AN ABSTRACT OF THE THESIS OF

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Steve Radosevich

Himalaya blackberry (*Rubus armeniacus*) is a widespread, exotic, invasive plant now common over much of western Oregon and Washington. An observational experiment revealed that disturbance to a monoculture of Himalaya blackberry allows the soil seed bank to be expressed and return the inhabited area to an earlier successional stage. This stage of succession may be more manageable and closer to a desirable vegetative condition than Himalaya blackberry. A split-plot experiment that imposed the effects of plowing and herbicide application after mowing, as well as shade treatments at different levels, indicated that each treatment, separately and together, effectively inhibit the regrowth of Himalaya blackberry. These results provide a framework for managing large areas inhabited by Himalaya blackberry.

Factors Affecting the Regrowth of Himalya Blackberry
(*Rubus armeniacus*)

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Chapter 1. Introduction

1.1. Problems With Invasive Species

Over forty years ago, Elton (1958), in reference to exotic organisms, stated that ecologists were witness to "one of the great historical convulsions in the world's fauna and flora." Now at the dawn of a new century, the danger of invasive species to native ecosystems continues, and the costs grow, both monetarily and quantitatively (Bazzaz, 1986; Hacker and Gaines, 1997; Pimentel et al., 2000). Invasive species alter the structure and function of the ecosystems that they occupy (Jordan and Jannink, 1997; Hacker and Gaines, 1997; White and Schwarz, 1998; Manchester and Bullock, 2000; McDowell, 2002). However, because of concern about pesticides in the environment and the release of non-indigenous biological control agents in the environment, the methods to reduce the abundance of invasive species are subject to tighter scrutiny than ever before. This leads to a limited range of control options (Randall, 1996; Jordan and Jannink, 1997).

President Clinton issued Executive Order 13112 in 1999 to address the growing problem of invasive species in the United States (Federal Registry 64(25): 6183-86). That order resulted in the federal Invasive Species Management Plan, which calls for research on invasive species, preventative measures against introduction of new species, and habitat friendly methods to control established populations.

There have been numerous claims that increased knowledge about the biology of weeds or other invasive plants will aid in control of those species (Harper, 1965; Mills et al., 1993; Cousens and Mortimer, 1995; Bhowmik, 1997). However, to date, there are few instances where biological data collected in the field have actually been applied to enhance methods of control. Cousens and Mortimer (1995) suggest that such statements are more about ambition than the application of science.

1.1.1. Descriptions of biodiversity.

Biodiversity includes the different species of plants and other life forms that make up a habitat. Species variety is one of the factors of an ecosystem that provide services to the system through the functions of each factor (Randall, 1996). For example, leaves have different shapes (factor). Different shaped leaves may allow water to reach the soil in different amounts or quality (function), and each provides water for ecosystem use (service) (Davis et al., 1996; Baruch and Goldstein, 1999).

Some factors of biodiversity are: genetic diversity, taxonomic differences, within species variation, community groups or associations, and the variety of interactions among the organisms and the abiotic environment in natural systems (Randall, 1996; Jordan and Jannink, 1997). The functions that the various factors perform are as varied as the ecosystems that they form, but primary and net production, decomposition, stabilization and filtration are the main roles of the factors of biodiversity. Food, clean water, recycled nutrients, clean air, genetic stability, and erosion prevention are direct services benefiting humans that are performed by ecosystems that maintain a high level of biodiversity (Wharton, 1979; Davis et al., 1996; Manchester and Bullock, 2000).

The effects that biodiversity have on ecosystems are not clearly defined (Mooney et al., 1996). Bazzaz (1996) states that the relationships may be indirect. He maintains, as an example, that one ecosystem process, resilience, is a function of soil factors like pH and texture, which may in turn be altered by non-native plants. Other scientists are less ambivalent (Baker, 1986; Randall, 1996) and suggest specific ways that ecosystems adversely respond to exotic species.

1.1.2. Definitions of invasive plant species.

An invasive species can be defined in a number of ways. Bazzaz (1986) makes a distinction between plants that are immigrants, colonizers and invaders. An immigrant is a new species to an area that integrates with the ecosystem but does not displace native vegetation. Colonizers, he divides into two categories, those that rely on disturbance and those that do not. The disturbance dependent colonizers behave opportunistically but may or may not be competitively adept. Those that do not rely on disturbance must be competitive and be able to access resources when native species are dormant or unable to make use of the resources. Bazzaz explains that an invader can out-compete local inhabitants for resources and then displace them.

On the other hand, Baker (1986) defines invaders as a combination of attributes that compares the original range of an invasive plant with the characteristics of the new habitat. The original habitat (i.e. source) of the invader and the new habitat (i.e. sink) must be comparable in at least some aspects (Baker, 1986; Dunning, 1992). Baker suggests that similar climate and vegetative life forms, as well as occupied soil types should not significantly differ. In addition, invaders should have generalized pollination systems that rely on wind, self-pollination, or use generalized insect visitors. They must have efficient seed dispersal mechanisms to allow rapid spread, and vegetative reproduction as assets for invasion (Baker, 1986).

While some investigators are precise in the meaning of certain terms, others consider some terms to be interchangeable. Ehrlich (1986) uses either "colonizer" or "invader" to mean a plant that has crossed a geological barrier. The plant then establishes itself and rapidly reproduces to expand its range and numbers. Bazzaz (1986) suggests that "alien" and "weed" are anthropomorphic terms that are to be avoided. Randall (1996) states that a weed is a pest plant and can be native or non-native. He describes native plants like native woody shrubs invading grassland due to a shift in fire activity as being weeds. He explains that non-natives can infest either agricultural or the natural environment. Baker's (1986) idea of a weed is a plant that grows anywhere that humans have significantly disturbed the area. He goes on to state that plant invaders are weeds even if they become the dominant vegetation in an environment, such as *Bromus tectorum* in the Great Basin of the United States (Pimentel et al., 2000).

McDowell (2002) presents a simple, yet elegant, definition for invasive plant species that will be used in this thesis. Paraphrasing her; 'an invasive species is a plant that is first introduced into a habitat; establishes itself and begins to reproduce and persist in its new home. Ultimately it is able to persist, reproduce, and spread at rates that displace indigenous species.

1.1.3. Relationship of the invasive plants species to biodiversity.

Invasive species threaten biodiversity and degrade ecosystems by changing the services that ecosystems provide (Mooney and Drake, 1986; Pimentel, 1986; Randall, 1996; Richard and Dean, 1998; White and Schwarz, 1998). Most natural systems have been invaded and are subject to new species continually (Mooney and Drake, 1986; Simberloff, 2000). Invading plants have displaced several native species (Morse et al., 1995; Hood and Naiman, 2000; Manchester and Bullock, 2000) and the spread of invaders in the United States is in excess of 700,000 hectares per year (Babbitt, 1998).

Documentation on the spread of exotic plant species indicates that some systems are more likely to be invaded than others, for example, grasslands, riparian zones, roadways, trodden paths, sand dunes and some open forest are more susceptible than other ecosystems (Baker, 1986). Rates of invasive plant population growth tend to be exponential, while the rates of area spread tend to be linear (Bazzaz, 1986; Roughgarden, 1986). There are, however, differences in the patterns of spread of invasive species. A steady advance of a front is common where there is a single locus of introduction. The more frequent type of spread with invasive species is by satellite populations (Figure 1.1), where dispersal and establishment of new populations occur that are dispersed from the initial introduction point (Baker, 1986; Moody and Mack, 1988). Both types of spread are used by Himalaya blackberry.

The purported effects of invasive species on biodiversity are varied, often depending on the perspective of the investigator. Some studies suggest that nonnative plants may be able to access soil nutrients and water at the expense of native plants (Orians, 1986; Bazzaz, 1986; Manchester and Bullock, 2000; Fotelli et al., 2001). Nonnative plant density also can affect pollination efficiency in many species (Randall, 1996; White and Schwarz, 1998). Grasslands inundated by foreign grasses have been subjected to fires more frequently than before invasion (Randall, 1996; Vitousek et al, 1996). In one case, the fire frequency increased from once every 60-100 years to once every 3-5 years (Wisenant cited in Pimentel et al., 2000). An increase in fire frequency amounts to a direct threat to human life and property (White and Schwarz, 1998), as well as to wildlife. The resulting changes in vegetation cause reductions in animal numbers suited to the native plant community (Pimentel et al., 2000).

Figure 1.1: Example of patches of Himalaya blackberry (top; note arrows) which can grow together to form monoculture stands (bottom; note oval).

Plant invasions degrade ecosystem services, displace native species, change habitat structure, support other exotic organisms (insects, viruses, fungi, etc.), and threaten genetic stability through hybridization with native species (Mills et al., 1993; Randall, 1996; Pastor et al., 1996). Taken a step further, invasions may cause cascade effects that lead to the decline and/or extinction of native species (White and Schwarz, 1998). Protection of these processes requires the ability to predict which plants are invasive and which habitats might be subject to them.

1.2. Characteristics of Invasive Plants

Attempts have been made to categorize the wide range of characteristics and environments of invasive plants (e.g. Baker, 1986). Baker's list, for example, is a combination of plant characteristics and site features (Baker, 1986). Other attempts to categorize invasive traits use computer programs that model or predict succession based on geographical position, stand type (e.g. sites ranging from urban to forest clearings), nutrient status, water availability, and substratum type (e.g. Prach et al., 1999).

