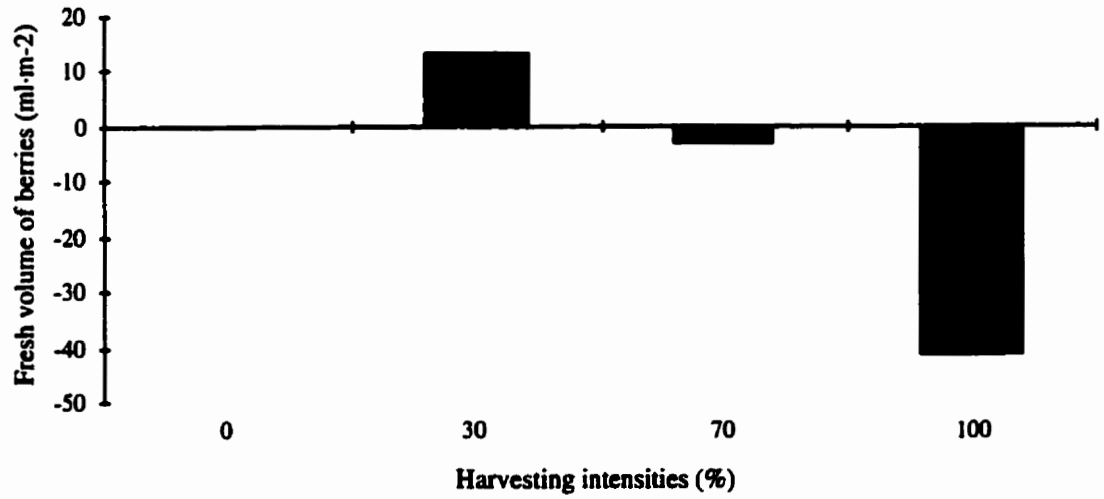

Figure 4.6. Change in *Vaccinium angustifolium* from 1996 (Y1) to 1997 (Y2) at various harvesting intensities in Ontario (n = 12). A) Percent cover (based on $1m^2$ plots); B) Mass of fresh berries ($g \cdot m^{-2}$); C) Volume of fresh berries ($ml \cdot m^{-2}$). No values exist for the 0% harvesting intensity for B) and C) because they remained unharvested. P values are from ANOVAs.

Table 4.9. *Vaccinium angustifolium* percent cover, fresh mass of berries (g) and fresh volume of berries (cups) in 1 m^2 plots in Ontario in 1996 (Y1) and 1997 (Y2) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE); n = 9 for all harvesting intensities

Harvesting	Percent cover		Fresh mass of berries (g)		Fresh volume of berries (ml)	
intensities (%)	Y1	Y2	Y1	Y2	Y1	Y2
0	51 ± 21	50 ± 24a	—	—	—	—
30	50 ± 19	51 ± 24a	30 ± 20	36 ± 26a	51 ± 36	64 ± 57a
70	51 ± 20	44 ± 18a	48 ± 28	41 ± 35a	79 ± 38	76 ± 73a
100	47 ± 15	45 ± 23a	103 ± 68	72 ± 71a	172 ± 116	131 ± 122a

Different letters indicate significant differences in the changes from Y1 to Y2 between treatments, $p \leq 0.05$

Fig 4.7-A

p = 0.014

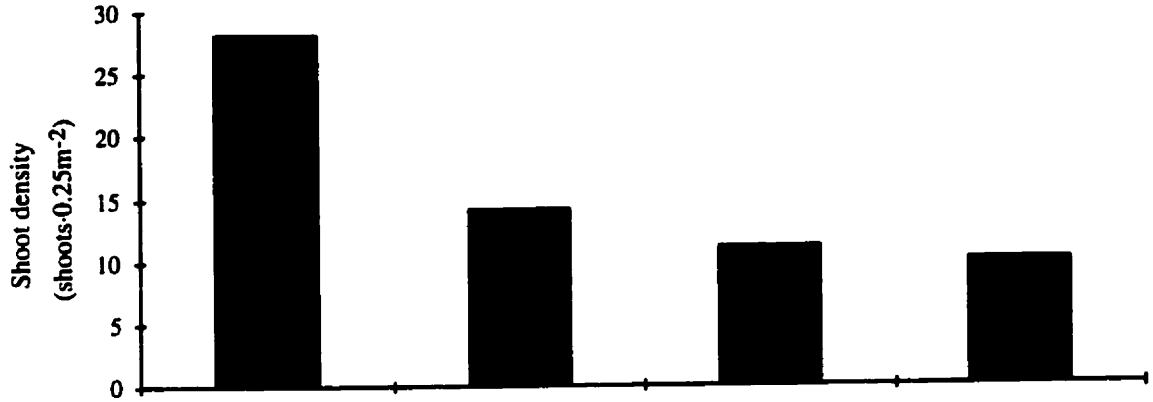

Fig 4.7-B

p = 0.072

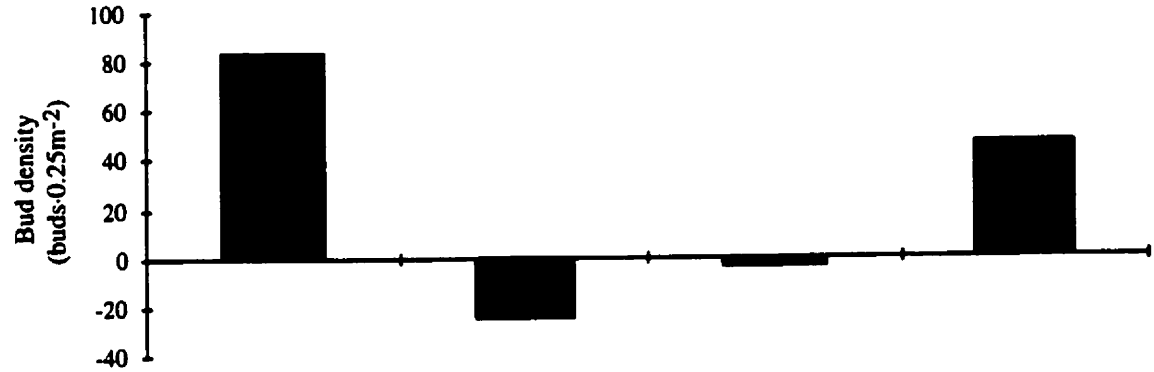

Fig 4.7-C

p = 0.062

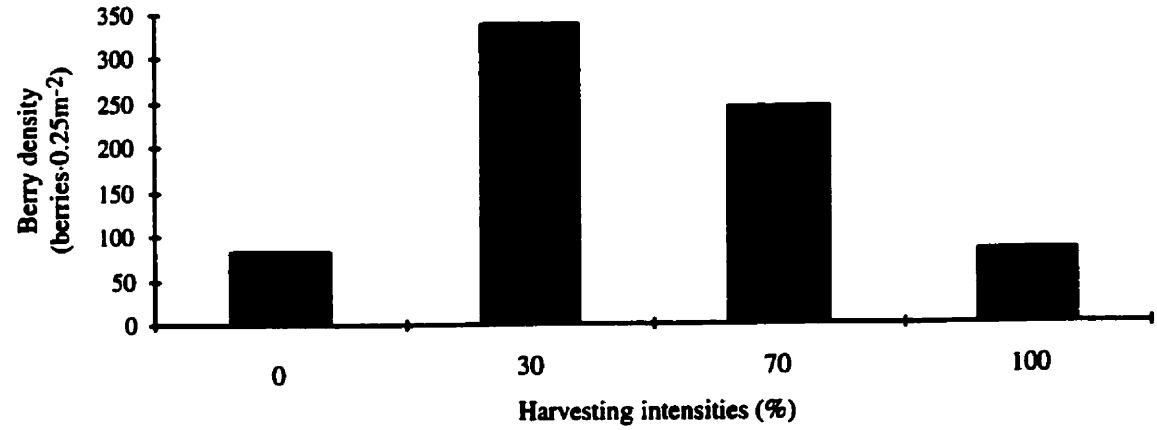

Figure 4.7. Change in *Vaccinium angustifolium* from 1996 (Y1) to 1997 (Y2) at various harvesting intensities in Ontario (n = 12). A) Shoot density (shoots·0.25m^{-2}); B) Bud density (buds·0.25m^{-2}); C) Berry density (berries·0.25m^{-2}). P values are from ANOVAs.

Table 4.10. *Vaccinium angustifolium* densities of shoots, buds and berries in 0.25 m^2 in Ontario in 1996 (Y1) and 1997 (Y2) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE). n = 9 for all harvesting intensities. Values were not converted to a standard 1 m^2 due to non-random sampling within the 1 m^2 quadrats.

	Shoot density (no. 0.25m^{-2})			Bud density† (no. 0.25m^{-2})		Berry density (no. 0.25m^{-2})	
Harvesting intensities (%)	Y1	Y2 - S	Y2 - F	Y2 - S	Y2 - F	Y1	Y2
0	24 ± 12	52 ± 20*a	49 ± 21	77 ± 54	160 ± 79*a	92 ± 39	173 ± 159a
30	29 ± 12	43 ± 22*b	45 ± 17	178 ± 54	153 ± 79a	95 ± 40	433 ± 180*a
70	28 ± 12	39 ± 15*b	42 ± 20	159 ± 98	155 ± 114a	120 ± 66	365 ± 348*a
100	22 ± 11	32 ± 13*b	34 ± 16	117 ± 37	163 ± 81a	97 ± 71	179 ± 114a

† Bud density data collected in the summer (S) before harvesting and fall (F) after harvesting in 1997 (Y2)

* Indicates significant differences between years, $p \leq 0.05$.

Different letters indicate significant differences in the changes from Y1 to Y2 between treatments, $p \leq 0.05$

= 8). Significant differences were also found between treatments (ANOVA, p = 0.0136, n = 9). A post hoc test found significant differences between the control and the other treatments (LSD, 30% - 0, p = 0.006; 70% - 0, p = 0.005; 100% - 0, p = 0.015; n = 9).

(c) Bud Density

A significant increase of 83 buds between years was observed in the control (T-test, p = 0.055, df = 8, Table 4.10). Although not statistically significant, a decrease was shown for the 30% harvesting intensity, very little change was shown in the 70% treatment and an increase was observed in the 100% harvesting treatment (Figure 4.7-B). The differences between harvesting intensities narrowly missed significance (ANOVA, p = 0.0722, n = 9).

(d) Berry Density

All treatments showed an increase in berry density from Y1 to Y2. The increase in berry density in the control was not a significant change (Figure 4.7-C). In the harvested treatments, as the harvesting intensity increased, the effect on berry density decreased. The greatest increase in berry density was observed in the 30% harvesting intensity, from 95 berries to 433 berries (T- test, p = 0.0001, df = 8, Table 4.10). A significant increase was also observed in the 70% treatment from 120 berries to 365 berries (T- test, p = 0.024, df = 8). Again, the differences between treatments narrowly missed significance (ANOVA, p = 0.0624, n = 9).

(e) Associated Plant Species

As in Manitoba, very few significant changes were observed in the percent cover of associated plant species (Table 4.11). Significant increases of *Agropyron repens* were observed for all harvesting intensities. The 30% treatment had the smallest increase from 0.11% to 0.67% (T-test, p = 0.05, df = 8). The control increased from a mean of 0.11% to 2.22% (T-test, p = 0.006, df = 8). The 100% treatment increased from 0.11 % to 1.11% (T-test, p = 0.005, df =8). The largest increase was observed in the 70% harvesting intensity from 0 to 2.67% (T-test, p = 0.008, df = 8).

Amelanchier alnifolia showed significant increases in percent cover in the 70% harvesting intensity from 3.56% to 7.22% (T-test, p = 0.056, df = 8). A similar increase was observed for *Diervilla lonicera* in the 70% treatment from 4.11% to 6.78% (T-test, p = 0.045, df = 8). An increase in the 30% harvesting treatment was observed for the moss, *Dicranum* spp., from 0.67% to 2.00% (T-test, p = 0.029, df = 8).

Finally decreases in percent cover were observed in the amount of bare ground/litter and the cover of *Danthonia spicata*. The 30% harvesting intensity had the only significant decrease in bare ground from 14% to 8% (T-test, p = 0.006, df = 8). *D. spicata* decreased in cover and frequency for three of the harvesting intensities. The control and the 70% treatment had similar decreases. The control decreased from 2.89% to 0.11% (T-test, p = 0.046, df = 8). The 70% treatment decreased from 2.78% to 0 (T-test, p = 0.013, df = 8). The 30% harvesting intensity decreased the least from 1.33% to 0 (T-test, p = 0.061, df = 8). The 30% and 70% treatments were similar because *D. spicata* was not present in any of the plots in Y2.

Table 4.11. Percent cover of selected species present in the *Vaccinium angustifolium* study sites in Ontario in 1996 (Y1, n=12) and 1997 (Y2, n=12) at various harvesting intensities. Values for Y1 and Y2 are means (± 1 SE). Dashes indicate absence from all plots.

	0% harvest				30% harvest				70% harvest				100% harvest			
Species	Y1		Y2		Y1		Y2		Y1		Y2		Y1		Y2	
Achillea millefolium	1.22	3.3	—		—		—		0.11	0.3	0.22	0.4	0.11	0.3	0.11	0.3
Agropyron repens	0.11	0.3	2.22	2.1	0.11	0.3	0.67	0.5	—		2.67	3.4	0.11	0.3	1.11	1.5
Alnus rugosa	—		—		—		0.11	0.3	—		0.11	0.3	—		—	
Amelanchier alnifolia	1.89	4.9	3.67	8.1	1.11	1.5	2.11	3.3	3.56	5.5	7.22	9.1	1.44	2.1	4.00	4.8
Antennaria sp.	0.67	1.7	1.11	2.2	—		0.11	0.3	—		—		0.56	1.7	0.11	0.3
Apocynum androsaemifolium	0.11	0.3	0.67	1.7	—		—		0.11	0.3	—		0.11	0.3	0.11	0.3
Aralia nudicaulis	1.00	1.6	1.22	2.2	1.33	2.1	1.22	2.2	0.44	0.5	0.11	0.3	1.22	2.2	1.22	3.3
Arctostaphylos uva-ursi	—		—		—		—		0.11	0.3	0.33	0.5	—		—	
Aster ciliolatus	0.22	0.4	—		2.44	6.6	0.33	0.5	0.22	0.4	0.11	0.3	0.78	1.6	0.11	0.3
Aster laevis	—		—		1.11	3.3	—		—		—		0.11	0.3	—	
Aster macrophyllus	—		0.56	1.7	—		1.44	3.2	—		0.56	1.7	—		1.22	2.2
Aster spp.	—		0.11	0.3	—		—		—		—		—		—	
Campanula rotundifolia	0.11	0.3	—		0.11	0.3	—		0.11	0.3	—		0.11	0.3	0.11	0.3
Carex spp.	—		—		—		0.11	0.3	—		0.11	0.3	0.22	0.4	0.11	0.3
Cladina mitis	0.11	0.3	0.89	1.6	1.11	2.2	0.89	1.6	0.11	0.3	0.33	0.5	2.89	4.3	1.78	2.4
Cladina rangifernia	6.89	8.1	7.00	8.0	9.89	13.9	10.33	13.0	3.78	4.0	7.44	8.5	9.67	13.2	10.78	9.2
Cladonia spp.	—		0.56	0.5	—		0.22	0.4	—		0.22	0.4	—		0.56	0.5
Comandra umbellata	—		0.11	0.3	—		0.56	1.7	—		1.11	2.2	—		—	
Danthonia spicata	2.89	3.6	0.11	0.3	1.33	2.1	—		2.78	2.6	—		1.33	2.1	0.22	0.4
Dicranum sp.	1.22	2.2	0.22	0.4	0.67	1.7	2.00	2.3	0.67	1.7	0.89	1.6	0.33	0.5	1.00	1.6

Species	0% harvest				30% harvest				70% harvest				100% harvest			
	Y1		Y2		Y1		Y2		Y1		Y2		Y1		Y2	
Diervilla lonicera	3.00	2.4	5.22	4.8	6.22	6.9	5.78	7.9	4.11	4.0	6.78	6.5	4.33	4.5	6.78	4.8
Epilobium angustifolium	0.22	0.4	0.22	0.4	—		0.11	0.3	0.11	0.3	0.11	0.3	—		—	
Epilobium palustre	—		0.11	0.3	—		0.11	0.3	—		—		—		0.11	0.3
Fragaria virginiana	0.22	0.4	0.33	0.5	0.22	0.4	0.67	1.7	0.33	0.5	—		0.33	0.5	0.78	1.6
Gaultheria procumbens	—		—		—		—		0.67	1.7	—		—		—	
Heuchera sp.	—		—		—		—		—		0.11	0.3	—		—	
Hieracium scabriusculum	0.78	1.6	0.67	1.7	0.11	0.3	0.11	0.3	—		—		—		0.11	0.3
Juniperus communis	—		—		—		—		—		—		0.11	0.3	1.67	3.5
Lathyrus ochroleucus	—		0.11	0.3	—		—		—		—		—	—	0.22	0.4
Lathyrus venosus	0.11	0.3	—		0.11	0.3	—		—		—		0.22	0.4	0.11	0.3
Luzula sp.	0.33	0.5	—		—		—		0.11	0.3	—		0.22	0.4	—	
Maianthemum canadense	3.22	3.3	4.00	8.0	2.11	3.3	2.67	3.4	1.44	1.3	1.33	1.4	0.89	1.6	1.11	1.5
Melampyrum lineare	0.22	0.4	—		—		—		0.22	0.4	—		—		—	
Oryzopsis asperifolia	0.11	0.3	—		0.22	0.4	—		0.33	0.5	—		0.11	0.3	0.22	0.4
Oryzopsis pungens	0.78	1.6	0.22	0.4	0.56	0.5	0.33	0.5	0.78	1.6	0.22	0.4	0.78	1.6	0.33	0.5
Picea glauca	—		—		—		—		—		10.00	30.0	—		—	
Pinus banksiana	—		8.33	25.0	0.11	0.3	1.11	2.2	—		—		—		7.22	21.7
Pleurozium schreberi	20.00	16.6	9.00	6.8	6.33	12.8	2.22	3.3	20.22	31.4	9.67	15.4	3.89	6.5	3.56	4.2
Poa sp.	—		—		—		—		—		0.11	0.3	—		—	
Polygonum cilinode	—		—		0.11	0.3	—		0.11	0.3	0.11	0.3	—		—	
Polypodium virginianum	—		—		0.11	0.3	—		—		—		0.11	0.3	0.11	0.3
Polytrichum commune	—		—		—		0.11	0.3	—		—		—		0.11	0.3
Polytrichum juniperinum	2.22	6.7	0.67	0.5	0.11	0.3	0.33	0.5	0.56	1.7	0.67	1.7	1.78	2.4	1.33	1.4

