CONTROL OF ENGLISH IVY (*HEDERA HELIX*)

IN OREGON PARKS

by

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English ivy is an invasive exotic plant species that has become problematic in western Oregon in recent years. It is a hardy, evergreen vine that invades forested areas and comes to dominate the vegetation by competitively excluding native plant species. In Oregon forested areas, infestation by ivy leads to a reduction in plant species diversity, and an alteration in vegetation structure that may favor exotic plant species. Various control methods have been tested for use in removing English ivy from infested areas. I conducted experiments to compare effectiveness, selectivity, and efficiency of two control methods: flaming and manual removal. The results indicate that manual removal is superior to flaming in all aspects, and suggest that long-term solutions to ivy control will need to focus on developing more efficient, selective methods of control.

I conducted a vegetation survey at Eugene's Skinner Butte, and applied these data to management decisions for an English ivy control program. Results show that ivy infestation is severe in the park's most biologically significant area, but that several native species maintain significant populations. The information gathered indicates that a more systematic, scientific approach to management would greatly increase the success of future programs. I incorporate this information into a program proposal for English ivy control at Skinner Butte Park that includes six complementary phases, each of which focuses on a specific aspect of invasive plant management.

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CHAPTER I

INTRODUCTION

Plant species vary widely in their ability to survive in environments outside of their native ranges. Some species tend to proliferate when introduced to new ecosystems, out-competing native vegetation and spreading to dominate certain vegetation types. Such plants are usually held in check in their original environments by factors such as disease, predation, biological competition, climate, and soil conditions. When new environments lack key limiting agents, however, these exotic species invade.

Invasive exotic plants, or invasives, modify the ecosystems they enter in a variety of ways, all of which can have serious long-term effects. As a minimum impact, they occupy a vacant habitat or niche, thus changing both floristic composition and species absolute density (Thomas 1980). More severely, they can displace and suppress growth of native plant species by competitive exclusion, or kill them by shading, strangling, or poisoning. These impacts may eventually result in serious reduction of regional biodiversity, large-scale change in community structure, and alteration of ecosystem function. Thus, exotic invaders constitute an often subtle but dangerous threat to the health and integrity of indigenous plant communities.

Invasion results when these plant species are introduced to ecosystems that are naturally susceptible to the pressures they apply. Introduction may be deliberate or accidental, and is almost always done by humans. Once there, natural and man-made disturbances create ecological "openings" for these invasive species to gain footholds into their new environments (Beerling 1995). These include fire, flooding, road building, and logging. Disturbances such as campsites and hiking trails can make parks and wilderness recreation areas particularly susceptible to such invasions. If allowed to gain footholds, exotic invasives can form formidable barriers to conservation efforts. Controlling them is therefore integral to effective maintenance of native ecosystems.

English ivy (*Hedera helix*) is a non-native species that has invaded a variety of wooded habitats in Oregon's Willamette Valley and Coast Range. It is especially problematic in urban parks, due to the proximity of landscape features where planted ivy grows, and the high degree of disturbance caused by constant use. Moreover, these parks often contain some of the few remaining natural habitats in the local surroundings, and frequently harbor populations of native species that are dwindling in range or number. Conservation of western Oregon's natural habitats and native species therefore requires that English ivy is not allowed to continue to invade and dominate the vegetation of these parks.

This thesis examines the biology of English ivy and the threats it poses to Oregon parks and preserves, discusses methods of ivy control, and recommends a control plan for English ivy in Skinner Butte Park. Chapter II covers relevant information about the anatomy, physiology, life history, ecology, and habitat of English ivy, with respect to its behavior in Oregon forests. In Chapter III, I categorize plant control methods and surveys those which relate to English ivy. In Chapter IV, I present a series of experiments aimed at measuring the effectiveness and efficiency of a new control technique, broadcast flaming. In Chapter V, I recommend an approach to management of ivy-infested parks that integrates understanding of the plant itself, knowledge of various control methods, and data on important site-specific factors. Finally, I discuss the goals, steps, and procedures of this type of management plan through the presentation of a program for control of English ivy in Skinner Butte Park.

CHAPTER II

ENGLISH IVY (*HEDERA HELIX*) BIOLOGY AND ECOLOGY

Description

English ivy is a climbing and ground-carpeting plant of the family Arialaceae (Fig. 1). Its leaves are dark green and sometimes bi-colored, and they persist throughout the year. Its woody stems form vines in the juvenile phase and bushes when mature, and may in some circumstances grow as thick as a tree trunk. The flowers are bisexual, pentamerous, and pale green, and are often arranged to form a terminal pinnacle. The mature fruit is a globe-shaped, blue to black, 3- to 5-seeded berry (Hackett and Srinivasan 1985).

English ivy has been in demand in the U.S. for decades as one of the most valuable ground and wall cover plants available (Headley et al. 1992). It is an effective soil stabilizer and requires almost no maintenance, as it is hardy and allows virtually nothing else to grow in its presence. Furthermore, as planting involves no more than inserting six-inch-long segments of stems into the soil, it is inexpensive to obtain and establish. These traits account for the widespread popularity of its use in urban parks and private landscapes, and along highways. In addition, this popularity is bolstered by the lack of alternatives: as ivy-covered ground requires no weeding, it is often one of the only options in areas where periodic maintenance is impractical, such as on freeway medians. Although efforts have been made to curb such use in recent decades, planting of new ivy continues (Dave Wagner, Dept. of Biology, U of O, Eugene, OR, 1997 pers. comm.).

The history of English ivy's introduction and invasion of the Western Hemisphere is unclear. It is native to most parts of Europe and much of western Asia, and was apparently first brought to the U.S. for use in gardens. Although its date of introduction is unknown, it had escaped from cultivation in the mid-Atlantic states by 1810, when a naturalist placed it on a list of exotic plants that had become naturalized in this country. He described it as "near gardens, and along roads and hedges," and categorized it among exotics that had "spread in their neighborhood, but never at a great distance," (Rafinesque Schmaltz 1978). It apparently neither arrived nor escaped cultivation in Oregon until much later. This occurred, however, some time before 1941, when a botanist described it as "sparingly established in woods and thicket along the lower Willamette River" (Franklin 1988). Since then, ivy has spread to become a problem in many parks and preserves.

Life History

Growth and development of English ivy follows an annual cycle in a complex series of reactions to environmental cues.

Each year ivy experiences a spring growth spurt that continues through the summer until cold weather returns in autumn. The length of this summer "burst" varies with climate: in Ithaca, N.Y. it lasts from May to September (Hackett and Srinivasan 1985), whereas in the Willamette valley this period is about two months longer, beginning in March and ending in October. Spring and summer leaves are initially large, thin, and light in color, but thicken and become covered in a leathery cuticle during autumn of their first year. This enables ivy to withstand frost stress and to continue to photosynthesize during the winter, and helps make it resistant to drought. Ivy flowers abundantly in autumn and bears small, hard berries that persist long after (Dave Wagner 1997 pers. comm.). Growth slows considerably during the winter months, and winter-borne leaves, which are thick and dark from the time they sprout, remain small until spring.

English ivy utilizes a suite of methods to adapt to varied and changing environments. Together these processes comprise a life history that enables it to grow in a wide range of situations. For example, vertically and horizontally oriented ivy shoots exhibit growth patterns that maximize each orientation's advantages. Frey and Frick (1987) found that, horizontal shoots partitioned new dry matter preferentially to increase shoot length, while vertical shoots grew so as to preferentially increase leaf lamina area. This ability may aid it in "finding trees" as it grows across a forest floor, and then, once growing upward, enable it to take full advantage of the increased light.

More importantly, English ivy's two distinct life stages enable it to adapt to changing forest conditions. These two stages differ markedly in growth patterns and morphological characteristics (Fig. 1). The juvenile stage, during which ivy cannot reproduce sexually (Frey and Frick 1987), is characterized by dark green, 3 to 5-lobed leaves, arrangement of all leaves on the same plane (1/2 phyllotaxy), and stems that sprout numerous adhesive adventitious roots (Hutchinson 1959). These roots serve to attach the ivy shoots to the substrate, allowing it to cling and climb. This vine-like growth pattern enables rapid spread by vegetative growth, allowing colonization of new areas, and acquisition of better light conditions. Abundant sunlight stimulates transition to the mature phase (Thomas 1980), which is characterized by ovate, unlobed leaves, spiral leaf arrangement (2/5 phyllotaxy), a lack of adventitious roots, and the ability to bear flowers and fruits (Davis et al. 1992). This phase is bushy and sun-tolerant, and these characteristics aid in obtaining the energy necessary for reproduction.

English ivy's development is carefully regulated by hormonal responses to external cues, which signal transformation from the stable juvenile phase to the environmentally specific mature phase. Ivy requires ten years or more from seed germination to formation of the first mature flowering branches, and may persist in the juvenile stage for decades before maturing. Juvenility is therefore the most important factor controlling flowering (Hackett and Srinivasan 1985). However, ivy can rejuvenate if shady conditions return, indicating the importance of environment. This complex behavior can be explained by experiments that suggest that juvenile tissues synthesize a hormone that causes the meristem to produce juvenile structures and physiology (Hackett and Srinivasan 1985). Mature form growth patterns therefore only occur when this substance is absent. For example, in an experiment in which increasing levels of the hormone GA_3 were applied to a mature ivy plant, low doses caused loss of flowering. With progressively higher doses, further changes followed: initiation of adventitious root formation, transition to 1/2 phyllotaxis, and finally acquisition of lobed leaf shape. For an English ivy plant growing in a natural setting, this means that it will only flower in optimal conditions. Combined with its long juvenile phase- which results in growth to a fairly large size before maturation- this environmentally responsive dichotomy reduces ivy's vulnerability to environmental stresses.

More specifically, this life history involving two environmentally specific forms enables ivy to use both high light levels and deep shade to its advantage. Mature phase English ivy has a significantly higher tolerance to sunlight than juvenile phase ivy. Leaves of the juvenile life phase resemble those of plants that are genotypically adapted to shade, whereas leaves of the adult life phase of the same plant, from the same shady habitat, can be characterized as the type of leaves found in genotypic "sun" species (Hoflacher and Bauer 1982). Juvenile ivy shows extreme tolerance to shade, even when compared to other shade-adapted plants. It can grow in as little as 1% of full sunlight and flourish in as little as 3% (Thomas 1980). Like most genotypic shade plants, photoinhibition occurs in juvenile ivy under high light flux, but unlike these plants, juvenile ivy can fully recover from damage by excessive light (Oberhuber and Bauer 1991). This gives it a strong competitive advantage over most understory shrubs and herbs. Mature-phase ivy lacks this tolerance to shade, but possesses the capacity to acclimate fully to high light levels. Acclimation occurs by thickening of the palisade parenchyma tissue, which is found in juvenile leaves as well as mature leaves, although not fully developed (Hoflacher and Bauer 1982). This juvenile shade tolerance and acclimation capacity in both life stages accounts for ivy's occurrence in widely differing light environments. Moreover, it helps explain why, in forested habitats, generally only the treetop (high light) segments of ivy plants are mature, whereas lower (shaded) shoots and ground growth remain juvenile.