Many difficulties exist in predicting invasions (Manchester and Bullock, 2000). For example, most introductions of exotics into a new setting are not successful (Wilson, F., 1965; Simberloff, 1986), and we will never know the number of introduced species that failed to establish. An estimate is that 0.1 percent of all imported species are actually invasive (Williamson, 1993 as cited in Manchester and Bullock, 2000). Obviously, a comparison between successful and non-successful invaders is impossible, and begs the question; "Are there any common attributes among the failures?" Another category of problem species is invasion from intended introductions. Whether for biological control, food, or forage, plants and animals sometimes escape domesticated surroundings and become established. Fortunately, most escapees are not genetically equipped to survive without human help (Baker, 1986).

Of those species that are able to establish, persist, and spread in new surroundings, the reasons for success are as varied as the plants themselves. Two areas in particular receive most attention. The characteristics of the invading species are an obvious focus of study. Similarities between habitats, old and new, also are at least as important (Raunkiaer, 1934; Baker, 1986).

1.2.1. Biological Factors Contributing to Successful Invasion

One of the reasons often cited for successful biological invasion is the idea that species that are introduced into a new environment leave their natural biological controls behind (Elton, 1958, Baker and Stebbins, 1965; Blossey and Notzold, 1995). While this idea contributes to the justification for importation of biological control agents (McDowell, 2002), it has both supporters (Blossy and Notzold, 1995) and critics (Willis et al., 1999). The concept fails to account completely for why many introduced species are not invasive. In a classic discussion cited in Baker and Stebbins, (1965), Debach asks Baker if release from natural enemies should be included in his list of ideal weeds. Baker concurs and suggests that perhaps resistance to fungi, viruses, and parasites should also be included. Stebbins then pointed out that "in the Mediterranean areas resistance to cattle, sheep, goats, donkeys, cows, and women who cut the wood should also be included!"

In the same vein of biological control and natural restraints, Bazzaz (1986) explains that disease, whether a natural enemy or not, may not in all cases slow invasion. He uses *Bromus tectorum* in western North America as an example. Up to 48 percent of the seedlings of that grass die annually, but the spread continues in spite of a disease that is responsible for the mortality rate (Bazzaz, 1986). There are simply enough survivors to maintain the rate of spread.

At a physiological level, McDowell (2002) demonstrates that photosynthetic characteristics are the "defining difference" between two *Rubus* species: trailing blackberry (native) and the invasive species Himalaya blackberry in the Pacific Northwest of the United States. Relative growth rates, root and shoot ratios, self pollination, and genetically based adaptive capacities are also mentioned as plant characteristics that can help define invasive species (Baker, 1986; Bazzaz, 1986; Jordan and Jannink, 1997; Manchester and Bullock, 2000; McDowell and Turner, 2002).

Spatial and temporal scales are important factors when comparing habitats. An example of a comparison based on time would be that invaders must exhibit the ability to acquire resources when local plants are dormant (Bazzaz, 1986).

Maillet and Lopez-Garcia (2000) observe that weedy species tend to germinate in late spring and early summer and that they also flower in late summer and early fall. The timing of the life cycles of such weedy species, among other qualities, makes them prone to establishment in disturbed areas.

1.2.2. Spatial scale

Spatial scale refers to the horizontal arrangement of groups of plants (Radosevich et al., 1997), whether populations or associations, and their dispersal patterns. Many authors cited seed size, size of plant, vegetative reproduction, or generalized pollination systems as plant characteristics of invaders affected by spatial scale (Baker, 1986; Maillet and Lopez-Garcia, 2000; Pimentel et al., 2000; McDowell, 2002).

To say that an invasive species forms a monoculture requires a definition of scale. One needs to know if a small area surrounding a waterway is the focus of study or whether an entire landscape is included. Dunning et al. (1992) described landscapes as a composition of habitat types and as a spatial arrangement. Their study suggests that four features in a region may have a bearing on whether expansion of populations of any kind occurs. One of the features only applies to animals, because it requires the organism to move around. The other three apply to plants and will be described.

Dunning et al. (1992), described a system of complementary services whereby an organism requires two different resources, but only one is in the patch where the organism is located. The other resource is located in a nearby patch and is needed for the organism's survival. Given is a plant in an open, grassy patch that has all the water and nutrients that it requires, but is in need of a seed dispersal agent. Birds that live for the most part in a shrubby or forested patch nearby can supply that service by visiting the plant to obtain food and remove the seed.

The second feature is a source-sink relationship where a plant may have enough resources in its patch to survive but not enough for the population to grow. The original location may serve as a source for propagules to populate other nearby areas but lack resources to reproduce in large numbers. Dunning et al. (1992) provide an example of a type of grass that grows in two adjacent habitats where one population augments satellite populations in abundant years. The source site is abundant in everything except space. It supplies seed for satellite sites that lack nutritional resources to provide adequate population replacement over time. Refreshing gene pools, i.e. gene pools necessary for the health and evolution of the satellite population, also is important in this case.

The last example (Dunning, 1992) is a neighborhood effect and includes features of the areas contiguous to a target population. In the neighborhood effect, the local vegetation surrounding a plant population of interest can affect the movement of hostile or beneficial insects, which can directly determine the well being of the plants. The size and shape of the surrounding features can hinder competitors or predators. Fragmentation, edge effects, and corridors are examples of indirect effects that have bearing on beneficial insects, for example, and therefore, on the plants of interest (Dunning et al, 1992).

1.2.3. Habitat comparison

Another aspect of interest in many studies, besides characteristics of the invasive species, is the comparison between environments, old and new, or the condition of the new habitat. It was once proposed that invaders must have a disturbed habitat in order to gain a foothold (Elton, 1958). That notion was modified to "almost always" (Baker, 1986), and later minimized to "most invaders posses an ability" to invade disturbed environments (Bhowmik, 1997, Hacker and Gaines, 1997; Maillet and Lopez-Garcia, 2000). A frequent observation is that some ecosystems are more prone to invasion than others (Harper, 1965; Baker, 1965, 1986). The most likely regions are grasslands, riparian zones, waterways, roadways, footpaths, sand dunes and light forest (Baker, 1986; Harper, 1986). That these areas are also likely to be disturbed by human activity has not gone unnoticed.

The similarity between climates of the homeland and that of the new species' settlement are included as a driving factor by most researchers seeking common mechanisms of invasive plants (Baker, 1986; Maillet and Lopez-Garcia, 1999; Manchester and Bullock, 2000). The major focus on climate is temperature range and total moisture, but distinctions such as a Mediterranean climate that has cool, wet winters and warm, dry summers show that climate regimes are also important (Harper, 1965; Baker, 1986; Pimentel et al., 2000).

Nutrient availability, mocorrhizal fungi and soil pH, as well as texture and depth of the soil are characteristics that help to determine whether a plant can survive in a new habitat. The similarities in soil condition and the type of substratum between the origin and destination are frequently used as indicators of invasibility (Baker, 1986; Prostko et al., 1992; Pimentel et al., 2000). Bazzaz (1996) considers these factors along with soil moisture and the size of disturbed area in the new habitat to be decisive factors driving changes, and thus providing the suitability of the new habitat to the new organism.

" The true test of a theory is its predictive power" (Wilson, E.O., 1965). However, biological experts agree that the variability of characteristics of invasive species prevents development of an adequate generalized theory (Blossey and Notzold, 1995; Bhowmik, 1997; Hacker and Gaines, 1997; McDowell, 2002). If a model has too few parameters, it will tend to make incorrect predictions about the success or failure of invasions under varying circumstances (Simberloff, 1986). It follows that too many parameters are either unwieldy or tend to be too site specific. But even if great numbers of variables are needed to predict invasion, the cause is worth the effort because of the ability of invading species to alter the structure and function of ecosystems (Mooney and Drake, 1986; Mooney et al., 1996).

One characteristic that is most included in a list of predictors of invasive species is how a plant behaves in its native range. The plant's original status can be a clue as to its behavior in a similar, but new habitat (Maillet and Lopez-Garcia, 2000). Of the plants that are considered agricultural weeds in France, 69 percent were agricultural weeds in their original range and tended to be annuals. However, of those plants that are considered weeds in a natural environment in France, only 26 percent were weeds in their home environment, and they tended to be herbaceous perennials and shrubs (Maillet and Lopez-Garcia, 2000). If the variability of characterization about invasive species defies generalization (McDowell, 2002) and demonstrates low predictive ability, then either an adequate general theory does not exist, or more information is needed.

1.2.4. Research about individual invasive species.

The reality that invasive species damage the environment requires action. But what action and in what direction should that effort be applied? Invading species take up energy, nutrients, and water while altering the ecosystem they inhabit; therefore the individual species is important at the ecosystem level (Vitousek, 1986; Chapin and Körner, 1996). There is a need for information about the plants that have already invaded, but that information is often unavailable or scattered within the scientific literature (Baker, 1986).

Characteristics of individual species may provide clues to a predisposition toward invasiveness. Waddington (1965) compared the transplantation of individual species as a series of experiments in evolution. He felt that such studies probably held more information than laboratory experiments. Twenty years later, Vitousek (1986) reiterated that message by reasoning that, "although some argued that ecosystem dynamics were better studied as a whole, if individual species were capable of transforming structure and function of ecosystems, then individual species were clearly important at the ecosystem level".

Recently, McDowell (2002) proposed that species that had invaded a habitat were able to do so because they responded to local stimuli in a similar manner as the local vegetation. I would add to McDowell's conservative proposal, that since some exotic plants are invasive, perhaps they respond more efficiently than the native plants to local stimuli. Bazzaz (1986) supports this conjecture. He notes that invaders not only modify the existing community, but they are able to "usurp" resources at the expense of resident vegetation.

