Charles W. Heckman, USDA Forest Service, Pacific Northwest Research Station, 3625 93rd Avenue SW, Olympia, Washington 98512, e-mail cwheckman@hotmail.com

The Encroachment of Exotic Herbaceous Plants into the Olympic National Forest

Abstract

A floral survey in the Olympic National Forest and its surroundings revealed that a considerable number of introduced ruderal plant species have made deep inroads into the stands of native flora. Some of them, which are mainly of European and Asian origin, have been planted deliberately to stabilize the soil along roadsides and after clear cutting and burning. However, they have already established reproductive communities that are capable of spreading rapidly without additional human help, as they have already done in almost all regions of the earth subject to a temperate climate. Plotting the data from the Geographical Information System, it was shown that 12% of an area totaling 388 km^2, located mainly in the Olympic National Forest, was occupied totally or in large part by this mainly ruderal flora, which accounted for at least 50% and usually nearly 100% of all plants within the area on which they occurred. This represents a major qualitative and quantitative biogeographical alteration in the regional flora of a national forest generally considered to be only slightly affected by human activity.

Introduction

A phytogeographical process initiated by the wanderings of human beings has been changing the world's flora throughout recorded history, but for the past century, this process has been accelerated at an alarming rate. It has resulted in the formation of new floral aggregations, recruited mainly from Europe and Asia and transported to biotic communities located on all continents except Antarctica (Hitchcock & Cronquist 1973; Weihe 1972). In many places, these species have been intentionally planted, whereas in others, they arrived as contaminants of seed. Once established on a continent, they often spread rapidly because of their great potential for massive seed dispersal (Baker 1974). The result has been the formation of ruderal communities throughout the temperate zones of the world from subtropical and Mediterranean to sub-arctic regions. The formation of these communities has been facilitated by anthropogenic alterations of the vegetation, particularly those related to housing, road building, and leisure activities. These exotic species have been augmenting and even displacing endemic floral aggregations on an ever growing area of the earth's surface (Wilgen and Richardson 1985; Kowarik, 1995). As pointed out by De Ferrari and Naiman (1994), even the widespread interest in this phenomenon has resulted in relatively few studies on a landscape scale. However, the problem of exotic plants in the State of Washington has been drawing a considerable amount of public attention. A list of the introduced species first reported in the state from 1950 to 1996 and a discussion of the role some of them have assumed has been provided by Toney et al. (1998).

The purpose of this study was to determine the structure of the biotic communities in which the introduced species develop, estimate their present quantitative impact in the coastal forest on the Olympic Peninsula of Washington, and provide a synopsis of the history of its development and spread. It must be emphasized that these communities are fundamentally different from those which were formerly encountered in the local ruderal habitats. It is an aggregation of international origin rather than native. The spread of the species is progressing at an extremely rapid pace, especially in the Pacific Northwest of North America. For example, only 40 species of non-native plants had been identified on the Olympic Peninsula prior to 1900, and 143 before 1936 (Jones 1936). By 1995, 333 non-native species, accounting for 25% of the flora, were found on the Olympic Peninsula (Buckingham et al. 1995). However, many of the same exotic ruderal species, mainly from Europe, are presently encountered in such places as Japan (Kitamura et al. 1987), Australia, New Zealand, and South Africa (Weihe 1972), as well as in North America. Previous ecological studies that have provided information on the exotic flora of the Olympic Peninsula have focused on the forest succession (Fonda 1974) and those species penetrating the forest along the courses of

the Dungeness and Hoh Rivers (De Ferrari and Naiman 1994). There have also been studies that concentrated mainly on communities of native plants in the Olympic Mountains (Fonda and Bliss 1969; Henderson et al. 1989), as well as the general flora of the region, cited above. This study, conducted mainly in the Sol Duc River Valley, focuses on the importance of roads, particularly the many unpaved logging roads, as avenues of invasion. It is the first attempt to evaluate the quantitative impact of the present management practices conducive to the introduction and spread of the foreign ruderal species on the landscape.

