APPLICATION OF THE EDYS MODEL TO EVALUATE CONTROL METHODS FOR INVASIVE PLANTS AT YAKIMA TRAINING CENTER, WASHINGTON

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14. ABSTRACT
SERDP project CS1145 explored alternative control and assessment strategies for knapweeds and annual brome, two non-indigenous plant taxa, on US military installations. These plant taxa infest large areas of the Western United States and they are a major concern for military bases. Heavy maneuvering of troops and equipment causes large disturbances where native vegetation is stressed, soil is lost, and invasive noxious plants often take hold. Replacing stands of noxious weeds with native plant communities on military training grounds will reduce soil erosion and create more sustainable ecological systems. Non-indigenous invasive plants can also reduce and destroy forage for livestock and wildlife, displace native plant species, increase fire frequency, reduce recreational opportunities, and can poison domestic animals. It is imperative to find economical, ecologically sound methods to control these weeds to minimize control costs and degradation of military training grounds.

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1.0 SUMMARY

This section of the final report presents the results of the simulation modelling portion of the overall project designed to evaluate various methods of control of cheatgrass and knapweed at the Yakima Training Center (TC), Washington. The field experiment portion of the project tested the effectiveness of various control methods on these two invasive species over a 4-year study period. The purposes of simulation modeling were to 1) evaluate the long-term effects of the control methods by projecting the results of the field experiments over a 50-year period, 2) provide a tool by which the interactions among the various control methods could be evaluated, and 3) determine the effects that variations in environmental factors (e.g., precipitation, grazing, military training) might have on the experimental results. Simulation modeling is the only effective method of evaluating experimental results over longer periods of time and of efficiently evaluating expected responses to relatively large numbers of variations in environmental factors.

The simulation modeling for this project was conducted using the EDYS ecological model. EDYS is a PC-based, mechanistic model that provides a powerful tool for evaluating ecological responses to a wide variety of natural and anthropogenic stressors over time, on spatial scales ranging from small plots to large landscapes and watersheds. EDYS has been applied to over 40 ecological communities within deserts, forests, grasslands, shrublands, wetlands, and highly disturbed areas. The objective of this EDYS application was to evaluate long-term ecological responses to a set of management options experimentally tested at Yakima TC to control two invasive species and to project rates and patterns of vegetation recovery through secondary succession.

Our first step was to validate the EDYS model for this site. This was done by parameterizing the model for the initial conditions at the beginning of the field experiments, simulating the changes in the vegetation over the four-year experimental period, and then comparing these simulation results to data from the field experiments. Following this validation procedure, 50-year simulation runs were conducted to evaluate long-term responses to the control methods. Effects of variations in environmental and management factors were then simulated to estimate how these factors might impact the control of cheatgrass and knapweed and the recovery of the native vegetation.

The field experiments were applied to two sites at Yakima TC, and EDYS was applied to these same two sites. One site was dominated by cheatgrass and the other was a big sagebrush community that had been invaded by knapweed and cheatgrass. The first site was designated the brome site and the second site was designated as the knapweed site. Each site consisted of a 4000 m^2 treatment area, divided into 40 10 m x 10 m treatment plots. The EDYS footprint consisted of 40 cells at each of the two sites, each cell corresponding to a treatment plot. Twenty plant species were included in this application, along with the four treatments (prescribed fire/biological control, seeding to native and introduced perennial species, application of sugar, and microbial application). The four treatments were modeled as single factors and each of the combinations used in the experimental study. A control (no treatment applied) was included for each site. In addition to the treatments, natural ecological stressors (precipitation fluctuations, natural fire, intra- and inter-specific competition, ecological succession, natural herbivory by insects and rabbits, and livestock grazing) and military training (tracked and wheeled vehicles) were also included as environmental factors.

Two species, cheatgrass and tumblemustard, comprised almost all of the biomass at the brome site. Mean overall accuracy of the 4-year EDYS simulations at the brome site, compared to the

experimental results, was 89% for cheatgrass and 88% for total biomass. Accuracy for tumblemustard was lower (62%). At the end of the four-year simulation, cheatgrass was the dominant species in all plots, regardless of treatment. This was also the case in the field experiment. These validation results indicate that EDYS was successful in simulating the vegetation dynamics at the brome site.

EDYS was then used to simulate vegetation dynamics at this site over a longer period of time (50 years). These simulations indicated that under control conditions (i.e., no treatments), the cheatgrass site would become dominated by big sagebrush and rabbitbrush after 50 years. These simulations also indicated that the fire, sugar, and microbial treatments, as applied in the field experiments alone and in combination, had no long-term affect on secondary succession at this site. This may have been the result of the short-term application of the treatments. Fire was applied only in the first year, microbial inoculation was applied two years, and sugar was applied only for four years. The seeding treatment, however, did have a long-term affect on secondary succession. Based on the simulations, seeding with native and introduced perennial grasses resulted in a grass-dominated community at the end of 50 years, rather than a shrub-dominated community without seeding.

At the knapweed site, diffuse knapweed declined dramatically in all of the experimental plots in 2001, regardless of treatment. By the fourth year of the experiment, knapweed remained very low in all treatments, compared to initial conditions. Over the four-year experimental period, big sagebrush and perennial grasses increased under most treatments, and cheatgrass increased on half the treatments and decreased on half. When averaged over all plots and all treatments, cheatgrass was the most abundant species in 2003, with a mean aboveground biomass of 30 g/m^2. Big sagebrush averaged 9 g/m^2 and perennial grasses averaged 27 g/m^2.

The 4-year EDYS simulations produced similar results. Knapweed declined dramatically, as it did in the experimental study plots, and cheatgrass became the most abundant species at the site. Perennial grasses were the second most abundant group, followed by big sagebrush. As in the experimental study, each of these three groups of plants (cheatgrass, perennial grasses, and big sagebrush) increased in 2003 compared to initial conditions. Fourth-year accuracy varied among species, with values for the major species ranging from 52% for Sandberg bluegrass to 100% for bluebunch wheatgrass. Accuracy for total aboveground biomass in the fourth year was 93%.

The EDYS simulations resulted in cheatgrass becoming the most abundant species by the fourth year in all treatments except the sugar treatment, which was dominated by perennial grasses. This was similar to the experimental results. Therefore, the model accurately simulated the overall treatment responses. At the end of the 50-year simulations all treatments converged to a big-sagebrush community, with a strong perennial grass component. As at the brome site, the treatments had some initial influence on successional development, but these differences were no longer present after 50 years.

Herbivory, by insects and rabbits, significantly reduced biomass on the brome site. The densities for these herbivores may have been too high in the simulations (3 grasshoppers/m^2 and 0.3 rabbits/ha). Because only two species were present initially (cheatgrass and tumblemustard), grazing pressure on seedlings of other species was very high. On the knapweed site, herbivory caused a decline in total biomass over 50 years. In Year 50, total aboveground biomass was reduced 88% with light rabbit and insect herbivory, 92% with moderate herbivory, and 96% with heavy herbivory. Big sagebrush biomass was reduced to almost zero at all herbivore densities, when without herbivory it was the dominant species by Year 20. Rubber rabbitbrush became the dominant species, with herbivory, although biomass was low. Thus, herbivory at the densities modelled with EDYS will decrease total production and change species composition.

When light cattle grazing was included in the EDYS simulation, minor decreases were observed in plant biomass in the brome and knapweed communities. Grazing did affect long-term community dynamics in both sites, however. In the both sites, by Year 50, rabbitbrush was the dominant species, with Russian knapweed becoming second in dominance. The moderate grazing simulation resulted in 75% less biomass than in the ungrazed simulation in the brome site and the community changed from cheatgrass-tumblemustard dominated to rabbitbrush-Russian knapweed dominated. The heavy grazing simulation resulted in an 80-85% reduction in biomass, compared to no grazing. The composition of the community with heavy grazing also changed, from the originally cheatgrass-tumblemustard dominated to one dominated totally by Russian knapweed. Heavy grazing greatly decreased rabbitbrush biomass. For the knapweed site, the moderate and heavy grazing simulations did not produce substantial changes with respect to the light grazing simulation. The total production at the end of the 50-year simulation was nearly identical, irrespective of the level of grazing. This was because the remaining species (rabbitbrush and Russian knapweed) were not consumed by livestock.

When impacts of military vehicles were included in the model, total aboveground biomass was reduced and vegetation composition was affected. If the vehicle use occurred only early in a 50-year simulation, vegetation biomass was reduced in the five or so years following the disturbance. In the long-term, however, the vegetation recovered and was similar to an undisturbed community. In undisturbed communities, shrubs were the major species at the end of 50 years, while in sites impacted by military vehicles every five years needle-and-thread was the dominant species at the brome site and only a small amount of big sagebrush was left on the knapweed sites. These results show that if the system is impacted by vehicles, vegetation will be negatively impacted and species composition will be different from an undisturbed community. The long-term results depend on how often the community is disturbed.

These modeling results suggest that over relatively short periods of time (< 10 years), some of the treatments may provide methods of reducing cheatgrass. This is especially true for reseeding and application of sugar. However, over longer periods of time (> 20 years) and in the absence of further disturbance, these sites will revert to a big sagebrush-perennial grass community, given similar precipitation patterns as have occurred in the area over the past 50 years. None of the treatments, except reseeding, had a measurable effect on this successional pattern in the long-term. Reseeding with perennial grasses had the long-term effect of increasing perennial grasses and decreasing shrubs. Impacts by rabbit, insect, and cattle grazing and by military vehicle training will negatively impact vegetation biomass and species composition. The degree of impact is dependent upon the density of herbivores and frequency of training.

2.0 INTRODUCTION

The establishment of non-native invasive species on disturbed lands that were previously dominated by native plants, and the long-term dominance of these sites by these invasive species, are the results of interactions among a number of ecological and management factors. Likewise, the successful control of these invasive species and re-establishment of the native plant communities also involves complex ecological interactions over time. The challenge of successful re-establishment is further complicated by variations in management and climatic scenarios that a site might be exposed to over the period of re-establishment.

Field experiments are important for the purposes of testing concepts and refining methodologies relative to control of invasive species and the re-establishment of native plant communities. Without field experimentation, revegetation would be based entirely on trial and error. However, the usefulness of field experimentation is limited, in part, by 1) the relatively short time periods that they are conducted over and 2) the environmental conditions that occurred during the experimental period. The cost of field experiments increase the longer the experiments are conducted and the more environmental variations that are included in the design.

Simulation modeling provides one method of addressing the limitations of field experiments. When combined with field experiments, simulation modeling can be used to evaluate the results of the field experiments over longer periods of time and under many more variations of environmental factors than are practical with field experiments. Successful simulation modeling is a two-step process. First, the simulation model being used must be shown to be able to adequately simulate the results of the field experiments. Otherwise, there is little reason to have confidence in the results of the model relative to longer-term responses and variations in environmental factors. Once this validation process is accomplished, the second step of applying the model to longer-term responses and variations in environmental factors can be implemented.

The simulation model used in this project is the EDYS (Ecological DYnamics Simulation) model. EDYS is a PC-based, mechanistic, spatially explicit, and temporally dynamic simulation model (Childress and McLendon 1999, Childress et al. 1999a, 1999b). It simulates changes in soil, water, plant, animal, and landscape components resulting from natural and anthropogenic ecological stressors (McLendon et al. 1999a, Childress et al. 2001). EDYS has been applied to a wide variety of ecosystems, management scenarios, and disturbance regimes in Arizona, California, Colorado, Maine, Montana, Nevada, New Mexico, Texas, Utah, Washington, Wyoming, Australia, and Indonesia (McLendon et al. 1996, 1999a, 1999b, 1999c, 2000a, 2001, 2002), Ash and Walker (1999), and Chiles and McLendon (2004).

At Yakima Training Center (TC), EDYS was applied first to the 4-year experimental study to determine its potential for simulating the observed experimental responses in the plant communities. EDYS was then used to evaluate the relative impacts of 5 natural ecological stressors and 7 management options on the vegetation dynamics of the two experimental sites over a 50-year period. This report presents details of the EDYS application at Yakima TC, including parameterization values, source references, and simulation results.

3.0 GENERAL DESCRIPTION OF EDYS

This section presents a broad over-view of the EDYS model. More detailed presentations are available in Childress and McLendon (1999) and Childress et al. (1999a, 1999b, 2001).

3.1 EDYS Modules

EDYS consists of Climate, Soil, Hydrologic, Plant, Animal, Stressor, Spatial, Landscape, and Management modules. Climatic inputs can be historical or stochastically generated, or a combination of both. The Soil Module is divided into layers (horizons, subhorizons, or artificial layers), the number, depth, and physical and chemical characteristics of which are site-specific for each application. The Hydrologic Module provides for infiltration and water movement through the soil profile, surface movement of water, surface erosion, sediment movement, subsurface movement of water, and changes in water quality (Figure 1).

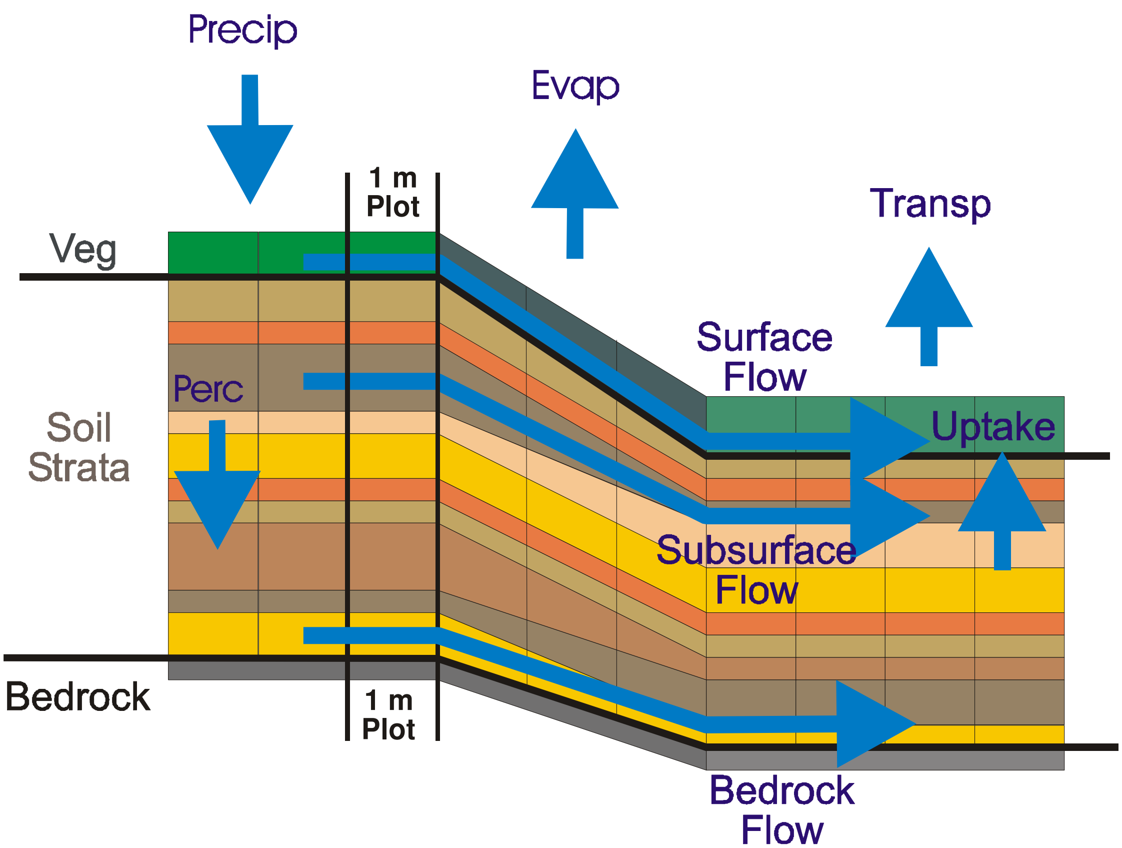

Figure 1. Hydrological Dynamics in the EDYS Landscape Module

The Plant Module includes above- and belowground components for each species included in each user-defined suite (Figure 2).

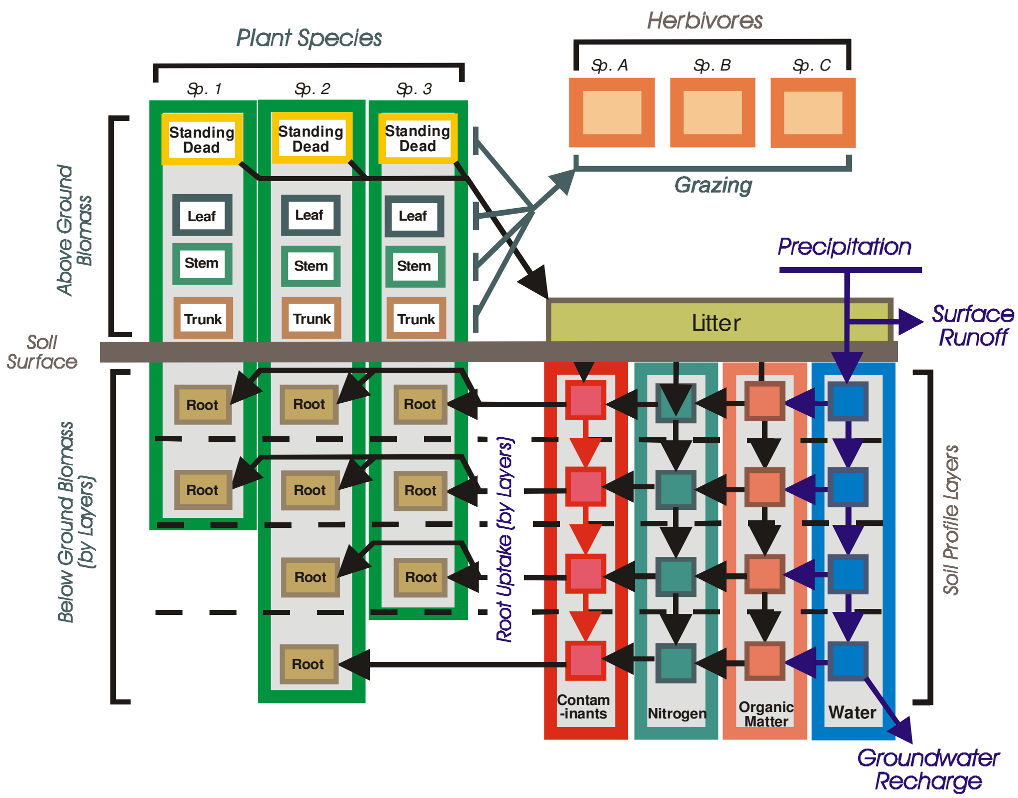

Figure 2. EDYS Plot-Level Structure

Plant growth is dynamic in relation to plant components (roots, trunk, stems, leaves, seeds, and standing dead), season, resource requirements (water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (preferences, utilization potential, competitive success) for each species (e.g., insects, rodent, native ungulates, livestock). The Stressor Module includes drought, nutrient availability, fire, herbivory, trampling (foot and vehicle), contaminants, shading, and competition (soil moisture, nutrients, food). The Spatial Module allows growth of individual plants (e.g., trees) and distribution patterns (e.g., colonies, fire patterns, soil heterogeneity) to be explicitly represented in the simulations. The Landscape Module (Figure 3) allows for multi-scale simulations: fine scale (1 m^2 or smaller), patches (e.g., 100 m^2), communities (e.g., 1-10 hectares), and landscapes and watersheds (1 km^2 and larger). Time intervals vary from day (e.g., precipitation events, plant water demand, fire, herbivory), to month (e.g., species composition), to year and longer (e.g., climatic cycles).

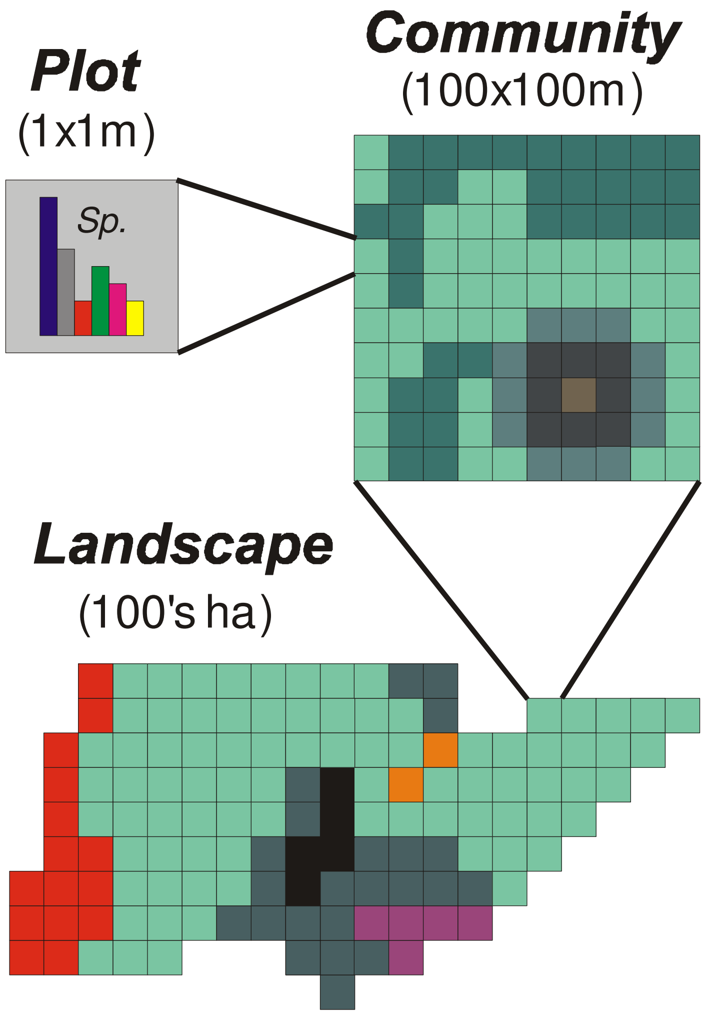

Figure 3. Scaling of the Plot, Community, and Landscape Modules in EDYS

3.2 EDYS Simulation Outputs

Each simulation run of EDYS produces a large volume of data for all state variables (e.g., plant biomasses, soil water and nutrient contents, total surface runoff) and processes (e.g., water and nutrient transport and balances, plant production). These data are stored in a series of large text tables, typically on a monthly basis. Many of these data are also presented in graphical displays at the end of the simulation run (e.g., Figure 4).

These extensive output files serve a number of useful functions. These data are required for accurately testing and calibrating the EDYS application for particular communities and sites. In addition, these data can be sent in "real time" to other models running simultaneously.

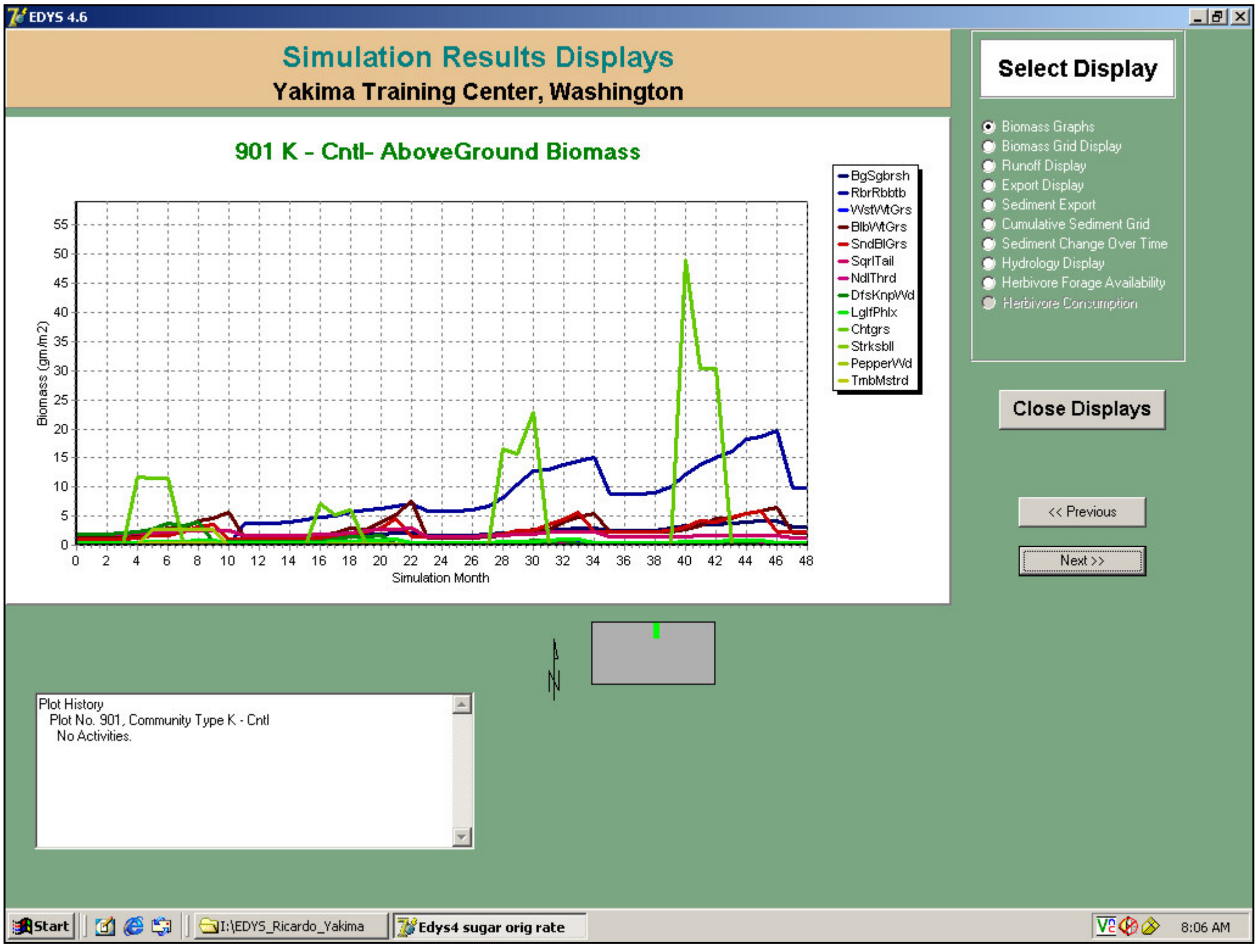

Figure 4. Monthly Aboveground Biomasses of Plant Species in a 4-yr Simulation Run of the Knapweed Community at Yakima Training Center

Among the various outputs produced in each EDYS simulation run are tables describing water pools and dynamics as well as summary graphical displays of total landscape runoff and export (Figure 5). These outputs allow projection of the effects of different climatic regimes, ecological stressors, vegetation dynamics, and management practices on surface and subsurface water quantity and quality.