1.2.5. A Conceptual Framework for the Control of Invasive Plant Species

Hacker and Gaines (1997) present a conceptual model suggesting that direct positive interactions to ecosystem function can benefit from disturbance. The basis for their model relies on the "intermediate disturbance hypothesis" from Connell (1978) that maintains that mortality to a competitive dominant from disturbance can provide an opportunity for increased species diversity. Plants that are normally unable to compete with dominant species are relieved of competitive pressure when the prevailing plant species is disturbed. This results in more plants with diverse morphological and /or physiological characteristics and capable of surviving in the absence of the dominant species.

The intermediate disturbance hypothesis is difficult to test (Ricklefs, 1979; Townsend et al., 1997). The underlying mechanisms that drive the response of the environment to disturbance are not completely understood, and there may be confounding factors that correlate with either disturbance and/or species abundance. However, proof of the hypothesis notwithstanding, the theoretical framework provides the foundation for manipulation of a habitat by suggesting that disturbance levels are relative to the organisms of interest, and that one measure of disturbance intensity is measured by the percentage of space that is disturbed (Begon, et al., 1996) Additionally, the practical application of the hypothesis relies on natural situations and, perhaps even more significantly, the results demonstrate both realism and utility (Townsend et al., 1997).

Connell (1978) defines disturbance as damage suffered by organisms that lead to partial or total destruction of the individual or group of individuals. However, Hacker and Gaines (1997) provide additional conditions that rely on more than mere disturbance, regardless of the relative level of damage imposed on the competitive dominant species. They refer to an "enemy free space" that provides an area that allows less competitive organisms room to establish and grow. Further, many authors (e.g. DeAngilis et al., 1987; Bertness and Calloway, 1994; and Jones et al., 1994) suggest that facilitator species can improve conditions for less common plants once stress and disturbance have been applied to the competitive dominant.

1.2.6. Summary

Invasive species alter ecosystems and threaten biodiversity. Although there are a number of characteristics that many invasive species share, both in biology and in abiotic factors, there is no satisfactory generalized theory that enables scientists to predict which species will be invasive and which will not. Either the characterizations are too general, or they tend to be site specific. Many investigators (Waddington, 1965; Mooney and Drake, 1986; Bazzaz, 1986; Vitousek, 1986) think that further studies of specific plants that have already invaded an ecosystem are the fertile ground for further studies in this area.

Within this context I conducted research to address basic questions about the life history and control of Himalaya blackberry. Specifically, I hypothesize that if existing Himalaya blackberry populations are subjected to the stresses of plant competition and the impacts of disturbance with treatments like mowing or chemical herbicides, growth and spread of the blackberry patches may slow. Additionally, I hypothesize that shade can successfully retard the growth of blackberry and could be used as part of a successful, integrated management program against Himalaya blackberry. Such a control program might protect and enhance the biodiversity of areas subjected to invasion by Himalaya blackberry. Both competition and shade will apply additional stress to previously manipulated blackberry plants by limiting resources. Shade reduces a predominate resource, light, while plant competition reduces several environmental resources available in aggregate, including light. The intermediate disturbance hypothesis provides the theoretical framework for a method to abate the spread of Himalaya blackberry.

CHAPTER 2. Effects of Soil Disturbance, Shade and Vegetation on Himalaya Blackberry Cane Growth

2.1. Introduction

Himalaya blackberry (*Rubus armeniacus*) is a plant species that has invaded and naturalized in western North America. It invades riparian areas, reduces species diversity, forms monoculture stands, and changes the way the ecosystem provides services to animals and humans in the areas it invades (The Nature Conservancy, 2000; McDowell, 2002). Other than herbicide studies and hybridization research in horticulture, little is known about Himalaya blackberry. As an invasive plant species, Himalaya blackberry requires substantial further study about its life history and ways to slow its spread (Waddington, 1965; Baker, 1986; Mooney and Drake, 1986; Bazzaz, 1986; Simberloff, 1986; Vitousek, 1986; Tilman, 1988; Norris, 1997).

2.1.1. Nomenclature of Himalaya blackberry.

Himalaya blackberry suffers from an abundance of scientific synonyms. Among the synonyms that have been used are: *Rubus procerus, R. discolor, R. fruiticosus, R. praecox, R. hedycarpus* var. *armeniacus*, *R. ulmifolius*, and *R. sanguineus*. Adding to the confusion, the plant is found in such diverse areas as Hawaii, the Netherlands, and Western Oregon, and has been labeled with a variety of local names.

Rubus armeniacus belongs to a large group of brambles, the *Rubus fruiticosus* complex, and thus, is sometimes mistakenly called *Rubus fruiticosus* (Grime, 1988; Ceska, 1999). Himalaya blackberry (*Rubus armeniacus*), is only one of several species in the complex, so *R. fruiticosus* is not the species name.

Both "*Rubus procerus*" and "*Rubus discolor*" are commonly used as synonyms for Himalaya Blackberry (*Rubus armeniacus)*. However, *Rubus procerus* Mueller has been incorrectly applied to *Rubus armeniacus*. The reason behind the misapplication is that *Rubus armeniacus* has also been confused with *Rubus praecox* Bertol, and *Rubus praecox* is a synonym for *Rubus procerus* Mueller. *Rubus praecox* is an endemic species that grows only in wildland areas of Europe (Weber, H.E. cited by Ceska, 1998).
Rubus discolor Weihe & Nees is another name that has been applied to *Rubus armeniacus*, but *Rubus discolor* is a synonym of *Rubus ulmifolius* Schott. (Holeb, J. cited by Ceska, 1999), which is another European species not found in the Pacific Northwest. It has been suggested that a mis-identification of *Rubus armeniacus* as *Rubus ulmifolius* led to the use of *Rubus discolor* (Ceska, 1999). However, the leaves of *R. ulmifolius* are smaller than those of Himalaya blackberry (*R. armeniacus*), and the thorns of *R. ulmifolius* are curved on both the dorsal and ventral edges of its canes (Watson, 1958). Thorns of Himalaya blackberry are curved only on the ventral side of canes (Figures 2.1 and 2.2).

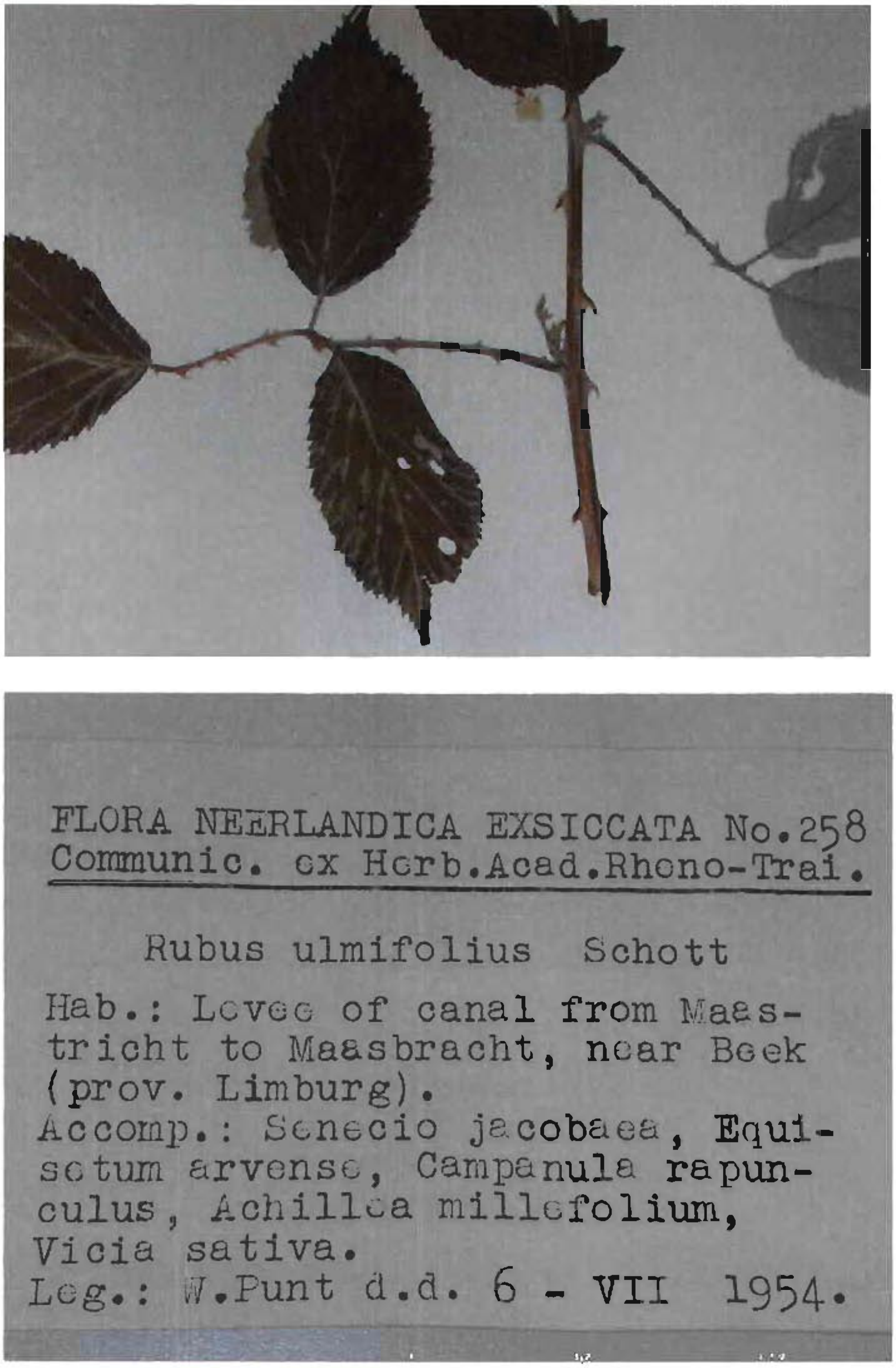

Figure 2.1: Herbarium sample and tag of *Rubus ulmifolius* from Oregon State University. Note that both the dorsal and ventral edges of the thorns are recurved.

