RESTORATION ECOLOGY OF LUPINE (*LUPINUS PERENNIS*) IN THE NORTH UNIT OF ILLINOIS BEACH STATE PARK: TWO-YEAR RESULTS

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ABSTRACT

Lupine (*Lupinus perennis*) is a perennial legume restricted to sand savanna habitat in the Great Lakes region. This species is locally distributed in black oak (*Quercus velutina*) sand savanna along the Lake Michigan shoreline in Illinois Beach State Park, Lake Co., Illinois; but it is absent from apparently suitable habitat in the north portion of the park. We conducted experimental introduction of this lupine in the north park unit in 1996 and 1997, using seed planting and translocation of greenhouse-propagated seedlings. Both techniques resulted in similar survivorship, and a total of 195 plants were established in 1996. Seedling survivorship dropped from 42.4% to 26.8% following a 20-day June-July period of high temperatures without rainfall. Their percent survivorship was greater in burned than in unburned habitat, and survivorship was negatively correlated with increasing light intensity caused by openings in the savanna canopy. By 1997, survivorship of seeds in 1996-burned habitat dropped to 18.3%, and remained negatively correlated with the canopy light gradient. An additional 453 seeds were planted in 1997 in burned and unburned habitat. Overall survivorship was 20.3%, with no correlation with the canopy light gradient, probably due to more frequent 1997 rainfall. However, survivorship was higher in burned (28.3%) than unburned (11.3%) habitat. After two years, at least 222 lupine plants were established in the study area, and their survivorship and growth was positively affected by prescribed burning, high rainfall frequencies, and protection from dessication by partial shade from savanna canopy oaks.

INTRODUCTION

Lupine (*Lupinus perennis*[1]), a perennial legume of sand soils, is the obligate host plant (Opler & Krizek 1984) for the U.S. threatened (Clough 1992) Karner blue butterfly (*Lycaeides melissa samuelis*). Although lupines occur in sand savanna throughout most of northeastern Illinois (Jones & Fuller 1955), Karner blues appear to have been restricted in Illinois to the Lake Michigan shoreline (Panzer & Stillwaugh 1993). The only modern Illinois Karner blue records are 1992 collections from Illinois Beach State Park (Spencer 1993), where the species has not been relocated (Panzer & Stillwaugh 1993). The nearest extant Karner blue metapopulation is in the Indiana Dunes (Shuey 1993, Grundel *et al*. *In press*). The cause for the apparent loss of Karner blues from Illinois Beach is unknown, but persistence of a butterfly metapopulation probably would have been restricted by the linear distribution of discretely local lupine populations (Figure 1), the ~1 kilometer (0.621 mile) dispersal distance of the butterfly (Givnish *et al*. 1988), and habitat fragmentation of the state park by development for visitor use.

Both lupines and Karner blues require sand savanna habitat in the Great Lakes region, and both may be susceptible at different life stages to the fire regimes necessary to maintain this vegetation. Lupines reportedly decline with fire suppression (Swink & Wilhelm 1994), and have greater biomass and seed production after dormant season fire (Grigore & Tramer 1996). However, seeds germinate during April (N. Pavlovic, pers. comm.), and seedlings are killed by late spring fire (Grigore & Tramer 1996). Lupines survive fire impacts by persisting and spreading vegetatively, and probably reproduce by seed during years without late-season fire.

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[1]Plant nomenclature follows Swink & Wilhelm (1994).

In addition to lupines, Karner blues require savanna heterogeneity that provides mixtures of open and closed canopy conditions (Grundel *et al*., *in press*); but they are susceptible to egg mortality from burning of grass litter (Shuey 1994). Karners survive this paradox by persisting in metapopulations in which females disperse from fire refugia to colonize new or formerly occupied habitats (Givnish *et al*. 1988; Shuey 1993, 1994).

OBJECTIVES

If Karner blue butterflies are to be successfully restored to Illinois habitat along Lake Michigan, lupine populations will have to be expanded beyond their current distribution to provide maximum habitat potential for butterfly metapopulation persistence. A 2.2 km (1.37 mi) void in lupine distribution occurs between the southern-most Wisconsin population at Chiwaukee Prairie, Kenosha Co., Wisconsin and the northern-most Illinois population (Figure 1). Introduction of lupines to the north unit of Illinois Beach State Park would help provide butterfly metapopulation linkage in this area. This study was designed to initiate experimental lupine restoration in the north unit of Illinois Beach. We asked whether survivorship and growth of *in situ* germinated seedlings and transplanted *ex situ* grown seedlings differed across the savanna canopy light gradient and in relation to burn-unburned treatments. This allows establishment of a “win-win” situation, in which lupines are established while experimentation helps identify successful establishment methods.

STUDY AREA

The Lake Michigan shoreline ecosystem in Lake Co., IL and adjacent Kenosha Co., WI comprises a 1.5 km (~1 mi) wide ridge-and-swale sand deposit that extends for 22.6 km (14 mi). This sand plain is transient in time and is oldest near the Illinois Wisconsin border (Figure 1). Beach ridges, which provide substrate for dry-mesic savanna and lupines, are developed from eolian sand, with ages ranging from 2,000-3,000 years BP in the south to >3500 years BP in the north (Hester & Fraser 1973, Fraser & Hester 1974). The highest ridges reach 180 m (590 ft) elevation, about 1.5 m (5 ft) above dune swales, and their soils are shallow and well drained. As a result of rapid drainage, the dune vegetation is subject to stochastic, severe drought effects during perods of low rainfall and high temperatures, which characterize July and August weather.

Lupines are locally distributed in the study area, with at least six populations ranging from 1,400 to 4,550 plants (Figure 1, Panzer & Stillwaugh 1993). In Wisconsin, lupines occur adjacent to the Holocene bluffline along the western edge of the Chiwaukee Prairie, a sand prairie and savanna located just north of the Illinois state line. At Illinois Beach, lupines occur primarily in sand savanna, with the largest populations in fire-managed habitat in the south state park unit within a State Nature Preserve (Bowles & McBride 1995). Here, lupines occur between 20-50% frequency in areas with 50-70% canopy cover, about 10% open sand, and dominance by the grass *Stipa spartea* and the forbs *Coreopsis lanceolata,* and *Helianthus occidentalis*. North of Illinois Beach at Hosah Prairie (Figure 1), lupines occur in more shaded savanna (>80% canopy cover) that has less fire frequency. Lupines are less frequent in this area and *Carex pensylvanica* and *Helianthus divaricatus* are most abundant.

For this experimental restoration, we selected a northern extension of the beach ridge that harbors the Hosah Prairie lupine population. The study site (Figure 2) is 1.6 km (1 mi) north of Hosah, and located in the NW1/4 SW1/4 S14, T46N, R23E (Zion, Ill. 7.5' Quadrangle). This ridge was inspected in 1995 and found to contain sand savanna with canopy heterogeneity thought to be capable of supporting an experimental lupine population that might eventually support Karner blue butterflies. This habitat was apparently grazed in the 1930's (Pepoon 1937), which could have eliminated any original lupine populations and lowered plant species diversity.

METHODS

Seed collection and propagation

Lupines are self-incompatible, requiring outcrossing for seed production (Michaels 1995). To avoid inbreeding and to enhance lupine reproductive success (Fenster & Dudash 1994), we used two different lupine seed sources. Seeds were randomly collected among plants in 1994 from the nearest eastern population, in Lake County, Indiana, and in 1995 and 1996 from the Illinois Beach Nature Preserve north of the Dead River. All seeds were stored under dry refrigerated conditions. Lupines have seed morphs with differing seed coat permeability, and germination is enhanced by moist stratification and scarification (Grigore & Tramer 1996). To standardize germination, we pooled seed morphs, scarified all seeds, and provided a two-week moist stratification prior to planting.