Species	0% harvest				30% harvest				70% harvest				100% harvest			
	Y1		Y2		Y1		Y2		Y1		Y2		Y1		Y2	
Populus tremuloides	—		—		1.11	2.2	2.33	6.6	—		0.11	0.3	0.22	0.4	0.56	1.7
Potentilla tridentata	—		—		0.56	1.7	0.56	1.7	—		0.11	0.3	0.11	0.3	0.11	0.3
Prunus pensylvanica	—		—		0.78	1.6	1.67	5.0	1.22	3.3	2.33	5.0	—		—	
Prunus virginiana	0.11	0.3	—		—		—		1.11	3.3	—		0.56	1.7	—	
Rhus glabra	—		0.11	0.3	—		—		—		—		—		—	
Ribes glandulosum	—		0.11	0.3	0.11	0.3	0.11	0.3	—		—		—		—	
Ribes sp.	—		—		—		—		—		—		—		0.11	0.3
Rosa acicularis	—		—		—		—		—		0.11	0.3	0.11	0.3	0.56	1.7
Rubus idaeus	—		—		—		0.56	1.7	—		0.11	0.3	—	—	0.11	0.3
Solidago hispida	0.11	0.3	0.33	0.5	—		—		—		—		0.11	0.3	0.11	0.3
Sonchus arvensis	—		—		—		—		—		—		0.11	0.3	—	
Spiraea alba	—		—		0.11	0.3	—		0.22	0.4	—		—		—	
Symphoricarpos albus	—		—		—		0.11	0.3	—		—		—		—	
Taraxacum officinale	—		—		—		—		—		—		—		0.11	0.3
Thalictrum sp.	0.11	0.3	—		—		—		—		—		—		0.11	0.3
Vaccinium spp.†	51.11	20.9	50.00	23.7	50.00	19.4	51.11	23.6	51.11	19.6	44.44	18.3	47.22	15.0	45.00	22.5
Vicia americana	—		0.11	0.3	0.11	0.3	0.11	0.3	—		—		—		0.11	0.3
Viola adunca	0.11	0.3	—		—		0.11	0.3	—		0.11	0.3	—		0.11	0.3
unidentified grasses	0.56	1.7	0.33	0.5	—		0.11	0.3	0.67	1.7	0.22	0.4	0.22	0.4	—	
bare ground/litter	14.11	13.2	7.33	6.5	14.00	15.9	8.11	10.4	14.11	13.4	11.11	7.4	9.44	8.5	7.00	6.7

†*Vaccinium angustifolium* and *V. myrtillodies* present

CHAPTER 5 DISCUSSION

Protocols for establishing sustainable harvest levels were designed and tested for *Acorus americanus* and *Vaccinium angustifolium*. Throughout the course of the study, many difficulties were encountered in assessing plant productivity. Therefore, innovative and untested methods were applied. Some challenges were fully addressed while others remain for future research. This study provides a foundation for developing sound monitoring programs for the sustainable harvest of *A. americanus* and *V. angustifolium*.

5.1 *Acorus americanus*

5.1.1 Manitoba Results

The monitoring protocols designed for *Acorus americanus* detected several effects resulting from differing harvesting intensities. In the monoculture stands of *A. americanus* in Manitoba, the effects due to harvesting intensity were generally well defined.

(a) Density, Mass, and Percent Cover

Of particular importance, this study showed a trend of decreasing *A. americanus* rhizome dry mass with increasing harvesting intensity (Figure 4.1-C). Figure 4.1-C illustrates very little difference between the 30% and 70% harvesting intensity and a large difference between these treatments and the 100% harvesting intensity. The differences between treatments in rhizome dry mass narrowly missed significance supporting the changes seen in Figure 4.1-C .

Similar trends were observed in shoot density and *Acorus* percent cover. The trends illustrated in Figure 4.1-A and -B are supported by significant between treatment differences. For shoot density, no significant differences were found between the control and the 30% or 70% harvesting intensity but significant differences were found between the 100% harvesting intensity and all other treatments (Table 4.1). This may indicate that harvesting 30% or 70% may have similar effects and therefore the greater harvesting level may be appropriate for hand harvesting. However, these conclusions are based on two years data. Longer monitoring must be implemented to examine the possible differences for long term effects of harvesting at these levels.

Significant differences for percent cover between treatments were found (Figure 4.1-B and Table 4.1). Interestingly, the significant difference between the control and 70% harvesting and no difference between 70% harvesting and the 100% harvesting may indicate that the harvesting effects of 70% are greater than the 30% harvesting intensity, that had no significant difference from the control. Harvesting 100% of *A. americanus* rhizomes resulted in great reductions in rhizome dry mass, and significant decreases in shoot density and percent cover (Figure 4.1). These results supported the expectation that *A. americanus* productivity would be reduced when rhizomes, essential for vegetative reproduction, were harvested.

Percent cover estimates were effective at detecting changes within treatments, thereby complementing the shoot density information. In harvested treatments, significant decreases in the percent cover (Figure 4.1-B) and shoot density (Figure 4.1-A) were observed as harvesting intensity increased. This indicates that the vigor of the shoots produced the year after harvesting was affected by the harvesting intensity. Interestingly, some of the 100% harvested plots were easily identifiable in the second year due to the lack of any vegetation in the $1m^2$ area where harvesting had occurred. Of particular importance, these results indicated that harvesting 100% of the rhizomes had a detrimental effect on the reproduction of *Acorus*. Despite the high levels of variability of rhizome dry mass within

treatments, each year differences between treatments were evident (Figure 4.1). These results indicated that harvesting *Acorus* by hand at 30% or 70% produces similar effects. However, these results only represent the change over one year. The long-term effects of harvesting at 30% or 70% may be drastically different.

(b) Rhizome - Shoot Correlation Study

Counting the shoots was an effective means of assessing above ground productivity in *A. americanus* since it was quick, easy and non-destructive. Its effectiveness was strengthened by the significant differences found between treatments (Table 4.1). Unfortunately, the shoot density did not give any indication to the below ground productivity of *A. americanus* as shoot density and rhizome dry mass were not correlated (Figure 4.2). As a result, it was not possible to accurately assess the below ground changes occurring in the harvested plots, as they could not be compared to the unharvested control. This is problematic since monitoring below ground productivity should involve a non-destructive method such that the control remains undisturbed and unharvested. Regrettably, no solution was found for this impediment.

(c) Associated Plant Species

Few significant changes in the percent cover of other plant species were associated with varying harvesting intensities (Table 4.2). This may be due to the differences in frequency and abundance and the low percent cover observed for associated species between sampling units. *Carex* was the only associated plant to show significant decreases between years (Table 4.2). However, the control also decreased in percent cover between years. Therefore, the harvesting of *Acorus* did not affect the *Carex* cover. Interestingly, *Butomus umbellatus* and *Equisetum* sp. were not found in the Manitoba plots in 1997. One possible explanation is that these species may be more sensitive to the disturbance

caused by harvesting than the other species observed, resulting in their decline in 1997. Alternatively, many *Equisetum* species are annuals (Looman and Best 1987) and only infertile stems were observed in 1996. Therefore, it may be possible that the absence of *Equisetum* may be due to the chance that no *Equisetum* spores fell within the study plots in 1997. Increasing the sample size would be necessary to detect the effects of harvesting intensity of the percent cover of other species.

5.1.2 Recommendations

(a) Rhizome Growth Rates

The monitoring protocols can be improved in several ways other than those already mentioned. Firstly, further study into rhizome growth rates per year may help to minimize the effects of harvesting. Presently, rhizome growth rates are unknown, but this information is important because if the rhizomes are slow growing, narrow strips of approximately 10 cm would be appropriate for harvesting, whereas, if the rhizomes grow quickly, wider strips could be harvested.

(b) Human Resources

An immense difficulty with the monitoring protocols was the lack of sufficient manpower to complete data collection in a timely manner. For example in 1996, all of the harvesting was completed by two people over a period of three weeks. The arduous task of harvesting *A. americanus* rhizomes would be ideally shared by many people to prevent injuries to the researchers. In 1997, additional human resources were supplied by the Sagkeeng First Nation. As a result, collection of the rhizomes and site data was completed in less than 10 days.

Additionally in 1996, all of the processing and cleaning was completed by one person over a three month period. Consequently, some rhizomes sat in cold storage for up to three months where the decomposition of some rhizomes occurred. This likely contributed to some of the variability in mass observed in 1996. In 1997, rhizomes were processed and dried within a matter of weeks after harvesting so no rhizome decomposition occurred. For this monitoring protocol to run smoothly and efficiently a minimum of four people are required.

(c) Transportation

During the first field season, a canoe was used to reach the *Acorus* sites. This increased the travel time to and from sites, and restricted the amount of plant material that could be transported at one time. Furthermore, the sometimes turbulent Winnipeg river threatened the safety of researchers while in the canoe. In 1997, a small motor boat was used to transport the four researchers to and from sites. This is recommended for future monitoring as it decreased the travel time and increased safety of transport of people and materials to and from the sites. However, it should be noted that use of a motor boat did increase the financial costs.

(d) Harvesting Plot Shape

A change in plot shape may also minimize the effects of harvesting 100% of the rhizomes. If plots were elongated the harvested area would have a greater surface area surrounded by actively growing plants to recolonize more quickly. A long, narrow plot would have been impractical for this study as harvesters had to stand very close to the area being harvested. Therefore, more *A. americanus* plants would have been trampled using long, narrow plots.

(e) Increase Sampling

More sites along the Winnipeg river should be established in an attempt to decrease the variability within treatments. The rhizome dry weight and the percent cover of other species present in the study plots were all highly variable and additional samples should reduce this variability. Furthermore, more sensitive methods should be used to investigate the effects on associated plants since estimating percent cover did not detect many significant changes. This was probably because other species were present in low frequencies and low abundance. In a previous study, point sampling technique in a 0.25 m^2 gridded quadrat was used to survey experimental wetland communities (Weiher and Keddy 1995). This technique may provide the finer scale necessary to detect *A. americanus* harvesting effects on associated plant species.

(f) Investigate Associated Environmental Parameters

Environmental parameters should be examined to see if they play a role in some of the observed effects. For instance, water quality should be tested for contaminants since the Winnipeg river is a busy waterway for motor boats. Indeed, some oil and/or gasoline residue was occasionally observed in the sites. Soil analysis should also be performed to see if there are differences in mineral and nutrient availability between sites. Finally, monitoring of water levels, controlled by Manitoba Hydro, should be incorporated since water levels may play a role in plant productivity. High water levels would require more energy resources to be used for the shoot elongation, while at water levels greater than 40 cm *Acorus* ramets do not survive (Shipley *et al.* 1991) and low water levels before winter sets in may result in ice scouring of the rhizomes and damage or death due to wave action in the early spring (Shipley *et al.* 1991, Wilcox and Meeker 1991). In addition, Wilcox and Meeker (1991) showed too little or too much disturbance from water-fluctuations results in differences in dominant species and reduced structural diversity in littoral zones.

Furthermore, Keddy and Ellis (1985) demonstrated that *Acorus* seeds will not germinate unless they are submerged. These parameters were not included in these monitoring protocols due to a lack of time and resources.

(g) Mechanize harvesting

If *A. americanus* was harvested for economic purposes, a mechanized harvesting method would likely be essential. Harvesting *Acorus* rhizomes by hand is not cost effective due to its labor intensiveness. A small, durable machine with two blades that could cut a 10 - 20 cm swath through the top 15 - 20 cm of soil and rhizomes in an aquatic environment would be required. *Acorus* produces a dense mat of thick, tough rhizomes, however the leaves of *Acorus* are quite delicate and susceptible to damage. For example, in Manitoba during 1996, the canoe was docked at one end of site one and we walked back and forth to deposit samples. Within one afternoon, a path was unintentionally established in the *Acorus* population where the leaves were trampled. This path was evident for the rest of the season (Figure 5.1) indicating the particularly sensitive nature of this plant to human disturbance. For this reason, 100% mechanized harvesting of long narrow plots may produce fewer detrimental effects than hand harvesting at lower intensity, despite the larger negative effects produced by 100% harvesting. Clearly, more work is required to determine the most effective and least harmful method for the harvesting of *A. americanus*.

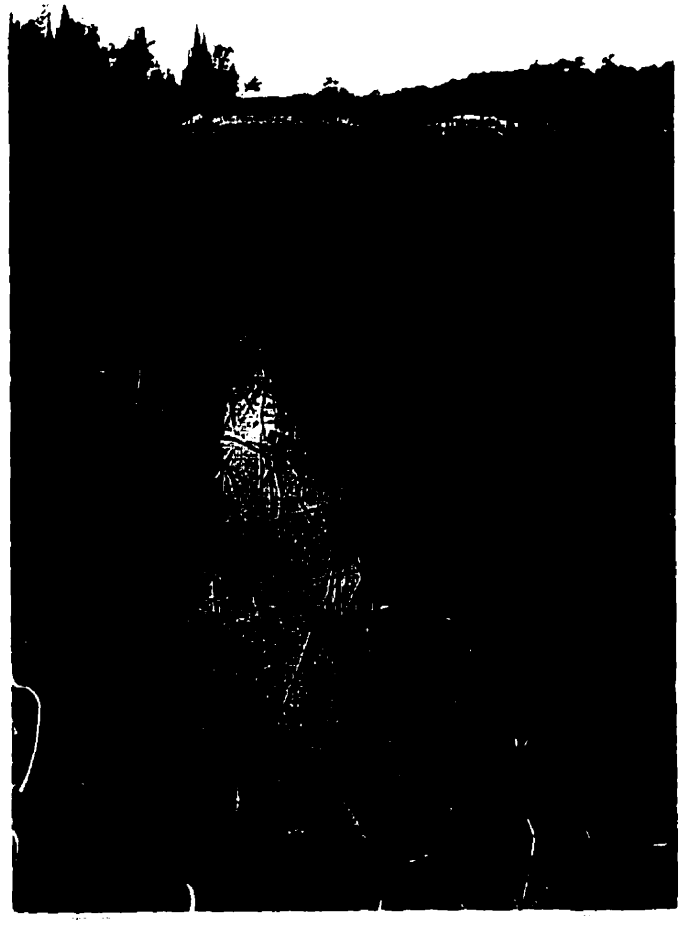

Figure 5.1 Path to canoe unintentionally established over one afternoon in 1996 by walking back and forth to canoe. This example illustrates that *Acorus americanus* leaves are easily trampled.

5.1.3 Ontario Results

In Ontario, the *Acorus* monitoring protocols suffered due to a lack of suitable study sites. Miscommunication with elders as to what constituted a "good" harvesting site may have been the problem when selecting study species for the area. The *Acorus* site established in Ontario was floristically very different from those established in Manitoba, as a monoculture of *Acorus* was not present (Figures 3.5 - 3.8). Furthermore, despite one week of searching in 1996 and 1997 for additional sites by land and water, the site established was the only one found where *Acorus* was growing. Consequently, no significant effects between years were shown due to the highly variable nature of the site and due to the small sample size. However, despite this significant differences between treatments were found in the shoot density. Interestingly, the same differences found in Manitoba for shoot density were found in Ontario. No significant differences were found between the control and the 30% or 70% harvesting intensity but significant differences were found between the 100% harvesting intensity and all other treatments (Table 4.3). This supports the trend that as harvesting intensity increases productivity of *A. americanus* decreases.

5.1.4 Recommendations

The area surrounding the Ojibiways of Onegaming reserve in Ontario was not suitable for the study of *Acorus* and could not support any sustainable commercial harvest even on a very small scale from the observations of this study. Therefore, *A. americanus* would not be an acceptable candidate for economic development in the area studied in Ontario.

5.2 *Vaccinium angustifolium*

5.2.1 Manitoba and Ontario Results

(a) Percent Cover, Mass, and Volume

The monitoring protocols designed for *Vaccinium angustifolium* were able to detect effects of harvesting at differing intensities. The percent cover, mass and volume of fresh berries proved to be efficient measures of productivity between years. Of particular importance, this study showed different harvesting intensities affected berry production.

As harvesting intensity increased, the mass of berries decreased from year to year. This trend is strengthened by the fact that it was evident in Manitoba and Ontario (Figures 4.4-B and 4.6-B, Tables 4.5 and 4.9). However, when the berry mass changes between treatments were compared no significant differences were found in Manitoba or Ontario (Tables 4.5 and 4.9). Additionally, no significant differences were found for the changes in volume between treatments in Manitoba or Ontario (Tables 4.5 and 4.9). This may have been due to the variability of berry production found within treatments. As this was the first study to investigate the effects of various harvesting intensities on berry yield, and data were only gathered for two years it was difficult to evaluate the true effectiveness of the monitoring protocols. Therefore, the trends observed are relied upon more heavily as indicators of change rather than statistical significance itself.

Many studies (Black 1963, Jordan and Eaton 1995, Penney *et al.* 1997) have looked at second year cropping after rotational burning and showed that second crop blueberry yields are consistently smaller than first crop yields. In these studies, 100% of the berries were harvested, so the 100% harvesting intensity results are comparable with these. In this study berry production in the second year following 100% harvesting was also decreased from the first year's harvest. Jordan and Eaton (1995) found a decrease in

berry production to be largely attributed to increased resource allocation to vegetative growth after the first crop is harvested, whereas, the first year after burning relatively more resources are allocated to bud, flower and berry production. This may explain the general decreases observed in the 100% harvesting intensity.

Curiously, harvesting 30% or 70% of the berries resulted in little or no change in the next year's berry production. The comparison of the change in berry mass or volume resulting from the harvesting of 30%, 70% or 100% of the berries over a specific area was not entirely unbiased. Of course, if 100% of the berries are harvested the mass and volume will be greater than if 30% of the berries are harvested. A relatively large mass or volume allows a greater range for change from one year to the next, just as a relatively small mass or volume leaves a small margin for change. Indeed, this may in part explain the differences between treatments illustrated in Figures 4.4 and 4.6. Further study is required to determine if the trends found are as a result of harvesting intensities or sampling design.

The idea that resources are allocated to vegetative production after 100% harvesting (Jordan and Eaton 1995) was supported by the change in percent cover of *V. angustifolium* in Manitoba (Figure 4.4), whereby, a significant decrease between years for percent cover was seen in the control and no appreciable decrease was seen in the 100% harvesting treatment (Table 4.5). The figure suggests that the 100% plots actually increased in percent cover relative to that seen in the control. However, when tested no significant differences were found between treatments for percent cover (Table 4.5). Interestingly, this trend of increasing percent cover with increasing harvesting intensity was not observed in Ontario where there were no significant changes observed in the percent cover of *V. angustifolium* between years or between treatments (Table 4.9). The difference observed between provinces may be attributable to differences in nutrient resources at the two locations, however this was not tested.