Location

The spread of the international ruderal vegetation was analyzed in and at the edges of the Olympic National Forest in western Washington, U.S.A. The quantitative spread of these ruderal species was determined in the northern part of the forest, which is drained mainly by the Sol Duc River (Figure 1). Although such a study could have been made almost anywhere in the temperate zones, the location along the Pacific Coast in northwestern North America is of special interest because the native flora is typically dominated by conifers, ferns, mosses, lichens, and other vascular plants that are especially adapted to the conditions in cool rainforests or moist coastal forests. Very few of the native species show the adaptations similar to those of the exotic ruderal plants, as discussed below, and only a few of the ruderal species are likely to have reached the Pacific Northwest without human assistance. Clear lines of demarcation between the invading and natural flora were observed at the start of the study, and these are described in detail below (Structure of the Ruderal Aggregations).

Material and Methods

The cartography of the vegetation was completed using recent aerial photos of the Sol Duc River Valley and parallel ridges in or adjacent to the Olympic National Forest. The regional vegetation was observed on the ground, and the structure of the various plant communities was determined.

Figure 1. The location of the site surveyed (black rectangle) on the Olympic Peninsula in the State of Washington.

The species present along transects at least 10 m wide through the forest and along various roads and streams were determined. The locations of the species aggregations on the areas covered by the maps were then plotted according to the findings made during the field survey. Care was taken to visit all of the distinct zones observable in the photos, including mature forest, replanted forests in various stages of development, clearcuts, lands used for agriculture or animal husbandry, roadsides, the riparian zone along streams, and the vicinity of buildings. Surveys were also made along logging roads reaching to the top of the ridges located within the area surveyed. Only gardens around private houses were omitted form the survey, because the amount of the area covered by such gardens was insignificantly small, and many of the plants growing in them are not viable in natural communities. The presence of the ruderal vegetation either alone or interspersed with other plant aggregations on cleared areas was then plotted on the map, and the number of square meters it covered was calculated on the horizontal plane of the maps. By this method, some underestimation of the area it covered is possible because areas on hillsides are actually greater than they appear on the maps. The area of all unpaved roads with a strip 1 m wide along each side as well as a 5 m area on each side of Highway 101, which transects the area surveyed, was added to the total. The paved area of the highway was not included in the total area inhabited by ruderal vegetation. This may also result in an underestimation of the area occupied by ruderal plants because they usually cover much more than 5 m on each side of the main roads and more than 1 m along minor logging roads. The area of unpaved roads themselves was included in the total because the ruderal plants often grow in the middle of them.

A total of 388.2 km^2 was surveyed using aerial photos that had been taken in 1994 and digitized as data in a Geographic Information System (GIS). The approximate percentage cover of the total area largely dominated by herbaceous plants predominantly belonging to the exotic ruderal community was calculated using the program ArcView™ by marking all bare areas and cut woodlands in early stages of regeneration together with the marginal strips along all roads. Field surveys were conducted by walking the transects during the spring and summer of 1998, noting the species present 5 m on each side of the way, and photographing the vegetation to confirm the presence of the ruderal species on these areas.

It was further determined that only a few additional forested areas had been cleared of trees since the GIS data were obtained in 1994, and these were still only partially colonized by plants, with many areas still bare of nearly all vegetation. The charts prepared were compared with those produced to map the seral stages of the native vegetation during previous years and stored in the GIS in order to provide an additional check of the accuracy of the mapping. The data used for comparison were obtained from an unpublished forest service report on the Sol Duc Pilot Watershed Analysis by Mr. David Peter. The program ARC/INFO™ was used to calculate the area of the region surveyed on which the ruderal flora occurred at the time the aerial photos were taken.

Results

Structure of the ruderal aggregations

While walking along the transects, it became apparent that the exotic ruderal species generally form aggregations that exclude native herbaceous species along roadsides and similar disturbed areas (Table 1). In undisturbed forests dominated by the species listed in Table 2, it was usually found that no exotic species were present. From these observations and from photographs made in the region, it became evident that the majority of the area has either 100% or 0% coverage by exotic species.