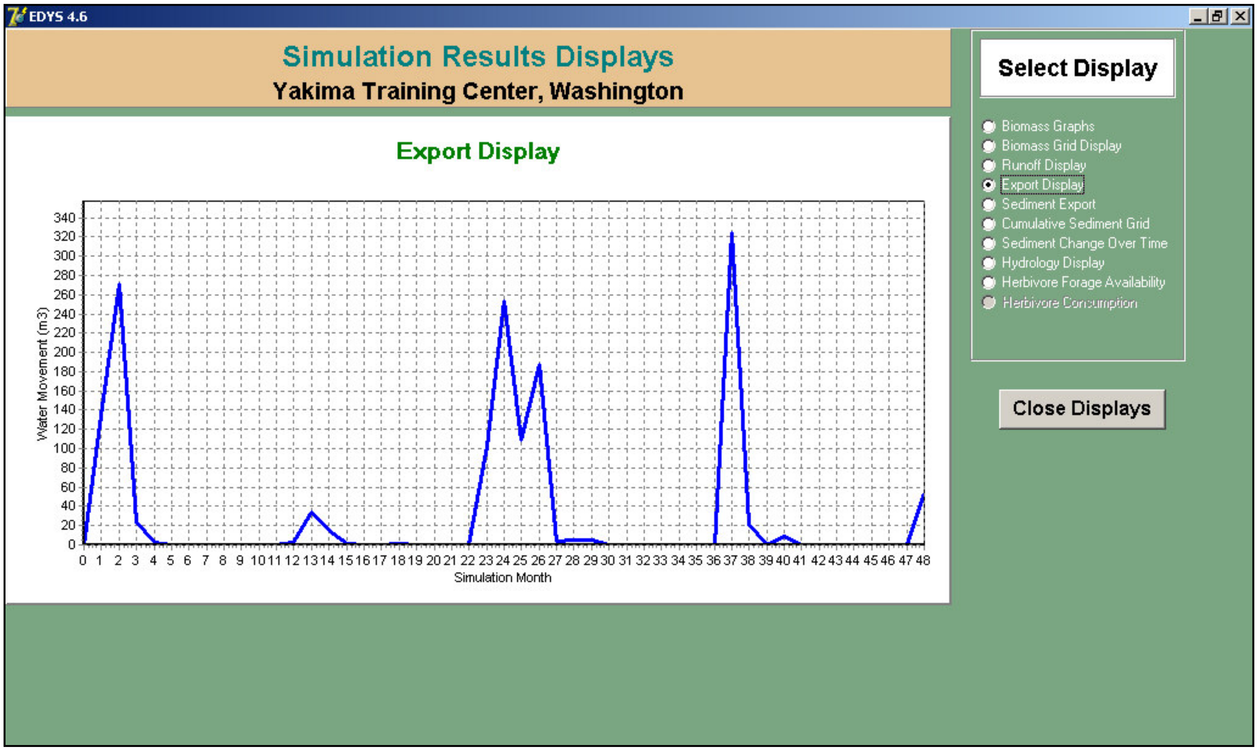

Figure 5. Projected Subsurface Export from the Knapweed Community at Yakima Training Center

4.0 YAKIMA LANDSCAPE

Yakima Training Center (YTC) is a 1295 km^2 military training facility located in the Yakima and Kittitas counties of eastern Washington. YTC is one of the largest remaining pieces of shrub-steppe habitat in the state. However, large expanses of cheatgrass are present as well. The landscape selected for this EDYS application consisted of two study sites, each 4,000 m^2 in size. The first site, dominated by cheatgrass (*Bromus tectorum* L.), is located at the eastern edge of Training Area 4, on an upper terrace of the Columbia River floodplain. The second site, a sagebrush community invaded by both diffuse knapweed (*Centaurea diffusa* Lam.) and cheatgrass, is located in Assembly Area 1.

4.1 Climatic Data

A 56-year daily precipitation file for the landscape was created using existing precipitation data from Yakima Air Terminal/McAllister Field Airport (Latitude 46°34'N, Longitude 120°32'W). The 56-year mean annual precipitation is 20.96 cm (8.25 inches). Annual totals are presented in Table 1 and average monthly values are presented in Table 2.

Table 1. Annual precipitation totals (cm) used in the Yakima Landscape EDYS application

Year	Total (cm)	Year	Total (cm)	Year	Total (cm)	Year	Total (cm)
1948	32.11	1962	18.95	1976	10.62	1990	15.65
1949	11.51	1963	20.75	1977	20.12	1991	19.33
1950	29.69	1964	19.18	1978	20.37	1992	21.62
1951	26.01	1965	15.11	1979	17.40	1993	15.04
1952	15.49	1966	20.32	1980	28.63	1994	19.69
1953	21.31	1967	11.48	1981	21.97	1995	35.26
1954	16.48	1968	24.03	1982	27.64	1996	37.54
1955	28.52	1969	17.63	1983	33.58	1997	17.48
1956	19.33	1970	20.32	1984	22.91	1998	21.06
1957	27.84	1971	19.94	1985	14.99	1999	15.24
1958	21.11	1972	18.62	1986	22.94	2000	21.49
1959	15.42	1973	22.78	1987	21.01	2001	23.90
1960	19.28	1974	20.83	1988	13.84	2002	16.66
1961	25.25	1975	22.43	1989	17.50	2003	18.75

Table 2. Monthly precipitation totals (cm) for the Yakima Landscape, averaged over a 56-year period.

Month	Average (cm)	Standard Deviation
Jan	3.30	2.17
Feb	2.08	1.44
Mar	1.67	1.39
Apr	1.38	1.18
May	1.41	1.26
Jun	1.62	1.57
Jul	0.55	0.57
Aug	0.74	1.10
Sep	0.97	1.06
Oct	1.37	1.30
Nov	2.62	1.96
Dec	3.24	2.63

4.2 Spatial Data

A 10 m x 10 m cell size was used in this application. For each study site, 40 cells were included in the landscape mosaic. A uniform elevation throughout the landscape was assumed because impacts of the treatments were being analyzed on a small scale.

4.3 Edaphic Data

Three soil series were used in the EDYS application (Table 3), based on NRCS soils maps for the area. The knapweed control site and the knapweed treatment site are located about 24 km from each other and, thus, have different soil types. The brome control and treatment sites were located next to each other and, therefore, have the same soil type. Physical data for the soil series were taken from the NRCS Soil Survey for Yakima County listed on the NRCS web site. Organic matter and soil nitrogen (total and available) data were compiled from soil profiles listed in Soil Survey Staff (1975). Specifics for each soil series are presented in Appendix 1.

Table 3. Soil series used for each of the four topographic units for the Yakima Landscape EDYS application.

Topographic Unit	Soil Series
Knapweed Control Plots	Vantage-Benwy-Argabak Complex
Knapweed Treatment Plots	Selah Silt Loam
Cheatgrass Control Plots	Esqutzel Silt Loam
Cheatgrass Treatment Plots	Esqutzel Silt Loam

In EDYS, initial values are entered for each of the soil variables, for each soil series. These are the values that appear in Appendix 1. Values for each of these variables can change during a simulation run, depending on the dynamics of environmental conditions. For example, organic matter content in a given layer will decrease daily because of decomposition, but may also increase daily because of organic matter input from root death or from litter inputs. Nitrogen content will vary on a daily basis because of 1) plant uptake, 2) release from decomposition and mineralization, 3) downward transport through infiltration of soil water, and 4) inputs from atmospheric deposition. Depth of the surface layer may decrease because of erosion. Bulk density may increase because of soil compaction from vehicle training.

4.4 Vegetation Data

4.4.1 Plant Species

The number of plant species included in an EDYS simulation is flexible and is specified in the initial parameterization. Regardless of how many species are selected, the suite remains a simplified representation of the actual vegetation, since some species are excluded. In order to account for overall community dynamics (e.g., total aboveground biomass), the ecological contribution of species not specifically included in the model must somehow be considered. This is accomplished in EDYS by using composite species.

In EDYS, a composite species consists of a major species plus those minor species most ecologically similar to the respective species. For example, *Descurainia sophia* is a relatively minor species at both Yakima sites, averaging less than 0.05 g/m^2 at the brome site and 0.01 g/m^2 at the knapweed site (averaged over 2000-2001). Ecologically, this species is similar to *Sisymbrium altissimum*, which is a major species at the brome site and a secondary species at the knapweed site. In EDYS, the biomass values for *D. sophia* are added to the values for *S. altissimum*. This allows for the simulated biomass totals at a site to be comparable to the sampled totals and allows for proper mass balance accounting for such components as litter, water use, and nitrogen dynamics. In effect, this estimates the responses of the minor species on the basis of the responses of their most similar major species.

Species occurring in minor amounts and that are not otherwise of primary ecological or management importance are included in a composite species for three reasons. First, there generally are very little ecological data available on minor species, therefore parameterization values used in the model for these minor species would simply be estimated from the data for the major species. Second, the more that estimated values are used, the more "noise" is entered into the simulation results. Third, adding more species increases the run times and the memory required for each simulation. These increases are acceptable if they result from a more accurate representation of the simulated system. However, these increases are not acceptable if the increase in complexity is the result of more, but inaccurate, data.

Field data collected in the study plots provided information on plant species to be used in this application. A total of 49 species were reported on the experimental plots in 2000, however, most of these 49 species occurred in very low amounts. By eliminating the minor species, 20 plant species were chosen for the Yakima application (Table 4). Biomass values for the minor species were included in the total aboveground biomass for the respective composite species (Table 5). Of the 11 species recorded at the brome site in 2000, three accounted for 99% of the relative biomass (Table 6). Of the 31 species recorded at the knapweed site in 2000, 9 accounted for 85% of the relative biomass (Table 6).

Table 4. Twenty plant species selected for inclusion in the Yakima Landscape EDYS application.

Species	Common Name	Mean biomass (g/m^2) 2000-2001	Lifeform
Artemisia tridentata	Big sagebrush	3.05	Shrub
Chrysothamnus nauseosus	Rubber rabbitbrush	0.10	Shrub
Achnatherum hymenoides	Indian ricegrass	0.32	Perennial grass
Agropyron cristatum	Crested wheatgrass	1.18	Perennial grass
Elymus elymoides	Squirreltail	0.65	Perennial grass
Pascopyrum smithii	Western wheatgrass	0.44	Perennial grass
Poa secunda	Sandberg bluegrass	3.29	Perennial grass
Psuedoroegneria spicata	Bluebunch wheatgrass	4.03	Perennial grass
Stipa comata	Needle-and-thread	1.08	Perennial grass
Achillea millefolium	Yarrow	0.26	Perennial forb
Acroptilon repens	Russian knapweed	1.06	Perennial forb
Astragalus caricinus	Buckwheat milkvetch	1.41	Perennial forb
Centaurea diffusa	Diffuse knapweed	4.09	Perennial forb
Erigeron pumilus	Shaggy daisy	1.38	Perennial forb
Oenothera pallida	Evening primrose	0.40	Perennial forb
Phlox longifolia	Longleaf phlox	0.27	Perennial forb
Bromus tectorum	Cheatgrass	37.84	Annual grass
Erodium cicutarium	Storksbill	0.30	Annual forb
Lepidium perfoliatum	Pepperweed	0.49	Annual forb
Sisymbrium altissimum	Tumble mustard	8.40	Annual forb

Table 5. List of the 20 composite species, along with the species included in each composite species, used in the EDYS application for the Yakima landscape.

Composite Species	Included Species
Artemisia tridentata	*Artemisia tridentata, Artemisia rigida, Purshia tridentata*
Chrysothamnus nauseosus	*Chrysothamnus nauseosus, Chrysothamnus viscidiflorus*
Agropyron cristatum	*Agropyron cristatum, Agropyron fragile* ssp. *sibiricum*
Pascopyrum smithii	*Pascopyrum smithii*
Agropyron spicatum	*Psuedoroegneria spicata, Pseudoroegneria spicata* ssp. *inermis*
Acnatherum hymenoides	*Acnatherum hymenoides, Achnatherum robustum*
Poa secunda	*Poa secunda, Poa bulbosa*
Elymus elymoides	*Elymus elymoides*
Stipa comata	*Stipa comata, Aristida purpurea, Stipa lemmonii*
Achillea millefolium	*Achillea millefolium, Crepis atribarba, Lomatium triternatum, Senecio* sp.
Acroptilon repens	*Acroptilon repens, Chaenactis douglasii, Eriogonum strictum, Physalis virginiana, Pterogonum alatum*
Astragalus caricinus	*Astragalus caricinus, Astragalus speirocarpus, Lupinus bingenensis, Medicago sativa*
Erigeron pumilus	*Erigeron pumilus, Erigeron filifolius*
Oenothera pallida	*Oenothera pallida, Gayophytum decepiens, Artemisia ludoviciana* ssp. *ludoviciana,*
Phlox longifolia	*Phlox longifolia, Allium accuminatum, Asclepias pumila, Phlox gracilis* ssp *humilis, Triteleia grandiflora*
Bromus tectorum	*Bromus tectorum, Vulpia octoflora*
Centaurea diffusa	*Centaurea diffusa, Agoseris heterophylla, Conyza canadensis, Holosteum umbellatum, Matricaria recutita, Tragopogon dubius*
Erodium cicutarium	*Erodium cicutarium, Ceratocephala testiculata, Collomia grandiflora, Collomia linearis, Epilobium brachycarpum, Epilobium minatum, Lappula occidentalis, Linanthus septentrionalis, Phacelia linearis*
Lepidium perfoliatum	*Lepidium perfoliatum, Chorispora tenella, Draba verna, Kochia scoparia, Polemonium micranthum, Salsola kali*
Sisymbrium altissimum	*Sisymbrium altissimum, Descurainia pinnata, Descurainia sophia, Descurainia richardsonii, Lactuca saligna, Lactuca serriola*

Table 6. Relative biomass values (% mean composition) of individual species at the Yakima Training Center in 2000 and 2001.

Species	Brome Site		Knapweed Site	
	2000	2001	2000[a]	2001[a]
Bromus tectorum	66.9	88.6	30.1	32.2
Sisymbrium altissimum	29.3	4.4	1.5	0.4
Psudoroegneria spicata			9.4	21.2
Artemisia tridentata			8.0	10.4
Centaurea diffusa			14.0	3.7
Poa secunda			10.2	6.2
Erigeron pumilus			3.6	4.9
Astragalus caricinus			3.6	4.6
Agropyron cristatum	0.1	t	3.3	3.1
Acroptilon repens	2.5	3.9		
Stipa comata			2.9	3.4
Elymus elymoides			1.8	1.9
Achnatherum hymenoides			0.5	2.1
Eriodium cicutarium	0.1	2.2	t	0.1
Lepidium perfoliatum			1.6	0.6
Pascopyrum smithii			1.6	0.2
Achillea millefolium			0.7	0.9
Phlox longifolia			0.8	0.7
Oenothera pallida			1.5	
Poa bulbosa			1.1	
Artemisia ludoviciana			0.5	0.5
Stephanomeria paniculata			0.5	0.5
Tragopogon dubius	0.1	t	0.4	0.3
Chorispora tenella		0.7	0.1	t
Ceratocephala testiculata		t	0.1	0.6
Collomia grandiflora	0.9		0.2	0.5
Chrysothamnus nauseosus			0.4	0.1
Chaenactis douglasii			0.5	
Chrysothamnus viscidiflorus			0.3	t
Descurainia sophia	t	0.2	t	
Senecio sp.			0.2	
Kochia scoparia	t			
Eriogonum alatum	t			
Salsola kali	0.1	t	t	t

[a]Numbers may not add up to 100 because minor species were left off this list, but they still contributed to the total percent composition.

4.4.2 Parameterization Data

Parameterization data were supplied to EDYS in 26 parameterization matrices (Appendix 2). The values contained in these matrices were derived from several sources: 1) site-specific data collected from the Yakima experimental plots, 2) data from the scientific literature, 3) data from the MWH database, and 4) authors expert opinions.

4.5 Animal Data

Two native animal species were simulated in this application: insects (grasshoppers) and rabbits. Herbivory by insects and rabbits was assumed to be uniform throughout the study sites and was based on animal densities. Densities used for insects were 3, 6, and 12 individuals per square meter. Rabbits were simulated at densities of 0.30, 0.56, and 0.78 individuals per hectare.

4.6 Natural Stressors

Five natural stressors were included in this application: interspecific competition for belowground resources (water, nutrients), drought, nitrogen availability, fire, and herbivory by native animals (insects, rabbits). In EDYS, ecological responses by each plant species to each of these stressors are modelled by use of 1) supply and demand and 2) ecophysiological relationships defined by the parameterization matrices (Appendix 2). For example, successional patterns are simulated by changes in relative biomass of the species over time in response to the interaction of these stressors. This might function in the following manner. This might function in the following manner. If species A has a higher water use efficiency than species B, species A will produce a higher proportion of biomass than species B in dry years, provided an equal amount of water is available to both species. However, species B may have a different root architecture than species A, which allows species B to access the water in deeper soil layers unavailable to species A. Therefore, species B may be more "protected" from drought than species A because of its deeper root system. In addition, fires may be more frequent in dry years and species B may be better adapted to fire stress than species A. Both of these factors, deeper roots and better adaptation to fire, may provide species B with sufficient competitive advantage over species A to offset the higher water-use efficiency of species A.

Daily precipitation values are used based on the constructed historic data set (Table 1). These constitute the default precipitation level for the application. The values can be increased or decreased by the user to simulate above-average precipitation or drought. Nutrient content, primarily nitrogen content, is set by the soil content of the soil series and each soil layer may vary. The default frequency for natural fire is monthly. Its occurrence and spread are based on appropriate fuel load, moisture content, and stochastic factor.

4.7 Management Scenarios

Management scenarios include optional values for those factors directly influenced by human activities. Seven management options are included in this application: 1) introduction of knapweed seedhead weevil and root-boring beetle (knapweed site only), 2) seeding of native and introduced perennial grasses and one forb, 3) prescribed fire (brome site only), 4) sugar application, 5) microbial inoculation, 6) livestock grazing, and 7) military training (tracked vehicles, wheeled vehicles).

4.8 Model Implementation of Treatments

Knapweed seedhead weevil and root beetle treatment was modelled by simulating the impact of both insects on plant parts (i.e., seeds and roots). To apply this treatment, the start month and year are selected to simulate introduction of the insects. Frequency of infestation must also be designated. Because these insects will spread over time, a monthly rate of spread (meters) has to be entered as well. To simulate impacts of these insects on knapweed, an impact proportion (i.e., amount of reduction in seed and root biomass) is set. The actual impacts of root and seed feeders were determined by analyzing results of field experiments at the Yakima site. An extensive literature search was also conducted to determine how these insects impact diffuse knapweed growth and spread.

The seeding option places a given amount of native and introduced perennial grass and forb seed into the seedbank of each cell within the selected area. The seeding treatment is simulated by designating the seed mix, seed amount, and the areas, dates, and frequency of seeding. Some of the species in the seed mix applied at YTC were not included in the EDYS application and, therefore, substitutions were made. Table 7 lists the species included in the seed mix and those species included in the EDYS seeding scenario, along with amount of seed applied.

Table 7. Species included in the seeding mix applied to the Yakima Landscape EDYS application.

Species in Seeding Mix	Species Substituted in EDYS Application	lbs/acre
Agropyron fragilis	*Agropyron cristatum*	6.02
Agropyron intermedium	*Pascopyrum smithii*	1.55
Pseudoroegneria spicata	no substitution	3.77
P. spicata spp. *inermis*	*Pseudoroegneria spicata*	2.88
Achnatherum hymenoides	no substitution	1.35
Achillea millefolium	no substitution	1.42
Poa secunda	no substitution	0.60

For the prescribed fire treatment, the user selects when the burn is to take place (month, year) and how often the prescribed fire will occur (e.g., every four years). The effectiveness and the spatial distribution of the fire are simulated based on the composition, biomass, and distribution of the vegetation in each cell within the burn area at the time of the fire. Fire was prescribed on the brome site in July, 2000. The knapweed site did not receive a prescribed fire.

The purpose of the sugar treatment was to reduce nitrogen availability in the soils of the study plots by applying a carbon source (i.e., sugar) to immobilize soil nitrogen. To simulate the impact, the user selects the year and frequency of application and how much the free nitrogen in the soil is reduced. The soil free nitrogen is allowed to recover one month after application. The impact of sugar application was determined by analyzing results from Yakima study plots.

For the microbial inoculation treatment, the user selects the year and month of donor soil application and the frequency with which soil is inoculated. A water/nutrient uptake factor (i.e., how much amount of nutrient and water uptake is enhanced) and a decomposition rate factor (i.e., how much rate of decomposition is enhanced) are chosen that allow EDYS to effectively simulate impacts of microbial inoculation. The actual impact of microbial inoculation on plant water and nutrient uptake and decomposition dynamics was estimated by analyzing plant biomass data collected in study plots.

Four livestock stocking rates are included in the application that the user may select for a particular simulation. The four standard stocking rates are no grazing, light grazing (120 acres/AU), moderate grazing (64 acres/AU), and heavy grazing (32 acres/AU). The user may also designate any alternative stocking rate, rather than only select from the four standard stocking rates. Year-long grazing is assumed for this application.

Two native animal species were simulated in the herbivory management scenario: insects and rabbits. Herbivory by insects and rabbits was assumed to be uniform throughout the study sites and was based on animal densities. Densities used for insects were 3, 6, and 12 individuals per square meter. Rabbits were simulated at densities of 0.30, 0.56, and 0.78 individuals per hectare.

Military training is implemented by selecting 1) which of four vehicle types (M-1 Abrams, M-2 Bradley, HMMWV, truck) and number of each type to be included, 2) the training area in which the activities will occur, 3) the intensity of the training (i.e., how many vehicle miles per vehicle type), and 4) when the training occurs (months, years). Additional vehicle types, such as the Light Armored Vehicle (LAV), can be added to future updates of the model if desired. Once these parameters are designated, EDYS calculates ecological impact in one of two methods, depending on which is designated by the user. In both methods, there is an impact associated with each vehicle type on each plant species for each pass of the vehicle (Matrix 23, Appendix 2). In the first method, this calculated impact is distributed stochastically across the designated training area, and in the second method it is averaged over the entire designated training area.

5.0 RESULTS OF FIELD EXPERIMENTS

5.1 Field Data

The goal of the field experiment was to determine how treatments would impact spread of the invasive species *Bromus tectorum* (cheatgrass) and *Centaurea diffusa* (diffuse knapweed). The impact of four factors on vegetation dynamics of the two training areas (brome and knapweed sites) was studied at YTC. At the brome site these four factors included 1) two levels of fire (fire, no fire), 2) two levels of seeding (seeded, not seeded), 3) two levels of nitrogen limitation (sugar added, no sugar added), and 4) two levels of microbial inoculation (inoculated, not inoculated). At the knapweed sites these four factors included 1) two levels of knapweed-feeding insects (bug, no bug), 2) two levels of seeding (seeded, not seeded), 3) two levels of nitrogen limitation (sugar added, no sugar added), and 4) two levels of microbial inoculation (inoculated, not inoculated).

For each site (brome or knapweed) there were eight combinations of the four treatments, including:

1. No fire/no bug, no seed, no sugar, no inoculation
2. Fire/bug, no seed, no sugar, no inoculation
3. Fire/bug, seed, no sugar, no inoculation
4. Fire/bug, no seed, sugar, no inoculation
5. Fire/bug, seed, sugar, no inoculation
6. Fire/bug, seed, no sugar, inoculation
7. Fire/bug, no seed, sugar, inoculation
8. Fire/bug, seed, sugar, inoculation.

There were five replications of each treatment combination, for a total of 40 plots per site. Table 8 lists the date, frequency, and amount of each treatment applied to the YTC study sites.

Table 8. Timing of treatment application in the brome and knapweed sites at YTC.

Site	Treatment	Date Applied	Frequency	Amount Applied
Knapweed	Biological control (*Larinus minutus*)*	June 29, 2000	1 time only	700 adult insects (20 per plot on 35 plots)
Brome	Prescribed fire	July 21, 2000	1 time only	35 of 40 plots burned
Knapweed and Brome	Seeding	Sept. 26, 2000 Dec. 1, 2001	Twice in four years	227 g seed/plot (on 35 plots)
Knapweed and Brome	Sugar application	May, July, Sept, Nov, 2000 and April, May, June, Nov, 2001-2003	4 times per year	1600 kg carbon/ha/yr (on 35 plots)
Knapweed and Brome	Microbial inoculation	Sept. 26, 2000 Spring, 2002	Twice in four years	400 g dry soil per plot (on 35 plots)

*The root-boring beetle *Sphenoptera jugoslavica* has been widely established in Washington State (50-90% of mature plants infested) and therefore it was not released on study sites, although impacts were monitored and modelled.

Aboveground clippable biomass was collected each year in June at all of the experimental plots and data for the brome and knapweed sites are listed in Tables 9 and 10 respectively. These tables give the average biomass of the major composite species from five replicate plots for each treatment combination. Although only biomass by major species are shown in these tables, the total biomass is the sum of all species present in the plot (major composite species plus minor composite species not listed). The major species at the YTC brome site were cheatgrass and tumblemustard and the major species at the knapweed site were big sagebrush (*Artemisia tridentata*), cheatgrass, diffuse knapweed, Sandberg bluegrass (*Poa secunda*) and bluebunch wheatgrass (*Psuedoroegneria spicatum*).

Substantial changes in the vegetation occurred between 2000 and 2003 at both the brome and knapweed sites. At the brome site, cheatgrass, on average, decreased in all treatment plots in the second year and then increased in the third and fourth years (Table 9). This decrease in the second year would appear to the result of burning because in the control plots brome increased. With the exception of the second year, biomass of cheatgrass in the control plots increased from the first to the fourth years. Tumblemustard also decreased in the second year on control plots, although these plots were not burned. This decrease may have been the result of sheep grazing on this site in the second year.

Table 9. Total aboveground clippable biomass for major species (composite species) at the brome site at YTC. Numbers shown are averages of five plots. ACRE3 is *Acroptilon repens*, BRTE is *Bromus tectorum*, ERCI6 is *Erodium cicutarium*, SIAL2 is *Sisymbrium altissimum*. Total is the sum of all species.

Trt	Year	Removal	Seeding	Sugar	Soil	ACRE3	BRTE	ERCI6	SIAL2	Total
1	2000	no burn	no seed	no sugar	uninoc	0.00	75.10	0.00	28.15	103.62
1	2001	no burn	no seed	no sugar	uninoc	0.00	96.30	0.00	4.11	101.27
1	2002	no burn	no seed	no sugar	uninoc	0.00	105.59	0.00	43.11	149.52
1	2003	no burn	no seed	no sugar	uninoc	0.00	112.66	0.00	24.77	137.44
2	2000	burn	no seed	no sugar	uninoc	8.21	55.90	0.65	28.13	93.12
2	2001	burn	no seed	no sugar	uninoc	9.04	33.43	0.92	2.24	45.92
2	2002	burn	no seed	no sugar	uninoc	14.49	133.02	8.29	16.30	175.91
2	2003	burn	no seed	no sugar	uninoc	14.20	181.24	10.21	26.83	233.37
3	2000	burn	Seed	no sugar	uninoc	0.00	54.04	0.37	24.11	78.60
3	2001	burn	Seed	no sugar	uninoc	0.00	45.35	4.13	3.04	52.70
3	2002	burn	Seed	no sugar	uninoc	0.00	129.55	13.86	18.36	162.48
3	2003	burn	Seed	no sugar	uninoc	0.00	154.90	12.96	19.66	189.60
4	2000	burn	no seed	sugar	uninoc	0.00	74.09	0.00	33.18	107.76
4	2001	burn	no seed	sugar	uninoc	0.00	26.44	0.84	1.10	28.29
4	2002	burn	no seed	sugar	uninoc	0.00	77.04	4.36	12.36	95.85
4	2003	burn	no seed	sugar	uninoc	0.00	102.04	8.08	13.57	123.89
5	2000	burn	Seed	sugar	uninoc	0.00	61.21	0.06	31.24	92.81
5	2001	burn	Seed	sugar	uninoc	0.00	29.92	1.00	1.35	32.35
5	2002	burn	Seed	sugar	uninoc	0.00	99.02	4.29	12.16	116.00
5	2003	burn	Seed	sugar	uninoc	0.00	142.55	4.40	19.00	166.75
6	2000	burn	Seed	no sugar	inoc	11.78	74.29	0.02	34.55	128.58
6	2001	burn	Seed	no sugar	inoc	4.85	36.44	0.30	2.63	44.66
6	2002	burn	Seed	no sugar	inoc	11.16	148.47	0.27	19.19	180.36
6	2003	burn	Seed	no sugar	inoc	21.12	190.51	1.30	24.23	238.28
7	2000	burn	no seed	sugar	inoc	0.00	83.03	0.00	31.85	115.03
7	2001	burn	no seed	sugar	inoc	0.00	30.62	0.00	0.46	31.13
7	2002	burn	no seed	sugar	inoc	0.00	109.00	0.00	9.18	118.45
7	2003	burn	no seed	sugar	inoc	0.00	169.49	0.00	14.41	184.09
8	2000	burn	Seed	sugar	inoc	0.00	67.02	0.06	27.57	94.82
8	2001	burn	Seed	sugar	inoc	0.00	19.95	0.66	1.05	22.97
8	2002	burn	Seed	sugar	inoc	0.00	83.00	3.64	11.43	99.17
8	2003	burn	Seed	sugar	inoc	0.00	123.08	6.39	19.61	163.64

At the knapweed site, diffuse knapweed decreased dramatically in all treatment plots in the second year and biomass was very low by the fourth year of the study (Table 10). The seedhead flower weevil, *Larinus minutus*, which was introduced into study plots has been shown to be very effective in reducing numbers of diffuse knapweed plants. A single weevil larvae will generally consume all of the seeds in a seedhead and, in addition, adult weevils will extensively defoliate flowering plants (Lang et al. 1996, Kashefi and Sobhian 1998, Seastedt et al. 2003). Several studies have shown a dramatic decline in diffuse knapweed, such as the one measured in this study, with the introduction of *Larinus minutus* (Dr. Judith Myers, personal communication; Dr. Tim Seastedt, personal communication).