1996 experiments

Seeds from Lake County, Indiana were used to test *in-situ* field germination. All seeds were inoculated with *Rhizobium* bacteria, which form nitrogen fixing nodules that benefit lupine establishment in poor soils (Allen & Allen 1981). On 9 May, 1996, we planted 660 seeds in habitat that was burned in spring, 1996, and 82 seeds in unburned habitat on the same beach ridge. An unbalanced design was used to enhance seedling establishment because we expected greater seed germination in burned habitat. Planting sites were located along stratified random 30-meter transects laid out orthoganal to the beach ridge. In burned habitat, each of 11 transects had three random meter square plots in which 20 seeds were planted 0.1-meter apart in two parallel rows separated by 0.1 meter. One full transect and one additional 0.5 meter-square plot (with 22 seeds) were established in unburned habitat. All transects and plots were permanently marked. Plot markers were not made highly visible to avoid loss to park visitors, which use a trail that bisects the study area. As a result, plot locations had to be re-surveyed for monitoring, and three plots could not be relocated in 1997.

Seeds collected at Illinois Beach State Park in 1995 were greenhouse-germinated in spring 1996 for translocation into the study site. This experiment used 142 moist-stratified and scarified seeds propagated in a 1:1 sand:greenhouse soil mix. After germination, half of the seedlings were inoculated with *Rhizobium* to compare its effect on their establishment after translocation. Sixty-six of these seedlings were translocated to the study site on 7 July 1996. Single seedlings were planted at either end of each set of parallel 0.5 meter seed planting rows, resulting in two plants in each meter square plot.

1997 experiments

Seeds collected from Illinois Beach State Park in 1996 were used to test *in-situ* field germination in burned and unburned habitat in 1997. All seeds were inoculated with *Rhizobium* bacteria. A dormant season burn was applied to the east half of the beach ridge study site in spring 1997, prior to seed planting. On 26 March, 1997, we planted 460 seeds in a 20-plot subset of the 33 plots located in the 11 transects established in burned habitat in 1996. We used two plots in each of 10 of the original 11 transects established in burned habitat in 1996. In 19 of the plots, 24 seeds were planted (1 plot had 21 seeds) 0.1-meter apart in three parallel rows located orthoganally to the seed planting rows established in 1996. This resulted in a “cross” shaped planting diagram in each meter square plot. One plot could not be relocated, and a second could not be used for analysis because of its location on a trail. This resulted in 18 of the plots occurring in either burned (n = 7 plots) or unburned (n = 11 plots).

Data collection

Vegetation data were collected at each of the 33 planting plot site locations in burned habitat. Herb layer vegetation was sampled by species presence, and forb, shrub, and graminoid cover in 0.5 meter-square plots centered over the seed planting rows. Tree frequency, density and diameter at one meter were collected in .005 ha ($50m^2$) circular plots (r = ~4m) centered over each planting site. Photosynthetically active radiation (PAR in μmol m^{-2} s^{-1}) was measured on 24 July 1996 with a Lycor LI-250 meter by averaging 10 instantaneous readings at 0.1-meter intervals one meter above the seed planting plots. In 1996, lupine seedling survivorship was quantified on 7 July and on 24 July 1996. Survivorship of translocated lupines was also determined on 24 July 1996. In 1997, all lupine seedling survivorship was quantified on 18 June, At that time, the sizes of lupines planted in 1996 were quantified by counting the number of leaves on each plant.

Data analysis

Ground-layer data were ordinated by Detrended Correspondence Analysis (DCA) and classified by Two-way-species-indicator-analysis (TWINSPAN) on PCORD software (McCune 1993). DCA aligns species along strong environmental gradients, while TWINSPAN determines floristic groups that usually correspond to the first DCA axis (Gauch 1982). TWINSPAN separated three community types, which were compared for differences in mean PAR intensity, tree stem size, and basal area. Regression analysis was used to compare survivorship of lupine seedlings with PAR on 7 July and 24 July 1996, and survivorship of the same cohort in relation to PAR on 18 June 1997. Chi-square analysis was used to test proportional differences in seedling survivorship between burn and non-burn treatments in 1996 and in 1997, and differences in juvenile survivorship in burn and non-burn treatments in 1997. Analysis of variance (ANOVA) was used to test differences in mean number of leaves per plant among juvenile lupines in burned and unburned habitat at low and high light levels on 18 June 1997.

RESULTS

Weather

Northeastern Illinois experienced unseasonably cool temperatures and excessive rainfall from mid-April until late June 1996, which probably enhanced lupine germination and establishment (Figure 3). However, this was followed by a 20-day (25 June-14 July) period without rainfall, during which regional temperatures averaged 86.25° (± 3.65 sd) and probably stressed seedlings. Spring weather conditions were similar in 1997, but there were no extended summer periods without ranfall.

Vegetation structure and light levels

Black oak (*Quercus velutina*) is the single canopy tree species characterizing the study site. The savanna canopy structure ranges from oak grub sprouts (probably from past fires) to larger canopy trees, with ground-layer dominance by the grasses *Stipa spartea* and *Poa compressa,* the forb *Comandra umbellata*, and the woody plants *Rhus radicans* and *Rosa carolina*. Based on differing abundances of other ground-layer species (Table 1), DCA and TWINSPAN divided savanna vegetation into three types (Figure 4), that also relate to differences in woody structure and PAR (Table 2). Savanna Type I is characterized by the grasses *Andropogon scoparius* and *Koeleria micrantha,* and the forb *Liatris aspera*. It has intermediate *Q. velutina* stem frequency and density, but comparatively small stem size, low basal area, and high PAR essentially representing full sun (Table 2). Savanna Type II is characterized by *Calamovilfa longifolia* and *Tradescantia ohiensis*, low tree frequency and density, large stem size, and intermediate basal area and PAR. Savanna Type III is characterized by *Carex penslyvanica, Helianthus divaricatus*, *Smilacina stellata* and *Juncus balticus,* high stem frequency and density, intermediate stem size, high basal area, and low PAR. PAR intensity ranged from 16.1 ±1.23 (x10^2) in the Type I savanna to 11.5 ±1.59 (x10^2) in the Type III savanna (Table 2), and was thus reduced by about 29% in areas of greatest basal area.

<u>Lupine germination and survivorship, and the effects of light level</u>

On 7 July 1996, 280 seedlings were present, representing 42% germination of the 660 field-planted lupine seeds, with plants present in all 33 plots. However, light intensity measured by PAR had a significant negative effect on lupine survivorship (Figure 5). On 24 July 1996, after the 20-day drought period, 177 (26.8%) of the seedlings still maintained green leaf tissue and appeared alive. By then PAR intensity had a greater significant negative effect on lupine survivorship, increasing the negative slope of the regression line (Figure 5).

Eighty-two (57%) of the greenhouse-planted lupine seeds germinated. Only 15 (22.7%) of the translocated lupines appear to have survived through 24 July 1996. This survivorship did not differ from that of seedlings established from directly planted seeds (X^2 = *1.23,* P = .268); but, significantly more translocated plants (X^2=4.43, P=.036) survived that were inoculated (38.7%) than those that were not inoculated (8.6%).