(b) 30% and 70% Harvesting Intensities

Obtaining accurate 30% and 70% harvesting levels of the blueberries proved to be one of the most challenging obstacles encountered by the blueberry monitoring protocols. Two methods in order to achieve objective harvest levels were tested. In 1996, 100% plots were harvested first and average masses were calculated. Then 30% or 70% of that mass, corrected for the *V. angustifolium* percent cover of each plot was taken as the mass to be harvested in 30% or 70% plots, respectively. On several occasions, the mass calculated was greater than could possibly be harvested from the plot. Therefore, rough estimates of 30% or 70% of berries were often subjectively imposed by the researcher harvesting the berries.

In 1997, the berry density was summed for a $0.25m^2$ area of each plot and a 'correction factor' was calculated (see methods) for the 30% and 70% plots. Again, 100% plots were harvested first and weighed. The mass of the 100% plot in each block was multiplied by the 'correction factor' to calculate the mass to be harvested from the 30% and 70% plots.

This method worked better than the first year's method however, some masses were still calculated that were not possible to fulfill with the berries present in the plot. This may have been due to increased herbivory in the second year. Large quantities of bear scat were discovered adjacent to some of the plots in the second year, suggesting that some of the berries may have been eaten prior to the harvesting period. Increasing the sample size in each province would decrease the variability observed in the blueberry plots due to ecological factors like herbivory.

(c) Shoot Densities

Harvesting intensities had opposite effects on shoot densities between years in Manitoba and Ontario (Figures 4.5-A and 4.7-A). The shoot density increased with harvesting intensity in Manitoba and decreased with harvesting intensity in Ontario. No significant differences were found between treatments in Manitoba (Table 4.6). This may be attributed to the amount of variation for stem densities within treatments. However, significant increases were found in the 30% and 100% harvesting intensities between years. In Ontario, significant changes between years were also found (Table 4.10). It is well documented that *V. angustifolium* naturally increases in cover by producing more stems as the plant matures to replace older, less productive stems (Hall *et al.* 1979, Hepler and Yarborough 1991, Nams 1994). Therefore, these increases may have been a result of natural aging in the population. However, the differences seen between provinces make the interpretation of the results very difficult. Perhaps the absence of increase in the control treatment in Manitoba may have be due to chance or the variation within the treatment. Examining the Ontario results alone appears to indicate that increasing harvesting intensity has a negative effect on shoot density.

(d) Bud Density

The effect of harvesting intensity on bud density was also unclear. The high variability within treatments resulted in changes in bud density that were difficult to interpret (Tables 4.7 and 4.11). Moreover, each fruit set was counted the summer of 1997 for before harvesting bud densities (each bud produces one cluster of berries - a fruit set). In the fall of 1997, floral buds were counted for after harvesting bud densities. In the fall of 1996, more buds may have been produced yet failed to set berries because they may have been damaged or killed over the winter. If this was the case it may have resulted in an

underestimate of buds in the summer of 1997, and consequently, resulted in an over estimation of the change in bud density.

Regardless, significant increases in bud density were observed in the 100% harvesting intensity and the control in Manitoba and Ontario, respectively (Figures 4.5-B and 4.7-B , Tables 4.7 and 4.11) despite the variability within treatments. This contradicts Jordan and Eaton (1995) who showed no significant changes in the bud density at 100% harvesting intensity. The difference between our results and theirs is likely a consequence of different observation methods. However, they showed a significant decrease in the number of flowers/bud that resulted in reduced berry yields (Jordan and Eaton 1995). No significant differences were found between treatments although differences between treatments in Ontario narrowly missed significance (Tables 4.7 and 4.11, Figure 4.7-B). Interestingly, a similar pattern was found in both provinces. The controls had the greatest increases in bud density, then 100% harvesting intensity had the next greatest increase, the 30% harvesting treatment increased the least in Manitoba and decreased the most in Ontario and the 70% harvesting intensity was intermediate to the 30% and 100% harvesting intensities. The pattern found in two separate locations was contrary to expectations based on past studies (Jordan and Eaton 1995). If the control did not have the greatest increase, one might conclude that intense harvesting stimulated bud production. However, as this is not the case, the bud density remains a puzzle.

(e) Berry Density

The effect of differing harvesting intensities on berry density was also unclear. Again, due to the high variability in berry density, increased sampling may be required to demonstrate the effects of harvesting intensity on berry density. Despite this, similar trends were observed in Manitoba and Ontario (Figures 4.5-C and 4.7-C). Significant increases

in berry density between years were observed for the 30% and 70% harvesting intensity in Ontario (Table 4.10) and increases in the same treatments were observed in Manitoba between years although they were not significant (Table 4.6). In both provinces, the controls and 100% harvesting intensities did not produce as many berries in 1997 as plots where 30% or 70% of the berries were harvested (Figures 4.5-C and 4.7-C). These results were unexpected. However, no significant differences were found between treatments although, as with bud density, the differences between treatments in Ontario narrowly missed significance (Figure 4.7-C). Since this was the first study to investigate harvesting blueberries at various intensities no literature exists to compare with these peculiar results. One may speculate that harvesting some or most of the berries stimulates berry production in the following year. However, although more berries were produced, no appreciable gains in berry mass were observed (Figures 4.4-B and 4.5-C, 4.6-B and 4.7-C). This indicated that the berries may have been of a reduced size. This idea was supported by the decrease in volume observed for 70% harvesting in Manitoba (Figure 4.4-C). However, the increase in berry density following 30% and 70% harvesting support the trends observed in berry mass and volume.

(f) Associated Plant Species

The effect of harvesting on associated species was not detected by the monitoring protocol. Changes in these species appeared to be of little consequence because estimates of percent cover were usually less than 5% and the changes were therefore a matter of 2 or 3%. This suggests that estimates of percent cover that were rounded to the nearest 5%, are too coarse for monitoring the changes in other species present in the study plots and in the future methods more sensitive at detecting fine scale changes should be applied. A greater species diversity was observed in 1997 than in 1996. A number of species was present in 1996 and absent in 1997 and some species appeared in 1997 that were not seen in 1996 in

Manitoba sites (Table 4.7). For example, *Agropyron repens* and *Anemone canadensis* are two species widely distributed throughout the boreal forest (Johnson *et al.* 1995) which were observed in plots in 1996 yet were not observed in the plots in 1997. Although interesting, due to the coarse scale used for examining associated plant species, no trends of the effects of harvesting are clearly evident on any of these species. Associated plants must be examined with a finer scale technique than estimating the percent cover.

5.2.2 Recommendations

The percent cover, mass and volume of fresh berries proved to be efficient parameters for monitoring changes in blueberry production. Conversely, the collection of data on shoot density, bud density and berry density was a lengthy and laborious process involving hours of crouching which provided few significant results. In fact, measuring these parameters was so time-consuming and caused so much physical (intestinal) discomfort, that alternative methods (see below) for collecting this data should be tested. In general, more sampling is necessary due to the extreme variability of blueberry production observed in natural stands of *V. angustifolium* (Hepler and Yarborough 1991).

(a) Plot Size for Shoot, Bud and Berry Densities

Nams (1994) found 0.025 m^2 is the most efficient and precise quadrat size for measuring blueberry stem density. Furthermore, Nams (1994) found that smaller quadrats were better for worker morale, since the larger the quadrat, the more difficulty there is in counting numerous stems. In our study, a 0.25 m^2 area of each plot was sub-sampled for densities of stems, berries and buds. Refined sub-sampling techniques of the plots may reduce the variability that was seen in the shoot density, bud density and berry density.

Counting the buds and berries on a per stem basis may decrease the variability within treatments and allow for more accurate counting. Furthermore, if berries were harvested at various harvesting intensities on a per stem basis it may help to reduce the margin for change as previously discussed, thereby mitigating the bias of harvesting over a larger area.

(b) Stems Per Unit Area

The measurements of numbers of stems per unit area rather than shoots per unit area should be considered since this appears to be the standard method for evaluating above ground vegetative productivity in the blueberry industry (Yarborough *et al.* 1986, Eaton 1994, Nams 1994, Jordan and Eaton 1995, Penney *et al.* 1997). Shoots, as defined for this study, consisted of one to many stems all originating from the same place in the ground or more precisely, a ramet.

Stem densities were likely overlooked for this study because non-destructive sampling methods were practiced. Many researchers first clip the blueberry plots and then count the number of stems clipped (Ismail *et al.* 1981, Jensen 1986). Nams (1994) compared the accuracy of counting stems in quadrats in the field and clipping stems and counting them in the lab and found no significant difference in accuracy between the two methods.

Stem densities may be a more accurate, and therefore, a more sensitive method of assessing the effects of harvesting intensity on vegetative reproduction. Accordingly, stems should be counted rather than shoots for future blueberry monitoring protocols and a smaller area should be sub-sampled.

(c) Bud Density Changes

To avoid difficulties in the future, bud densities should: (1) be recorded at the same time every year (2) be counted on a per stem basis and (3) the number of flowers/bud should also be counted. Finally, (4) the variability in bud densities (Tables 4.7 and 4.11) indicate that a larger sample size may be required.

(d) Collection Demonstration at the Start of Every Day

The Y2-S Manitoba shoot densities are much lower than the Y2-F shoot densities (Table 4.6) which may make changes in stem density (Figure 4.5- A) appear as though harvesting intensity did have an effect. The differences between Y2-S and Y2-F shoot densities may be partly attributed to variability between data collectors.

During the summer months of 1997 (Y2) employees from the Sagkeeng First Nation assisted in data collection. As previously mentioned, Nams (1994) identified differences between observers as a large source of variation in data. One initial training session provided to those untrained in botany was most likely inadequate for teaching the abstruse task of identifying what we defined as a shoot. For future reference, Nams (1994) recommends a brief demonstration at the beginning of every data collection day to reduce variability between researchers. In comparison, the shoot densities for Y2-S and Y2-F in Ontario were collected only by primary researchers and there is very little variation between the summer and fall densities (Table 4.10).

(e) Associated Environmental Parameters

In the future, if resources permit, other environmental factors should be considered. Soil samples may show differences in mineral, nutrient and water availability which could explain some of the differences observed from year to year and between treatments. Insufficient quantities of minerals, nutrients or water may limit blueberry growth. Additionally, light readings may also show differences from plot to plot and could explain some of the vast differences in berry productivity seen in the blueberry (Aalders *et al.* 1969, Hoefs and Shay 1981). We attempted to control for such environmental variables by using a nested experimental design (Figure 3.9). However, if these environmental factors were added, they would allow for more precision in assessing the monitoring protocol.

(f) Seedling Regeneration

Seedling regeneration requires examination both in the harvesting area and the surrounding areas to investigate whether sexual propagation, and therefore genetic diversity, is affected by harvesting.

5.3 Conclusions

Monitoring protocols for two very different species were tested in Manitoba and Ontario to assess the impact of harvesting *Acorus americanus*, a traditional native medicinal plant, and *Vaccinium angustifolium*, the lowbush blueberry.

First Nations communities were successfully included in the study. Good working relationships were established with the environmental officers of both communities through the initial contact with the chiefs. The cooperation of experienced and knowledgeable community elders was achieved through the environmental officers. Furthermore, these elders guided researchers to traditional harvesting locations. Once the protocols were established Sagkeeng First Nation provided additional human resources to facilitate in data collection and to train community members in monitoring protocols. Sagkeeng is actively seeking the means to continue the monitoring protocols.

The monitoring protocols were an effective means of assessing *Acorus* productivity. This is significant since this is the first study to examine the effects of harvesting *Acorus* rhizomes. Monitoring various harvesting intensities of *A. americanus* for two growth seasons demonstrated a decrease in productivity in terms of shoot density, percent cover and rhizome dry mass, with increased levels of harvesting, especially after 100% harvesting. We also discovered that 30% and 70% harvesting levels elicit similar responses although this may not be true over the long term. Suggestions were made for future modification to the monitoring protocols, including: (1) changing the quadrat shape from a square to an elongated rectangle; (2) using a finer scale method for assessing the abundance of associated plants; (3) monitoring several environmental factors, such as water temperature, water quality, water levels, soil nutrients, and light levels; and (4) establishing more study sites.

The information obtained from this and future studies would help in determining sustainable harvest levels and in making the harvesting economically viable. This would also require studies that investigate (i) rhizome growth rates, (ii) a non-destructive method

to assess the below ground biomass of unharvested plants to more accurately monitor the productivity of the control plots, (iii) the bioengineering of a harvesting machine for *A. americanus* and , (iv) propagation of more *A. americanus* sites.

Monitoring different harvesting levels of *Vaccinium angustifolium* for two years produced unexpected results. This project is the first to examine effects of different harvesting (other than 100%) levels on blueberry production. As harvesting intensity increased, mass, volume and berry density tended to decrease. Interestingly, harvesting some (30%) or most (70%) of the berries appears to have had a stimulatory effect on berry density, resulting in an increased yield compared with the control or the 100% harvesting intensity. As this is the first study of its kind, one can only speculate as to the biological reasons behind this phenomenon. Recommendations were made for future research to improve the monitoring protocols for *V. angustifolium* by: (1) counting stem densities rather than 'shoot' densities; (2) using a 0.025 m^2 quadrat to count stem densities, bud densities, and berry densities; (3) counting bud and berry densities on a per stem basis as well as a per unit area basis (4) improving the method for harvesting 30 or 70% of berries; (5) using a finer scale method for assessing the abundance of associated species; (6) monitoring several environmental factors, such as edaphic factors and light levels; (7) examining seedling establishment in and around study areas (8) establishing more study sites.

It is hoped that the recommendations made here will be implemented to further explore the effects of harvesting these non-timber boreal forest products as an alternative to forestry and/or as an opportunity for people living in economically depressed areas in boreal forest regions to supplement their incomes.

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Appendix I Letters to Chiefs

November 7,1995.

Chief Larry Barker
Hollow Water
General Delivery
Wanipigow, MB
R0E 2E0

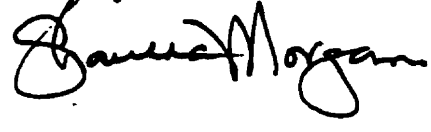
Dear Mr. Barker,

Hello, my name is Shaunna Morgan. I am a Cree from Waskaganish, Quebec. I have also lived in Webequie, Ontario. After living on these reserves I have come to realize the necessity of economic development for the people living in remote areas where employment opportunities are few. As you may or may not know there is increasing interest in harvesting natural non timber forest products in a sustainable manner. In a recent conversation with my uncle, Albert Diamond, he told me of a family that harvested wild cranberries in the summer and was paid about four thousand dollars by a Montreal restaurant for the harvest. Perhaps there are similar opportunities in this region for such enterprises. In our forests there are many plants of potential economic significance such as wild fruits, teas, herbal remedies and mushrooms.

If you are interested in exploring the economic potential of plants in your area I would be willing to work together with you and other interested members of your community on this project. One possible project would be the selection of a fruit, an edible fungus, and a plant that can be used in a herbal remedy that could be harvested on a seasonal basis. We might describe their distribution and abundance and establish a monitoring program so that appropriate harvest levels could be set without impairing the viability of the plant. The input of interested and knowledgeable members of your community would be necessary to help in the selection of appropriate species and suitable harvest areas. I believe that this would provide useful information for members of your band interested in supplementing their income by harvesting non timber botanical products from the forest in a sustainable way. You would gain valuable information on both the potentially economic plants and the surrounding forest by allowing me to do the botanical study for you.

I am a student at the University of Manitoba beginning my Master's Degree in Botany. My personal funding is provided by the Cree School Board of Quebec and the project has some initial funding from the Canadian Shield Foundation. I would like to gather data for my thesis by doing such a project during the summers of 1996 and 1997. I believe this will be an important economic opportunity and will contact you very soon.

Sincerely,



Shaunna Morgan.

_____ No, this band is not interested in collaborating in research on the sustainable use of plant products from the forest. Please do not contact us again concerning this matter.

Signature _____

Position _____

_____ Yes, this band is interested in collaborating in research on the sustainable use of plant products from the forest. We would like to discuss details with you.

(please print clearly)

Contact name _____

Position _____

E-mail address _____

Mailing Address _____

_____

_____

Phone number _____

Fax number _____

Signature _____

Position _____

December 27, 1995.

Chief Larry Barker
Hollow Water
General Delivery
Wanipigow, MB
R0E 2E0

Dear Mr. Barker

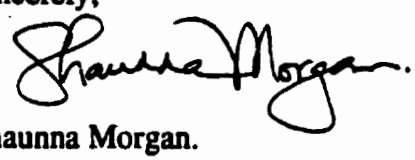
I hope you received my first letter on establishing a monitoring program for the sustainable harvesting of special botanical non-timber forest products and have had sufficient time to consider the proposal. Enclosed is a form to be filled out if you are interested in working with me in the future and a self-addressed stamped envelope to expedite matters. If for some reason you did not receive my first letter please contact me and I will fax a copy of the original to your office.

Shaunna Morgan
Department of Botany
505 Buller Building
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

Tel: (204) 474-9368
Fax: (204) 261-8474

I look forward to receiving your response.

Sincerely,



Shaunna Morgan.

_____ Yes, this band is interested in collaborating in research on the sustainable use of plant products from the forest. We would like to discuss details with you.

Contact name _____

Position _____

E-mail address _____

Mailing Address _____

_____

_____

Phone number _____

Fax number _____

Signature _____

Position _____

Appendix II. Vascular[1] plant, non-vascular[2] plant and lichen[3] species list for NTFP study sites in Manitoba and Ontario in 1996 and 1997. A) *Acorus americanus* sites B) *Vaccinium angustifolium* sites.