Mixtures of exotic and native species are encountered along a narrow ecotone between ruderal roadside communities and undisturbed forest. These characteristically appear as grasses invading stands of forest floor vegetation. Other mixtures of native and introduced species are present on clearcut areas. It was observed that after the trees are removed, most of the shade-adapted plants of the forest floor quickly succumb to dryness and strong illumination. However, thick stands of the sword fern [*Polystichum munitum* (Kaulf.) Presl.], are able to persist for long periods of time among the encroaching exotic herbs, which are usually intentionally seeded on the clearcuts to prevent erosion. These remain as the only representatives of the native herbaceous flora, but they also gradually disappear with time. On the Olympic Peninsula, the woody plants that

TABLE 1. Species of the ruderal vegetation that colonize areas of the Olympic Peninsula disturbed by man and the geographical origins of the component species. The distribution of the individual species in ruderal habitats is influenced locally by such factors as the amount of moisture present and the amount of shading by adjacent forests. However, deliberate seeding of the roadsides and clearings cut in the forest is still a primary factor determining where the species will be encountered. Most identifications were made using Hitchcock & Cronquist (1973), but the nomenclature was updated to follow that of Buckingham et al. (1995). The superscript after the name refers to the first report of the species on the Olympic Peninsula, according to Jones (1936) and Buckingham et al. (1995).

Species	Probable origin
Pteridophyta	
Equisetum arvense L.[1]	North America, Europe
Dicotyledonae	
Achillea millefolium L.[2]	North America, Europe, Asia
Anaphalis margaritacea (L.) Bentham & Hooker[1]	North America, Europe, Asia
Barbarea verna (Mill.) Ascherson[4]	Europe
Barbarea vulgaris Robert Brown[4]	Europe, Asia
Bellis perennis L.[3]	Europe
Calystegia sepium (L.) Robert Brown[3]	Europe
Capsella bursa-pastoris (L.) Medicus[2]	Europe, Asia
Chrysanthemum leucanthemum L.[3]	North America, Europe, Asia
Cirsium arvense (L.) Scopoli[3]	Europe
Cirsium edule Nuttall[1]	North America
Cirsium vulgare (Savi) Tenore[3]	Europe
Digitalis purpurea L.[2]	Europe, Asia
Epilobium angustifolium L.[1]	North America, Europe, Asia
Erodium cicutarium (L.) l'Héritier[4]	Europe, Asia
Gnaphalium uliginosum L.[4]	Europe, Asia
Heracleum lanatum Michaux[1]	North America, Siberia
Hieracium aurantiacum L.[4]	Europe
Hypericum perforatum L.[3]	Europe, Asia, North Africa
Hypochaeris radicata L.[2]	Europe
Lactuca muralis (L.) Fresenius[3]	Europe
Lapsana communis L.[3]	Europe, Asia
Lathyrus latifolius L.[4]	Europe
Lotus pedunculatus Cavanilles[4]	Eurasia, Africa, Australia
Lysimachia punctata L.[4]	Europe, Asia
Lythrum salicaria L.[4]	Europe
Medicago lupinula L.[3]	Europe, Asia, North Africa
Melilotus officinalis (L.) Lamarck[4]	Europe, Asia
Myosotis arvensis (L.) Hill[3]	Europe, Asia, North Africa
Plantago lanceolata L.[2]	Europe
Plantago major L.[2]	Europe
Polygonum cuspidatum Siebold & Zuccarini[4]	Japan
Polygonum sachalinense Schmidt[4]	Eastern Asia
Prunella vulgaris L. var. *vulgaris*[4]	Europe
Ranunculus acris L.[3]	Europe
Ranunculus repens L.[2]	Europe
Rumex acetosella L[2].	Europe
Rumex crispus L.[2]	Europe, Asia
Sagina procumbens L.[3]	Europe
Senecio jacobaea L.[4]	Europe
Solidago canadensis L.[1]	North America
Sonchus oleraceus L.[3]	Europe, Asia
Taraxacum officinale F.Weber ex Wiggers[2]	Europe, Asia
Trifolium hybridum L.[3]	Europe