In general at the knapweed site, total biomass decreased in the second year in most of the plots, perhaps due to the prescribed burn. Cheatgrass decreased in all plots except the control during the second year.

Table 10. Total aboveground clippable biomass for major species (composite species) at the knapweed site at YTC. Numbers shown are averages for five plots. ARTR6 is *Artemisia tridentata*, BRTE is *Bromus tectorum*, CEDI3 is *Centaurea diffusa*, POSE is *Poa secunda*, and PSSP6 is *Pseudoroegneria spicata*. Total is the sum of all species.

Trt	Year	Removal	Seeding	Sugar	Soil	ARTR2	BRTE	CEDI3	POSE	PSSP6	Total
1	2000	no bug	no seed	no sugar	uninoc	8.59	13.41	15.64	3.20	2.07	54.53
1	2001	no bug	no seed	no sugar	uninoc	8.46	22.16	5.28	5.50	1.77	47.09
1	2002	no bug	no seed	no sugar	uninoc	10.85	17.22	2.69	6.46	4.15	61.69
1	2003	no bug	no seed	no sugar	uninoc	14.87	24.98	1.70	8.95	2.02	60.05
2	2000	bug	no seed	no sugar	uninoc	0.87	38.75	18.45	9.88	4.23	113.76
2	2001	bug	no seed	no sugar	uninoc	0.22	19.46	1.14	1.52	11.31	44.28
2	2002	bug	no seed	no sugar	uninoc	5.30	24.34	3.74	18.70	18.24	94.85
2	2003	bug	no seed	no sugar	uninoc	2.67	61.92	0.32	9.20	31.78	124.09
3	2000	bug	Seed	no sugar	uninoc	1.94	31.99	15.00	15.13	6.47	102.58
3	2001	bug	Seed	no sugar	uninoc	1.11	12.86	0.12	3.33	3.03	33.45
3	2002	bug	Seed	no sugar	uninoc	7.61	20.84	2.53	19.93	13.19	90.30
3	2003	bug	Seed	no sugar	uninoc	4.27	41.23	0.35	13.45	15.91	99.59
4	2000	bug	no seed	sugar	uninoc	8.87	35.79	11.53	11.94	9.91	100.46
4	2001	bug	no seed	sugar	uninoc	5.06	5.70	1.05	2.24	9.14	27.40
4	2002	bug	no seed	sugar	uninoc	6.27	14.01	5.41	3.88	13.27	57.86
4	2003	bug	no seed	sugar	uninoc	10.02	22.20	1.40	2.08	23.41	77.56
5	2000	bug	Seed	sugar	uninoc	12.41	51.05	10.52	14.35	4.02	120.70
5	2001	bug	Seed	sugar	uninoc	1.07	6.48	1.29	0.61	5.23	19.66
5	2002	bug	Seed	sugar	uninoc	6.99	14.99	2.74	3.05	5.88	49.64
5	2003	bug	Seed	sugar	uninoc	7.87	35.97	0.95	5.25	12.23	85.66
6	2000	bug	Seed	no sugar	inoc	27.81	29.82	14.89	16.48	18.07	131.85
6	2001	bug	Seed	no sugar	inoc	4.89	14.62	1.12	2.03	10.38	41.87
6	2002	bug	Seed	no sugar	inoc	23.57	25.80	1.50	25.23	14.89	106.36
6	2003	bug	Seed	no sugar	inoc	20.85	45.99	1.34	17.91	11.69	118.53
7	2000	bug	no seed	sugar	inoc	9.63	31.44	19.27	12.65	18.29	111.29
7	2001	bug	no seed	sugar	inoc	8.37	2.70	1.00	1.10	10.00	36.10
7	2002	bug	no seed	sugar	inoc	6.82	6.65	2.75	3.35	5.25	54.18
7	2003	bug	no seed	sugar	inoc	10.90	16.98	2.08	2.76	13.11	65.54
8	2000	bug	Seed	sugar	inoc	3.41	28.29	19.95	14.65	18.50	129.77
8	2001	bug	Seed	sugar	inoc	0.57	3.30	0.41	0.46	6.55	21.62
8	2002	bug	Seed	sugar	inoc	1.18	2.91	1.71	1.67	13.02	48.30
8	2003	bug	Seed	sugar	inoc	3.94	10.22	0.88	1.68	33.46	87.30

Because all possible combinations of treatments were not applied to field plots, to determine effects of a particular treatment the results from two different treatment combinations must be compared. For example, to determine the effects of sugar application, the results of treatment 2 (burn, no seed, no sugar, no inoculation) and treatment 4 (burn, no seed, sugar, no inoculation) should be compared.

For the brome site, burning was effective in reducing cheatgrass the year after the burn (66% reduction), but not after three years (60% increase)(Table 11). Seeding of native and introduced perennials had no consistent effect on cheatgrass growth after four years, increasing biomass in one set of plots and decreasing it in the other two sets of plots. Sugar application was effective in reducing cheatgrass after four years (29% average decrease). Inoculation was not effective in reducing cheatgrass after four years (25% average increase). On average, tumblemustard increased 18% in plots due to seeding and decreased 23% in plots due to sugar application. A small increase was seen in tumblemustard in plots with soil inoculation.

Table 11. Effect of treatments on total aboveground biomass (g/m^2) of cheatgrass and tumblemustard at the YTC brome site.

Trt	Treatment Combination	Cheatgrass				Tumblemustard			
		2000	2001	2002	2003	2000	2001	2002	2003
	Effect of fire								
1	Control	75	96	106	113	28	4	43	25
2	Burned	56	33	133	181	28	2	16	27
	% change	-25	-66	+25	+60	0	-50	-63	+8
	Effect of seeding								
2	Burned	56	33	133	181	28	2	16	27
3	Burn/Seed	54	45	130	155	24	3	18	20
	% change	-4	+36	-2	-14	-14	+50	+13	-26
4	Burn/Sugar	74	26	77	102	33	1	12	14
5	Burn/Sugar/Seed	61	30	99	143	31	1	12	19
	% change	-18	+15	+29	+40	-6	0	0	+36
7	Burn/Sugar/Inoculation	83	31	109	170	32	1	9	14
8	Burn/Sugar/Inoculation/Seed	67	20	83	123	28	1	11	20
	% change	-19	-35	-24	-28	-13	0	22	43
	% average change (seed)	-13	+5	+1	-1	-11	+17	+12	+18
	Effect of sugar								
2	Burn	56	33	133	181	28	2	16	27
4	Burn/Sugar	74	26	77	102	33	1	12	14
	% change	+32	-21	-42	-44	+18	-50	-25	-48
3	Burn/Seed	54	45	130	155	24	3	18	20
5	Burn/Seed/Sugar	61	30	99	143	31	1	12	19
	% change	+13	-33	-24	-8	+29	-67	-33	-5
6	Burn/Seed/Inoculation	74	36	149	191	35	3	19	24
8	Burn/Seed/Inoculation/Sugar	67	20	83	123	28	1	11	20
	% change	-9	-44	-44	-36	-20	-67	-42	-17
	% average change (sugar)	+12	-33	-37	-29	+9	-61	-33	-23
	Effect if inoculation								
3	Burn/Seed	54	45	130	155	24	3	18	20
6	Burn/Seed/Inoculation	74	36	149	191	35	3	19	24
	% change	+37	-20	+15	+23	+46	0	+6	+20
4	Burn/Sugar	74	26	77	102	33	1	12	14
7	Burn/Sugar/Inoculation	83	31	109	170	32	1	9	14
	% change	+12	+19	+42	+67	-3	0	-25	0
5	Burn/Sugar/Seed	61	30	99	143	31	1	12	19
8	Burn/Sugar/Seed/Inoculation	67	20	83	123	28	1	11	20
	% change	+10	-33	-16	-14	-10	0	-8	+5
	% average change (inoculation)	+20	-11	+13	+25	+11	0	-9	+8

At the knapweed site after four years, the seedhead weevil and root-boring beetles were observed in both control and treatment plots and, therefore, effects of this treatment could not be determined. Changes in biomass with seeding, sugar application, and inoculation at the knapweed site are shown in Tables 12, 13, and 14, respectively. Seeding of native and introduced perennial grasses decreased cheatgrass slightly (14%), but had no consistent effect on knapweed, sagebrush, perennial grasses, or forbs. Sugar application, on average, decreased cheatgrass (54%) and forbs (83%), but did not cause consistent changes in knapweed, sagebrush, or perennial grasses. Microbial inoculation decreased perennial grasses (59%) but had no consistent effect on knapweed, sagebrush, cheatgrass or forbs.

Table 12. Effect of seeding on vegetation total aboveground biomass (g/m^2) at the YTC knapweed site.

Species	Year	Bug	Bug/Seed	Bug/Sugar	Bug/Sugar/ Seed	Bug/Sugar/ Inoculation	Bug/Sugar/ Inoculation/Seed
Knapweed	2000	18	14	11	10	19	20
	2001	1	1	1	1	1	0
	2002	7	5	5	2	2	2
	2003	2	1	1	1	2	1
Sagebrush	2000	1	2	9	12	10	3
	2001	0	1	5	1	8	1
	2002	5	8	6	7	7	1
	2003	3	4	10	8	11	4
Perennial grasses	2000	20	21	22	13	32	33
	2001	13	8	7	6	12	6
	2002	39	37	13	5	10	15
	2003	44	31	30	18	18	35
Cheatgrass	2000	39	32	36	51	31	28
	2001	20	13	6	7	3	3
	2002	24	21	14	15	7	3
	2003	62	41	22	36	17	10
Forbs	2000	5	5	3	9	3	2
	2001	1	1	0	1	0	0
	2002	3	4	1	2	1	1
	2003	4	7	1	1	1	0

Table 13. Effect of sugar application on vegetation total aboveground biomass (g/m^2) at the YTC knapweed site.

Species	Year	Bug	Bug/Sugar	Bug/Seed	Bug/Seed/ Sugar	Bug/Seed/ Inoculation	Bug/Seed/ Inoculation/Sugar
Knapweed	2000	18	11	14	10	14	20
	2001	1	1	1	1	1	0
	2002	7	5	5	2	1	2
	2003	2	1	1	1	1	1
Sagebrush	2000	1	9	2	12	28	3
	2001	0	5	1	1	5	1
	2002	5	6	8	7	24	1
	2003	3	10	4	8	21	4
Perennial grasses	2000	20	22	21	13	35	33
	2001	13	7	8	6	9	6
	2002	39	13	37	5	27	15
	2003	44	30	31	18	30	35
Cheatgrass	2000	39	36	32	51	30	28
	2001	20	6	13	7	15	3
	2002	24	14	21	15	26	3
	2003	62	22	41	36	46	10
Forbs	2000	5	3	5	9	0	2
	2001	1	0	1	1	0	0
	2002	3	1	4	2	3	1
	2003	4	1	7	1	1	0

Table 14. Effect of inoculation on vegetation total aboveground biomass (g/m^2) at the YTC knapweed site.

Species	Year	Bug/ Seed	Bug/Seed/ Inoculation	Bug/Sugar	Bug/Sugar/ Inoculation	Bug/Seed/ Sugar	Bug/Seed/ Sugar/Inoculation
Knapweed	2000	14	14	11	19	10	20
	2001	1	1	1	1	1	0
	2002	5	1	5	2	2	2
	2003	1	1	1	2	1	1
Sagebrush	2000	2	28	9	10	12	3
	2001	1	5	5	8	1	1
	2002	8	24	6	7	7	1
	2003	4	21	10	11	8	4
Perennial grasses	2000	21	35	22	32	13	33
	2001	8	9	7	12	6	6
	2002	37	27	13	10	5	15
	2003	31	30	30	18	18	35
Cheatgrass	2000	32	30	36	31	51	28
	2001	13	15	6	3	7	3
	2002	21	26	14	7	15	3
	2003	41	46	22	17	36	10
Forbs	2000	5	0	3	3	9	2
	2001	1	0	0	0	1	0
	2002	4	3	1	1	2	1
	2003	7	1	1	1	1	0

6.0 SIMULATION RESULTS

The Yakima experimental design consisted of ten replications of eight treatment combinations, for a total of 80 experimental plots (40 at the brome site and 40 at the knapweed site). Each of these 80 plots was included in the EDYS application. Initial biomass values for each plant species were based on the 2000 biomass data supplied by Colorado State University. EDYS then simulated the dynamics of each of these 80 plots over a four-year time period based on 1) the precipitation values received during the period of simulation, 2) the experimental treatments imposed on each plot, and 3) no livestock grazing, herbivory, or military training on the plots. The simulated values were then compared plot-by-plot to their values from the 2000, 2001, 2002, and 2003 sampling. The primary purpose of comparing simulation results to experimental results is to verify that the modelling results are reasonable and to establish a level of accuracy for these results. The purpose of the simulation modelling itself is to provide a tool that can be used in land-management decision making to estimate the responses of the target variables to various management scenarios over time.

The vegetation parameter used to evaluate these management scenarios was aboveground biomass (g/m^2) collected each June. For shrubs, the value was clippable aboveground biomass (stems and leaves), which is approximately one-half of total aboveground biomass. For grasses and forbs, it was total aboveground biomass.

6.1 Brome Community

6.1.1 Community-Wide Accuracy

EDYS was parameterized for the brome community for each of the different plot-level treatments. The initial conditions were typical of conditions in 1999. The simulation runs were for 4 years. Simulation values were compared to field-collected aboveground biomass data for all 40 plots for each of the four years. Because on many of the plots only two species were present, values were compared for cheatgrass, tumblemustard, and total aboveground biomass only. The results of the EDYS simulations for the four years at the brome site plots (mean of forty plots) are shown in Table 15.

Table 15. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site with a four-year simulation run. The numbers shown are the means of eight treatments with five replications each.

Species	Mean June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	13.2	112.6	55.4	143.3	149.0
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.2	0.3	0.4
Crested wheatgrass	0.0	0.2	0.8	2.2	3.6
Western wheatgrass	0.0	0.0	0.1	0.4	0.9
Bluebunch wheatgrass	0.0	0.5	1.7	3.7	5.6
Indian ricegrass	0.0	0.0	0.1	0.3	0.7
Sandberg bluegrass	0.0	0.1	0.2	0.5	0.6
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.1	0.1
Yarrow	0.0	0.1	0.3	0.6	0.8
Russian knapweed	2.2	1.5	1.1	1.1	1.4
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.3	0.3	0.4
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	8.0	72.0	44.4	122.7	119.8
Storksbill	0.1	1.4	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	2.9	36.3	5.8	10.8	14.3
Litter	18.6	18.3	85.1	141.2	265.5

The 95% confidence intervals of the population means of each of the composite variables were calculated for the 2000 to 2004 sampled values. These intervals give the statistical ranges for the means of each variable that are the best statistical estimates of the true value of that mean. As such, they are a measurement of the sample accuracy for that variable. These values were then compared to the 95% confidence intervals of the EDYS predicted values for the variables.

For 10 of the 12 comparisons, 95% confidence intervals of the sampled and EDYS results overlapped for total biomass, cheatgrass, and tumblemustard (Figure 6), indicating that the EDYS simulation was at least as accurate as the sampling technique for these three variables. Therefore, the model simulated well the total biomass and cheatgrass productions in all years. Tumblemustard production was well simulated in 2002 and 2003, but it was underestimated in 2000 and 2001. This was probably a reflection of temporal and spatial heterogeneity in the community. In addition, sheep were grazed in the experimental plots in Year 2 and this may have caused modelling results to be less accurate because sheep grazing was not included in this application and because no quantitative data exist regarding plant consumption of the sheep. Tumblemustard appeared to be affected by the grazing but cheatgrass did not, perhaps because it has a different life cycle and emerges later in the year.

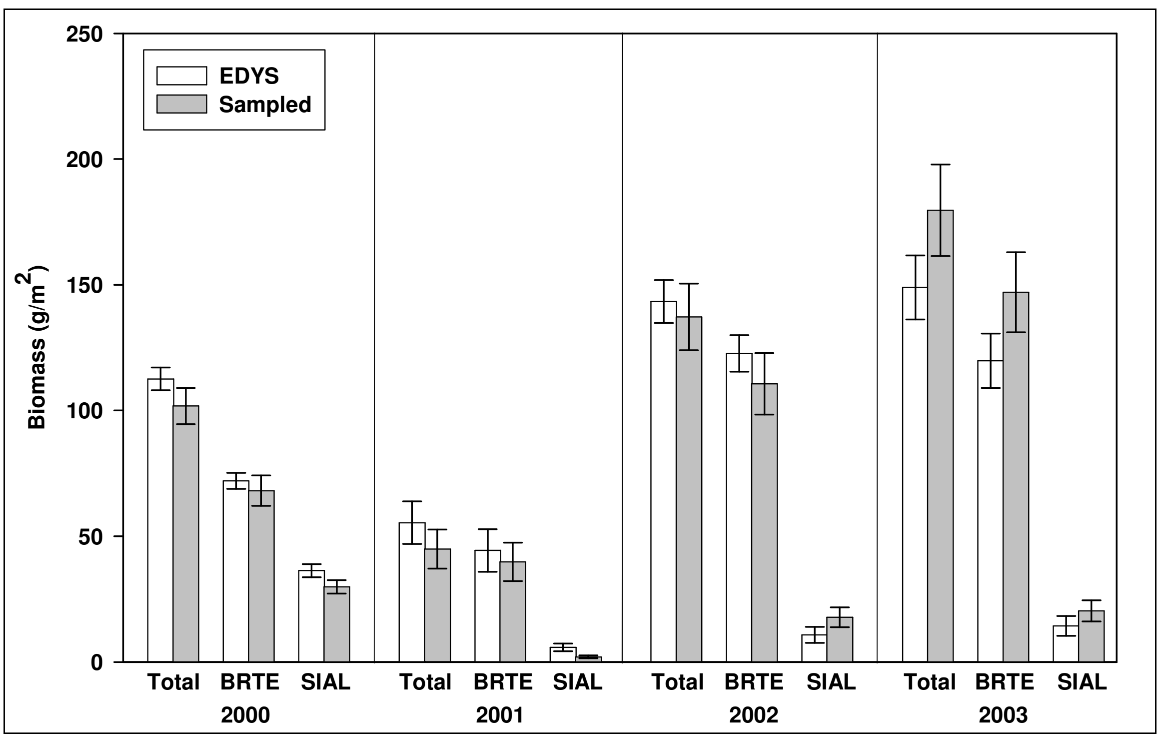

Figure 6. Comparison of aboveground biomass values (g/m^2) between actual and EDYS simulation results for the YTC brome site. Error bars show 95% CI.

The accuracy of the EDYS projections was, on average, higher for cheatgrass (89%) than for tumblemustard (62%)(Table 16). Overall, EDYS projections were more accurate in the first and third years than for the second and fourth years.

Table 16. Percent accuracy for the Yakima brome site with a four-year simulation run. The numbers shown are the means of eight treatments with five replications each.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	72.03	68.09	0.945
2001	44.36	39.81	0.897
2002	122.74	110.59	0.901
2003	119.78	147.06	0.815
Tumblemustard			
2000	36.30	29.85	0.822
2001	5.84	2.00	0.342
2002	10.77	17.76	0.606
2003	14.29	20.26	0.705
Total aboveground			
2000	112.59	101.79	0.904
2001	55.36	44.91	0.811
2002	143.34	137.22	0.957
2003	148.95	179.63	0.829

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

6.1.2 Baseline Conditions (Control)

Baseline conditions were defined as the vegetation changes that would occur in the absence of further human impacts such as seeding, cattle grazing, military training, or prescribed burning. The initial conditions were those typical of present conditions and the simulation runs were for 4 and 50 years. The results of the EDYS simulations for the four years at the brome site control plots (no burn, no seed, no sugar, no inoculation) are shown in Table 17. The two primary species were cheatgrass and tumblemustard.

Table 17. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation) and a four-year simulation run (means of five plots each).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	9.9	114.4	80.5	152.5	134.7
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.2	0.3	0.4
Crested wheatgrass	0.0	0.1	0.1	0.2	0.2
Western wheatgrass	0.0	0.0	0.0	0.1	0.1
Bluebunch wheatgrass	0.0	0.4	1.0	1.1	1.4
Indian ricegrass	0.0	0.0	0.0	0.0	0.0
Sandberg bluegrass	0.0	0.1	0.2	0.3	0.4
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.1	0.1
Yarrow	0.0	0.1	0.2	0.2	0.2
Russian knapweed	0.0	0.1	0.2	0.2	0.3
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.3	0.4	0.6
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	6.7	73.7	65.6	129.0	106.7
Storksbill	0.0	1.0	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	3.2	38.4	12.1	20.4	23.7
Litter	0.0	0.0	121.7	186.2	320.4

Percent accuracy between predicted (EDYS) and sampled results was fairly high for cheatgrass and total biomass (Table 18). Accuracy was not as high for tumblemustard, perhaps because it was the species most impacted by sheep grazing in 2001. Overall, percent accuracy was lowest in 2001, and this was most likely due to impacts from sheep grazing (e.g., removal of biomass through grazing, trampling, etc.).

Table 18. Percent accuracy for the four-year modelling run for the Yakima brome site under baseline conditions.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	73.66	75.10	0.981
2001	65.60	96.30	0.681
2002	128.98	105.60	0.819
2003	106.69	112.70	0.947
Tumblemustard			
2000	38.36	28.15	0.734
2001	12.09	4.11	0.340
2002	20.36	43.11	0.472
2003	23.73	24.77	0.958
Total aboveground			
2000	114.38	103.62	0.906
2001	80.45	101.27	0.794
2002	152.52	149.52	0.980
2003	134.66	137.44	0.980

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

To simulate long-term vegetation changes in these sites, 50-year EDYS runs were conducted. This long-term scenario provides a reasonable estimate of what will happen to this community if left undisturbed for 50 years. Although cheatgrass was a dominant species in the four-year simulation, by Year 20 this species was no longer present at the site (Table 19). Conversely, big sagebrush and rubber rabbitbrush become dominants of this community. These results seem reasonable because these plots originally contained a sagebrush community before they were disturbed. Tumblemustard disappeared almost completely by Year 10.

Both cheatgrass and tumblemustard are invasive annuals that out compete native species by germinating and flowering in cool weather when native annuals are still seedlings (Allen and Knight 1984). Once cheatgrass and tumblemustard are established, they persist by out competing other species for resources (usually water), effectively dispersing seeds, and displaying phenotypic plasticity (Allen and Knight 1984). Cheatgrass establishment can almost always be associated with a disturbance of some type (Klemmedson and Smith 1964). If no further disturbance occurs, bunchgrasses can out-compete cheatgrass. Cheatgrass is also less tolerant to drought than perennial species. Hosten and West (1994) showed that cheatgrass production declined drastically after three years of drought, while perennial grass production increased without disturbance. In this study, cheatgrass flourished after a severe disturbance (i.e., fire), but declined gradually without disturbance and tended to disappear after 11 years. McLendon and Redente (1992) suggested that cheatgrass is able to dominate disturbed sites because of its high nitrogen use efficiency. However, if disturbance ceases and nitrogen becomes less available, perennial vegetation can slowly regain dominance of the site (McLendon and Redente 1992). Because shrubs and perennial grasses dominate after about 15 years, these EDYS results appear to provide a realistic scenario of what will occur in this community over time.

Table 19. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation) and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	114	88	231	353	413	481
Big sagebrush	0	0	2	26	65	115	176
Rubber rabbitbrush	0	0	18	118	132	109	82
Crested wheatgrass	0	0	3	12	31	54	85
Western wheatgrass	0	0	4	24	43	47	46
Bluebunch wheatgrass	0	0	9	13	14	13	11
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	8	26	33	35	34
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	1	6	31	37	47
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	1	1	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	5	5	3	1	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	74	34	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	38	1	0	0	0	0
Litter	0	0	440	118	93	133	96

6.1.3 Prescribed Burning

The simulated prescribed fire burned 35 of the 40 cells at the brome site in Year 1. The prescribed fire scenario for the burn was that every cell was exposed to the fire (i.e., every cell edge was "torched"), whether or not the specific cell burned was dependent on its fuel load. For the prescribed burn simulation, all plots were burned (except the control plots) in July, 2000. Fire has been reported to be an effective method for controlling cheatgrass (Evans and Young 1984).

The plots were burned after the 2000 biomass sampling, so effects are reflected in the 2001 biomass values (Table 20). In the field, cheatgrass did decline somewhat in 2001, most likely because a portion of the seedbank was consumed by the fire. The decline in cheatgrass was correctly simulated by EDYS. In 2002 and 2003, however, cheatgrass production increased, reaching even higher levels than at the beginning of the experiment. This increase was also correctly simulated by EDYS. Our results are in agreement with those of Hosten and West (1994) who reported an increase in cheatgrass in two consecutive years after a fire in central Utah. Tumblemustard and total aboveground production varied in a similar fashion as cheatgrass, decreasing immediately after the fire and increasing in the subsequent years.

Table 20. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	28.3	116.9	66.0	163.8	157.6
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.0	0.1	0.2	0.3
Crested wheatgrass	0.0	0.1	0.1	0.1	0.2
Western wheatgrass	0.0	0.0	0.0	0.0	0.1
Bluebunch wheatgrass	0.0	0.3	0.6	0.8	0.9
Indian ricegrass	0.0	0.0	0.0	0.0	0.0
Sandberg bluegrass	0.0	0.1	0.2	0.2	0.3
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.0	0.0
Yarrow	0.0	0.1	0.1	0.1	0.1
Russian knapweed	17.2	8.6	3.1	3.5	4.2
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.2	0.2	0.4
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	8.1	74.7	52.6	142.5	139.1
Storksbill	0.5	3.6	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	2.5	28.9	8.4	15.6	11.7
Litter	74.4	71.9	74.4	127.9	265.7

In general, the percent accuracy of the four-year simulation was not as high for burned plots as it was for baseline conditions (Table 21). As in the baseline conditions, however, accuracy was low in the second year. On average, cheatgrass accuracy (77%) was higher than for tumblemustard (66%). Accuracy was very low in the second and fourth years for tumblemustard. Perhaps the decrease in accuracy in the second year was because the effects of sheep grazing were not included in the model. Grazing may have removed much of the tumblemustard vegetation, but in the model no such removal occurred.

Table 21. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning and a four-year simulation.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	74.73	55.90	0.748
2001	52.61	33.43	0.635
2002	142.54	133.02	0.933
2003	139.11	181.24	0.768
Tumblemustard			
2000	28.93	28.15	0.972
2001	8.43	2.49	0.266
2002	15.62	19.43	0.958
2003	11.67	27.39	0.435
Total aboveground			
2000	116.89	93.12	0.797
2001	66.05	45.92	0.695
2002	163.78	175.91	0.931
2003	157.55	233.37	0.675

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Although these plots were burned in the first year, no disturbance occurred in subsequent years. The 50-year simulation showed that without any further disturbance the vegetation should resemble an undisturbed community after a few years (Table 22). As in the model of the undisturbed community, cheatgrass declines by Year 20 and shrubs and perennial grasses dominate. Tumblemustard is no longer present after ten years. Thus, with only one burn, the vegetation follows a natural succession pattern. Hosten and West (1994) reported a very similar pattern for cheatgrass, i.e., an increase in production in the year immediately after the fire and a negligible production 11 years after the fire. These findings lend support to the theory that cheatgrass (and other invasive species) thrive under conditions of disturbance, but are less competitive under undisturbed conditions where plant resources are abundant.

Table 22. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	28	117	84	224	345	407	463
Big sagebrush	0	0	1	27	66	113	167
Rubber rabbitbrush	0	0	13	101	121	103	80
Crested wheatgrass	0	0	2	9	21	37	54
Western wheatgrass	0	0	3	20	36	39	37
Bluebunch wheatgrass	0	0	8	18	24	28	31
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	6	26	35	38	38
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	1	5	30	44	55
Yarrow	0	0	0	0	0	0	0
Russian knapweed	17	9	12	14	8	3	1
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	3	3	2	1	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	8	75	33	0	0	0	0
Storksbill	1	4	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	29	0	0	0	0	0
Litter	74	72	439	122	92	133	93

6.1.4 Treatment Combinations

The complexity of the model increases with each additional treatment that is added. Vegetation dynamics in the plots that were burned and seeded were simulated with EDYS. With this treatment combination, as with the burning treatment, cheatgrass was the dominant species in each year (Table 23). Although cheatgrass production declined in the year following the fire, in the third and fourth years it was higher than in the first year. The combination of burning and seeding has been shown to effectively reduce cheatgrass biomass in other systems (Evans and Young 1984). However, because the seedbank was not totally destroyed by the fire, cheatgrass returned the year after the fire and out-competed perennial grass and forb seedlings.