In 1997, three plots could not be relocated. Among the remaining plots that were monitored, the cohort of 1996-planted seedlings had dropped to 121 plants, whose percent survivorship per plot was still significantly affected by light level (F = 6.38, P = .018). On 24 July 1996, the plots containing these plants had 151 plants, which indicates that over-winter survivorship was 80.7%. The three missing plots had an additional 29 plants, more than 20 of which may have survived into 1997. On 18 June 1997, 20.3 % of the 1977 spring-planted seeds appeared to have survived, although one missing plot could not be censused. Survivorship of these plants did not correlate with the savanna canopy light gradient (F = 0.14, P = 0.709), but was strongly affected by fire (see below).

<u>Effects of fire on lupine survivorship and growth</u>

Fire had significant positive effects on lupine survivorship in 1996 and in 1997 (Figure 6). In 1996, 26.8% seedling survivorship occurred in dormant-season burned habitat in comparison to only 3.7% in recently unburned habitat. In 1997, 93.6% of the 1996 cohort survived in habitat that was burned that spring, in comparison to 54.9% survivorship in unburned habitat, which was burned in 1996. Among spring planted seeds in 1997, 28.3% survived in the habitat that was spring-burned, while 11.3% survived in habitat that was burned in 1996. Growth of the 1996 lupine cohort in 1997 was positively affected by fire, which interacted with light levels (Figure 7). Here, mean number of leaves per plant averaged 5.4 (±0.4) in burned habitat in comparison to 3.9 (±0.32) leaves in unburned habitat. However, plant size averaged 7 ±1.10 leaves in burned habitat under high light levels, which was higher than all other experimental combinations (Figure 7).

DISCUSSION

<u>Status of the restored lupine population</u>

At the end of July 1996, a total of 222 lupines appear to have survived experimental seed planting and translocation at Illinois Beach, and an additional 20 plants may survive in missing plots. In contrast to the 25% or less second year survivorship found by other studies (Zaremba *et al*. 1991, Boyonoski 1992), our 80% survivorship indicates that optimum habitat conditions are present at the study site. Our findings also indicate that direct establishment of plants from seed may allow survival rates that are similar to those obtained by translocating plants. Seed planting is far more effecient than translocation because it eliminates greenhouse propagation and handling of plants, and allows more rapid establishment or a greater number of plants. None of our restored plants flowered in 1997, and time required to reach flowering sizes is unknown.

Vegetation structure

Vegetation structure in the study area appeared to fall within the range of conditions capable of supporting lupine populations. Light levels at the study site ranged from almost full sun in savanna with lowest basal area to 29% less PAR in savanna with highest basal area. Although many plants (*e.g.* the prairie grass *Stipa spartea*) dominated all savanna types, other species indicated sensitivity to this light gradient. Prairie vegetation such as *Andropogon scoparius* and *Koeleria micrantha* were restricted to areas of greater light, while the savanna species *Carex pensylvanica* and *Helianthus divaricatus* characterized areas of lower light. In comparison, local native lupine populations occupy plant communities that include open sand prairie at Chiwaukee Prairie, open sand savanna with 50-70% canopy cover supporting *Coreopsis palmata* and *Helianthus occidentalis* at Illinois Beach, and light gaps in >80% closed sand savanna with *Carex pensylvanica and Helianthus divaricatus* (Bowles & McBride 1995).

Factors affecting survivorship

Multiple factors appear to affect lupine survivorship, including preplanting *Rhizobium* innoculation, burn-nonburn treatments, rainfall and temperature variability, and savanna canopy effects on light levels. These factors are hierarchical and appear to interact, with weather extremes having an overriding effect on fire and light levels, and fire interacting with canopy light level and having an overriding effect on innoculation.

Rhizobium inoculation, which increases N fixation, apparently enhanced survivorship of seedlings translocated into burned habitat, maintaining 38.7% survivorship in comparison to 8.6% in nontreated seedlings. *Rhizobium* may have enhance the 26.8% first-year survivorship of seedlings produced from seeds directly planted in burned habitat, as all of these seeds were inoculated. However, extremely low survivorship in unburned habitat indicates that absence of fire may have a greater effect than *Rhizobium* on initial survivorship.

Dormant season fire is well known for its positive effects on herbaceous plant biomass, flowering, and seed production, including such effects on lupine (Grigore & Tramer 1996). Indeed, the much greater percent survivorship of seedlings and juveniles under the burn treatments in this study suggest that failure to use a preplanting prescribed burn could cause a loss of a large number of seedlings. The even greater survivorship rate of second year plants with fire almost exluded all mortality from this cohort under a fire treatment, and allowed greatest lupine growth under highest light conditions. However, high rates of seedling mortality could occur if burns are implemented after lupine germination (Grigore & Tramer 1996).

Stochastic weather extremes appear capable of either enhancing or negatively impacting lupine establishment. Lupine seedlings appear vulnerable to unpredictable drought, as indicated by the decline from 42.4% to 26.8% survivorship after drought in early July, 1996. This mortality increased an already significant negative relationship between increasing light levels and lupine survivorship. As a result, more surviving plants occurred under savanna canopy shade, which would provide greater protection from dessication caused by drought. These effects probably contribute to the restriction of this plant to sand savanna in the Great

Lakes region. However, the less severe weather conditions in 1977 apparently moderated potential negative impacts of high light levels, indicating the stochastic nature of weather effects on lupines.

Potential for eventual Karner blue restoration

These preliminary results suggest that lupine restoration is possible at Illinois Beach North, which could set the stage for reintroduction of Karner blue butterflies. However, additional factors need consideration for developing a habitat suitable for Karners. Large lupine plant sizes and high local densities may be needed to attract and sustain use by Karner blues Grundel *et al*. (*in press*). The smallest native lupine population at Illinois Beach was estimated by Panzer & Stillwaugh (1993) at 1-2000 plants. We suggest a minimum of 2000 plants as a restoration goal for Illinois Beach North, with 20-50% lupine sampling frequencies within lupine colonies. With a ~20% establishment rate, this would require planting of 10,000 lupine seeds in appropriate habitat.

Both canopy structure and vegetative composition affected Karner success in Indiana (Grundel *et al*., *in press*). Canopy heterogeneity was important, as greatest Karner oviposition rates and larval growth occurred in 30-60% canopy cover, while adult males used canopy opening where more nectar sources were present. In Indiana, first brood Karners preferentially used (in decreasing order) species such as *Arabis lyrata, Euphorbia corollata, Coreopsis lanceolata, Rubus flagellaris* and *Erigeron strigosus* as nectar plants, while second brood Karners used *Helianthus divaricatus, E. Corollata, Melilotus alba, Monarda punctata,* and *Solidago speciosa.* Except for *Euphorbia corollata*, few of these plants are frequent in the study area, and their introduction may be needed to increase habitat use by Karners. Extant lupine populations in the south unit of Illinois Beach support greater plant species diversity, and could serve as models for community restoration into the north unit (Appendix II).

SUMMARY AND RECOMMENDATIONS

1) Continued lupine restoration should use areas of sand savanna with canopy cover that reduces light by about 30%, which provides shade protection during drought years.
2) As a result, management should not reduce oak canopy cover in the study area.
3) Because of the ease in inoculating and directly planting seeds, and comparable survivorship of seeds and translocated seedlings, direct seeding is a cost-efficient method for lupine introduction.
4) Supplemental watering could be used to increase seedling survivorship during drought periods.
5) Continued monitoring is needed to determine the length of time required for plants to reach reproductive stages.
6) Prescribed burns should be use to enhance seedling establishment and plant growth.
7) Further investigation is needed to determine the appropriate abundances of lupines needed to support a Karner blue population.
8) Further work is needed to determine if the study area provides the necessary presence and abundance of appropriate nectar sources for Karner blues, and if these species will require introduction to help maintain a Karner blue population.