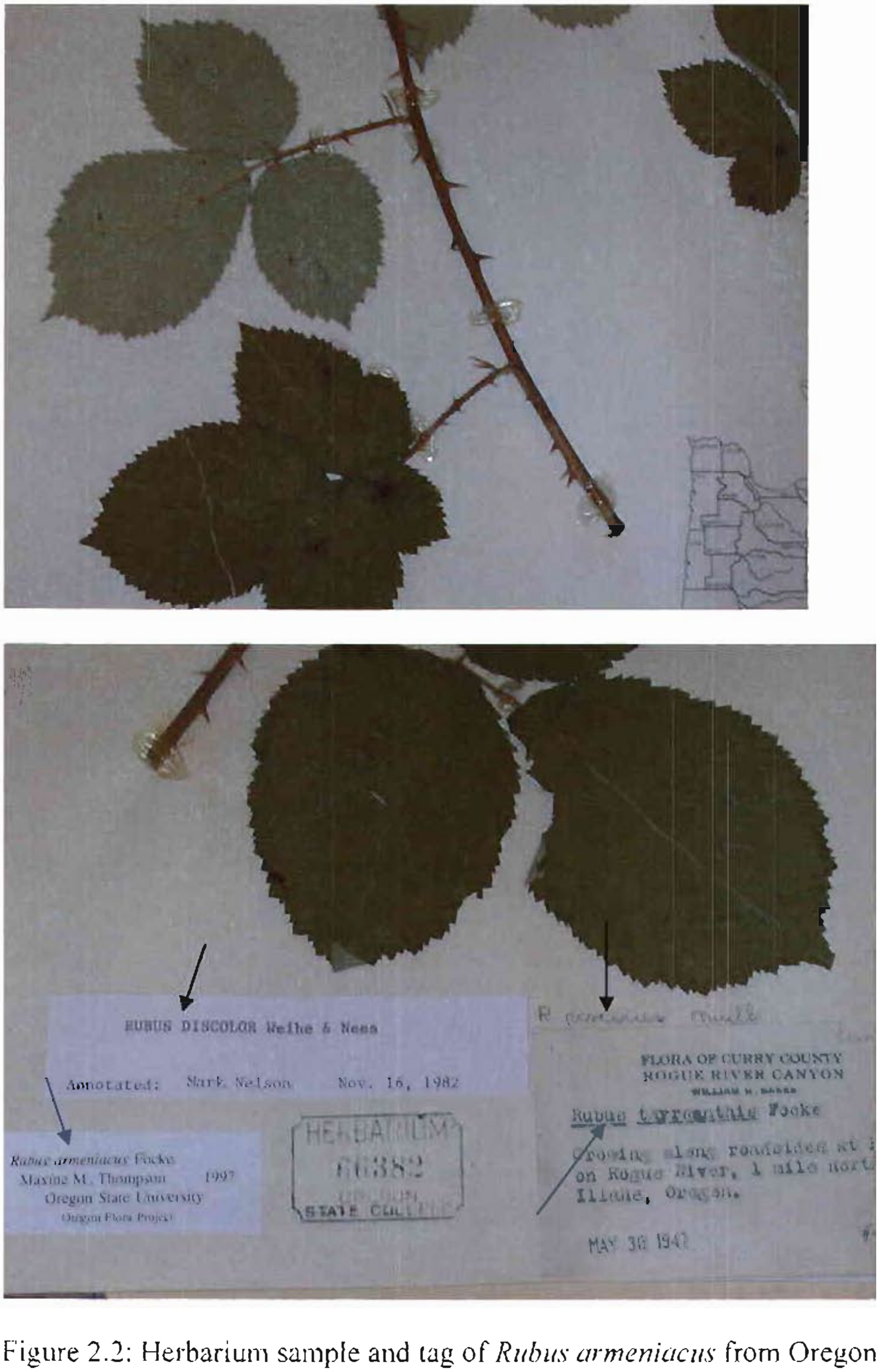

Figure 2.2: Herbarium sample and tag of *Rubus armeniacus* from Oregon State University. Note that dorsal edge of thorn is straight and ventral edge is curved. Tags illustrate confusion over the proper scientific name.

J. Holub, a botanist who specializes in the study of *Rubus* species, identified the plant known in the Pacific Northwest as Himalaya or Himalayan blackberry as *Rubus armeniacus* Focke, from samples collected by Ceska in British Columbia, Canada (Ceska, 1998). Later H. E. Weber, another *Rubus* specialist, made a second observation while traveling in the Pacific Northwest. Further, Hummer (personal communication), with the National Clonal Germplasm Repository (NCGR), Corvallis, Oregon, also believes *Rubus armeniacus* to be the correct title for Himalaya blackberry. At the repository, *Rubus* specimens are collected, documented, preserved, evaluated, and distributed worldwide (NCGR, 2002). Dr. Richard Halse, curator of the herbarium at Oregon State University, confirmed the name. Therefore, I use *Rubus armeniacus* Focke as the appropriate scientific name for Himalaya blackberry in this study.

2.1.2. Characteristics of Himalaya blackberry.

Himalaya blackberry (*Rubus armeniacus* Focke) is an invasive bramble that occupies riparian areas, fence-rows and old-fields of the Pacific Northwest, British Columbia and parts of California (Figure 2.3). Human or natural disturbance often results in openings in vegetation and colonization by Himalaya blackberry. Such colonization can result in decreased benefits to humans and other organisms (Elton, 1958; Vitousek, 1986; Bazzaz, 1986;

Figure 2.3: Typical infestations of Himalaya Blackberry; along a fence row (top) and right-of-way (bottom) in the Corvallis area. Note: Orange color is indicative of fall foliage.

Dunning et al., 1992; Endler, J.A., 1993; Bhowmik, 1997; McDowell, 2002). Thickets of Himalaya blackberry form monoculture stands that can alter fire regimes, change the course of succession, and displace native organisms (Randall, 1996; McDowell, 2002).

The species was introduced to North America in the late nineteenth century, escaped cultivation, quickly spread and is now considered naturalized (Ceska, 1999; TNC, 2000). Most literature on the species concerns its horticultural uses or methods of control (e.g. Oregon State University Extension Service, 1997; TNC, 2000; USDA, 2003). Little is known about the biology or successional status of *R. armeniacus* other than it is aggressive and vigorous (TNC, 2000; USDA, 2003). The brambles of *R. armeniacus* attain a height of three or more meters and form tangled thickets that block the movement of large animals and humans (Vitousek, 1990). As the canes spread, they form a near monoculture, allowing for only an occasional plant of different species to grow. Himalaya blackberry reproduces both vegetatively and by seed. Primary canes grow from a crown to a length of up to 10 meters in a single season, which lasts from early spring until late summer. The primary cane may root at its tip. A cane that has tip-rooted is recognizable by examining the thorns at the new crown. The original cane retains thorns that point in the direction of the 'mother' plant. The thorns on newly produced canes point toward the ground (Figure 2.4).

Figure 2.4: A blackberry crown originally from a primary cane that has rooted at its tip. Cane on the left is the tip that rooted. The other two are canes that have sprouted from the tip and adventitious roots. Note the opposite direction of thorns on the two types of primary canes.

During the spring, there are usually four live canes that arise from a root crown, two new primary canes and two one-year-old canes that produce secondary canes, flowers and fruit. In winter, fruiting canes senesce while the two remaining canes produce secondary branches and set fruit the following year.

R. armeniacus forms monocultures and appears to exclude native vegetation. Possible mechanisms for exclusion include shading or other resource depletion from crowding (NRC, 1986; Farmer et al., 1988; Radosevich et al., 1997). Recent studies suggest that *R. armeniacus* is more efficient than native *Rubus* species in nitrogen use, which indicates that the photosynthetic capacity of *R. armeniacus* exceeds that of native blackberries (McDowell, 2002). Unfortunately, the literature reveals little about interactions of *R. armeniacus* with existing vegetation, its effects on native populations, the habitats that it favors, or habitats that slow its spread.

Little has been reported on the adaptations that existing flora or fauna have made to the presence of Himalaya blackberry. Some information sources suggest that rats (*Rattus rattus*) use the brambles for food and shelter (Hickman, 1993; University of California, 2000), while anecdotal information indicates that some native birds also have adopted the brambles for food and shelter (Whelan, 1992; Dave Budeau, personal communication). There is concern that eradication of some non-native, invasive species like Himalaya blackberry may pose a threat to organisms that adapt and use them. If there are organisms that have adapted to, and depend on, *Rubus armeniacus*, then research to discover alternative sources of food and cover following restorations of areas occupied by *R. armeniacus* should be made.