A)

Scientific name	Authority	Family	Common name	MB	ON
Acorus americanus	(Raf.) Raf.	Acoraceae	Sweetflag	X	X
Bidens cernua	L.	Compositae	Stick tight		X
Butomus umbellatus	L.	Butomaceae	Flowering rush	X	
Calamagrostis canadensis	(Michx.) Nutt.	Gramineae	Blue-joint		X
Carex sp.	L.	Cyperaceae	Sedge	X	X
Cicuta bulbifera	L.	Umbelliferae	Bulb-bearing water hemlock	X	X
Cicuta maculata	L.	Umbelliferae	Water hemlock	X	
Eleocharis palustris	(L.) R.& S.	Cyperaceae	Creeping spike-rush	X	
Equisetum sp.	L.	Equisetaceae	Horsetail	X	
Galium boreale	L.	Rubiaceae	Northern bedstraw		X
Polygonum amphibium	L.	Polygonaceae	Water-smartweed		X
Polygonum coccineum	Muhl.	Polygonaceae	Long-spiked water-smartweed		X
Polygonum lapathifolium	L.	Polygonaceae	Willow-weed		X
Potentilla palustris	(L.) Scop.	Rosaceae	Marsh cinquefoil	X	X
Sagittaria cuneata	Sheldon	Alismataceae	Arum-leaved arrowhead	X	
Sagittaria rigida	Pursh	Alismataceae	Sessile-fruited arrowhead	X	X
Scirpus cyperinus	(L.) Kunth	Cyperaceae	Wool-grass	X	X
Sparganium eurycarpum	Engelm.	Sparganiaceae	Giant bur-reed	X	X
Typha latifolia	L.	Typhaceae	Common cat-tail	X	
Zizania aquatica	L.	Gramineae	Wild rice	X	

B)

Trees					
Abies balsamea	(L.) Mill.	Pinaceae	Balsam fir	X	
Betula papyrifera	Marsh.	Betulaceae	White birch	X	
Picea glauca	(Moench) Voss.	Pinaceae	White spruce	X	X
Pinus banksiana	Lamb.	Pinaceae	Jack pine	X	X
Populus tremuloides	Michx.	Salicaceae	Trembling aspen	X	X
Tall shrubs					
Alnus rugosa	(Du Roi) Spreng.	Betulaceae	Speckled alder		X
Amelanchier alnifolia	Nutt.	Rosaceae	Saskatoon	X	X
Prunus pensylvanica	L. f.	Rosaceae	Pin cherry	X	X
Prunus virginiana	L.	Rosaceae	Choke cherry	X	X
Salix spp.	L.	Salicaceae	Willow	X	
Low shrubs					
Arctostaphylos uva-ursi	(L.) Spreng.	Ericaceae	Bearberry	X	X
Comandra umbellata	(L.) Nutt.	Santalaceae	Bastard-toad flax	X	X
Diervilla lonicera	Mill.	Caprifoliaceae	Bush-honeysuckle	X	X
Fragaria virginiana	Dcne.	Rosaceae	Wild strawberry	X	X
Gaultheria procumbens	L.	Ericaceae	Checkerberry	X	X
Juniperus communis	L.	Pinaceae	Common juniper		X
Potentilla tridentata	Ait.	Rosaceae	Three-toothed cinquefoil	X	X

Scientific name	Authority	Family	Common name	MB	ON
Low shrubs continued					
Rhus glabra	L.	Anacardiaceae	Smooth sumac	X	X
Ribes glandulosum	Grauer	Saxifragaceae	Skunk currant		X
Ribes sp.	L.	Saxifragaceae	Currant		X
Rosa acicularis	Lindl.	Rosaceae	Prickly rose	X	X
Rubus idaeus	L.	Rosaceae	Red raspberry	X	X
Spiraea alba	Du Roi	Rosaceae	Meadow sweet	X	X
Symphoricarpos albus	(L.) Blake	Caprifoliaceae	Snowberrry	X	X
Vaccinium angustifolium	Ait.	Ericaceae	Low blueberry	X	X
Vaccinium myrtilloides	Michx.	Ericaceae	Velvet-leaf blueberry	X	X
Grasses, Sedges and Rushes					
Agropyron repens	L. Beauv.	Gramineae	Quack grass	X	X
Agropyron trachycaulum	(Link) Malte	Gramineae	Slender wheatgrass	X	X
Agrostis hyemalis	(Walt.) BSP.	Gramineae	Hairgrass	X	
Carex spp.	L.	Cyperaceae	Sedge	X	X
Danthonia spicata	(l.) Beauv.	Gramineae	Poverty oat grass	X	X
Luzula sp.	DC.	Juncaceae	Wood-rush	X	X
Muhlenbergia racemosa	(Michz.) BSP.	Gramineae		X	
Oryzopsis asperifolia	Michx.	Gramineae	White-grained mountain rice grass	X	X
Oryzopsis pungens	(Torr.) Hitchc.	Gramineae	Northern rice grass	X	X
Phleum pratense	L.	Gramineae	Common timothy	X	
Poa sp.	L.	Gramineae	Blue grass	X	X
Schizachne purpurascens	(Torr.) Swallen	Gramineae	Purple oat grass	X	
unidentified grasses				X	X
Herbs					
Achillea millefolium	L.	Compositae	Common yarrow	X	X
Anaphalis margaritacea	(L.) Clarke	Compositae	Pearly everlasting	X	
Anemone canadensis	L.	Ranunculaceae	Canada anemone	X	
Antennaria sp.	Gaertn.	Compositae	Pussy-toes		X
Apocynum androsaemifolium	L.	Apocynaceae	Spreading dogbane	X	X
Aquilegia canadensis	L.	Ranunculaceae	Wild columbine		
Aralia nudicaulis	L.	Araliaceae	Wild sarsaparilla	X	X
Aster ciliolatus	Lindl.	Compositae	Lindley's aster	X	X
Aster laevis	L.	Compositae	Smooth aster		X
Aster macrophyllus	L.	Compositae	White wood aster		X
Aster spp.	L.	Compositae	Aster		X
Aster umbellatus	Mill.	Compositae	Flat-topped white aster	X	
Campanula rotundifolia	L.	Campanulaceae	Harebell		X
Cypripedium acaule	Ait.	Orchidaceae	Stemless lady's slipper	X	
Epilobium angustifolium	L.	Onagraceae	Fireweed	X	X
Epilobium palustre	L.	Onagraceae	Marsh willow herb	X	X
Galium boreale	L.	Rubiaceae	Northern bedstraw	X	
Heuchera sp.	L.	Saxifragaceae	Alumroot		X
Hieracium scabriusculum	Schwein.	Compositae	Hawkweed	X	X
Lactuca canadensis	L.	Compositae	Sow thistle	X	

Scientific name	Authority	Family	Common name	MB	ON
Herbs continued					
Lathyrus ochroleucus	Hook.	Leguminosae	Cream-colour vetchling	X	X
Lathyrus venosus	Muhl.	Leguminosae	Wild peavine	X	X
Lygodesmia juncea	(Pursh) D. Don	Compositae	Skeletonweed	X	
Maianthemum canadense	Desf.	Liliaceae	Wild lily-of-the-valley	X	X
Melampyrum lineare	Desr.	Scrophulariaceae	Cow-wheat	X	X
Polygonum cilinode	Michx..	Polygonaceae	Bindweed		X
Sanicula marilandica	L.	Umbelliferae	Snakeroot	X	
Solidago hispida	Muhl.	Compositae	Goldenrod.	X	X
Solidago sp.	L.	Compositae	Goldenrod	X	
Sonchus arvensis	L.	Compositae	Field sow thistle		X
Taraxacum officinale	Weber	Compositae	Common dandelion	X	X
Thalictrum sp.	L.	Ranunculaceae	Meadow-rue		X
Trientalis borealis	Raf.	Primulaceae	Northern starflower	X	
Trifolium hybridum	L.	Leguminosae	Alsike clover	X	
Vicia americana	Muhl.	Leguminosae	American vetch	X	X
Viola adunca	Sm.	Violaceae	Early blue violet	X	X
Viola sp.	L.	Violaceae	Violet	X	
Lichens, Mosses, Ferns and Fern Allies					
Cladina mitis [3]	(Sandst.)Hale&Culb	Cladoniaceae	Yellow reindeer lichen	X	X
Cladina rangifernia [3]	(L.) Harm.	Cladoniaceae	Reindeer lichen	X	X
Cladonia spp.[3]		Cladoniaceae		X	X
Umbilicaria sp.[3]		Umbilicariaceae	Rock tripe	X	X
Dicranum sp. [2]	Hedw.	Dicranaceae	Fork moss	X	X
Pleurozium schreberi [2]	Mitt.	Entodontaceae	Red-stemmed feather moss	X	X
Polytrichum commune [2]	Hedw.	Polytrichaceae		X	X
Polytrichum juniperinum [2]	Hedw.	Polytrichaceae		X	X
Sphagnum spp.[2]	L.	Sphagnaceae	Peat moss	X	
Lycopodium complanatum [1]	L.	Lycopodiaceae	Ground cedar	X	
Polypodium virginianum [1]	L.	Polypodiaceae	Rock polypody	X	X
Pteridium aquilinum [1]	(L.) Kuhn.	Polypodiaceae	Bracken fern	X	

X indicates presence in the location.

[1] follows Scoggan (1978 - 1979)

[2] follows Ireland (1982)

[3] follows Hale (1979)

Appendix III. *A. americanus* plot identification numbers for sites in Manitoba and Ontario. The compass bearings and distances were measured from the identification point for each block. In Ontario, the distances were measured to the SE corner of each plot

Location	Site	Block	Plot	Compass Bearing (°)	Distance (m) to SW corner	Harvesting Intensity
Manitoba	1	1	1	310	6.5	30
	1	1	2	320	10.85	100
	1	1	3	337	9.45	70
	1	1	4	338	4.9	0
	1	2	1	342	15.76	30
	1	2	2	354	15.37	70
	1	2	3	2	16.17	100
	1	2	4	358	18.4	0
	1	3	1	376	14	30
	1	3	2	282	15	70
	1	3	3	316	14	100
	1	3	4	342	15.35	0
	2	1	1	344	9.3	70
	2	1	2	338	11.8	100
	2	1	3	0	10.6	0
	2	1	4	128	10.9	30
	2	2	1	348	11.2	30
	2	2	2	342	14	70
	2	2	3	340	13.7	100
	2	2	4	334	11.4	0
	2	3	1	306	8.7	100
	2	3	2	318	11.3	0
	2	3	3	282	10	30
	2	3	4	276	11.95	70
	3	1	1	120	12.65	70
	3	1	2	126	9.75	100
	3	1	3	147	11.4	30
	3	1	4	158	10.15	0
	3	2	1	116	10.55	100
	3	2	2	120	9.5	30
	3	2	3	188	9.6	0
	3	2	4	200	10.9	70
	3	3	1	92	9.2	70
	3	3	2	96	11.35	100
	3	3	3	128	8.8	0
	3	3	4	140	5.55	30
Ontario	1	1	1	179	7.8	30
	1	1	2	191	5.2	70
	1	1	3	226	6.55	100
	1	1	4	235	8.6	0
	1	2	1	132	11.55	30
	1	2	2	172	7.5	0
	1	2	3	181	7.8	100
	1	2	4	245	8.6	70
	1	3	1	165	11	30
	1	3	2	174	8.55	100
	1	3	3	251	6.4	0
	1	3	4	286	17.15	70

Appendix IV ANOVAs and Box Plots

1.a) ANOVA and post hoc tests performed on the $\log_{10}$ changes from Y1 to Y2 on *Acorus americanus* shoot density in Manitoba (Table 4.1).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

32 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.016200	0.016200	0.25067	0.6205
hi	3	0.889425	0.296475	4.5874	0.0098
Error	28	1.80957	0.064628		
Total	31	2.69900			

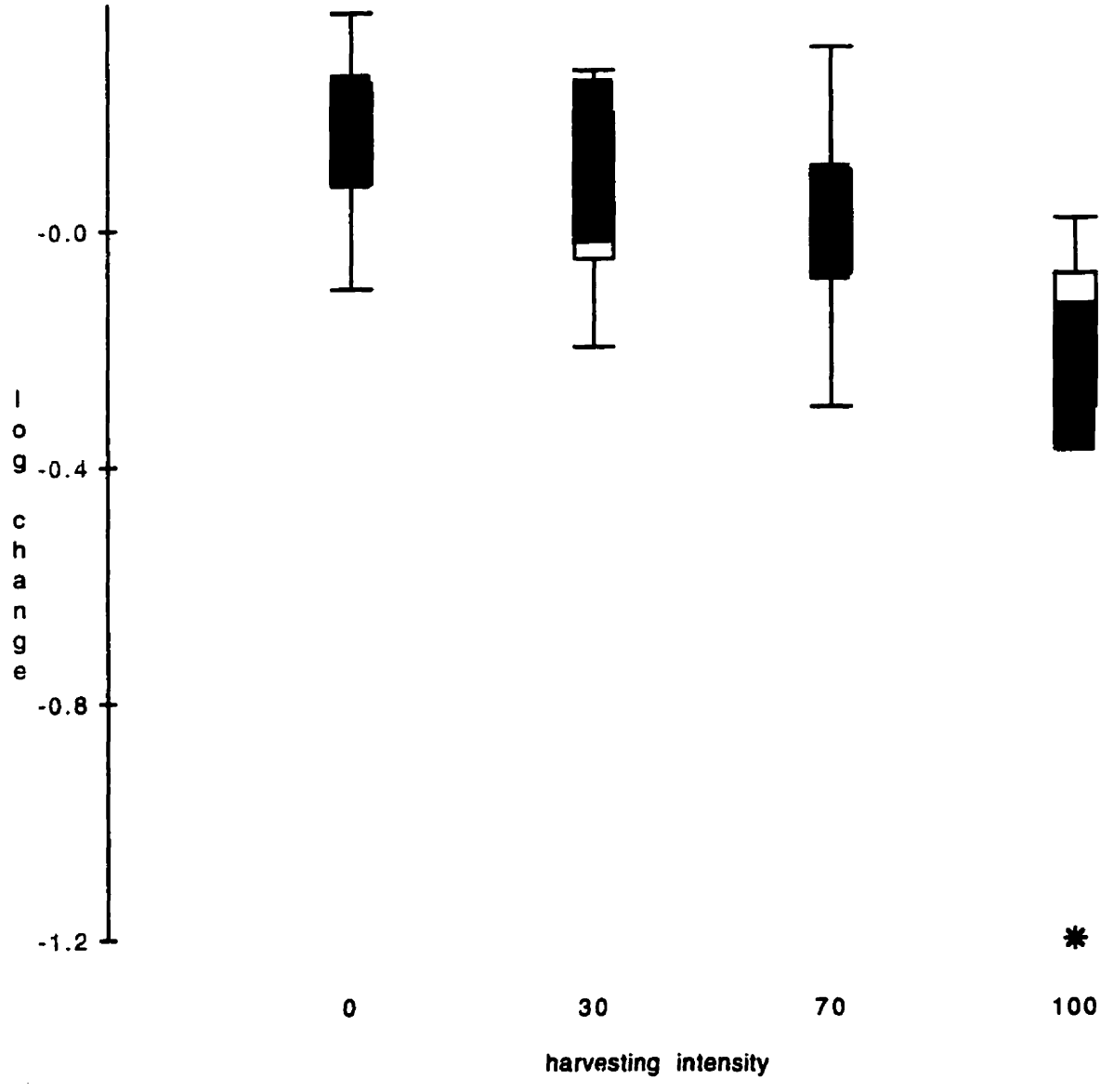
Results for factor hi

Coefficients

Expected Cell Means

LSD Post Hoc Tests

	Difference	std. err.	Prob
30 - 0	-0.076250	0.1271	0.553414
70 - 0	-0.143750	0.1271	0.267686
70 - 30	-0.067500	0.1271	0.599581
100 - 0	-0.440000	0.1271	0.001742
100 - 30	-0.363750	0.1271	0.007886
100 - 70	-0.296250	0.1271	0.027200



1.b) Box plot created from the $\log_{10}$ changes of *Acorus americanus* shoot density from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.1).

2.a) ANOVA and post hoc tests performed on the $\log_{10}$ changes from Y1 to Y2 on *Acorus americanus* percent cover in Manitoba (Table 4.1).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

32 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	1.91933	1.91933	29.653	≤ 0.0001
hi	3	1.06266	0.354221	5.4726	0.0043
Error	28	1.81235	0.064727		
Total	31	2.87502			

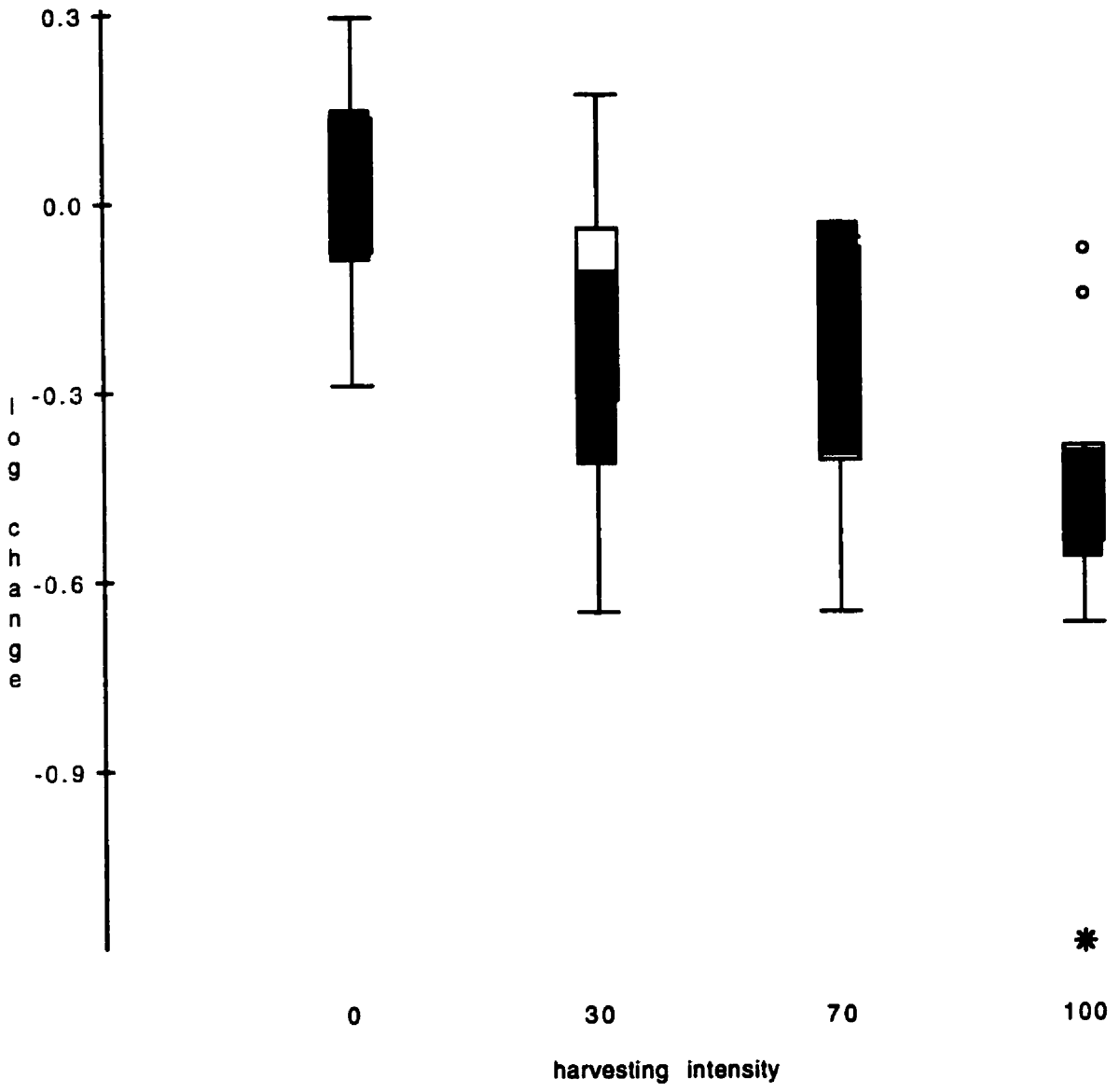
Results for factor hi

Coefficients

Expected Cell Means

LSD Post Hoc Tests

	Difference	std. err.	Prob
30 - 0	-0.229375	0.1272	0.082136
70 - 0	-0.279250	0.1272	0.036601
70 - 30	-0.049875	0.1272	0.697970
100 - 0	-0.513000	0.1272	0.000385
100 - 30	-0.283625	0.1272	0.033970
100 - 70	-0.233750	0.1272	0.076763



2.b) Box plot created from the $\log_{10}$ changes of *Acorus americanus* percent cover from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.1).