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Table 1. Plant species frequencies in sand savanna lupine restoration plots at Illinois Beach North. Arranged by combined frequencies, and by frequencies in TWINSPAN savanna categories.

Species	combined Frequency	Relative Frequency	TWINSPAN categories I	II	III
Stipa spartea	97.0	10.9	100	90	100
Rosa carolina	84.85	9.5	100	100	83.3
Poa compressa	81.8	9.15	90.9	70	83.3
Rhus radicans	72.7	8.16	72.7	80	66.7
Commandra umbellata	57.6	6.5	54.5	59	66.7
Euphorbia corollata	57.6	6.5	100	30	44.7
Aster ericoides	51.5	5.8	45.5	60	50
Andropogon scoparius	33.3	3.7	66.7	30	0
Physalis virginiana	24.2	2.7	41.7	10	18.2
Koeleria micrantha	15.2	1.7	41.7	0	0
Carex muhlenbergii	9.1	1.0	25	0	0
Liatris aspera	6.1	0.7	16.7	0	0
Melilotus alba	6.1	0.7	16.7	0	0
Artemisia caudata	3	0.3	8.3	0	0
Cyperus filiculmis	3	0.3	8.3	0	0
Rubus occidentalis	3	0.3	8.3	0	0
Calamavilfa longifolia	21.2	2.4	8.3	60	0
Amorpha canescens	9.1	1.0	8.3	20	0
Potentilla arguta	15.2	1.7	8.3	30	9.1
Helianthemum canadense	6.1	0.7	8.3	10	0
Arabis lyrata	6.1	0.7	8.3	10	0
Andropogon gerardii	3	0.3	0	10	0
Equisetum hyemale	3	0.3	0	10	0
Euphorbia polygonifolia	3	0.3	0	10	0
Lithospermum canescens	3	0.3	0	10	0
Petalostemum purpureum	3	0.3	0	10	0
Populus tremuloides	3	0.3	0	10	0
Sorghastrum nutans	3	0.3	0	10	0
Tradescantia ohiensis	36.4	4.1	0	90	27.3
Helianthus occidentalis	6.1	0.7	0	20	0
Oenothera biennis	6.1	0.7	0	20	0
Arenaria lateriflora	6.1	0.7	0	10	9.1
Rudbeckia hirta	6.1	0.7	0	10	9.1
Coreopsis palmata	6.1	0.7	0	10	9.1
Achillea millefolium	9.1	1.0	0	20	9.1
Solidago speciosa	18.2	2.0	16.7	10	36.4
Smilacina stellata	15.2	1.7	0	10	27.3
Carex pensylvanica	15.2	1.7	0	10	36.4
Asparagus officinalis	12.1	1.4	0	10	27.3
Juncus balticus	21.2	2.4	0	10	54.5
Helianthus divaricatus	9.1	1.0	0	0	27.3
Elymus canadensis	6.1	0.7	0	0	18.2
Fragaria virginiana	6.1	0.7	0	0	18.2
Asclepias syriaca	3	0.3	0	0	9.1
Carex sp	3	0.3	0	0	9.1
Daucus carota	3	0.3	0	0	9.1
Smilacina racemosa	3	0.3	0	0	9.1
Solidago gigantea	3	0.3	0	0	9.1
Teucrium canadense	3	0.3	0	0	9.1
Viburnum prunifolium	3	0.3	0	0	9.1
Viola sp	3	0.3	0	0	9.1
Vitis sp	3	0.3	0	0	9.1

Table 2. Differences in *Quercus velutina* stand structure and PAR (x10^2) in savanna types classified by TWINSPAN at Illinois Beach State Park. Values per hectare are projections from .005 ha plot data. PAR is in µmol s^{-1} m^{-2} x 10^2.

Savanna Type	Mean stem size	Stem density./ha	Grub density/ha	Mean basal area/ha	Mean PAR x 10^2
I	0.91 ± 0.08	367.4	267.2	282.00	16.1 ±1.23
II	2.24 ± 0.60	140.0	100.0	776.20	12.8 ±1.89
III	1.41 ± 0.15	509.6	291.2	1038.73	11.5 ±1.59

Table 3. Lupine seedling survivorship. Survivorship data for 1996 represents 24 July monitoring. Data for 1997 represents 18 June monitoring.

Planting and treatment	Number planted	Number and % survivorship
Translocated greenhouse-propagated seedlings		
Total	66	15 (22.7%)
inoculated	31	12 (38.7%)
not inoculated	35	3 (8.6%)
1996 field - planted seeds		
Total	742	180 (24.3%)
burned	660	177 (26.8%)
unburned	82	4 (4.9%)
1997 field - planted seeds		
Total	460	101 (22.0%)
burned	240	68 (26.8%)
unburned	213	24 (11.3%)
unknown	17	9 (52.9%)
Total surviving in 1997	1268	222+ (17.5+%)

Appendix II. Plant species composition (relative abundance) in savanna habitats with lupine at Illinois Beach State Park (Transects No.1 & No.2), Hosah Prairie, and Spring Bluff Nature Preserve (Bowles & McBride 1995).

Species	Illinois Beach T1	Illinois Beach T2	Hosah Prairie	Spring Bluff
Coreopsis lanceolata	13.38	11.92	1.14	-----
Poa compressa/pratensis	11.97	9.27	12.57	17.06
Lupinus perennis	9.86	4.63	2.86	-----
Helianthus occidentalis	7.75	8.61	-----	-----
Stipa spartea	7.75	8.61	-----	7.93
Carex muhlenbergii	7.04	-----	0.57	4.88
Sorghastrum nutans	5.63	5.96	-----	-----
Euphorbia corollata	4.93	3.97	5.14	7.32
Comandra richardsiana	3.52	0.66	2.29	6.71
Prunus virginiana	3.52	3.31	1.14	-----
Rosa carolina	3.52	3.97	-----	-----
Smilacina stellata	2.11	3.97	1.71	1.22
Koeleria cristata	2.11	3.97	0.57	-----
Arabis lyrata	2.11	-----	-----	-----
Asclepias tuberosa	2.11	3.97	-----	-----
Solidago rigida	2.11	-----	-----	-----
Hieracium canadense fas.	2.11	-----	-----	0.61
Liatris aspera	1.41	2.64	-----	-----
Andropogon gerardi	1.41	0.66	6.29	-----
Physalis virginiana	0.70	-----	-----	0.61
Tradescantia ohiensis	0.70	0.66	1.14	2.44
Helianthemum	0.70	-----	-----	-----
Rudbeckia hirta	0.70	0.66	0.57	-----
Aster azureus	0.70	0.66	0.57	-----
Anemone cylindrica	0.70	1.99	1.14	1.83
Rhus radicans	0.70	-----	1.71	-----
Asparagus officinalis	0.70	0.66	-----	-----
Quercus velutina	-----	4.64	1.71	1.22
Carex pensylvanica	-----	3.31	9.71	-----
Sisyrinchium albidum	-----	1.99	-----	-----
Phlox pilosa	-----	1.32	2.29	-----
Andropogon scoparius	-----	0.66	-----	-----
Panicum villosissimum	-----	0.66	-----	-----
Juncus balticus	-----	0.66	0.57	-----
Vitis riparia	-----	0.66	6.29	1.22
Helianthus divaricatus	-----	-----	9.14	-----
Maianthemum canadense	-----	-----	4.57	3.05
Achillea millefolium	-----	-----	4.57	5.49
Monarda fistulosa	-----	-----	4.00	-----
Solidago speciosa	-----	-----	3.43	3.66
Arenaria lateriflora	-----	-----	2.86	-----
Rosa sp.	-----	-----	2.29	-----
Rubus occidentalis	-----	-----	2.29	-----
Amorpha canescens	-----	-----	1.14	-----
Equisetum arvense	-----	-----	1.14	2.44
Rhamnus frangula	-----	-----	0.57	0.61
Viola sp.	-----	-----	0.57	-----
Smilax	-----	-----	0.57	-----
Epipactus helleborine	-----	-----	0.57	-----
Taraxacum officinale	-----	-----	0.57	-----
Lonicera	-----	-----	0.57	2.44
Fragaria virginiana	-----	-----	0.57	1.83
Asclepias syriaca	-----	-----	0.57	-----
Linaria vulgaris	-----	-----	-----	9.15
Equisetum hymale	-----	-----	-----	5.49
Potentilla simplex	-----	-----	-----	3.66
Panicum implicatum	-----	-----	-----	2.44
Hieracium pratense	-----	-----	-----	1.83
Prunus serotina	-----	-----	-----	1.22
Lespedeza capitata	-----	-----	-----	1.22
Festuca ovina	-----	-----	-----	1.22
Potentilla arguta	-----	-----	-----	0.61
Baptisia leucantha	-----	-----	-----	0.61

