

## DISTRIBUTION AND DECLINE OF NATIVE GRASSLANDS AND OAK WOODLANDS IN THE PUGET LOWLAND AND WILLAMETTE VALLEY ECOREGIONS, WASHINGTON

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### ABSTRACT

The primary objective of this project, covering the Puget Lowland and Willamette Valley ecoregions within Washington state, was to create a unified digital map of (1) untilled dry to mesic grasslands existing on soil types known to support pre-European settlement grasslands, and (2) tree canopies dominated or co-dominated by Oregon white oak (*Quercus garryana* Dougl. ex Hook.). Data were drawn from a number of previous mapping efforts and supplemented by additional aerial photo review and ground-truthing. Data on existing woodlands and grasslands were standardized into cover types based on the dominance of oaks and conifers in woodlands, and the relative dominance of native and non-native species in grasslands. Soils that have been documented to support pre-settlement grasslands were mapped in two classes: prairie soils defined by formation under a grass cover, and rocky soil complexes consisting of heterogeneous bedrock-derived soils that support some percentage of their area in grasslands or "balds". These soil type maps were used to derive minimum estimates of pre-settlement grassland extent for comparison with extant cover types. Extant grasslands occupy only 9%, and native grasslands only 2.6%, of minimum pre-settlement grassland extent. Oak canopies generally consist of small patches and are often urbanized to varying degrees. Pre-settlement grasslands, extant grasslands, and oak canopies are all most extensive in the southern Puget Sound area. The distribution of three ecoregional endemic plant species, *Aster curtus* Cronq., *Castilleja levisecta* Greenm., and *Trillium parviflorum* Soukup, is compared to the distribution of extant grasslands, oak canopies and pre-settlement grassland soils.

### INTRODUCTION

Native grasslands and oak woodlands are some of the most imperiled ecosystems in western Washington (Dunn and Ewing 1997). For example, native grasslands in the south Puget Sound area have declined to less than 3% of their pre-European settlement areal extent (Crawford and Hall 1997). Factors contributing to the decline and degradation of these ecosystems include fire suppression and associated conifer tree invasion, invasion of non-native species, grazing, and urban and agricultural conversion (Giles 1970, Agee 1993, Clampitt 1993, Crawford and Hall 1997).

Many species of flora and fauna associated with these unique habitats are of conservation concern due to declines in population, local extirpation, or close associations with the declining habitat. These include the western gray squirrel (*Sciurus griseus*), Mazama

pocket gopher (*Thomomys mazama*), Lewis' woodpecker (*Melanerpes lewisii*), white-breasted nuthatch (*Sitta carolinensis aculeata*), streaked horned lark (*Eremophila alpestris strigata*), western meadowlark (*Stunella neglecta*), Oregon vesper sparrow (*Pooecetes gramineus affinis*), western bluebird (*Sialia mexicana*), racer (*Coluber constrictor*), mardon skipper (*Polites mardon*), Puget blue (*Plebejus icaroides blackmorei*), whulge checkerspot (*Euphydryas editha taylori*), zerene fritillary (*Speyeria zerene bremnerii*), white-topped aster (*Aster curtus*), golden paintbrush (*Castilleja levisecta*), common bluecup (*Githopsis specularioides*), and rose checkermallow (*Sidalcea malviflora* spp. *virgata*) (Dunn and Ewing 1997).

Native grasslands and oak woodlands in the Puget Lowland and Willamette Valley ecoregions (Omernik 1987) are found in dry environments formerly strongly

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influenced by frequent fires, many if not most of which were ignited by Native Americans (Norton 1979). Oak woodlands may be dominated by Oregon white oak (*Quercus garryana* Dougl. ex Hook.), or co-dominated by that species and Douglas-fir (*Pseudotsuga menziesii*), Oregon ash (*Fraxinus latifolia*), bigleaf maple (*Acer macrophyllum*), or Pacific madrone (*Arbutus menziesii*). They range from open savannas of scattered trees to dense-canopied forests, with a range of herbaceous or shrubby understory types (Agee 1993, Chappell and Crawford 1997). They primarily occur on dry sites or in moist riparian environments within prairie, or formerly prairie, landscapes.

Native grasslands are dominated or co-dominated primarily by Roemer's fescue (*Festuca idahoensis* var. *roemeri* Pavlick), red fescue (*Festuca rubra* L.), or California oatgrass (*Danthonia californica* Boland.), and harbor a great variety of forbs that sometimes co-dominate with the grasses or occasionally have greater total cover than the grasses (Chappell and Crawford 1997). Many former native grasslands are now dominated or co-dominated by non-native grasses, or have been invaded by shrubs, especially Scot's broom (*Cytisus scoparius* (L.) Link), Nootka rose (*Rosa nutkana* K. Presl), and common snowberry (*Symphoricarpos albus* (L.) Blake). Native grasslands sometimes occur as large "prairies" on level or mounded plains, with deep, uncompacted, relatively well drained soils, especially glacial outwash deposits. Puget grasslands also occur as "balds" on shallow, rocky soils, especially on moderate to steep south- to west-facing slopes. A few native grasslands are also located on sandy or gravelly coastal bluffs.

Prior to this project, digital maps of oak woodlands or grasslands existed for specific geographic areas of western Washington, including Fort Lewis, McChord Air Force Base, and Thurston County (Kessler 1990, Macklin and Thompson 1992, Crawford et al. 1995, Rolph and Houck 1996). A map of oak woodlands in the remainder of Pierce County was completed in 1999. In addition, the Washington Natural Heritage Program has been compiling locations of high-quality native grasslands and oak woodlands for many years. A single ecoregion-wide digital cover of oak woodlands and grasslands was envisioned by multiple cooperating partners as a valuable tool for biological conservation and resource planning.

The primary objective of this project, covering the Puget Lowland and Willamette Valley ecoregions within Washington state, was to create a unified digital map of (1) untilled grasslands now existing on soil types that formerly supported native grasslands, and (2) oak dominated or co-dominated canopies. The map's scale and level of detail are designed to be appropriate for both regional-level conservation planning and county-level planning and development screening. Secondary objectives were to compare the existing distribution of these communities with estimated pre-European settlement distribution of grasslands based on soil surveys, and with known distribution of selected rare plant species.

### METHODS

This project drew on several previous mapping efforts covering specific geographic areas within the study area and mapped the remaining unmapped areas. Other maps used (referred to hereafter as source maps) were of oak woodlands in Thurston County (Kessler 1990), Fort Lewis (Macklin and Thompson 1992), and McChord Air Force Base (Rolph and Houck 1996), prairies on Fort Lewis (Crawford et al. 1995), and occurrences of high-quality native plant communities recorded in the Washington Natural Heritage Information System. Mapping of oak woodlands in Pierce County outside the military reservations began in 1993 with help from Tahoma Audubon Society volunteers. The Pierce County map was completed in early 1999 and work on the remaining gaps in coverage was started and completed in 1999. The study area consisted of the Washington portions of Puget Lowland and Willamette Valley Level III ecoregions as defined by Omernik (1987) (Figure 1), and the Chehalis River valley in Grays Harbor County.

A standard methodology for mapping was developed and applied to the Pierce County oak woodlands and all subsequent mapping of gaps in coverage. The mapping involved a combination of aerial photography interpretation and field verification. Polygons were mapped on 1:12,000 orthophotos.

Soil surveys and previous field knowledge were used to determine geographic areas to concentrate survey efforts. Native dry to mesic grasslands now occur, or

were reported to occur historically in soil surveys, on the following soil series or types: Spanaway, Nisqually, Carstairs, San Juan, Guemes, Doty, Winlock, Coupeville, Ebeys, Sequim, Sifton, Mossyrock, Pondilla, Snakelum, Townsend, Rock Outcrop, Rock Land, Lithic Haploxerolls, Rough Stony Land, Rough Broken Land, or complexes involving one of these types (Fowler and Ness 1954, Anderson et al. 1955, Ness and Richins 1958, Schlots et al. 1958, Ness and Fowler 1960, McGee 1972, McCreary 1975, Halloin 1987, Pringle 1990, unpubl. data). Mapping of existing grasslands was confined to these soil types or complexes. Previous field surveys had located geographic areas where the abundance of Oregon white oak was sufficient to allow development of stands that met our minimum mapping criteria. A few isolated oak stands were located through word of mouth.