Herbicide applications, mowing, and mechanical removal are the present methods of control for *R. armeniacus*. However, societal pressure and growing evidence of negative impacts on ecosystems from the use of chemicals provides the impetus for other ways to control invasive organisms. Other than mowing and fire, which retard the density of *R. armeniacus* for short periods of time, and volunteer efforts at manual removal, there are few known methods for habitat friendly abatement of Himalaya blackberry. Grazing with livestock has been used in some areas, but control lasts only as long as the livestock are present. The impact of livestock on riparian zones, habitat for *R. armeniacus*, is also a concern.

2.2. Observations of the growth form of *Rubus armeniacus* in three habitats

A number of studies suggest that the size and shape of plants can confer a competitive advantage (Wilson, 1988; Farmer et al., 1988; Dekker, 1997; Baruch and Goldstein, 1999) implying that morphology and growth rate of some plants (e.g. large leaves, height, deeper roots, etc.) enable these plants to sequester resources more efficiently than nearby vegetation.

Three habitat areas were chosen to observe the growth form of Himalaya blackberry in this study: a Douglas-fir (*Pseudotsuga menziesii*) plantation, a Garryana oak (*Quercus garryana*) stand, and a native ash (*Fraxinus latifolia)* thicket. These areas were chosen for observation because Himalaya blackberry growth appeared to be inhibited by them. All of the observation sites are located at the E.E. Wilson Wildlife Refuge, and all, including the experimental site (described later), are within a mile of each other. Elevation, rainfall, and temperature are similar.

Observations were made of blackberry cane diameter and length, and fruit production.Measurements of instantaneous light intensity also were made in each of the habitats using a Li-Cor® PAR sensor. There were differences in the amount of light that reached the understory in each of the observed habitat types. The light readings under the oak habitat were only seven percent of the light that would occur in an open field on a clear, mid-summer day, while ash thickets were 13 percent of full sunlight, and the Douglas-fir plantation averaged 22 percent. The varied light levels and the different growth habits of Himalaya blackberry under each of the observed habitats suggest that the growth of Himalaya blackberry might be a function of the shade level under closed canopies. Thus, the observations became the basis for the shade experiment described later in this thesis.

2.2.1. Douglas-fir plantations.

The Douglas-fir (*Pseudotsuga menziesii*) plantation had the widest range of illumination of the three habitats, which spanned from deep shade (5 mmol/m^2) under the canopy to full sunlight (2000 mmol/m^2) in tree crown openings. Generally, the plantation floor received about 30 percent more light than either the ash thicket or the oak stand.

Under the Douglas-fir canopy, thicket development of Himalaya blackberry was inhibited. Canes sometimes grew through the shaded areas and some canes formed adventitious roots at their tips when they reached a sunlit gap. The primary canes can grow up to 10-15 meters in a year (personal observation). In some cases, patches of open sunlight under a Douglas-fir canopy were farther than a cane could extend in a growing season. Then, a cane rooted from the tip into the duff and soil from which new sprouts grew (Figure 2.4, p 28). The new canes grew until an opening in the canopy was reached where they formed a new thicket. Himalaya blackberry thickets found in canopy openings in the plantation consist of a central bramble, intertwined with multiple vines.

2.2.2. Closed oak canopies.

Establishment of Garryana oak (*Quercus garryana*) is believed to have been aided by the past fire regime of pre-European people. Periodically, the under brush and grasses were burned so that preferred vegetation like camas bulbs and acorns could be harvested. Non-native settlers altered that fire regime, and as a result, some locations developed into closed canopy oak stands, with maple and other trees also present (Franklin and Dyrness, 1973). In addition to herbaceous plants and woody shrubs growing under the oak canopy, naturalized cherry trees (*Prunus* spp.) form part of the overhead cover of these stands near the experimental site.

Without fire and grazing pressure, oaks and other trees form an extensive closed canopy. Himalaya blackberry often grows into the lower branches of the trees at the edge of these stands. However, the species rarely grows farther than a few feet inside the canopy. The blackberry canes are unable to span the distances from the canopy edge to well-lit ground on the other side, but the mechanism may or may not be light availability under the canopy.

2.2.3. Ash thickets.

Oregon ash trees (*Fraxinus latifolia*) form dense thickets in low lying, wet areas and riparian areas. They differ from oak groves and Douglas-fir plantings, because they are located in areas that are partially submerged during the rainy season in western Oregon.

Although the canopies of the ash trees are contiguous, the structure and spacing of the branches and leaves allow mottled light to penetrate to the ground in these stands. Blackberries often form a solid bramble patch along the borders of ash thickets. Himalaya blackberry also grows into the shade of ash groves, though they often fail to develop fully. Such canes are restricted to about one meter in height, and are reduced in girth from those growing in open sunlight or openings in Douglas-fir plantations. There are few panicles or fruit produced on the blackberry canes growing in ash thickets.

2.3. Experiments

2.3.1. Experiment 1: Response of Himalaya blackberry to disturbance and competition

2.3.1.1. Methods

2.3.1.1.1. Experimental site preparation.

On June 28, 2000, an old-field, seasonally wet area of about 0.6 hectares and about ninety percent covered with Himalaya blackberry at E.E. Wilson Wildlife Refuge near Corvallis, Oregon was mowed. The overall experimental area was then divided into two experimental sites. An inventory of blackberry crowns in fifty-three 40.5 m^2 areas was completed on July 31, 2000. Average crown density was 3.3 crowns/m^2. Sixty eight percent of the crowns began to grow again by July 31, and inventory areas that were counted last had a higher number of sprouts than those counted earlier. Debris was raked aside to assist counting, then replaced. A 4050 m^2 area was then plowed, disked, and raked in mid-August, 2000 to remove as many of the mowed root crowns as possible.

The area in Experiment 1 was then divided into four blocks, so this experiment consisted of four 45 m x 22.5 m (1,012.5 m^2) blocks, which were further divided into three treatment plots each. Treatment plots were, therefore, 15m x 22.5m (337.5 m^2). Treatments (plots), applied randomly to each plot in each block, were: (1) planted with three-year-old seedling Douglas-fir on a 3 m x 3m grid, (2) planted with Douglas-fir as above and seeded with a mixture of Italian ryegrass and red fescue, or (3) planted with the perennial grass mixture only. The experiment was conducted as a complete block design with three treatments and four blocks (replications).

In June 2001, visual estimates of coverage by blackberry were made. Vegetation from the soil seed bank emerged during the winter and had grown in and covered the Douglas-fir seedlings. This vegetation was mowed during the spring and landscape cloth was laid between the rows of Douglas-fir. Blackberry vines between each Douglas-fir seedling also were removed at that time. Estimation of coverage by Himalaya blackberry was monitored for the years 2001 and 2002.

2.3.1.1.2. Soil seed bank sampling.

During the first inventory of crowns (June 28, - July 31, 2000) the soil seed bank was sampled to determine what seeds remained in the soil after being under a monoculture of Himalaya blackberry for a number of years. Duff was brushed aside and a sample was taken from the top 15 cm of soil. As the experimental area in Experiment 1 was plowed, disked, and raked, a second seed bank sample was taken from the bottom of the plow furrows, 30-45 cm.

from the soil surface. A total of 53 samples were taken during each sampling time. All samples were placed in a refrigerator until March, 2001 when they were prepared for germination testing.

Sets of germination beds were constructed on slatted, 2.5 m^2 wood tables. Ten-centimeter frames were assembled around the perimeters of each tabletop and lined with plastic. The frame was filled with Perlite®, to a depth of 5 cm and covered with 1.5 cm of sterile potting soil.

Each soil sample was mixed thoroughly, and a 10-gram sub-sample was distributed evenly over a 30 cm x 30 cm area in the prepared germination beds. These sub-samples were randomly assigned to locations in the germination beds. The beds were mist irrigated and checked twice a week for germinating plants.

Seedlings were allowed to grow until they could be identified and then removed. Identification of seedlings continued for eight weeks. At the end of the identification period, seedling germination from the soil sub-samples were compared to a plant species census from the Adair experimental site.

2.3.1.2. Results: Response of Himalaya blackberry to disturbance and competition.

2.3.1.2.1. First year observations.

Seeds present in the soil seed bank germinated and quickly covered both the grass-seeded and the Douglas-fir planted treatments. Three types of vetch (*Vicia sativa, V. americana*, and *V. villosa*) comprised the first flush of this initial vegetation. Himalaya blackberry was detected under the vetch canopy, as well as that of *Chrysanthemum leucanthemum* , *Ranunculus uncinatus*, *Plantago major* and *P. lanceolata*, *Cirsium vulgare* and *C. arvensa*, *Dipsacus fullonum*, *Erodium cicutarium* and *Geranium molle*. *Vicia* declined in abundance by June, 2001. Beginning in May, 2001 a second flush of vegetation grew through the vetch. This vegetation was composed primarily of *Solanum nigrum* and *S. dulcamara*, *Daucus carota,* and several unidentified grasses. Himalaya blackberry accounted for less than 25 percent of the total area occupied in any of these plots, and no cane grew taller than one meter. No significant flowering or fruiting occurred.

Himalaya blackberry crowns were counted immediately after mowing in June, 2000, and the number of crowns that regrew were noted. Re-growth appeared sparse at first. However, within a month, more than 90% of the crowns sprouted. Another crown assessment was made in April, 2002, but only included areas that were not covered by landscape cloth. Because the landscape cloth covered one of the treatments, there was no attempt to separate the crown densities by treatment. Crown density remained lower than before treatments (Table 2-1) were made.

The flushes of plant growth from the soil seed bank were more robust than expected. This observation is in agreement with the intermediate disturbance hypothesis (Connell, 1978) and direct positive intervention ideas of Hacker and Gaines (1997). Although the original density of the Himalaya blackberry made it difficult to census plant richness (number of species in an area) in the midst of the blackberry thickets, there became a more equal distribution (species evenness) of species (Table 2-2), and consequently, greater species diversity (a combination of evenness and richness) at the experimental site (Barbour et al., 1987).