Table 23. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding and a 4-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	7.6	97.8	51.7	137.0	173.9
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.0	0.1	0.3	0.3
Crested wheatgrass	0.0	0.1	1.2	4.0	6.2
Western wheatgrass	0.0	0.0	0.2	0.8	1.6
Bluebunch wheatgrass	0.0	0.4	2.0	6.0	9.2
Indian ricegrass	0.0	0.0	0.1	0.7	1.5
Sandberg bluegrass	0.0	0.1	0.4	0.9	1.2
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.1	0.0
Yarrow	0.0	0.1	0.4	1.0	1.4
Russian knapweed	0.0	1.9	3.1	3.5	4.2
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.2	0.3	0.4
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	4.3	60.3	33.4	98.6	116.8
Storksbill	0.5	2.3	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	2.8	32.1	9.9	20.3	30.6
Litter	52.8	53.1	68.2	126.6	246.9

Accuracy for vegetation on the burned and seeded plots was fairly high (Table 24). Accuracy was higher on average for cheatgrass (79%) than for tumblemustard (65%). The second-year modelling accuracy was very low for tumblemustard, perhaps because the effects of sheep grazing were not included in the model. The highest average percent accuracy was seen for total biomass (89%), probably because some minor species were accurately modelled and contributed to the total.

Table 24. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning and seeding.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	60.35	54.04	0.896
2001	33.40	45.35	0.736
2002	98.65	129.55	0.761
2003	116.79	154.90	0.754
Tumblemustard			
2000	32.10	24.11	0.751
2001	9.89	3.04	0.308
2002	20.34	18.36	0.903
2003	30.63	19.66	0.642
Total aboveground			
2000	97.80	78.60	0.804
2001	51.73	52.70	0.982
2002	136.97	162.48	0.843
2003	173.89	189.60	0.917

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

The 50-year projection of the community with burning and seeding differed from the previous two simulations in that perennial grasses dominate instead of shrubs. Crested wheatgrass, bluebunch wheatgrass, Indian ricegrass, Sandberg bluegrass, and yarrow were all included in the seed mixture. These species have better possibilities to dominate because seeds from the seeding mix remain in the seed bank and germinate when conditions are right. As in the undisturbed and burned communities, cheatgrass is non-existent by Year 20 (Table 25).

Table 25. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	8	98	149	271	439	462	508
Big sagebrush	0	0	1	9	20	31	45
Rubber rabbitbrush	0	0	7	19	20	14	10
Crested wheatgrass	0	0	22	46	91	112	135
Western wheatgrass	0	0	23	92	144	142	138
Bluebunch wheatgrass	0	0	18	21	22	18	15
Indian ricegrass	0	0	12	52	91	92	106
Sandberg bluegrass	0	0	10	23	31	31	30
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	4	20	21	30
Yarrow	0	0	1	0	0	0	0
Russian knapweed	0	2	5	2	1	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	1	1	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	4	60	47	0	0	0	0
Storksbill	1	2	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	32	0	0	0	0	0
Litter	53	53	250	134	112	151	109

The EDYS model accurately predicted the cheatgrass response to sugar application (Table 26). In the field, sugar was applied to plots to immobilize nitrogen and reduce the competitive ability of cheatgrass. At the end of four years, cheatgrass in plots with sugar applied had 29% less biomass than those without sugar applied. Although cheatgrass was lower in plots with sugar applied, actual biomass still increased over the four years and it still was the dominant species. Similar results are seen in the EDYS simulation as well.

Table 26. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, sugar application and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Total	11.1	120.7	40.2	118.9	93.8
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.2	0.3	0.4
Crested wheatgrass	0.0	0.1	0.1	0.2	0.2
Western wheatgrass	0.0	0.0	0.0	0.1	0.1
Bluebunch wheatgrass	0.0	0.4	1.0	1.1	1.3
Indian ricegrass	0.0	0.0	0.0	0.0	0.0
Sandberg bluegrass	0.0	0.0	0.0	0.1	0.1
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.0	0.1
Yarrow	0.0	0.1	0.2	0.1	0.1
Russian knapweed	0.0	0.2	0.4	0.3	0.3
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.3	0.3	0.3
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	8.1	71.0	35.1	113.2	84.7
Storksbill	0.0	0.6	0.0	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	3.0	47.7	2.4	2.8	5.6
Litter	0.0	0.0	92.8	131.5	250.0

Average accuracy was higher for cheatgrass (81%) than for tumblemustard (45%), while total biomass accuracy (79%) was lower than that for cheatgrass (Table 27).

Table 27. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning, sugar application and a four-year simulation run.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	71.04	74.09	0.959
2001	35.09	26.44	0.753
2002	113.15	77.04	0.681
2003	84.74	102.04	0.830
Tumblemustard			
2000	47.74	33.18	0.695
2001	2.38	1.10	0.465
2002	2.83	12.36	0.229
2003	5.60	13.57	0.413
Total aboveground			
2000	120.75	107.76	0.892
2001	40.18	28.29	0.704
2002	118.86	95.85	0.806
2003	93.78	123.89	0.757

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Over a 50-year period, shrubs become the dominant vegetation and cheatgrass and tumblemustard die off (Table 28). Crested wheatgrass, western wheatgrass, and needle-and-thread grass are the primary grasses in these plots. Thus, although on the short term an effect due to sugar was measured, over a long-term period the vegetation resembles the undisturbed and burned communities. A longer period of sugar application might produce different results.

Table 28. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning and sugar application and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	11	121	68	220	342	409	481
Big sagebrush	0	0	1	22	54	96	147
Rubber rabbitbrush	0	0	16	118	131	108	81
Crested wheatgrass	0	0	4	18	45	83	123
Western wheatgrass	0	0	5	32	56	61	60
Bluebunch wheatgrass	0	0	7	14	15	13	11
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	1	6	8	9	9
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	1	5	30	39	49
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	1	1	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	3	4	3	1	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	8	71	27	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	48	1	0	0	0	0
Litter	0	0	462	118	92	135	99

Each of the previous three treatments (i.e., burning, seeding, and sugar application) has shown fairly high accuracy for cheatgrass and when the three treatments were modelled together the results were also similar to field data. Over the four-year period, cheatgrass increased while tumblemustard decreased abruptly in the second year, perhaps due to the impacts of sheep grazing (Table 29). Perennial grasses dominate over forbs and shrubs, although biomass of every species except cheatgrass is comparatively low in Year 4.

Table 29. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding, sugar application and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	10.5	115.6	51.7	131.3	133.1
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.1	0.2	0.4
Crested wheatgrass	0.0	0.5	1.3	4.0	6.9
Western wheatgrass	0.0	0.0	0.2	0.8	2.0
Bluebunch wheatgrass	0.0	0.8	2.3	6.0	9.3
Indian ricegrass	0.0	0.0	0.1	0.6	1.3
Sandberg bluegrass	0.0	0.0	0.3	0.7	1.0
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.0	0.1
Yarrow	0.0	0.1	0.4	0.9	1.3
Russian knapweed	0.0	0.2	0.3	0.3	0.3
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.2	0.2	0.3
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	7.8	69.3	44.1	114.4	102.4
Storksbill	0.1	1.0	0.0	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	2.6	43.1	1.8	2.7	7.6
Litter	21.3	21.4	73.8	136.6	246.6

Although the modeling increased in complexity with the addition of another treatment, the percent accuracy was still fairly high (Table 30). Average accuracy of cheatgrass (79%) was higher than for tumblemustard (54%).

Table 30. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning, seeding, sugar application and a four-year simulation run.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	69.25	61.21	0.884
2001	44.14	29.92	0.678
2002	114.40	99.02	0.866
2003	102.35	142.55	0.718
Tumblemustard			
2000	43.13	31.35	0.727
2001	1.81	1.45	0.799
2002	2.66	12.27	0.216
2003	7.61	19.12	0.398
Total aboveground			
2000	115.59	92.81	0.803
2001	51.71	32.35	0.626
2002	131.27	116.00	0.884
2003	133.12	166.75	0.798

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Over a 50-year period, the perennial grasses crested wheatgrass and western wheatgrass dominate the site, while cheatgrass disappears after Year 10 (Table 31). Shrub biomass was relatively low on these plots, perhaps because seeding provided a competitive advantage for the perennial grasses. Almost no forbs are present in the plots by Year 50.

Table 31. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding, sugar application and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	**Year 1**	**Year 10**	**Year 20**	**Year 30**	**Year 40**	**Year 50**
Total	10	116	130	262	450	484	542
Big sagebrush	0	0	1	9	19	30	44
Rubber rabbitbrush	0	0	6	19	19	14	10
Crested wheatgrass	0	0	24	53	115	149	184
Western wheatgrass	0	0	22	89	140	135	132
Bluebunch wheatgrass	0	1	20	27	31	28	23
Indian ricegrass	0	0	8	38	73	73	85
Sandberg bluegrass	0	0	6	22	32	34	33
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	4	20	21	31
Yarrow	0	0	1	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	1	1	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	8	69	39	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	43	0	0	0	0	0
Litter	21	21	332	131	115	152	115

The vegetation dynamics of the burned/seeded/inoculated plots resemble those of the burned-only plots and EDYS simulated these changes well. At the end of four years, the biomass of cheatgrass was higher on the burned/seeded/inoculated plots and burned-only plots than on any of the others (Table 32).

Table 32. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding, soil inoculation and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	15.0	119.3	57.8	158.2	200.8
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.2	0.3	0.4
Crested wheatgrass	0.0	0.2	1.4	4.1	6.4
Western wheatgrass	0.0	0.0	0.2	0.8	1.5
Bluebunch wheatgrass	0.0	0.6	2.6	6.4	9.9
Indian ricegrass	0.0	0.0	0.1	0.6	1.4
Sandberg bluegrass	0.0	0.0	0.3	0.8	1.0
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.1	0.0
Yarrow	0.0	0.1	0.4	1.0	1.4
Russian knapweed	0.0	0.2	0.4	0.5	0.6
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.3	0.4	0.6
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	12.0	83.2	42.2	122.4	150.5
Storksbill	0.0	1.0	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	3.0	33.4	9.1	20.4	26.4
Litter	0.0	0.0	87.3	152.2	283.8

Accuracy for tumblemustard was higher for the EDYS simulation of this treatment than most of the previous treatments (Table 33). All years had a high accuracy, with the exception of 2001. Average accuracy was 84, 80, and 86% for cheatgrass, tumblemustard, and total biomass, respectively.

Table 33. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning, seeding, soil inoculation and a four-year simulation run.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	83.20	74.29	0.893
2001	42.17	36.44	0.864
2002	122.39	148.47	0.824
2003	150.52	190.51	0.790
Tumblemustard			
2000	33.42	34.55	0.967
2001	9.09	2.77	0.305
2002	20.41	19.78	0.969
2003	26.45	25.27	0.956
Total aboveground			
2000	119.29	128.58	0.928
2001	57.76	44.66	0.773
2002	158.20	180.36	0.877
2003	200.84	238.28	0.843

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

With a combination of burning, seeding, and soil inoculation, perennial grasses begin to dominate the site between 10 and 20 years, according to the EDYS simulation (Table 34). By Year 50, crested wheatgrass, western wheatgrass, and Indian ricegrass are the dominant grasses, of which crested wheatgrass and Indian ricegrass were seeded in the first four years. Shrubs are a very minor portion of the biomass, while cheatgrass and tumblemustard totally disappear.

Table 34. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding, soil inoculation and a 50-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	15	119	160	283	440	459	503
Big sagebrush	0	0	1	8	17	26	38
Rubber rabbitbrush	0	0	8	20	20	14	10
Crested wheatgrass	0	0	23	47	89	109	132
Western wheatgrass	0	0	23	87	134	132	128
Bluebunch wheatgrass	0	1	27	32	31	26	21
Indian ricegrass	0	0	12	58	95	97	112
Sandberg bluegrass	0	0	10	25	34	33	32
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	4	19	21	30
Yarrow	0	0	1	0	0	0	0
Russian knapweed	0	0	1	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	2	1	1	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	12	83	51	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	33	0	0	0	0	0
Litter	0	0	202	136	113	152	109

Cheatgrass was the dominant species in the plots with burning, sugar application and soil inoculation over a 4-year period (Table 35). Biomass of all other species was very low. In the field plots, soil inoculation caused a 25% increase in cheatgrass in Year 4 over the untreated plots while sugar application caused a decline of 29% over untreated plots in Year 4.

Table 35. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, sugar application, soil inoculation and a 4-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	12.4	110.5	49.5	144.3	150.7
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.2	0.3	0.4
Crested wheatgrass	0.0	0.2	0.4	0.4	0.6
Western wheatgrass	0.0	0.0	0.0	0.1	0.1
Bluebunch wheatgrass	0.0	0.6	1.4	1.6	2.2
Indian ricegrass	0.0	0.0	0.0	0.0	0.0
Sandberg bluegrass	0.0	0.0	0.1	0.1	0.1
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.0	0.1
Yarrow	0.0	0.1	0.2	0.2	0.2
Russian knapweed	0.0	0.2	0.4	0.3	0.4
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.3	0.3	0.4
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	9.4	74.5	44.5	138.6	142.9
Storksbill	0.0	1.0	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	3.0	33.4	1.5	1.9	2.9
Litter	0.0	0.0	82.4	130.2	248.4

For the simulation including burning, sugar application, and soil inoculation, average accuracy for cheatgrass (80%) was almost twice as high as that for tumblemustard (42%). Mean accuracy for total biomass was 81%.

Table 36. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning, sugar application, soil inoculation and a 4-year simulation run.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	74.53	83.03	0.898
2001	44.49	30.62	0.688
2002	138.60	109.00	0.786
2003	142.87	169.49	0.843
Tumblemustard			
2000	33.36	31.85	0.955
2001	1.53	0.51	0.333
2002	1.92	9.35	0.205
2003	2.86	14.45	0.198
Total aboveground			
2000	110.54	115.03	0.961
2001	49.52	31.13	0.629
2002	144.26	118.45	0.821
2003	150.66	184.09	0.818

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of the 50-year simulation, shrubs and perennial grasses made up an equal portion of the total biomass and almost all forbs had disappeared (Table 37). Cheatgrass and tumblemustard disappeared between Years 10 and 20.

Table 37. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, sugar application, soil inoculation and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	12	111	85	238	361	429	502
Big sagebrush	0	0	1	25	60	106	164
Rubber rabbitbrush	0	0	19	116	129	106	80
Crested wheatgrass	0	0	7	21	48	84	119
Western wheatgrass	0	0	5	27	50	57	57
Bluebunch wheatgrass	0	1	20	34	37	35	31
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	1	6	8	9	9
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	1	5	26	32	42
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	1	1	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	3	3	2	1	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	9	75	26	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	33	0	0	0	0	0
Litter	0	0	443	120	95	136	101

When all four treatments were added into the model, cheatgrass was still the dominant species after four years (Table 38). As in the previous treatment with burning, sugar application, and soil inoculation, biomass of all other species was very low. Bluebunch wheatgrass increased over the four years and biomass was higher than in the previous treatment, probably because these plots were seeded.

Table 38. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding, sugar application, soil inoculation and a 4-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	10.9	105.5	45.5	140.9	147.1
Big sagebrush	0.0	0.0	0.1	0.1	0.1
Rubber rabbitbrush	0.0	0.1	0.2	0.3	0.5
Crested wheatgrass	0.0	0.2	1.4	4.3	7.7
Western wheatgrass	0.0	0.0	0.2	0.9	2.1
Bluebunch wheatgrass	0.0	0.6	2.7	6.6	10.6
Indian ricegrass	0.0	0.0	0.1	0.7	1.4
Sandberg bluegrass	0.0	0.0	0.3	0.7	0.9
Squirreltail	0.0	0.0	0.0	0.0	0.0
Needle-and-thread	0.0	0.0	0.0	0.1	0.1
Yarrow	0.0	0.1	0.4	1.0	1.5
Russian knapweed	0.0	0.2	0.4	0.4	0.4
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.0	0.1	0.3	0.3	0.4
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	0.0	0.1	0.1	0.1	0.1
Cheatgrass	7.9	69.5	37.4	123.2	115.2
Storksbill	0.0	1.0	0.1	0.0	0.0
Pepperweed	0.0	0.1	0.0	0.0	0.0
Tumblemustard	3.0	33.4	1.5	2.0	5.7
Litter	0.0	0.0	80.0	138.5	262.5

Average accuracy was higher, as in most of the other model runs, for cheatgrass (78%) than for tumblemustard (50%) (Table 39). Average accuracy for total biomass was 75%.

Table 39. Percent accuracy for the four-year modelling run for the Yakima brome site with prescribed burning, seeding, sugar application, soil inoculation and a four-year simulation run.

Variable	Predicted	Sampled	Accuracy
Cheatgrass			
2000	69.47	67.02	0.965
2001	37.38	19.95	0.534
2002	123.23	83.00	0.674
2003	115.21	123.08	0.936
Tumblemustard			
2000	33.39	27.57	0.826
2001	1.49	1.07	0.719
2002	2.04	11.79	0.173
2003	5.74	19.67	0.292
Total aboveground			
2000	105.49	94.82	0.899
2001	45.49	22.97	0.505
2002	140.88	99.17	0.704
2003	147.10	163.64	0.899

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

When the four treatments were modelled together for 50 years, perennial grasses became dominant while forbs had almost disappeared (Table 40). As in most of the other treatment combinations, cheatgrass and tumblemustard disappeared between 10 and 20 years.

Table 40. EDYS simulation of vegetation dynamics at the Yakima Landscape brome site, with prescribed burning, seeding, sugar application, soil inoculation and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m²)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	11	105	140	265	451	481	536
Big sagebrush	0	0	1	11	23	36	53
Rubber rabbitbrush	0	0	7	22	23	17	12
Crested wheatgrass	0	0	26	52	117	148	181
Western wheatgrass	0	0	24	95	147	140	136
Bluebunch wheatgrass	0	1	20	25	26	22	18
Indian ricegrass	0	0	8	40	75	75	86
Sandberg bluegrass	0	0	5	16	22	22	21
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	4	18	20	29
Yarrow	0	0	1	0	0	0	0
Russian knapweed	0	0	1	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	1	1	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	8	69	45	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	33	0	0	0	0	0
Litter	0	0	296	132	115	151	113

6.1.5 Herbivory

At the brome site with light herbivory included (3 insects/m^2 and 0.30 rabbits/ha), biomass of all species declined to zero between years 1 and 10 (Table 41). Initially, only two species, cheatgrass and tumblemustard, were present on the plots and the herbivores will readily consume both of these species if more preferred species are not available (Appendix Table 24). In Year 1, cheatgrass biomass was 8% lower in plots with herbivores than in plots without and tumblemustard was 71% lower. As the other species began to grow, the herbivores eat the seedlings and remove the vegetation. In the model, herbivores do not leave if the food supply becomes low and, therefore, they will be present to consume vegetation as it sprouts. Perhaps densities for these herbivores were too high for this vegetation composition and different results might be seen if the densities were lower.

Table 41. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with light herbivory from insects (3 per m^2) and rabbits (0.30 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	81	0	0	0	0	0
Big sagebrush	0	0	0	0	0	0	0
Rubber rabbitbrush	0	0	0	0	0	0	0
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	0	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	0	0	0	0
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	68	0	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	11	0	0	0	0	0
Litter	0	0	94	94	94	94	94

When moderate herbivory (6 insects/m^2 and 0.56 rabbits/hectare) was included in the model, all species disappear between Year 1 and Year 10 (Table 42). In Year 1 cheatgrass biomass was 19% lower in plots with herbivory than in plots without herbivory and tumblemustard biomass was 90% lower.

Table 42. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with medium herbivory from insects (6 per m^2) and rabbits (0.56 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	65	0	0	0	0	0
Big sagebrush	0	0	0	0	0	0	0
Rubber rabbitbrush	0	0	0	0	0	0	0
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	0	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	0	0	0	0
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	60	0	0	0	0	0
Storksbill	0	0	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	4	0	0	0	0	0
Litter	0	0	59	59	59	59	59

When heavy herbivory (12 insects/m^2 and 0.78 rabbits/hectare) was included in the model, in the first year cheatgrass biomass was 49% lower in plots with herbivory than in those without (Table 43). Tumblemustard was completely eaten in the first year. All biomass had disappeared by Year 10.

Table 43. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with heavy herbivory from insects (12 per m^2) and rabbits (0.78 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	38	0	0	0	0	0
Big sagebrush	0	0	0	0	0	0	0
Rubber rabbitbrush	0	0	0	0	0	0	0
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	0	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	0	0	0	0
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	38	0	0	0	0	0
Storksbill	0	0	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	0	0	0	0	0	0
Litter	0	0	33	33	33	33	33

6.1.6 Grazing

When the impacts of light grazing (120 Ac/AU) were included in the model, total aboveground biomass was 48% lower than in undisturbed plots at Year 50 (Table 44). Community dynamics were also changed by grazing. Although big sagebrush was the dominant species by Year 50 in the ungrazed plots, no sagebrush plants were present in the grazed plots. Instead, rubber rabbitbrush dominated grazed plots. Biomass of all grasses and forbs was zero throughout the 50-year study. In the ungrazed plots, perennial grasses had between 11 and 85 g/m^2 of biomass at Year 50, but in the grazed plots perennial grasses do not establish because the cattle eat the new seedling shoots and stems. Russian knapweed increased in biomass from Year 1 to Year 10 and then slowly decreased over the rest of the study.

Table 44. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with light grazing (120 acres per animal unit) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	108	49	91	180	216	249
Big sagebrush	0	0	0	0	0	0	0
Rubber rabbitbrush	0	0	1	55	173	214	249
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	0	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	0	0	0	0
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	1	12	7	2	1
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	69	46	24	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	38	1	0	0	0	0
Litter	0	0	513	371	86	116	89

The moderate grazing simulation resulted in 66% less biomass than in the ungrazed simulation (Table 45). The long-term species replacement trends were similar to the light grazing community. The community changed from cheatgrass-tumblemustard dominated to rabbitbrush-Russian knapweed dominated. In the moderate grazing simulation, however, Russian knapweed achieved higher relative dominance than in the light grazing simulation because rabbitbrush tended to have lower production. In addition, cheatgrass increased in growth from Year 1 to Year 10, while in undisturbed plots it decreased from Year 1 to Year 10. By Year 20 in the grazed plots, cheatgrass had disappeared.

Table 45. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with moderate grazing (64 acres per animal unit) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	**Year 1**	**Year 10**	**Year 20**	**Year 30**	**Year 40**	**Year 50**
Total	10	104	107	78	87	131	162
Big sagebrush	0	0	0	0	0	0	0
Rubber rabbitbrush	0	0	0	12	46	86	123
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	0	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	0	0	0	0
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	1	18	41	45	39
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	64	104	47	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	38	1	0	0	0	0
Litter	0	0	417	428	254	211	157

When heavy herbivory (32 acres per animal unit) was simulated in the model, total biomass at Year 50 was 85% lower than in undisturbed plots. Sagebrush biomass was zero and rubber rabbitbrush biomass was very low. Russian knapweed increased from Year 20 to Year 50 and was the dominant species at the end of the study.

Grazing, regardless of cattle density, can impact plant production and species composition. Even at the lightest density modelled, the dominant species at the end of the long-term simulation was different from the undisturbed plots, and all of the grasses had disappeared.

Table 46. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with heavy grazing (32 acres per animal unit) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	94	12	23	55	74	74
Big sagebrush	0	0	0	0	0	0	0
Rubber rabbitbrush	0	0	0	0	1	2	4
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	0	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	0	0	0	0
Squirreltail	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	1	14	54	71	71
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0
Cheatgrass	7	55	11	8	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0
Tumblemustard	3	38	0	0	0	0	0
Litter	0	0	174	204	297	304	274

6.1.7 Military Training

Military training was evaluated in three simulations. In the first simulation, the entire area was considered to have been subjected to a single pass of an M-1 Abrams tank. This was modeled in June of Year 5. No subsequent training impacts were included in this scenario. The second simulation was similar to the first, except that the training scenario was repeated once every five years. The third scenario was also similar to the first scenario, except that the training vehicle was a Humvee instead of an M-1.

When impacts of an M-1 Abrams tank passing through the plots in Year 5 was included in the model, total biomass was not much lower (4%) in these plots than in undisturbed plots in Year 50 (Table 47). When the tank passed through in Year 5, total biomass dropped and then started to increase again after the disturbance. Species composition was also affected. In the undisturbed plots big sagebrush was the dominant species, followed by crested wheatgrass and rubber rabbitbrush. In plots with the tank impacts in Year 5, big sagebrush and crested wheatgrass have about the same amount of biomass and are the major species. Big sagebrush biomass was 38% lower and crested wheatgrass was 28% higher in plots with the tank disturbance than in undisturbed plots. Needle-and-thread was slightly higher in disturbed plots over undisturbed plots, while biomass of western wheatgrass and Sandberg bluegrass was not changed.

Table 47. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with military training (M-1 Abrams tank training in Year 5) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	114	45	59	216	339	400	462
Big sagebrush	0	0	0	1	16	39	71	110
Rubber rabbitbrush	0	0	0	9	113	128	107	81
Crested wheatgrass	0	0	0	2	13	36	67	109
Western wheatgrass	0	0	0	3	24	44	49	49
Bluebunch wheatgrass	0	0	1	5	11	11	10	8
Indian ricegrass	0	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	4	25	34	37	36
Squirreltail	0	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	1	7	42	58	69
Yarrow	0	0	0	0	0	0	0	0
Russian knapweed	0	0	0	1	1	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	4	7	4	2	1
Evening primrose	0	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0	0
Cheatgrass	7	74	28	28	0	0	0	0
Storksbill	0	1	0	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0	0
Tumblemustard	3	38	14	2	0	0	0	0
Litter	0	0	415	455	119	92	137	98

Total biomass was greatly reduced when impacts of an M-1 Abrams tank driving over the plots every five years was included in the model (Table 48). At the end of 50 years, total biomass was 83% lower in disturbed plots than in undisturbed plots. Needle-and-thread was the dominant species and most of the other species had disappeared by this time. Thus, repeated disturbance by an army vehicle will change the succession of the community to primarily shrubs to needle-and-thread.

Table 48. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with military training (M-1 Abrams tank training every 5 years) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	114	45	25	24	41	61	81
Big sagebrush	0	0	0	0	0	1	1	2
Rubber rabbitbrush	0	0	0	2	2	0	0	0
Crested wheatgrass	0	0	0	1	3	1	0	0
Western wheatgrass	0	0	0	1	3	4	6	7
Bluebunch wheatgrass	0	0	1	2	1	0	0	0
Indian ricegrass	0	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	3	11	4	1	0
Squirreltail	0	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	3	31	54	72
Yarrow	0	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	1	1	0	0	0
Evening primrose	0	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0	0
Cheatgrass	7	74	28	12	0	0	0	0
Storksbill	0	1	0	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0	0
Tumblemustard	3	38	14	2	0	0	0	0
Litter	0	0	415	481	276	225	235	198

Results for the HMMWV training are identical to the M-1 Abrams tank training because, although the two vehicles have a different "footprint", their cumulative impacts are the same. These results show that if the system is disturbed by army vehicles, vegetation will be negatively impacted and species composition will be different from an undisturbed community. The long-term results depend on how often the community is disturbed (Table 49).