The unusual timing of ivy's inflorescence is likewise carefully controlled by environmental cues. Unlike most temperate angiosperms, which flower in spring and summer, ivy flowers in autumn. Two key factors, photoperiod and temperature, interact to induce inflorescence in a series of steps. Ivy is an obligatory short-long day (SLD) plant (Wallerstein and Hackett 1989), and as such, requires a period of short days followed by long days in order to flower. It does not flower in mid-summer, however, because high temperatures prevent inflorescence production. The temperature at which long days are applied is critical: in an experiment done by Wallerstein and Hackett (1989), the inflorescence initiation response obtained was saturating at 16°C, only marginal at 21°C, and absent at 24°C. As a result, ivy only flowers when the combined long days and cool temperatures of early autumn signal the induction of flowering.

Ecology of Invasion

English ivy most effectively invades forested and semi-forested areas, although it can also move into treeless areas that have been disturbed (Thomas 1980). It tends to prefer sites in which the vertical structure of the forest has been disrupted, for example, by thinning the trees. Shade provided by trees facilitates invasion, but disturbances that partially increase incident light on the forest floor aid the process immensely (Thomas 1980). This seemingly paradoxical phenomenon results from the creation of an intermediate light intensity that enables peak growth rates.

Ivy comes to dominate an area through a series of steps, beginning with its introduction, which occurs either by intentional planting, vegetative spread from an adjacent site, or from dispersed seed. Once established, it undergoes rapid vegetative growth, spreading across the ground and up tree trunks. Its dense ground cover suppresses herbaceous plants, which require more abundant sunlight, and, as it climbs trees, it slowly kills them by shading out their leaves (Thomas 1980). This occurs because an individual tree branch receives energy only from its own leaves, never from other parts of the tree. As a result, branches with little access to sunlight die and fall off (Wilson 1984). Thus, ivy kills individual branches until the tree eventually dies.

As branches die and fall, the increased sunlight reaching the ivy stimulates maturation of successively lower segments. When the entire tree eventually dies and falls, sunlight flooding onto the forest floor stimulates transition of ground cover ivy to the mature phase. Mature ivy forms small, somewhat hard, seed-bearing fruits that birds eat and disperse (Dave Wagner 1997 pers. comm.), and the cycle repeats. Over time, the ivy ground cover thickens, allowing fewer and fewer herbs to grow beneath it. Meanwhile, the climbing stems increasingly overtake trees and ultimately kill off the forest overstory. The end result, in an eastern U.S. hardwood forest, has been a transition to an ivy-dominated habitat where only a few woody shrubs and very few trees interrupt the dense blanket of ivy (Thomas 1980).

Various traits contribute to English ivy's success as an invader. These include its ability to grow in a wide range of soils (Headley et al. 1992); high tolerance to shade in the juvenile phase, rapid vegetative growth and vine-like growth pattern; year-long growing season; and bearing of fruit during winter. Its juvenile-stage shade tolerance, which aids ivy enormously in colonizing new areas, is probably a major factor in its ability to invade undisturbed habitats (Dave Wagner 1997 pers. comm.). This shade tolerance reduces the need for an ecological "opening" to establishment, because it gives ivy two key strengths: by enabling ivy to grow in the low light of the forest floor, this tolerance helps ivy to first establish itself and then to competitively exclude other plant species. Thus, not only urban and high-use parks but also virtually untouched forests are susceptible to its invasion.

Once ivy has established itself in a forest understory, its capacity for rapid, vine-like vegetative growth in the juvenile stage provides an efficient means by which to overtake and shade out other plants. By growing across the ground and forming a carpet, it creates a dense expanse of shade from a relatively small amount of foliage. By doing so it makes the habitat less suitable for other plant species, and eventually succeeds in killing and suppressing sprouting of competitors. Its year-long growing season, which enables it to take advantage of the winter to grow in the absence of competitors, speeds the process. Even in cold climates, during the winter it can fill dormant herbaceous plants' niches, or extend outward on deciduous tree branches. This winter growth positions the ivy plant to suppress spring herb sprouts or shade out budding tree leaves (Thomas 1980).

English ivy's seed dispersal mechanisms are important in enabling its colonization of areas distant from those it has previously invaded. In Oregon, these small, hard berries, which ripen in late fall and persist through the winter, are often one of the few winter food sources available to birds. As the majority of native plants bear summer and autumn fruits, the timing of ivy fruit production enables maximal dispersal by birds. Although ivy berries are neither sweet nor fleshy, the lack of alternatives in winter results in considerable ivy berry consumption by birds (Dave Wagner 1997 pers. comm.), which then fly to new, sometimes distant locations, deposit the seeds, and thus begin the colonization process.

Factors that limit ivy's growth appear to be far less numerous than those that provide competitive advantages. As there are over 400 varieties of English ivy (Headley et al. 1992), variants can be found that can grow in diverse conditions. Moreover, as a species, ivy is resistant to seasonal variability: it can withstand periods of drought, high light, and freezing with little or no permanent damage. It is therefore difficult to find natural control factors that are consistently effective.

Habitat

In its natural habitat, English ivy exists as part of a scrub community dominated by various mixtures of small trees and shrubs, undershrubs, and woody climbers and sprawlers. The canopy is usually low -- between one and five meters high -- and the species-poor ground layer consists almost exclusively of English ivy. As the community develops, the canopy closes, creating a deep shade that excludes all herbaceous plants and reduces other common shade plants to sparse or puny individuals. English ivy, however, often grows extensively in this dark niche (Rodwell 1991). This scrub vegetation complex is invasive and, in the intensively-used British landscape, develops on derelict land and in gardens and fields where maintenance has been relaxed. It is a sub-climax community that eventually develops into woodland dominated by hardwood trees such as *Quercus* (oak) and *Fagus* (beech) spp. (Rodwell 1991).

Ivy is restricted in its native ecosystem primarily by climate, but also by soil acidity and grazing by deer and rabbits. In the British Isles, the combination of cold climate and acidic soil limits its range to the southern two thirds of the country (Rodwell 1991). Grazers have also been known to hinder ivy, although their widespread significance is uncertain. For example, in areas where rabbit populations have been decimated by myxomatosis, ivy/scrub communities commonly take over the site (Rodwell 1991). In continental Europe, European roe deer (*Capreolus capreolus*) may impact

English ivy growth heavily, as it is their main autumn and winter food source. This deer's eating habits are highly selective, and dietary analysis has shown that ivy comprises 31% of autumn food intake and 22% of winter consumption (Duncan et al. 1997). Very little work has been done, however, to ascertain the impacts of such grazing on English ivy communities.

Ivy's behavior in its native ecosystems is also partially controlled by the plants with which it shares a habitat. Unlike most North American forest plants, many possess traits that enable them to successfully grow and compete with English ivy. For example, the oak and beech species of ivy's native woodlands may be resistant to invasion by evergreen vines due to retention of their dead leaves throughout the winter. This offers some shade deterrent to climbing ivy during tree dormancy, by reducing the advantage in ivy's year-long growing season (Thomas 1980). The scrub brushes and hedges that comprise the sub-climax vegetation type in which ivy grows, such as hedge hawthorn (*Cretaegus monogyna*), are resistant to ivy as well. They grow above the ivy's deep shade, but their stems are too small for ivy to easily find and climb. Thus, their growth patterns prevent ivy from shading out their leaves.

An unfavorable climate, however, is by far the most consistent ivy growth deterrent. Although resistant to seasonal variability and capable of surviving in a variety of environments, English ivy tends to invade and dominate only in shady areas of moist, temperate regions. Here, mild climate and lush vegetation provide the moderate annual temperatures and intermediate light intensities conducive to rapid ivy growth. Ivy is not invasive in some climates because stresses such as high light flux and low temperature remove the competitive advantages that enable it to become a threat. For instance, dry climates tend to lack the abundant foliage that provides necessary shade, and cold climates' growing seasons tend to be too short for ivy to become invasive. Thus, English ivy is a threat only where shade is available and the climate is sufficiently warm.

Too much sunlight can be extremely inhibitory to English ivy invasion. Although an ivy plant growing in high light can acclimate to the strong sun by maturing, in doing so it must forfeit its ability to invade: only juvenile ivy can spread and climb, which is necessary for colonization of nearby sites. Furthermore, ivy's high shade tolerance- the key to its ability to exclude neighboring plants in a forest understory- gives it no competitive advantage in high light areas. Thus, competition by other plants can act to limit its growth in such regions. As a result, ivy does not tend to invade treeless areas unless they experience periodic disturbance. An excellent example of this phenomenon is the vegetation pattern of Skinner Butte, where the ivy grows extensively in wooded areas but stops sharply where the trees border grassland.

Low temperatures are only seriously limiting where winters are too cold for the survival of ivy's evergreen leaves. But although its leaves freeze at -3.5°C, it is still capable of full recovery even after a winter in which temperatures drop well below that. For instance, in an experiment that tracked an ivy plant through an Austrian winter, Oberhuber and Bauer (1991) found that, although its leaves froze almost daily from mid-November to mid-January, the ivy recovered full photosynthetic capacity by spring. Even in deciduous forest understories, where the synergistic effect of high light and frost stress can cause almost triple the damage from high light alone, ivy is capable of complete recovery in all leaves (Oberhuber and Bauer 1991). This high recovery potential, therefore, makes ivy remarkably resistant to seasonality and only limited by consistently or extremely unfavorable climatic conditions.

Observations on Growth Rate

I found no examination of English ivy's seasonal growth and rate of spread in the available literature. This information, however, would be valuable to planners in that it provides an idea of the consequences of delaying control procedures for a few years. In order to determine the rate of ivy spread in an Oregon forest, I measured portions of ivy shoots growing across the ground in an understory, and from that, calculated seasonal growth. I selected 28 shoots according to a stratified random sampling design, and measured the length of each selected shoot's new growth. Each shoot's most recent growth is distinguishable from older portions of the stem by color: matter added since the beginning of the spring growth spurt is light green, whereas older shoot matter, which has acclimated to winter cold, is dark brown. Moreover, leaves that sprout in winter tend to be small, dark, and thick, in contrast to spring sprouts, which are much larger, lighter and thinner. As the stem color change is gradual, with no definite border, I measured the length of the region from the joint of the latest winter-sprouted leaf to the shoot tip.

The growing season was defined as the period from late March, when the 1997 spring growth spurt began, to early October, when growth again slowed. Dates were determined by monitoring the growth of two shoots. In both shoots, between March 21 and April 4 , growth jumped from an average of 1.9 cm/week to 4.7 cm/week. This rapid growth continued into September, but had returned to 1.6 cm/week by October 18. Sampling was done in early September, as subsequent darkening of shoots and leaves blurs the distinction between new matter and old matter. Rapid shoot growth continued, however, for another month. Thus, I calculated seasonal growth by multiplying mean green-region length by 1.18, or 6.5/5.5.

Statistical analysis of shoot green-region lengths estimated growth since late March (mean ± 1.96SE) at 89 ±9 cm, and gave an estimated mean seasonal growth of 105 cm. Thus, ivy can spread in an Oregon forest understory at a rate of over one meter per year, facilitating its characteristic rapid invasion. This information should therefore be useful in projecting the rate at which infestation spreads in areas where no control procedures are applied.

Suggestions for Further Research

Because the majority of available information about English ivy has been gathered in the eastern U.S. and Europe, application of this information in the setting of an Oregon forest may be difficult. These forests differ in climate, species composition, and vegetation structure. It is therefore necessary to account for these factors when considering how English ivy is likely to behave in Oregon. The effects of these differences, however, have not been studied. Below, I outline the most pressing questions, suggest hypotheses, and propose research projects that would test those hypotheses.