All polygons were assigned a cover type designation and a confidence rating of low, moderate, or high. Eight cover type categories were mapped. "Oak-dominant forest or woodland canopy" is distinguished by >25% cover of oak in the main and upper canopy layers and <25% cover of conifers in the main and upper canopy layers. "Oak-conifer forest or woodland canopy" is similar but with > 25% cover of conifers in the main and upper canopy layers. "Scattered oak canopy" is distinguished by a sparse tree canopy of 5-25% cover of which at least half is oak. All these oak canopy types imply nothing about land use: developed, undeveloped, and agricultural areas were mapped if they met the canopy criteria.

"Native grassland" is herbaceous vegetation dominated by native species. "Semi-native grassland" is dominated by a mixture of native and non-native species, with at least 10% cover of natives. "Exotic grassland" is completely dominated by non-native species, with <10% cover of native species. "Unsurveyed grassland" is untilled grassland detected on aerial photos but not visited in the field. "Shrubland potentially restorable to grassland" is shrub-dominated vegetation located on soil survey map units that supported pre-settlement grasslands.

Within the areas identified for concentrated mapping effort, we reviewed the most recent available black-and-white and color aerial photos and identified areas that appeared to meet the criteria for one of our cover types.

Many of these sites had been visited previously during Natural Heritage Program inventories or by Tahoma Audubon Society volunteers who mapped oak woodlands on street maps. Many polygons could thus be verified with existing information. Others could be verified with a combination of nearby field work and aerial photos where oaks were clearly distinguishable. Many polygons were marked as needing field verification. Of these, oak woodland polygons that could be seen from roads were field verified. Oak polygons needing field verification that were not seen from roads were given a low confidence rating. Grassland polygons were placed in the "unsurveyed grassland" cover type category if they were not been previously visited.

Minimum map unit sizes were established for each cover type. Minimum map units were one acre for oak-dominant and oak-conifer cover types, 3 acres for scattered oak canopy, and 1-20 acres for grasslands and shrublands. To account for differences in natural size of prairies versus rocky bald grasslands, we used different minimum map units for the two environments. On glacial outwash plains (prairies), the minimum map unit was 5 acres for native grassland, and 20 acres for unsurveyed, semi-native, and non-native grasslands and shrublands. On rocky balds or on coastal bluffs, the minimum map unit was 1 acre for native grassland and 5 acres for unsurveyed, semi-native, and non-native grasslands and shrublands.

The other map sources (Fort Lewis, McChord, Thurston Co. oaks) were evaluated for their consistency with these standard mapping criteria. If cover type categories were similar to those in the standards, then the other map was incorporated "as is" with a moderate confidence rating. If cover type categories deviated from those in the standards, then a judgement was made with regard to cross-walking the cover types of the source map with the standard cover types. Some source map cover types or polygons were dropped completely from the coverage if they did not meet the minimum standards criteria. Some other source map cover types were retained, but with a low confidence rating indicating uncertainty about meeting the minimum criteria for mapping.

A layer of soil types known to support pre-European settlement grasslands, covering the Washington portion

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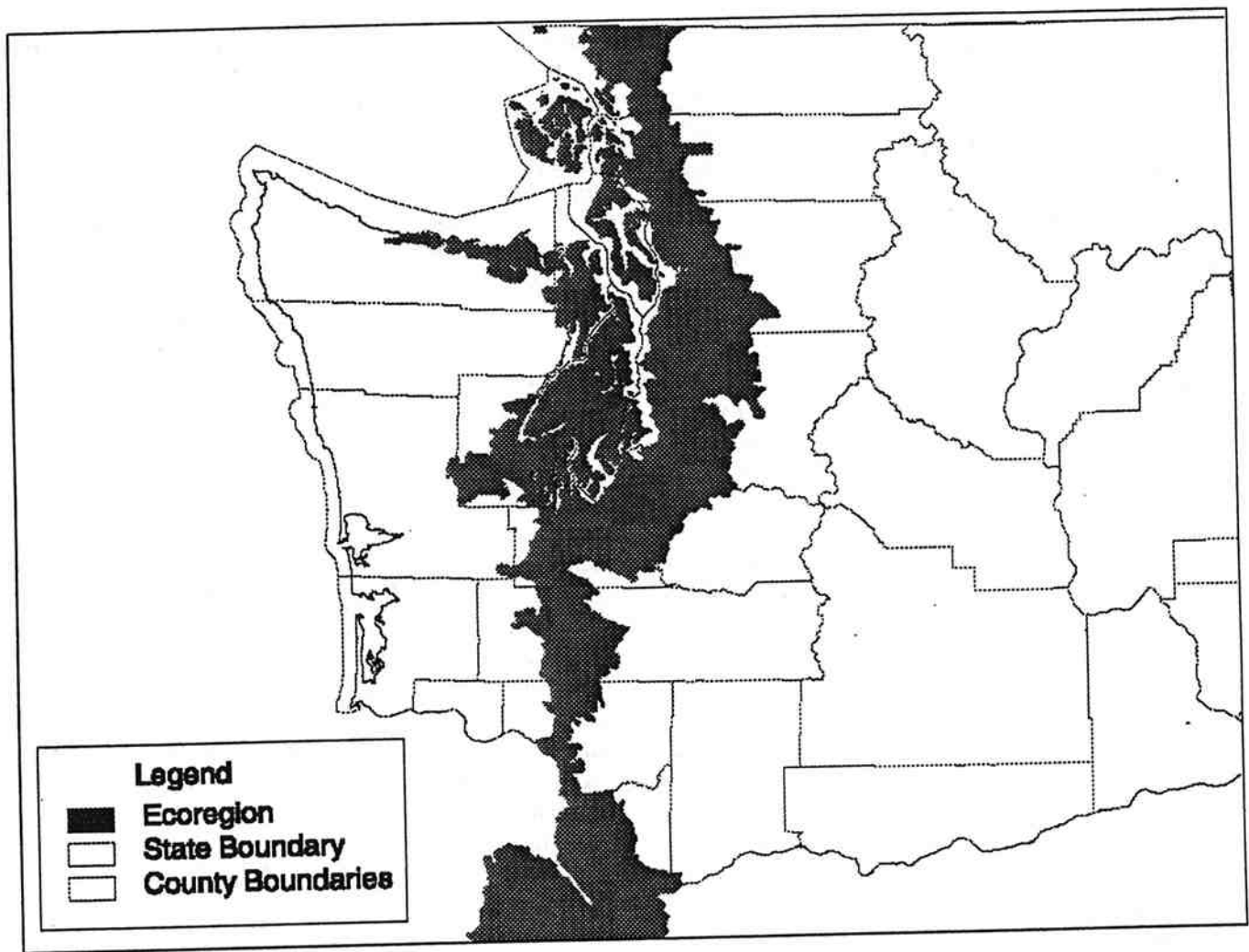


Figure 1. Map of the Puget Lowland and Willamette Valley ecoregions in Washington state.

of the ecoregions, was created from several soil surveys (Fowler and Ness 1954, Anderson et al. 1955, Washington Department of Natural Resources 1998). Fourteen soil series are described in the county soil surveys as having been formed, in part, by the dominance of grass cover and having supported pre-settlement prairies. We assumed that the extent of these soil series are a conservative estimate of the area of pre-settlement prairies and savannas, and we mapped as them "pre-settlement prairie soils." In addition, a number of soil types and complexes support a mosaic of grassland balds and wooded or forest vegetation. These soils typically have bedrock parent materials and areas of shallow soil. They also include serpentine soils. These bedrock-associated soil types and complexes

were mapped as "rocky soil complexes" where pre-settlement grasslands occupied some variable percentage of the mapped area. Rocky soil complexes in the foothills of the northern Cascades were not included due to wet climatic conditions and very limited potential for grassland balds.