3.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Acorus americanus* rhizome dry mass in Manitoba (Table 4.1).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

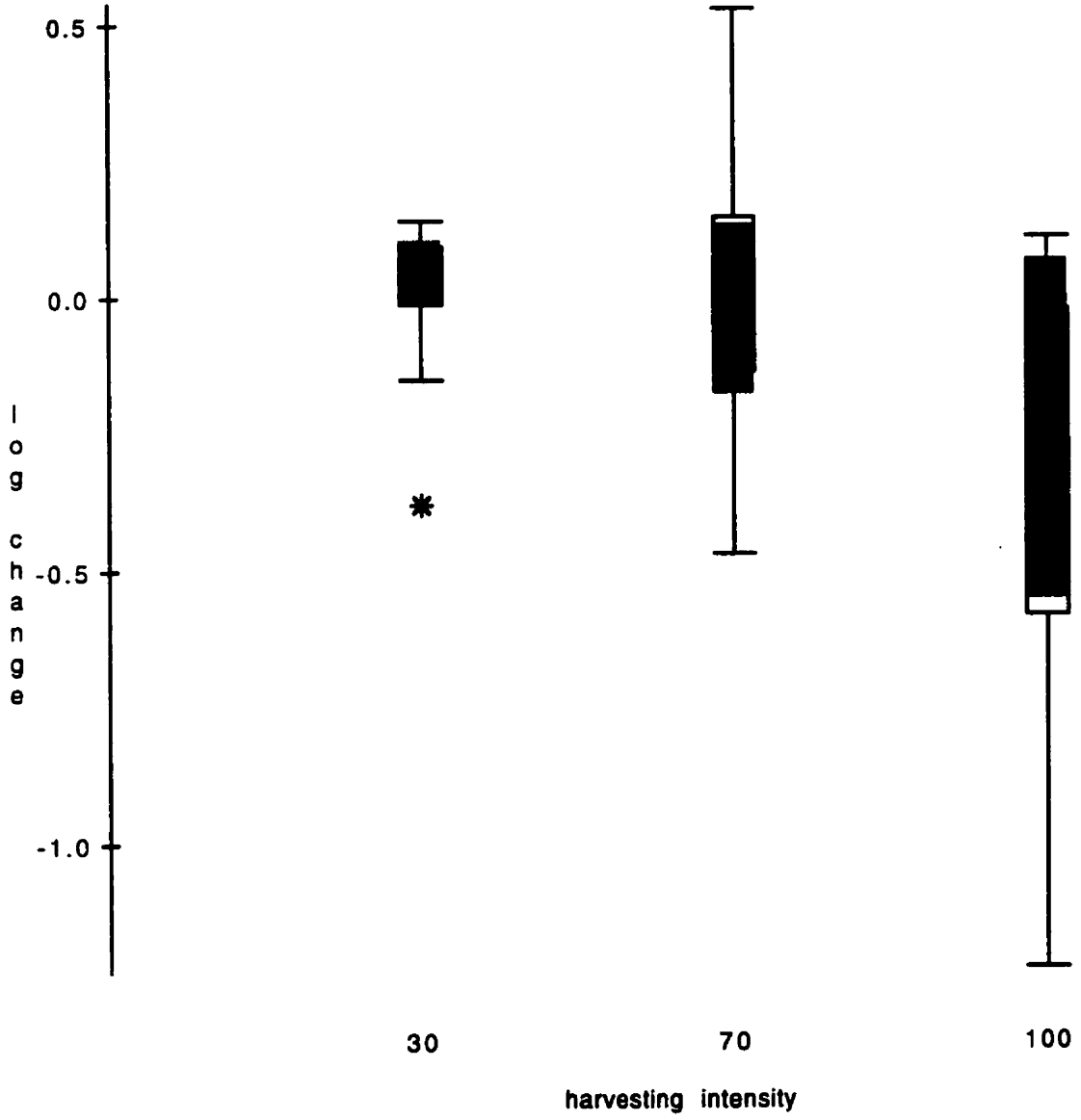
24 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.349692	0.349692	3.3372	0.0820
hi	2	0.662189	0.331094	3.1597	0.0631
Error	21	2.20050	0.104786		
Total	23	2.86269			

Results for factor hi



3.b) Box plot created from the $\log_{10}$ changes of *Acorus americanus* rhizome dry mass from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.1).

4.a) ANOVA and post hoc tests performed on the $\log_{10}$ changes from Y1 to Y2 on *Acorus americanus* shoot density in Ontario (Table 4.3).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

8 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.014516	0.014516	8.2717	0.0452
hi	3	0.043462	0.014487	8.2554	0.0345
Error	4	0.007020	0.001755		
Total	7	0.050481			

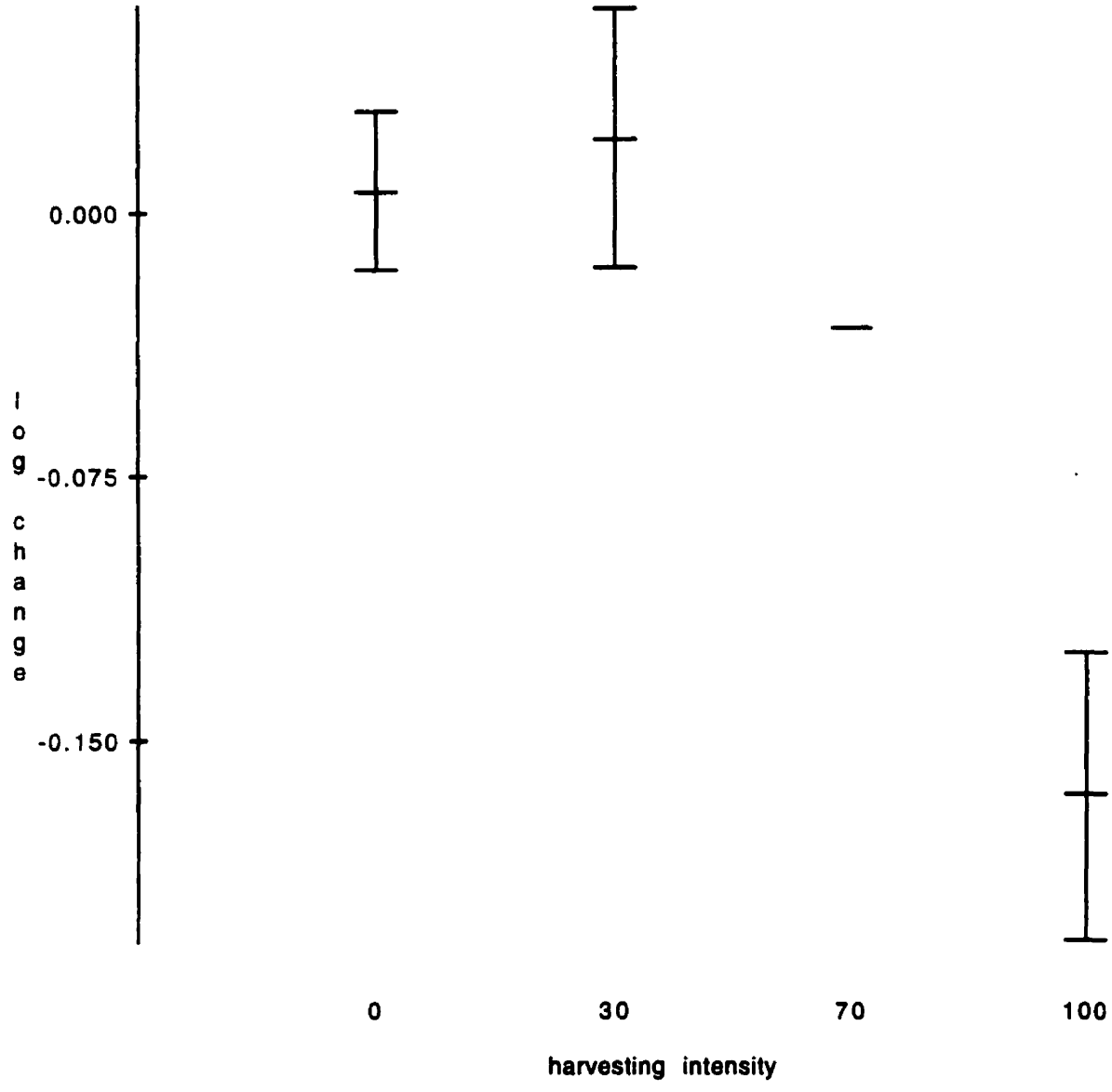
Results for factor hi

Coefficients

Expected Cell Means

LSD Post Hoc Tests

	Difference	std. err.	Prob
30 - 0	0.015249	0.0419	0.734281
70 - 0	-0.038312	0.0419	0.412167
70 - 30	-0.053561	0.0419	0.270196
100 - 0	-0.171834	0.0419	0.014830
100 - 30	-0.187082	0.0419	0.011110
100 - 70	-0.133522	0.0419	0.033301



4.b) Box plot created from the $\log_{10}$ changes of *Acorus americanus* shoot density from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.3).

5.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Acorus americanus* percent cover in Ontario (Table 4.3).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

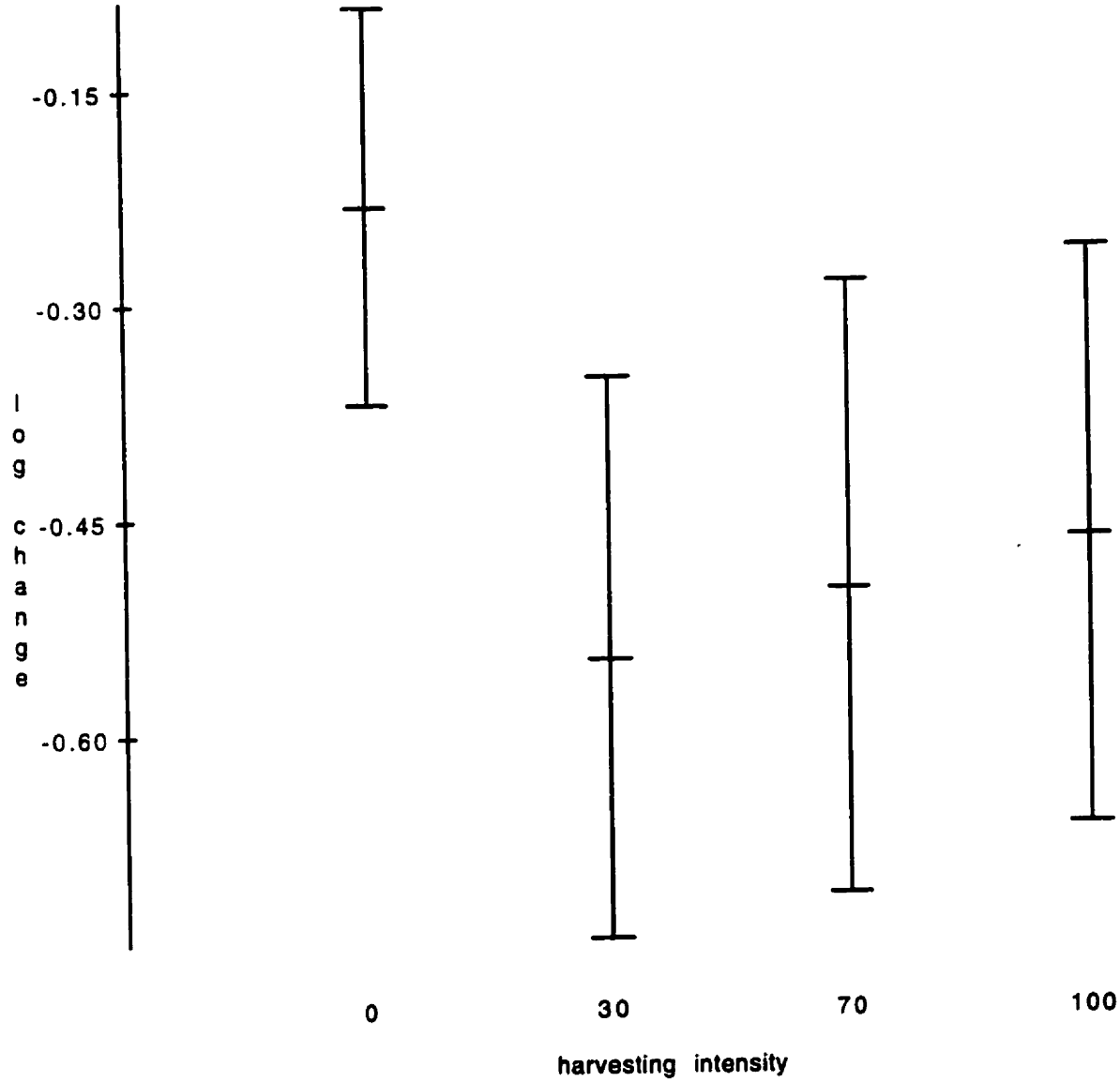
8 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	1.52173	1.52173	21.196	0.0100
hi	3	0.118608	0.039536	0.55070	0.6742
Error	4	0.287171	0.071793		
Total	7	0.405779			

Results for factor hi



5.b) Box plot created from the $\log_{10}$ changes of *Acorus americanus* percent cover from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.3).

6.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Acorus americanus* rhizome dry mass in Ontario (Table 4.3).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

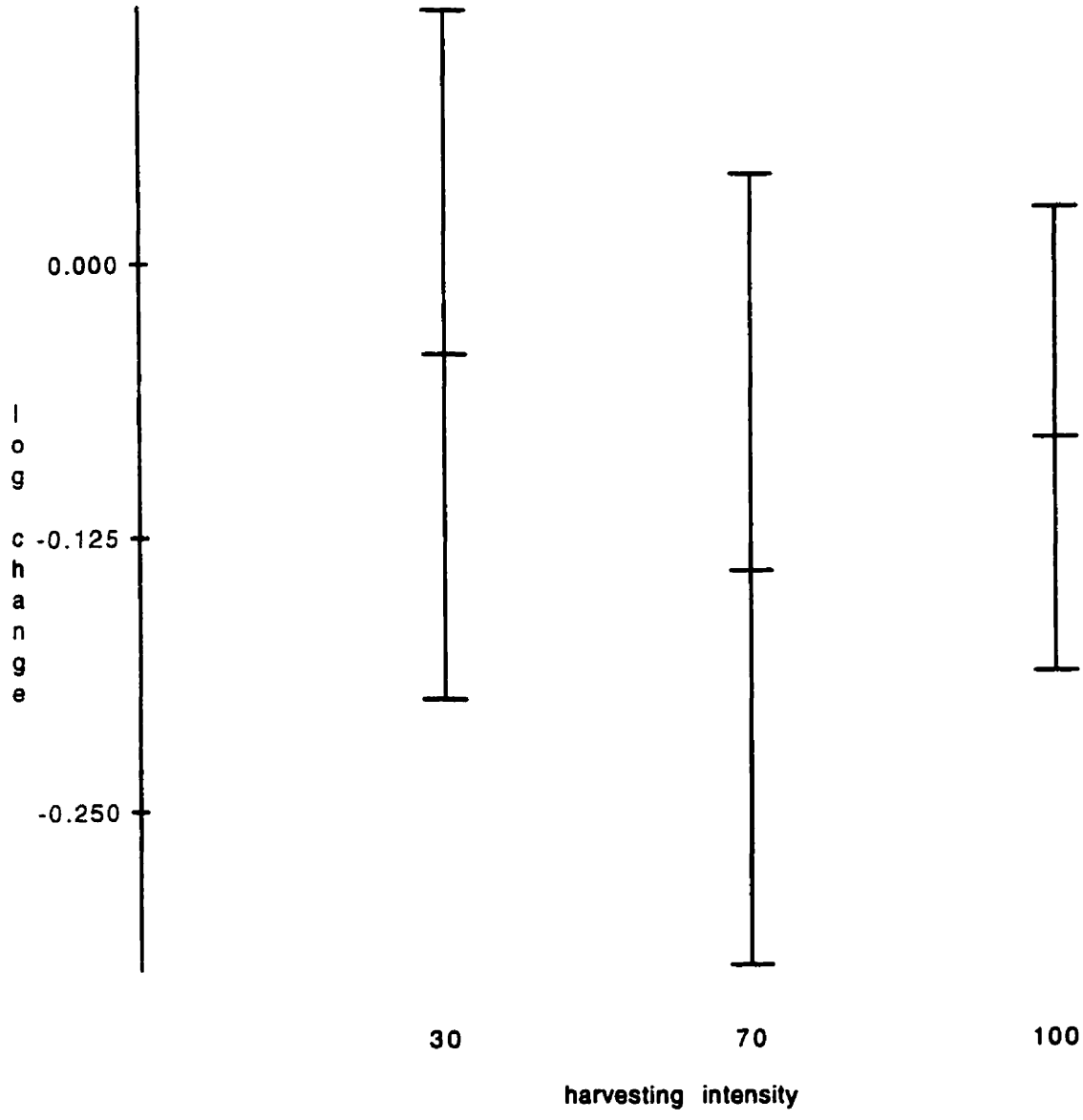
6 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.046245	0.046245	1.0140	0.3881
hi	2	0.010001	0.005001	0.10964	0.8996
Error	3	0.136824	0.045608		
Total	5	0.146825			

Results for factor hi



6.b) Box plot created from the $\log_{10}$ changes of *Acorus americanus* rhizome dry mass from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.3).

