Production and Invasion of Butterfly

Bush (*Buddleja davidii*) in Oregon

by

Julie Ream

A PROJECT

submitted to

Oregon State University

University Honors College

and Bioresource Research

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Bioresource Research,
Sustainable Ecosystems (Honors Scholar)

Presented May 31, 2006
Commencement June 2006

AN ABSTRACT OF THE THESIS OF

Julie Ream for the degree of Honors Baccalaureate of Science in Bioresource Research, Sustainable Ecosystems presented on May 31, 2006. Title: Production and Invasion of Butterfly Bush (*Buddleja davidii*) in Oregon.

Abstract approved:

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Butterfly bush (*Buddleja davidii*), an ornamental native to China, is an invasive species in Oregon and many other areas. In Oregon, butterfly bush invades disturbed areas, particularly riparian areas. The Oregon nursery industry has the highest farm-gate value of all agricultural commodities and butterfly bush is a significant plant to them. However, the nursery industry does not appear to be a major source of invasion because of their pruning production practices. Butterfly bush is a unique plant because it does not release its seed until mid to late winter. The dispersal mechanisms of butterfly bush are not well documented, but wind is one possibility. Formulations of glyphosate effectively control butterfly bushes up to two years old. Both spraying a dilute herbicide on the entire plant and painting herbicide concentrate on recently cut stumps are effective in controlling butterfly bush, but stump painting may be the preferred option in natural areas that butterfly bush invades.

Key words: butterfly bush, *Buddleja davidii*, invasive, Oregon, glyphosate control

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APPROVED:

Co-Mentor, representing Horticulture

Co-Mentor, representing Botany and Plant Pathology

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College and Bioresource Research. My signature below authorizes release of my project to any reader upon request.

Julie Ream, Author

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DEDICATION

My family, Tom, Nancy, and Megan Ream for their eternal and unconditional love, support, confidence and pride

Production and Invasion of Butterfly Bush (*Buddleja davidii*) in Oregon

Chapter 1: Introduction

Non-indigenous species (NIS) are one of the greatest threats to biodiversity in the 21^{st} century (Milennium Ecosystem Assessment 2005). In the United States alone, over 3,000 species of non-native plants have been identified, 400 of which are considered invasive. Nationwide, researchers estimate that invasive plants cover approximately 53.8 million hectares and are expanding at about 690,000 hectares per year (Pacific Northwest Research Station 2005). Butterfly bush (*Buddleja davidii*) is a NIS in Oregon and listed as a noxious weed by the Oregon Department of Agriculture (ODA). Though the study of its effects on biodiversity remains incomplete and unclear, it is well established in wild areas of western Oregon. We will first review some concepts of invasion ecology and then discuss specific traits of butterfly bush to better understand its impact on natural systems.

Terms used in this thesis

There is much ambiguity in the field of invasion ecology over the definitions of native, exotic, naturalized, invasive, and noxious plants. In the Pacific Northwest, a plant can be considered native to a habitat if it existed in that habitat prior to Euro-American settlement in the early 1800s (Wilson et al. 1991), and this definition is used here. Plants that are not native have been called many things including exotic, alien, non-native, introduced, and non-indigenous. The term ‘alien’ has been associated with racially insensitive attitudes towards immigration (Peretti 1998). Immigrant workers are often described as ‘illegal aliens’ or ‘undocumented aliens,’ labels that some consider offensive. Regardless of their racial connotation, terms like exotic and alien conjure negative attitudes towards a species. Most ecologists are now using the term *non-indigenous species* (NIS) to neutrally describe plants that are not native to a particular habitat. Richardson et al. (2000) define a non-indigenous plant as one whose presence in an area is due to intentional or accidental introduction by humans. In order to be in accord with the above definition of native, this statement must be qualified. We define a plant non-indigenous to Oregon as one whose presence in an area is due to intentional or accidental introduction by humans after the onset of Euro-American settlement in the early 1800s.

Once NIS arrive in new habitats , they move through a development continuum and either become problematic or show themselves to be harmless. Richardson et al. (2000) name five levels of this ‘naturalization’ process, also known as the invasion process. The five stages are casual alien plants, naturalized plants, invasive plants, noxious plants, and transformers. Casual alien plants do not form self-replacing populations, and rely on continuous human introduction to colonize new areas. Most plants commonly used in the ornamental landscape industry would be considered casual (Reichard and White 2001). Most plants used in the ornamental landscape industry are not invasive. A commonly accepted rule is the so-called ‘tens rule.’ The tens rule states that one in ten imported plants will appear in the wild. Of those that appear in the wild, one in ten become well established, and of those plants established, one in ten become pests (Williamson and Fitter 1996).

According to Richardson et al. (2000), naturalized plants are NIS that self-replace consistently and sustain populations over many life cycles without or in spite of human intervention. However, the offspring of naturalized plants rarely spread far from parent plants and do not necessarily invade natural, semi-natural, or human-made ecosystems. Richardson et al. (2000) also discuss the nuances over how other ecologists define 'naturalization'. They found that most ecologists (29%) through their writings identify naturalization and invasion as the same phenomena. Another large group (25%), including Richardson et al. (2000), believe that naturalized plants are those "that reproduce and sustain populations without direct intervention by humans, often producing plentiful offspring, mainly close to parent plants."

Invasive plants, according to Richardson et al. (2000), are not tied to any environmental or economic impact but are naturalized plants that produce reproductive offspring in high numbers that often disperse far away from parent plants. They define 'far' as further than 100 m away from a parent plant in less than 50 years. This ability to establish new populations substantially removed from parent plants causes a greater threat than a naturalized plant because now the species has potential to spread over a considerable area. The one criterion of Richardson et al. (2000) that is glaringly contradictory to most other ecologists is that of economic or environmental impact. Most ecologists recognize that an invasive species is one that causes or has the potential to cause harm to people or natural systems. In 1999, President Clinton, in the much publicized Executive Order 13112 regarding invasive species, states that an invasive species is an "alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." Richardson et al. (2000) argue that impact should not be part of the invasion definition, that other descriptive terms are already used to imply negative impact such as 'weed' or 'pest'. They offer many examples of what they call *benign invaders* whose environmental impact is below any practical detection. Mouse-ear cress (*Arabidopsis thaliana*) is one of their examples, a very common but arguably insignificant weed throughout the Willamette Valley of Oregon. Despite this convincing argument, it is of practical sense that nursery producers and land managers acknowledge that most ecologists and governing agencies believe impact is an important component of invasion.

According to Richardson et al. (2000), the next stage of invasion is noxious plants, or weeds, and comprises 50-80% of invasive plants. They define noxious plants as invasive plants that cause damage to an area's ecosystems and/or economy, or harm human health. Their use of the term noxious does not mesh well with its most common uses in the U.S. Throughout the U.S., the term *noxious* weed is used often but has no ecological basis. Local officials normally use this term to classify problematic plants. Many entities have *noxious weed lists*. There is a federal noxious weed list, as well as many municipal, county and state noxious weed lists. Some non-profit organizations also create their own lists. These lists are specific to the region they represent, they are subject to the opinions of those who create them and they are rarely similar. These weed lists, especially those created by government entities, usually carry some sort of regulatory or planning review action. Noxious weed lists are developed with political and budgetary considerations. Some mandate control of listed plants. Weeds that are truly problematic may or may not be placed on the list if the government entity cannot afford to control the plant. Some of the worst weeds are not listed because their level of infestation may be too high to make eradication or control feasible (Myers and Bazely 2003).

The ODA has its own noxious weed list. The ODA defines noxious weeds as any plant that is injurious to public health, agriculture, recreation, wildlife, or any public or private property (Anonymous 2005). Butterfly bush is classified by the ODA as a noxious weed, making it slightly different than a noxious plant according to Richardson et al. Richardson et al. (2000) do not mention injury to agriculture, recreation, or any public or private property as criteria for declaring an invasive plant a noxious plant. However, one can read into Richardson's mention of damage to an area's ecosystem or economy as including some of the specific things mentioned in the ODA's definition. Therefore, we conclude that butterfly bush is a noxious plant under both definitions.

Plants at the fifth and final level of the naturalization process are called transformers. Transformers are invasive plants that change the condition, character, or nature of ecosystems over a large area relative to the extent of that ecosystem (Richardson et al. 2000).

According to the definitions described above, butterfly bush is a noxious weed, an invasive plant that harms the economy, ecology, or human inhibitors in an area. Butterfly bush could prove to be a transformer in Oregon in the future, but the results of this study are not adequate to support that designation.

Traits of the genus *Buddleja*

Horticulturalists first introduced butterfly bush from its native China to Britain in the 1890s (Owen and Whiteway 1980) and it spread to North America via unknown methods (Dole 1998). The *Buddleja* genus consists of an estimated 150 species indigenous to southeast Asia, South Africa, the Mascarene Islands, and Central and South America. Botanists name the Asiatic plants ‘old world’ and the American plants ‘new world.’ Fewer species are native to South Africa and the Mascarene Islands than the other two regions and in general their traits are undocumented. The American plants are of somewhat greater interest, but the majority of research has been conducted on the old world species because they are popular ornamentals in Europe and North America. However, research investigating these species is somewhat limited because the primary sources of plants for study are ornamental collections, which do not include all species. This is the case because many areas of the genus’s native range are fairly inaccessible, and thus only a small proportion of the species are well researched (Moore 1960a).

There is great diversity in the *Buddleja* genus, making it possible for the native latitudinal range to run from 40^{o} north to 40^{o} south. The chromosome numbers of species range from diploid to the 16-ploid level. Usually polyploid species evolve from diploid parents, and further speciate by other means. In this genus, one example of further speciation is the different structures of leaves and flowers in different species. Some species, like *B. crispa* (diploid), have only a few florescent nodes and only slightly reduced leaves. Other species, such as *B. davidii* (polyploid), have dozens of florescent nodes and leaves reduced to little more than bracts. These and other differences common among the species suggest that polyploids may have evolved from diploids (Moore 1960a).