As an example of an application of the mapping project, we compared the distribution of three Puget-Willamette endemic species tracked by the Washington Natural Heritage Program with the mapped distribution of extant and pre-European settlement grasslands and oak canopies. Locations of selected rare plant species were drawn from the Washington Natural Heritage Information System. Extant species occurrences were

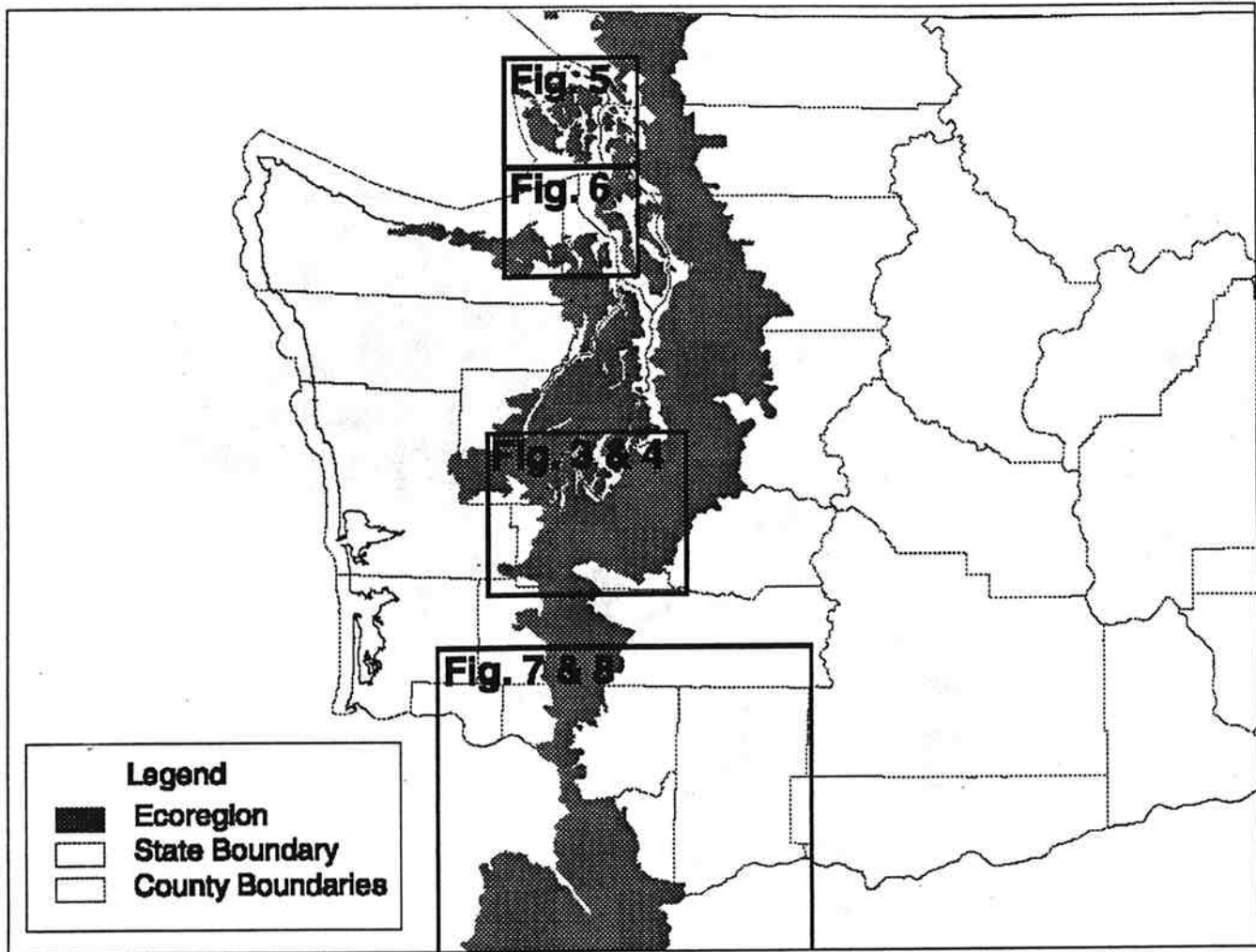


Figure 2. Geographic location of figures illustrating distribution of oak woodlands, grasslands, and prairie soils.

intersected with polygons of extant oak canopy and extant grassland. All species occurrences (extant, historic, and extirpated) were intersected with polygons of pre-settlement prairie soil and rocky soil complex.

**RESULTS**

The southern Puget Sound area, primarily in Pierce and Thurston counties, has the largest areas of pre-settlement grassland soils, extant grasslands, and oak canopies (Figures 2, 3 & 4). The rocky soil complex is most extensive in the San Juan Islands archipelago of San Juan, Skagit and Whatcom counties (Figures 2 & 5). Extant grasslands are still numerous, though often

small, as grassy balds on rocky soil complex in the San Juans Islands (Figure 5). Parts of Whidbey Island, Island County, and the northeastern Olympic Peninsula, Clallam and Jefferson counties, have extensive areas of prairie soils, very little of which support extant untilled grasslands (Figures 2 & 6). The southern portion of the Puget Lowland, south of Thurston County, and the northern end of the Willamette Valley ecoregion have many small oak stands (Figures 2 & 7), a few fairly large areas of prairie soil, and no extant untilled grasslands (Figure 8). The largest contiguous areas of oak-dominant canopy occur along Scatter Creek in Thurston County and east of Washougal in Clark and Skamania counties.



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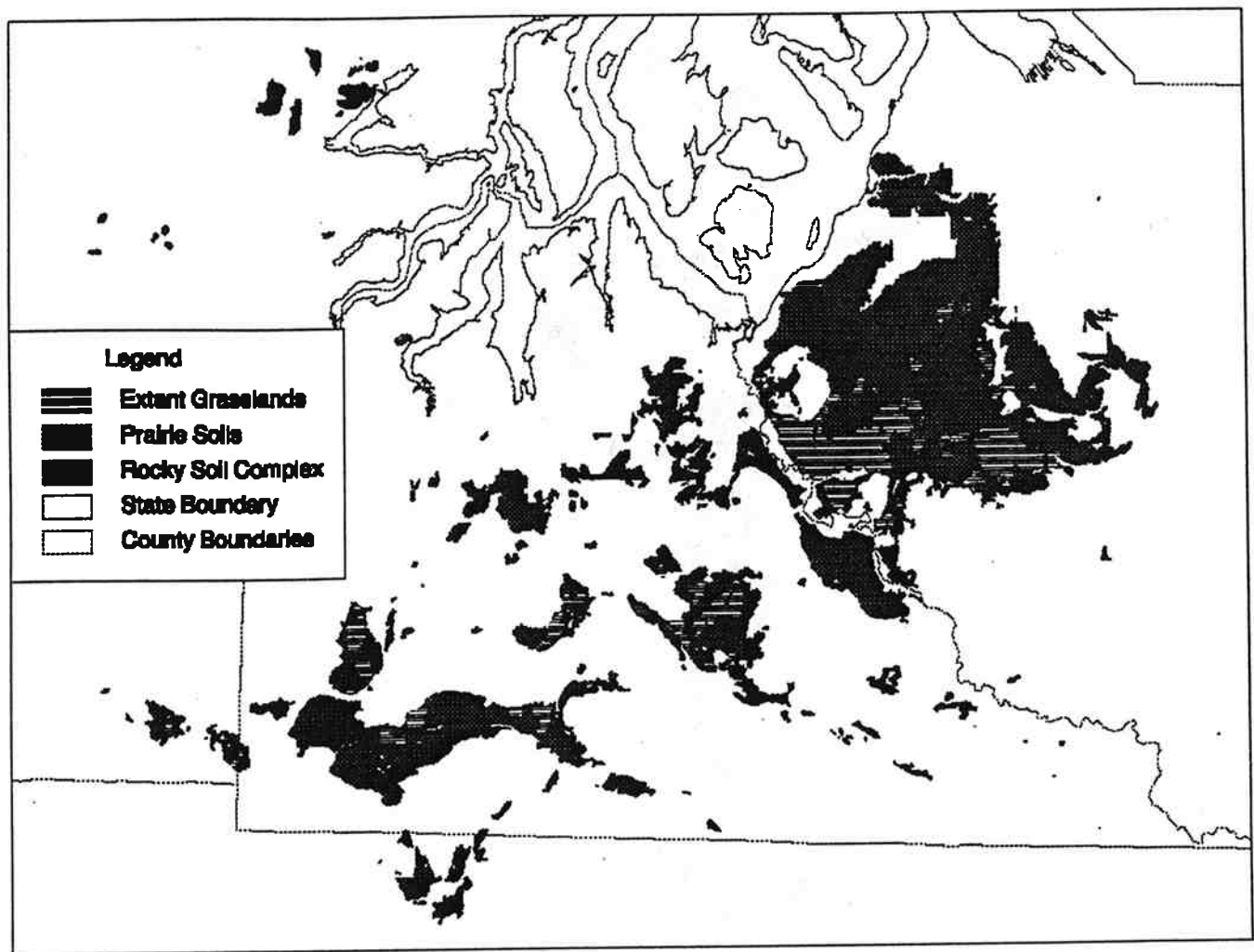