Table 2.1: Total crowns and crown density of Himalaya blackberry after mowing, but before treatments in June, 2000, and two years after treatment in April, 2002.

	Total crowns immediately after mowing	Total crowns April, 2002	Density June, 2000 (crowns/m^2)	Density April, 2002 (crowns/m^2)
Total Numbers	6273	*1786		
Average Crowns per Plot	112	51	3.3	2.0

* In 2002, crowns were counted from 18 plots that were not covered with landscape cloth and averaged.

Table 2-2: Comparison between species from germination test vs plants found at the Adair experimental site. An 'x' means that the plant species was found at the site or germinated in the greenhouse. A zero (0) indicates that the species was missing.

Plant	Greenhouse	Adair	Plant	Greenhouse	Adair
Amaranthus spp	*x*	*x*	*Matricaria matricariodes/(discoidea)*	x	x
Capsella bursa-pastoris	*x*	*x*	Unknown *Bryophyta* (Moss)	x	x
Cardimine occidentalis	*x*	*x*	*Polysticum unitum*	0	x
Chenopodium album	*x*	*x*	*Poa annua*	x	x
Chrysanthemum leucanthemum	*x*	*x*	*Plantago*	x	x
Cirseum vulgare	*0*	*x*	*Ranunculus*	0	x
Cirsium arvense	*x*	*x*	*Rubus armeniacus*	x	x
Trifolium repens	*x*	*x*	*Rumex acetosella*	0	x
Daucus carota	*0*	*x*	*Senecio viscosus*	0	x
Dipsacus fullonum	*x*	*x*	*Siysimbrium officianale*	x	x
Epilobium ciliatum	*x*	*x*	*Solanum nigrum*	0	x
Galium aparine	*x*	*x*	*Solanum americanum*	x	x
Geranium bicknellii	*x*	*x*	*Vicia americana*	x	x
Hypericum spp	*x*	*x*	*Vicia gigantea*	x	x
Lactuca serriola	*x*	*x*	*Vicia villosa*	x	x
Laminaceae	*x*	*x*	*Vicia sativa*	x	x

2.3.1.2.2. Second year observations.

In early spring, 2002, vetch did not reach the height of the previous year, while other plant species germinated and were more prominent than in the first year. Patches of teasel (*Dipsacus fullonum*), Shasta daisy (*Chrysanthemum leucanthemum*), and a strong sward of grasses (Fescue and Rye) that had been sown the previous year covered most of the area. Fescues have a reputation for delayed establishment in short-term studies (Shinn and Thill, 2004). Himalaya blackberry still covered less than 25 percent of the plots it inhabited. Himalaya blackberry crowns averaged 2.0 crowns/m^2 in April, 2002 (Table 2.1) and few canes reached a meter in height.

2.3.1.3. Conclusions from experiment 1.

Four important findings were made following the first and second years of study. (1) The seed bank under the Himalaya blackberry exists for a number of years, although some *Cirsium* species and other plants with lightweight seeds may have blown into the site during a previous year. (2) Direct manipulation of Himalaya blackberry by plowing and disking facilitates restoration of the sites. (3) It is possible to physically manipulate a large area of Himalaya blackberry to an earlier point in succession, in this case grasses and forbs. (4) Even though Himalaya blackberry was the focus of this experiment, the entire habitat responded to treatment of this one exotic plant species.

2.3.2. Experiment 2: Effect of tillage, artificial shade, and herbicide on Himalaya blackberry growth.

2.3.2.1. Methods

2.3.2.1.1. Experimental preparation for plots.

An area adjoining Experiment 1 was divided into four 30 m x 15 m (450m^2) blocks (1800m^2 total area). Each block was then divided into four plots to which the following treatments were randomly assigned: (1) mowed and plowed, (2) mowed, plowed and disked, (3) mowed and herbicide applied, and (4) mowed only. The treatments that included plowing and disking were accomplished at the same time as Experiment 1 (mid-August, 2000). The herbicide (Round-up®) was applied at the rate of 2.5 oz/gal according to the manufacturer's guidelines on October 24, 2000.

2.3.2.1.2. Experimental preparation for sub-plots.

During the winter of 2000-2001 shade structures (sub-plots) were constructed in each of the main plots. These arched structures were 1 m x 2 m, and 1 m high. Each structure was covered with shade cloth that blocked either 73 or 55 percent of the incoming light, respectively. An uncovered area (0% shade) that was the same size as the shade structures was used for comparison. The experiment was conducted as a split-plot design with four blocks, 4 plots (treatments) in each block, and 3 sub-plots (shade levels). The effect of treatments on Himalaya blackberry regrowth was measured as the dried, above-ground biomass of Himalaya blackberry canes and leaves that grew in the growing season from spring of 2001 to spring of 2002.

Light was measured periodically under the shaded sub-plots using a Li-Cor® model LI-185-A quantum sensor. Readings were made twice a month, beginning in January, 2001. Light levels were recorded in the open and under the shaded structures.

Light readings under the shade-cloth structures varied, depending on weather conditions. On clear days, light inside the structure was 42 and 27 percent of direct sun for the 55 and 73 percent shade material used, respectively. However, when days were cloudy or hazy, the 55 percent cloth allowed 70 percent of the sunlight into the structure, while the 73 percent cloth allowed 43 percent (Figure 2.5).

The total biomass of the Himalaya blackberry was harvested from the entire area of each sub-plot between March and May, 2002. Biomass was placed in bags and weighed. The bags were then allowed to air dry over the summer, after which they were again weighed. The vines that originated from inside the unshaded areas were not contained by shaded structures, thus allowing biomass from the unshaded area to grow outside the area of measurement. Samples were obtained by harvesting entire canes that originated from the unshaded area and were also dried and weighed. Data were analyzed using a method for split-plot experiments using S-Plus 6.1®.

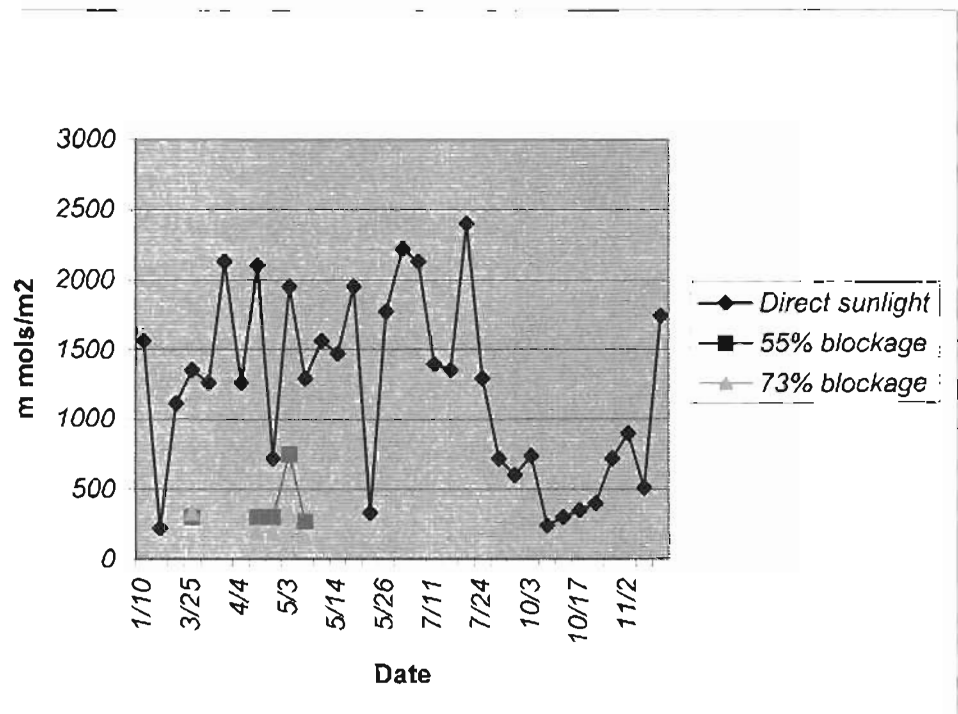

Figure 2.5: Light intensity throughout a growing season in the open and under 55 and 73% shade structures. Measurements were taken under shade canopies in spring only.

In March, 2003, an equal number (total n=78) of stems of primary canes that grew under the two levels of shaded canopies (55 percent and 73 percent) were measured at 15 cm above the soil surface for diameter and compared using a two-sample t-test. The results were analyzed using S-Plus 6.1 ®, and graphs were made using Excel® and S-Plus.

2.3.2.2. Results of Experiment 2: Effects of tillage, herbicide and shade on Himalaya blackberry regrowth.

An analysis of variance (ANOVA) for split-plot designs was used to compare the dry weight of Himalaya blackberry ($g/m^{2)}$ from each sub-plot. A strong block effect (p value = 0.03) was found. There was a significant difference (p value = 0.03) between the average weights of the biomass of Himalaya blackberry from main plots with differing treatments.

The mow-only treatment was significantly less successful at inhibiting regrowth of Himalaya blackberry than the other treatments (p value = 0.03)(Table 2-3), whether separated by shade level (Figure 2-7) or shade levels were combined and averaged (Figure 2-6). Shade levels, irrespective of main treatment, were equally effective in reducing Himalaya blackberry biomass production (Table 2-3, Figure 2-8). However, the interaction of main treatments and shade level (Table 2-3, Figure 2-7) revealed that the following

Table 2-3: Dried Himalaya blackberry biomass (g/m^2) from each plot separated by treatments. While the mow-only (control) contained almost double the biomass of the three treated plots, wide sample variation led to no statistically significant differences.