Oregon forests consist mainly of evergreen conifers, unlike the hardwood forests of the eastern U.S. and England, where ivy's behavior has been more thoroughly researched. Because conifers maintain shady understory conditions throughout the year, ivy misses the autumn and spring "windows" of intermediate light and mild temperatures that provide optimal growing conditions. However, as Oregon forests are dominated by conifers, winter understory light intensity is low. Thus, ivy in Oregon does not suffer the damage from winter photoinhibition that occurs in the deciduous forests of the eastern U.S. Furthermore, English ivy experiences a longer growing season in Oregon due to the mild Pacific Northwest climate. In this habitat, therefore, ivy likely experiences optimal conditions less frequently, but is exposed to fewer stresses. The effects of this combination of conditions on the rate at which ivy kills trees is unknown. A comparative study on rate of spread in various locations and forest types would aid in answering this question.

Structure and species composition of understory vegetation accounts for much of the reason that English ivy is invasive in Oregon. As Oregon understory communities contain few species that can successfully compete with English ivy, they undergo drastic restructuring upon invasion. England's forest ground cover consists almost entirely of woody shrubs and climbers, which are structurally and physiologically resistant to competitive pressure by ivy (Rodwell 1991). In contrast, Oregon understory species include a wide array of annuals and herbaceous perennials, which are poorly adapted to competition by evergreen sprawlers, and thus face the threats of permanent displacement and local extirpation due to exclusion by English ivy. Instead, in Oregon, other invasives appear more capable than native species of resisting or avoiding competitive exclusion by ivy. For instance, Himalayan blackberry (*Rubus discolor*), a tremendously invasive Asian thorn shrub that has rapidly spread throughout western

Oregon, behaves similarly to Britain's native hawthorn scrub in relation to English ivy. The blackberry shoots grow directly above the ivy to form a dense, tangled, species-poor ground vegetation layer. This suggests that ivy will likely cause a shift in understory vegetation from native herbaceous wildflowers to exotic scrubs and sprawlers. Thus, it seems reasonable to hypothesize that forested areas of invaded Oregon parks will eventually transform into species-poor ivy/scrub communities similar in structure to those found in England, and consist almost entirely of non-native species. Experiments designed to determine the outcome of competition between various understory species and English ivy could test this hypothesis.

Figure 1. English ivy (*Hedera helix*) mature form (left) and juvenile form (right).

CHAPTER III

METHODS OF ENGLISH IVY CONTROL

Approaches to Control

Control of invasive plants is difficult because deterring the invader's growth often damages native plants more than it harms the target species. Indeed, invaders are invasive largely because they are so resistant to environmental stress (Beerling 1995). Furthermore, their invasibility is usually due in part to prolific and efficient reproduction. Thus, preventing regrowth and continued reproduction is often more difficult than initial removal. Invasive plant management is therefore a complex, multi-step process that is most effective when it utilizes a variety of approaches that target different aspects of the invader's life history. The most desirable approach to control of invasive plants integrates several categories of control methods, so as to optimally exploit the advantages of each, and to buffer the system from damage due to side effects. This approach is generally accepted as the most effective, economical, and environmentally sound long-term pest control strategy (Hoshovsky 1985).

From a practical viewpoint, methods of invasive plant management can be categorized as follows: physical, thermal, chemical, managerial, and biological (Hoshovsky 1985). Each of these categories contains methods that have been tested on English ivy or may prove useful for its control. Physical ivy control methods include both manual and mechanical removal techniques; thermal control consists of broadcast application of heat by flaming; chemical control consists of broadcast herbicide application; managerial methods include encouragement of competitive displacement by native plants and prescribed grazing; biological control involves introduction of pathogens that are highly selective for English ivy.

Physical Control

Physical control methods that have been tested for use on English ivy range from mowing and digging to cutting and pulling. Digging and pulling have successfully eliminated ivy ground growth, whereas mowing is ineffective (Elmore et al 1986). This is likely due to the plant's anatomy: ivy stores almost all of its energy in the stems, and very little in the small root system. Thus, re-sprouting from damaged roots is difficult for ivy, but damaged leaves and stems are quickly repaired with energy stored in stem tissues. Digging involves complete removal of stems and roots with a shovel. Pulling may be by hand or with tools such as a polaski, a fire-fighting tool with a long handle and a heavy head of perpendicular axe-like blades, that can be used to hook and pull ground growth. Control by both methods is immediate, and there is little regrowth, but pulling is far more frequently employed than digging. Pulling is highly selective and permits removal without damage to surrounding native vegetation (Hoshovsky 1985). Moreover, unlike digging, pulling leaves the soil relatively intact, reducing the occurrence of negative impacts such as increased erosion and higher susceptibility to subsequent invasion.

The greatest drawback to this method is that it is labor intensive. Although use of clippers and a polaski can cut treatment time in half, pulling requires many hours of labor even to clear fairly small tracts of land. For instance, the approximately five acres that were hand-cleared in Alton-Baker Park took weekend volunteer groups of 20-30 people about two years to complete (Dave Wagner 1997 pers. comm.). In areas where much larger pieces of land are involved, or where human resources are limited, it may therefore not be a realistic option. Furthermore, although less disruptive to the soil than digging, manual ivy removal does leave the treated area's ground bare. In this way, it creates openings for invasion by other exotics, or re-establishment of ivy by vegetative spread from a nearby site.

For ivy removal on trees, cutting of climbing stems is the single most effective method. It consists of using tools such as large clippers to cut all stems in a ring around a tree, near the base of the trunk. Debbie Pickering (The Nature Conservancy, Eugene, OR, 1997 pers. comm.) recommends leaving a gap from ankle- to knee-level to ensure than no stems have been missed. This method is popular because it is 100% effective, efficient, and causes little disturbance. Furthermore, as it leaves the dying ivy stems on the tree, it is not only easy, but also allows their stored nutrients to be slowly cycled back into the forest.

Thermal Control

Thermal control of English ivy consists of broadcast flaming of the leaves, with the intent to burn the cuticle without charring the leaves. One inexpensive method involves using a kerosene or propane torch to sweep a foot-long flame across ivy ground growth. This approach causes permanent wilt (Randall and Unger 1995b), motivating the ivy to expend its stored energy in an attempt to repair the dying leaves, thus preventing resprouting. It is superior to pulling in that it does not disturb the soil and requires less manpower. Moreover, if done properly, flaming can be highly selective, leaving non-target species unharmed. Flaming has been utilized as a means by which to remove the ivy at the same rate that the natives re-colonize, as a prelude to the final step of manually removing the stems (Randall and Unger 1995b). However, both its ability to allow native plants to move in as the ivy dies, and its effectiveness in killing ivy, are poorly understood. Moreover, the impacts of variables such as timing, and number and spacing of treatments, are unknown. Experiments aimed at answering some of these questions are presented and discussed in Chapter IV.

As with any situation in which fire is involved, there are potential hazards and necessary precautions. Use of this method is not recommended if a dry leaf litter layer is present, as it can start a fire, limiting its use to wetter times of the year. It also requires the same readiness and tools that are used with prescribed burns (Randall and Unger 1995b).

Chemical Control

Many brands of both pre- and post-emergence herbicides have been tested for effectiveness in impeding English ivy growth, and the majority do poorly. Use of pre-emergence herbicides involves application to the soil of un-infested regions to prevent invasion. Post-emergence herbicide application consists of broadcast spraying of leaves and stems, as English ivy's growth patterns make more selective methods, such as injection, impractical. Most pre-emergence herbicides have almost no effect on English ivy growth, and those that do only moderately hinder it (Monaco 1974). Post-emergence herbicides tend to fare better, but invariably require a second factor, such as proper timing, pre-cutting, use of surfactants, high concentration, or multiple applications, to seriously harm the ivy. Glyphosphate and 2,4-D can work well; fosamine ammonia (Krenite) and Garlon are less effective. Use of these herbicides is complicated by English ivy's resistance to herbicides, which is due to limited uptake by its waxy leaves (Randall and Unger 1995a).

But although it can be a complex process, correct use of post-emergence herbicides can result in complete and permanent ivy removal. For example, glyphosphate (Roundup) has exterminated ivy when applied at 3.0 kg/ha to plants in March, whereas identical treatments in June were only 85% effective (Randall and Unger 1995a). Two applications of 2,4-D (Weeder 64) at 1.1 kg/ha has resulted in complete control as well, while one treatment only slightly deterred growth (Derr 1993). In addition, herbicides are favorable because they do not physically disturb the soil, and because they tend to kill ivy slowly, over a period of weeks or months (Derr 1993) By preventing the occurrence of bare ground, this deters infestation by other exotics.

Herbicides do, however, have more serious drawbacks than other control methods. They are a form of pollution, so their use may harm the ecological community more than the ivy infestation. As a result, use of products that are less effective but break down rapidly, such as fosamine ammonia, may sometimes be preferable (Randall and Unger 1995b). Furthermore, herbicides must be sprayed on ivy to be effective, but this broadcast application kills not only the target species, but most (or all) other species as well (Hoshovsky 1985). These factors limit their use to areas where ivy dominance is so complete that few or no other plant species are present.

One approach of herbicide use that has not been examined for English ivy, but would likely be effective, efficient, and highly selective, is direct injection. As the English ivy cover in large areas is often only one or a few individual plants that have sent out shoots and adventitious roots, injecting shoots at intervals may well kill an entire stand. Moreover, this approach avoids the negative effects of broadcast spraying of herbicides.

Managerial Control

Managerial control is concerned with promoting native species that act as either predators or competitors of the target plant. Deer and rabbits, which often control English ivy by grazing in its native habitats (Rodwell 1991), possibly do so in North America as well. Few studies, however, have examined these interactions, and it is unclear whether native deer and rabbit species are adapted to handle ivy's chemical defenses, or what concentration of such predators is necessary for control, and whether they would choose to eat ivy over native plant species. Moreover, maintenance of grazer populations in some areas may be difficult. For instance, placing deer in urban parks, where the ivy problem is greatest, would hardly be practical.

In contrast, active promotion of competitive native plant species shows promise as a simple and effective method. As English ivy tends to dominate so completely, this approach is unlikely to be effective alone, but may be a key piece of an integrated control plan when used as a follow-up measure. It minimizes the effects of site disturbance and speeds recovery, thus giving the treated area a measure of resistance against erosion, re-infestation by ivy, and invasion by other exotics.

Plant forms that compete most competently with ivy are those which persist throughout the year, grow in low light, and whose shape does not facilitate climbing or covering by ivy shoots. These include vines, dense shrubs, and some ferns. For example, in Oregon, sword fern has these characteristics, and tends to persist among English ivy longer than other native species. Planting of such native plants, subsequent to ivy removal, stabilizes and occupies bare ground, and provides a base population of native plants. This reduces erosion and helps the site to resist re-infestation, may be extremely valuable in areas where ivy dominance is so complete that few native species are available to re-colonize the treated area. Recovery in these instances may be so slow that the ground remains bare for years, or is re-colonized by exotics.