Figures

1. Lake Michigan shoreline sand depostit showing locations of extant lupine populations (solid circles) and proposed lupine reintroduction site (open circle).

Figure 2. Location of beach ridge (between arrows) used for experimental lupine introduction at Illinois Beach North. Scale: 5 cm = 0.60 km (5 in ~ 1.0 mi).

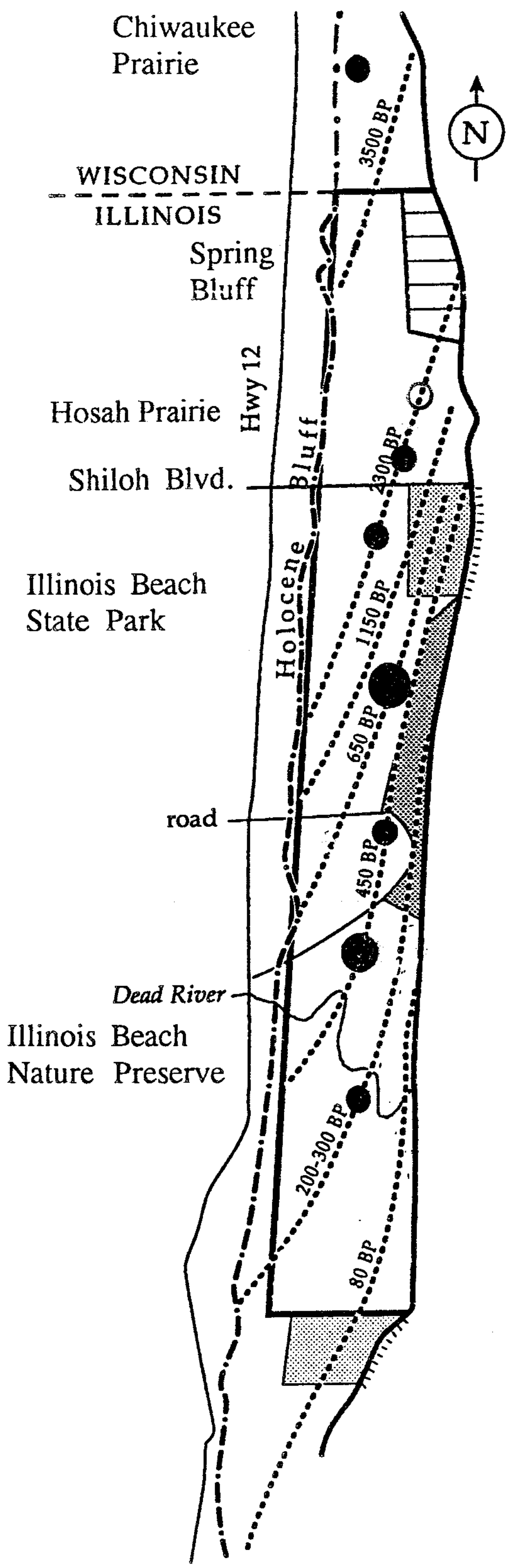
Figure 3. Weather data

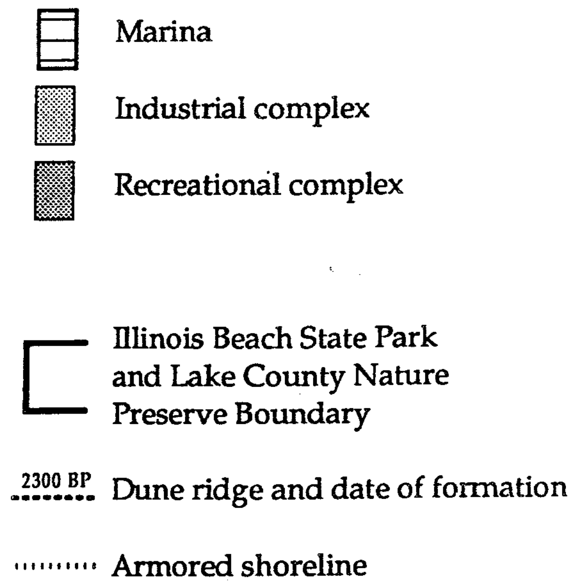
Figure 4. Detrended Correspondence Analysis (DCA) of lupine restoration plots at Illinois Beach North. Stand numbers (I-III) represent TWINSPAN classification of savanna vegetation. Axis 1 represents increasing basal area and decreasing light.

Figure 5. Relationship between percent lupine survivorship (S) on 7 July 1996 (circles) and 24 July 1996 (triangles) and light levels measured in PAR at Illinois Beach North.

7 July 1994 regression line: S = 45 -1.33 x PAR ($x10^2$) (F = 12.49, P= .001),
24 July regression line: S = 55.37 -2.134 x PAR ($x10^2$). (F = 19.97, P <.0001).
Figure 6. Positive fire effects on survivorship of lupine seedlings in 1996 (upper graph) and in 1977 (center graph), and on juvenile lupines in 1977 (lower graph).

Figure 7. Factorial comparison of fire and light intensity (in PAR) effect on mean number of leaves per plant in juvenile lupines. Low light intensity = 11.5 x 10^2 PAR, high light intensity = 16.1 x 10^2 PAR. ANOVA: light treatment: F = 2.63, P = .1096; fire treatment: F = 5.15, P = .0264; light x fire: F = 4.75, P = .0328.