In addition to exhibiting these structural differences members of the genus run the gamut of flowering periods and cold hardiness. The species can be broken down into two main categories of flowering times: short-day and long-day. The short-day species flower at times of the year when the day length is between 12 and 13 hours; in their native range, that constitutes to flowering through winter, if temperature permits, or only in early spring. Long-day species, or summer-flowering species, grow rapidly and flower freely from late July until the first frost (Moore 1960b). Moore argues that the long days in June initiate flowering and that a day of 15+ hours greatly accelerates flowering and growth of these species (1960b). Four species are listed as short-day species that flower in the spring: *B. tibetica, B. farreri, B. sterniana*, and *B. heliophile*. *B. heliophile* is somewhat unique among short-day species because some branches produce flowers in autumn and other branches generate resting buds which open the following spring. These resting buds flower in spring and early summer only, neither through summer nor in autumn. This behavior is similar to that of *B. japonica*. *B. asiatica* and *B. salviifolia* flower continuously in relatively short days with mild temperatures. The long-day species begin flowering in mid to late July and flower continuously throughout the summer until the first frost. Many of the plants cultivated as ornamentals are long-day species, including but not limited to *B. davidii*, *B. lindleyana*, and *B. fallowiana.* Most known polyploids (nine of ten) are long-day bloomers whereas most of the diploid species (ten of 11) are short-day bloomers (Moore 1960b). A similar trend is noticed in cold hardiness. None of the polyploid species are fully winter hardy, though some are root-hardy. In contrast, the species most tolerant of cold are diploid. This correlates with the different ploidy levels preferring short or long days for flowering times. It can be inferred that short-day flowering plants may be more tolerant of cold and thus probably diploids. A similar inference can be drawn about long-day species: they likely have little cold hardiness and are polyploids (Moore 1960b).

In addition to hardiness and flowering time differences, the reproductive potential of *Buddleja* species varies. With the growing concern over invasive properties of *B. davidii*, researchers at Longwood Gardens in Pennsylvania conducted research into other cultivated species of this genus in search of a possible alternative to butterfly bush. Researchers observed noticeable differences in the amount of seed produced and germination rates between species. *B. lindleyana* or 'Miss Vice' produced no seed per infructescence, or flower, and *B. davidii* 'Potter's Purple' produced 1.25 g (approximately 40,000 seeds) per infructescence. Researchers classified the intermediate species as either sparse or prolific seed producers. *B. fallowiana, B. hemslayana, B. longifolia, B. nivea* and *B. ×weyeriana* (a cross between *B. globosa* and *B. davidii*), produced sparse seed amounts, or less than 0.05 g seed per infructescence. In contrast, all of the *B. davidii* cultivars are prolific seed producers, some producing amounts in excess of 0.5 g seed per infructescence. Out of 35 *B. davidii* cultivars tested, only two—'Orchid Beauty' and 'Summer Rose'—produced less than 0.1 g seed per infructescence. The seed germination rates also varied, from 2% in *B. ×weyeriana* 'Moonlight' to 92% in *B. davidii* var. *nanhoensis* 'Alba.' All of the *B. davidii* cultivars had high germination rates (> 80%) whereas the other species tested had low germination rates (< 20%). Despite the evidence of significant differences between species, most species other than

B. davidii are less attractive and an inadequate substitute for *B. davidii* cultivars in the ornamental trade. Therefore, *B. davidii* remains the primary species cultivated in North America and Europe (Anisko and Im 2001).

Butterfly bush's global invasiveness

Though many members of the genus are not problematic, *B. davidii* is invasive in many areas, including Oregon. The ODA originally listed butterfly bush in February 2004 as a Class 'B' weed on the noxious weed list, causing concern to the nursery industry. Listing a plant as a Class B noxious weed has no regulatory effects, but rather intends to provide land managers a list of problematic plants so they can set priorities in weed management. As defined by the ODA, 'B' noxious weeds are regionally abundant and may require the implementation of a statewide management plan to control, but the goal is containment rather than eradication, because it is unlikely eradication is possible. 'B' weeds are also targets for biological control (Anonymous 2005). In late 2004, officials elevated *B. davidii,* but not its named cultivars, to the noxious weed quarantine list (personal communication, Tim Butler, ODA). When a species is quarantined, the intrastate propagation, sale, and transport are prohibited. Though this effort may help contain the problem, all butterfly bushes sold in Oregon are of named cultivated varieties, such as 'Black Knight' and 'White Profusion,' but are still members of the species. Named cultivars of butterfly bush are simply selections from random seedlings that possess a combination of desirable characteristics such as flower color and plant form. Neither named cultivars nor their offspring are different from unnamed specimens of *B.*

davidii. It is possible for a named cultivar to escape and develop characteristics of the straight species rather than the cultivar(s) that were its parents. In the wild, the majority of plants appear as the straight species, with flower color ranging from light pink to magenta, but there are some with white flowers. If no one is growing or selling the straight species in Oregon, then where else could plants in the wild originate from besides names cultivars? The effectiveness of quarantining only the straight species and not the named horticultural varieties is questionable. A quarantine on only unnamed cultivars will do little to halt the spread of butterfly bush in Oregon.

Butterfly bush has colonized areas in multiple countries. It is invasive in both Oregon and Washington and naturalized in other states including California, Pennsylvania, North Carolina, Virginia, Delaware, Maryland, New Jersey, Kentucky, and West Virginia (Anisko and Im 2001). British ecologists consider butterfly bush a naturalized plant that has a somewhat positive impact (Owen and Whiteway 1980). In England, butterfly bush colonizes urban areas rather than natural areas. Butterfly bush began to colonize wasteland and construction sites in England in the 1930s, and experienced a population boom after World War II with the increased amount of urban rubble resulting from extensive bomb damage. To many Britons, butterfly bush is a plant that returns life to places where life has been destroyed, resulting in a generally positive opinion of butterfly bush. In England, butterfly bush has filled a vacant niche that does not threaten native species by thriving on building sites, old city walls, and limestone quarries. In addition, some British biologists believe that the plant is highly beneficial to insects including butterflies that, prior to the introduction of butterfly bush, had no consistent nectar source (Owen and Whiteway 1980).

New Zealand, on the other hand, considers the plant invasive. The general opinion among ecologists from New Zealand is that butterfly bush is invasive, but not necessarily noxious (Bellingham et al. 2005). Butterfly bush invades areas on both the North and South islands of New Zealand, but there is more published research on the North Island populations, partially because butterfly bush is a weed in forest plantations on the North Island. Butterfly bush suppresses the growth of radiata pine (*Pinus radiata*) seedlings, the dominant tree species in Kiwi forest plantations, by reducing light availability to tree crowns during reforestation. Other weed species decreased the growth rate, but none of those studied caused as large a decrease as butterfly bush. However, the seedling mortality was greatest in the presence of butterfly bush (Richardson et al. 1996).

Though butterfly bush is a pest to Kiwi foresters, floodplain research in New Zealand has shown that though butterfly bush adversely affects native species in early succession stages, its short life span (<30 years) speeds up the development of native forest vegetation. A comparable early succession native species, kanuka (*Kanuka ericoides*), has a life span of as long as 300 years. Kanuka and other long-lived native species are rapidly out-competed by butterfly bush in alluvial succession (Smale 1990). As a result of the intense replacement of long-lived native alluvial species by butterfly bush, floodplains that butterfly bush inhabits, if left undisturbed, could develop into native forest in a much shorter time period than floodplains dominated by native alluvial shrubs like kanuka. One exception to this generality is the native tutu (*Coriaria arborea*), an early succession alluvial plant with a comparable life span to butterfly bush (<50 years). Tutu successfully coexists with butterfly bush during early succession stages and in some cases out-competes it (Smale 1990). Bellingham et al. (2005)

conducted a study on floodplain succession on the South Island and found a similar occurrence. On floodplains in the Kowhai River Valley, butterfly bush dominated early succession habitats, but native plants continued to dominate later succession habitats in the same area.

In Oregon and Washington, butterfly bush invades in ways similar to those described above. Similarly to England, it invades urban rubble in the form of abandoned industrial sites and road shoulders. Butterfly bush also invades reforestation areas and riparian areas in Oregon as it does in New Zealand. Oregon foresters consider butterfly bush a pest because it out-competes Douglas-fir (*Pseudotsuga menziesii*) seedlings in recent timber clear-cuts, similar to recognition of butterfly bush as a pest to radiata pine timber production.

Butterfly bush also invades riparian areas in Oregon, as in New Zealand. Research in Washington has found that compared to native colonizers (cottonwood and willow), butterfly bush contributes a significantly greater amount to in-channel roughness and has a much denser system of fine roots (more like that of willow). This may have consequences to ecological processes such as accretion of sediment and channel migration. Butterfly bush is found higher on the bar in general than the other two species, which suggests that it is either less tolerant of flooding or less tolerant of high velocity flooding (personal communication, Jennifer Leach, Univ. of Washington). Observations in Oregon have found that butterfly bush is replacing native willows and cottonwood along riparian areas (personal communication, Angie Kimpo, natural resource scientist, City of Portland). Others have noticed butterfly bush spreading along riparian corridors in Oregon, taking up a lot of space on cobble bars and floodplains of rivers, and replacing willows and oaks in those ecosystems (personal communication, Kyle Strauss, the Nature Conservancy). Observations from Douglas County, OR, have indicated that butterfly bush has not been spreading in urban areas. However, rural locations around the county where homeowners tend to plant larger acreages and do not prune or deadhead as much have been observing invasive tendencies. Currently, no riparian areas in Douglas County are known to be invaded by butterfly bush (personal communication, Steve Renquist, Douglas County Extension Agent).