Biological Control

Biological control consists of deliberate introduction of natural enemies that are specific to the target plant. These enemies, which may be predators or pathogens and are most commonly insects or fungi, are usually exotic and may also be invasive. As the processes of biological control are complex, such introductions have in many cases created new problems that were worse than those which they attempted to solve. Thus, they must be thoroughly researched before implementation, to prevent the occurrence of biological disasters (Hoshovsky 1985). Importation of pathogens is probably unsuitable for use on English ivy, both because it can be so problematic and also because English ivy has very few natural enemies. Its suite of chemical defenses includes phenolic compounds and triterpanoid saponins that have antifungal, anthelmintic, antileishmanial, and antimutagenic components (Elias et al. 1991). This chemical defense system is so effective that invertebrate grazers do not consume it even when it is abundant (Hatziioannou et al. 1994), and humans sometimes suffer allergic contact dermatitis from handling the leaves (Randall and Unger 1995a). As a result, biological control attempts would likely not be successful enough to justify the risks of importing exotic pathogens.

Deliberate infection of ivy stands with pathogens already present in Oregon, however, may prove worthwhile. Use of native or previously imported pathogens avoids the risks involved in introducing new species, and may significantly set back ivy growth. In Europe, several species of Coleomycete fungi have been found that can severely damage infected English ivy (Muntañola-Cvetkovic and Vukojevic 1992); in Oregon, diseased and damaged leaves are common and sometimes extensive. This suggests that exotic pathogens may have already been imported and available for use as a means of ivy control. However, I have found no evidence that this approach has been tested or attempted.

Conclusions

English ivy, like many invasive species, is extremely resistant to control of any kind. Its growth patterns, hardiness, and chemical defenses make it almost impervious to many control methods, and also enable it to recover from the extensive damage caused by others. Thus, a control program for English ivy should attempt to integrate different control methods in a manner that attacks the most possible aspects of its defense system, thereby preventing recovery. Of the methods that have been tested for use on ivy, manual removal appears to be the most plausible option, but should be followed by introduction of competitive native species to cleared sites. In addition, broadcast application of chemical herbicides may be a necessary step to control in extreme circumstances. However, each of these methods has considerable drawbacks, and any effective ivy removal program using existing methods will require a great deal of time and effort. The most promising solution therefore involves developing new control methods, or adapting old methods to use on English ivy. For instance, perhaps injecting herbicides into plants that have already been weakened by previously-imported pathogens could work well. Altogether, the suite of possible and existing methods is both extensive and maneuverable, and it seems likely that control of English ivy can in the future be effective, selective, and economically feasible.

CHAPTER IV

IMPACTS OF TWO ENGLISH IVY (*HEDERA HELIX*) CONTROL METHODS ON AN IVY-DOMINATED FOREST UNDERSTORY

Introduction

English ivy (*Hedera helix*) is an invasive, exotic vine that has become a problem in many forested areas of North America. It displaces native vegetation, kills trees, suppresses herbs, and eventually changes native forests into species-poor, ivy-dominated scrub communities. It has become a problem in western Oregon conifer forests, and threatens these regions' biological diversity and habitat integrity. Effective control of this species is therefore integral to maintenance of native forest ecosystems.

Several methods of English ivy control have been quantitatively tested. Hand-pulling has been shown to be the most effective and selective method of removing ivy from invaded areas (Elmore et al. 1986, Hoshovsky 1985), but in areas of high ivy cover, such intensive removal may leave the ground bare and susceptible to increased erosion or invasion by other exotics. Thermal control in the form of flaming has recently been hailed as a means by which to set the ivy back slowly, to allow native vegetation to grow in as the ivy recedes, and avoid leaving an empty niche (Randall and Unger

1995b). In areas densely carpeted with English ivy, however, it has been unclear whether or not enough native vegetation is present to do so. Until now, no quantitative data has been available for comparison of each treatment's effectiveness. The objectives of this research are therefore to evaluate and compare quantitatively (1) the impacts on English ivy of each of the three treatments -- flaming once, flaming twice, and hand-pulling; (2) the time required to complete each treatment; and (3) the response of other plant species to each treatment.

Materials and Methods

Four 9m x 9m plots were marked in a coniferous forest understory. Each was divided into four treatment areas with a 1m-wide buffer strip between them. Within each plot, each treatment area was randomly assigned one of four treatments: hand-pull, flame once, flame twice, or control (no treatment). Estimates of cover were then taken by the Braun-Blanquet method (Table 1) of one 1m x 1m square at the same edge of each plot and one 1m x 1m square at each plot's center. These estimates included all herbs, shrubs, and ferns. The treatments were then applied, and start and finish times were recorded.

Hand-pulling of ivy was done with a polaski and clippers. Stems were dislodged from the ground and removed. The soil was disturbed as little as possible. Flaming was done with a propane torch, and involved sweeping the flame across the ivy cover with enough heat to burn the leaf cuticles but not char them. As with hand-pulling, other plants were avoided. The second flaming of the twice-flamed plots was applied five weeks after the first treatment. In all treatment applications, native species were avoided, but other exotic invasives were not.

Cover estimates for ivy were taken three months after each treatment's final step was completed. Thus, those of plots flamed twice were taken five weeks later than those of all other plots. This was done to standardize recovery time. Cover estimates of all other plant species were taken, in all plots, five months after completion of the first round of treatments. This provided a standard colonization period, and the longer interval was intended to amplify results. Change in cover of all species were calculated for each plot, and results were subjected to analysis of variance with mean separation using the Least Significant Difference Test at $p=0.05$.

Results

In treated plots, reduction in cover of samples taken at plot edges did not differ significantly (ANOVA: $F_{1,22}=0.009$; $P>0.05$) from those taken at plot centers. Furthermore, as the sample means were well within 1.96 S.E. of each other, the two data sets were grouped and analyzed as one.

Impact of treatments on English ivy. Ivy cover tended to decrease in treated plots, although in some treated plots it increased or remained constant (Table 2). Change in total ivy cover was estimated at -9% in plots flamed once; -25% in plots flamed twice; -72% in manually treated plots; and +25% in control plots (Fig. 2). In other words, 9% of the ground in treated plots was cleared by flaming once, 25% was cleared by flaming twice, and 72% was cleared by manual ivy removal. Analysis of Variance indicated that mean cover change in all treated plots showed a highly significant difference from control plot cover change (ANOVA: $F_{1,14}=13.75$; $P<0.01$). Mean amount of ground cleared by treatments in manually treated plots was 47% greater than in plots flamed twice, and 63% greater than that of plots flamed once. These differences were very highly significant (ANOVA: $F_{1,14}=95.1$; $P<0.001$). Mean ivy cover reduction in plots flamed once did not differ significantly from zero (ANOVA: $F_{1,14}=1.32$; $P>0.05$).

Treatment time. Each one-plot manual removal treatment required an average of 44 minutes. Time required to flame one plot averaged 10 minutes, and plots flamed twice received an average of 20 minutes of treatment. Thus, reduction in ground covered by ivy per minute of treatment averaged 1.7%/min in manually treated plots, 1.3%/min in plots flamed twice and 0.9%/min in plots flamed once. Note that the time required to treat plots flamed twice does not include the extra time needed to go to the site twice.

Response of other plants to treatments. Sword fern (*Polystichum munitum*) was the only native species abundant enough to statistically analyze. Change in sword fern cover in all plots was very close to zero, ranging from an average of -3% in plots flamed once, to +4% in manually treated plots (Fig. 3). Moreover, analysis of variance indicated no significant difference in cover change between flamed plots and manually treated plots (ANOVA: $F_{1,14}=2.59$; $P>0.05$). Himalayan blackberry (*Rubus discolor*), the only exotic species sufficiently abundant for analysis of cover change, reacted similarly to the treatments. Blackberry cover change also remained close to zero, ranging from no change to +6% (Fig. 3), and no significant difference was found in cover change between flamed and manually treated plots (ANOVA: $F_{1,14}=1.93$; $P>0.05$).

Discussion

Manual removal of English ivy was both more effective and more efficient than flaming. It resulted in greater overall decrease in ivy cover, and also caused greater ivy cover decrease per minute of treatment application. The inability of flaming to seriously deter ivy growth may have been due to the structure of the ivy plant, in which its mass of stems serves as a store for abundant energy. As an entire understory can be covered by only one or a few plants, nearby stems may have shuttled resources to the damaged parts and aided in recovery. It is likely that the drain on stored resources inflicted by flaming was not enough to set the ivy back. Cover change in edge plots and center plots did not differ significantly, suggesting that either this phenomenon did not occur, or that the plots were too small to show it. An edge effect may become visible, and flaming may prove to be more effective, if larger plot sizes are treated. This could reduce the effect of resource transfer both by increasing the distance resources must travel to reach damaged parts, and by reducing the proportion of healthy shoots (energy suppliers) to damaged shoots (energy consumers).

The main advantage promoted for flaming over manual ivy control is that it kills ivy gradually, allowing native plants to re-colonize the treated area as ivy dies, and thus preventing the occurrence of bare ground. No such process occurred, however, in these experiments. In contrast, native plant cover showed almost no change, and results suggest that flaming may have actually deterred growth of native plants. Indeed, flaming appeared to cause greater damage to existing sword ferns than manual control, as the fern fronds were more difficult to avoid with the flame. The lack of re-colonization by native plants may be due to the extreme ivy dominance, which, after years of shading out seedlings, could reduce the size of the seed bank considerably. It may also result from the timing of the treatments (late spring), or lack of disturbance to the soil, which would both delay seedling sprouting. Even if seedlings were to sprout soon after treatment, second and third flamings would likely kill them. Thus, if the aim is to allow natives to grow in as the ivy dies, no more than one flaming would be practical, and this research indicates that one flaming alone impacts ivy growth very little. Manual control therefore remains as the best alternative available to planners today for effective, efficient, and selective control of English ivy.

Table 1. Braun-Blanquet cover estimation categories used in experiments and vegetation surveys, with respective ranges and midpoints.

Cover Category	Cover Range	Midpoint
1	<1%	0.5%
2	1-5%	3%
3	5-25%	15%
4	25-50%	37.5%
5	50-75%	62.5%
6	75-100%	87.5%

Figure 2. Difference in percent of ground covered by English ivy before and after each treatment. Positive numbers indicate an increase in cover, whereas negative numbers signify a decrease.