Table 49. EDYS simulation of vegetation dynamics at the Yakima Landscape brome control site with military training (HMMWV training every 5 years) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	10	114	45	25	24	41	61	81
Big sagebrush	0	0	0	0	0	1	1	2
Rubber rabbitbrush	0	0	0	2	2	0	0	0
Crested wheatgrass	0	0	0	1	3	1	0	0
Western wheatgrass	0	0	0	1	3	4	6	7
Bluebunch wheatgrass	0	0	1	2	1	0	0	0
Indian ricegrass	0	0	0	0	0	0	0	0
Sandberg bluegrass	0	0	0	3	11	4	1	0
Squirreltail	0	0	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	3	31	54	72
Yarrow	0	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0	0
Diffuse knapweed	0	0	0	0	0	0	0	0
Shaggy daisy	0	0	0	1	1	0	0	0
Evening primrose	0	0	0	0	0	0	0	0
Longleaf phlox	0	0	0	0	0	0	0	0
Cheatgrass	7	74	28	12	0	0	0	0
Storksbill	0	1	0	0	0	0	0	0
Pepperweed	0	0	0	0	0	0	0	0
Tumblemustard	3	38	14	2	0	0	0	0
Litter	0	0	415	481	276	225	235	198

6.1.8 Brome Modelling Summary

For most of the four years, 95% confidence intervals of the actual and EDYS results overlap for total biomass, cheatgrass, and tumblemustard (Figure 6), indicating that the EDYS simulation was at least as accurate as the sampling technique for these three variables. The accuracy of the EDYS projections was, on average, higher for cheatgrass (89%) than for tumblemustard (62%)(Table 16). Overall, EDYS projections were more accurate in the first and third years than for the second and fourth years.

The purpose of the 50-year simulation was to determine what would happen to this vegetation community in the long term. The EDYS simulations indicate that, if left undisturbed, the control plots invaded by cheatgrass will eventually succeed to a natural sagebrush community (Table 50). Several of the treatments such as prescribed burning or sugar application have no long-term effect on community dynamics, according to the EDYS model simulations. In these plots the vegetation at the end of 50 years is the same as the vegetation in the undisturbed plots. In plots that were seeded with perennial grasses, the dominant species were perennial grasses while in those plots that were not seeded the dominant vegetation was big sagebrush and rubber rabbitbrush.

Table 50. Dominant vegetation species in the YTC brome EDYS simulations after four and 50 years.

Treatment	Dominant Species	
	4 years	**50 years**
Control – Undisturbed	Cheatgrass Tumblemustard	Big sagebrush Rubber rabbitbrush Crested wheatgrass
Burned	Cheatgrass Tumblemustard	Big sagebrush Rubber rabbitbrush Crested wheatgrass
Burned, seeded	Cheatgrass Tumblemustard Bluebunch wheatgrass	Crested wheatgrass Western wheatgrass Indian ricegrass
Burned, sugar application	Cheatgrass	Big sagebrush Rubber rabbitbrush Crested wheatgrass
Burned, seeded, sugar application	Cheatgrass	Crested wheatgrass Western wheatgrass Indian ricegrass
Burned, seeded, inoculation	Cheatgrass Tumblemustard Bluebunch wheatgrass	Crested wheatgrass Western wheatgrass Indian ricegrass
Burned, sugar application, inoculation	Cheatgrass	Big sagebrush Rubber rabbitbrush Crested wheatgrass
Burned, seeded, sugar application, inoculation	Cheatgrass Bluebunch wheatgrass Crested wheatgrass	Crested wheatgrass Western wheatgrass Indian ricegrass

Results of the EDYS simulations indicate that the primary factor affecting species composition at the end of 50 years is seeding of perennial grasses. When plots were seeded, crested wheatgrass, western wheatgrass, and Indian ricegrass were the primary species. In those plots that were not seeded, big sagebrush, rubber rabbitbrush, and crested wheatgrass were the dominant species. Crested wheatgrass and Indian ricegrass were included in the seed mix but western wheatgrass was not.

Herbivory, regardless of insect and rabbit density used in the simulation, significantly reduced biomass on plots by Year 10. Realistic simulations of the results of herbivory by native animals was limited because of lack of population numbers for the site.

The EDYS simulation of light grazing in the brome community showed that little changes occurred in plant production in the first year in comparison to the control pots subjected to no grazing. By Year 50, rabbitbrush was the dominant species, with Russian knapweed becoming second in dominance. The moderate grazing simulation resulted in 60% less biomass than in the ungrazed simulation. The long-term species replacement trends were similar to the light grazing community. The community changed from cheatgrass-tumblemustard dominated to rabbitbrush-Russian knapweed dominated. The heavy grazing simulation resulted in 85% less biomass production than the ungrazed simulation. The community with heavy grazing also changed completely, from a cheatgrass-tumblemustard dominated to one dominated totally by Russian knapweed. Heavy grazing greatly decreased rabbitbrush biomass.

When impacts of military vehicles were included in the model, total aboveground biomass is reduced on the plots and vegetation composition was affected. If the vehicle passes through early in a 50-year simulation, vegetation biomass was reduced in the five or so years following the disturbance. In the long-run, however, the vegetation recovered and was similar to an undisturbed community. In undisturbed communities, shrubs are the major species at the end of 50 years, while in sites disturbed by military vehicles every five years needle-and-thread was the dominant species. These results show that if the system is disturbed by army vehicles, vegetation will be negatively impacted and species composition will be different from an undisturbed community. The long-term results depend on how often the community is disturbed.

6.2 Knapweed Community

6.2.1 Community-Wide Accuracy

EDYS was parameterized for the knapweed community, for each of the different plot-level treatments. The initial conditions were those typical of present conditions. The simulation runs were for 4 years. Simulation values were compared to field-collected aboveground biomass data for all 40 plots for each of the four years.

At the end of four years, cheatgrass was the dominant species when all 40 plots were averaged together (Table 51). Bluebunch wheatgrass, Sandberg bluegrass, and big sagebrush were the second-most dominant species and each increased over the four-year period. This was consistent with the field data.

Table 51. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site and a four-year simulation run. The numbers shown are the means of eight treatments with five replications each.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	50.5	70.4	51.6	95.8	96.4
Big sagebrush	1.00	1.7	4.4	7.6	12.3
Rubber rabbitbrush	0.0	0.1	0.4	0.9	1.2
Crested wheatgrass	1.7	1.1	1.2	2.5	2.4
Western wheatgrass	0.0	0.2	0.3	0.8	1.1
Bluebunch wheatgrass	9.7	6.2	8.2	16.6	18.0
Indian ricegrass	0.0	0.1	0.3	0.7	0.8
Sandberg bluegrass	4.1	4.3	6.9	11.5	14.7
Squirreltail	1.9	1.7	0.8	0.9	0.8
Needle-and-thread	0.8	2.2	6.4	9.7	8.1
Yarrow	0.1	0.1	0.2	0.5	0.4
Russian knapweed	0.3	0.4	0.1	0.1	0.1
Buckwheat milkvetch	1.7	1.2	0.7	0.9	0.9
Diffuse knapweed	23.5	13.9	2.8	1.4	0.7
Shaggy daisy	1.3	1.1	0.7	0.9	0.9
Evening primrose	0.2	0.2	0.1	0.1	0.1
Longleaf phlox	1.5	1.0	0.8	0.9	1.0
Cheatgrass	1.8	28.9	15.8	39.5	32.0
Storksbill	0.8	1.3	0.0	0.0	0.0
Pepperweed	0.2	3.1	0.2	0.0	0.0
Tumblemustard	0.1	1.6	1.1	0.4	1.1
Litter	86.7	121.7	201.3	239.7	285.4

For eight out of the twelve comparisons, 95% confidence intervals of the actual and EDYS results overlap for both species (Figure 7), indicating that the EDYS simulation was at least as accurate as the sampling technique for these three variables. Average percent accuracy of the modelling results for the major species were big sagebrush (67%), bluebunch wheatgrass (79%), Sandberg bluegrass (52%), diffuse knapweed (62%), cheatgrass (74%), and total biomass (74%) (Table 52).

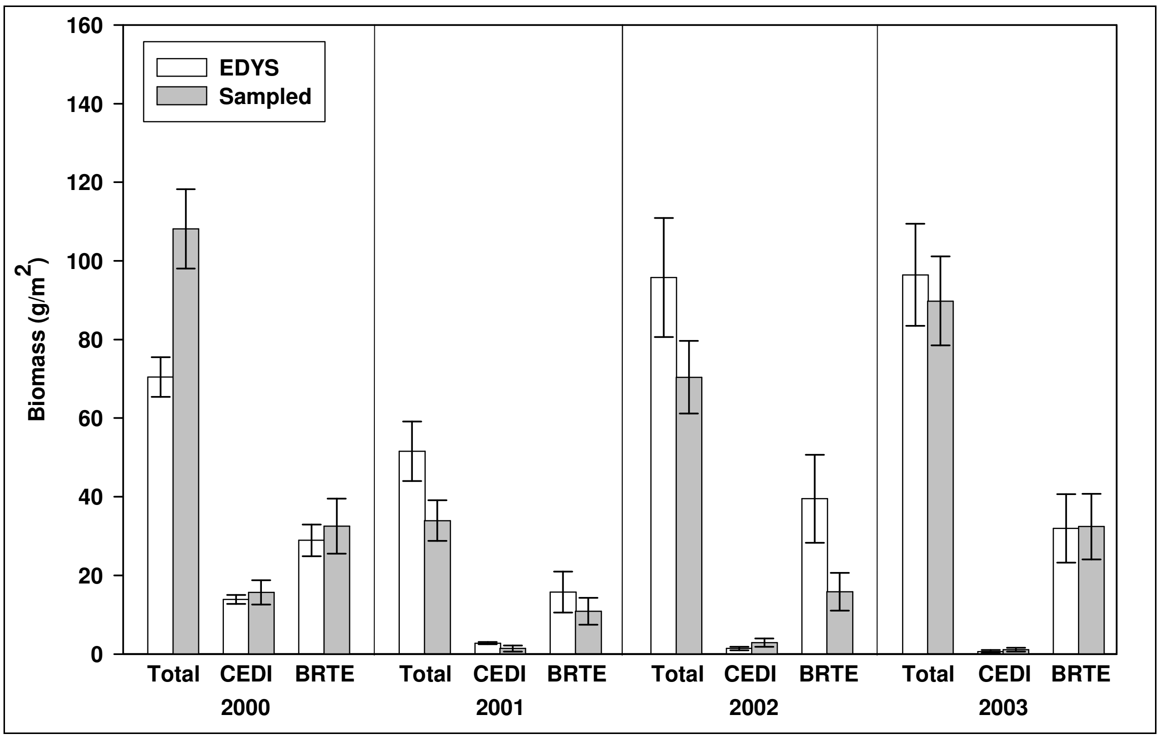

Figure 7. Comparison of aboveground biomass values (g/m^2) between actual and EDYS simulation results for the YTC knapweed site.

Table 52. Percent accuracy for the four-year modelling run for the Yakima knapweed site.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	1.72	9.19	0.187
2001	4.44	3.72	0.838
2002	7.57	8.57	0.883
2003	12.33	9.42	0.764
Bluebunch wheatgrass			
2000	6.21	10.19	0.610
2001	8.24	7.18	0.871
2002	16.64	10.99	0.660
2003	17.97	17.95	0.999
Sandberg bluegrass			
2000	4.33	12.29	0.352
2001	6.91	2.10	0.303
2002	11.47	10.28	0.897
2003	14.74	7.66	0.520
Diffuse knapweed			
2000	13.89	15.66	0.887
2001	2.76	1.43	0.516
2002	1.43	2.89	0.496
2003	0.65	1.13	0.579
Cheatgrass			
2000	28.91	32.57	0.888
2001	15.77	10.91	0.692
2002	39.52	15.84	0.401
2003	31.95	32.44	0.985
Total			
2000	70.42	108.12	0.651
2001	51.55	33.93	0.658
2002	95.76	70.40	0.735
2003	96.43	89.79	0.931

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

6.2.2 Baseline Conditions

The community dynamics of the control plots were modelled without any disturbance included. In this simulation, at the end of four years, sagebrush and cheatgrass were the dominant species (Table 53). Diffuse knapweed biomass decreased during this time and almost no other forbs were present by Year 4.

Table 53. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, under baseline conditions (i.e., no bug, no seeding, no sugar application, and no inoculation) and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	32.4	41.7	26.0	47.0	50.9
Big sagebrush	1.2	2.7	5.3	8.3	12.8
Rubber rabbitbrush	0.0	0.5	1.4	2.8	3.2
Crested wheatgrass	0.6	0.3	0.2	0.2	0.2
Western wheatgrass	0.0	0.4	0.0	0.1	0.1
Bluebunch wheatgrass	4.0	2.6	2.2	3.4	3.7
Indian ricegrass	0.0	0.0	0.0	0.0	0.0
Sandberg bluegrass	4.5	2.6	2.0	3.5	4.4
Squirreltail	1.0	0.6	0.4	0.4	0.3
Needle-and-thread	0.0	0.0	0.3	0.5	0.4
Yarrow	0.0	0.0	0.0	0.0	0.0
Russian knapweed	0.0	0.1	0.0	0.0	0.0
Buckwheat milkvetch	0.0	0.1	0.0	0.0	0.0
Diffuse knapweed	17.5	10.8	3.8	4.7	2.9
Shaggy daisy	0.0	0.1	0.0	0.0	0.0
Evening primrose	0.0	0.1	0.0	0.0	0.0
Longleaf phlox	1.6	0.6	0.6	0.6	0.6
Cheatgrass	1.7	14.6	8.3	22.3	22.3
Storksbill	0.3	1.0	0.0	0.0	0.0
Pepperweed	0.0	4.0	0.5	0.0	0.0
Tumblemustard	0.0	0.7	1.0	0.2	0.0
Litter	102.9	123.4	167.3	196.4	243.1

The major species at the knapweed site were sagebrush, bluebunch wheatgrass, Sandberg bluegrass, diffuse knapweed, and cheatgrass and thus accuracy was determined for these species. At the end of four years, accuracy was high between predicted and actual values for sagebrush (86%), cheatgrass

(89%), and total biomass (85%), but fairly low for bluebunch wheatgrass (55%), Sandberg bluegrass (49%), and knapweed (59%)(Table 54).

Table 54. Percent accuracy for the four-year modelling run for the Yakima knapweed site under baseline conditions (no bug, no seed, no sugar, no inoculation).

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	2.67	8.59	0.311
2001	5.26	8.46	0.622
2002	8.30	10.85	0.765
2003	12.77	14.87	0.859
Bluebunch wheatgrass			
2000	2.55	2.07	0.812
2001	2.18	1.77	0.813
2002	3.37	4.15	0.813
2003	3.68	2.02	0.549
Sandberg bluegrass			
2000	2.62	3.20	0.819
2001	2.00	5.50	0.364
2002	3.47	6.46	0.537
2003	4.40	8.95	0.492
Diffuse knapweed			
2000	10.82	15.64	0.692
2001	3.82	5.28	0.723
2002	4.68	2.69	0.575
2003	2.88	1.7	0.591
Cheatgrass			
2000	14.62	13.41	0.917
2001	8.26	22.16	0.373
2002	22.32	17.22	0.771
2003	22.33	24.98	0.894
Total			
2000	41.66	54.53	0.764
2001	26.02	47.09	0.553
2002	47.02	61.69	0.762
2003	50.93	60.05	0.848

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of 50 years, sagebrush was the dominant species on the undisturbed plots (Table 55). The dominance of sagebrush started in the first four years and is in agreement with the data collected in the field. Sandberg bluegrass, a perennial grass, was the second-most abundant species, although its biomass was small compared to sagebrush. All forbs and cheatgrass had disappeared by Year 30. Thus, if the system is left undisturbed, it is predicted that perennial species such as sagebrush and native grasses will eventually out-compete cheatgrass.

Table 55. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, under baseline conditions (i.e., no bug, no seeding, no sugar application, and no inoculation) and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	36	44	86	191	298	358	416
Big sagebrush	1	2	41	128	210	272	330
Rubber rabbitbrush	0	1	12	21	20	14	9
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	2	4	4	4
Bluebunch wheatgrass	4	3	4	5	8	10	10
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	3	17	29	39	43	46
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	0	0	1	6	17	15	15
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	21	13	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	0	0	0	0	0
Cheatgrass	2	15	10	0	0	0	0
Storksbill	0	1	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	103	126	292	124	62	92	66

6.2.3 Biological Control

Introduction of seedhead-feeding and root-feeding insects has been proposed as a natural means of knapweed control. Species such as *Larinus minutus* have been shown to be more effective than others such as *Urophora* sp. Within four years of introduction of *Larinus*, diffuse knapweed had declined to almost nothing (Table 56). However, as knapweed decreased, cheatgrass increased and was the dominant species by 2003. Perennial grasses such as bluebunch wheatgrass and Sandberg bluegrass increased in biomass during this time as well, but did not out-compete cheatgrass. Thus, in the EDYS simulation, as in the field, essentially no difference was observed between control plots and those with insects released to control knapweed. However, at the end of the four years, control plots contained *Larinus* and, therefore, it was impossible to determine if the decline in knapweed was due to insects or to environmental factors.

Table 56. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects) and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	41.4	66.2	43.0	139.9	136.2
Big sagebrush	0.0	0.3	1.8	2.6	4.6
Rubber rabbitbrush	0.0	0.2	0.7	1.4	2.5
Crested wheatgrass	4.9	3.5	3.3	5.7	6.8
Western wheatgrass	0.0	0.4	0.4	0.9	1.2
Bluebunch wheatgrass	6.8	4.5	6.2	14.1	18.0
Indian ricegrass	0.0	0.0	0.1	0.1	0.2
Sandberg bluegrass	4.5	4.2	7.5	15.5	25.0
Squirreltail	1.0	0.9	0.4	0.4	0.4
Needle-and-thread	0.0	0.4	4.0	4.8	4.7
Yarrow	0.0	0.0	0.0	0.0	0.0
Russian knapweed	0.0	0.2	0.0	0.0	0.0
Buckwheat milkvetch	0.0	0.1	0.1	0.1	0.1
Diffuse knapweed	19.8	11.9	2.2	0.8	0.2
Shaggy daisy	0.0	0.2	0.2	0.3	0.4
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	1.6	0.6	0.6	0.9	0.8
Cheatgrass	1.7	31.4	14.2	90.9	66.2
Storksbill	1.0	1.4	0.0	0.0	0.0
Pepperweed	0.0	4.9	0.3	0.0	0.0
Tumblemustard	0.0	1.0	0.6	1.3	5.3
Litter	80.0	110.1	189.9	225.4	312.2

Accuracy between EDYS modelling results and actual field data was higher for cheatgrass than for the other major species (Table 57). Accuracy for total biomass was fairly high, especially in Years 2 and 4. Average accuracy was 38% for big sagebrush, 70% for bluebunch wheatgrass, 46% for Sandberg bluegrass, 46% for diffuse knapweed, 69% for cheatgrass, and 79% for total biomass.

Table 57. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects).

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	0.29	0.87	0.333
2001	1.84	0.22	0.120
2002	2.57	5.3	0.484
2003	4.59	2.67	0.582
Bluebunch wheatgrass			
2000	4.55	4.23	0.930
2001	6.16	11.31	0.545
2002	14.09	18.24	0.773
2003	18.02	31.78	0.567
Sandberg bluegrass			
2000	4.16	9.88	0.421
2001	7.53	1.52	0.202
2002	15.55	18.70	0.831
2003	24.95	9.20	0.369
Diffuse knapweed			
2000	11.90	18.45	0.645
2001	2.25	1.14	0.508
2002	0.81	3.74	0.217
2003	0.16	0.32	0.488
Cheatgrass			
2000	31.40	38.75	0.810
2001	14.23	19.46	0.731
2002	90.85	24.34	0.268
2003	66.15	61.92	0.936
Total			
2000	66.20	113.76	0.582
2001	43.00	44.28	0.971
2002	139.91	94.85	0.678
2003	136.20	124.09	0.911

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Sagebrush was the dominant species at the end of the 50-year modelling run (Table 58). However, its dominance was lower than in the control treatment. This was due, at least in part, to the lower biomass of sagebrush on the initial years of the study. Perennial grasses such as bluebunch wheatgrass, Sandberg bluegrass, and needle-and-thread grass had also increased by the end of the simulation. Cheatgrass was gone by Year 20, as were most of the forbs.

Table 58. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects) and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	41	66	185	275	373	426	491
Big sagebrush	0	0	15	45	78	117	168
Rubber rabbitbrush	0	0	6	10	10	7	6
Crested wheatgrass	5	3	14	16	18	20	21
Western wheatgrass	0	0	5	15	21	22	21
Bluebunch wheatgrass	7	5	39	61	75	90	103
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	4	53	59	70	79	94
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	0	0	20	68	101	90	79
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	20	12	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	0	0	0	0	0
Cheatgrass	2	31	30	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	5	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	80	110	152	125	96	134	101

6.2.4 Treatment Combinations

In plots with biological control and seeding, cheatgrass was the dominant species at the end of four years (Table 59). Biomass of bluebunch wheatgrass and Sandberg bluegrass was higher than in the plots with biological control and no seeding. Diffuse knapweed biomass decreased dramatically in the four years, as was observed in the previous treatments.

Table 59. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	37.1	64.5	41.4	113.7	141.2
Big sagebrush	0.0	0.4	2.4	3.4	6.5
Rubber rabbitbrush	0.0	0.1	0.3	0.5	1.0
Crested wheatgrass	0.0	0.1	1.4	4.3	5.4
Western wheatgrass	0.0	0.1	0.3	1.1	1.8
Bluebunch wheatgrass	4.5	3.5	7.0	21.0	31.0
Indian ricegrass	0.0	0.0	0.2	0.8	1.6
Sandberg bluegrass	4.0	5.1	8.9	16.3	26.3
Squirreltail	1.3	1.2	0.6	0.6	0.5
Needle-and-thread	1.0	2.4	7.5	11.9	11.8
Yarrow	0.0	0.0	0.3	1.0	1.1
Russian knapweed	0.0	0.2	0.0	0.0	0.0
Buckwheat milkvetch	0.7	0.4	0.4	0.5	0.6
Diffuse knapweed	21.4	12.8	2.4	0.9	0.1
Shaggy daisy	0.0	0.2	0.3	0.4	0.5
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	1.4	1.5	1.3	1.7	1.8
Cheatgrass	1.6	29.3	7.0	47.7	44.8
Storksbill	1.0	1.4	0.0	0.0	0.0
Pepperweed	0.0	4.7	0.3	0.0	0.0
Tumblemustard	0.0	0.9	0.7	1.3	6.3
Litter	86.1	112.1	190.3	243.8	289.0

Accuracy was higher for cheatgrass than for the other dominant species, especially in Years 1 and 4 (Table 60). Percent accuracy for total biomass was fairly high. Average accuracy was 44% for big sagebrush, 53% for bluebunch wheatgrass, 51% for Sandberg bluegrass, 42% for diffuse knapweed, 71% for cheatgrass, and 75% for total biomass, respectively.

Table 60. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects) and seeding.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	0.37	1.94	0.192
2001	2.36	1.11	0.470
2002	3.42	7.61	0.449
2003	6.54	4.27	0.653
Bluebunch wheatgrass			
2000	3.48	6.47	0.538
2001	6.95	3.03	0.436
2002	20.97	13.19	0.629
2003	31.04	15.91	0.513
Sandberg bluegrass			
2000	5.07	15.13	0.335
2001	8.91	3.33	0.374
2002	16.29	19.93	0.818
2003	26.32	13.45	0.511
Diffuse knapweed			
2000	12.81	15.00	0.854
2001	2.40	0.12	0.050
2002	0.91	2.53	0.361
2003	0.15	0.35	0.417
Cheatgrass			
2000	29.29	31.99	0.916
2001	7.03	12.86	0.547
2002	47.67	20.84	0.437
2003	44.78	41.23	0.921
Total			
2000	64.46	102.58	0.628
2001	41.42	33.45	0.808
2002	113.69	90.30	0.794
2003	141.24	99.59	0.705

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of 50 years, the dominant species were sagebrush, bluebunch wheatgrass, Sandberg bluegrass, and needle-and-thread (Table 61). Cheatgrass had disappeared from the plots by Year 20, as did most forbs.

Table 61. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	37	64	208	320	400	451	524
Big sagebrush	0	0	22	53	91	137	195
Rubber rabbitbrush	0	0	2	3	3	2	2
Crested wheatgrass	0	0	9	10	11	12	13
Western wheatgrass	0	0	6	12	15	15	14
Bluebunch wheatgrass	4	3	59	84	97	112	122
Indian ricegrass	0	0	3	3	3	3	3
Sandberg bluegrass	4	5	50	59	68	80	98
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	1	2	51	94	111	91	76
Yarrow	0	0	1	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	1	0	0	0	0	0	0
Diffuse knapweed	21	13	0	0	0	0	0
Shaggy daisy	0	0	1	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	1	2	1	0	0	0	0
Cheatgrass	2	29	1	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	5	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	86	112	95	128	99	136	103

In plots with sugar application and biological control, at the end of four years knapweed declined drastically and bluebunch wheatgrass, sagebrush, and cheatgrass were the dominant species (Table 62). Sugar application increases heterotrophic microbial growth, causing available nitrogen to be lower. Lower nitrogen availability favors growth of perennial species such as sagebrush and bluebunch wheatgrass in comparison to annual species.

Table 62. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), sugar application and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	36.4	67.5	35.4	57.8	60.6
Big sagebrush	1.2	1.9	4.9	8.6	13.7
Rubber rabbitbrush	0.0	0.0	0.1	0.2	0.3
Crested wheatgrass	0.0	0.1	0.1	0.1	0.1
Western wheatgrass	0.0	0.2	0.4	0.9	1.2
Bluebunch wheatgrass	9.4	6.3	9.3	17.1	20.7
Indian ricegrass	0.0	0.0	0.1	0.1	0.1
Sandberg bluegrass	0.5	2.3	3.5	4.8	6.3
Squirreltail	1.0	1.1	0.5	0.6	0.5
Needle-and-thread	0.0	0.4	4.4	5.6	4.1
Yarrow	0.0	0.0	0.0	0.0	0.0
Russian knapweed	0.0	0.2	0.1	0.0	0.0
Buckwheat milkvetch	0.0	0.2	0.1	0.1	0.1
Diffuse knapweed	19.8	12.2	2.3	0.9	0.5
Shaggy daisy	0.0	0.2	0.4	0.4	0.4
Evening primrose	0.0	0.2	0.1	0.1	0.1
Longleaf phlox	1.6	0.6	0.6	0.8	0.9
Cheatgrass	1.9	36.1	8.0	17.3	11.3
Storksbill	1.0	1.5	0.0	0.0	0.0
Pepperweed	0.0	2.6	0.1	0.0	0.0
Tumblemustard	0.0	1.2	0.2	0.1	0.0
Litter	97.0	122.3	205.6	255.6	284.3

Accuracy for most of the species and for total biomass was fairly high for this simulation (Table 63). Accuracy for total biomass in Year 3 was 99.9% and average accuracy for the 4-year period was 81%. Average accuracy was 66% for big sagebrush, 82% for bluebunch wheatgrass, 49% for Sandberg bluegrass, 48% for diffuse knapweed, 75% for cheatgrass, and 81% for total biomass.

Table 63. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects) and sugar application.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	1.91	8.87	0.216
2001	4.87	5.06	0.962
2002	8.56	6.27	0.732
2003	13.68	10.02	0.733
Bluebunch wheatgrass			
2000	6.34	9.91	0.640
2001	9.32	9.14	0.980
2002	17.10	13.27	0.776
2003	20.75	23.41	0.886
Sandberg bluegrass			
2000	2.25	11.94	0.188
2001	3.51	2.24	0.638
2002	4.84	3.88	0.802
2003	6.35	2.08	0.328
Diffuse knapweed			
2000	12.23	11.53	0.943
2001	2.34	1.05	0.449
2002	0.93	5.41	0.172
2003	0.49	1.40	0.351
Cheatgrass			
2000	36.14	35.79	0.990
2001	8.01	5.70	0.711
2002	17.28	14.01	0.811
2003	11.26	22.20	0.507
Total			
2000	67.45	100.46	0.671
2001	35.40	27.40	0.774
2002	57.83	57.86	0.999
2003	60.55	77.56	0.781

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

By Year 10, big sagebrush and bluebunch wheatgrass were the dominant species on the plots (Table 64). Cheatgrass and most forbs had disappeared by this time. At the end of the 50-year run, the plots were dominated primarily by big sagebrush, with some bunchgrasses also present.