France also considers butterfly bush invasive, and Australia, Fiji, and Hawaii see butterfly bush as a potential threat (Conservatoire Botanique 2006).

Thesis statement

We hypothesize that butterfly bush is invasive in a variety of ecosystems in Oregon, that the nursery industry is a major seed source for continued invasion, that wind disperses butterfly bush seed over great distances, and that herbicides are an effective control method for invasive populations of butterfly bush. In order to test these hypotheses, we developed four research objectives. Our first objective was to investigate where the plant was invading in Oregon and describe those areas in an effort to identify sites that would be most prone to invasion. To determine the source of these invasions, a second objective was to document nursery management practices regarding production of butterfly bush. A third objective, also with the goal of understanding the source of invasions, was to document seed release and dispersal characteristics of the plant. Our fourth and final objective was to investigate management practices that successfully control butterfly bush in order to help land managers control existing invasions.

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Chapter 2: Invaded Natural Areas

Nonnative invasive species threaten native environments in a variety of ways. Invasive species compete with natives for resources and alter natural cycles. In addition, some hybridize with native species and thereby alter the native genome. There are also some cases of increased frequency or intensity of disturbance cycles due to invasions (Reichard and White 2001).

No definite adverse effects due to butterfly bush invasion in the United States have been observed. In contrast, the plant has been considered invasive in New Zealand since the early 1990s. Richardson et al. (1996) identified butterfly bush as a plant that interferes with commercial crops by shading out young radiata pine seedlings. Another study illustrated differences in phosphorus and nitrogen chemistry on floodplains inhabited by butterfly bush compared to floodplains inhabited by native species. Tutu is a native nitrogen fixing plant on the South Island of New Zealand. Bellingham et al. (2005) compared tutu-inhabited floodplains to butterfly bush-inhabited floodplains for N:P stoichiometry. They found accumulations of phosphorus and no change in the nitrogen concentrations in mineral soil on floodplains where butterfly bush invaded. In contrast, mineral soil nitrogen increased with above-ground tutu biomass and phosphorus concentrations were unaffected. A key finding of the authors' was that butterfly bush invasion alters soil N:P stoichiometry.

Though scientists have recorded no evidence of such adverse effects in the United States, some land managers consider butterfly bush a pest. Some foresters in southwestern Oregon consider butterfly bush a more significant pest on their land, especially in reforestation areas, than Scotch broom (*Cytisus scoparius*) (personal communication, Steve Wickham and Jim Carr, foresters). In addition to reforestation areas, butterfly bush invades riparian areas, roadsides, industrial sites, and a few urban parks in Oregon. When the ODA listed butterfly bush in early 2004, they knew little more about the plant than where it invades. In order to slow further spread of butterfly bush, we found it necessary to collect more detailed data about where it invades. We hope to slow the plant's spread by determining which habitats butterfly bush is likely to invade. Close monitoring of sites prone to invasion will allow rapid response to small invasive populations of butterfly bush before they escalate into larger colonies that are more difficult to control.

MATERIALS AND METHODS

Through consultation with the ODA, the Nature Conservancy, Portland Parks and Recreation managers, and other groups and individuals, we identified five primary geographic areas where invasive populations of butterfly bush occurred: the southern Oregon Coast Range, urban sites in Coos Bay and North Bend, pieces of park land as well as roadside and industrial sites throughout the Portland metro area, Salmon Creek in the foothills of the Cascades near Oakridge, and the Sandy and Clackamas rivers east of Portland in primarily rural areas. For a full list of sites, see Table 1 in Appendix A.

Research sites were delineated within each geographic area. Multiple sites were identified in each of the primary geographic areas, so that a total of 30 sites were investigated.

The center of each research site was established at the point of densest invasion within the site. In some cases, topography or barriers (roads, cliffs, and rivers) made this impossible, in which case I located the center of the site as close to the target as possible. Once we established the center of the research site, one person remained there and another walked 20 m in at least four different directions. The butterfly bush closest to this 20 m mark but within it was identified as an edge point. We then measured actual distances from the center to the edge points and recorded angles between edge points. We used these measurements to determine the area of the research site.

We collected information about the general site characteristics of the area, and specific data from within the edge points. General site characteristics included the following: landscape position; canopy type, cover, and components; distances to potential seed sources (roads, trails, rivers, etc.) and identification of those seed sources; heights and components of different vegetation layers; a characterization of the soil disturbance regime; the stages of growth (seedling, immature, mature) and height range of butterfly bush present; the densities of both mature and immature butterfly bush plants; and the aspect and slope of the site. We used climate data from the Oregon Climate Service to determine average annual precipitation. We also characterized the site as one of five types: riparian, roadside, reforestation, old industrial, or other natural area.

We examined five randomly assigned subplots within each site. We delineated the subplots using a 1 m^2 quadrat. Within each subplot, we collected the following data: percentage of vegetation that was forbs or grasses, butterfly bush seedling density, predominant vegetation, percentage of ground that was exposed and the percentage that was covered with litter or plants, and a subjective soil typing. In addition to a subjective soil typing, we collected multiple soil cores to a depth of 15 cm from each subplot and at the center of invasion and mixed them in one bag. We had the combined samples analyzed for soil texture class (% sand, silt, and clay) and concentrations of potassium (K) and calcium (Ca). Data were analyzed with regression analysis to determine relationships between site characteristics and butterfly bush densities. Data were also subjected to analysis of variance using the general linear model to compare sites assigned various classification labels.

RESULTS AND DISCUSSION

There were no significant ($\alpha = 0.05$) correlations between butterfly bush density and other data collected. Furthermore there were no significant differences in butterfly bush density when analyzed by site classifications. Lack of significant correlations and differences are probably due to a small sample size (n=30). Due to the inherent variability in nature, a sample size closer to 100 or 200 would be required to obtain statistically significant differences. However, we did observe important trends in the data, which will be discussed here.

Site disturbance history affected butterfly bush density (Fig. 2.1). The densest invasions occurred in areas with regular disturbance. Most notable were areas disturbed by annual seasonal flooding, a trait typical of most rivers in western Oregon. Research sites with regular disturbance had more than twice the density of plants compared to undisturbed sites. The average densities are low (0.12 plants/m^2, regular disturbance, and 0.06 plants/m^2, undisturbed) because the areas of the research sites were large. Density or numbers of butterfly bush in a given area may not be representative of the level of infestation in riparian and other areas, partially due to the girth and height of butterfly bush. Despite low density, butterfly bush was the dominant plant in many of the observed sites. When compared to other NIS in riparian areas (ie Scotch broom), butterfly bush appears bushier. This bushiness effectively shades out other potential colonizers, including butterfly bush's own seedlings, and thus butterfly bush may have the same impact that twice as many Scotch broom plants would have in a given area despite having a lower density.

Canopy cover also affected butterfly bush density, with greater density in areas with less cover (Fig. 2.2). At one research site on Salmon Creek near Oakridge, butterfly bush thrived on both sides of the bridge, but no plants were under the bridge, and plants close to the bridge that would experience partial shading for a majority of the daylight hours were notably less vigorous. Butterfly bush's apparent requirement for full sun limits its ability to maintain populations as other species, such as black cottonwood and alder, increase in height and eventually overtake butterfly bush (Smale 1990). However, butterfly bush's apparent ability to suppress other species when they are seedlings causes some harm in reforestation areas. Butterfly bush shades out young commercial timber seedlings and slows their growth rate, thereby delaying harvest (Richardson et. al 1996). This delay in harvest combined with the cost of controlling butterfly bush amount to greater economic loss for foresters in both New Zealand and in Oregon.

Butterfly bush density is greatest in areas with regular disturbance, little or no shade, and rock or gravel soils. Many sites do not have all of these traits, but the riparian sites surveyed consistently had all of the above characteristics. Density of invasion is greatest in riparian sites (Fig. 2.3) due to the aforementioned site characteristics that make them prone to invasion. Reforestation sites have the second greatest density. Reforestation areas occur across the landscape, but the early succession stage that butterfly bush requires to persist is temporary in nature, and eventually the trees will out-grow butterfly bush and the invasive populations in those areas will disappear. In contrast, riparian sites in western Oregon are perpetually in the early succession stage, allowing butterfly bush to persist indefinitely.

CONCLUSIONS

Of the five site types invaded by butterfly bush, riparian areas are the most threatened due to the site characteristics of regular disturbance, little or no canopy cover, and rocky or gravelly soils; conditions that favor butterfly bush invasion. Invasions in reforestation areas may cause economic damage by increasing the cost of timber production due to forest seedling mortality and greater herbicide usage. But reforestation areas are sites managed for profit, and therefore can be controlled. In addition, the invasions on timberland are more temporary in nature because commercial trees will eventually out-grow butterfly bush. In the meantime, however, the plants serve as a seed source and antagonize forester's efforts at reforestation, and thus should be controlled.

Roadside sites may cause increased costs in road maintenance due to the necessary removal of butterfly bush plants. However, these sites are easily accessed and intensively managed, thus invasive populations can be controlled. Similarly to reforestation sites, roadside plants can serve as a seed source and car traffic on the road can serve as a rapid spread vector (Hodkinson and Thompson 1997), and thus the invasions must be managed. Many of the industrial areas surveyed were abandoned and therefore unmanaged, but management could easily occur in these locations. Many industrial sites are close to roads, and most are easily accessed once permission is granted, and thus control would be fairly easy. However, many of these industrial sites are close to rivers and could serve as a seed source for invasions downstream if left unmanaged. Most of the sites lumped into the 'other natural areas' category were invasions of one or two plants in urban parks. Parks are managed, and incorporating control of butterfly bush would be fairly easy and highly effective due to the small population numbers.