Table 1 continued, next page

Species	Probable origin
Trifolium pratense L.[2]	Europe, Asia
Trifolium repens L.[2]	Europe, Asia, North Africa
Vicia sativa L.[2]	Europe, Asia, North Africa
Monocotyledonae	
Agrostis capillaris L.[4]	Europe, Asia, North Africa
Agrostis stolonifera L.[4]	Europe
Avena fatua L.[4]	Europe, Asia, North Africa
Bromus hordeaceus L.[4]	Europe
Dactylus glomerata L.[2]	Europe, Asia
Elymus glaucus Buckley[1]	North America
Elymus trachycaulus (Link) Gould[4]	North America
Holcus lanatus L.[4]	Europe, Asia, North Africa
Holcus mollis L.[3]	Europe
Juncus balticus Willdenow[1]	North America, Europe
Juncus bufonius L.[1]	North America, Europe, Asia
Juncus effusus L.[1]	North America, Europe
Lolium perenne L.[2]	Europe
Phleum pratense L.[2]	Europe, Asia
Poa trivialis L.[4]	Europe, Asia, North Africa
Vulpia myuros (L.) C.C. Gmelin[4]	Europe
Vulpia octoflora Walter[1]	North America

[1]A probable native species (Jones, 1936).
[2]Introduced prior to 1900.
[3]Not reported before 1900 but known to have been introduced prior to 1936.
[4]Not known to have been introduced until after 1936.

develop on cleared areas are generally native, but the spread of exotic woody plants, such as Scots broom, [*Cytisus scoparius* (L.) Link], can be expected in the near future.

To illustrate the structure of the vegetation typically encountered while walking through areas subjected to human influence, a transect from the middle top to middle bottom of Figure 2 can be taken. Beginning at the bottom, a roadside aggregation is encountered in which nearly 100% of the herbaceous plants are exotic, but surviving sword fern tufts are occasionally scattered among the ruderal vegetation.

In contrast to the herbaceous plants, the woody vegetation consists of 100% native species at most locations. Surviving vine maples, *Acer circinatum*, and species of *Rubus* are particularly characteristic of the region. Near the edge of the deciduous trees at the bottom of the picture, a narrow ecotone is encountered, in which there is a mixture of native and exotic herbaceous plants. Beneath the trees themselves, the native species gain the upper hand and account for well over 50% of the species present. Moving out of the trees onto the clearcut at mid-level in the photo, another ecotone is encountered, followed by an area on which almost 100% of the herbaceous species are exotic. Rarely, isolated edible thistles (*Cirsium edule*) occur among the exotic species in the clearcuts, but non-native thistles are more abundant. In the clearcut shown, there is a seasonal succession involving exotic grasses, the common foxglove (*Digitalis purpurea*), scattered composites, clovers (*Trifolium* spp.), and docks (*Rumex* spp.). In addition to the exotic herbaceous species, a few native woody species and small native conifers can also be found.

Moving beyond the road in Figure 2, a closed section of forest is encountered. While about 100% of the herbaceous plants along the roadside are exotic, those under the forest canopy are nearly 100% native. There is a very narrow ecotone at the edge of the forest in which there is some mixture of native and exotic species. In summary, the transect through this photograph (Figure 2) runs through unshaded areas in which nearly 100% of the herbaceous plants are exotic, through closed canopy forest in which little more than 0% of the herbaceous plants are exotic, and through narrow ecotones and open canopy woods in which there

TABLE 2. The most abundant native plant species dominating the climax stage forests in the region surveyed and their native ranges. Pacific Northwest refers to the Pacific Watershed of North America and adjacent Rocky Mountains.