Table 64. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), sugar application and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	36	67	206	364	471	537	597
Big sagebrush	1	2	81	172	253	322	387
Rubber rabbitbrush	0	0	2	2	2	1	1
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	6	12	15	14	13
Bluebunch wheatgrass	9	6	62	87	105	118	123
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	0	2	19	24	28	30	34
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	0	0	35	65	67	50	37
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	20	12	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	1	0	0	0	0
Cheatgrass	2	36	1	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	3	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	97	122	100	118	91	128	98

When biological control, seeding, and sugar application were modelled together, Sandberg bluegrass, bluebunch wheatgrass and sagebrush were the dominant species at the end of four years (Table 65). Diffuse knapweed biomass was less than 1 g/m^2 and cheatgrass biomass had declined. Seeding of perennials and lowering of available soil nitrogen promoted the growth of perennial species over forbs and the annual grass, cheatgrass.

Table 65. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding, sugar application and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	41.1	78.6	45.0	76.7	72.4
Big sagebrush	1.0	1.7	4.6	8.2	13.3
Rubber rabbitbrush	0.0	0.1	0.2	0.5	0.8
Crested wheatgrass	0.0	0.1	1.0	3.6	3.1
Western wheatgrass	0.0	0.1	0.3	1.2	1.7
Bluebunch wheatgrass	4.5	3.4	5.3	13.0	14.4
Indian ricegrass	0.0	0.0	0.1	0.7	0.7
Sandberg bluegrass	2.6	4.6	7.8	11.7	15.9
Squirreltail	4.2	3.4	1.8	2.0	1.9
Needle-and-thread	1.0	2.6	8.3	12.9	9.7
Yarrow	0.0	0.4	0.4	0.9	0.6
Russian knapweed	0.0	0.2	0.0	0.0	0.0
Buckwheat milkvetch	0.7	0.4	0.3	0.4	0.4
Diffuse knapweed	21.4	12.9	2.5	1.0	0.5
Shaggy daisy	0.0	0.2	0.2	0.2	0.2
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	1.4	1.5	1.0	1.1	1.2
Cheatgrass	3.2	41.2	10.7	19.1	7.8
Storksbill	1.0	1.4	0.0	0.0	0.0
Pepperweed	0.0	3.2	0.2	0.0	0.0
Tumblemustard	0.0	1.2	0.2	0.1	0.0
Litter	91.7	118.6	206.9	251.2	292.0

Of the dominant species, accuracy between EDYS values and actual sampled values was highest for bluebunch wheatgrass (Table 66). Total biomass accuracy ranged from 44 to 85%. Average accuracy was 45% for big sagebrush, 78% for bluebunch wheatgrass, 25% for Sandberg bluegrass, 56% for diffuse knapweed, 60% for cheatgrass, and 65% for total biomass, respectively.

Table 66. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects), seeding, and sugar application.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	1.67	12.41	0.134
2001	4.62	1.07	0.232
2002	8.22	6.99	0.851
2003	13.27	7.87	0.593
Bluebunch wheatgrass			
2000	3.37	4.02	0.838
2001	5.32	5.23	0.982
2002	13.04	5.88	0.451
2003	14.42	12.23	0.848
Sandberg bluegrass			
2000	4.61	14.35	0.321
2001	7.81	0.61	0.078
2002	11.74	3.05	0.260
2003	15.94	5.25	0.329
Diffuse knapweed			
2000	12.95	10.52	0.812
2001	2.46	1.29	0.525
2002	0.97	2.74	0.355
2003	0.52	0.95	0.545
Cheatgrass			
2000	41.22	51.05	0.807
2001	10.66	6.48	0.608
2002	19.14	14.99	0.783
2003	7.80	35.97	0.217
Total			
2000	78.56	120.70	0.651
2001	45.02	19.66	0.437
2002	76.72	49.64	0.647
2003	72.36	85.66	0.845

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

By Year 10, sagebrush, bluebunch wheatgrass, Sandberg bluegrass and needle-and-thread grass were the dominant species (Table 67). Cheatgrass was no longer present in the plots by Year 10 and most of the forbs had very little biomass.

Table 67. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding, sugar application and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	41	79	219	345	430	493	552
Big sagebrush	1	2	65	136	214	292	371
Rubber rabbitbrush	0	0	2	3	2	1	1
Crested wheatgrass	0	0	6	6	6	6	6
Western wheatgrass	0	0	8	15	19	18	16
Bluebunch wheatgrass	4	3	36	48	54	57	55
Indian ricegrass	0	0	2	2	2	2	1
Sandberg bluegrass	3	5	43	52	56	61	63
Squirreltail	4	3	1	0	0	0	0
Needle-and-thread	1	3	55	82	77	57	39
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	1	0	0	0	0	0	0
Diffuse knapweed	21	13	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	1	2	1	0	0	0	0
Cheatgrass	3	41	0	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	3	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	92	119	86	118	88	121	91

At the end of the four-year simulation, cheatgrass was the dominant species in the plots receiving biological control, seeding and soil inoculation (Table 68). Sandberg bluegrass, big sagebrush, and bluebunch wheatgrass had about half the biomass of cheatgrass. Biomass of all forbs was very low.

Table 68. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding, soil inoculation and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	45.0	73.9	60.7	149.1	137.7
Big sagebrush	2.0	3.0	6.9	12.8	22.4
Rubber rabbitbrush	0.0	0.1	0.3	0.5	0.8
Crested wheatgrass	0.0	0.1	1.3	3.7	3.8
Western wheatgrass	0.0	0.1	0.2	0.8	1.1
Bluebunch wheatgrass	4.5	3.5	5.7	15.6	17.8
Indian ricegrass	0.0	0.0	0.2	0.7	1.3
Sandberg bluegrass	5.3	6.1	10.0	17.0	23.5
Squirreltail	1.3	1.2	0.6	0.6	0.5
Needle-and-thread	2.2	5.6	12.2	18.5	18.2
Yarrow	0.0	0.0	0.3	0.9	0.8
Russian knapweed	0.0	0.2	0.0	0.0	0.0
Buckwheat milkvetch	0.5	0.8	0.5	0.6	0.5
Diffuse knapweed	24.3	14.5	2.7	0.9	0.1
Shaggy daisy	0.8	0.5	0.6	0.8	0.9
Evening primrose	0.0	0.1	0.1	0.1	0.1
Longleaf phlox	1.4	1.5	1.0	1.2	1.1
Cheatgrass	1.6	32.3	17.8	74.0	43.4
Storksbill	1.0	1.4	0.0	0.0	0.0
Pepperweed	0.0	2.4	0.1	0.0	0.0
Tumblemustard	0.0	0.5	0.3	0.6	1.6
Litter	88.3	118.2	195.2	224.4	283.6

In plots with insects, seeding, and soil inoculation, modelling accuracy for cheatgrass was fairly high, with the exception of Year 3 (Table 69). Average accuracy was 57% for big sagebrush, 59% for bluebunch wheatgrass, 50% for Sandberg bluegrass, 52% for diffuse knapweed, 76% for cheatgrass, and 71% for total biomass.

Table 69. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects), seeding, and soil inoculation.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	3.00	27.81	0.108
2001	6.95	4.89	0.704
2002	12.84	23.57	0.545
2003	22.35	20.85	0.933
Bluebunch wheatgrass			
2000	3.50	18.07	0.194
2001	5.66	10.38	0.545
2002	15.57	14.89	0.957
2003	17.81	11.69	0.656
Sandberg bluegrass			
2000	6.08	16.48	0.369
2001	10.04	2.03	0.202
2002	16.99	25.23	0.673
2003	23.49	17.91	0.763
Diffuse knapweed			
2000	14.47	14.89	0.972
2001	2.68	1.12	0.418
2002	0.93	1.50	0.617
2003	0.08	1.34	0.058
Cheatgrass			
2000	32.26	29.82	0.924
2001	17.81	14.62	0.821
2002	73.95	25.80	0.349
2003	43.42	45.99	0.944
Total			
2000	73.88	131.85	0.560
2001	60.67	41.87	0.690
2002	149.09	106.36	0.713
2003	137.74	118.53	0.861

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Total aboveground biomass was 32% greater at Year 50 when biological control, seeding, and inoculation were included in the simulation than when no treatments were included (Table 70). Biomass increased over the 50 years and at the end of the simulation big sagebrush was the dominant species. There were several perennial grasses present at Year 50 but all forbs and cheatgrass had disappeared.

Table 70. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding, soil inoculation and a 50-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	45	74	217	338	423	486	550
Big sagebrush	2	3	73	150	234	317	402
Rubber rabbitbrush	0	0	2	2	1	1	1
Crested wheatgrass	0	0	6	7	7	6	6
Western wheatgrass	0	0	3	5	6	6	5
Bluebunch wheatgrass	4	3	29	37	41	43	40
Indian ricegrass	0	0	2	2	2	2	1
Sandberg bluegrass	5	6	40	49	52	56	57
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	2	6	60	87	78	56	38
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	1	1	0	0	0	0	0
Diffuse knapweed	24	14	0	0	0	0	0
Shaggy daisy	1	1	1	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	1	2	1	0	0	0	0
Cheatgrass	2	32	0	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	2	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	88	118	85	114	85	117	89

In plots with insects, sugar application, and soil inoculation, bluebunch wheatgrass, big sagebrush, and cheatgrass were the dominant species at the end of four years (Table 71). Diffuse knapweed biomass was very low at the end of the simulation.

Table 71. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), sugar application, soil inoculation and a four-year simulation run (mean of five plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	38.1	68.6	38.9	55.0	59.5
Big sagebrush	1.2	1.9	4.8	8.6	13.4
Rubber rabbitbrush	0.0	0.0	0.1	0.2	0.3
Crested wheatgrass	0.4	0.2	0.2	0.2	0.2
Western wheatgrass	0.0	0.2	0.4	0.8	1.1
Bluebunch wheatgrass	9.4	6.3	8.7	14.0	16.4
Indian ricegrass	0.0	0.4	1.2	2.0	2.0
Sandberg bluegrass	0.5	2.2	3.4	4.5	5.6
Squirreltail	1.0	1.1	0.4	0.5	0.4
Needle-and-thread	0.0	0.4	4.3	5.5	3.9
Yarrow	0.0	0.2	0.2	0.2	0.2
Russian knapweed	0.0	0.2	0.0	0.0	0.0
Buckwheat milkvetch	1.3	0.7	0.6	0.7	0.8
Diffuse knapweed	19.8	12.2	2.3	0.9	0.5
Shaggy daisy	0.0	0.2	0.4	0.4	0.4
Evening primrose	0.0	0.2	0.1	0.1	0.1
Longleaf phlox	1.6	0.6	0.6	0.7	0.8
Cheatgrass	1.9	36.3	10.6	15.5	13.2
Storksbill	1.0	1.4	0.0	0.0	0.0
Pepperweed	0.0	2.6	0.1	0.0	0.0
Tumblemustard	0.0	1.2	0.2	0.1	0.0
Litter	76.7	103.3	188.3	236.9	266.6

Accuracy for total biomass was 93% in Year 2, 99% in Year 3, and 91% in Year 4 (Table 72). Average accuracy was 60% for big sagebrush, 60% for bluebunch wheatgrass, 43% for Sandberg bluegrass, 41% for diffuse knapweed, 58% for cheatgrass, and 86% for total biomass.

Table 72. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects), sugar application, and soil inoculation.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	1.91	9.63	0.198
2001	4.85	8.37	0.579
2002	8.59	6.82	0.794
2003	13.35	10.90	0.816
Bluebunch wheatgrass			
2000	6.29	18.29	0.344
2001	8.73	10.00	0.873
2002	14.02	5.25	0.374
2003	16.35	13.11	0.802
Sandberg bluegrass			
2000	2.21	12.65	0.174
2001	3.42	1.10	0.322
2002	4.48	3.35	0.748
2003	5.64	2.76	0.489
Diffuse knapweed			
2000	12.18	19.27	0.632
2001	2.33	1.00	0.428
2002	0.93	2.75	0.338
2003	0.50	2.08	0.238
Cheatgrass			
2000	36.30	31.44	0.866
2001	10.57	2.70	0.256
2002	15.50	6.65	0.429
2003	13.25	16.98	0.780
Total			
2000	68.60	111.29	0.616
2001	38.91	36.10	0.928
2002	54.96	54.18	0.986
2003	59.47	65.54	0.907

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Sagebrush was the dominant species by Year 10 and continued to dominate throughout the 50-year simulation (Table 73). Bluebunch wheatgrass was the second-most abundant species by Year 50, followed by needle-and-thread and Sandberg bluegrass. No forbs or cheatgrass were present.

Table 73. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), sugar application, soil inoculation and a 50-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	38	69	202	344	447	520	579
Big sagebrush	1	2	86	178	258	332	396
Rubber rabbitbrush	0	0	2	2	2	1	1
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	0	0	6	12	14	12	11
Bluebunch wheatgrass	9	6	44	58	74	88	96
Indian ricegrass	0	0	7	7	7	6	6
Sandberg bluegrass	0	2	19	22	26	29	32
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	0	0	36	64	66	51	38
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	1	1	1	0	0	0	0
Diffuse knapweed	20	12	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	1	0	0	0	0
Cheatgrass	2	36	0	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	3	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	77	103	108	113	88	124	95

When all four treatments were included in one simulation (biological control, seeding, sugar application, and soil inoculation), bluebunch wheatgrass and cheatgrass were the dominant species at the end of four years (Table 74).

Table 74. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding, sugar application, soil inoculation and a 4-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	83.1	100.9	98.8	97.1	89.1
Big sagebrush	1.2	1.8	3.9	6.8	10.4
Rubber rabbitbrush	0.0	0.0	0.1	0.2	0.3
Crested wheatgrass	1.8	1.6	1.5	3.7	3.3
Western wheatgrass	0.0	0.2	0.2	0.6	0.8
Bluebunch wheatgrass	21.4	12.3	13.7	24.5	24.2
Indian ricegrass	0.0	0.0	0.1	0.6	0.6
Sandberg bluegrass	2.9	2.7	3.8	6.1	8.0
Squirreltail	4.9	3.2	2.1	2.3	2.1
Needle-and-thread	1.2	4.0	8.0	14.3	9.8
Yarrow	0.0	0.0	0.2	0.6	0.4
Russian knapweed	0.0	0.1	0.0	0.0	0.0
Buckwheat milkvetch	10.6	5.9	4.0	4.7	4.9
Diffuse knapweed	31.5	17.9	3.2	1.2	0.5
Shaggy daisy	0.6	1.4	0.3	0.4	0.4
Evening primrose	1.3	0.6	0.5	0.6	0.7
Longleaf phlox	2.1	1.2	0.8	0.9	0.9
Cheatgrass	1.9	37.9	51.0	29.3	21.8
Storksbill	1.0	1.3	0.0	0.0	0.0
Pepperweed	0.0	2.7	0.1	0.0	0.0
Tumblemustard	0.7	6.1	5.3	0.3	0.0
Litter	70.7	128.4	222.7	287.5	343.6

Accuracy for this simulation was lower than in previous simulations, perhaps because of the increased complexity inherent with four treatments (Table 75). Average accuracy was 31% for big sagebrush, 60% for bluebunch wheatgrass, 20% for Sandberg bluegrass, 58% for diffuse knapweed, 35% for cheatgrass, and 62% for total biomass.

Table 75. Percent accuracy for the four-year modelling run for the Yakima knapweed site with biological control (knapweed-feeding insects), seeding, sugar application, and soil inoculation.

Variable	Predicted	Sampled	Accuracy
Big sagebrush			
2000	1.81	3.41	0.530
2001	3.89	0.57	0.147
2002	6.83	1.18	0.173
2003	10.42	3.94	0.378
Bluebunch wheatgrass			
2000	12.29	18.50	0.664
2001	13.69	6.55	0.479
2002	24.54	13.02	0.531
2003	24.23	33.46	0.724
Sandberg bluegrass			
2000	2.70	14.65	0.184
2001	3.84	0.46	0.120
2002	6.07	1.67	0.275
2003	8.00	1.68	0.210
Diffuse knapweed			
2000	17.88	19.95	0.896
2001	3.16	0.41	0.130
2002	1.18	1.71	0.690
2003	0.54	0.88	0.618
Cheatgrass			
2000	37.86	28.29	0.747
2001	51.01	3.30	0.065
2002	29.26	2.91	0.099
2003	21.75	10.22	0.470
Total			
2000	100.88	129.77	0.777
2001	98.78	21.62	0.219
2002	97.06	48.30	0.498
2003	89.11	87.30	0.980

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of the 50-year simulation, big sagebrush was the dominant species on the plots (Table 76). Minor species included needle-and-thread, Sandberg bluegrass, and bluebunch wheatgrass but no forbs or annual grasses were present.

Table 76. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed site, with biological control (knapweed-feeding insects), seeding, sugar application, soil inoculation and a 50-year simulation run (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	83.1	100.9	173.0	278.9	368.1	428.2	494.1
Big sagebrush	1.2	1.8	49.4	114.3	183.4	248.3	316.1
Rubber rabbitbrush	0.0	0.0	0.8	1.1	1.0	0.8	0.6
Crested wheatgrass	1.8	1.6	8.4	10.0	11.5	13.2	14.0
Western wheatgrass	0.0	0.2	3.7	8.0	10.6	10.9	10.6
Bluebunch wheatgrass	21.4	12.3	23.0	16.8	20.8	29.7	37.0
Indian ricegrass	0.0	0.0	1.5	1.7	1.9	1.9	2.0
Sandberg bluegrass	2.9	2.7	22.5	27.0	33.1	39.7	46.5
Squirreltail	4.9	3.2	1.0	0.2	0.1	0.0	0.0
Needle-and-thread	1.2	4.0	57.2	98.6	105.4	83.7	67.3
Yarrow	0.0	0.0	0.2	0.1	0.0	0.0	0.0
Russian knapweed	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Buckwheat milkvetch	10.6	5.9	3.4	0.9	0.2	0.0	0.0
Diffuse knapweed	31.5	17.9	0.0	0.0	0.0	0.0	0.0
Shaggy daisy	0.6	1.4	0.3	0.1	0.0	0.0	0.0
Evening primrose	1.3	0.6	0.4	0.1	0.0	0.0	0.0
Longleaf phlox	2.1	1.2	0.5	0.1	0.0	0.0	0.0
Cheatgrass	1.9	37.9	0.6	0.0	0.0	0.0	0.0
Storksbill	1.0	1.3	0.0	0.0	0.0	0.0	0.0
Pepperweed	0.0	2.7	0.0	0.0	0.0	0.0	0.0
Tumblemustard	0.7	6.1	0.0	0.0	0.0	0.0	0.0
Litter	70.7	128.4	156.1	109.8	81.7	115.0	88.8

6.2.5 Herbivory

When light herbivory (3 insects/m^2 and 0.30 rabbits/hectare) was included in the model, total biomass declined (Table 77). Total aboveground biomass was reduced 88% in Year 50 compared to undisturbed plots. Big sagebrush growth was reduced to almost zero, compared to being the dominant species by Year 20, in the absence of herbivory. In the undisturbed plots, rabbitbrush production was very low, but with light herbivory the shrub became the dominant species by Year 10. Rabbits prefer sagebrush leaves over rubber rabbitbrush leaves (Appendix Table 24) and this preference may have given rabbitbrush a competitive edge over sagebrush.

Table 77. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with light herbivory from insects (3 per m^2) and rabbits (0.30 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	28	5	22	31	38	49
Big sagebrush	1	2	1	1	1	1	1
Rubber rabbitbrush	0	0	3	21	30	37	48
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	2	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	2	0	0	0	0	0
Squirreltail	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	17	9	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	0	0	0	0	0	0
Cheatgrass	2	10	0	0	0	0	0
Storksbill	1	0	0	0	0	0	0
Pepperweed	0	2	0	0	0	0	0
Tumblemustard	0	0	0	0	0	0	0
Litter	103	124	158	184	165	155	137

When moderate herbivory (6 insects/m^2 and 0.56 rabbits/hectare) was included in the model, total biomass was 92% lower than in plots without herbivory (Table 78). Big sagebrush maintained 1 g/m^2 of biomass while rubber rabbitbrush became the dominant species between years 20 and 30. At the end of 50 years biomass of rubber rabbitbrush was 71% higher than in undisturbed plots at the same time.

Table 78. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with medium herbivory from insects (6 per m^2) and rabbits (0.56 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	12	1	2	12	25	32
Big sagebrush	1	1	1	1	1	1	1
Rubber rabbitbrush	0	0	0	1	11	24	31
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	0	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	1	0	0	0	0	0
Squirreltail	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	17	7	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	0	0	0	0	0	0
Cheatgrass	2	2	0	0	0	0	0
Storksbill	1	0	0	0	0	0	0
Pepperweed	0	1	0	0	0	0	0
Tumblemustard	0	0	0	0	0	0	0
Litter	103	123	133	137	153	166	149

With heavy herbivory (12 insects/m^2 and 0.78 rabbits/hectare) biomass was reduced even more than with light herbivory (Table 79). Total aboveground biomass was 96% lower than without herbivory. As with light herbivory big sagebrush maintained about 1 g/m^2 in plots and rubber rabbitbrush was the dominant species, although biomass was very low.

Table 79. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with heavy herbivory from insects (12 per m^2) and rabbits (0.78 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	22	2	3	7	15	17
Big sagebrush	1	1	1	1	1	1	1
Rubber rabbitbrush	0	0	0	1	6	14	16
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	1	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	1	0	0	0	0	0
Squirreltail	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	17	8	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	0	0	0	0	0	0
Cheatgrass	2	9	0	0	0	0	0
Storksbill	1	0	0	0	0	0	0
Pepperweed	0	1	0	0	0	0	0
Tumblemustard	0	0	0	0	0	0	0
Litter	103	123	145	150	160	171	167

6.1.6 Grazing

When light cattle grazing (120 Ac/AU) was included in the model, total aboveground biomass was 59% lower than in undisturbed plots at Year 50 (Table 80). Sagebrush was the dominant species at the end of the 50-year run in control plots, but in lightly grazed plots both sagebrush and rubber rabbitbrush were major species. During this time, sagebrush biomass decreased while rubber rabbitbrush biomass increased, compared to ungrazed. All grasses and forbs disappeared over time with grazing, with the exception of Russian knapweed. Biomass of Russian knapweed increased in the last 20 years of the simulation.

Table 80. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with light grazing (120 acres per animal unit) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	40	31	67	114	145	169
Big sagebrush	1	3	9	34	58	73	84
Rubber rabbitbrush	0	1	14	33	53	64	71
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	2	1	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	1	2	0	0	0	0
Squirreltail	1	1	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	3	8	13
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	17	11	1	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	0	0	0	0	0
Cheatgrass	2	15	3	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	103	122	271	203	168	156	164

With moderate levels of grazing (64 acres per animal unit), total aboveground biomass was 78% lower in grazed plots than in undisturbed plots at Year 50. Sagebrush was no longer present in plots and rubber rabbitbrush was the dominant species at the end of the simulation. Russian knapweed biomass increased in the last 20 years of the study but all other grasses and forbs were gone.

Table 81. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with moderate grazing (64 acres per animal unit) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	38	14	33	50	82	93
Big sagebrush	1	3	2	1	1	1	1
Rubber rabbitbrush	0	1	11	31	44	61	70
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	1	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	1	0	0	0	0	0
Squirreltail	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	5	20	22
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	17	11	1	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	0	0	0	0	0
Cheatgrass	2	14	0	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	103	122	243	232	237	229	213

Results for the impacts of heavy grazing (32 acres per animal unit) on vegetation were very similar to those with a moderate level of grazing (Table 82). Total aboveground biomass was 78% lower in grazed plots than in control plots. Sagebrush biomass was negligible and rubber rabbitbrush was the dominant species. Russian knapweed was the only forb left at Year 50 and all other grasses were gone as well.

Table 82. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with heavy grazing (32 acres per animal unit) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	33	12	30	44	76	90
Big sagebrush	1	2	1	1	1	1	1
Rubber rabbitbrush	0	1	10	29	37	54	68
Crested wheatgrass	1	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	1	0	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0
Sandberg bluegrass	5	1	0	0	0	0	0
Squirreltail	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	0	0	0	0
Yarrow	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	7	21	21
Buckwheat milkvetch	0	0	0	0	0	0	0
Diffuse knapweed	17	11	1	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0
Longleaf phlox	2	1	0	0	0	0	0
Cheatgrass	2	10	0	0	0	0	0
Storksbill	1	1	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0
Litter	103	121	225	222	231	234	213

6.1.7 Military Training

Military training was evaluated in three simulations. In the first simulation, the entire area was considered to have been subjected to a single pass of an M-1 Abrams tank. This was modeled in June of Year 5. No subsequent training impacts were included in this scenario. The second simulation was similar to the first, except that the training scenario was repeated once every five years. The third scenario was also similar to the first scenario, except that the training vehicle was a Humvee instead of an M-1.

When impacts of an M-1 Abrams tank driving through the plots in Year 5 was simulated with EDYS, total biomass was only 3% lower than in plots with no training at the end of 50 years (Table 83). No differences were observed in species composition in plots with the tank disturbance than in plots without the disturbance. Thus, a one-time disturbance event of this type will not negatively affect vegetation over the long term.

Table 83. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with military training (M-1 Abrams tank training in Year 5) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	42	12	70	163	278	342	404
Big sagebrush	1	3	1	27	112	202	270	331
Rubber rabbitbrush	0	1	0	7	18	19	14	9
Crested wheatgrass	1	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	1	4	5	5
Bluebunch wheatgrass	4	3	2	4	2	1	1	1
Indian ricegrass	0	0	0	0	0	0	0	0
Sandberg bluegrass	5	3	3	12	25	36	39	42
Squirreltail	1	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	1	5	16	14	15
Yarrow	0	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0	0
Diffuse knapweed	17	11	1	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0	0
Longleaf phlox	2	1	1	0	0	0	0	0
Cheatgrass	2	15	4	18	0	0	0	0
Storksbill	1	1	0	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0	0
Litter	103	124	306	333	148	60	89	64

When impacts of the M-1 Abrams tank driving through the plots every five years was simulated, vegetation was negatively impacted (Table 84). Total biomass was only 6 g/m^2 by Year 20 and stayed about this amount throughout the study. Because the tank crushes vegetation, a vehicle disturbance every five years apparently does not allow sufficient time for the plants to recover.

Table 84. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with military training (M-1 Abrams tank training every 5 years) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	42	12	18	5	5	5	6
Big sagebrush	1	3	1	1	2	2	3	3
Rubber rabbitbrush	0	1	0	0	0	0	0	0
Crested wheatgrass	1	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	3	2	1	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0	0
Sandberg bluegrass	5	3	3	6	1	0	0	0
Squirreltail	1	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	1	2	2	2	2
Yarrow	0	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0	0
Diffuse knapweed	17	11	1	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0	0
Longleaf phlox	2	1	1	0	0	0	0	0
Cheatgrass	2	15	4	8	0	0	0	0
Storksbill	1	1	0	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0	0
Litter	103	124	306	375	364	339	316	291

When impacts of a HMMWV driving through the plots every five years were included in the model, impacts were the same as with the M-1 Abrams tank (Table 85). Vegetation was very low by Year 20 and stays that way throughout the simulation.

Table 85. EDYS simulation of vegetation dynamics at the Yakima Landscape knapweed control site with military training (HMMWV training every 5 years) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	33	42	12	18	5	5	5	6
Big sagebrush	1	3	1	1	2	2	3	3
Rubber rabbitbrush	0	1	0	0	0	0	0	0
Crested wheatgrass	1	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0	0
Bluebunch wheatgrass	4	3	2	1	0	0	0	0
Indian ricegrass	0	0	0	0	0	0	0	0
Sandberg bluegrass	5	3	3	6	1	0	0	0
Squirreltail	1	1	0	0	0	0	0	0
Needle-and-thread	0	0	0	1	2	2	2	2
Yarrow	0	0	0	0	0	0	0	0
Russian knapweed	0	0	0	0	0	0	0	0
Buckwheat milkvetch	0	0	0	0	0	0	0	0
Diffuse knapweed	17	11	1	0	0	0	0	0
Shaggy daisy	0	0	0	0	0	0	0	0
Evening primrose	0	0	0	0	0	0	0	0
Longleaf phlox	2	1	1	0	0	0	0	0
Cheatgrass	2	15	4	8	0	0	0	0
Storksbill	1	1	0	0	0	0	0	0
Pepperweed	0	4	0	0	0	0	0	0
Tumblemustard	0	1	0	0	0	0	0	0
Litter	103	124	306	375	364	339	316	291

6.2.8 Knapweed Modelling Summary

For the majority of the four years, 95% confidence intervals of the actual and EDYS results overlap for cheatgrass, knapweed, and total biomass (Figure 7), indicating that the EDYS simulation was at least as accurate as the sampling technique for these three variables. Average percent accuracy of the modelling results was 67% for big sagebrush, 79% for bluebunch wheatgrass, 52% for Sandberg bluegrass, 62% for diffuse knapweed, 74% for cheatgrass, and 74% for total biomass, respectively.