7.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* percent cover in Manitoba (Table 4.5).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

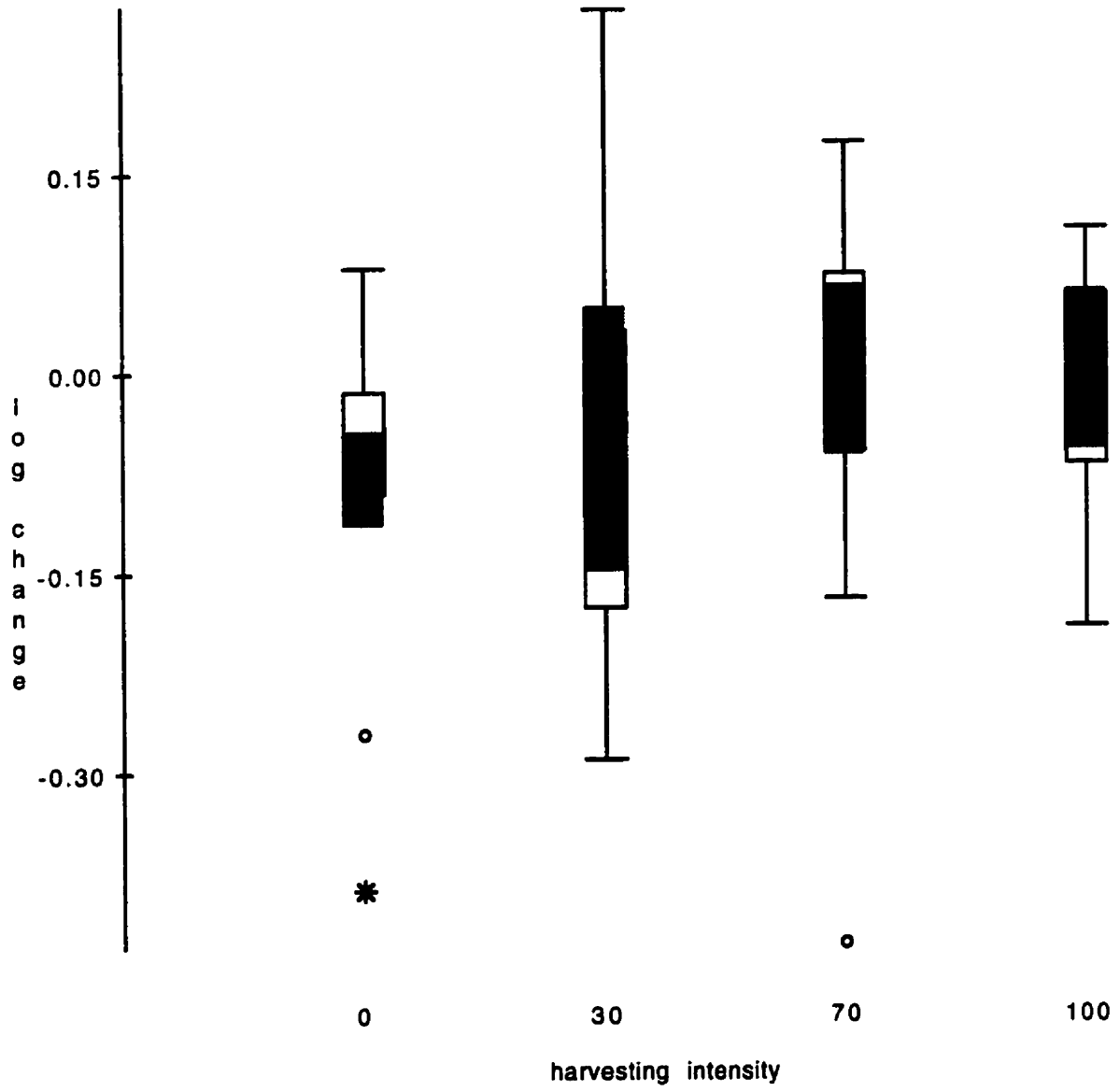
44 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.117421	0.117421	5.8986	0.0197
hi	3	0.039719	0.013240	0.66509	0.5784
Error	40	0.796261	0.019907		
Total	43	0.835980			

Results for factor hi



7.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* percent cover from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.4).

8.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* mass of fresh berries in Manitoba (Table 4.5).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

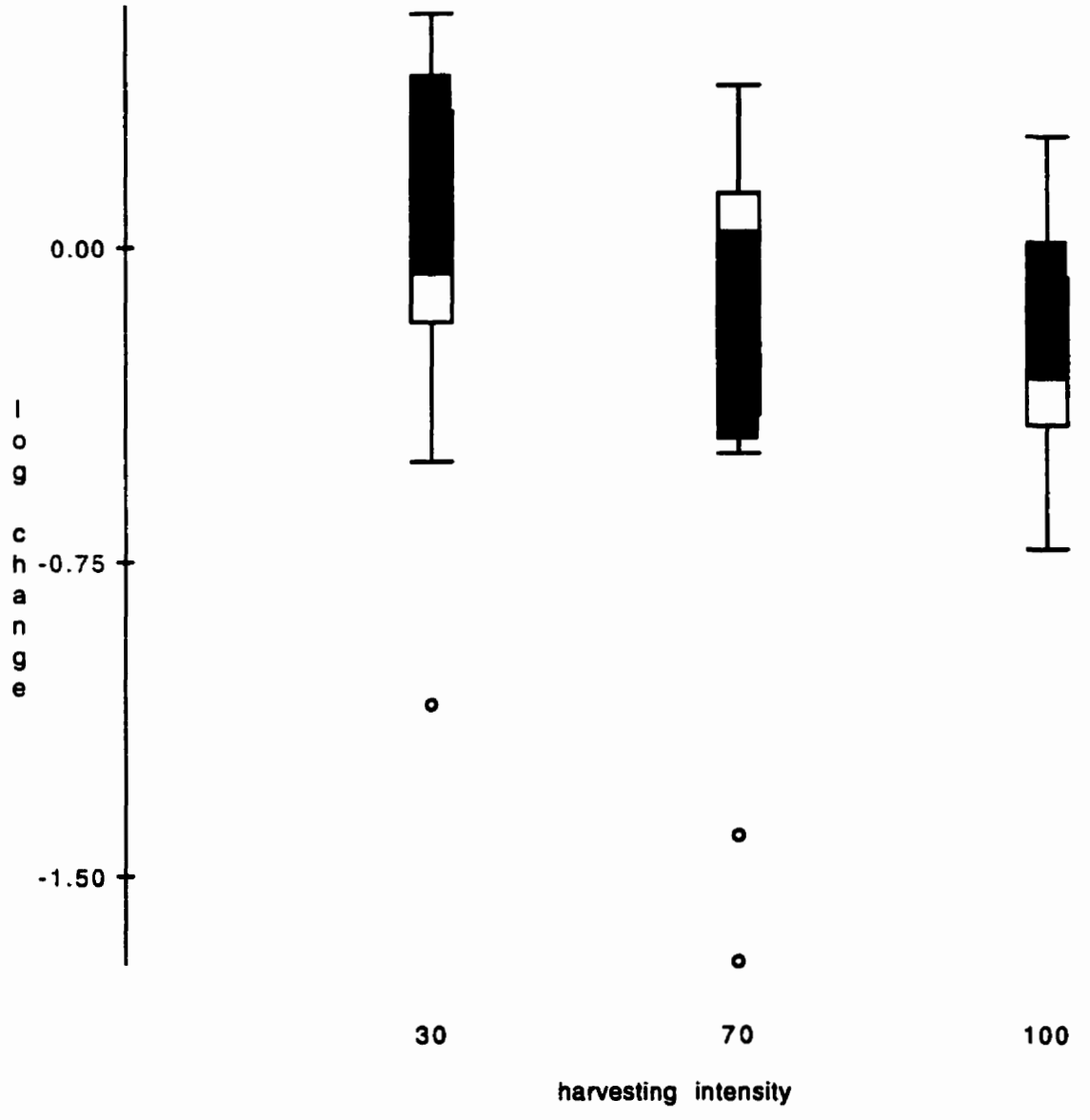
33 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	1.14539	1.14539	4.4304	0.0438
hi	2	0.619360	0.309680	1.1979	0.3159
Error	30	7.75584	0.258528		
Total	32	8.37520			

Results for factor hi



8.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* mass of fresh berries from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.4).

9.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* volume of fresh berries in Manitoba (Table 4.5).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

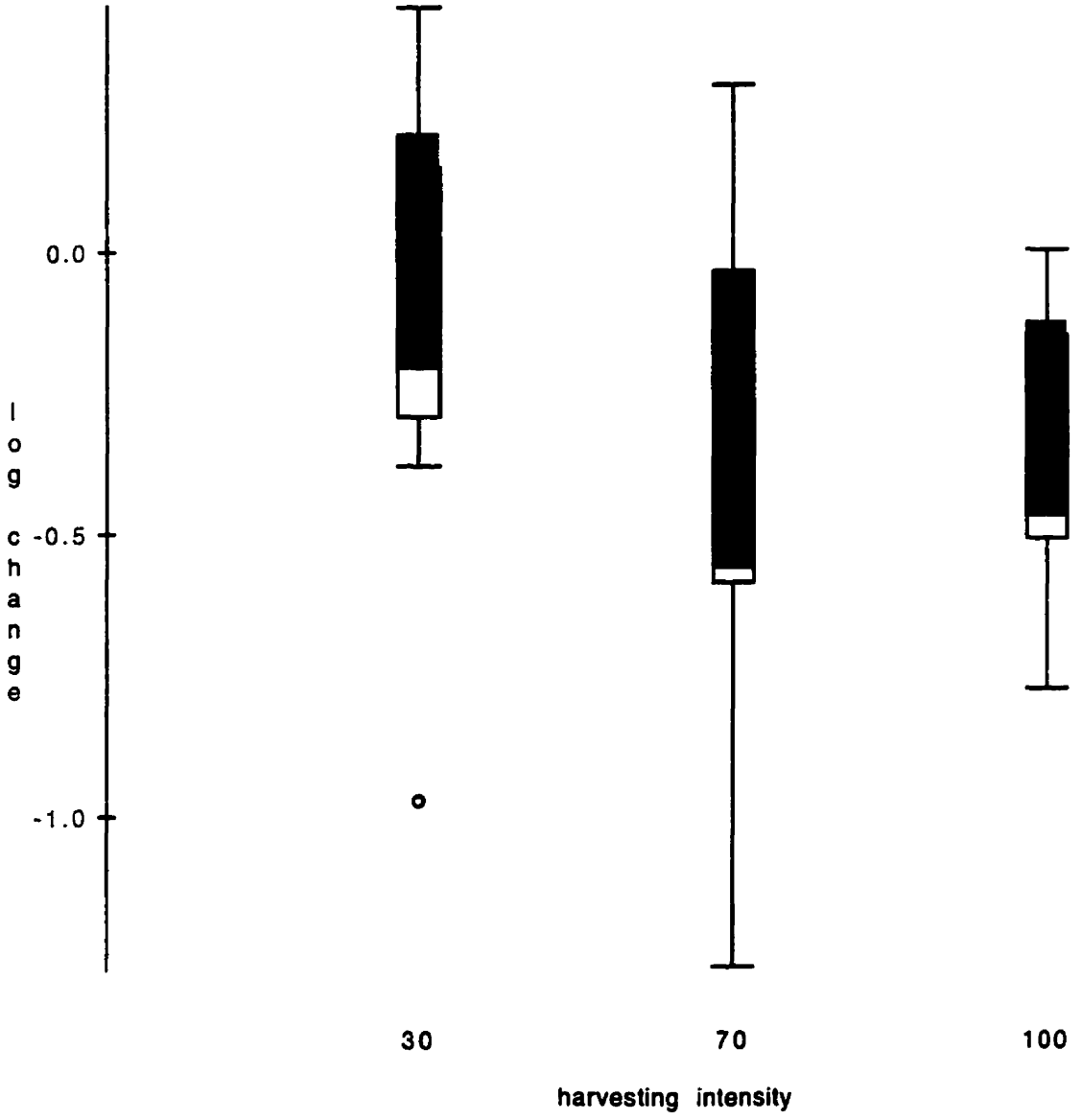
33 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	2.27530	2.27530	14.125	0.0007
hi	2	0.544949	0.272475	1.6916	0.2013
Error	30	4.83239	0.161080		
Total	32	5.37734			

Results for factor hi



9.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* volume of fresh berries from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.4).

10.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* shoot density in Manitoba (Table 4.6).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

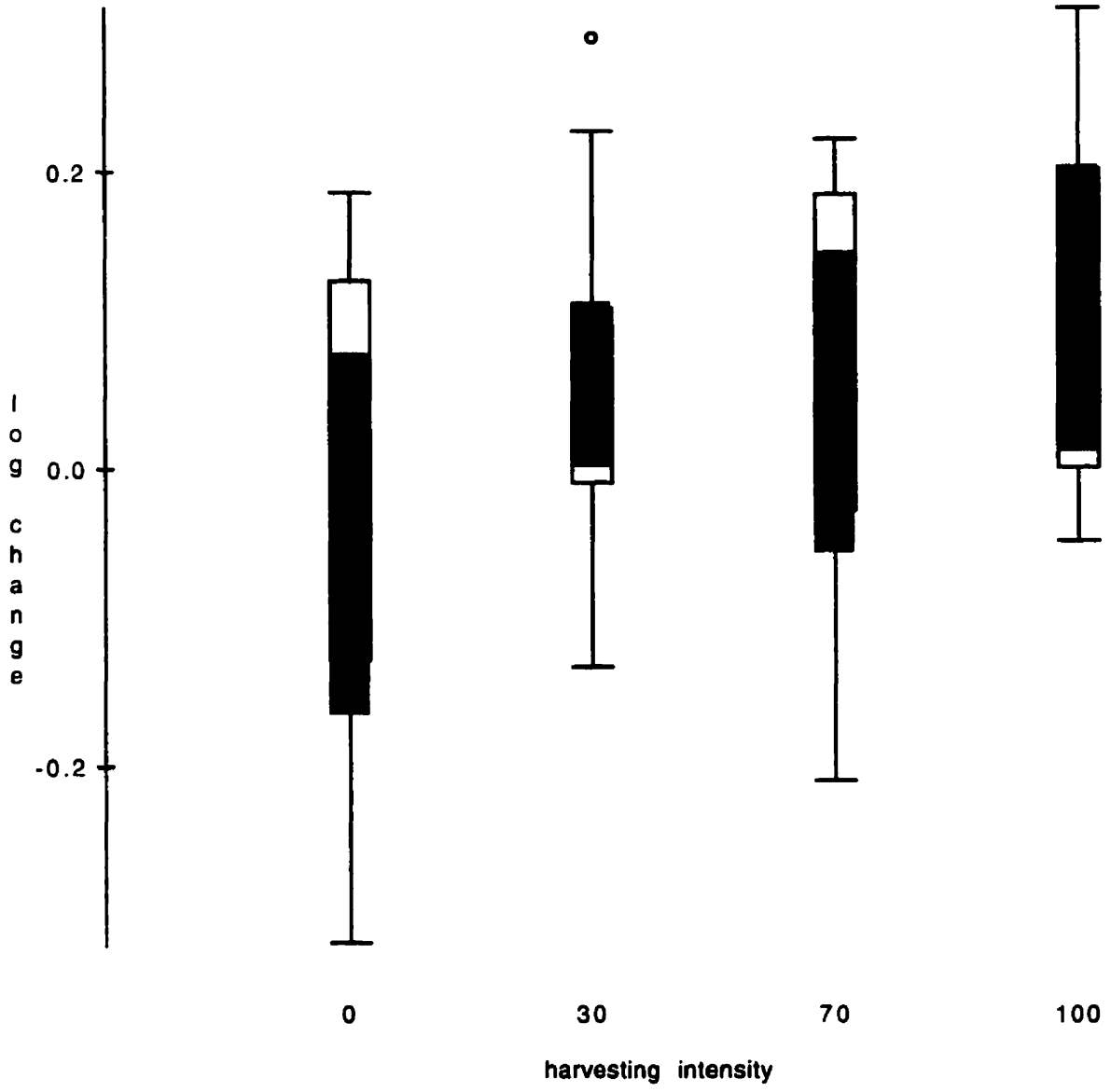
44 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.118715	0.118715	6.3962	0.0155
hi	3	0.096986	0.032329	1.7418	0.1739
Error	40	0.742402	0.018560		
Total	43	0.839388			

Results for factor hi



10.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* shoot density from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.5).