Figure 3. Pre-settlement grassland soils and extant grasslands (native, semi-native, non-native, and unsurveyed) in the southern Puget Sound area, Thurston, Pierce, Mason, and Lewis counties.

Most of the extant mapped polygons are oak canopies, with oak-dominant canopies being the most numerous in terms of polygons (Figure 9). Unsurveyed grassland polygons are the most numerous among the grassland cover types. The areal extent of the cover types reveals a much different pattern (Figure 10). There is a more even distribution among the cover type categories in areal extent than in numbers of polygons. The most extensive cover type is oak - conifer canopy at more than 10,000 acres. However, this cover type has the greatest uncertainty about its mapped extent due to the difficulty of distinguishing it on aerial photographs. The remainder of the other categories range from about 2000 to about 6000 acres in extent. Mean areal extent

of polygons is 7 acres for oak-dominant canopy, 15 acres for oak-conifer polygons, 43 acres for unsurveyed grassland, 62 acres for native grassland, and 68 acres for semi-native and non-native grasslands.

Pre-European settlement prairie soils occupy over 170,000 acres and rocky soil complexes occupy about 38,000 acres (Figure 11). We estimated, based on our field experience and information contained in soil surveys, that about 25% of the rocky soil complexes supported pre-settlement grassland balds. By combining this estimate of pre-settlement rocky balds with pre-settlement prairie soils, we obtained an overall estimate of 180,444 acres of pre-settlement grasslands.

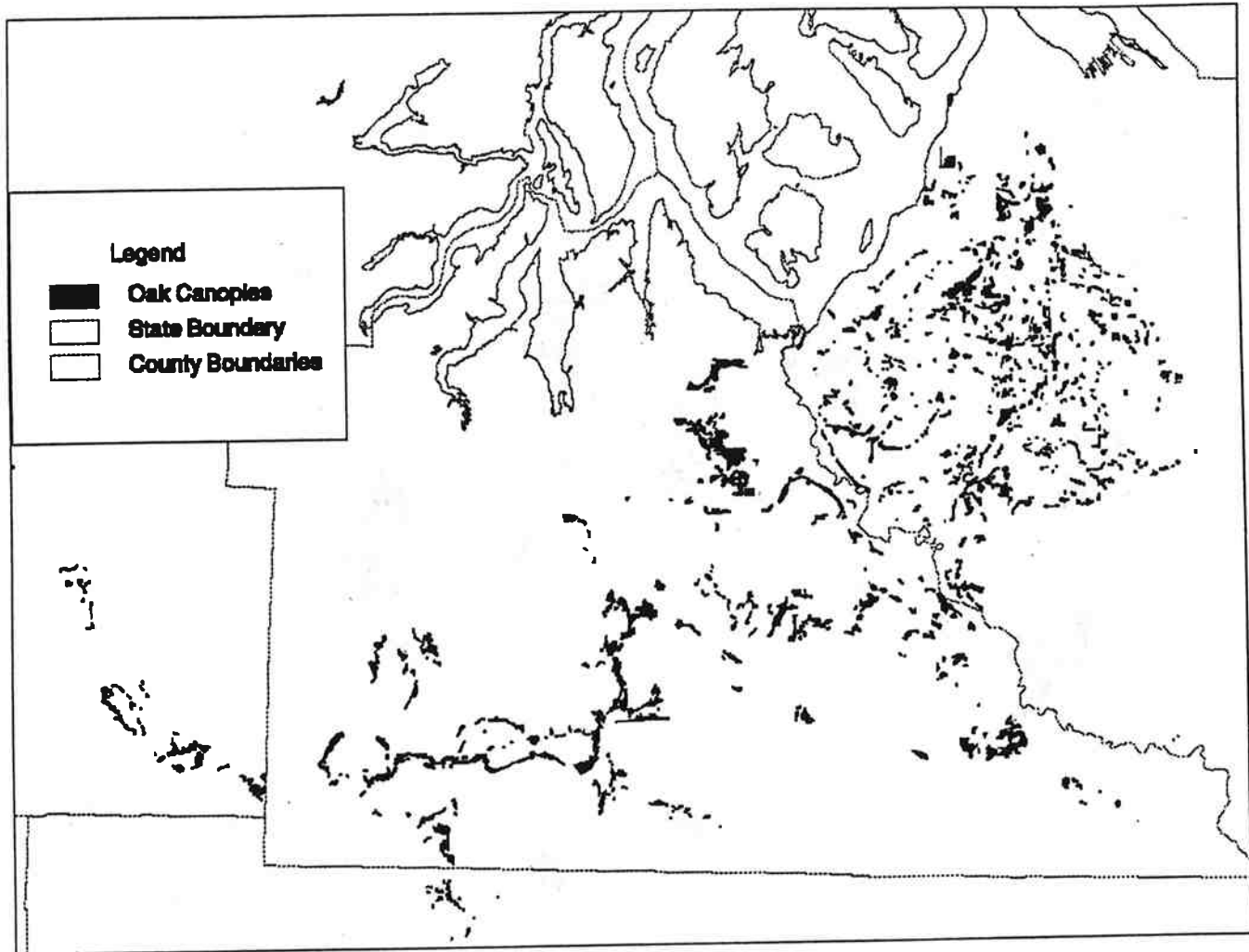


Figure 4. Pre-settlement grassland soils and extant oak canopies (oak-dominant, oak-conifer, and scattered oak) in the southern Puget Sound area.

in the Puget Lowland and Willamette Valley ecoregions in Washington (Figure 11)

Extant grasslands occupy 9.3% of the estimated pre-European settlement grassland extent (Figure 11). This includes native, semi-native, non-native, and unsurveyed untilled grasslands. Known native grasslands occupy only 2.6%, and unsurveyed grasslands 3%, of the estimated pre-settlement grassland extent.

There is considerable correspondence between the occurrence of two of the three rare plant species and the maps of existing oak canopies and grasslands and of pre-settlement grassland soils (Figure 12). White-

topped aster (*Aster curtus*) shows a high degree of overlap with grasslands and a little over half of small-flowered trillium (*Trillium parviflorum*) occurrences overlap with oak canopy polygons. Golden paintbrush (*Castilleja levisecta*) showed a lower co-occurrence with the mapped vegetation and soil units.