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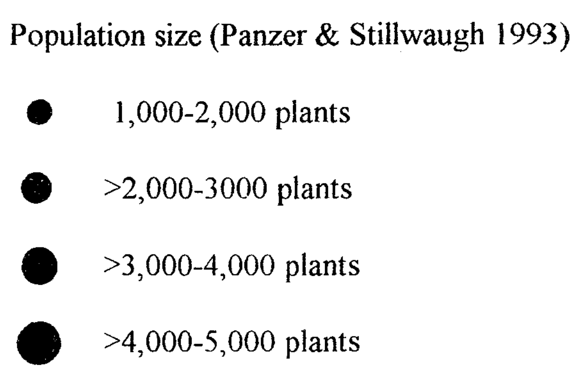


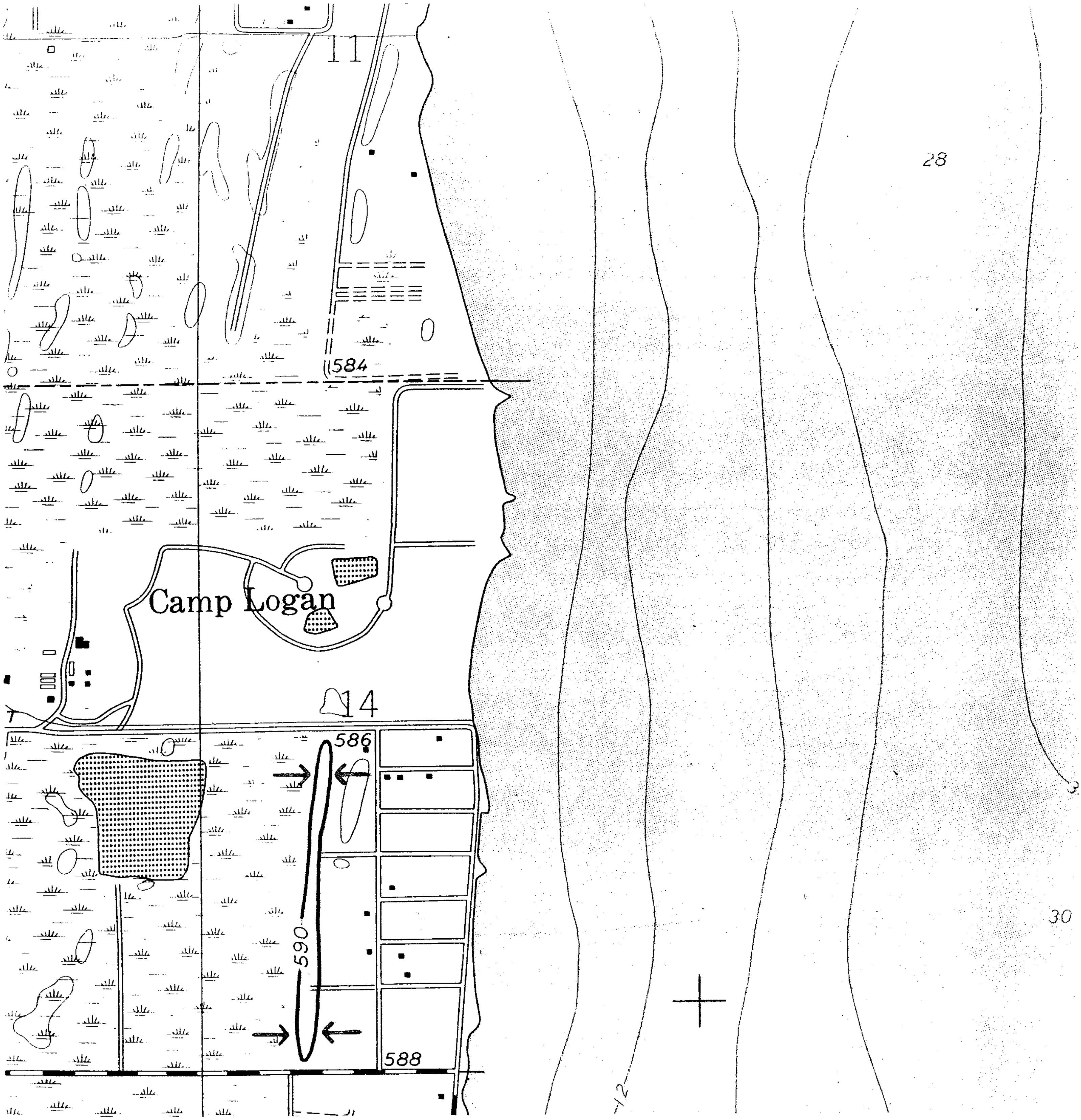
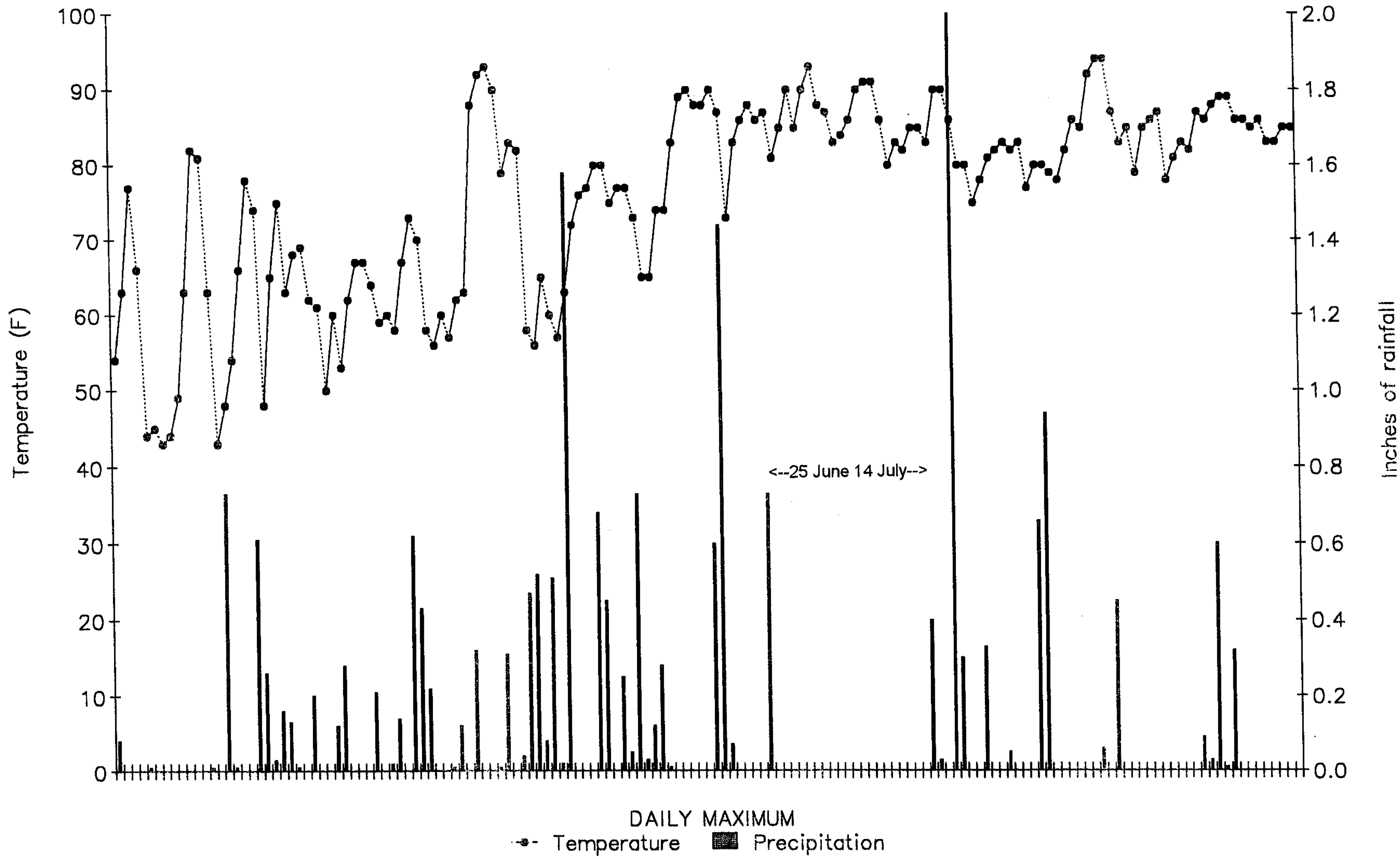
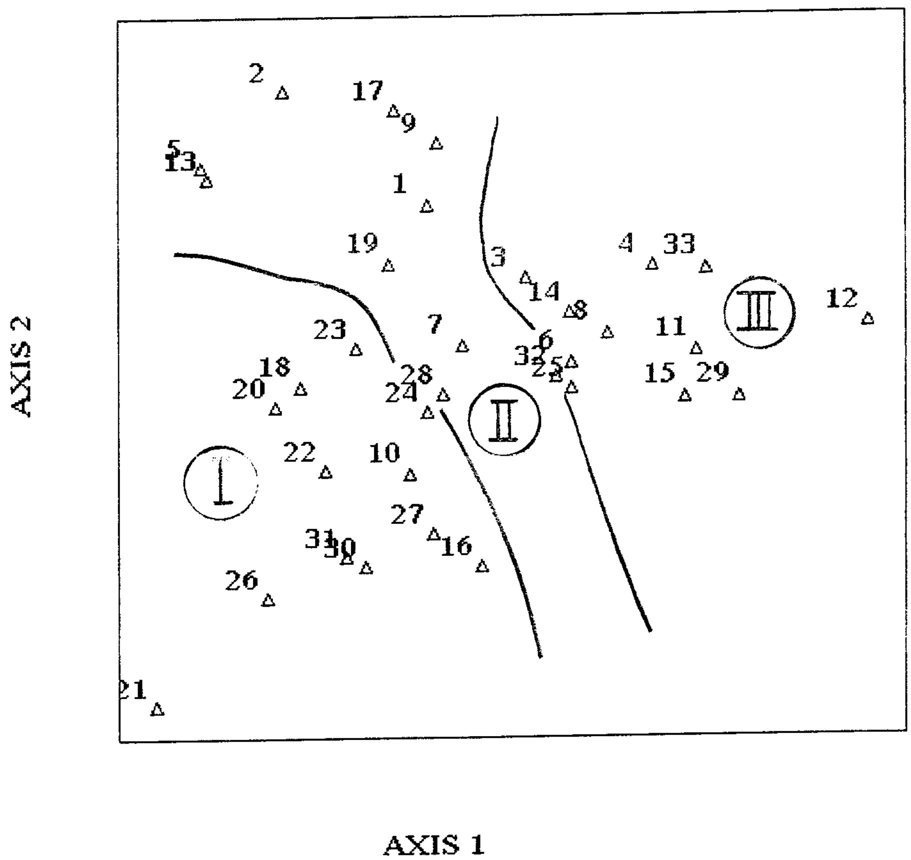