11.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* bud density in Manitoba (Table 4.6).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

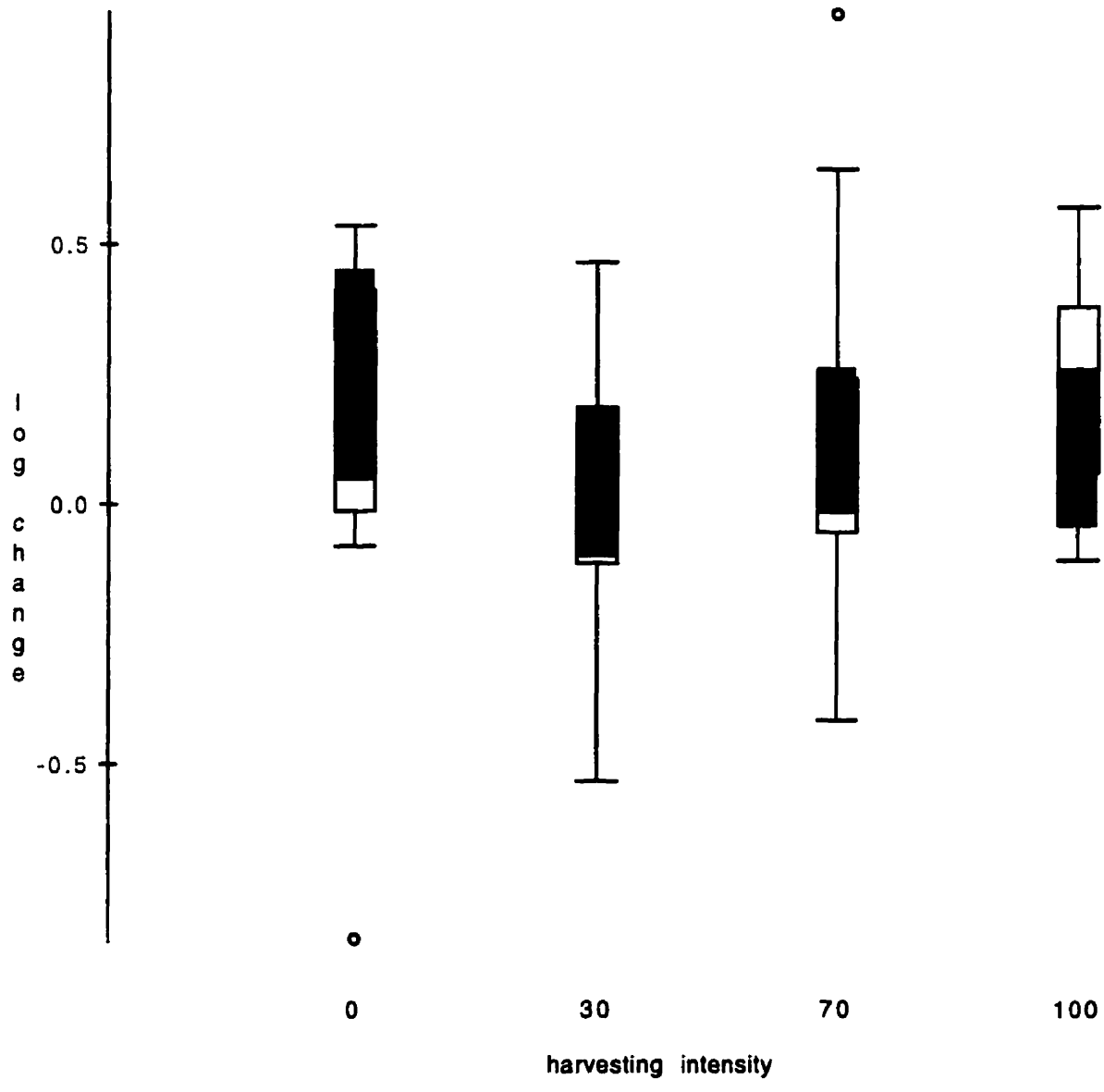
44 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.804673	0.804673	7.6132	0.0087
hi	3	0.232098	0.077366	0.73198	0.5391
Error	40	4.22778	0.105695		
Total	43	4.45988			

Results for factor hi



11.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* bud density from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.5).

12.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* berry density in Manitoba (Table 4.6).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

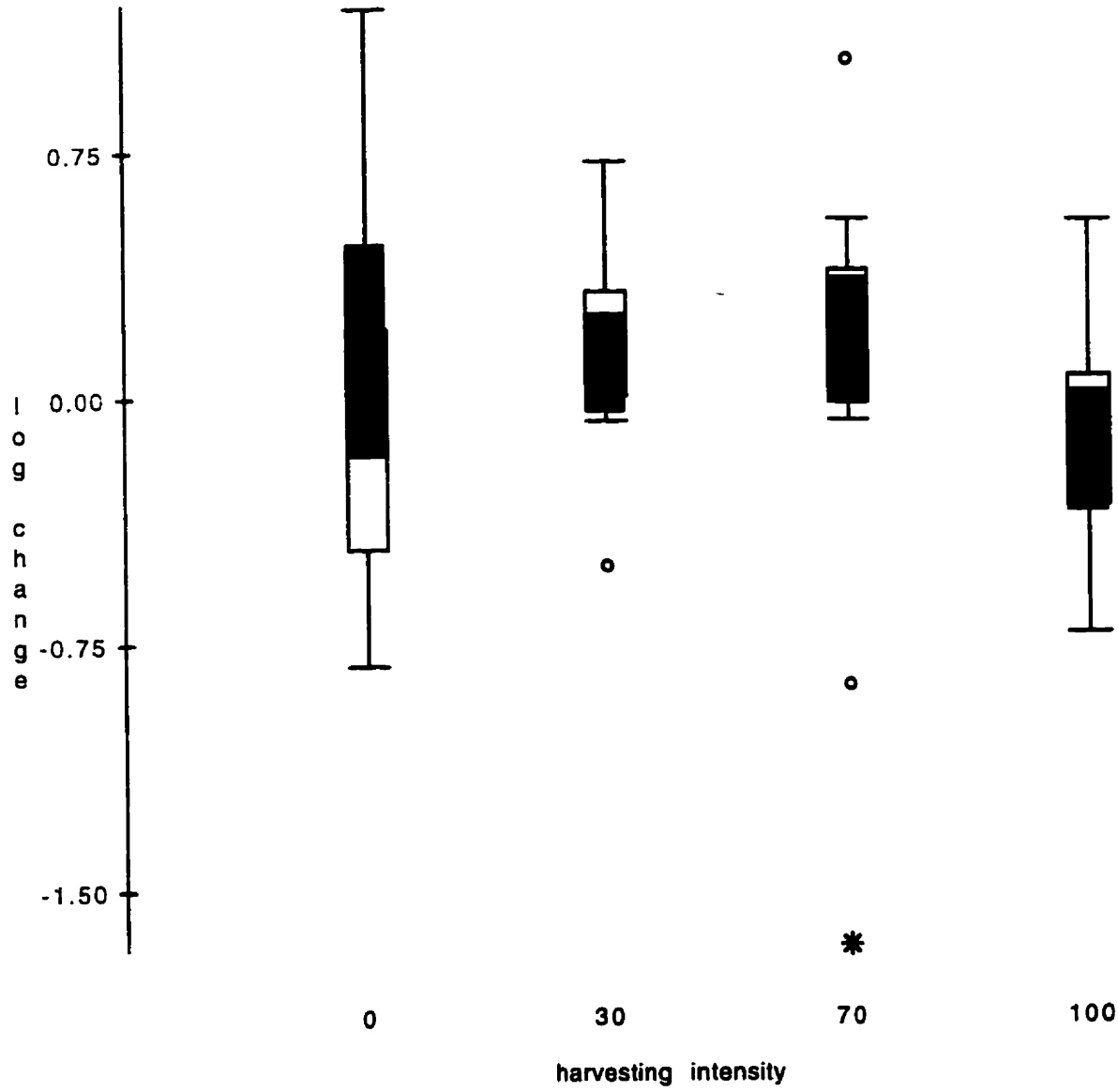
44 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.000291	0.000291	0.00102	0.9747
hi	3	0.420702	0.140234	0.49013	0.6911
Error	40	11.4447	0.286116		
Total	43	11.8654			

Results for factor hi



12.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* berry density from Y1 to Y2 at various harvesting intensities in Manitoba (Figure 4.5).

13.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* percent cover in Ontario (Table 4.9).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

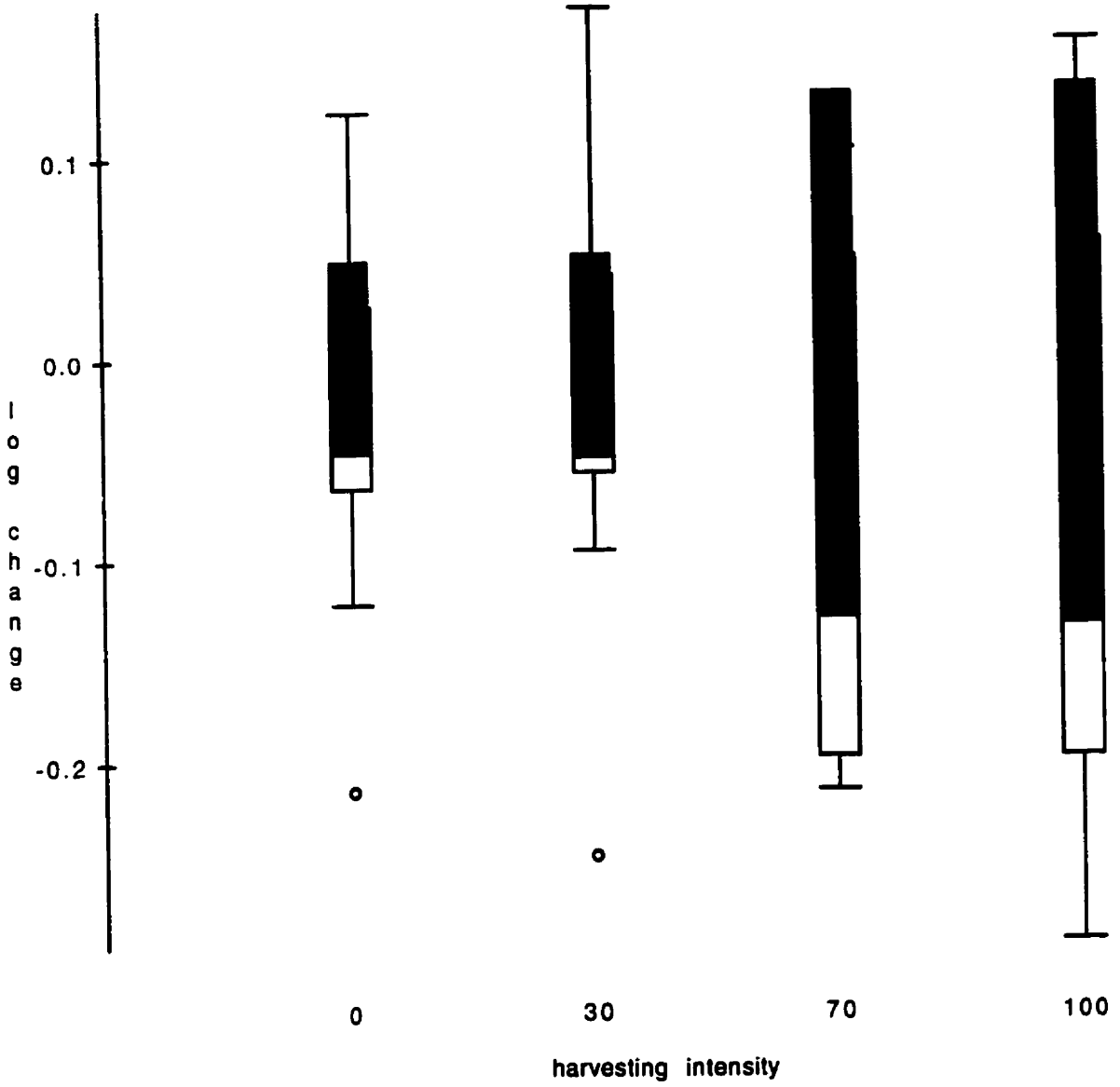
36 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.039878	0.039878	2.4096	0.1304
hi	3	0.016673	0.005558	0.33582	0.7995
Error	32	0.529592	0.016550		
Total	35	0.546266			

Results for factor hi



13.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* percent cover from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.6).

14.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* mass of fresh berries in Ontario (Table 4.9).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

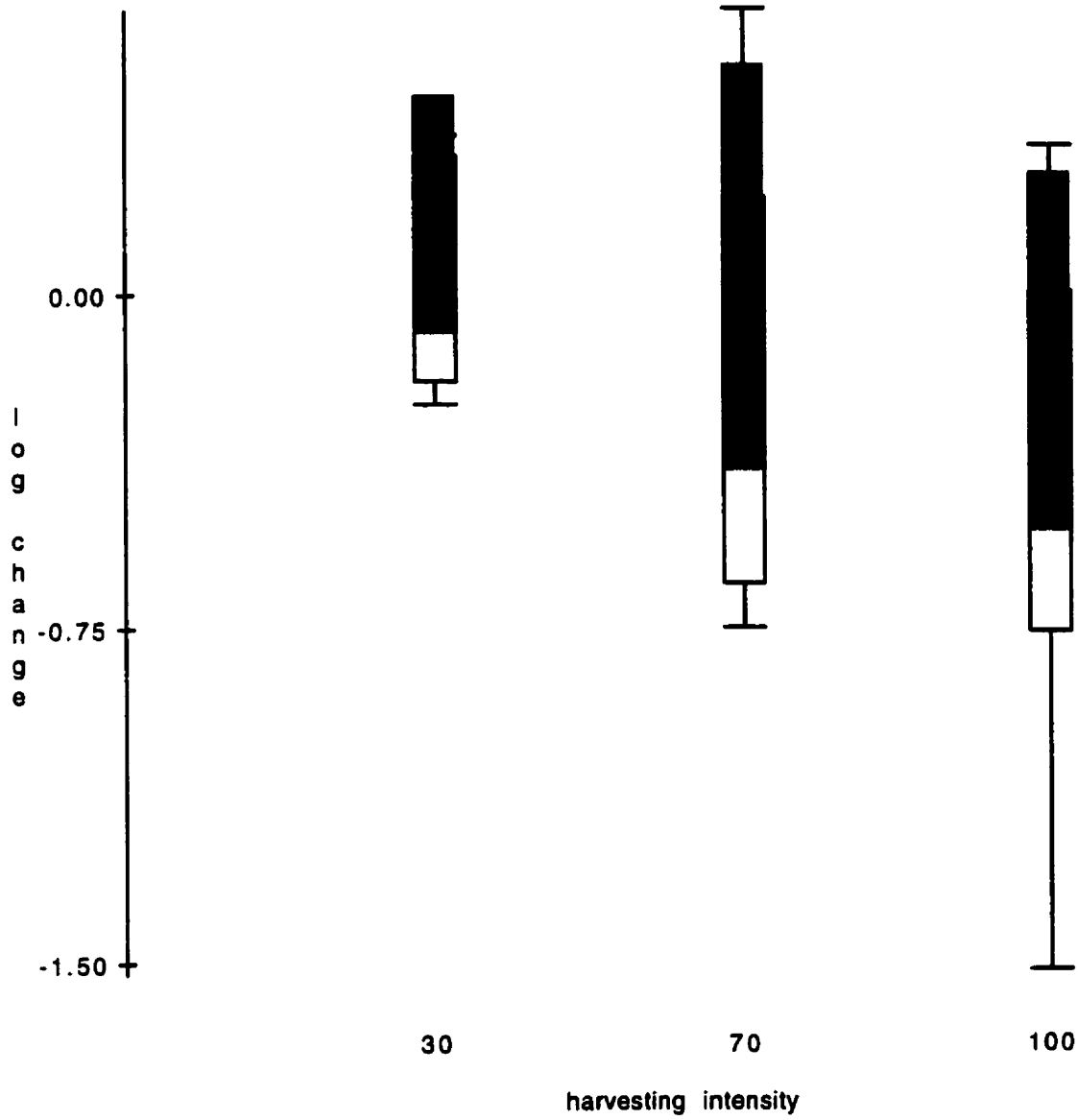
27 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.582095	0.582095	2.2765	0.1444
hi	2	1.07136	0.535682	2.0950	0.1450
Error	24	6.13674	0.255698		
Total	26	7.20810			

Results for factor hi



14.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* mass of fresh berries from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.6).

15.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* volume of fresh berries in Ontario (Table 4.9).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

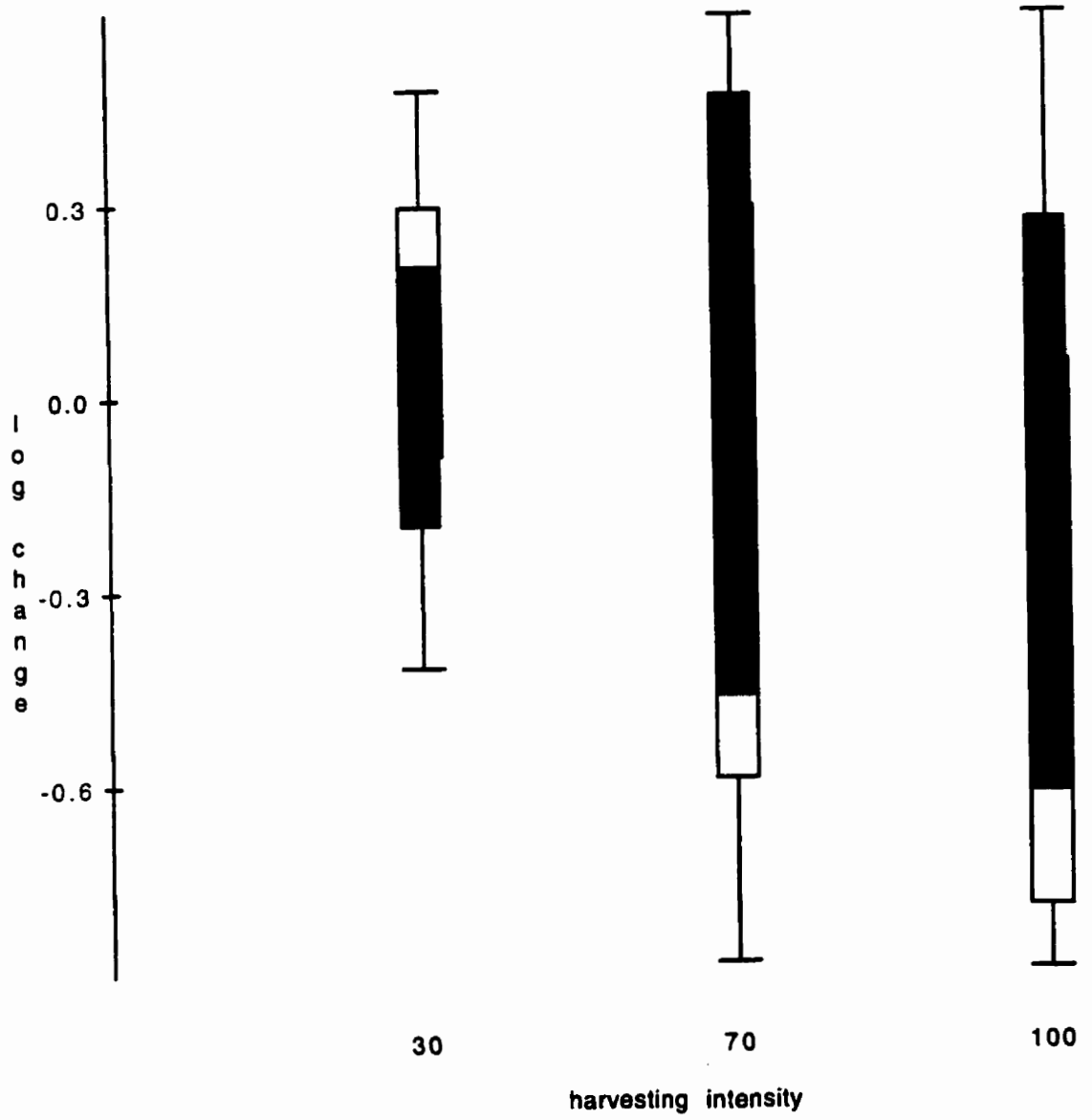
27 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.264854	0.264854	1.2798	0.2691
hi	2	0.406767	0.203384	0.98273	0.3889
Error	24	4.96699	0.206958		
Total	26	5.37375			

Results for factor hi



15.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* volume of fresh berries from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.4).