In contrast, riparian areas are difficult to access and typically unmanaged, but evidence shows that these are the areas of densest invasion. Riparian areas are the most threatened in Oregon and will continue to be due to the inaccessibility of the sites, the near-permanent existence of riparian invasions, and a lack of public funds dedicated to controlling invasions in general. We urge strong measures to eradicate these populations so these areas and the remaining lakes, streams, and rivers of Oregon will continue to serve as a haven for native species and a recreation and aesthetic resource for the citizens of Oregon.

TABLES AND FIGURES

Figure 2.1: Butterfly bush density increases with increased disturbance

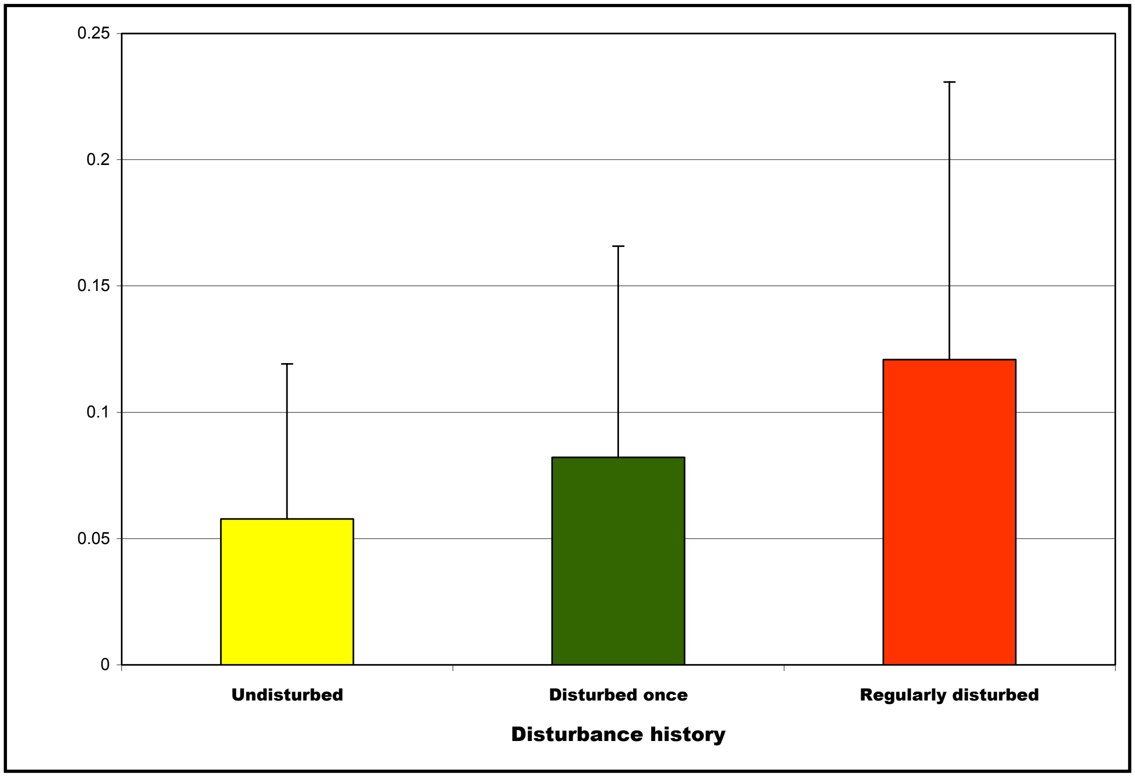


Figure 2.2: Butterfly bush density decreases as the amount of shade increases

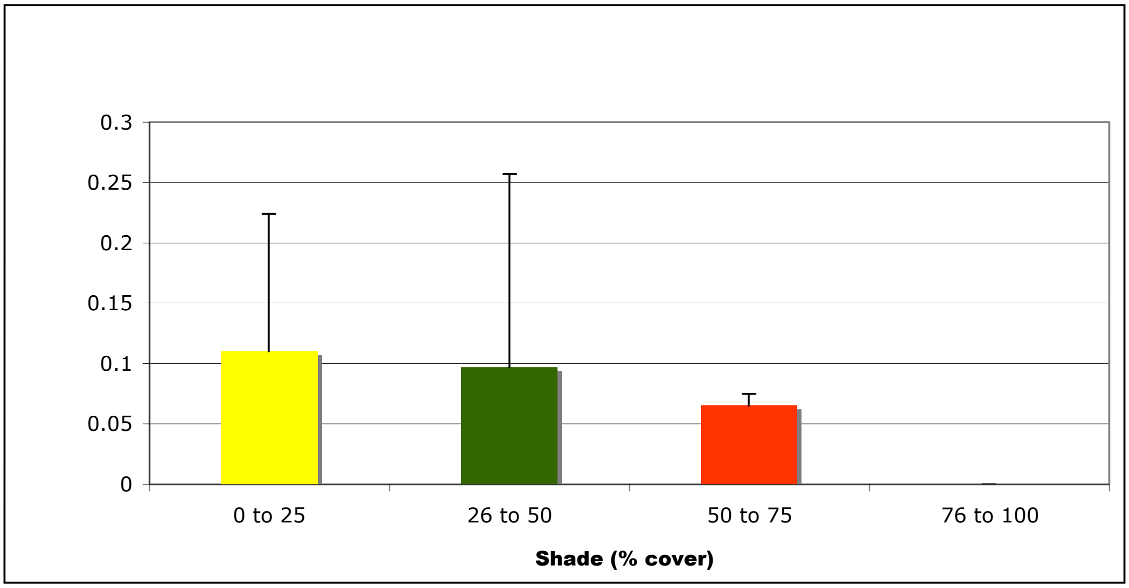
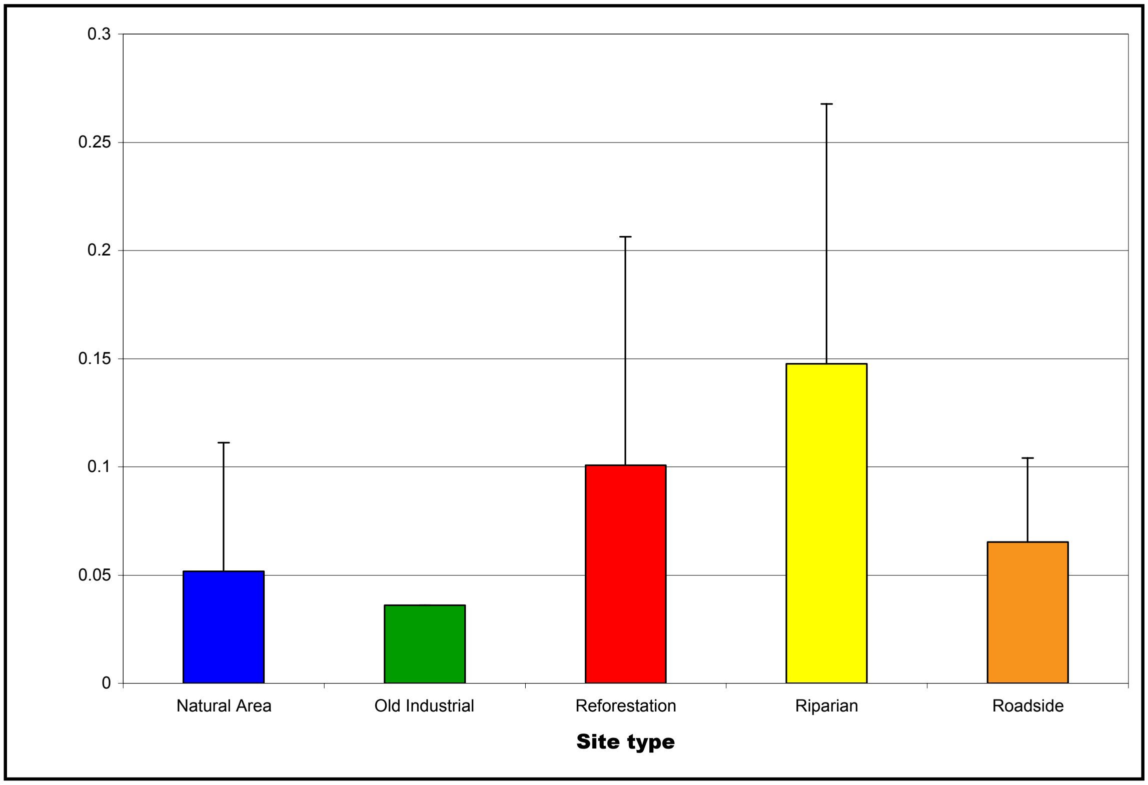


Figure 2.3: Butterfly bush density varies by site type



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Chapter 3: Nursery Production

The nursery and greenhouse industry has the greatest farmgate value of all Oregon's agricultural commodities. In 2004, nursery and greenhouse industry sales were $844 million (Goodwin 2004), compared to cattle ($592 million) and small woodlots and Christmas trees ($346 million) (OSU Extension Service 2005). Butterfly bush is an economically important species for the nursery industry because of its wide popularity with consumers. Butterfly bush is easy to care for, it survives in a variety of soil conditions, and the beauty and scent of its prolific blooms draw hordes of butterflies and other attractive pollinators to the backyard landscape. Butterfly bush also draws birds for the insect meals hosted by the plant (Dole 1998).

Horticulturalists have introduced numerous non-indigenous plants for profit, thus the nursery industry is often blamed for allowing and even encouraging invasive behavior to develop. A study by Reichard and White (2001) estimates that 82% of 235 woody plant species identified as invasive were originally used for functional (erosion control) and aesthetic landscaping purposes. One possible explanation for this large percentage are the common life history characteristics of invasive plants including: small and numerous seeds, physiological robustness or hardiness, small genome size, good dispersal ability, and a lack of inter-specific mutualistic relationships with other organisms. Unfortunately, some of the traits that tend to create invasive behavior are the same traits horticulturalists search for and consider advantageous in the development of successful, profitable ornamental plants (Myers and Bazely 2003).