Species	Native Range
Trees	
Acer macrophyllum Pursh	Pacific Northwest
Alnus rubra Bongard	Pacific Northwest
Pseudotsuga menziesii (Mirbel) Franco	Western North America
Tsuga heterophylla (Rafin) Sargent	Pacific Northwest
Thuja plicata D. Don	Pacific Northwest
Woody vegetation in understory and edges of clearings	
Acer circinatum Pursh	Pacific Northwest
Oplopanax horridus (Smith) Miquel	Northern North America
Rubus parviflorus Nuttall	Western North America
Rubus spectabilis Pursh	Pacific Northwest
Sambucus racemosa pubens (Michaux) House	North America
Herbal understory growth	
Claytonia cordifolia (Watson) Pax & Hoffmann	Western North America
Cornus unalaschkensis Ledebour	Pacific Northwest
Listera caurina Piper	Western North America
Lycopodium clavatum L.	Circumboreal to tropics
Oxalis oregana Nuttall	Pacific Northwest
Pteridium aquilinum (L.) Kuhn	Cosmopolitan
Bryophtyes	
Hyloconium splendens (Hedwig) Bruch,Schimper, & Gümbel	North America, Europe, Africa, New Zealand
Hypnum circinale Hooker	Pacific Northwest
Isothecium stoloniferum Bridel	Western North America
Kindbergia oregana (Sullivant) Ochyra	Pacific Northwest
Polytrichum juniperinum Hedwig	Cosmopolitan
Rhizomnium glabrescens (Kindberg) Koponen	Western North America
Rhytidiadelphus loreus (Hedwig) Warnstorf	North America, Europe
Thuidium recognitum (Hedwig) Lindberg	Northern Hemisphere

is some mixture of native and exotic species. The newly logged side of the hill in the upper left quarter of the figure is almost bare of vegetation. The native understory plants have died off since the logging, and the exotic plants have only recently begun to move onto the clearing.

The introduced ruderal plants observed during the field study are shown in Table 1. A number of additional alien species were reported for the Olympic Peninsula by De Ferrari and Naiman (1994) and Buckingham et al. (1995). The majority of the species originated in northern Europe and have spread throughout many parts of the temperate zones (Weihe 1972). Some of them are native to eastern Asia. A few are thought to have been present in North America since prehistoric times, and some of these have apparently been introduced to the Pacific Northwest from other parts of the continent during recent human migrations.

Spread of the exotic ruderal species

The field surveys during spring and summer showed that the ruderal plants are virtually the only vegetation along most roadsides, encroach extensively into the clearcuts in the forest, and share the areas with plants of subsequent seral stages until the conifer forests have almost completely regenerated. Along numerous transects through the forests, none of the species in Table 1 were ever encountered on the floor of intact, mature forests or along unmodified streams, but

Figure 2. Hillsides near the site of the survey in Clallam County showing typical closed forest and clearcut areas. A transect through the center of this photo from top to bottom reveals the "all or none" nature of exotic species aggregations in the local herbaceous flora. In contrast, the woody plants belong almost exclusively to native species. For details, see text.

they persisted on unused roads and former clearings that had been fully overshadowed by young conifers.

A simplified map showing the Sol Duc River and the locations occupied wholly or predominantly by the ruderal community, which consists almost exclusively of species that have become pan-temperate, is provided in Figure 3. A planimetric analysis of the map indicates that a total of 45.935 km^2 are occupied by that community. which equals 11.8% of the total area of the region covered by the photos. Because the region surveyed lies mainly within a national forest and is uninhabited, this percentage of land on which the native flora of herbaceous plants has been replaced almost entirely by species introduced from other continents is considerable. It should also be remembered that this large area does not include parts of forest and woodland in which a few exotic species are encroaching among the native forest floor species. Such encroachment can be expected to occur most frequently along streams and rivers and on natural clearings. In the inhabited parts of the Olympic Peninsula, a much greater percentage of the flora is accounted for by this pan-temperate ruderal community because the ruderal community is also promoted by agriculture.

The ruderal community is clearly a primary seral stage that is gradually displaced as the sere progresses. The plants are useful for stabilizing the soil on cleared areas. For this reason, they are frequently planted intentionally, which has contributed to their rapid colonization of such large areas in the region. The introductions of plants, however, has not always had benign results. Much effort is currently being devoted to eradicate the Scot's broom, which has become a very troublesome weed since its introduction. Several introduced herbaceous species are poisonous to domestic animals. For example, the tansy ragwort (*Senecio jacobaea*) produces alkaloids that are toxic to horses and cattle (Whitson et al. 1991), and expensive eradication programs to eliminate it have been proposed. The meadow buttercup (*Ranunculus acris*) is also poisonous to cattle (Parish et al. 1996). The area already colonized by the ruderal community is considerable, so