## DISCUSSION

Our work quantitatively documents the dramatic decline of native grasslands from their pre-European settlement distribution in western Washington. The map of existing oak woodlands and grasslands illustrates the high degree of fragmentation of the remaining examples

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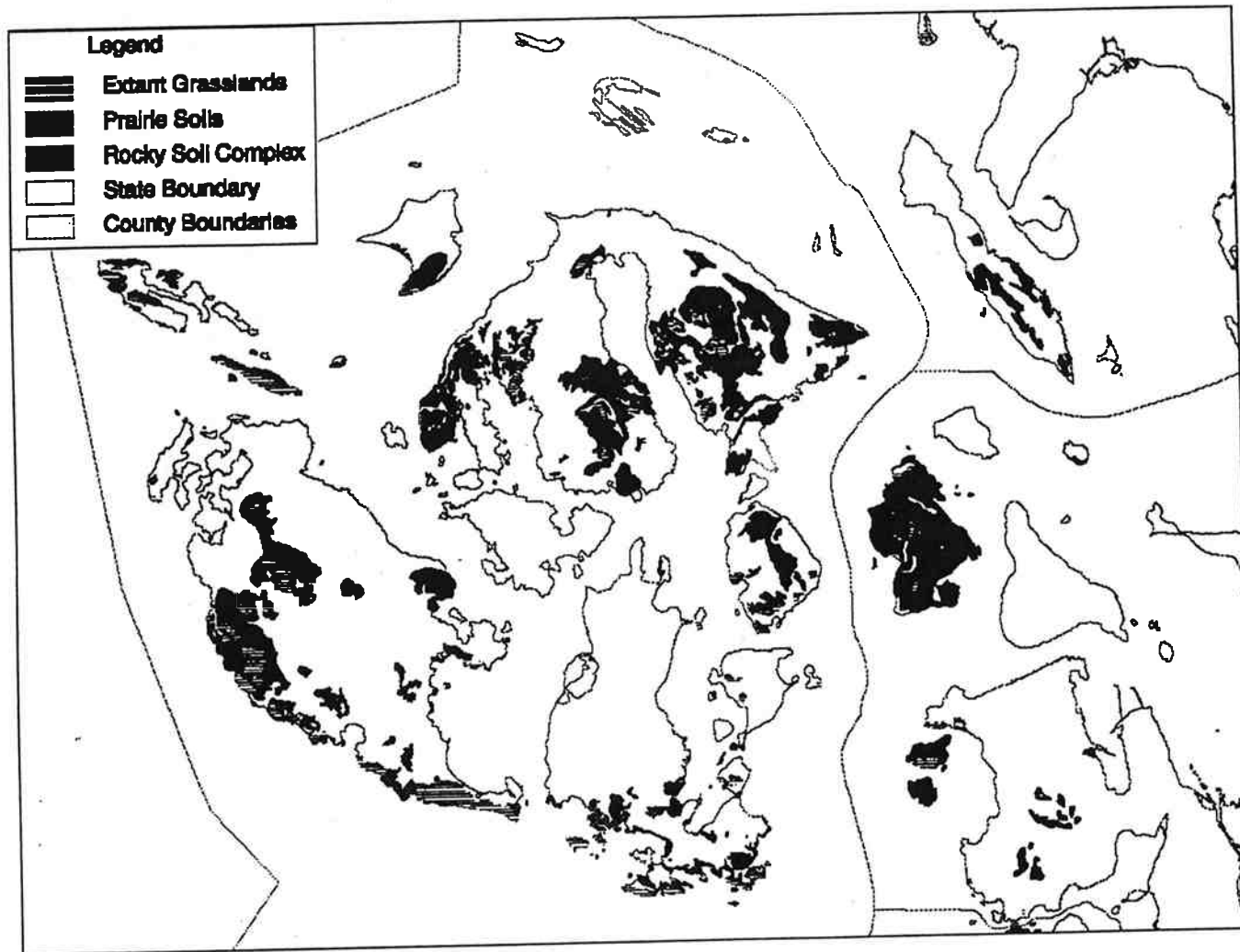


Figure 5. Pre-settlement grassland soils and extant grasslands (native, semi-native, non-native, and unsurveyed) in the San Juan Islands area, San Juan, Skagit, and Whatcom counties.

of these ecosystems (Figures 2-4). This fragmentation is related both to the massive scale of habitat conversion in these ecoregions and to natural factors limiting the distribution of these communities to specific physical environments.

Oak woodlands and grassland balds probably naturally occurred in relatively small patches within a matrix of more extensive communities. Their areal extent has probably declined, but their patchy or fragmented landscape pattern may not have changed much. What would have changed in the case of these small patch communities is the nature of the matrix within which

they occur, formerly consisting mainly of prairies or forests and currently containing large amounts of suburban development and agricultural lands. Prairies were naturally more extensive than oak woodlands and grassland balds, occurring as large patches within a forest matrix. In contrast to oak woodlands and grass balds, fragmentation of prairies has undoubtedly been much accentuated by land conversion and habitat degradation.

Differences in mean polygon size among the cover types are due in part to differences in the actual size of patches, as noted previously. Another factor that



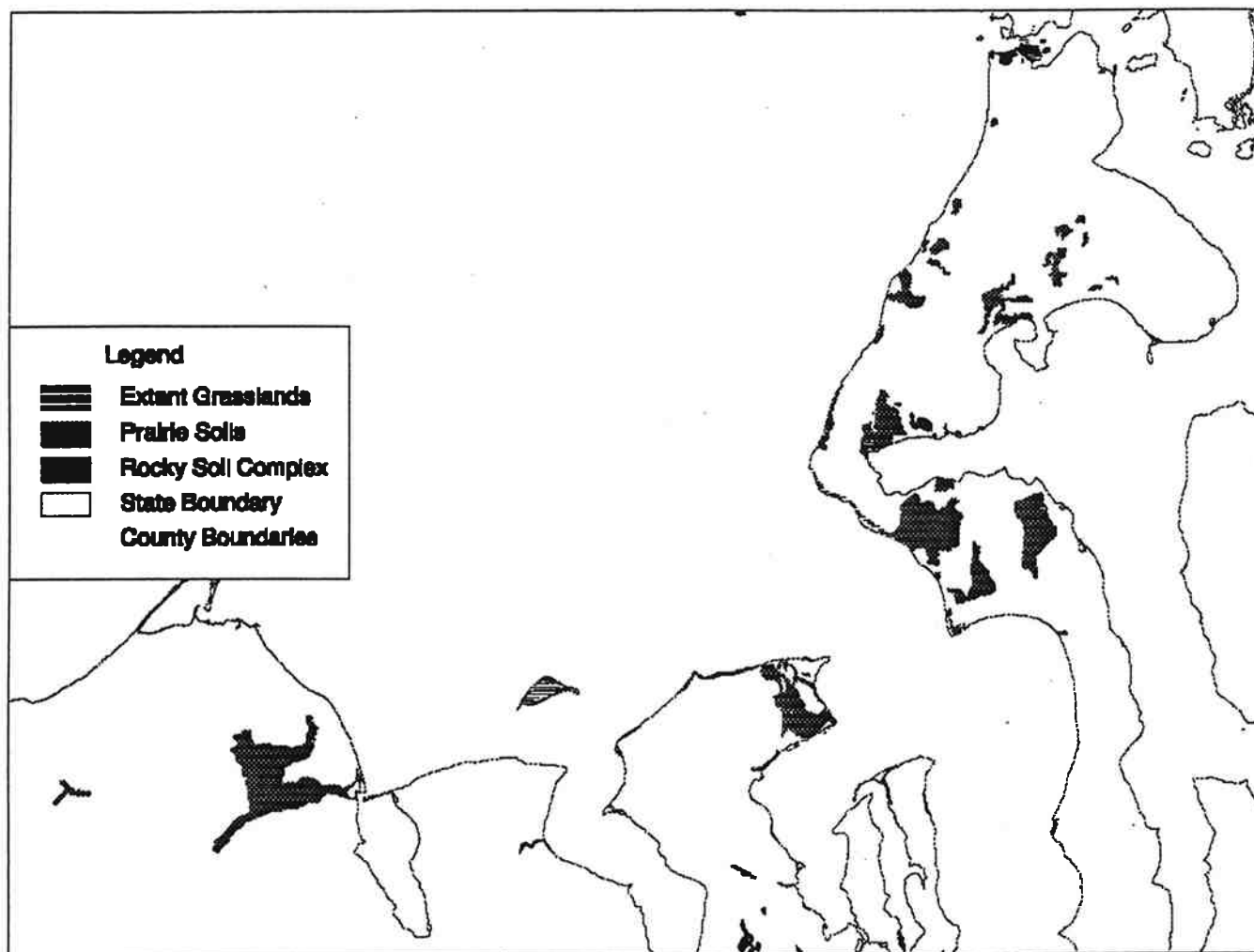


Figure 6. Pre-settlement grassland soils and extant grasslands (native, semi-native, non-native, and unsurveyed) on portions of Whidbey Island and the northeastern Olympic Peninsula, Island, Jefferson, and Clallam counties.

contributed to these differences, though, was minimum map unit size. Oak canopies tended to have smaller polygon sizes in part because the minimum map unit for them was smaller than for grasslands.