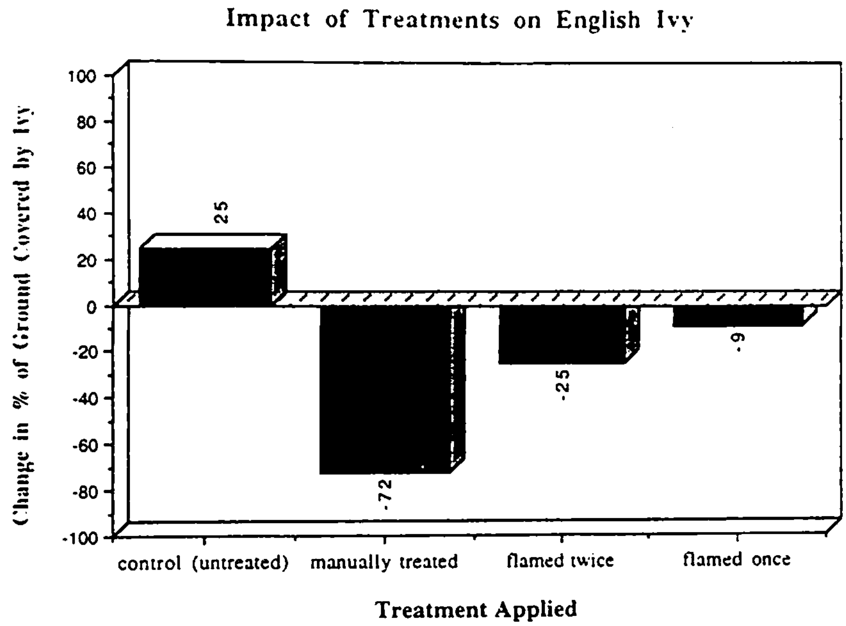
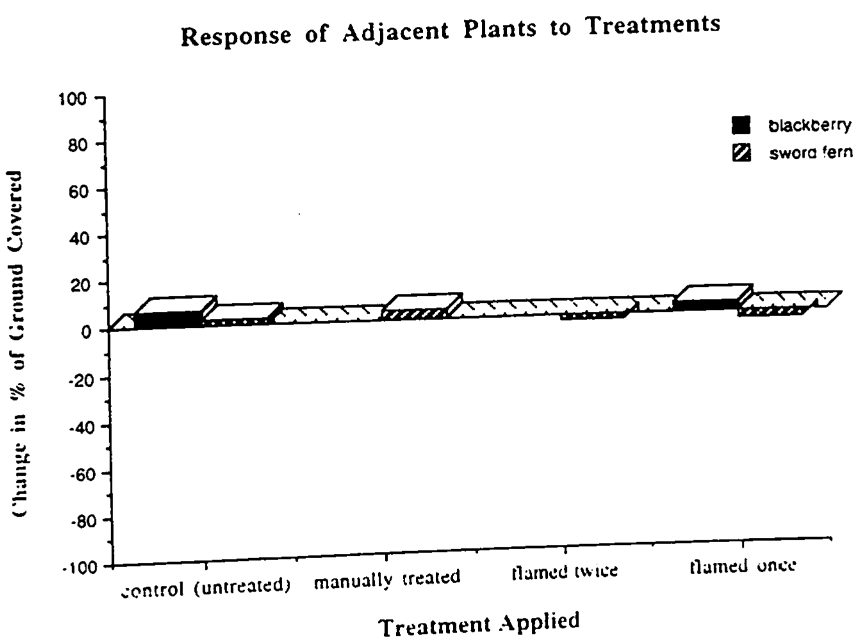


Figure 3. Difference in percent of ground covered by sword fern and Himalayan blackberry.



CHAPTER V

MANAGEMENT OF OREGON PARKS INFESTED BY ENGLISH IVY

Overview of Invasive Plant Management

Management programs for exotic invasive species aim to integrate various control methods in a manner that most effectively and efficiently removes the target species under the environmental conditions and resource constraints specific to the target site. Control methods should therefore complement each other, with each procedure addressing different aspects of the problem and minimizing the effects of other procedures' weaknesses. For instance, manual removal effectively controls English ivy, but leaves the treated site disturbed and susceptible to erosion, re-infestation by ivy, and invasion by other exotic species. However, subsequent planting of the site with hardy native plants may reduce the effects of these drawbacks by stabilizing the soil and reducing the amount of available niche space. This example illustrates how this approach can enable not only accomplishment of initial goals for target species removal, but also minimize disturbance to the site and help prevent recurrent problems with the target species. For Oregon parks infested with English ivy, I recommend a program that consists of five-phases, in which each phase addresses a different concern, and completion of each phase is necessary for implementation of the next. This approach reduces the likelihood of incomplete treatment, which almost invariably results in the invasive species' return to dominance. Thus, it both increases the chances of implemented control procedures' success, and minimizes waste of resources.

The program's five phases are: I) research, II) goal setting, III) community outreach, IV) implementation, V) monitoring, and VI) maintenance. Phase I is necessary because characteristics of the target species, of the site itself, and of possible control methods, all affect program design. Phase I may be divided into general research and site-specific research, and therefore includes research on the target species' biology and ecology, the impacts of possible control procedures, and site-specific environmental conditions, both physical and biotic. Its general research consists of conducting literature searches and experiments that are aimed at understanding the behavior of the target plant and the impacts of various control methods. Site-specific research, in contrast, involves surveying and sampling vegetation at the site, to determine the vegetation composition and the invasive plant species' distribution. Goal setting is phase II, as this process integrates knowledge of the target species with understanding of site-specific conditions, to recognize the limits of control procedures and their viability as solutions. However, implementation of these procedures cannot begin without first acquiring and allocating resources, which is done in part in phase III, the community outreach phase. As management plans must balance desires with available resources, phase III is involved with prioritizing goals and actively seeking human and material resources. During this phase, park personnel enlist aid from members of the community by educating citizens about the problem and explaining how they can help.

Actual removal and restorative procedures occur during phase IV. These procedures should involve methods of demonstrated effectiveness that are specifically tailored to the target site, and would likely utilize the volunteer labor enlisted in phase III. Phase V, monitoring, serves to determine the control plan's effectiveness and indicate when maintenance procedures should be applied. Monitoring involves on-site research such as sampling and surveying vegetation distribution and abundance. Phase VI, maintenance, serves to complete the processes of target species removal and native species restoration, as well as to prevent re-infestation by the target species and invasion by other exotics. Maintenance procedures utilize the control methods applied in Phase IV, which may be modified or adapted to a smaller scale. Finally, most areas invaded by one exotic species are home to several such species, which compete with each other as well as the native vegetation for space. Removal of one invader may therefore serve to increase the spread of another. Thus, in a full program for native ecosystem restoration, single-species management plans should complement each other. If, however, only one plan is implemented, it should attempt to hinder the spread of non-target invasives in the process of controlling the target species.

Management of English Ivy at Skinner Butte

I will apply the above concepts of invasive plant management to Skinner Butte Park, an Oregon park that has been invaded by English ivy. This park has been selected as the target site because it is typical of ivy-infested areas in this region: it is a high-use urban park that contains a small but biologically significant native conifer forest.

Skinner Butte Park is a 100-acre park in which approximately 25% of its area contains English ivy. The majority of the ivy is concentrated on the butte itself and in the trees along the nearby Willamette River. Some ivy can also be found in more cultivated regions, such as parking lot medians. Over the past hundred years, the forested area on Skinner Butte has increased considerably due to intentional tree planting and reduced fire frequency: fires formerly maintained a prairie vegetation in this part of the Willamette Valley, but have been systematically suppressed since the arrival of white settlers (Ed Alverson, The Nature Conservancy, Eugene, OR, 1997 pers. comm.). Aerial photographs document this transition, during which forested north-facing slopes remained intact, but formerly treeless grass/sedge-covered southern slopes became inhabited by a conglomerate of coniferous and hardwood trees (Fig. 4).

English ivy may be a threat to many native species in the older north-slope forest. The forest is home to several native wildflowers, including tall bugbane (*Cimicifuga elata*), an herbaceous annual federally listed as a species of concern. Available information suggests that it may be threatened or endangered, but lack of data on its population size and distribution has prevented the meriting of such a status (Ed Alverson 1997 pers. comm.). Tall bugbane grows in forest understories in, and west of, the Cascade mountains in Oregon and Washington, but its populations are small and scattered, making the community of about 100 plants present on Skinner Butte botanically significant. English ivy could severely reduce this bugbane population directly, by competitive exclusion, or indirectly by altering the forest habitat.

A number of other native plants that are not listed as rare or endangered, but that are valuable members of native ecosystems, are also put at risk of extirpation or serious depletion within the park by the encroaching English ivy. These include the trees themselves, which ivy kills by smothering and shading out the leaves. Many understory plants depend on these trees, which provide shade and habitat for a variety of plant and animal species, and are therefore integral to both their survival and the existence of the forest. In addition, several native wildflowers, including western trillium (*Trillium ovatum*), fairybells (*Disporum* spp.), and Solomon's seal (*Smilacina* spp.), face competition for space and nutrients by the spreading ivy.

Phase I: Research

The general research segment of phase I, which is presented in chapters II-IV of this thesis, serves provide a general framework on which planners may base a management program for English ivy. Site-specific research, in contrast, aims to enable planners to tailor the management program to the environmental conditions present at the site, increasing the likelihood of success. Site-specific conditions influence management decisions in that they may render some control methods inappropriate or impractical, and may dictate the extent to which restorative procedures, such as reseeding, are necessary. Such conditions, which will be investigated in this section, include native species composition and distribution, topography, land-use practices, and site location. Site-specific research involves surveying the target site and sampling vegetation to determine the distribution and abundance of the target species, acquire relevant information about its physical and biotic environment, and identify special problems or concerns.

This research may be divided into two types of surveys: a broad primary survey, and more focused and intensive secondary surveys. During the primary survey, the major plant communities are categorized, the most dominant and common species are identified, and patterns of land use are noted (Cain and Castro 1959). These data are used to prepare a map that shows the major features of community distribution, with special focus on distribution of the target species. The intensive surveys that follow cover only selected areas, and are concerned with gathering quantitative and semi-quantitative data (Cain and Castro 1959) that is relevant to control of the target plant and protection of native plant species. Below, I discuss the methods and results of surveys done at Skinner Butte Park, and their implications to management of English ivy within the park.

Primary Survey. I focused the site-specific research at Skinner Butte Park on the butte itself, as this area contains the biologically significant native conifer forest, Moreover, it is a virtual island, separated from other semi-natural park areas by roads and cultivated fields. Thus, these borders provided convenient means by which to limit the surveyed area. Initial reconnaissance surveys, in which the main vegetation types were identified and mapped, showed six major plant communities (Fig. 5), that were categorizable by dominant overstory species:

1. Douglas-fir (*Pseudotsuga menzeisii*);
2. Bigleaf maple (*A. macrophyllum*);
3. Treeless -- grasses, sedges, and shrubs;
4. Mixed deciduous -- maple (*Acer* spp.), oak (*Quercus* spp.) and sweet cherry (*Prunus avium*);

5. Mixed coniferous/deciduous -- incense cedar (*Calocedrus decurrens*), Douglas-fir (*P. menzeisii*), pine (*Pinus* spp.), oak (*Quercus* spp.) and maple (*Acer* spp.);
6. Incense cedar (*C. decurrens*).

Native understory species were found only in plant communities 1 and 2. Sword fern (*Polystichum munitum*) appeared to be the most abundant native species in community 1, as did common snowberry (*Symphoricarpos albus*) in community 2. Exotic invaders, however, were the most dominant understory species. Himalayan blackberry (*Rubus discolor*) was present in all vegetation types, and grew in extensive patches. Scotch broom (*Cytisus scoparius*) was found in communities 2-5, and was particularly abundant in treeless areas and mixed communities. English ivy was found in all vegetation types, but was extensive only in the presence of conifers (Fig. 5). Ivy distribution included the entire floor of community 1 (located on the butte's north slope), and most parts of the mixed coniferous/ deciduous and incense cedar woods (communities 5 and 6). This correlation between ivy and conifer locations suggests that ivy initially became established in the older Douglas-fir forest, and has spread beneath the increased shade created as conifers (climax species) replace deciduous hardwoods (early successional species) in the former grass/sedge-lands of the butte's south face.