Figure 2. Location of beach ridge (between arrows) used for experimental lupine introduction at Illinois Beach North. Scale: 5 cm = 0.60 km (5 in ~ 1.0 mi).

FIGURE 3. APR.—AUG. 1996 TEMPERATURE &
PRECIPITATION IN NORTHEASTERN ILLINOIS





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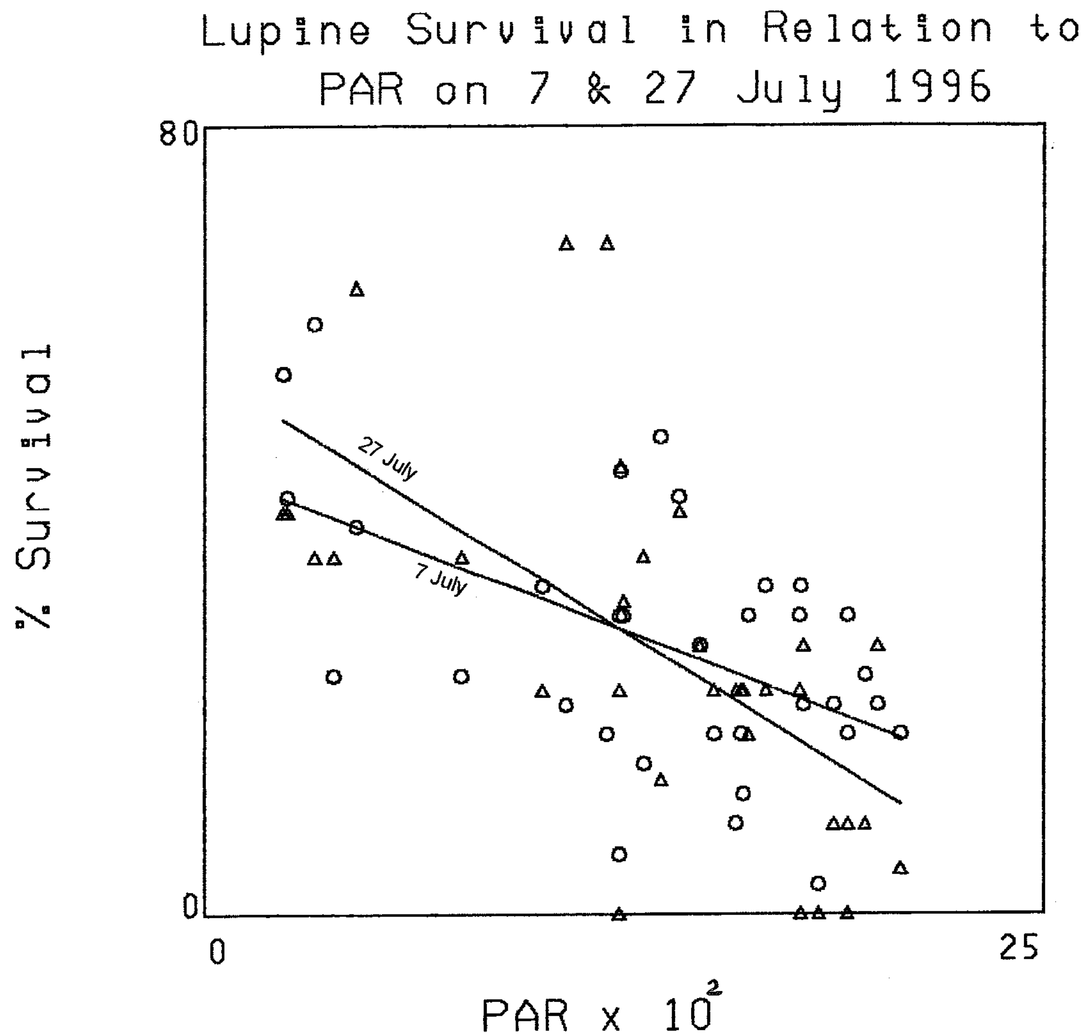