Because oak woodlands were mapped based on canopy characteristics regardless of understory conditions or land use, a substantial, but currently un-quantified, percentage of the oak canopies are located on urban or suburban residential land. The vast majority of the scattered oak canopy cover type is located on urban or agricultural lands. Anecdotal observations suggest that even in rural areas, a disproportionate percentage of oak woodlands appear to be chosen as housing sites. For these reasons, the total mapped areal extent of oak

canopies is probably an overestimate of functional habitat for other native plants and wildlife.

The most extensive mapped cover type, oak-conifer forest or woodland canopy, is also perhaps the most threatened with near-term loss. Ecological succession in the absence of fire often leads to invasion of oak woodlands by conifers and likely results in the eventual conversion of the oak community to a conifer forest (Sprague and Hansen 1946, Franklin and Dyrness 1973, Kertis 1986, Salstrom 1989, Agee 1993). The majority of the existing oak-conifer cover type is so far along this successional trajectory that conifers threaten to soon dominate. Most of these mixed oak stands are

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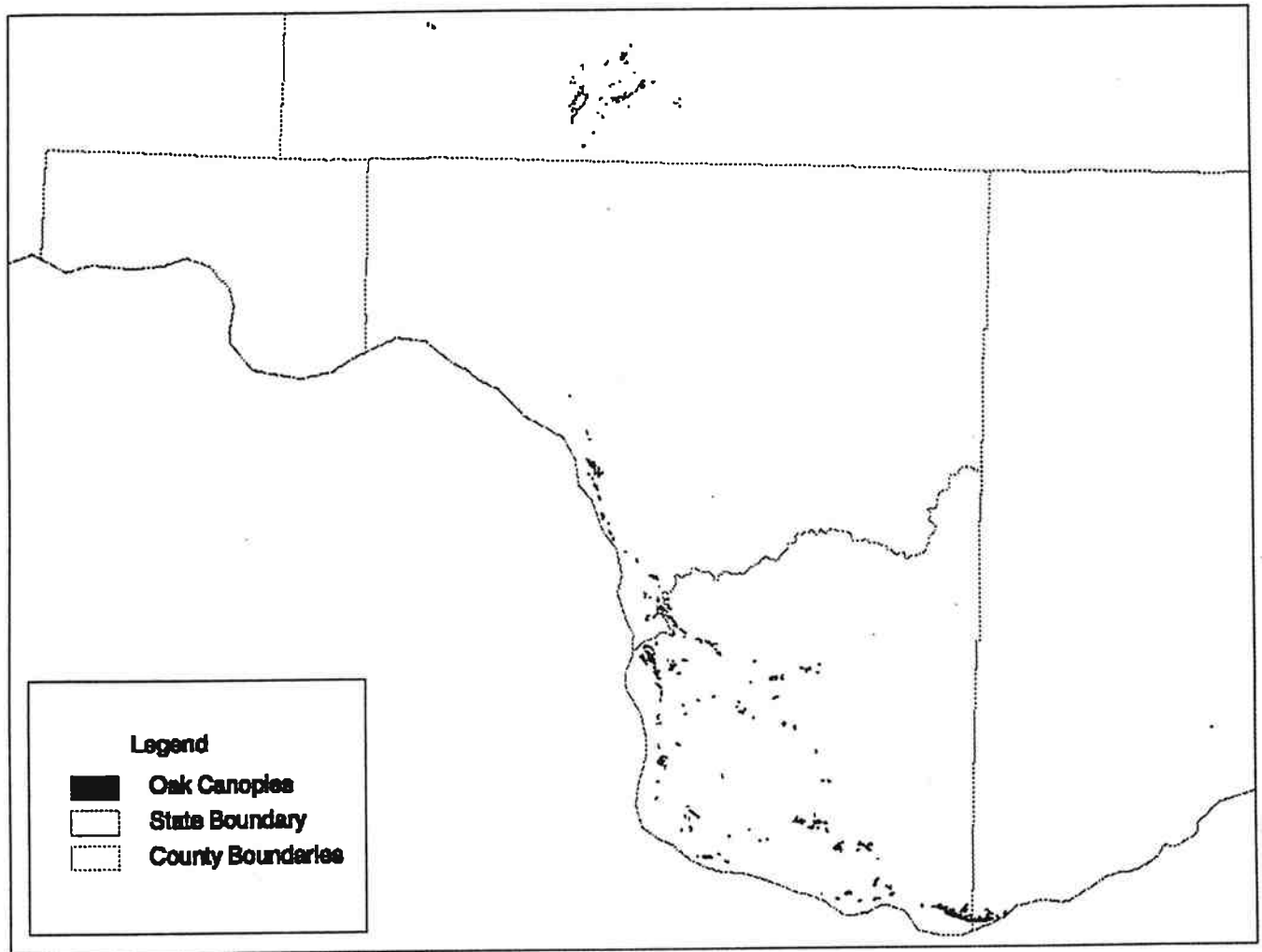


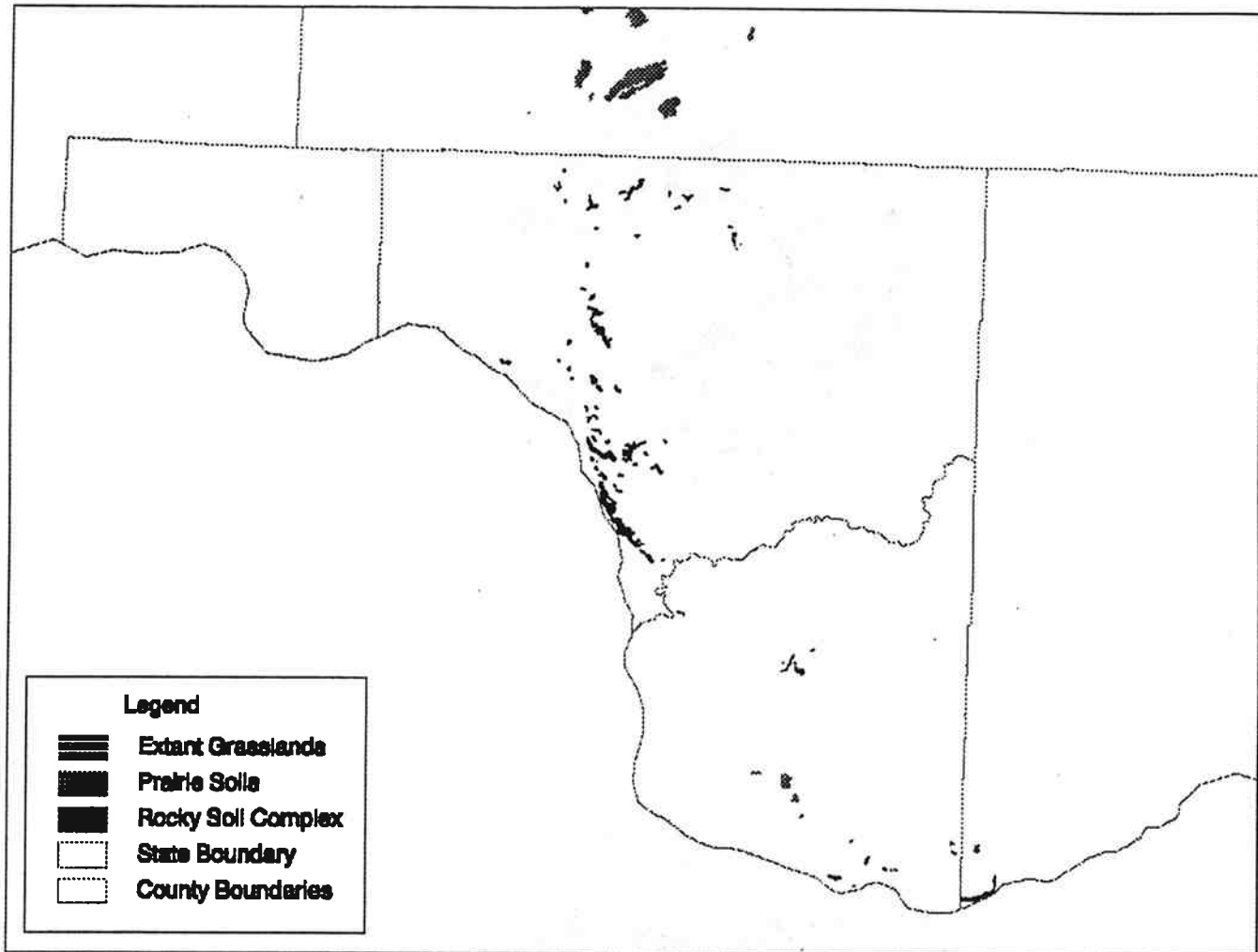
Figure 7. Existing oak canopies (oak-dominant, oak-conifer, and scattered oak) in the southern Puget Lowland and northern Willamette Valley, Clark, Cowlitz, Lewis, and Skamania counties.