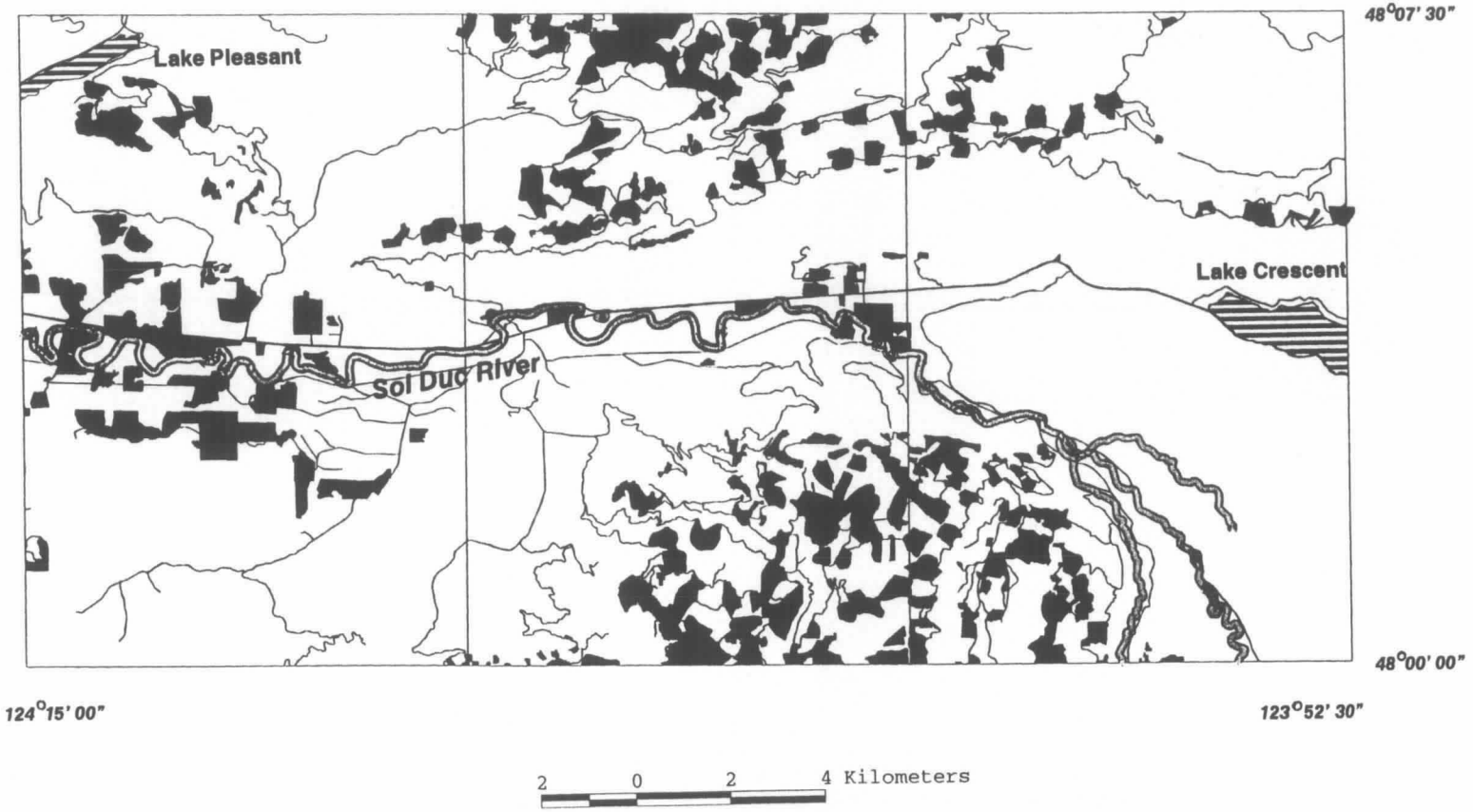

Figure 3. The area of 388.25 km^2 surveyed during the study with the subareas occupied wholly or to a large degree by ruderal flora shown in black. The double black lines outline the Sol Duc River, while the narrow lines indicate roads along which the ruderal plants grow. On this map, the area occupied by the herbaceous ruderal flora, which consists nearly 100% of exotic species, is at least 45.935 km^2 or 11.83% of the total.

judging from the fact that these species had not reached the region at all until the late 19th or early 20th century, the present extent of their coverage represents a major floral change in the Pacific Northwest region of North America.