Treatment	55 % Shade	73% Shade	Full Sunlight	Totals	LSD.1
Mow Only	588.25	357.89	530.44	1476.58	160.29
Mow + Herbicide	321.73	170.09	286.00	777.82	106.03
Mow +Plow	117.64	272.85	312.76	703.25	137.86
Mow + Plow & Rake	255.13	194.18	338.33	787.64	96.78
Totals	1282.76	995.00	1467.53	3745.29	
LSD.1	228.99	98.47	128.77		

*LSD = Least Significant Difference = $t_{\text{(from two-tailed tables)}}$ * ($\sqrt{[2(s^2/n)]}$). This is the smallest difference that, when divided by the standard error of the difference, gives exactly the Student's t that one would find for a 90% probability of the result being due to the treatments rather than chance.

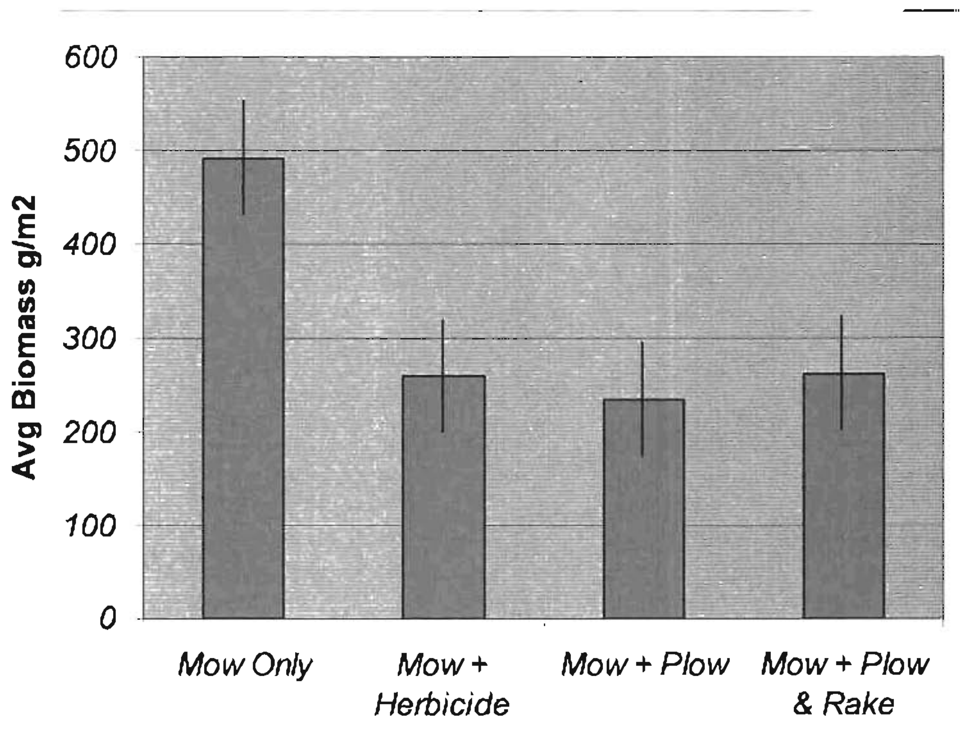

Figure 2-6: Average dry biomass of Himalaya blackberry resulting from four main treatments. The average was obtained from a total of all results from each treatment, regardless of shade level. The mow-only treatment averaged more biomass than other treatments ($p = 0.03$). No statistical difference between other treatments was found. Vertical lines represent one standard error in both directions.

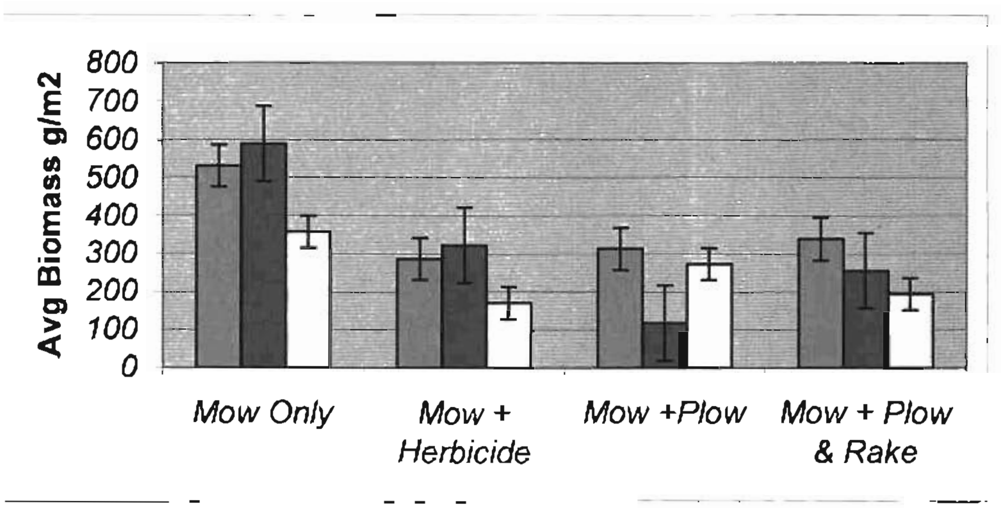

Figure 2.7: Biomass resulting from blackberry foliage (g/m^2) according to treatments and shade level. Blue is 0% shade, red is 55% shade, and yellow represents the 75% shade level. Vertical lines represent one standard error for shade treatments.

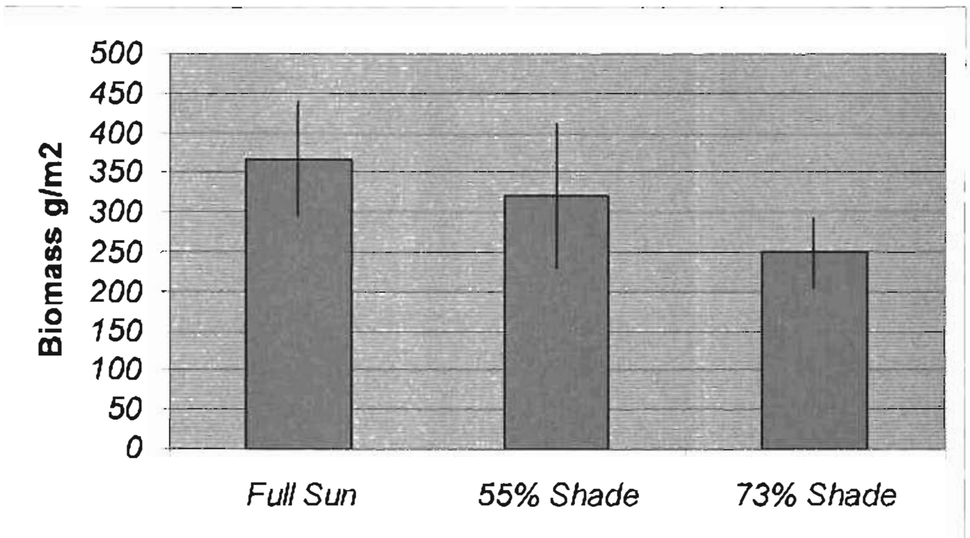

Figure 2-8: The biomass of Himalaya blackberry foliage when separated by shade level. The average was obtained from a total of all results from each shade level regardless of treatment. The difference seems apparent, but variation in the results does not yield statistically significant results. Vertical lines represent one standard error in both directions.

differences exist. In the mow only main treatment, the Himalaya blackberry biomass produced under the 73% shade level is lower than the biomass produce under either the 55% shade level or the no shade level, but there is no difference in biomass between the 55% level and no shade. In the mow plus herbicide main treatment, the biomass produced under the 73% shade level is lower than the biomass produced under either the 55% shade level or no shade. There is no difference in biomass between the 55% shade level and no shade. In the mow plus plow main treatment, the biomass from under the 55% shade level is lower than the biomass from under the 73% shade level and no shade. There is no difference between the biomass from under the 73% level or no shade. Finally, in the mow plus plow and rake main treatment, the Himalaya blackberry biomass produced under the 73% shade level is lower than either the 55% shade level or no shade, and the 55% shade level is lower than no shade.