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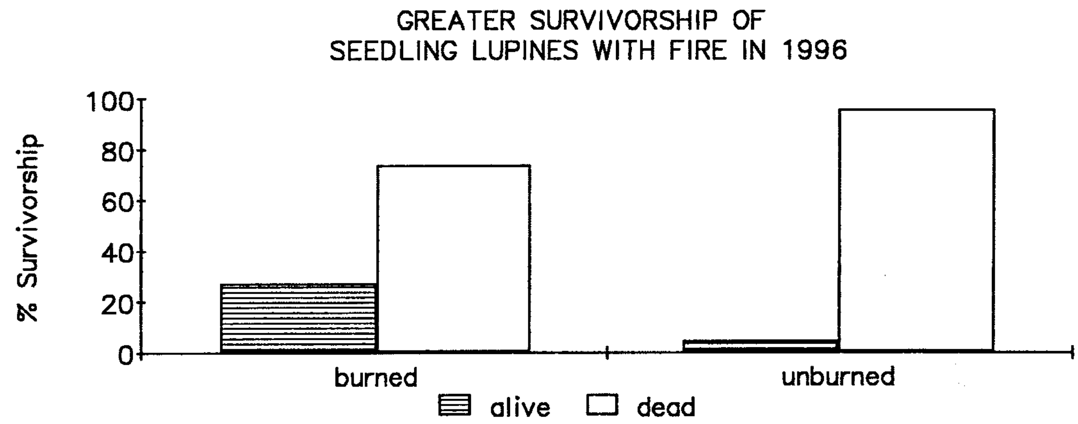
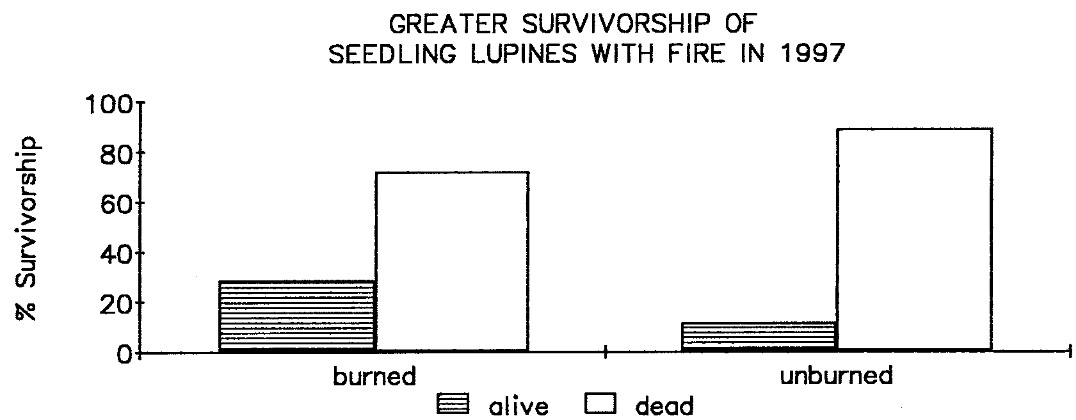
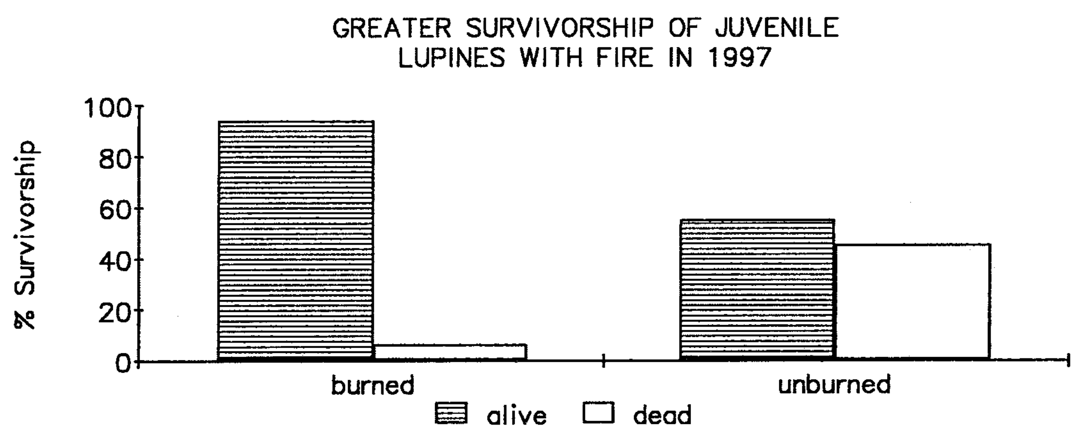


X^2 = 19.80, P <.0001



X^2 = 19.27, p <.0001



X^2 = 27.73, p <.0001

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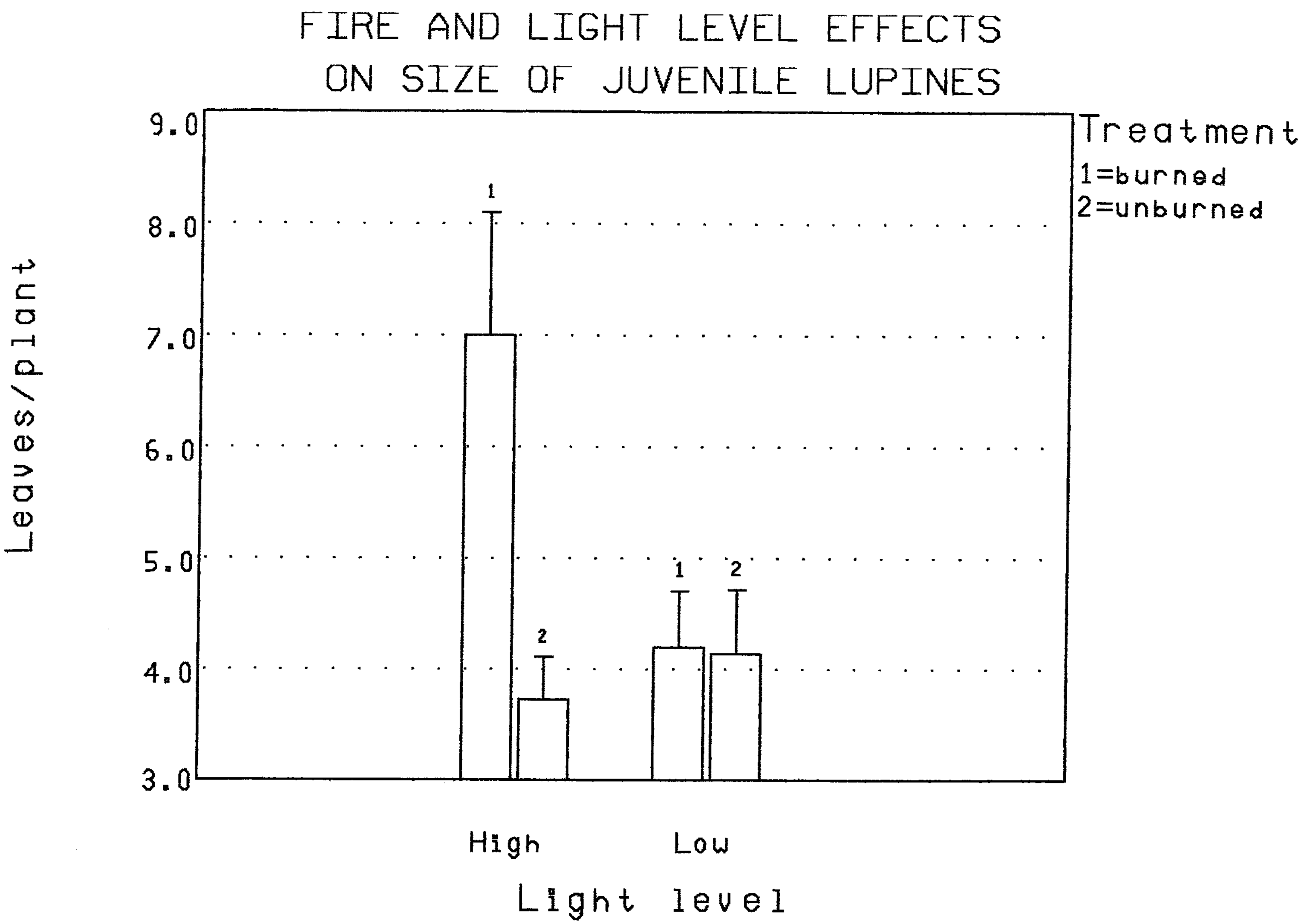

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