Intensive surveys. Intensive surveys focused on plant community 1, as this is the only area in the park in which native understory species are threatened by English ivy. Both understory species and overstory trees were surveyed. The understory survey was aimed at determining species relative abundance, which were measured in terms of cover, a measure of the percent of ground shaded by the leaves and stems of each species, and sociability, an index of distributional patterns such as crowding and dominance. Categories of cover (Table 1) and sociability (Table 2) were recorded for all plants in twenty 1m x 1m plots, and for ivy alone in an additional 28 plots, whose locations were determined by a stratified random sampling design. Each species' total coverage was calculated by multiplying frequency (proportion of plots containing the species) by average cover per site.

A total of thirteen species were found in the understory, of which ten were native species and three were exotic invaders (Table 4). The exotic species consisted of English ivy (*H. helix*), Himalayan blackberry (*R. discolor*), and English holly (*Ilex aquifolium*). English ivy, by far the most abundant species, grew in extensive patches or in mostly pure mats. Ivy showed at least 15% coverage in all sampled plots, and covered an estimated 66% of the total forest floor (Fig. 6). Second to ivy in abundance were native sword fern and Smith's fairybells (*Diasporum smithii*), which both grew only in small groups and covered an estimated 6% of total ground area. All other species had estimated total cover values of less than 5%, and occurred in small patches or groups, or as solitary individuals (Table 4). It should be noted that the survey was done in September, after the above-ground portion of many summer herbs, including tall bugbane, had died. Thus, this sample likely under-represents the area's herbaceous wildflower distribution and abundance over an entire year, and lacks some data that are important to management decisions, such as that of the tall bugbane population.

The goal of the overstory survey was to determine the degree of English ivy infestation on forest trees, as well as the relative abundance of each tree species within the community. Forty-eight trees were sampled by the point-centered quarter method, in which twelve points were selected by a stratified random sampling design. Each point was designated as the origin of four quadrants, and the nearest tree from each quadrant was sampled. For each tree, species name, and the presence (+) or absence (-) of ivy were recorded. Four tree species were found: bigleaf maple comprised 69% of sampled trees and 23% were Douglas-fir, while grand fir (*Abies grandis*) and sweet cherry (*Prunus avium*) each represented 2% of the total (Table 5). English ivy was found growing up the trunks of 92% of the sampled trees, with no apparent species preference. Severity of infestation ranged from the presence of one small shoot to almost complete coverage by thick, bushy vines. I also noted evidence of previous control efforts on many trees-- dead, severed ivy vines still clinging to trunks.

The results of these two surveys indicate that English ivy infestation is extreme both on the ground and in the trees, and that all tree species are at risk. Although some native understory plant species are maintaining sizable populations, the estimated abundance of most species sampled is small. These results suggest that, like the understory vegetation examined in Chapter IV, native species abundance is too low for immediate re-establishment in treated areas. Thus, the control plan should include procedures aimed at restoring native vegetation. Moreover, two non-target exotic species have successfully become established in the understory, indicating that successful restoration of native species will require control of these species as well as English ivy. However, as data concerning species richness and abundance of herbaceous annuals and perennials are incomplete or absent, further research is necessary before implementation begins. I recommend springtime survey of understory vegetation, which would provide the quantitative data on herbaceous understory species that may later be used to assess the program's success.

Phase II: Program Goals

The information presented in Chapters II through IV of this thesis makes clear that partial ivy removal would neither solve the problem of ivy infestation, nor alleviate it for more than a short period of time. Thus, the management plan's primary goal is eradication of English ivy from Skinner Butte. Moreover, site-specific research indicates that priority should be given to arboreal ivy. This should prevent further tree death from competitive exclusion by ivy, which is important because native understory species depend on the environmental conditions provided by the threatened trees. In terms of plant communities, priority should be given to community 1, the only area with both extensive ivy infestation and an extant native plant component. Second priority should go to communities 5 and 6 -- areas containing extensive ivy growth but few native understory species -- and finally, communities 2, 3, and 4, which contain less extensive infestations of English ivy. This approach aims to relieve the most severe pressures inflicted by English ivy first, as removal will be a long-term process that may take several years to complete. Finally, this program aims accomplish this goal in five to seven years, as this both provides a reasonable time frame for control efforts and encourages immediate and continued action. From a long-term viewpoint, this approach would save time and energy, as ivy spreads about one meter per year at this site (see Chapter II), and the amount of work necessary to treat this problem is therefore increasing rapidly.

Phase III: Community Outreach

Community outreach is a vital step to invasive plant management in urban parks, as the problem often extends beyond both park boundaries and the limits of available resources (Michael Robert, Hendricks Park, Eugene, OR 1997 pers. comm.). The scarcity of funds available to city governments for allocation to parks makes aid from community members necessary to such projects' survival. One of the most valuable forms of community aid is volunteer participation, such as work to implement control methods. This is important because the recommended procedures are often labor intensive, and few funds are available for wages (Michael Robert 1997 pers. comm.). For these reasons, volunteers at Skinner Butte would likely need to comprise the vast majority of the large work force required for manual removal.

A second vital form of community aid involves parallel removal of the target species on nearby land. This prevents post-treatment spread of the target species from adjacent sites, and re-colonization of the park. At Skinner Butte, cooperative work should focus on land adjacent to the park, as much of this land is on the butte itself, and severely ivy-infested. Much of these sites' ivy is contiguous with park ivy, and could vegetatively spread across park boundaries. Moreover, ivy could spread to the park by seed dispersal from non-adjacent neighborhood yards, where it is a common landscape feature. As these phenomena could seriously undermine efforts to eradicate ivy within the park, the work of nearby landowners in removing the ivy on their land may be vital to the program's success.

Education is the focus of most community outreach programs, as citizens' support relies largely on awareness and understanding of the problem, and of why their support is needed. Education programs may utilize a variety of presentation styles, both written and oral . Written methods, which have been effectively used by officials and Eugene's Hendricks Park (Michael Robert 1997 pers. comm.), include placing signs and flyers at park entrances and trailheads, or in neighborhood mailboxes. These methods are advantageous in that signs and flyers may be used for years with little more work involved than the initial preparation. Active methods are likely to be more labor intensive, but also more successful in recruiting participants, as personal interaction may aid in selling the idea. These methods include oral presentations and question-and-answer sessions, as well as door-to-door solicitation of support.

At Skinner Butte Park, I recommend using written methods to educate the public about English ivy, and supplementing these with recruitment of cooperation and support by the more interactive oral methods. Written methods should be applied first, and should include posting signs and distributing brochures both within the park and in the surrounding neighborhood. Within the park, signs should be placed at key points, such as by the picnic tables at the northern base of the butte, at the major trailheads, and by the parking lot on top of the butte. The subject matter in these signs should be divided into sections that each answer one of four important questions: 1) What is English ivy?, 2) How is it a threat to this park?, 3) What is being done to combat it?, and 4) How can community members help? Furthermore, these signs should provide phone numbers that interested persons may call for further information, and state that park personnel are available to answer questions. Boxes may also be built below these signs and stocked with brochures that contain the same information, so it can be taken home and examined at leisure. However, use of brochures in this manner can become a problem, as the brochures are a litter source.

Outside the park, these brochures should be placed in mailboxes throughout the neighborhood, and distributed to community organizations that might be interested in volunteering. Placing brochures in neighborhood mailboxes, especially on property that contains English ivy contiguous with that which grows inside the park, should encourage owners of nearby land to remove any ivy growing there, or to allow removal by volunteers. Moreover, park officials should contact the owners of adjacent land to discuss the situation directly and answer questions.

For enlistment of volunteer labor, brochures may be distributed to members of community groups such as Nearby Nature and the Oregon Native Plant Society. I recommend contacting these groups first, as they have coordinated volunteer efforts for many similar projects, including control of English ivy in parts of Alton Baker Park (Dave Wagner 1997 pers. comm.) and are interested in issues relating to exotic invasive plant species. In addition, high school and university honor societies and student interest groups are often in search of worthwhile projects. Park officials could offer to give presentations, answer questions, and discuss the management plan at such groups' meetings. They should also work with group members to set up and organize volunteer work parties, in order to facilitate maximum involvement.

Phase IV: Implementation of Control Procedures

The decision of which control methods to implement relies mainly on the management program's goals, the size of the area to be managed, the degree of infestation. As the Skinner Butte Park program goals include both eradication of English ivy and protection of native plant species, control should therefore include both removal and restorative procedures. Moreover, due to the small size of Skinner Butte, and reasonable abundance of several understory plant species even in the most infested areas, I do not recommend broadcast chemical control: it is non-selective and polluting, and may present a threat to the health of neighbors and park visitors. Thus, it should be reserved for large areas where ivy is virtually the sole understory plant. I also do not recommend biological control, because the area to be treated is small, and ivy control on the butte would not be worth the risks involved. Manual control appears to be the best option for this park, as it is effective, highly selective, and more efficient than flaming, based on my experiment (see Chapter IV). In addition, as manual control leaves the ground bare at the treated site, managerial control methods should be employed following manual removal. This should serve to reduce erosion and re-infestation, and promote recovery of native species.

Manual control. Manual treatment includes removal of both arboreal and ground-growth ivy. Arboreal ivy may be removed with large clippers, and removal should consist of clipping, in a ring around the tree, all ivy vines growing up the trunk. Creating a gap in the vines from about ankle level to knee level will ensure that none accidentally remain uncut. Treatment of arboreal ivy should begin with its most severely infested trees, as they are in immediate danger of damage or death. Removal of ground growth should consist of pulling out ivy roots and stems, and I recommend using tools that increase efficiency, such as polaskis and clippers (see Chapter III). Workers manually removing English ivy should attempt to be as selective as possible, leaving native species unharmed. Furthermore, they should attempt to remove other invasive exotic species present, in addition to English ivy. On Skinner Butte, workers should be able to recognize

English holly and Himalayan blackberry, the two most abundant invaders, and know to remove them.

As manual control is disruptive to the treated habitat, removal should be done in increments, allowing time for partial recovery of one section before moving on to the next. Priority has been given to community 1, as it contains native understory species, but as ivy removal should be incremented, I recommend alternately treating sections of community 1 and other areas of the butte. Moreover, I suggest proceeding according to the Bradley weed control approach, which recommends first treating the extreme edges of the infestation and working toward the denser center (Hoshovsky 1985). This should facilitate natural processes of recovery by native species, allowing them to help stabilize each cleared area. In addition, removal efforts should begin at the top of the butte and proceed downhill, as ivy shoots tend to grow downhill. This will reduce re-infestation of ivy by vegetative spread from untreated segments.

I suggest that community 1 should consist of four sections, with removal from one section occurring every March for four years. This will allow time for native species planted following manual control to become established before further treatments are applied, limiting the amount of bare ground at any one time. Moreover, March appears to be the most ideal time to pull ivy, as during this time, English ivy's resource reserves are likely to be at their lowest levels. Other communities should also be treated during the spring, for these same reasons, in the same manner: following the recommended priorities and beginning at the edges of each patch of ivy.