At the end of four years, cheatgrass was the dominant species in all plots, except those that received sugar (Table 86). In plots with added sugar, bluebunch wheatgrass had a higher biomass than cheatgrass. Application of sugar decreases available nitrogen and, thus, gives a competitive advantage to perennial species. In the brome sites, perennial grasses dominated in plots that were seeded but in the knapweed sites seeding did not appear to have any impact. A possible reason for this was the higher initial presence of shrubs in the knapweed site. Shrubs were very low on the brome site at the beginning of the study and, thus, the seeded grasses would not have had competition from shrubs.

All of the plots converged to a sagebrush community at the end of the 50-year simulations. There did not seem to be any real difference in the community dynamics as were seen in the brome site. Regardless of the treatment, big sagebrush, Sandberg bluegrass, bluebunch wheatgrass, and needle-and-thread grass dominated the community. These model results seem to be a realistic picture of long-term community dynamics.

Table 86. Dominant vegetation species in the YTC knapweed EDYS simulations after four and 50 years.

Treatment	Dominant Species	
	4 years	**50 years**
Control – Undisturbed	Cheatgrass Big sagebrush	Big sagebrush Sandberg bluegrass
Bug	Cheatgrass Sandberg bluegrass Bluebunch wheatgrass	Big sagebrush Bluebunch wheatgrass Sandberg bluegrass Needle-and-thread
Bug, seeded	Cheatgrass Bluebunch wheatgrass Sandberg bluegrass	Big sagebrush Bluebunch wheatgrass Sandberg bluegrass Needle-and-thread
Bug, sugar application	Bluebunch wheatgrass Big sagebrush Cheatgrass	Big sagebrush Bluebunch wheatgrass Sandberg bluegrass Needle-and-thread
Bug, seeded, sugar application	Sandberg bluegrass Bluebunch wheatgrass Big sagebrush	Sandberg bluegrass Bluebunch wheatgrass Needle-and-thread
Bug, seeded, inoculation	Cheatgrass Big sagebrush Sandberg bluegrass	Big sagebrush Sandberg bluegrass Bluebunch wheatgrass Needle-and-thread
Bug, sugar application, inoculation	Bluebunch wheatgrass Big sagebrush Cheatgrass	Big sagebrush Bluebunch wheatgrass Needle-and-thread Sandberg bluegrass
Bug, seeded, sugar application, inoculation	Bluebunch wheatgrass Cheatgrass	Big sagebrush Needle-and-thread Sandberg bluegrass

Herbivory caused a decline in total biomass over 50 years. In Year 50, total aboveground biomass was reduced 88% with light rabbit and insect herbivory, 92% with moderate herbivory, and 96% with heavy herbivory. Big sagebrush production was reduced to almost zero at all herbivore densities, whereas without herbivory it was the dominant species by Year 20. Rubber rabbitbrush became the dominant species with herbivory, although biomass was low. Thus, herbivory at the densities modelled with EDYS will decrease total production and change species composition.

The EDYS simulation of light grazing in the knapweed community showed that little change occurred in plant production in the first year in comparison to the control pots subjected to no grazing. Light grazing resulted in 59% less total aboveground production in grazed plots compared to ungrazed plots at the end of the simulation. By Year 50, rabbitbrush was the dominant species, with Russian knapweed becoming second in abundance. The moderate and heavy grazing simulations did not produce substantial changes with respect to the light grazing simulation. The total production at the end of the 50-year simulation was nearly identical, irrespective of the level of grazing. This was because the remaining species (rabbitbrush and Russian knapweed) were not consumed by livestock.

When impacts of an M-1 Abrams tank driving through the plots in Year 5 was simulated with EDYS, total biomass was only 3% lower than in plots without disturbance at the end of 50 years. No differences were observed in species composition in plots with the tank traffic than in plots without training. Thus, a one-time disturbance event of this type will not negatively affect vegetation over the long term. When repeated impacts of the M-1 Abrams were included in the model, vegetation was negatively impacted. Total biomass was only 6 g/m^2 by Year 20 and stayed about this amount throughout the study. Vehicle disturbance every five years apparently does not allow sufficient time for the plants to recover.

7.0 CONCLUSIONS

The EDYS model adequately simulated the patterns of vegetation change that resulted from natural stressors and weed management scenarios at the Yakima Training Center. At the brome field site, cheatgrass production declined in the first year as a result of the fire treatment, but increased in the third and fourth years. This growth pattern was common to all the plots receiving the fire treatment and was very well simulated by the EDYS model. At the knapweed site, diffuse knapweed production declined in all treatment plots, including the controls while cheatgrass declined in the second year and then increased in the third and forth years. In addition, the increase in sagebrush dominance throughout the four years of the study was characteristic in all the study plots at the knapweed site. All of these vegetation changes were successfully simulated, indicating that the EDYS model can be an effective tool in environmental management.

At the brome site, the accuracy of the model varied from 81% to 96% for total aboveground biomass and from 81% to 95% for the dominant species, cheatgrass. At the knapweed site, the accuracy of the model varied from 65% to 93% for total aboveground biomass. For diffuse knapweed, the accuracy varied from 50% to 89% and for cheatgrass the accuracy varied from 40% to 98%.

Some changes were seen in the 4-year simulation when treatments were entered into the model. At the end of the 4-year simulation without any disturbance, cheatgrass was the dominant species. Although cheatgrass remained the dominant species regardless of treatment, bluebunch wheatgrass became a major species on the plots after four years, when seeding was implemented. Thus, seeding of perennials at the brome site has the potential to change community dynamics. At the knapweed site, cheatgrass was also the dominant species on most plots. Knapweed declined rapidly in every simulation, regardless of treatment. These results mimic well the results measured in the field. In plots with sugar application, bluebunch wheatgrass became the primary species, indicating that the model adequately simulates the impacts of nitrogen limitations on plants.

The 50-year EDYS simulations showed the possible long-term vegetation dynamics that would occur with differences in the treatments. A consistent trend that occurred regardless of the treatment, was the decline of the invasive weed population after 10 or 20 years with no disturbance. While the weed population declined with time, perennial grasses and shrubs tended to gain dominance. At the brome site, the cheatgrass population was negligible or non-existent by Year 20 (Figure 8). This is in agreement with long term studies reporting a decline in cheatgrass in the absence of disturbances such as fire, grazing, or abnormally high precipitation. Although the increasing dominance of cheatgrass in many western landscapes may suggest an irreversible trend, the EDYS simulations indicate that cheatgrass dominance may not occur in the absence of disturbances. However, this is not to say that cheatgrass will decline naturally over time.

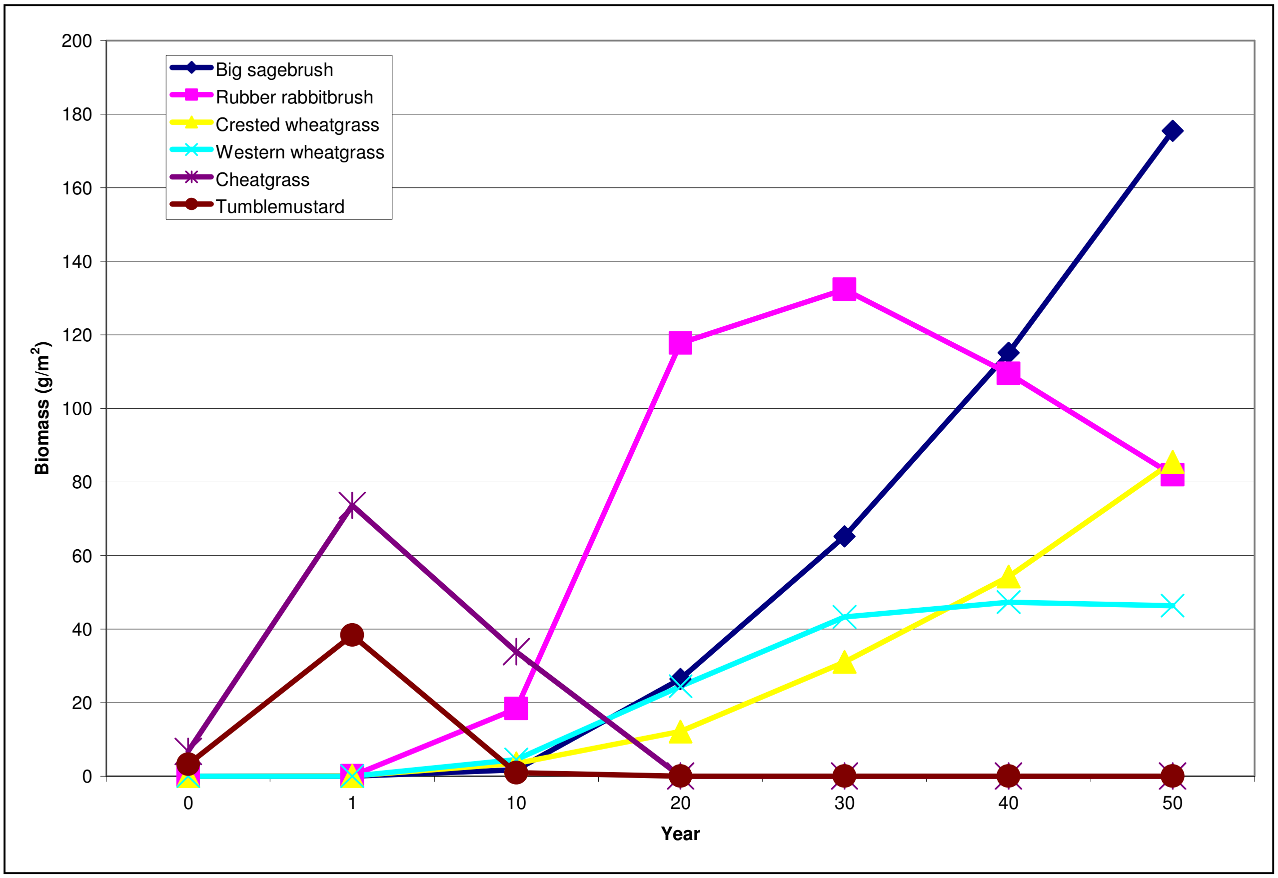

Figure 8. Change in vegetation composition over a 50-year period at the Yakima brome control site.

At the brome site at the end of the 50-year period, shrubs dominated the plots that were not seeded and perennial grasses dominated the plots that were seeded. These results demonstrate the long-term trend of shrubs to gain dominance in areas where the grass populations are low. Desert shrubs are more resilient and more tolerant to drought than grasses. However, the benefits of seeding perennial grasses are reduced by competition from annuals. EDYS projections and field data showed that seeding was not successful while cheatgrass was abundant in the community.

At the knapweed site, diffuse knapweed decreased dramatically in Year 2 in almost all plots and, by Year 10, the population of diffuse knapweed was almost non-existent. Probable causes for this decline were lower rainfall experienced during the last three years of the study period and the effect of the biological control agents. At this site, cheatgrass out-competed the diffuse knapweed during the four years of the study. This suggests that the biological control agents were important in the decline of knapweed. However, it may also indicate that knapweed is less drought tolerant than cheatgrass.

In the long-term simulations of the knapweed site, annuals decreased while perennials increased in the absence of disturbance. At the knapweed site, shrubs were dominant at the end of the 50-year simulation period. This occurred regardless of the seeding treatment, which was in contrast to the simulations in the brome site. The reason for this was that shrubs were already present at the knapweed community at the beginning of the study. At both sites, most of the treatments had only short-term effects.

Several disturbances were simulated in the model to determine what would happen to the vegetation over a 50-year period. At the brome site with light herbivory included, biomass of all species declined to zero between years 1 and 10. Initially, only two species, cheatgrass and tumblemustard, were present on the plots and the herbivores will consume both of these species if more preferred species are not available. As the other species began to grow, the herbivores ate the seedlings. In the model, herbivores do not leave if the food supply becomes low and, therefore, they will be present to consume vegetation as it sprouts. Perhaps densities for these herbivores were too high for this vegetation composition and different results might be seen if the densities were lower.

At the knapweed site, herbivory caused a decline in total biomass over 50 years. In Year 50, total aboveground biomass was reduced 88% with light rabbit and insect herbivory, 92% with moderate herbivory, and 96% with heavy herbivory. Big sagebrush growth was reduced to almost nothing at all herbivore densities, when without herbivory it was the dominant species by Year 20. Rubber rabbitbrush became the dominant species, although biomass was low. Thus, herbivory at the densities modelled with EDYS will decrease total production and change species composition.

Grazing, regardless of cattle density, can impact plant production and species composition. Even at the lightest density modelled, the dominant species at the end of the long-term simulation was different from the undisturbed plots, and all of the grasses had disappeared. These model simulations assume continuous grazing from Year 1, but if deferment were practiced then grasses may have a chance to establish.

In the brome plots regardless of livestock grazing intensity, total aboveground biomass was lower than in undisturbed plots at Year 50. Although big sagebrush was the dominant species by Year 50 in the ungrazed plots, no sagebrush plants were present in the grazed plots. Instead, rubber rabbitbrush dominated grazed plots. Biomass of all grasses and forbs was zero throughout the 50-year study. Russian knapweed increased in biomass and was the only forb left in the plots. In the knapweed plots, total biomass was much lower with grazing than without grazing. As in the brome plots, sagebrush biomass decreased while rubber rabbitbrush biomass increased, compared to ungrazed. All grasses and forbs disappeared over time with grazing, with the exception of Russian knapweed. Biomass of Russian knapweed increased in the last 20 years of the simulation.

When impacts of an M-1 Abrams tank passing through the plots in Year 5 was included in the model, total biomass was not much lower (4%) in these plots than in undisturbed plots in Year 50. In the undisturbed plots big sagebrush was the dominant species, followed by crested wheatgrass and rubber rabbitbrush, while in plots with the tank disturbance, big sagebrush and crested wheatgrass have about the same amount of biomass and are the major species. Total biomass was greatly reduced when impacts of an M-1 Abrams driving over the plots every five years are included in the model. At the end of 50 years, total biomass was 83% lower in disturbed plots than in undisturbed plots. Needle-and-thread was the dominant species and most of the other species had disappeared by this time. Thus, repeated disturbance by an army vehicle will change the succession of the community to primarily shrubs to needle-and-thread. These results show that if the system is frequently disturbed by vehicles, vegetation will be negatively impacted and species composition will be different from an undisturbed community. The long-term results depend on how often the community is disturbed.

In the knapweed community, when impacts of an M-1 Abrams tank driving through the plots in Year 5 was simulated with EDYS, total biomass was only 3% lower than in plots without disturbance at the end of 50 years. No differences were observed in species composition in plots with the tank disturbance than in plots without the disturbance. Thus, a one-time disturbance event of this type will not negatively affect vegetation over the long term. When repeated impacts of the M-1 were included in the model, vegetation was negatively impacted. Total biomass was only 6 g/m^2 by Year 20 and stayed about this amount throughout the study. Vehicle impacts every five years apparently does not allow sufficient time for the plants to recover. These simulations demonstrate how military vehicle activity may negatively impact vegetation biomass production and secondary succession.

Overall, the EDYS model was a useful tool to simulate changes in vegetation community structure and to predict long-term community changes. Some changes in species biomass were adequately simulated, such as an increase in brome during the four years or a rapid decline in knapweed in the second year. The 50-year runs also seem to adequately predict what will happen in these two sites because late-successional species increase and early-successional species die off.

Accuracies for some species, such as cheatgrass in the brome site, were higher than for other species, such as diffuse knapweed in the knapweed site. However, the variation in EDYS simulations was overall not significantly different from the variation in the field sampling results, indicating that the simulations were as accurate as the field sampling techniques. Some data limitations did hinder the achievement of better accuracy values. These limitations included lack of a reliable source for weather data that reflected the actual precipitation conditions of the study parcels, the likely accidental intrusion and grazing of sheep to some parcels, and the lack of literature data for plant parameters of some species.

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APPENDIX 1

Soil Series

Vantage-Benwy-Argabak Complex

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	0.1282	0.238	0.458	612.50	49.49
2	A	25	0.1282	0.238	0.458	520.63	42.07
3	A	25	0.1282	0.238	0.458	459.38	37.12
4	Bat	25	0.1485	0.262	0.474	438.75	35.45
5	Bat	50	0.1485	0.262	0.474	742.50	59.99
6	Bat	50	0.1485	0.262	0.474	607.50	49.09
7	Bt	25	0.2406	0.327	0.503	255.00	20.60
8	Bt	25	0.2406	0.327	0.503	223.13	18.03
9	Bt	25	0.2406	0.327	0.503	191.25	15.45
10	Bt	50	0.2406	0.327	0.503	318.75	25.76
11	Btq	50	0.2406	0.327	0.503	255.00	20.60
12	Btq	50	0.2406	0.327	0.503	191.25	15.45
13	2R	100	0.0024	0.003	0.005	3.83	0.31
Total		**525**				**4819.45**	**389.41**

Esqutzel Silt Loam

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	Ap1	25	0.0956	0.310	0.424	750.00	60.60
2	Ap1	25	0.0956	0.310	0.424	660.00	53.33
3	Ap2	50	0.0956	0.310	0.424	1140.00	92.11
4	Ap2	75	0.0956	0.310	0.424	1620.00	130.90
5	AB	125	0.0915	0.290	0.403	2250.00	181.80
6	AB	125	0.0915	0.290	0.403	1950.00	157.56
7	AB	150	0.0915	0.290	0.403	1980.00	159.98
8	AB	150	0.0915	0.290	0.403	1800.00	145.44
9	Bk1	125	0.1058	0.300	0.478	1300.00	105.04
10	Bk1	125	0.1058	0.300	0.478	1137.50	91.91
11	Bk1	125	0.1058	0.300	0.478	975.00	78.78
12	Bk2	125	0.1058	0.300	0.478	812.50	65.65
13	Bk2	275	0.1058	0.300	0.478	16.25	1.31
Total		**1500**				**16391.25**	**1324.41**

Selah Silt Loam

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	Ap	25	0.1139	0.301	0.485	875.00	70.70
2	Ap	75	0.1139	0.301	0.485	2343.75	189.38
3	A	50	0.1139	0.301	0.485	1437.50	116.15
4	A	50	0.1139	0.301	0.485	1312.50	106.05
5	A	50	0.1139	0.301	0.485	1125.00	90.90
6	AB	50	0.1660	0.337	0.510	1060.00	85.65
7	AB	50	0.1660	0.337	0.510	927.50	74.94
8	Bt1	50	0.1413	0.316	0.500	728.75	58.88
9	Bt2	50	0.1413	0.316	0.500	596.25	48.18
10	Bt2	50	0.1413	0.316	0.500	530.00	42.82
11	Btk	75	0.1532	0.302	0.493	695.63	56.21
12	Btk	100	0.1532	0.302	0.493	795.00	64.24
13	2Bkqm	250	0.0015	0.003	0.005	7.95	0.64
Total		**925**				**12434.83**	**1004.73**

APPENDIX 2

Parameterization Matrices for the Yakima, Washington EDYS Application

01. ALLOCATION (Mature)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.42	0.07	0.25	0.16	0.10	0.00
Rubber rabbitbrush	0.42	0.07	0.25	0.15	0.11	0.00
Crested wheatgrass	0.25	0.20	0.10	0.10	0.35	0.00
Western wheatgrass	0.35	0.20	0.10	0.10	0.25	0.00
Bluebunch wheatgrass	0.35	0.20	0.10	0.10	0.25	0.00
Indian ricegrass	0.17	0.32	0.18	0.18	0.18	0.00
Sandberg bluegrass	0.25	0.20	0.10	0.10	0.35	0.00
Squirreltail	0.06	0.26	0.12	0.12	0.30	0.00
Needle-and-thread	0.25	0.20	0.20	0.20	0.25	0.00
Yarrow	0.09	0.09	0.20	0.40	0.22	0.00
Russian knapweed	0.09	0.09	0.20	0.40	0.22	0.00
Buckwheat milkvetch	0.09	0.09	0.20	0.40	0.22	0.00
Diffuse knapweed	0.09	0.09	0.20	0.40	0.22	0.00
Shaggy daisy	0.09	0.09	0.20	0.40	0.22	0.00
Evening primrose	0.09	0.09	0.20	0.40	0.22	0.00
Longleaf phlox	0.09	0.09	0.20	0.40	0.22	0.00
Cheatgrass	0.05	0.20	0.10	0.15	0.50	0.00
Storksbill	0.09	0.09	0.20	0.40	0.22	0.00
Pepperweed	0.09	0.09	0.20	0.40	0.22	0.00
Tumble mustard	0.09	0.09	0.20	0.40	0.22	0.00

An EDYS application requires both an initial spatial representation of the plant communities across the simulated landscape and initial biomass values for each of the plant species in each of the plant communities. The initial biomass values are provided in Matrix 26.

The biomass values from Matrix 26 specify how much aboveground biomass is to be entered for each species. However, EDYS also requires a plant-part allocation (distribution) of this biomass (i.e., how much of the initial biomass is leaves, how much is stems, etc.). Matrix 01 provides this initial allocation of the biomass into plant parts.

The first step in determining the allocation values for each species is to determine the root:shoot ratios. These are taken from the literature for each species or, if data are lacking for the species, the most-similar species. Literature root:shoot values are of two types: 1) ratios for mature plants and 2) ratios for plants less than one-year old. The two ratios may be very different for the same species, especially for herbaceous perennials. For example, crested wheatgrass plants have root:shoot ratios on the order of 0.81, compared to a ratio for annual production of 0.18. The reason for the difference is that most of the aboveground biomass in herbaceous perennials is annual, i.e., it dies at the end of each growing season. In contrast, much of the belowground biomass is perennial. Therefore, over time, the proportional amount of roots increases. Cumulative ratios are used in Matrix 01. Ratios for annual production are used in Matrix 02. Sources of root:shoot ratios used in the Yakima application are presented in Appendix Table 1.

The root:shoot ratio is used to determine how much root biomass should be added to the initial shoot biomass provided by Matrix 26, to determine total initial biomass for each species. Total initial root biomass is then allocated between coarse and fine roots.

Initial aboveground biomass is allocated into trunk (crown for grasses), stems, leaves, and seeds (flowers + seeds). The biomass values resulting from the application of Matrix 01 are only initial values used to begin a simulation. As the simulation progresses, these biomass values change on a daily basis, in response to the dynamics of growth, senescence, herbivory, fire, training, etc.

02. ALLOCATION (Current)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.11	0.34	0.09	0.18	0.28	0.00
Rubber rabbitbrush	0.10	0.30	0.10	0.25	0.25	0.00
Crested wheatgrass	0.09	0.09	0.20	0.40	0.22	0.00
Western wheatgrass	0.06	0.24	0.20	0.25	0.25	0.00
Bluebunch wheatgrass	0.09	0.09	0.20	0.40	0.22	0.00
Indian ricegrass	0.12	0.34	0.09	0.16	0.29	0.00
Sandberg bluegrass	0.09	0.09	0.20	0.40	0.22	0.00
Squirreltail	0.04	0.04	0.08	0.22	0.34	0.00
Needle-and-thread	0.04	0.04	0.15	0.15	0.28	0.00
Yarrow	0.09	0.09	0.20	0.40	0.22	0.00
Russian knapweed	0.09	0.09	0.20	0.40	0.22	0.00
Buckwheat milkvetch	0.09	0.09	0.20	0.40	0.22	0.00
Diffuse knapweed	0.09	0.09	0.20	0.40	0.22	0.00
Shaggy daisy	0.09	0.09	0.20	0.40	0.22	0.00
Evening primrose	0.09	0.09	0.20	0.40	0.22	0.00
Longleaf phlox	0.09	0.09	0.20	0.40	0.22	0.00
Cheatgrass*						0.00
Storksbill	0.09	0.09	0.20	0.40	0.22	0.00
Pepperweed	0.09	0.09	0.20	0.40	0.22	0.00
Tumble mustard	0.12	0.13	0.15	0.30	0.30	0.00

*See matrix 02a for values for cheatgrass.

This matrix provides the allocation values for monthly production. For each gram of dry matter biomass produced by a plant species, a certain portion goes to coarse roots, a portion to fine roots, a portion to trunk, etc.

02a. ALLOCATION (Current) – *Bromus tectorum*

Species	Month	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Cheatgrass	Jan	0.10	0.30	0.15	0.15	0.30	0.00
Cheatgrass	Feb	0.10	0.30	0.12	0.13	0.35	0.00
Cheatgrass	Mar	0.08	0.30	0.15	0.15	0.32	0.00
Cheatgrass	Apr	0.08	0 .25	0.15	0.15	0.37	0.00
Cheatgrass	May	0.08	0.20	0.15	0.17	0.40	0.00
Cheatgrass	June	0.08	0.20	0.15	0.17	0.40	0.00
Cheatgrass	July	0.08	0.20	0.15	0.17	0.40	0.00
Cheatgrass	Aug	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	Sep	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	Oct	0.05	0.45	0.10	0.10	0.30	0.00
Cheatgrass	Nov	0.05	0.45	0.10	0.10	0.30	0.00
Cheatgrass	Dec	0.10	0.30	0.15	0.15	0.30	0.00

03. GREEN-OUT ALLOCATION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.00	0.30	0.00	0.20	0.50	0.00
Rubber rabbitbrush	0.00	0.30	0.00	0.35	0.35	0.00
Crested wheatgrass	0.00	0.09	0.00	0.50	0.41	0.00
Western wheatgrass	0.00	0.20	0.00	0.20	0.60	0.00
Bluebunch wheatgrass	0.00	0.09	0.00	0.50	0.41	0.00
Indian ricegrass	0.00	0.30	0.00	0.20	0.50	0.00
Sandberg bluegrass	0.00	0.09	0.00	0.50	0.41	0.00
Squirreltail	0.00	0.30	0.00	0.30	0.40	0.00
Needle-and-thread	0.00	0.35	0.00	0.15	0.50	0.00
Yarrow	0.00	0.09	0.00	0.50	0.41	0.00
Russian knapweed	0.00	0.09	0.00	0.50	0.41	0.00
Buckwheat milkvetch	0.00	0.09	0.00	0.50	0.41	0.00
Diffuse knapweed	0.00	0.09	0.00	0.50	0.41	0.00
Shaggy daisy	0.00	0.09	0.00	0.50	0.41	0.00
Evening primrose	0.00	0.09	0.00	0.50	0.41	0.00
Longleaf phlox	0.00	0.09	0.00	0.50	0.41	0.00
Cheatgrass	0.00	0.20	0.00	0.20	0.60	0.00
Storksbill	0.00	0.09	0.00	0.50	0.41	0.00
Pepperweed	0.00	0.09	0.00	0.50	0.41	0.00
Tumble mustard	0.00	0.09	0.00	0.50	0.41	0.00

This matrix provides the allocation values for production in a month when either dormancy is broken (e.g., spring green-up) or regrowth is triggered following a major defoliation event (e.g., heavy grazing, trampling, fire). The primary difference between this matrix and the current-growth allocation matrix (02) is that in green-out there is no allocation to coarse roots and to grass trunks. These are the primary storage regions for non-structural carbohydrates, which are used initially to produce regrowth (Stoddart et al. 1975:107, Garza et al. 1994).