likely to be lost without major restoration actions (see Hanna and Dunn 1997).

The majority of the shrublands mapped on prairie soils were dominated by Scot's broom (*Cytisus scoparius*). Our estimate, as of the time of mapping, is that 1% of pre-settlement grasslands are dominated by shrubs. Scot's broom is of particular concern as a non-native species that readily invades even good condition native prairies and alters their structure and composition dramatically (Parker 1996, Parker et al. 1997). Some areas dominated by broom or other shrubs have the potential to be restored to semi-native condition, as

evidenced by ongoing restoration activities at several sites in the southern Puget Sound area.

A comparison of the pre-European settlement grasslands with existing grasslands illustrates that there are significant geographic areas of pre-settlement grasslands that are functionally extirpated. These areas of local extirpation include the Cowlitz-Newaukum glacial deposits of central Lewis County, the Sifton soils of Clark County, central Whidbey Island prairies, and the Sequim prairie of Clallam County. Intensive restoration is about the only tool at our disposal for biodiversity management of grassland ecosystems in these areas.



**Figure 8.** Pre-settlement grassland soils and extant grasslands (native, semi-native, non-native, and unsurveyed) in the southern Puget Lowland and northern Willamette Valley, Clark, Cowlitz, Lewis, and Skamania counties.

Our maps highlight the tremendous ecoregional significance of the south Puget Sound prairies to the larger picture of biodiversity conservation in the state and globally. This is really the only area where there remains relatively large areas of grassland and oak woodland.

Beyond the south Puget Sound area, other conservation opportunities for these imperiled plant communities are highlighted by the map of existing grasslands and oak woodlands. Some of these include the numerous small grasslands and oak woodlands remaining in the San Juan archipelago, and the oak woodlands of the Chehalis River valley, in the vicinity of Cowlitz Prairie

and Lacamas Creek in Lewis County, near Kalama in Cowlitz County, and east of Washougal in Clark and Skamania Counties.

Our estimate of the decline of grasslands to about 9% of pre-European settlement areal extent (91% loss) is a conservative estimate of loss or decline because it is based primarily on soils that were very developed with extensive grass cover for long periods of time. Smaller or more ephemeral pre-settlement grasslands and savannas on less altered soils are not represented in our estimate, and if mapped, would result in a larger percentage decline or loss than we portray here.

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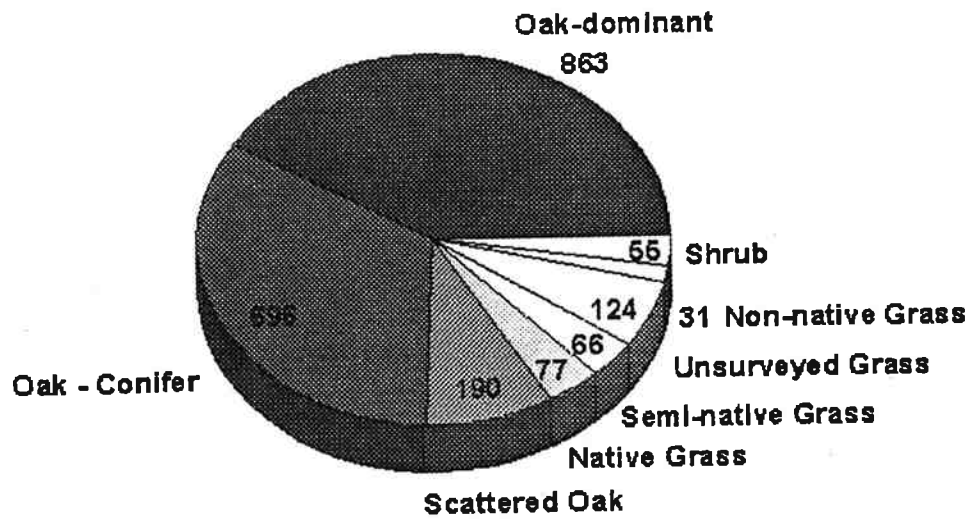


Figure 9. Total number of existing oak canopy and grassland polygons mapped in the study

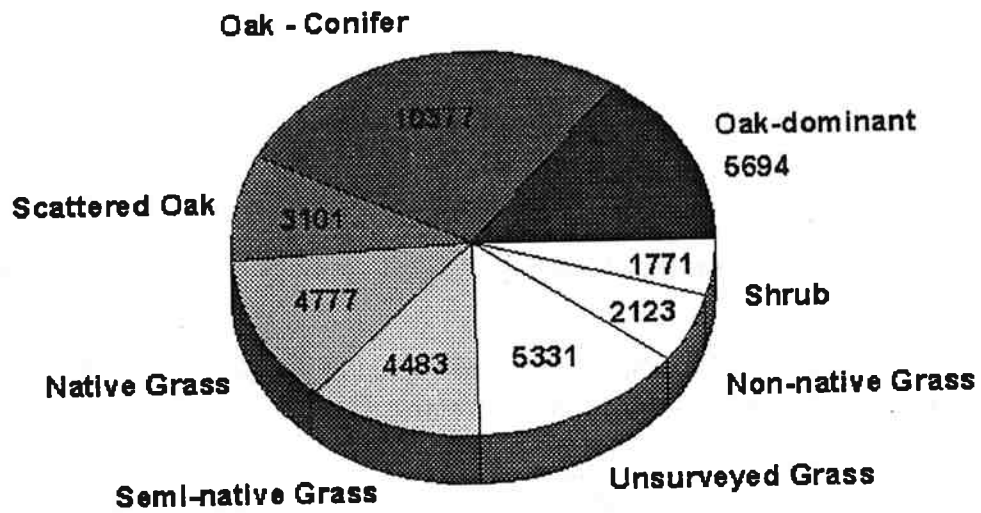


Figure 10. Areal extent in acres of existing oak canopy and grassland cover types mapped in the study area.