The sample of Himalaya blackberry stem diameters, when compared using a standard two-sample t-test, indicate that there is a significant difference (two sided p-value = 0.01, df-72), between stems from under the 55 % shade level of sunlight and stems grown in 73 % shade (Table 2.5). Stems from shaded structures that blocked 55 % of sunlight were 0.17 cm larger in diameter (Table 2-4, Figure 2.9) than stems grown in 73 % shade cloth structures (95 % confidence interval from 0.03 to 0.29 cm larger). Pearson's

Table 2.4: Differences in stem diameters (cm) resulting from two shade levels. By the beginning of the 3rd growing season shade reduced the vigor of resprouting Himalaya blackberry canes. Samples from under 55% shade is expected to be from 0.04 to 0.30 cm larger than a sample taken from 73% shade.

n = 74	55% Shade	73% Shade
Avg Diameter (cm)	0.57	0.41
Variance	0.07	0.07
P value	0.01	
95% Conf Interval	0.04 to 0.30	

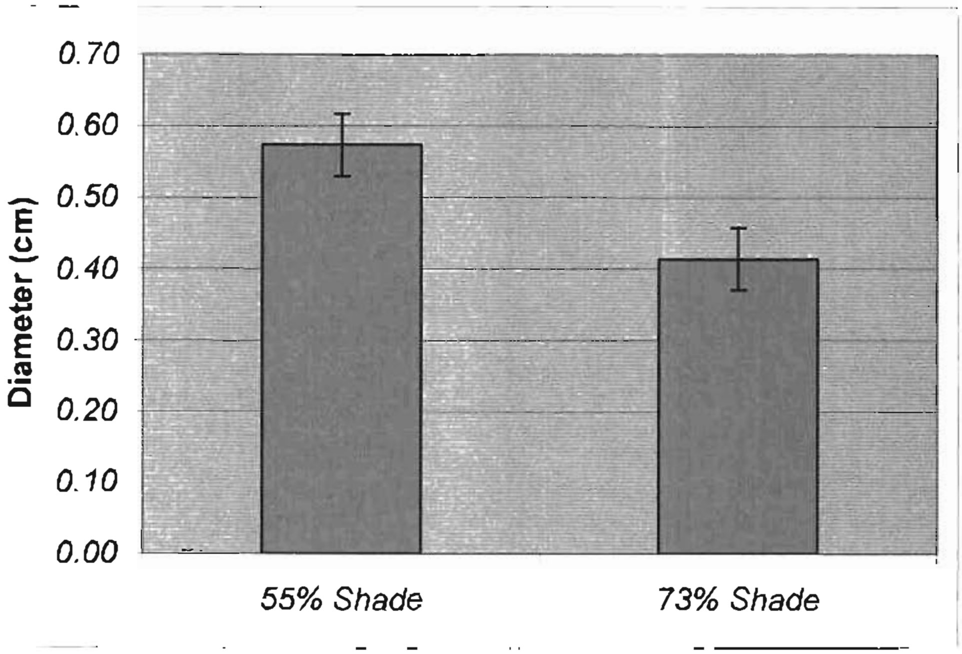

Figure 2.9: Comparison of stem diameters (cm) from under different shade treatments. The bars are standard error intervals. Diameters were measured at 15 cm above ground level (n = 74).

chi-squared (p value = 0.02) indicates strong correlation between diameter and shade levels.

From this experiment, it is apparent that the disturbance of a *Rubus armeniacus* monoculture by mowing, followed with a subsequent stressor such as plowing, can slow the regrowth of *R. armeniacus*. The efficacy among the stressor treatments used was similar. In general, further stress to regrowing Himalaya blackberry by shade (73% shade cloth structure) resulted in an interaction whereby even more growth suppression was evident.

Chapter 3. Implications of findings on Himalaya blackberry.

During Experiment 1, a soil seed bank was found under the canopy of Himalaya blackberry monoculture. Apparently this seed bank exists for a number of years. In Experiment 2, blackberries regrew quickly following mowing, but did not grow back as fast, when shaded, as some reports on mowing alone have indicated (Maia, 1997). Plowing and raking of the mowed Himalaya blackberry, followed by a subsequent flush of vegetation from the soil seed bank and planted grasses had an adverse effect on the regrowth of Himalaya blackberries and more species of plants replaced the blackberry.

In Experiment 2, only mowed-only treatments differed from other treatments, which were all equally effective on Himalaya blackberry growth suppression. Shade alone was ineffective. However, interactions between any of the main treatments and shade resulted in Himalaya blackberry suppression. Thus, the hypothesis that combined stresses to a monoculture of *Rubus armeniacus* was supported by these studies.

Ecological succession is the directional change in the composition of species overtime (Radosevich et al., 1997). However, a Himalaya blackberry monoculture may represent a static state of succession (Barbour et al., 1987; Radosevich et al., 1997), at least within the time frame of this study. Whether an "equilibrium" truly exists in a dynamic ecosystem is still debated (Elton, 1958; Rejmánek, 1989; di Castri, 1989; Bond, 1993; Lawton and Brown, 1993; Steinberg and Geller, 1993). So, it may be that recent efforts at habitat restoration have lost sight of the dynamic nature of ecological processes. For example, "The term 'habitat restoration' refers to the process of restoring the functional aspects of an ecosystem to a semblance of its pre-disturbance state" (Center for Habitat Restoration, 2002). The statement does not imply that once a semblance of the pre-disturbance state is accomplished that the habitat would be free to follow a successional path, nor does it imply an area could be managed to maintain the acquired physiognomy. It simply means that the habitat will be in a more desirable condition.

The temporary removal of the *R. armeniacus* in this study allowed the site to attain a condition that may or may not have existed prior to the Himalaya blackberry invasion. From a restoration point of view, the fact that the site is in an earlier successional state, now, suggests that it is closer to the "pre-disturbance" condition than when only Himalaya blackberry was present.

The response of the soil seed bank in this study, while made up of a mixture of native and nonnative plants, comprises a community of plant species, rather than a single one. The response of the soil seed bank had not been reported as a consequence of mechanical or chemical control treatments.

However, other exotic plants remain that are also considered invasive. Planting native herbs, grasses, or shrubs following the mechanical disturbance and seed bank response may accomplish the goal of a desired condition if a management program is also established. The results of the responses of Himalaya blackberry to disturbance and the variation in the growth and morphology of Himalaya blackberry under different growing conditions suggest that it is possible to abate the advance of the *Rubus armeniacus.*

In this study it was possible to treat a fairly large area where plant biodiversity had been reduced by a monoculture of blackberry. By doing so, the level of plant biodiversity changed in the area to a condition similar to an earlier stage of succession. The plowing of the soil and raking to remove the majority of root crowns of Himalaya blackberry provided an opportunity for other vegetation to respond to the canopy reduction of the invasive blackberry plants.

Shading Himalaya blackberry appeared to slightly reduce biomass accumulation, but results lack clear corroboration from statistical analysis. However, some indications, such as comparing stem diameters from different shade levels, suggest that more data will be needed to better quantify the results. The limited knowledge that was gained by manipulation of shade regimes may be applicable to longer-term management. The flush of vegetative growth in the first two springs following treatment is an important observation, because it indicates that Himalaya blackberry may not flourish in some shaded habitats that are common to the Pacific Northwest, and re-vegetation with herbaceous plants seems to be a superior, short term treatment rather than relying on shade from trees and shrubs to protect the area from re-infestation.

Taken together, the removal of Himalaya blackberry, re-vegetation from the soil seed bank or artificial seeding, and the manipulation of light levels by choosing appropriate vegetation to plant at restoration sites may provide a direction for management in areas that have been invaded by Himalaya blackberry (Figure 3.1). The use of mowing, which provides minimal impact, and for only a short time, can be more effectively replaced by disturbance and removal of the Himalaya blackberry root crowns. The use of herbicides may be reduced in such cases, because fewer crowns remain, and it takes longer for the Himalaya blackberry to return.

It became apparent that manipulations caused more change than just the reduction of *Rubus armeniacus.* While much of weed science has been directed toward the response of a given species to specific control measures, it is noteworthy here that the treatment of an individual plant species provoked a response from the entire habitat. Past assumptions about how a species responds to treatment seems inadequate when dealing with environments that are more natural than those in agricultural. Since the history of weed science shows that few, if any, plants that have been considered weeds have been eliminated (Dekker, 1997; Forcella, 1997; Mortensen et al., 1999), it may be that efforts that consider the response of entire habitats rather than a single species may be more productive than efforts to describe the response of only a single plant species.

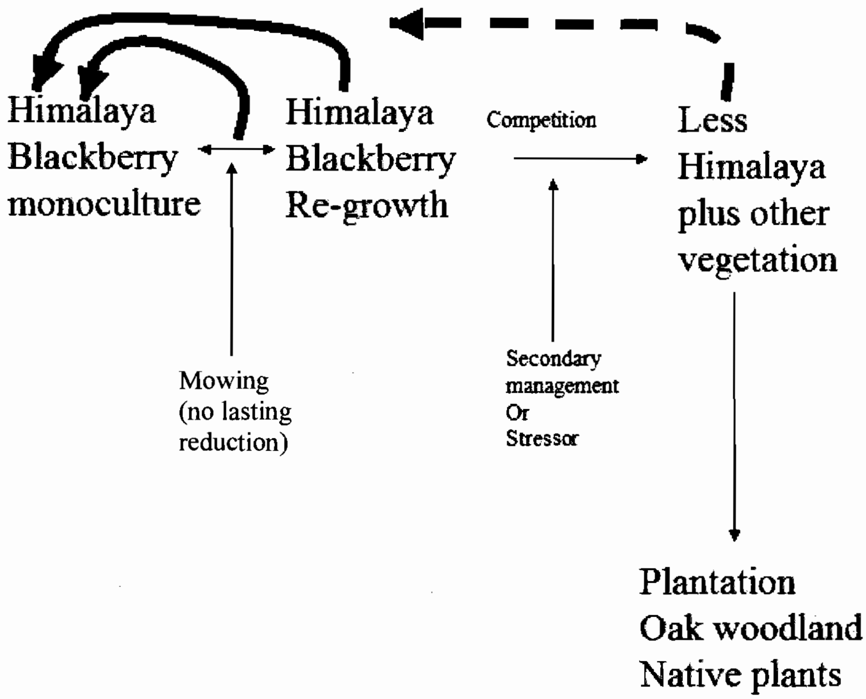

Figure 3.1. A flow chart showing that competition and/or shade as management tools or secondary stressors can break the cycle of rapid re-growth by Himalaya blackberry. As a result, it is easier to modify previously infested land to a more amenable use.

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