Managerial control. Managerial control procedures should follow each manual treatment. They may include the planting of competitive native species or seeding with a mixture of native annual and perennial herb seeds (see Chapter III). I recommend planting numerous sword ferns in treated sites, as sword fern appears to be the region's best native competitor to English ivy, and should therefore serve to hinder re-infestation by ivy and invasion by other exotic species. Moreover, young sword ferns are readily available, as they can be acquired in large quantities from nurseries. The aim of reseeding with herbaceous plants is to speed the recovery of understory species diversity, especially that of native herbaceous understory species. Seed mixtures can be either bought or made with seeds collected from the site. I suggest buying a pre-made mixture, as they are inexpensive and seed collecting is time consuming. However, I also recommend buying the mixture that most resembles the species composition of the treated site, and adding to this mixture some seeds collected directly from the site. Store-bought mixtures are not likely to contain seeds for rare species such as tall bugbane (*Cimicifuga elata*) at Skinner Butte. Furthermore, the addition of site-collected seeds may improve germination success, as individual plants often show a high degree of local adaptation.

Reseeding and planting should take place during early spring soon after the ground thaws. This provides time for seeded herbaceous plants to complete an entire life cycle, and gives planted ferns time to become established before winter. This will also reduce the likelihood of death due to late-summer drought. Furthermore, as this schedule coincides with recommended times for initial ivy removal in plant community 1, it would leave the ground in treated areas bare for only a short time. In other plant communities, attempts at establishing ferns and wildflowers may not be successful, due to variable shade, moisture, and temperature conditions. I do, however, recommend planting sword fern in community 6, which has an understory dominated by English ivy and large bare patches, as the benefits of colonizing the ground with a vigorous native species will likely outweigh the risk of failure. In the other communities, however, understory species composition is more complex and less ivy-dominated. They will therefore likely require removal of other invasives before restorative measures such as reseeding and planting can be successful.

Finally, as volunteers will probably comprise the majority of this work force, I recommend scheduling most treatment sessions for weekends. I also suggest that work sessions be organized based on four-hour shifts, as past volunteer efforts have shown that more work is accomplished per hour in half-day sessions than in full days. This also leaves half of the day free for other activities, which tends to result in increased participation (Hoshovsky 1985).

Phase V: Monitoring

Monitoring is a long-term process that is often overlooked in invasive plant management programs, although it can be essential to their success. Monitoring in this context involves collecting data on indicator variables, such as distribution and abundance, of species affected by control procedures. These data may be used to verify if the proposed goals have been met and to assess the treatments' effects. Thus, monitoring gives planners the power to adjust future treatment procedures according to demonstrated impacts on the site. Monitoring therefore enables them to ensure the long-term success of a management plan.

Although monitoring has tended to involve blind data-gathering with no pre-established focus or aim, it is far more useful to when geared toward identifying "hot spots," (problem areas) and analyzing trends. This can be accomplished by using specific success criteria and biologic indicators to efficiently collect the most valuable and relevant information (Noss 1990). Furthermore, a hierarchical approach, in which criteria and procedures become increasingly precise and accurate, more efficiently achieves this purpose. For instance, the first level of monitoring for invasive plant management may be a qualitative assessment done during a walk-over of the site, and should be sufficient to indicate problem areas. Then, if a "hot spot" were found, a quantitative survey could then be applied to answer specific questions.

The monitoring phase of an invasive plant management program should have three foci: 1) the target species, 2) other invasive exotics, and 3) the various native species involved. Success criteria and indicators must therefore be specific to each type. At Skinner Butte Park, the target plant is English ivy, and the management plan aims to eradicate it from the entire butte. Thus, a small presence of English ivy at treated sites demonstrates that this goal has not been met, and calls for implementation of maintenance procedures. In contrast, the program does not aim to eradicate other invasive exotics, but rather attempts to decrease or maintain present cover and abundance values. Success may therefore be measured by comparing post-treatment cover estimates with pre-treatment values: an increase would indicate that control methods should be applied. With respect to native species, determining success is complicated by the many species involved. However, measuring overall native cover, in which cover of all native species were summed and analyzed together, should simplify this process. Another solution would be to monitor selected indicator native species. As monitoring procedures aim to assess treatment success, indicators should include native species that are planted during implementation or are directly affected by treatments. At Skinner Butte, such species would include sword fern and the herbaceous species that comprise the chosen seed mixture. Success by both approaches may be determined by comparing the number of plants present during monitoring with the number planted during implementation of managerial control.

I recommend that the Skinner Butte monitoring program consist of two levels, as this degree of precision should be sufficient to ensure accomplishment of program goals. Primary monitoring should involve site walk-overs, in which abundance of indicator species is qualitatively assessed. This is simple and less time-consuming than other methods, but should reveal such "red lights" as English ivy presence or low sword fern density. Secondary monitoring should consist of sampling cover by the same methods used in phase I of this management program. These include sampling understory species cover and degree of ivy infestation on trees, and will allow for comparison of pre-treatment and post-treatment data. Such secondary monitoring procedures should be implemented every other monitoring session, even if primary monitoring procedures do not indicate any problems. This would provide quantitative results for use in designing future English ivy management plans, and should reveal any problems missed during the primary monitoring stage.

I recommend initially monitoring sites at Skinner Butte every six months, as the experiments discussed in Chapter IV indicated that resprouts of manually treated ivy may reach 5%

cover in four months. Thus, monitoring sessions six months after treatment would likely contain enough ivy to easily find, but in small enough quantities to quickly control. Moreover, one of these bi-yearly monitoring sessions should take place during late spring or early summer, when the above-ground portions of herbaceous annuals and perennials are alive. This will enable assessment of reseeding success. Once the vegetation structure on treated sites has stabilized somewhat, monitoring once every few years should be sufficient. However, this reduction should be gradual, and should proceed according to the degree of stabilization that data gathered during monitoring indicates has occurred.

Phase VI: Maintenance

The maintenance phase utilizes the control procedures implemented in phase IV, and data gathered during phase V, to ensure the achievement of the management program's goals, and lasting success of both the removal and restoration aspects of the plan. Recommended maintenance procedures include: clipping arboreal ivy from trunks, pulling the stems and roots of ivy ground cover, planting sword fern, and seeding with native herbs. The data gathered from monitoring may be used to modify these procedures to make them better fit site-specific conditions and the smaller scale of operation relative to phase IV. Maintenance should only be necessary when monitoring indicates that goals have not been met. It is, however, safe to assume that a reasonable amount of maintenance will be required the first few years after treatment, as no removal effort is always 100% effective. Moreover, as I have no data concerning the best way to apply proposed restorative measures, such as sword fern planting, it is likely that their success will require considerable follow-up work.

Conclusion

Management of English ivy is a complex process that must account for a variety of factors, and success often requires considerable time, effort, and commitment. However, unlike many exotic invasive species, such as Himalayan blackberry and Scotch broom, English ivy is clearly controllable. This is due to its dependence on vegetative reproduction rather than prolific production of resistant seeds, and its lack of a strong root system, which would enable rapid resprouting. For native ecosystem management in urban parks, this is of enormous significance. Urban parks are the sites most extremely infested, and therefore most severely altered, by English ivy. Ivy infestation can destroy the native ecosystem structure and species composition in such areas, although they are intended to be protected from factors that decrease biodiversity. Ivy infestation also tends to make natural areas less accessible to the public. Moreover, although English ivy is just one of many degradative factors to native habitats, ivy removal may enable native ecosystems to withstand unrelated stresses, by releasing them from its pressures.

The prime question posed to planners and park officials therefore concerns whether or not the benefits of control outweigh the costs. Chapter V indicates that, in the case of Skinner Butte -- a small, severely infested, biologically significant urban park -- control by presently available means is feasible for planners and park managers. However, it is also clear that in many cases, such as at sites that contain few native species or low levels of infestation, control may not be worthwhile, even given English ivy's rapid rate of spread. To be successful, future English ivy management plans will therefore need to approach control more systematically and scientifically than is common today. Moreover, long-term solutions to English ivy infestation will need to focus on developing new, more efficient control methods, or improving existing methods. For instance, my experiments suggested that flaming may prove to be effective if larger areas are treated.

Finally, prevention of continued planting of English ivy, a practice that is still common among landscapers and private citizens, is vital to the long-term success of control efforts. This will require increased education and communication among park managers and landscape architects. Further research should aim to find practical alternatives to English ivy, such as native or non-invasive species that are functionally comparable. Moreover, legal bans on planting

English ivy in some areas may be necessary. This will require research concerning ivy's seed dispersal, about which very little is known, and is important because if ivy spreads vegetatively the vast majority of the time, limits on planting may need to be less severe than if colonization by seedlings is common. Many of these changes may be several years away, but if they occur, it seems likely that permanent, widespread control of English ivy could be not only attainable, but worthwhile and practicable. Thus, ivy control could become an invaluable tool for maintaining the integrity of Oregon's native forest habitats.

Table 2. Midpoints of percent-cover estimates for English ivy (*Hedera helix*), sword fern (*Polystichum munitum*), and Himalayan blackberry (*Rubus discolor*) in all plots before and after treatments. Negative cover change values represent a decrease, and positive values signify an increase.

Treatment	Plot #	% *H. helix* cover		% change		% *P. munitum* cover		% change		% *R. discolor* cover		% change	
		May	August	Per site	Mean +1.96SE	May	October	Per Site	Mean	May	October	Per site	Mean
Control		37.5	87.5	50	25 + 9	0	0	0	1.5	0	0	0	5.9
(center)	7	62.5	87.5	25		0	0	0		15	37.5	22.5	
	11	62.5	87.5	25		37.5	37.5	0		0.5	3	2.5	
	16	62.5	87.5	25		37.5	37.5	0		0	0	0	
Control	3	62.5	87.5	25		37.5	37.5	0		0	0	0	
(edge)	7	62.5	87.5	25		0	0	0		15	37.5	22.5	
	11	37.5	37.5	0		15	15	0		0	0	0	
	16	62.5	87.5	25		3	15	12		0	0	0	
Manual Removal	4	62.5	3	-59.5	-72 + 10	37.5	37.5	0	4.3	0	3	3	-0.1
(center)	5	62.5	3	-59.5		15	15	0		0.5	3	2.5	
	10	87.5	0.5	-87		0	0	0		0	0	0	
	14	87.5	3	-84.5		3	15	12		0	0	0	
Manual Removal	4	62.5	15	-47.5		37.5	62.5	25		0	0	0	
(edge)	5	87.5	3	-84.5		15	15	0		3	0	-3	
	10	87.5	3	-84.5		0	0	0		3	0	-3	
	14	62.5	3	-59.5		3	0	-3		0	0	0	
Flamed Once	1	87.5	62.5	-25	-9 + 15	0	0	0	-2.8	0	0	0	4.25
(center)	8	37.5	62.5	25		0	0	0		3	15	12	
	12	62.5	62.5	0		37.5	37.5	0		0	0	0	
	13	62.5	37.5	-25		15	15	0		0	0	0	
Flamed Once	1	87.5	87.5	0		0	0	0		0.5	0	-0.5	
(edge)	8	62.5	62.5	0		0	0	0		15	37.5	22.5	
	12	87.5	87.5	0		0	0	0		0	0	0	
	13	62.5	37.5	-25		37.5	15	-22.5		0	0	0	
			September										
Flamed Twice	2	87.5	62.5	-25	-25 + 0	0.5	0	-0.5	-1.8	0	0	0	0
(center)	6	62.5	37.5	-25		37.5	37.5	0		15	15	0	
	9	62.5	37.5	-25		0	0	0		0.5	0.5	0	
	15	62.5	37.5	-25		15	3	-12		0	0	0	
Flamed Twice	2	87.5	62.5	-25		0	0	0		0	0	0	
(edge)	6	62.5	37.5	-25		15	0.5	-14.5		15	15	0	
	9	62.5	37.5	-25		0	0	0		0.5	0.5	0	
	15	62.5	37.5	-25		3	3	0		0	0	0	

Table 3. Braun-Blanquet sociability categories used in vegetation surveys, with respective descriptions.