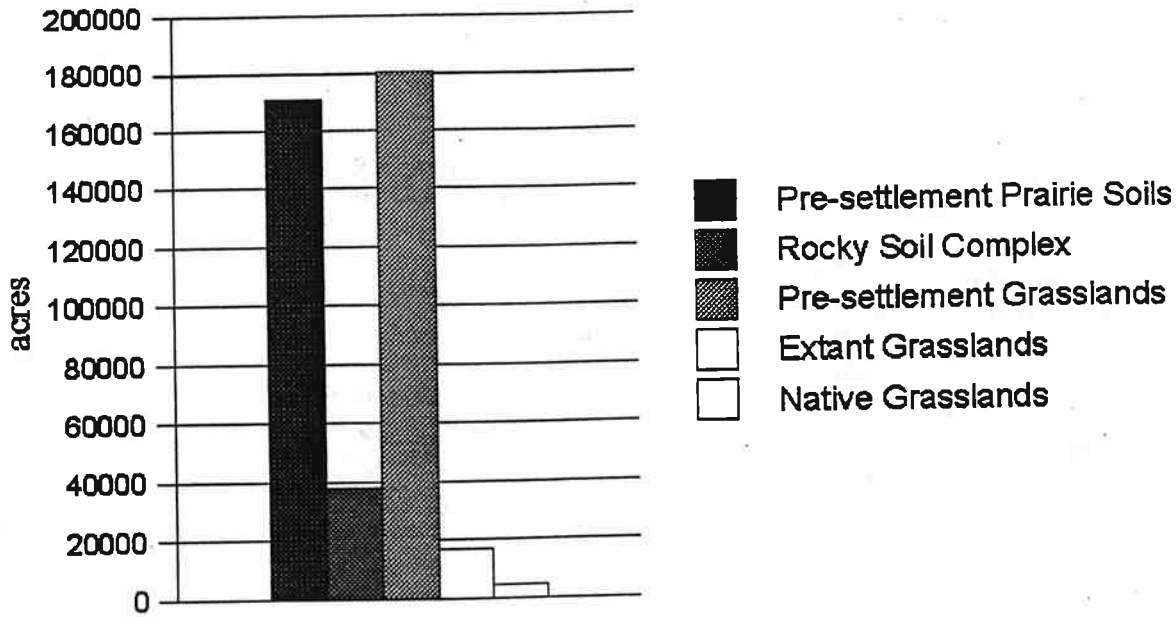


Figure 11. Areal extent in acres of pre-settlement grassland soils, estimated pre-settlement grasslands, extant grasslands, and native grasslands. Pre-settlement grasslands include bald grasslands that occur on rocky soil complex, as well as prairies (see text).

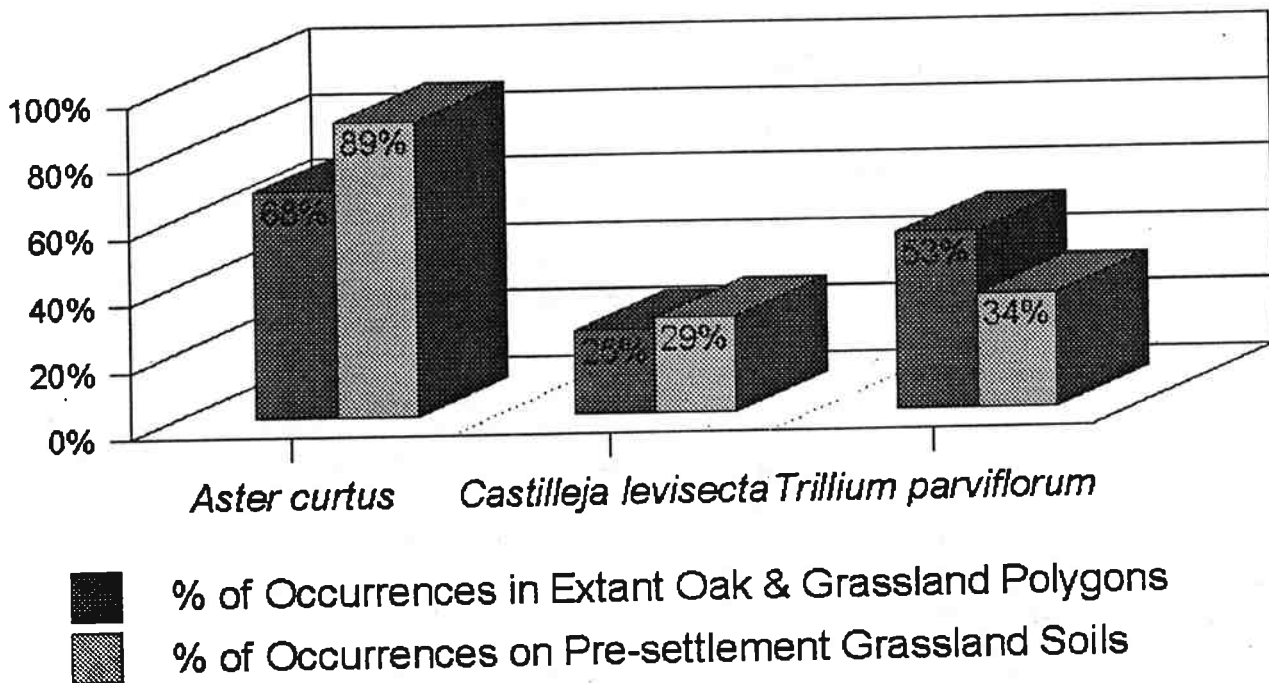


Figure 12. Co-occurrence of selected rare plant species with oak canopies and extant and pre-settlement grasslands.



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Our estimates of grassland decline in these ecoregions appear quite similar to those of Crawford and Hall (1997), who made a similar comparison for the southern Puget Sound area. They estimated 3% of pre-European settlement grassland extent remaining as good condition grassland, which corresponds approximately to our native grassland, and 8% in restorable condition, a combination of our native and semi-native grasslands. We found 2.6% of native grassland remaining (97.4% loss) and 5.1% of known restorable grassland (native and semi-native) remaining. The unknown in this comparison with Crawford and Hall's estimate is the unsurveyed grassland, which accounts for 3% of our pre-settlement grassland extent. Using our knowledge of historic land use patterns and locations of those unsurveyed grasslands, we consider it likely that the vast majority of them are non-native and semi-native grasslands. Proportionate loss of native and semi-native grasslands appears to have been slightly less in the southern Puget Sound area than in other areas of the Puget Lowland ecoregion (92% for the South Sound versus 95% for the entire ecoregion).

The strong co-occurrence of *Aster curtus* with existing and pre-European settlement grasslands is to be expected for a very local but fairly numerous ecoregional endemic (Clampitt 1993). The low level of co-occurrence of the rare grassland associate *Castilleja levisecta* with our mapped polygons is probably due to a small sample size (12 occurrences) combined with scale issues. Some of these occurrences probably occur on sites that are smaller than our minimum map unit. In addition, some of them occur in geographic areas that did not have any prairie soils mapped, indicating perhaps small and/or ephemeral grasslands that did not develop grassland soils or were not mapped as such because of their small size.

*Trillium parviflorum* is known to occur in moist, riparian or wetland oak woodlands (Washington Department of Natural Resources 1999) and therefore the co-occurrence of about half of the populations with oak canopies is to be expected. Interestingly, 34% of *T. parviflorum* populations also intersected prairie soil polygons, even though it is a forest species. There are two possible explanations for this apparent anomaly. Riparian forested areas are often not mapped as separate soil units from their surrounding matrix soils in the soil surveys. Because the trillium tends to occur in riparian oak and ash woodlands within prairie landscapes, some

of the smaller riparian areas where it occurs would therefore have been mapped as prairie soils. In addition, some populations of the species possibly could have expanded onto prairie soils from forested riparian areas or wetlands as succession in the wake of fire suppression resulted in forest establishment on former prairies.

The map of existing cover types raises interesting possibilities and needs for future inventory of both native plant communities and rare plant and animal species. For example, over 5000 acres of grasslands have not been field surveyed for their ecological condition. These areas, as well as other cover types mapped as part of this project, could provide fertile ground for inventories for species of concern associated with these community types.

Clearly, our results reinforce the importance of protecting and restoring what little remains of the oak woodlands and grasslands of western Washington.

The GIS ARCINFO cover of existing grasslands and oak woodlands is available for distribution to interested parties involved in research, conservation, or land use planning. Contact Steve Farone, Washington Natural Heritage Program, Wash. Dept. of Natural Resources, P.O. Box 47016, Olympia, WA 98504-7016.

### ACKNOWLEDGEMENTS

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R. & G. Gilbert?

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