Discussion

History of floral change

The encroachment of the pan-temperate ruderal community, mainly of European origin, into the Pacific Northwest is typical of a process that has been taking place throughout the temperate zones, mainly during this century. The pan-temperate ruderal community has spread rapidly with the systems of highways and logging roads and is presently altering the flora of the temperate zones in North and South America, Asia, and Australia, to various degrees, as demonstrated by the range information on the individual species, provided by Weihe (1972). The native plant aggregations of the rainforest region on the Olympic Peninsula of Washington are strikingly different in structure and ecological characteristics from those along the edges of the deciduous forests of Europe (Moravec et al. 1982), where much of the ruderal vegetation has had its origin. Table 2 provides a short list of some of the dominant native plant species of the forests on the Olympic Peninsula, which were characterized by Franklin & Dyrness (1973) as being mainly old growth forest, dominated by Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) and notable for the dense epiphytic flora. In addition to the abundant mosses (Schofield 1992), which coat much of the forest floor and the tree trunks, the vegetation is characterized by a particularly large variety of lichens (McCune & Geiser 1997). For this reason, the demarcation lines between the introduced community (Figure 4) and the native flora (Figure 5) are recognizable at a glance. In eastern North America, there is less distinction between the native and non-native vegetation because many of the introductions occurred well

Figure 4. A typical ruderal community in the middle of a little used dirt road during the late spring. The dominant species in this aggregation are *Trifolium repens* and *Bellis perennis*.

Figure 5. A native forest floor community of late spring dominated by *Linnaea borealis* and *Cornus unalaschkensis* Ledeb. that occupies open ground at the edges of roads and clearings before it is overgrown by the faster-growing introduced species.

over a century ago, and many species have already integrated themselves with the native flora (Fernald 1987). Sharp ecological demarcation lines are no longer apparent between New and Old World species. However, the encroachment of the ruderal plants has been no less dramatic.

The floral changes involving the ruderal species are still more significant for phytogeography than for economics, although this may change dramatically at any time. The ruderal species are considered to have a positive effect in holding the soil in place wherever human activity has stripped away the natural vegetation. Usually, native vegetation is able to displace the ruderal species during the course of the natural sere. However, introductions of some plant species, mainly those that become established in pastures, are having some severe economic effects because of their toxicity to domestic animals (Whitson et al. 1991; Parish et al. 1996), as mentioned above. The rapid growth of the introduced species works to the disadvantage of any native ruderal species present in the region. In the Pacific Northwest, the redwood sorrel (*Oxalis oregana* Nutt.), wild strawberry (*Fragaria virginiana* Duchesne), sweet-scented bedstraw (*Galium triflorum* Michx.), little buttercup (*Ranunculus uncinatus* D. Don.), red columbine (*Aquilegia formosa* Fisch.), Cooley's hedge-nettle (*Stachys cooleyae* Heller), and the twinflower (*Linnaea borealis* L.), which is a circumboreal species (Dempster 1993), are frequently observed in partially shaded locations at the edge of the forest along roads. However, the results of the observations along the transects confirmed that these are rapidly overgrown whenever the introduced ruderal species, particularly the grasses, begin to colonize the habitat. Figure 2 shows areas being rapidly overgrown by ruderal plants, and at these sites, no native ruderal species were ever observed. It can be assumed that prior to the coming of the first European settlers, the entire region provided few areas for

colonization by ruderal herbs, so the native species had little chance to develop varieties well adapted to this kind of habitat. One of the only ruderal species that has apparently been established on the Olympic Peninsula since prehistoric times is the field horsetail, (*Equisetum arvense*), which is still an abundant ruderal species is moist locations (Hauke 1993). However, it is nearly pantemperate in distribution and was apparently already present on several continents prior to the Quaternary Period (Hauke 1993), when the retreat of the glaciers permitted it to colonize the region now known as western Washington (Jones 1936).