Oregon exports approximately 66% of its nursery crops to other states and Canadian provinces outside of the Pacific Northwest (Goodwin 2004). Oregon nurseries that produce butterfly bush could contribute to the influx of seed into natural areas resulting in addition invasive populations. The objective of this research was to document how nursery management practices influence the flow of new seed into natural areas.

MATERIALS AND METHODS

We documented management practices at production and retail nurseries in western Oregon, totaling 31 nurseries. We surveyed production managers at nurseries, asking similar questions at both production and retail nurseries. To view the questions asked, see the surveys in Appendix B. After our discussions with managers, we were led to butterfly bush production areas. With no further assistance or influence, we walked both the rows in production areas as well as nursery perimeters scouting for escaped seedlings. For every meter of perimeter or production area, five minutes were dedicated to seedling search. If any were found, more time was allocated to that section, up to twenty minutes.

Retail nurseries in four primary locations were investigated: Corvallis (six), Eugene (three), Salem/Woodburn (four), and the Portland area (three). In Oregon, wholesale nursery production is located in the northern Willamette Valley surrounding Portland. The five top-producing counties for nursery products are Clackamas, Marion, Washington, Yamhill, and Multnomah; these five counties comprise 86% of the total production value (Goodwin 2004). As a result, most of the production nurseries we examined are in the northern part of the Willamette Valley, but we also documented practices at two nurseries near Salem and one each in Eugene and Corvallis. We limited our study to nurseries that sell butterfly bush. We documented management practices pertaining to butterfly bush, specifically regarding pruning, timing of propagation, potting, selling, and overwintering practices. Pruning is especially important because butterfly bush has been documented in Europe to release its seed in late winter following the summer in which it bloomed (Miller 1984). If this is also true in Oregon, then the timing of pruning of butterfly bush is critical to its potential spread.

RESULTS AND DISCUSSION

Production nurseries are those that grow crops and sell them in large numbers to other business entities licensed to sell them, including home and garden centers and retail nurseries. Production nurseries maintain crops on their property year-round and intensively manage their crops. In contrast, retail nurseries are those that sell crops primarily to the general public. They typically do not grow their own plants, but rather they purchase their crops in bulk from production nurseries. Retail nurseries generally only maintain crops for short periods of time (weeks) with the goal of selling the plants quickly.

We found no escaped seedlings at retail nurseries. Retail nurseries receive finished plants in early spring and ideally sell those plants by mid-summer. Butterfly bush that remain at the end of the sales season (March through October) are either discarded or severely pruned and stored in enclosed houses for winter protection. All flowers are removed in the aforementioned severe pruning process prior to over-wintering.

In total across all production nurseries, fewer than 50 seedlings were found, and half of those were found at a single small nursery with less stringent production practices. The remainder probably resulted from successful rooting of butterfly bush clippings (from routine pruning operations) in gravel production sites. These suspect plants were found only in the immediate production area and not around the perimeter, or escaping.

Production nurseries generally propagate butterfly bush by rooting vegetative cuttings. This process takes several weeks, afterwhich rooted cuttings are potted in larger containers (2.7 to 10 L). Plants are grown in these larger containers for 6 to 12 months, depending on each nursery's market requirements. This extended production time allows butterfly bush to produce mature seeds, however, other practices greatly limit the possibility of seed maturation.

Most production nurseries regularly prune butterfly bush and other plants to encourage thicker, denser vegetative growth. In the production cycle, flowers are not desirable because they deter vegetative growth. The result of this common practice is the removal of virtually all butterfly bush infructescences before seeds mature, thus eliminating the seed source. At the production nurseries where seedlings were found, the nursery either did not prune plants in this manner or an established landscape plant was located on the nursery site. Lack of pruning allows the infructescence to mature, thus providing a seed source. Even if nurseries pruned the plants only once at the end of the growing season (October or November), there was an absence of escaped seedlings.

A negative consequence of frequent pruning was observed in one nursery that failed to remove clippings. Cut stems of butterfly bush readily develop new roots in nurseries where containers are placed over gravel and irrigated daily. This environment allows plants to root in the gravel. This is a nuisance to the nursery, but of no consequence to the spread of butterfly bush into natural areas because of regular herbicide applications typically made in nursery production sites.

Research in England reports that butterfly bush does not release its seed until after the winter cycle (Miller 1984). It appears that this behavior is consistent in Oregon, as we found no escaped seedlings at retail nurseries where plants are not overwintered or at production nurseries that conduct aggressive pruning prior to winter. The observations we made support the idea that butterfly bush does not release its seed until after the winter cycle. Whether workers at production nurseries or buyers at retail nurseries removed the seed by way of pruning or purchasing, the nursery was not a source of escaped seedlings, at least not to the surrounding area. A reasonable question to ask is if the seed is not coming from the nurseries, where and or what is the source? The likely sources are established and poorly maintained (not pruned) landscape plants.

Though plants at nurseries may not be the source of the problem, plants sold by nurseries to consumers increase the amount of seed in Oregon by introducing more established landscape plants. Private gardeners often do not intensively manage their landscape plants. This reality prevents people from pruning trees and bushes as regularly as nursery professionals do. We conclude that unmanaged butterfly bushes in nurseries, private landscapes, and invaded wild areas are the primary source of seedlings and assist in the continued invasion of butterfly bush. Nursery production may be an indirect source of butterfly bush seed, in that consumers purchase these plants and plant them in the landscape and allow seed to mature. However, nursery production is not a direct source of seed.

This leads to another controversial discussion. If butterfly bush can be produced without posing a threat to local ecosystems, can nursery producers continue growing the plant and selling to other regions of the country where butterfly bush is not invasive? This is particularly relevant to Oregon nursery production considering markets are primarily (66%) to other regions of the country (Goodwin 2004) where butterfly bush is not considered invasive. Our research suggests that this is possible, whether or not state regulations dictated by the Oregon State Weed Board can make this legally feasible.

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Chapter 4: Seed Release and Dispersal

The role of humans in plant dispersal is consistent throughout history. People have been growing and trading crops since as early as 8000 BC. Originally, most plants traded had medicinal or agricultural value, but as a few civilizations gained excess wealth, gardening for pleasure was born. The men and women of the Renaissance brought the Western idea of ornamental gardening into being, and this activity spurred unprecedented plant exploration in the 17th century (Reichard and White 2001). The increased mobility of humans due to the invention of the automobile and airplane, among other things, has accelerated plant dispersal rates in modern times. Plants have been evolving for many years to exploit non-human animals as a dispersal vector, but there has been relatively less time to evolve to exploit humans as a dispersal vector. As a result, plants that humans help spread are largely opportunists whose attributes pre-adapt them for human dispersal (Hodkinson and Thompson 1997). Butterfly bush is one of these opportunists.

Butterfly bush produces numerous, small and persistent seeds, as many as 3 million per plant (Miller 1984). In addition, butterfly bush, once established, grows exponentially and can establish, mature, and reproduce in one growing season (Anisko and Im 2001). In addition to these competitive advantages, butterfly bush uses multiple means of dispersal including wind, water, animals, and human activities (ODA 2004). In Oregon, new populations seem to establish far removed from any possible seed source and in nutrient-poor areas where no other plants grow. This regular occurrence perplexes managers and helps generate a variety of casual theories on how butterfly bush disperses, including that birds eat the seeds and deposit them in fecal matter many kilometers away from the mother plant. Another possibility is that seeds get stuck in the fur and feathers of animals and the unknowing hosts carry seeds for kilometers. In addition, scientists in England have documented that butterfly bush seeds are found in mud on car tires (Hodkinson and Thompson 1997). These are all possible explanations, and in Oregon, many invasions can be tied to water and human dispersal because of where they occur: riparian areas and roadsides (mud on car tires). However, there are also invasions whose sources are unclear, and may be explained by wind dispersal.

Butterfly bush's seeds can be loosely classified as rolling autogyros (Augspurger 1986), and thus have a somewhat winged quality which assists in wind dispersal. These facts and the difficulty in identifying a discrete source of seed inspired a more thorough investigation into the wind dispersal of the seed.

In England, butterfly bush flowers in summer and then holds its seed until late fall or winter and releases them (Miller 1984). This unusually long seed maturation period and timing of seed release warranted investigation into whether or not this trait holds true in Oregon. If we found this to be true, an easy solution to reducing butterfly bush seed pressure in the future could be shared: deadhead flowers and prune bushes after the growing season in mid-fall to remove the seed before it matures on the plant.

MATERIALS AND METHODS

Release

In winter 2005-2006, we observed the release dates of two plants per cultivar of 15 different cultivars at both the OSU Main Campus in Corvallis and the North Willamette Research and Extension Station in Aurora, OR (Table 4.1). All plants were potted in 12 L black plastic containers. We checked plants weekly for seed release starting in December and increased it to two times per week in January.

We marked one to three infructescences on each plant for observation depending on the number of successfully pollinated infructescences. A few of the cultivars, though they appeared pollinated, never produced fully developed seed. Observations consisted of checking the marked infructescences to see if seed pods had opened or not and if open, whether or not seeds were being released.

Dispersal

The goal of these experiments was to get an approximation of the horizontal (dispersal) distance of butterfly bush seeds. The diminutive size of butterfly bush diaspores prevented direct measurement of dispersal or sinking velocity. Instead, we used equations from Augspurger (1986) in order to determine dispersal distance. Variables and the units of measurement are listed in **Table 4.2**.

The equations we used are as follows:

V_d= coefficient[(Wt/area)$^{1/2}$]

D= (h/V_d) xV_w

Where (Wt/area) is labeled wing-loading, and the coefficient varies depending on which aerodynamic group the seeds belong to. Butterfly bush most closely resembles seeds classified as rolling autogyros. The seeds of butterfly bush are smaller in weight than any of the seeds Augspurger examined, and smaller in area than all but one of the seeds Augspurger examined. We calculated rather than measured the sinking velocity (V_d) from weight and area and interpolated a value from Augspurger. This method is less accurate than direct observation, but we could find no other method to estimate dispersal distance, as little study has been done on dispersal distance of seeds as small as those from butterfly bush.