16.a) ANOVA and post hoc tests performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* shoot density in Ontario (Table 4.10).

DESIGN

Dependent Variable is: change

Factors

Name	Code	Nested in	F/R	Kind
harvest	hrt	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

36 total cases

ANOVA

Analysis of Variance For change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	1.56169	1.56169	70.228	≤ 0.0001
hrt	3	0.276837	0.092279	4.1497	0.0136
Error	32	0.711602	0.022238		
Total	35	0.988439			

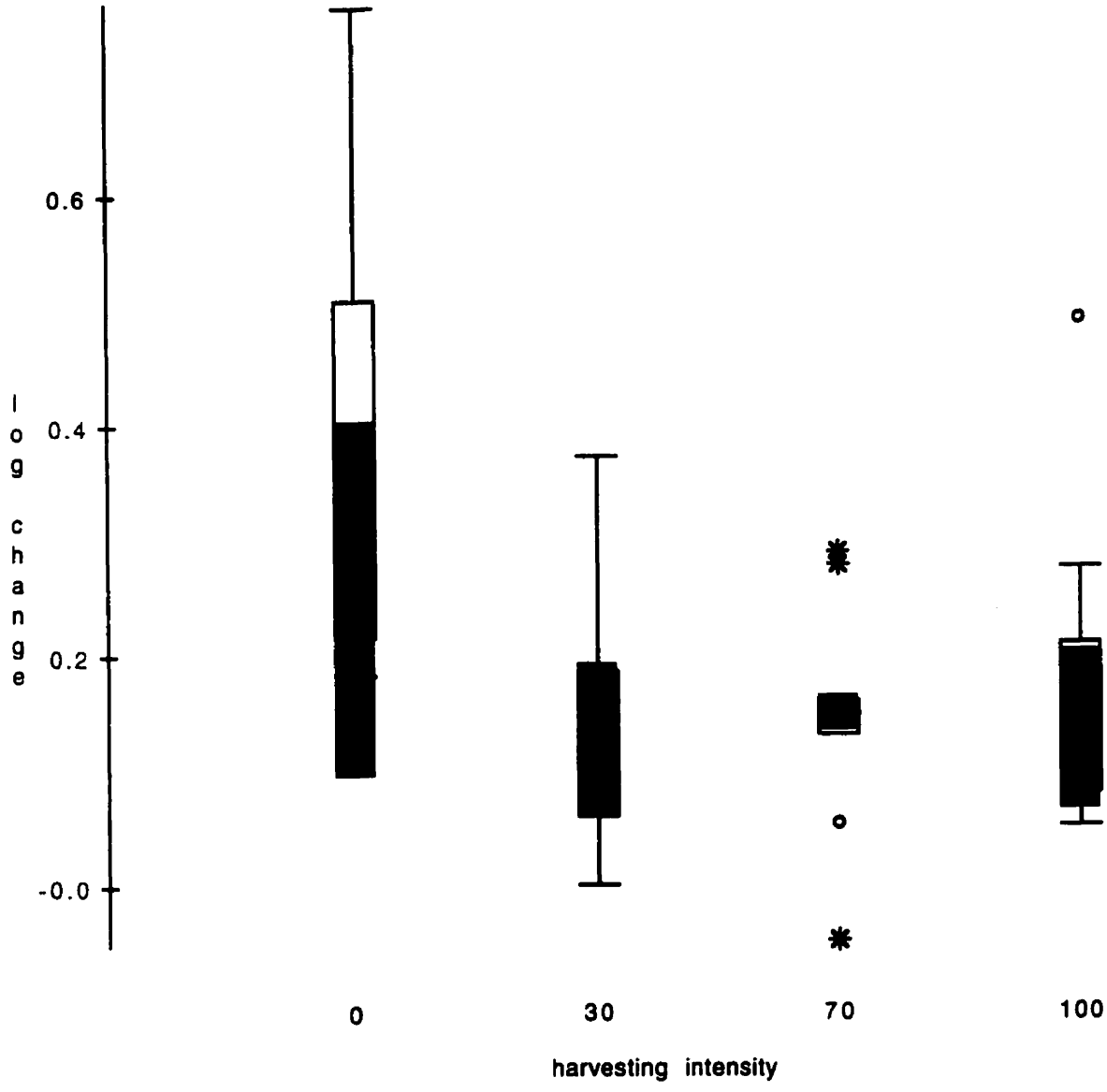
Results for factor hrt

Coefficients

Expected Cell Means

LSD Post Hoc Tests

	Difference	std. err.	Prob
30 - 0	-0.207117	0.0703	0.005955
70 - 0	-0.213222	0.0703	0.004772
70 - 30	-0.006105	0.0703	0.931338
100 - 0	-0.181643	0.0703	0.014538
100 - 30	0.025474	0.0703	0.719452
100 - 70	0.031579	0.0703	0.656300



16.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* shoot density from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.7).

17.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* bud density in Ontario (Table 4.10).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

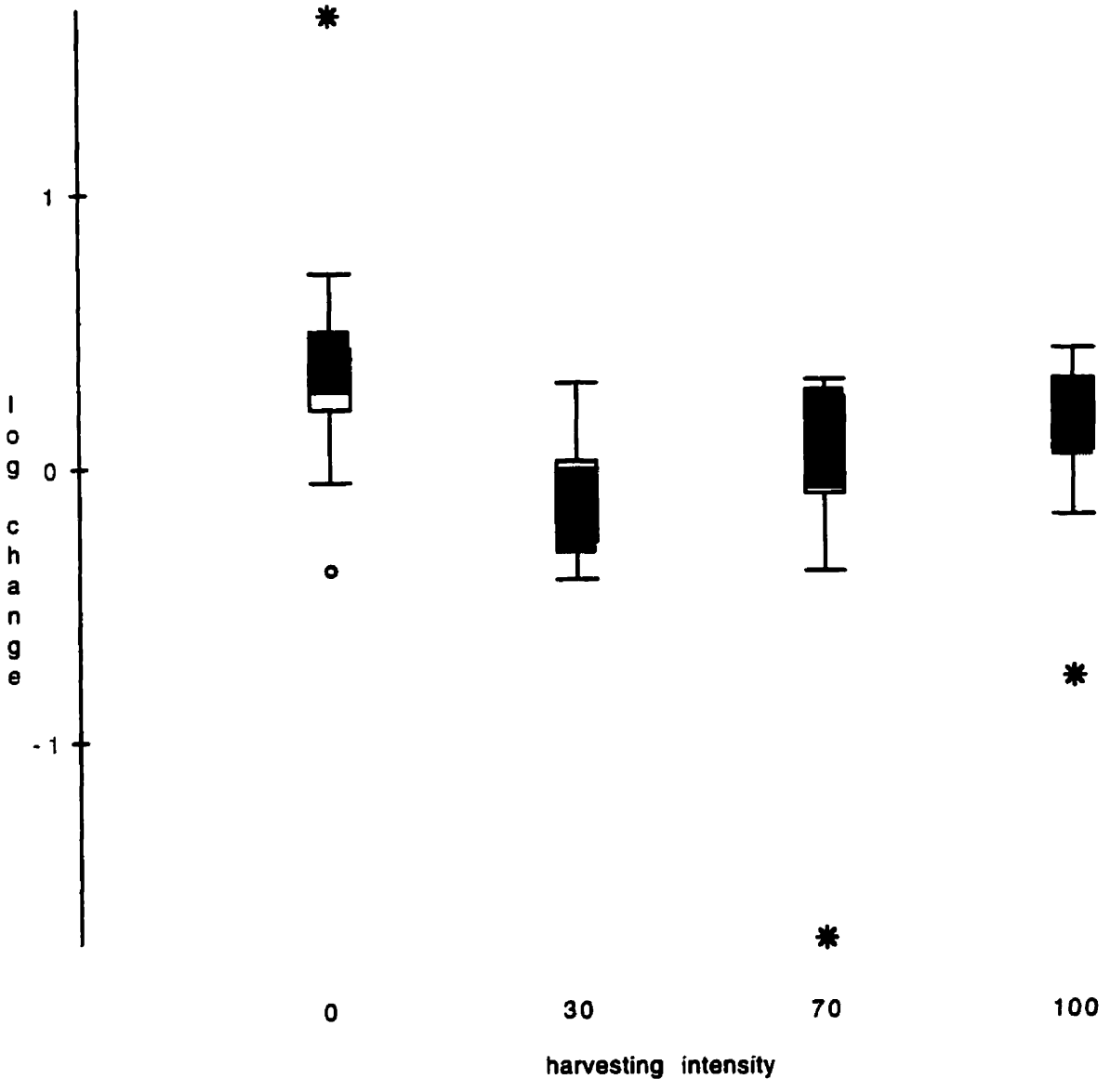
36 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	0.160621	0.160621	0.70860	0.4062
hi	3	1.74137	0.580456	2.5607	0.0722
Error	32	7.25358	0.226674		
Total	35	8.99495			

Results for factor hi



17.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* bud density from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.7).

18.a) ANOVA performed on the $\log_{10}$ changes from Y1 to Y2 on *Vaccinium angustifolium* berry density in Ontario (Table 4.10).

DESIGN

Dependent Variable is: log change

Factors

Name	Code	Nested in	F/R	Kind
harvesting intensity	hi	()	Fix	Disc

Partial (Type 3) Sums of Squares

Interactions up to 1 - way

No Modifications

RESULTS

General Results

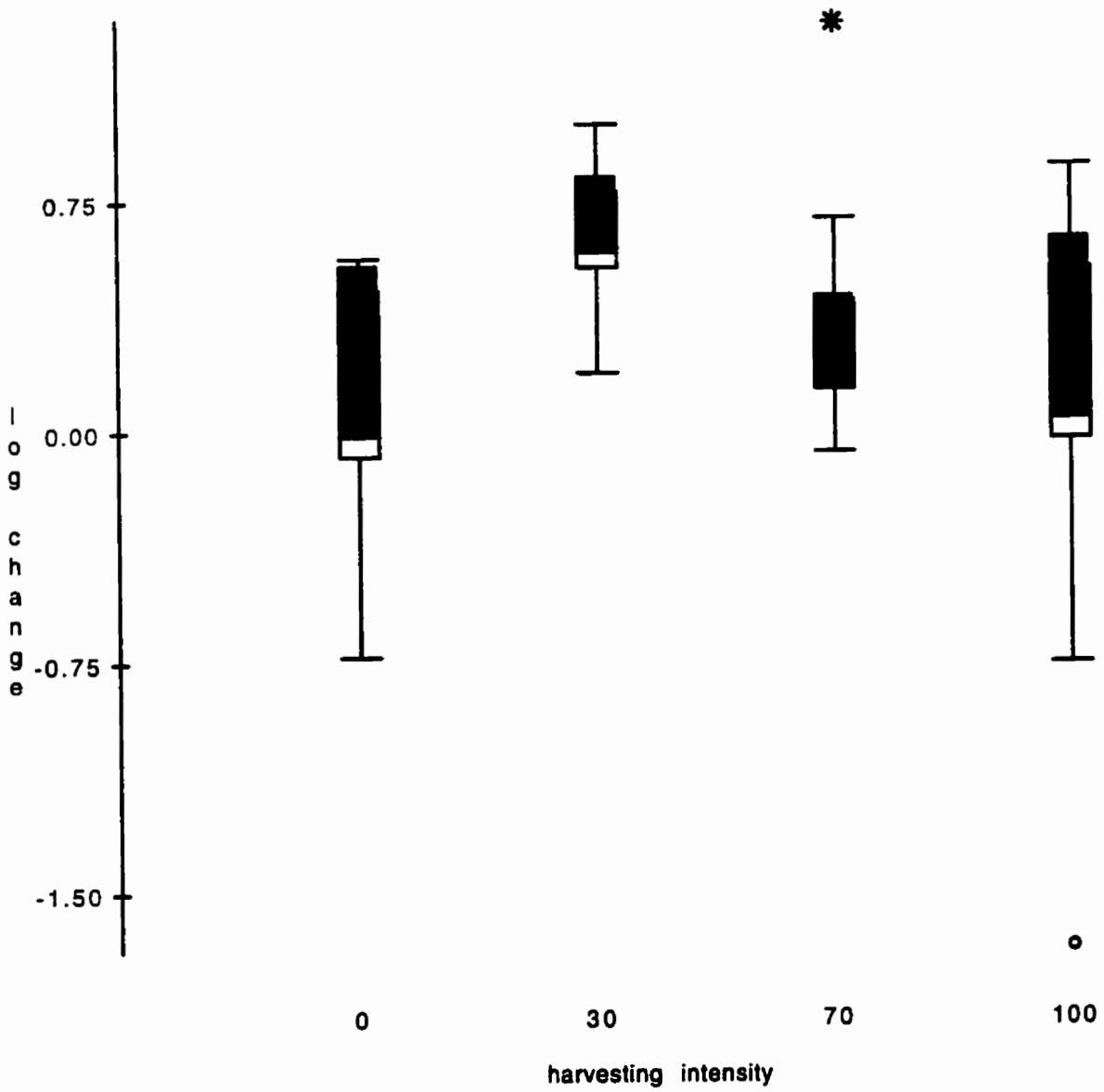
36 total cases

ANOVA

Analysis of Variance For log change
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	3.20994	3.20994	12.260	0.0014
hi	3	2.11725	0.705751	2.6955	0.0624
Error	32	8.37837	0.261824		
Total	35	10.4956			

Results for factor hi



18.b) Box plot created from the $\log_{10}$ changes of *Vaccinium angustifolium* berry density from Y1 to Y2 at various harvesting intensities in Ontario (Figure 4.7).

Appendix V Glossary*

Adventitious roots Roots developing from an unusual position, as roots originating on the stem.

Alternate arrangement Leaves arise singly at each node.

Axil The upper angle where the leaf stalk joins the stem

Blade The broad part of the of a leaf.

Calyx A collective term for the sepals of a flower.

Carminative A herbal remedy rich in volatile oils used for the stimulation of the digestive system (Howarth and Keane 1995).

Caespitose Growing in dense tufts.

Chamaephyte A Raunkiaer life form category where the resting buds are located just above the soil surface.

Corolla A collective term for the petals of a flower.

Corymb A round-topped or flat-topped, racemose inflorescence where the lower pedicels are longer than the upper pedicels.

Decoction A medicine extracted from plant material via boiling water (Merriam-Webster 1998).

Decumbent stems Stems growing prostrate to the ground but with ascending tips

Diploid A cell with two sets of chromosomes.

Edaphic Pertaining to the soil.

Elliptical Shaped like an ellipse, broadest in the middle and narrower at either end.

Ensiform Sword-shaped.

Entire A margin of a leaf that is not toothed, divided or notched

Equitant Leaf bases overlapping or straddling in two ranks.

Frugivore An animal that eats fruits (Merriam-Webster 1998).

Gametes A specialized cell, typically with one sex of chromosomes (haploid), sometimes called a sex cell. The gamete is produced join with another gamete in fertilization and produce a new diploid organism.

Geophyte A Raunkiaer life form category where the buds or shoot apical meristems arise from underground food storage organs, such as, rhizomes, tubers, and bulbs. These storage organs allow the plant to survive unfavorable conditions and produce new shoots when favorable conditions return.

Glabrous A smooth surface without hairs.

Glaucous A waxy, bluish-greenish color as in the bloom seen on plums.

Hybrid The offspring resulting from the crossing of two different species.

Imperfect seeds Ovules unsuccessfully pollinated or unpollinated (Bell 1957)

Inferior ovary An ovary with the sepals, petals and stamens attached above the ovary.

Inflorescence A flowering structure with more than one flower.

Infusion To steep plant material in a liquid (usually water) without boiling to extract the medicinal properties (Merriam-Webster 1998).

Lanceolate Shaped broad in the middle and tapering at both ends.

Litter horizon Accumulation of dead plant material on the soil surface.

Littoral zone The shallow area at the edge of fresh water where sunlight penetrates down to the water-soil interface.

Margin Leaf blade edge.

Obovate Shaped narrow at the leaf stalk and broader towards the tip.

Obpyramidal Inverse pyramidal shaped with the point of attachment at the tip.

Ovule The structure within the carpel that, after fertilization, will develop into the seed.

Pedicel Flower stalk of one flower in an inflorescence.

Peduncle The stalk of an inflorescence.

Perennial Plants that survive more than two seasons and produce flowers every year.

Perfect seeds Ovules successfully pollinated (Bell 1957)

Perigoniate Having sepals, petals and stamens attached to a tube surrounding a superior ovary.

Petiole Leaf stalk.

Pistil Collective term for the female portions of a flower, the stigma, style and ovary(ies).

Proximally Toward the end of the organ by which it is attached.

Pseudo-locule A false cavity in the ovary.

Pubescent Covered in soft downy hairs.

Racemes An elongated, unbranched inflorescence with flowers occurring on short stalks and maturing from the bottom upwards.

Ramet A distinct component of a clonal plant.

Raunkiaer life-form A classification system based on the position of the buds, arising from the vegetative storage organ produced to survive unfavorable conditions, relative to the soil. This system was proposed by the Danish botanist C. Raunkiaer

Rhizomes A creeping underground stem persisting from year to year and giving rise to roots and leaves.

Second year cropping Refers to the second crop of blueberries harvested in a three year rotation management plan where blueberry plants are pruned every third year after harvest (Jordan and Eaton 1995).

Sepal The outer whorl of flower parts usually small, green and leaf-like.

Serrate Coarsely (saw-like) toothed with teeth pointing forward.

Simple A leaf blade that is not divided into leaflets although it may be deeply lobed or cleft.

Spadix A floral spike on a swollen axis.

Spathe A large bract or pair of bracts subtending and often enclosing

Stamen Collective term for the male portions of a flower, filaments and anthers.

Stigma Pollen receptive area on the female reproductive portion of the flower.

Sympodial leaf The penultimate (next to last) leaf which bears the flower and fruiting structure in *Acorus americanus* (Thompson 1995).

Tap root A large, central root growing down in the soil.

Tepal Term referring to both sepals and petals where there is no distinction between sepals or petals.

Tetraploid Containing four complete sets of chromosomes in each cell.

Trimerous Floral parts contained in sets or multiples of three.

Vegetative The non floral parts of a plant.

Verrucose Covered with warty protrusions.

* All terms based on definitions by Allaby 1992 and Harris and Harris 1994 except where otherwise specified.