Sociability Category	Description
1	Solitary individuals
2	Small groups
3	Small patches
4	Extensive patches
5	Extensive mats, mostly pure

Table 4. Frequency, cover, and sociability values for each sampled understory species.

Common Name	Scientific Name	Frequency	Mean Cover Per Sample	Estimated Total Cover	Sociability
English Ivy	*Hedera helix*	1	66%	66%	4
Smith's Fairy Bells	*Diasporum smithii*	0.8	8%	6%	2
Sword Fern	*Polystichum munitum*	0.5	12%	6%	2
Common Snowberry	*Symphoricarpos albus*	0.4	12%	5%	3
Him. Blackberry	*Rubus discolor*	0.3	11%	3%	3
Dull Oregon-grape	*Mahonia nervosa*	0.1	15%	2%	1
Lady Fern	*Athyrium filix-femina*	0.1	15%	2%	2
Sweet Cherry	*Prunus avium*	0.1	3%	<1%	2
Wild Rose	*Rosa nutkana*	0.1	3%	<1%	1
Elderberry	*Sambucus racemosa*	0.05	15%	<1%	1
English Holly	*Ilex aquifolium*	0.05	15%	<1%	1
Thimbleberry	*Rubus parviflorus*	0.05	3%	<1%	2
Pathfinder	*Adenocaulon bicolor*	0.05	3%	<1%	2

Table 5. Relative abundance and degree of English ivy infestation of all sampled tree species.

Species Name	Number Sampled	Proportion of Total	Number With Ivy	Proportion With Ivy
Acer macrophyllum (Bigleaf Maple)	33	69%	31	94%
Pseudotsuga menzeseii (Douglas-fir)	11	23%	10	91%
Abies grandis (Grand Fir)	2	4%	2	100%
Prunus avium (Sweet cherry)	2	4%	1	50%
Total	48	100%	44	92%

Figure 4. Aerial photographs of Skinner Butte taken in 1936, 1952, and 1990, respectively. Note that original north-slope forest remains intact, but that southern-slope prairie vegetation has increasing tree cover.

Figure 5. Map of vegetation communities and English ivy distribution on Skinner Butte. Note correlation between ivy distribution and location of coniferous trees.

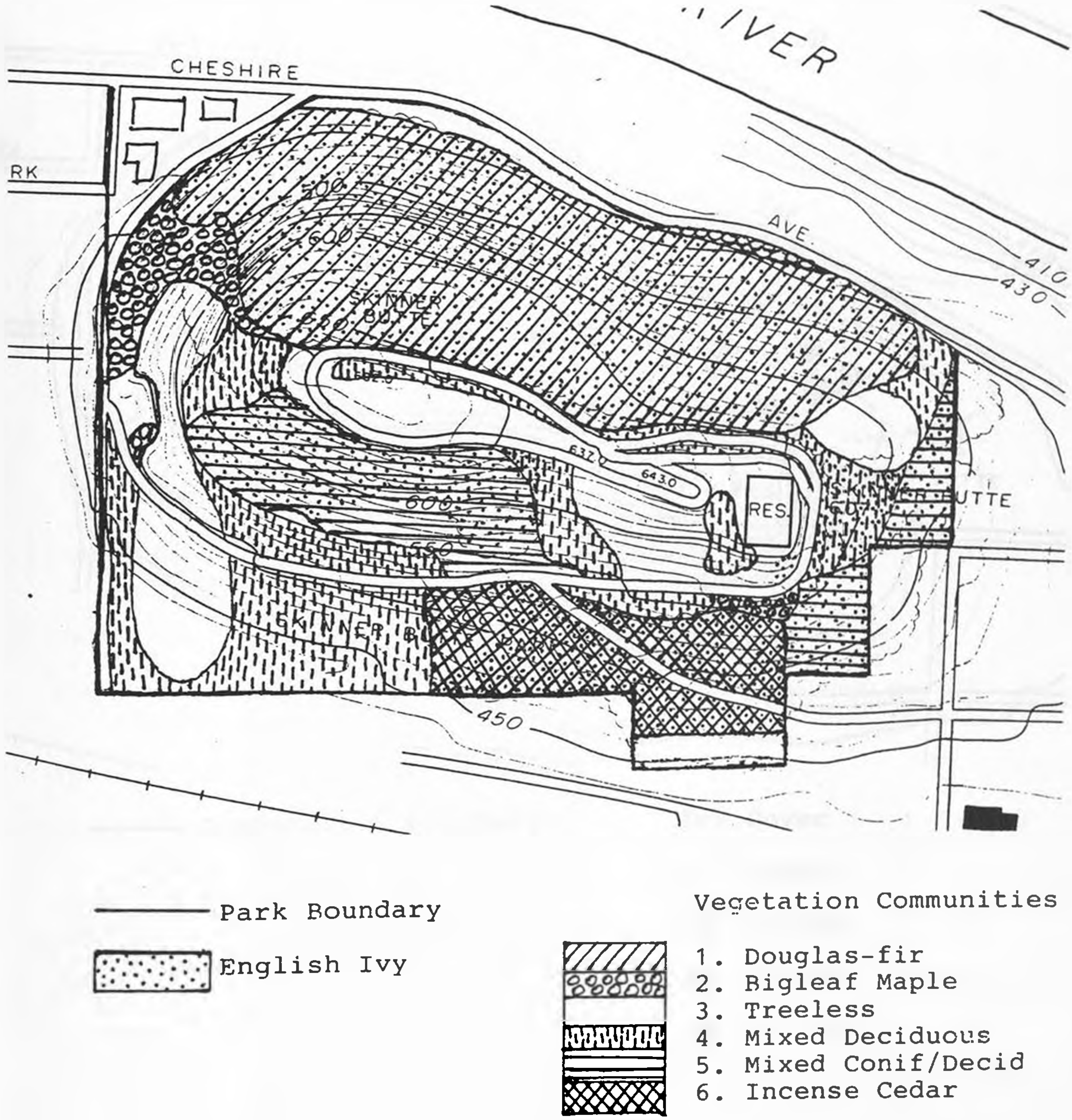
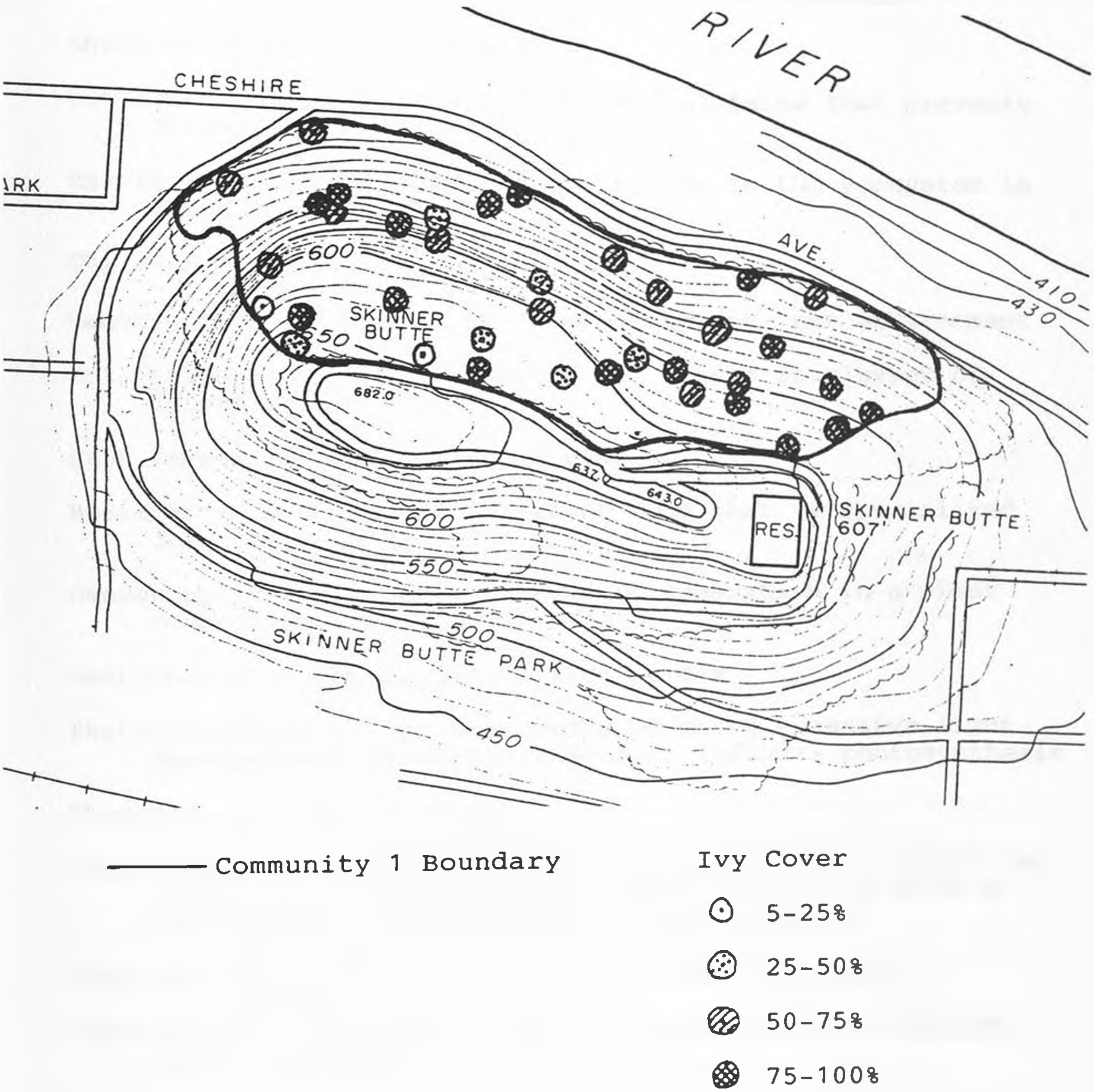


Figure 6. Map of estimated English ivy cover at sample sites. Average cover was 66%.



GLOSSARY

Adhesive adventitious roots -- roots that grow from the sides of stems and are used for clinging to surfaces

Angiosperms -- flowering plants

Cuticle -- the waxy covering on leaf surfaces that prevents excessive water loss

Exotic -- foreign, imported; not native to the ecosystem in which it is found

GA_3 -- a plant growth hormone

Genotypic -- determined by genetic content, not environment

Inflorescence -- (v) flowering; (n) flower or cluster of flowers

Leaf lamina -- leaf surface tissue

Meristem -- a region of the plant body that is specialized for tissue generation

Overstory -- the uppermost layer of vegetation in a plant community; consists of trees

Pentamerous -- consisting of five petals

Photoinhibition -- the phenomenon by which excessive light damages cell parts and therefore inhibits photosynthesis

Photoperiod -- day length

Stratified random sampling -- a sampling design in which the survey area is divided into equal units from which a fixed number of points are randomly sampled

Terminal -- positioned at the top or end of a stem

Understory -- the ground layer of vegetation in a forested plant community

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