To collect butterfly bush seed, we used plastic socks with holes only large enough to allow movement of air and water through the socks but small enough to exclude insects and retain released seed. During the winter of 2004-2005, we collected the seeds of one to three infructescences per plant, depending on the number of successfully pollinated flowers on each plant, and had two representative plants of seven different named cultivars of butterfly bush (Table 2 in Appendix A). Plants were potted in 12 L black plastic containers. In early spring 2005, once all seeds were released, we collected the seeds from the socks in plastic Gladware-type containers. Later that year, we averaged lengths and widths of one seed from each cultivar to calculate the average area of butterfly bush seeds. Measurements were completed on a total of eight seeds. In order to determine the average mass of one seed, we counted and weighed 100 seeds and divided total weight by 100. Values for all calculations are in **Table 4.2**.

Once we determined these values, we calculated the wing-loading (Wt/area) and consulted Augspurger's (1986) data to interpolate an approximate value for the rate of descent of one rolling autogyro seed in still air (V_d, sinking velocity). We estimated the average height of release through field observation to be 300 cm, and used this value, the estimated value for V_d, and averaged atmospheric wind speeds (V_w) unique to each geographic area butterfly bush invades in Oregon to calculate an approximate dispersal distance via wind. We obtained the values used to calculate a mean atmospheric wind speed in January (month of majority of seed release) by consulting Oregon Climate Service historical data for the Portland and Coast Range areas and calculated an average wind speed over four years of recent data for the Cascade foothills. Wind speeds are only recorded over a general area, and these three locations were the closest to our research sites for which there was available data.

RESULTS AND DISCUSSION

Release

Our results on seed release dates support Miller's (1984) argument that butterfly bush holds its seed until late fall or winter and then releases them (Table 4.1). We made observations at two locations: Oregon State University main campus (OSU) and the North Willamette Research and Extension Center (NWREC); both are in the Willamette Valley. In some cases, there is a long lag time between release at the NWREC and release at OSU. This is perhaps attributable to a difference in field conditions. The NWREC location is more protected, but that is the only concrete difference between the two locations. Despite the occurrence of lag times, all plants completed seed release within six weeks.

Despite differences in seed release between sites, it can still be concluded that butterfly bushes potted in black plastic containers do not release seed until at the earliest late December. For most of the cultivars, seed release does not begin until January. This knowledge can be used to prevent the spread of butterfly bush. If container plants do not release seed until late December or January, nursery managers can stop the release of seed by timing their pruning. Most nurseries already aggressively prune plants to encourage vegetation growth and to develop a denser shrub. By timing their traditional pruning in October or November, before seeds mature and are released, nursery managers can eliminate their plants as a source of seed. Individuals can practice this as well, but as mentioned, our subjects consisted of potted butterfly bushes and not landscape plants. Side observations we made in other aspects of our work may provide more support for this practice to be conducted on established plants as well.

In mid-October, I observed that wild plants at five research sites on the Sandy and Clackamas rivers were still holding on to their seed. In contrast, I observed established plants at another research site in mid-December had released their seed. We also observed that some plants in the landscaping near the offices at NWREC had also released their seed by mid-December. Despite contradictory observations in container plants, in can be inferred that established landscape plants probably do not release their seed until November or December. If this is in fact the case, than selectively timed pruning and deadheading of landscape plants in October could also eliminate established plants, along with plants potted in containers, as a seed source.

The ability to remove seed before the plant releases gives humans greater control over the spread of this invasive plant than many others. We strongly urge nursery managers, homeowners, landscapers, and gardeners to take advantage of this butterfly bush trait. Deadheading senesced infructescences throughout the growing season is possible, but arguably tedious. Regular deadheading is not necessary as long as all spent flowers are removed before November. Severely pruning established landscape butterfly bushes to a height of 45 cm eliminates all flower heads in a single pruning event, and results in a denser, more floriferous plant the following year. This is a management practice that can be followed by even the most casual gardener, and offers a way homeowners can keep their potentially invasive shrubs without posing a further risk to local ecosystems.

Dispersal

We determined that the approximate dispersal distance varied depending on location. The calculated dispersal distances are as follows: 14.2 m in the Portland area, 12.5 m in the southern Oregon Coast Range, and 2.9 m in the Cascade foothills (Table 4.3). These results contradict those by Miller (1984) who used physical traps to document seed dispersal distance. Miller reported that 95% of the seed fall outside of a 10 m radius. Miller recorded that each butterfly bush has about 3 million seeds, and she found only about 200,000 within a 10 m radius—most of which were directly beneath the plant. She could, at best, conclude that the majority of seeds were dispersing beyond 10 m. Though our calculations supply a reasonable conclusion, casual observations support the idea that something else is influencing dispersal distance in Oregon.

Where we find butterfly bush in the wild in Oregon, it is often the tallest plant and occasionally the only plant for several meters. This characteristic tallness is most likely due to the plant's rapid growth during the first years of its life. Because butterfly bush is the tallest plant in most of the areas it invades, it is not obstructed from sunlight or from wind. There is usually nothing to break the wind, and this may contribute to the vast distances between some invasions.

In addition to being the tallest plant in most areas it invades, butterfly bush has very light seeds. None of the seeds examined by Augspurger weigh as little as the seeds of butterfly bush do and only one has a similar area. The diminutive size of butterfly bush seeds made it impossible to measure the V_d directly because you cannot see the seeds well enough as they fall to measure the time accurately. Instead, we calculated the value for V_d using approximations of the area and the weight.

As far as we know, the only other method for calculating V_d involves detailed aerodynamic measurements. Despite the approximations in our approach, our results show that normal wind dispersal occurs on a scale (3 m-15 m) that is insufficient to explain the establishment of isolated populations. Alternative dispersal methods—unusually high wind events, birds, mammals, boots, and tires—require further study to explain butterfly bush long-distance invasion in non-riparian sites.

TABLES AND FIGURES

Table 4.1: Dates of initial seed release of 15 butterfly bush cultivars at two different locations in the Willamette Valley

OSU[z]		NWREC[y]	
Cultivar	Date of initial release	Cultivar	Date of initial release
Nanho Blue	Jan. 19 2006	Ellen's Blue	Dec. 29 2005
Nanho Purple	Jan. 19 2006	Harlequin	Dec. 29 2005
Potter's Purple	Jan. 19 2006	Petite Purple	Dec. 29 2005
Pink Delight	Jan. 19 2006	Pink Delight	Dec. 29 2005
Royal Red	Jan. 19 2006	White Ball	Dec. 29 2005
Summer Beauty	Jan. 19 2006	Lochnich	Jan. 3 2006
Petite Purple	Jan. 24 2006	Black Knight	Jan. 5 2006
Black Knight	Jan 31. 2006	Nanho Blue	Jan. 5 2006
Ellen's Blue	Feb. 2 2006	Niche's Choice	Jan. 5 2006
Guinevere	Feb. 2 2006	Potter's Purple	Jan. 5 2006
Niche's Choice	Feb. 7 2006	Orchid Beauty	Jan. 11 2006
Orchid Beauty	Feb. 7 2006	Guinevere	Jan. 20 2006
Lochnich	Feb. 21 2006	Royal Red	Jan. 20 2006
Harlequin	Seed never fully developed, no release	Summer Beauty	Jan. 20 2006
White Ball	Seed never fully developed, no release	Nanho Purple	Seed never fully developed, no release

[z] Oregon State University main campus, Corvallis, OR
[y] North Willamette Research and Extension Center, Aurora, OR

Table 4.2: Definitions and units of measurement of variables used in equations

Variable	Definition	Unit of Measurement
V_d	Average rate of descent of a single seed in still air	cm/s
Wt	Average weight of 1 seed	N
Area	Average area of 1 seed	m^2
D	Approximate dispersal distance	m
h	Average height of seed release (avg height of plants)	cm
V_w	Average atmospheric wind speeds for January	cm/s

Table 4.3: Variables used and values determined for seed dispersal

Variable	Value
V_d	101.6 cm/s
Wt	8.91 $x10^{-7}$ N
Area	7.17 $x10^{-7}$ m^2
D	14.2 m in Portland area sites 12.5 m in southern Coast Range sites 2.9 m in Cascade foothill sites
h	300 cm
V_w	Portland area: 479.98 cm/s S Coast Range: 423.39 cm/s Cascade foothills: 98.35 cm/s

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Chapter 5: Herbicide Trials

Controlling and/or eradicating existing invasive populations is critical, but once invasive plants establish themselves in wild areas, it can be difficult to control the populations. Little research has been conducted on how to control butterfly bush in the United States. There have been studies on biological control options in New Zealand. Scientists at the New Zealand Forest Research Institute have been studying the use of the weevil *Cleopus japonicus* for biological control of butterfly bush for over a decade, and the Environmental Risk Management Authority (a government entity) approved the importation and release of the weevil for the purpose of controlling butterfly bush in late 2005 (NZERMA 2005). Other species are also considered natural enemies of members of the genus *Buddleja*, including butterfly bush (*B. davidii*). The fungal species *Irenina buddlejae, Pseudocercospora buddleiae*, and *Septoria merrillii* are all natural enemies, and the infection of butterfly bush by *P. buddleiae* is documented. Thirteen arthropods are also considered natural enemies of *Buddleja* species: *Hemipyxis lusca, Hemipyxis plagioderoides, Hemipyxis tonkinensis, Hespera bipilosa, Hespera univestis, Stenoluperus nipponensis, Trachyaphthona bidentata, Trachyaphthona buddlejae, Trachyaphthona fulva, Pedronia planococcoides, Planococcus sinensis*, and *Dendrothrips stannardi* (Zheng et al. 2004).