As the sere progresses, these first stage species, some of which are encountered in sunny places on the forest floor, have been overgrown by native species of the next seral stage, mainly woody shrubs, such as the salmonberry (*Rubus spectabilis*) and thimbleberry (*Rubus parviflorus*). However, the native species of the second seral stage are being increasingly displaced by another European introduction, the Scot's broom. This displacement threatens to have economic consequences because simple efforts to eradicate the rapidly spreading import are proving unsuccessful, and more elaborate methods will probably be employed, which will be expensive but probably will not be effective, either. Unlike the ruderal herbs, the Scot's broom is thought to be capable of stopping the growth of young conifers.

The final seral stages are still dominated by native species, which eventually overshadow the sun-loving ruderal species and eliminate them from the area. However, Figures 2 and 3 show that with increasing human activity in the forest, the stands of native climax vegetation are increasingly fragmented into isolated stands surrounded by introduced species. The roads are particularly effective at dissecting the native forests, and they provide avenues of penetration that take the ruderal floral aggregations new to the region deep into the forest.

At the present time, the area occupied by the ruderal community, 11.83% of the total area surveyed, is enough to cause concern. This is particularly true because the advance of these species along the many small roadways in the forest permits this exotic vegetation to dissect the native forests into disjunct islands of conifers and their natural understory plants. This is a remarkable floral change considering that during the first half of the 19th century, the Olympic Peninsula was settled only by native Americans, whose hunting and fishing societies caused only minimal change to the forest. Settlement of the region by persons of European descent began only during the second half of the 19th century and progressed slowly. The floral changes in the region apparently began to accelerate considerably during the first half of the 20th century, and the advance of the ruderal community with the roads did not take place with any great speed until the second half of the century. As already discussed, Jones (1936) found that there had been a considerable augmentation of the non-native flora between 1900 and 1936. Since that time, the introduction of exotic species has intensified considerably (Buckingham et al. 1995). Judging from the trends that have taken place during this century and the time required for introduced species to become invasive (Kowarik 1995), nonnative species can be expected to bring about fundamental changes in the flora of the Olympic Peninsula during the next few decades.

Along the Dungeness and Hoh Rivers to the south, De Farrari and Naiman (1994) reported that 28% and 24%, respectively, of the plant species present were exotics. They discussed the role of these rivers as invasion routes for the introduced plants, confining their discussion mainly to natural dispersion and accidental transport of seed. In the Sol Duc Valley, however, the roads seem to be the main avenues of transport, and deliberate seeding of roadsides and clearcuts makes discussion of other dispersal mechanisms moot.

Outlook

Although there are presently few obvious dangers to the native flora due to invasive spreading of the introduced species, problems are sure to arise in the future. Kowarik (1995) was able to trace the development of introduced species in Brandenburg for a period of more than two centuries. In the case of woody plants, he noted that an average of 147 years elapsed between the introduction of species and the time they became invasive. He further found that it is not possible to predict which species will become troublesome for the native vegetation. Even if we assume that invasiveness will manifest itself among herbaceous plants more rapidly than among woody

species, decades may elapse before one of the newcomers begins to develop into a dangerous competitor of the native species. Several of the species in Table 1 seem to have the potential to become invasive. For example, Edwards et al. (1995) noted that the purple loosestrife (*Lythrum salicaria*) has a tendency to spread rapidly and form monospecific stands in other parts of North America. This shows that considerable trouble with the species already introduced can be expected during coming decades, and new exotic species are still being brought to the Pacific Northwest for landscaping purposes by both the timber industry and private groups ostensibly attempting to manage the environment. At the present time, a clear separation of communities of exotic species and those of native species is maintained because the exotic species are adapted to strong illumination, while the native plants are overwhelmingly adapted to the shade on the forest floor. The development of shade-tolerant populations of invasive exotic species is all that is necessary to open the way into the forest, permitting the new species to compete directly with the natives. It is time that attention be given to the serious consequences that can occur due to the introduction of foreign species for erosion control or to beautify the environment.

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