Prior to the approval of *C. japonicus* as a control agent, Kiwi land managers used herbicides to control butterfly bush, as evidenced by a news release from the Karori Wildlife Sanctuary. The managers at the wildlife sanctuary targeted gardeners, explaining that certain garden plants cause damage to natural areas. The managers suggested hand-pulling seedlings and smaller plants and cutting stumps of larger plants followed by herbicide application, namely glyphosate-containing herbicides (Karori 2004). Land managers in Oregon also use formulations of glyphosate to control butterfly bush (personal communication, Kyle Strauss, the Nature Conservancy). However, no one in Oregon has conducted extensive herbicide trials to determine the effectiveness of different control methods.

We conducted our herbicide trials in late fall because evidence from England shows that treatments in the late fall are more effective than treatments in early summer (Clay and Drinkall 2001). The objective of our research was to determine the most effective herbicide product and application method for controlling butterfly bush with consideration that many control programs will occur in herbicide-sensitive riparian areas.

MATERIALS AND METHODS

We conducted herbicide trials in 2004 and 2005. Uniform propagated plants in 10 cm pots of the cultivars ‘Black Knight’ and ‘Ellen’s Blue’ were planted in a Willamette silt loam soil on July 26, 2004. Liners were planted in a randomized complete block design with enough plants for 23 treatments and eight replications (for each cultivar). Five treatments were applied in 2004 when plants were only one year old, nine treatments were applied in 2005 when plants were two years old, nine more are reserved for treating in 2006 when plants are three years old. The same number of plants were planted July 5, 2005 in an identical experimental layout. This allowed us to repeat the experiment on 1 and 2-year-old plants and in the future, 3-year-old plants.

One-year-old plants

The rates of herbicide applied (Table 5.1) represent the maximum labeled concentration for spot spraying each product. We added a non-ionic surfactant to Garlon and Arsenal as recommended by each label. The herbicides used, the active ingredients of each one, and the percent herbicide concentrations can be found in **Table 5.1,** along with results. We applied herbicides on September 23, 2004. Plants were approximately 36 cm tall, 46 cm wide, and flowering profusely. We applied herbicides using a backpack sprayer with approximately 100 mL of herbicide solution per plant, enough to provide uniform spray coverage over the entire plant. We then rated plants at 1, 4, and 6 weeks after treatment (WAT) for control. We rated the plants using an injury scale from 0 to 10 where 0 = no plant injury, 3 = slight injury, 5 = moderate injury, 7 = severe injury, and 10 = complete death.

We repeated the experiment in 2005 on one-year-old shrubs planted in 2005. The same herbicides were applied September 9, 2005.

Two-year-old plants

We applied herbicides to two-year-old plants on September 9, 2005 when plants were approximately 2 m tall and wide, and all were flowering profusely. For these plants, we used two different application methods: spraying diluted herbicide to intact plants and stump-painting herbicide concentrate to recently cut stumps at a height of 40 cm. We applied the sprayed herbicides using a CO_2 backpack sprayer with a single 8004 flat fan nozzle at 35 psi. We applied painted herbicides to recently cut stumps in the concentrated form using foam paint brushes. Herbicides and rates for the two-year-old plants are listed in **Table 5.3,** along with results. Across both methods, we applied the herbicides in such a way that the amount of active ingredient applied to plants in paint and spray treatments was the same. We rated plants at 1, 2, 4 and 10 weeks after treatment (WAT) for control using the same rating scale defined above.

RESULTS AND DISCUSSION

One-year-old plants

All results for the 2004 trials are presented in **Table 5.1**. One week after herbicide application, Roundup Ultramax and Aquamaster (both formulations of glyphosate) provided similar and excellent control. Plants treated with Garlon were also severely injured, but slightly less than those treated with glyphosate. Plants treated with Arsenal appeared relatively unaffected, and were not noticeably different from non-treated controls.

By 4 WAT, control was complete with the two glyphosate-containing products, as all plants sprayed with these herbicides were dead. Plants treated with Garlon were severely injured, however, there was enough green tissue near the crown of the plant that might allow it to survive. Plants treated with Arsenal began to show signs of severe injury, but similar to Garlon, plants were not completely dead. At 6 WAT, plants treated with Garlon had green seed pods, while plants treated with other herbicides had no seed pods.

There were differences in cultivar response to the herbicides. Control of 'Ellen's Blue' with Garlon and Arsenal was slightly lower than that observed with 'Black Knight.' 'Ellen's Blue' has foliage that is more pubescent than that of 'Black Knight,' and thus appears more grey in color. This trait is common among butterfly bush cultivars, and the observed difference in control indicates that foliar pubescence might be an important factor in limiting the effectiveness of some herbicides.

We monitored the plants throughout 2005 to determine if plants regenerated from surviving roots. We found that none of the herbicide-treated plants (regardless of product) survived the winter after being treated with herbicide.

Control of one-year-old plants in 2005 was nearly identical to 2004 (Table 5.2). At 1 WAT, formulations of glyphosate provided moderate control of both cultivars, and by 2 WAT, all plants treated with glyphosate were dead. At 1 WAT, both Garlon and Arsenal provided hardly any control, but by 4 WAT, the herbicides had caused severe injury to the plants. Control was slightly less for 'Ellen's Blue' plants when they were sprayed with Arsenal, but there was no significant difference in control of cultivars sprayed with Garlon and both formulations of glyphosate. At 10 WAT, plants treated with Garlon or Arsenal were nearly dead, but some vegetation remained. Similar to the first trial, no herbicide-treated plant was alive the following spring.

Two-year-old plants

At 1 and 4 WAT, control ratings were higher on 'Black Knight' compared to 'Ellen's Blue' across all treatments (Table 5.3). By 4 WAT, sprayed Aquamaster (glyphosate) and Roundup Ultramax (glyphosate) provided better control than sprayed Arsenal (imazapyr) and Garlon (triclopyr). At 10 WAT, all treatments of glyphosate had caused either severe injury or plant death. Plant stumps painted with Arsenal had caused severe injury; spray treatments caused moderate injury to 'Black Knight' and slight injury to 'Ellen's Blue.' Across cultivars and methods, plants treated with Garlon experienced severe injury. Ratings were high among all painted treatments. However, because most of the plant was pruned off prior to application, these plants were difficult to rate accurately. Some branches remained at the base of the plant, by which we rated control.

Plants were large and unpruned at the time of treatment, and as a result spraying was arduous and would be even more difficult in natural areas where managers desire to preserve the surrounding vegetation. Painting herbicides appears to be an effective alternative to spraying, especially in sensitive ecosystems such as riparian areas.

Though control of both one and two-year-old plants using Garlon and Arsenal was less effective than with glyphosate, the winter of 2005-2006 was cold enough that plants injured, but not killed, by Garlon and Arsenal did not survive. This is a contrast to 2004, which had a much warmer, drier, winter. Despite the difference in winter temperatures, no one-year-old plants treated with herbicide survived in either 2004 or 2005.

Foresters have used aerial spraying in an attempt to control butterfly bush and have experienced little success (personal communication, Jim Carr, forester). Our data show successful control using spot spraying or stump painting. Furthermore, informal observation from land managers suggests that stump painting with glyphosate is effective in killing butterfly bush with a single application (personal communication, Kyle Strauss, the Nature Conservancy). Spraying herbicides is more efficient, requiring less labor and resources. However, our observation along with others' observations throughout the Pacific Northwest indicate that the most sensitive and threatened ecosystems are riparian areas. Spraying herbicides near riparian areas can have negative consequences on nearby desirable foliage, as well as aquatic organisms. Painting herbicides on recently cut stumps requires more labor and effort, however, it appears to be as effective and its application is more directed and precise. While not tested for viability, some seeds appeared to have matured on some herbicide treated plants. The degree to which seed survive and perpetuate the problem will depend on herbicide rate and timing. In contrast, cut and paint applications necessarily remove all flowers and potential seed prior to herbicide application. There is no chance for seed maturation as long as applications are done before the end of October. Though our data indicate that spray and cut-and-paint applications are effective, resources and circumstances will dictate which is more appropriate to the land manager.

TABLES AND FIGURES

Table 5.1: Postemergence control of 1-year-old butterfly bush in 2004

	1 WAT[z]				4 WAT				6 WAT			
Herbicide[y]	Black Knight		Ellen's Blue		Black Knight		Ellen's Blue		Black Knight		Ellen's Blue	
Aquamaster[x]	9.9	a[w]	9.0	a	10	a	10	a	10	a	10	a
Roundup UM[v]	9.6	a	9.0	a	10	a	10	a	10	a	9.9	a
Garlon[u]	7.9	b	7.9	b	9.5	a	8.8	a	9.1	b	7.9	b
Arsenal[t]	0.0	c	0.1	c	8.6	b	7.1	b	8.4	c	7.4	c
Control	0.1	c	0.0	c	0.0	c	0.0	c	0.0	d	0.0	d

[z]Weeks after treatment
[y]Herbicides applied Sep. 23 2004
[x]Active ingredient glyphosate, sprayed at 2% concentration
[w]Means within a column with similar letters are not significantly different (LSD, $\alpha = 0.05$)
[v]Active ingredient glyphosate, sprayed at 2.1% concentration
[u]Active ingredient triclopyr, sprayed at 3.0% concentration
[t]Active ingredient imazapyr, sprayed at 1.5% concentration

Table 5.2: Postemergence butterfly bush control on 1-year-old plants in 2005

	1 WAT[z]				4 WAT				6 WAT			
Herbicide[y]	Black Knight		Ellen's Blue		Black Knight		Ellen's Blue		Black Knight		Ellen's Blue	
Aquamaster[x]	5.0	a[w]	6.3	a	10	a	10	a	10	a	10	a
Roundup UM[v]	5.5	a	5.3	a	10	a	10	a	10	a	10	a
Garlon[u]	3.3	ab	5.3	a	7.4	c	7.0	b	10	a	9.8	a
Arsenal[t]	0.8	bc	0.8	b	8.9	b	6.8	b	9.8	a	9.1	b
Control	0	c	0	b	0	d	0	c	0	b	0	c

[z]Weeks after treatment
[y]Herbicides applied Sep. 23 2004
[x]Active ingredient glyphosate, sprayed at 2% concentration
[w]Means within a column with similar letters are not significantly different (LSD, $\alpha = 0.05$)
[v]Active ingredient glyphosate, sprayed at 2.1% concentration
[u]Active ingredient triclopyr, sprayed at 3.0% concentration
[t]Active ingredient imazapyr, sprayed at 1.5% concentration

Table 5.3: Postemergence butterfly bush control with selected herbicides and application methods on 2-year-old plants in 2005

Method	Herbicide[y]	1 WAT[z]				4 WAT				10 WAT			
		Black Knight		Ellen's Blue		Black Knight		Ellen's Blue		Black Knight		Ellen's Blue	
Paint	Aquamaster[x]	6.5	a[w]	4.3	a	10	a	9.4	a	10	a	9.4	ab
	Roundup UM[v]	5.6	a	4.0	ab	10	a	9.0	ab	10	a	9.9	a
	Arsenal[u]	2.6	c	1.9	d	9.3	b	6.9	c	10	a	7.9	cd
	Garlon[t]	3.1	bc	3.0	bc	9.5	ab	7.4	c	9.5	ab	8.4	bc
Spray	Aquamaster[s]	4.1	b	1.3	d	10	a	7.8	bc	9.5	ab	9.0	abc
	Roundup UM[r]	3.6	bc	1.3	d	9.8	ab	8.1	abc	9.0	ab	8.6	abc
	Arsenal[q]	1.1	d	0.0	e	6.5	d	2.6	d	6.8	c	3.5	e
	Garlon[p]	3.1	bc	2.1	cd	7.6	c	7.3	c	8.5	b	7.0	d
Control	Control	0	e	0	e	0	e	0	e	0	d	0	f

[z] Weeks after treatment
[y] Herbicide concentrates were painted on fresh cut stumps
[x]Active ingredient glyphosate, concentrate painted at 10 mL/plant
[w]Means within a column with similar letters are not significantly different (Duncan's multiple range test, $\alpha = 0.05$)
[v]Active ingredient glyphosate, concentrate painted at 10.5 mL/plant
[u]Active ingredient imazapyr, concentrate painted at 7.5 mL/plant
[t]Active ingredient triclopyr, concentrate painted at 15 mL/plant
[s]Active ingredient glyphosate, sprayed at 2.0% concentration
[r]Active ingredient glyphosate, sprayed at 2.1% concentration
[q]Active ingredient imazapyr, sprayed at 1.5% concentration
[p]Active ingredient triclopyr, sprayed at 3.0% concentration

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Chapter 6: Conclusions

Summary

From our research, we conclude that butterfly bush is problematic in many areas of western Oregon, but especially on riparian areas with floodplains and cobble bars. This is the case because many of these riparian areas have site characteristics that make them prone to invasion. Butterfly bush densities were greatest in natural areas with regular disturbance, little or no shade, and rock or gravel soils. All of these characteristics are common among riparian areas in western Oregon. In addition, our data showed that of all site types, riparian areas had the greatest density of butterfly bush. Many land managers in western Oregon have noticed that once a population is established in a riparian area, the invasion expands rapidly downstream. This is most likely due to the easy transit of seeds during times of high water. Butterfly bush does not release its seed until November at the earliest, just in time for river levels to rise. The seeds of butterfly bush are lightweight and small enough in size that they easily float in the water and may wash up on and colonize new floodplains downstream. Also, many of the riparian areas butterfly bush invades are difficult for humans to access, so management of the invasions is a challenge. In summary, the present and future invasion of butterfly bush threatens the riparian areas of western Oregon due to site characteristics that make them prone to invasion, the fact that riparian populations spread easily and rapidly downstream, and the difficulty in managing these populations.

The other areas that butterfly bush invades in Oregon—old industrial sites, roadsides, reforestation areas, and a limited number of undisturbed natural areas—are all fairly easily managed sites because of their accessibility. Although invasions in reforestation areas result in economic damage to foresters and populations on roadsides increase the cost of road maintenance, both of these types of sites are actively managed and therefore controlling butterfly bush is not a large challenge, just potentially more expensive. However, roadsides, reforestation areas, and old industrial sites can serve as a seed vector and invasive populations in these areas cannot be ignored.

We also determined from our research that due to certain nursery production practices, nurseries are not a major source of seed for invasion: unmanaged wild and landscape plants are. While nurseries contribute to the problem by selling butterfly bush to consumers, the lack of management by consumers is the major cause of increased invasion. From our seed release experiments, we determined that butterfly bush does not release its seed until late fall, November at the earliest. Most retail nurseries sell all stock before the end of the season (mid-October), and so eliminate themselves as seed sources. The majority of production nurseries prune and deadhead butterfly bushes to encourage thicker, denser vegetative growth. In addition to consistent pruning throughout much of the year, they also conduct an aggressive pruning at the end of the season in October or November, removing all infructescences and thereby eliminating their plants as seed sources. However, both categories of nurseries are delivering butterfly bushes to the consumer, and few consumers regularly prune and deadhead butterfly bushes. By neglecting to do so, consumers are allowing their plants to become a source of further invasion, and by continuing the sale of butterfly bush cultivars, nurseries are indirectly contributing to the spread of butterfly bush.

From our investigation into herbicide control, we determined that formulations of glyphosate are best at controlling both one and two-year-old plants, with slightly less, but not statistically less, control on ‘Ellen’s Blue,’ a cultivar with more foliar pubescence. This greater amount of pubescence may protect vegetation from damage, but formulations of glyphosate still successfully controlled ‘Ellen’s Blue.’ We conducted herbicide trials using two methods (spot spraying and stump painting) and determined that both were successful. As such, stump painting is an effective substitute for spraying, particularly in sensitive ecosystems such as riparian areas.

Recommendations

We urge land managers and the ODA to attack current butterfly bush invasions aggressively, concentrating their efforts in riparian areas. One method for controlling these populations is herbicide usage. Control is necessary to prevent the further spread of butterfly bush, and to minimize the potential damage to Oregon’s natural landscapes.

We recommend that all butterfly bush producers, owners, and gardeners regularly prune and deadhead butterfly bush plants, and if not regularly, to at least conduct an aggressive pruning in late September or during the month of October, removing all infructescences so plants currently in the landscape are not given time to release their seed.

In order to gain a better understanding of how the seeds of butterfly bush are dispersed and how far they can be transported, alternative dispersal methods in Oregon such as unusually high wind events, bird and mammal transport, and boot and tire transport need to be studied further as possible explanations of long-distance invasion of butterfly bush into non-riparian sites.

Butterfly bush has not yet become a problem as large as other invasive species but is still altering the natural areas of western Oregon. In Washington, a few land managers have observed that butterfly bush is more prevalent on the Skagit River than Japanese knotweed and is a priority weed in the upper Skagit watershed (personal communication with Melissa Holman, the Nature Conservancy). Now is the opportune time to stop a larger problem from developing.

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Appendices

Appendix A: Non-data tables

Table 1: List of research sites with GPS coordinates when available

Site Name	Site Type	GPS (Degrees north, degrees west)
Oaks Bottom Wildlife Refuge	Natural Area	45.47260, 122.65281
Coos Bay Olive Barbur Rd.	Roadside	
Menasha Landing 1, 5 mi	Reforestation	
Coos Bay Lutheran Church	Roadside	
N.Bend Newmark St near water	Roadside	
S. of St. Johns Bridge	Roadside	48.58497, 122.15584
Univ. of Portland RRx	Old Industrial	45.57203, 122.73301
Moore Mill Thornton Oar Ln	Reforestation	
Menasha #2 Lakeside, 6 mi	Reforestation	
Coos Bay Ivy Hills Rd	Roadside	
McLoughlin Blvd/Tacoma Access Rd	Roadside	45.46377, 122.63744
Johnson's Creek on Springwater Trail	Natural Area	45.46187, 122.61798
Under the Marquam Bridge	Riparian	45.50649, 122.67257
Spaghetti Factory	Old Industrial	45.49516, 122.66903
Willamette Bluffs Fire off Van Buren	Reforestation	45.582992, 122.75226
Salmon Creek Swimming Hole	Riparian	43.74725, 122.44396
Middle Fork N. Willamette	Riparian	43.77995, 122.53170
Salmon Creek Greenwater's Rest Area	Riparian	43.74057, 122.45917
Salmon Creek Fish Hatchery Rd	Riparian	43.74438, 122.44740
Clackamas McIver-Barton #1	Riparian	45.37224, 122.39876
Clackamas McIver-Barton #2	Riparian	45.37836, 122.40933
Sandy Dodge-Oxbow	Riparian	45.47069, 122.28885
Sandy Oxbow-Danby	Riparian	
Mt. Tabor Park, Portland	Natural Area	45.50948, 122.59124
OMSI Springwater Trail	Riparian	45.51455, 122.33748
Roger's Landing County Park	Natural Area	45.28718, 122.96957
Sandy Revenue-Dodge	Riparian	45.43511, 122.25565
Clackamas Barton-Carver #1	Riparian	
Clackamas Barton-Carver #2	Riparian	
Clackamas Barton-Carver #3	Riparian	

Table 2: List of cultivars from which seed was collected for dispersal calculations
Royal Red
Nanho Alba
White Profusion
Nanho Blue
Pink Delight
Black Knight
Windy Hill