04. SEED MONTH ALLOCATION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.11	0.34	0.04	0.09	0.25	0.17
Rubber rabbitbrush	0.10	0.30	0.05	0.12	0.22	0.21
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	1.00
Western wheatgrass	0.00	0.24	0.00	0.25	0.12	0.39
Bluebunch wheatgrass	0.00	0.00	0.00	0.00	0.00	1.00
Indian ricegrass	0.00	0.34	0.00	0.16	0.15	0.35
Sandberg bluegrass	0.00	0.00	0.00	0.00	0.00	1.00
Squirreltail	0.00	0.32	0.00	0.22	0.17	0.29
Needle-and-thread	0.00	0.38	0.00	0.15	0.14	0.33
Yarrow	0.00	0.00	0.00	0.00	0.00	1.00
Russian knapweed	0.00	0.00	0.00	0.00	0.00	1.00
Buckwheat milkvetch	0.00	0.00	0.00	0.00	0.00	1.00
Diffuse knapweed	0.00	0.00	0.00	0.00	0.00	1.00
Shaggy daisy	0.00	0.00	0.00	0.00	0.00	1.00
Evening primrose	0.00	0.00	0.00	0.00	0.00	1.00
Longleaf phlox	0.00	0.00	0.00	0.00	0.00	1.00
Cheatgrass	0.00	0.00	0.00	0.00	0.00	1.00
Storksbill	0.00	0.00	0.00	0.00	0.00	1.00
Pepperweed	0.00	0.00	0.00	0.00	0.00	1.00
Tumble mustard	0.00	0.00	0.00	0.00	0.00	1.00

This matrix provides the allocation values for production in months in which flowering and seed production occurs. For woody plants, 50% of trunk and stem growth and 10% of leaf growth is diverted to seeds. For herbaceous perennials, 100% of coarse root and trunk growth and 50% of leaf growth is diverted to seeds. For annuals, all growth is diverted to seeds. Some exceptions are made for species that are typically heavy seed producers or for species that are poor seed producers.

05. PLANT N CONCENTRATION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Big sagebrush	0.0090	0.0091	0.0850	0.0091	0.0182	0.0186	0.0070	0.0139	0.0097	0.0193	0.0186
Rubber rabbitbrush	0.0140	0.0150	0.0150	0.0164	0.0180	0.0186	0.0144	0.0150	0.0180	0.0200	0.0186
Crested wheatgrass	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Western wheatgrass	0.0070	0.0070	0.0120	0.0120	0.0130	0.0200	0.0100	0.0100	0.0070	0.0135	0.0200
Bluebunch wheatgrass	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Indian ricegrass	0.0100	0.0110	0.0120	0.0126	0.0130	0.0200	0.0084	0.0088	0.0120	0.0169	0.0200
Sandberg bluegrass	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Squirreltail	0.0090	0.0090	0.0090	0.0090	0.0095	0.0200	0.0080	0.0090	0.0095	0.0100	0.0200
Needle-and-thread	0.0120	0.0130	0.0130	0.0130	0.0135	0.0200	0.0120	0.0120	0.0130	0.0140	0.0200
Yarrow	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Russian knapweed	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Buckwheat milkvetch	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Diffuse knapweed	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Shaggy daisy	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Evening primrose	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Longleaf phlox	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Cheatgrass	0.0090	0.0090	0.0140	0.0106	0.0110	0.0173	0.0073	0.0073	0.0073	0.0142	0.0173
Storksbill	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Pepperweed	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Tumble mustard	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214

This matrix provides initial values for nitrogen (N) concentrations in plant tissues. The value in a particular tissue may vary from these values at any point in a simulation for either of two reasons. First, values may exceed these values because of "luxury consumption", i.e., the amount of N contained in the water absorbed by the plant may be sufficient to exceed these matrix values. Secondly, values may be less than the matrix values in some tissues because of internal transport of N from one tissue type to another during periods of green-out or rapid growth. The lower boundary for these concentrations are the maintenance levels, i.e., the concentration at which that particular tissue can remain alive but not growing. Maintenance levels are provided in Matrix 06 and are arbitrarily set at 75% of the Matrix 05 levels for non-legumes and 25% for legumes.

Matrix 05 values are based on tissue N concentrations of composite aboveground tissue for the species, or most-similar species. Most of these values were taken from a large set of unpublished values from tissue samples we have analyzed in connection with a number of research projects. A limited amount of these data have been published (McLendon and Redente 1992, Redente et al. 1992, McLendon and Redente 1994, Paschke et al. 2000). A more complete set of the data are currently being prepared for publication. Additional values were taken from the literature.

When available, values for separate tissue types were used. Most often, tissue type concentrations were estimated from averages found in the literature (Gigon and Rorison 1972, Barth and Klemmedson 1982, Gay et al. 1982, Nicholas and McGinnes 1982, Risser and Parton 1982, Vogt et al. 1982, Heil and Diemont 1983, Stout et al. 1983, Uhl and Jordan 1984, McClaugherty et al. 1985, Nadelhoffer et al. 1985, Sears et al. 1986, Agren and Bosatta 1987, O'Connell 1988, McNeill and Wood 1990, Tilman and Wedin 1991).

06. MAINTENANCE LEVELS

Species	75%	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Big sagebrush	0.7500	0.0090	0.0091	0.0850	0.0091	0.0182	0.0186	0.0070	0.0139	0.0097	0.0193	0.0186
Rubber rabbitbrush	0.7500	0.0140	0.0150	0.0150	0.0164	0.0180	0.0186	0.0144	0.0150	0.0180	0.0200	0.0186
Crested wheatgrass	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Western wheatgrass	0.7500	0.0070	0.0070	0.0120	0.0120	0.0130	0.0200	0.0100	0.0100	0.0070	0.0135	0.0200
Bluebunch wheatgrass	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Indian ricegrass	0.7500	0.0100	0.0110	0.0120	0.0126	0.0130	0.0200	0.0084	0.0088	0.0120	0.0169	0.0200
Sandberg bluegrass	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Squirreltail	0.7500	0.0090	0.0090	0.0090	0.0090	0.0095	0.0200	0.0080	0.0090	0.0095	0.0100	0.0200
Needle-and-thread	0.7500	0.0120	0.0130	0.0130	0.0130	0.0135	0.0200	0.0120	0.0120	0.0130	0.0140	0.0200
Yarrow	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Russian knapweed	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Buckwheat milkvetch	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Diffuse knapweed	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Shaggy daisy	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Evening primrose	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Longleaf phlox	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Cheatgrass	0.7500	0.0090	0.0090	0.0140	0.0106	0.0110	0.0173	0.0073	0.0073	0.0073	0.0142	0.0173
Storksbill	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Pepperweed	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Tumble mustard	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214

07. NITROGEN RESORPTION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.10	0.05	0.00	0.10	0.20	0.00
Rubber rabbitbrush	0.10	0.05	0.00	0.05	0.10	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	0.10	0.05	0.05	0.05	0.10	0.00
Bluebunch wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00
Indian ricegrass	0.05	0.03	0.00	0.05	0.05	0.00
Sandberg bluegrass	0.00	0.00	0.00	0.00	0.00	0.00
Squirreltail	0.05	0.03	0.00	0.05	0.05	0.00
Needle-and-thread	0.05	0.03	0.00	0.05	0.10	0.00
Yarrow	0.00	0.00	0.00	0.00	0.00	0.00
Russian knapweed	0.00	0.00	0.00	0.00	0.00	0.00
Buckwheat milkvetch	0.00	0.00	0.00	0.00	0.00	0.00
Diffuse knapweed	0.00	0.00	0.00	0.00	0.00	0.00
Shaggy daisy	0.00	0.00	0.00	0.00	0.00	0.00
Evening primrose	0.00	0.00	0.00	0.00	0.00	0.00
Longleaf phlox	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	0.00	0.00	0.00	0.00	0.00	0.00
Storksbill	0.00	0.00	0.00	0.00	0.00	0.00
Pepperweed	0.00	0.00	0.00	0.00	0.00	0.00
Tumble mustard	0.00	0.00	0.00	0.00	0.00	0.00

Many species of plants resorb a portion of nitrogen contained in tissue during senescence of the tissue and prior to death of that tissue. This is especially common in tree leaves. This matrix provides the maximum amount of nitrogen within each tissue type that can be resorbed prior to tissue loss. The values are general estimates based on differences between nitrogen contents in green tissues and nitrogen contents in dead tissues.

08. ROOT ARCHITECTURE

Species	Percent of Soil Profile Depth												Max Root Depth (mm)
	0-1	1-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	
Big sagebrush	0.04	0.1	0.12	0.17	0.15	0.14	0.1	0.09	0.03	0.03	0.02	0.01	3360
Rubber rabbitbrush	0.03	0.13	0.16	0.22	0.12	0.08	0.07	0.06	0.04	0.04	0.03	0.02	3300
Crested wheatgrass	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Western wheatgrass	0.10	0.20	0.25	0.12	0.07	0.06	0.05	0.05	0.04	0.03	0.02	0.01	3600
Bluebunch wheatgrass	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	1500
Indian ricegrass	0.12	0.24	0.22	0.16	0.10	0.07	0.04	0.01	0.01	0.01	0.01	0.01	450
Sandberg bluegrass	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	1500
Squirreltail	0.10	0.22	0.24	0.20	0.10	0.06	0.02	0.02	0.01	0.01	0.01	0.01	150
Needle-and-thread	0.08	0.08	0.11	0.14	0.12	0.12	0.12	0.07	0.06	0.05	0.03	0.02	1950
Yarrow	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Russian knapweed	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Buckwheat milkvetch	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Diffuse knapweed	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Shaggy daisy	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Evening primrose	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Longleaf phlox	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Cheatgrass	0.28	0.35	0.11	0.08	0.06	0.03	0.02	0.02	0.02	0.02	0.01	0.01	1500
Storksbill	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Pepperweed	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Tumble mustard	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	580

This matrix provides 1) the percentage of the total root biomass of each species that occurs at given depths (%) of soil profiles and 2) the maximum reported rooting depth for each species. We have collected a significant amount of root architecture data, both from the published literature and from our own studies. For each species, we compare the amount of roots reported by depth among all studies for which we have data available for that species. An example for little bluestem is presented in Appendix Table 3. These data are then used to calculate an average root biomass by depth values. We have found that root biomass by depth percentages are relatively consistent across soil profiles for a given species, even where the depths of the soil profiles vary significantly.

The root percentages (Matrix 08) are multiplied by the estimated initial root biomass value for that species (Matrix 01) to arrive at an initial root biomass within each layer for each soil profile in the landscape. These are initial values only. As the EDYS simulation progresses, root architecture changes because of root growth and the location (depth) of belowground resources. Daily root production, based in part on the appropriate allocation matrix (01-04), is added to the existing root biomass proportional to the amount of root biomass in each soil layer that supplied water to the plant in that particular day. This is based on two related concepts: 1) more root occurs in moist soil than in dry soil and 2) root growth in a soil layer is largely independent of soil moisture levels in other layers (Kramer 1969:136, Brown and Scott 1984:125, Huck 1984:59).

Maximum rooting depth sets the maximum depth to which a particular species can root. This is the maximum value found for that species, or the most-similar species, in the literature. We assume this limit to be primarily genetically determined, since we used the maximum reported depth. If we used the average maximum rooting depth, we would assume that the depth would be also be strongly influenced by environmental factors.

Sources of root architecture data are presented in Appendix Table 4. Sources of maximum rooting depth data are presented in Appendix Table 5.

09. ROOT UPTAKE AND COMPETITIVE EFFICIENCY

Species	Uptake Capacity	Biomass Adjustment
Big sagebrush	0.10	0.75
Rubber rabbitbrush	0.10	0.75
Crested wheatgrass	0.10	0.95
Western wheatgrass	0.10	0.9
Bluebunch wheatgrass	0.10	0.95
Indian ricegrass	0.10	1.00
Sandberg bluegrass	0.10	0.95
Squirreltail	0.10	1.00
Needle-and-thread	0.10	1.00
Yarrow	0.10	0.95
Russian knapweed	0.10	0.95
Buckwheat milkvetch	0.10	0.95
Diffuse knapweed	0.10	0.95
Shaggy daisy	0.10	0.95
Evening primrose	0.10	0.95
Longleaf phlox	0.10	0.95
Cheatgrass	0.10	1.00
Storksbill	0.10	0.95
Pepperweed	0.10	0.95
Tumble mustard	0.10	0.95

Uptake capacity is the maximum amount of monthly water demand that can be supplied by the root system in one day. This was estimated to be 10%.

Competitive efficiency is a measure of the relative efficiency of roots in water uptake. The fibrous root system of most short-grasses is used as the standard, and is assigned a competitive efficiency value of 1.0. Larger grasses, such as little bluestem, are assumed to have larger roots than shortgrasses. The larger roots of midgrasses are assumed to have a slightly lower efficiency for water uptake than the smaller roots of the shortgrasses. The larger roots of trees are assumed to be significantly less efficient, on a per gram basis, of water uptake than the smaller, fibrous roots of grasses. These relationships are based on the concept that water intake by roots is partly dependent on surface area of the roots.

10. PHYSIOLOGICAL RESPONSE MONTHS

Species	Green-out	Seed Sprout	Seed Set	Dormancy
Big sagebrush	3	3,6	6,9	11
Rubber rabbitbrush	3	3,5	6,9	11
Crested wheatgrass	3	3,8	5,8	10
Western wheatgrass	3	5,6	6,8	10
Bluebunch wheatgrass	3	3,6	6,8	11
Indian ricegrass	4	3,8	6,8	10
Sandberg bluegrass	3	3,6	5,8	10
Squirreltail	3	3,8	5,8	11
Needle-and-thread	9	9,4	3,5	7
Yarrow	2	3,8	5,8	10
Russian knapweed	4	3,8	5,8	10
Buckwheat milkvetch	3	3,8	5,8	10
Diffuse knapweed	3	3,4	6,8	9
Shaggy daisy	3	3,8	5,8	10
Evening primrose	4	3,8	5,8	10
Longleaf phlox	4	3,8	5,8	10
Cheatgrass	10	10,4	4,7	7
Storksbill	2	3,8	5,8	10
Pepperweed	3	3,8	5,8	10
Tumble mustard	10	10,5	5,8	9

This is the phenology matrix. It provides the data that are used in the model to determine which months various plant functions occur. Data sources included Harris 1967, Link et al. 1990, Pitt and Wikeem 1990, Powell 1990, and Duncan et al. 2001.

11. BIOMASS CONVERSION CONSTANTS

Species	Dry wt/ Wet wt	Moisture Interception/ g biomass	Basal cover/Trunk biomass
Big sagebrush	0.32	0.0085	50
Rubber rabbitbrush	0.32	0.0087	10
Crested wheatgrass	0.22	0.0082	2
Western wheatgrass	0.35	0.0084	3
Bluebunch wheatgrass	0.22	0.0082	2
Indian ricegrass	0.37	0.0084	3
Sandberg bluegrass	0.22	0.0082	2
Squirreltail	0.40	0.0077	2
Needle-and-thread	0.39	0.0075	2
Yarrow	0.22	0.0082	2
Russian knapweed	0.22	0.0082	2
Buckwheat milkvetch	0.22	0.0082	2
Diffuse knapweed	0.22	0.0082	2
Shaggy daisy	0.22	0.0082	2
Evening primrose	0.22	0.0082	2
Longleaf phlox	0.22	0.0082	2
Cheatgrass	0.30	0.0082	1
Storksbill	0.22	0.0082	2
Pepperweed	0.22	0.0082	2
Tumble mustard	0.22	0.0082	2

This matrix provides values for 1) conversions between dry weight and wet weight, 2) amount of moisture intercepted by the canopy of each species, and 3) conversions between basal area and trunk biomass. These calculations are required for various calculations used in the simulations.

The dry weight values for herbaceous species were taken from Morrison (1961:556-575), or estimated from values from that source. Moisture interception values were estimated. Basal area to trunk biomass values were estimated from calculations based on unpublished field data collected in McLendon et al. (1999c, 2000b). Values for herbaceous species were estimated.

12. WATER USE FACTORS

Species	Maintenance (mm/g bio/mo)	New biomass maintenance	Water to production	Green-out water use
Big sagebrush	0.000007	0.03	1.24	0.68
Rubber rabbitbrush	0.000007	0.04	1.00	0.68
Crested wheatgrass	0.000015	0.03	0.70	0.78
Western wheatgrass	0.000015	0.04	0.80	0.65
Bluebunch wheatgrass	0.000015	0.03	0.70	0.78
Indian ricegrass	0.000015	0.04	0.80	0.63
Sandberg bluegrass	0.000015	0.03	0.70	0.78
Squirreltail	0.000013	0.04	0.75	0.60
Needle-and-thread	0.000020	0.06	0.90	0.61
Yarrow	0.000015	0.03	0.65	0.78
Russian knapweed	0.000015	0.03	0.61	0.78
Buckwheat milkvetch	0.000015	0.03	0.84	0.78
Diffuse knapweed	0.000015	0.03	0.65	0.78
Shaggy daisy	0.000015	0.03	0.52	0.78
Evening primrose	0.000015	0.03	0.80	0.78
Longleaf phlox	0.000015	0.03	0.85	0.78
Cheatgrass	0.000015	0.04	0.20	0.70
Storksbill	0.000015	0.03	0.74	0.78
Pepperweed	0.000015	0.03	0.60	0.78
Tumble mustard	0.000015	0.03	0.48	0.78

This matrix provides four sets of numbers that are used by EDYS to calculate water requirements of the plants. Green-out water use is the amount of water used to change from dry weight to wet weight. It is 1.00 - dry weight (Matrix 11). Maintenance is the amount of water required to support 1 g of old-growth biomass for one month. Old-growth biomass is that amount of live biomass that was produced in previous years. New biomass maintenance is the amount of water required to sustain 1 g of new-growth biomass for one month, in months where no new growth takes place. If this amount of water is not available, a proportional amount of new-growth tissue is converted to standing dead biomass (i.e., drought loss). The maintenance water-use values are estimates.

Water to production is the amount of water (kg) required to produce 1 g of new biomass. These values are taken from literature data for water-use efficiencies (Appendix Table 6).

13. GROWTH RATE FACTORS

Species	Max growth rate	Max old biomass drought loss
Big sagebrush	0.5	0.25
Rubber rabbitbrush	0.8	0.30
Crested wheatgrass	3.2	0.40
Western wheatgrass	2.5	0.40
Bluebunch wheatgrass	3.0	0.40
Indian ricegrass	1.5	0.40
Sandberg bluegrass	3.0	0.40
Squirreltail	3.0	0.40
Needle-and-thread	2.0	0.80
Yarrow	2.0	0.40
Russian knapweed	1.8	0.40
Buckwheat milkvetch	2.0	0.40
Diffuse knapweed	1.8	0.40
Shaggy daisy	2.0	0.40
Evening primrose	2.0	0.40
Longleaf phlox	2.0	0.40
Cheatgrass	3.5	0.40
Storksbill	2.2	0.40
Pepperweed	2.5	0.40
Tumble mustard	3.0	0.40

Maximum growth rate is the estimated increase in aboveground biomass that could occur in one month under ideal conditions. It is a productivity value. A value of 1.00 results in biomass doubling each month. The growth rate value is multiplied by the amount of leaf-equivalent photosynthetically-active biomass (Matrix 15) to determine potential monthly production. For potential monthly production to be achieved, there has to be sufficient water, nutrients, and sunlight available to the species to achieve this production level. If any of these factors are limiting, potential monthly production is reduced proportionally. The amount of production actually achieved is then allocated according to the appropriate allocation matrix (01-04).

The highest productivity rates are assigned to annuals, followed by herbaceous perennials, and then woody species. The rates were estimated, based on experience. Values reported in the literature for similar species range from 0.18 to 4.5 (Powell 1990, Messina et al. 2002, Reich et al. 2003).

14. MONTHLY MAXIMUM GROWTH RATES

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Big sagebrush	0.10	0.10	0.50	0.80	1.00	1.00	0.90	0.80	0.50	0.30	0.10	0.10
Rubber rabbitbrush	0.00	0.10	0.50	0.80	1.00	1.00	1.00	0.80	0.60	0.30	0.00	0.00
Crested wheatgrass	0.00	0.00	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Western wheatgrass	0.00	0.00	0.30	0.90	1.00	1.00	0.80	0.70	0.70	0.50	0.20	0.00
Bluebunch wheatgrass	0.00	0.00	0.30	0.70	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Indian ricegrass	0.00	0.00	0.20	0.90	1.00	1.00	1.00	0.80	0.80	0.40	0.10	0.00
Sandberg bluegrass	0.00	0.00	0.50	1.00	1.00	1.00	1.00	0.60	0.40	0.30	0.05	0.00
Squirreltail	0.00	0.00	0.40	0.80	1.00	1.00	0.90	0.80	0.60	0.30	0.10	0.00
Needle-and-thread	0.00	0.10	0.50	1.00	1.00	0.70	0.30	0.10	0.50	0.80	0.40	0.10
Yarrow	0.00	0.10	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Russian knapweed	0.00	0.00	0.30	0.60	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Buckwheat milkvetch	0.00	0.00	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Diffuse knapweed	0.00	0.00	0.30	0.50	1.00	1.00	1.00	0.80	0.60	0.00	0.00	0.00
Shaggy daisy	0.00	0.00	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Evening primrose	0.00	0.00	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Longleaf phlox	0.00	0.00	0.40	0.80	1.00	1.00	1.00	1.00	0.50	0.30	0.00	0.00
Cheatgrass	0.10	0.30	0.50	1.00	1.00	1.00	0.20	0.00	0.00	0.60	0.50	0.25
Storksbill	0.00	0.10	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Pepperweed	0.00	0.00	0.50	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Tumble mustard	0.20	0.35	0.60	1.00	1.00	1.00	1.00	0.70	0.00	0.50	0.30	0.15

The potential growth rates in Matrix 13 are the estimates for ideal conditions. One limiting factor is temperature. Warm-season species are most productive during the warmer part of the year and cool-season species are more productive during the cool season. Matrix 14 provides a monthly growth curve for each species. The monthly growth rate value for the specific month is multiplied by the potential growth rate (Matrix 13) to determine the potential growth rate for that particular month. This is still a potential growth rate. It may be reduced because of water, nutrient, or sunlight limitations.

15. PLANT PART PRODUCTIVITY

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.0	0.0	0.0	0.0	1.0	0.0
Rubber rabbitbrush	0.0	0.0	0.0	0.4	1.0	0.0
Crested wheatgrass	0.0	0.0	0.0	0.6	1.0	0.0
Western wheatgrass	0.0	0.0	0.1	0.3	1.0	0.0
Bluebunch wheatgrass	0.0	0.0	0.0	0.6	1.0	0.0
Indian ricegrass	0.0	0.0	0.1	0.2	1.0	0.0
Sandberg bluegrass	0.0	0.0	0.0	0.6	1.0	0.0
Squirreltail	0.0	0.0	0.0	0.2	1.0	0.0
Needle-and-thread	0.0	0.0	0.1	0.3	1.0	0.0
Yarrow	0.0	0.0	0.0	0.6	1.0	0.0
Russian knapweed	0.0	0.0	0.0	0.6	1.0	0.0
Buckwheat milkvetch	0.0	0.0	0.0	0.6	1.0	0.0
Diffuse knapweed	0.0	0.0	0.0	0.6	1.0	0.0
Shaggy daisy	0.0	0.0	0.0	0.6	1.0	0.0
Evening primrose	0.0	0.0	0.0	0.6	1.0	0.0
Longleaf phlox	0.0	0.0	0.0	0.6	1.0	0.0
Cheatgrass	0.0	0.0	0.2	0.4	1.0	0.0
Storksbill	0.0	0.0	0.0	0.6	1.0	0.0
Pepperweed	0.0	0.0	0.0	0.6	1.0	0.0
Tumble mustard	0.0	0.0	0.0	0.6	1.0	0.0

Photosynthesis occurs in some plants only in leaves. In other species, limited photosynthesis can occur in other parts, such as stems. This matrix provides the values used to calculate total photosynthetically-active biomass for a species. A value of 1.00 is assigned to leaves. This assumes that these are the most productive part of the plant. Values less than 1.00 are assigned to the other plant parts. These values are estimates of the relative (compared to leaves) photosynthetic rate of each of these parts.

To determine total potential production at each time step (day) in EDYS, the biomass of each plant part is multiplied by the respective value in Matrix 15, and then the product is multiplied times the daily potential growth rate (Matrix 13 value divided by 30, adjusted for month of the year).

16. GREEN-OUT PLANT PART PRODUCTIVITY FACTOR

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.05	0.00	0.05	0.10	1.00	0.00
Rubber rabbitbrush	0.10	0.00	0.10	0.20	1.00	0.00
Crested wheatgrass	0.00	0.00	0.20	0.50	1.00	0.00
Western wheatgrass	0.10	0.00	0.20	0.50	1.00	0.00
Bluebunch wheatgrass	0.00	0.00	0.20	0.50	1.00	0.00
Indian ricegrass	0.05	0.00	0.10	0.50	1.00	0.00
Sandberg bluegrass	0.00	0.00	0.20	0.50	1.00	0.00
Squirreltail	0.05	0.00	0.10	0.50	1.00	0.00
Needle-and-thread	0.05	0.00	0.20	0.50	1.00	0.00
Yarrow	0.00	0.00	0.20	0.50	1.00	0.00
Russian knapweed	0.00	0.00	0.20	0.50	1.00	0.00
Buckwheat milkvetch	0.00	0.00	0.20	0.50	1.00	0.00
Diffuse knapweed	0.00	0.00	0.20	0.50	1.00	0.00
Shaggy daisy	0.00	0.00	0.20	0.50	1.00	0.00
Evening primrose	0.00	0.00	0.20	0.50	1.00	0.00
Longleaf phlox	0.00	0.00	0.20	0.50	1.00	0.00
Cheatgrass	0.00	0.00	0.50	0.50	1.00	0.00
Storksbill	0.00	0.00	0.20	0.50	1.00	0.00
Pepperweed	0.00	0.00	0.20	0.50	1.00	0.00
Tumble mustard	0.00	0.00	0.20	0.50	1.00	0.00

Green-out (regrowth) occurs following dormancy or severe defoliation. Green-out is triggered by cessation of the factor that caused defoliation (e.g., winter, fire, heavy grazing, trampling). Under these conditions, regrowth is initially fueled by translocation of stored non-structural carbohydrates. Therefore, there is a temporary decrease in the biomass of the plant parts where these carbohydrates were stored. In effect, the stored carbohydrates are converted to new tissue.

This matrix specifies where these reserves are stored and how much is available for regrowth. A value of 1.00 indicates that an amount of new growth equal to the existing biomass of that plant part can be produced in one month. A value of 0.50 indicates that an amount of new growth equal of half of the existing biomass of that plant part can be produced in one month. In all cases, this does not mean that the existing biomass of the plant part is actually reduced by this amount, only that this is the potential new growth that can be generated from this existing biomass. The physiological process that occurs is that a given mass of carbohydrates are withdrawn from the stored reserves, used to produce the new leaf tissue, and most of these reserves are replaced from the production of photosynthates from the new leaves (Smith 1962, Garza et al. 1994). The values in Matrix 16 simply indicate a net one-month production rate.

17. LIGHT COMPETITION FACTOR (SHADING)

Shading Species	Shaded Species: Big Sbrush	Rub Rbrush	Crest Wgrass	West Wgrass	BB Wgrass	Ind Rgrass	Sand Bgrass	Squirrl Tail	Needle Thread	Yarrow	Russ Kweed	Buck Mvetch	Dfs Kweed	Shaggy Daisy	Evng Prose	Lglf Phlox	Cheat grass	Peppr weed	Tmbl Mstrd
Big sagebrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rubber rabbitbrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bluebunch wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indian ricegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sandberg bluegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Squirreltail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Needle-and-thread	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yarrow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Russian knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buckwheat milkvetch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diffuse knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shaggy daisy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evening primrose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longleaf phlox	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Storksbill	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pepperweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tumble mustard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Shading generally reduces the productivity of a shaded species, provided that the reduction in light intensity is sufficient. Commonly, there is no shading effect initially, as the shading species begins to grow, because the shading species has insufficient canopy development to significantly reduce the intensity of the sunlight. As the biomass of the shading species increases, the canopy coverage increases and the light intensity under the canopy decreases. In some cases, some shading is actually beneficial to the shaded species because the reduced sunlight results in lower temperatures and therefore lower transpirational water loss. A values of 0.00 indicates that the potential growth (grams of new biomass) of the shaded species is not reduced by the shading species.

8. PHYSIOLOGICAL CONTROL CONSTRANTS

Species	Growing season max root:shoot	Growing season green-out shoot:root	Max 1-mo seed germination	Max 1st-mo seedling growth
Big sagebrush	4.0	0.26	0.54	20.0
Rubber rabbitbrush	1.9	0.26	0.30	20.0
Crested wheatgrass	2.0	1.14	0.44	40.0
Western wheatgrass	3.0	0.14	0.69	30.0
Bluebunch wheatgrass	2.0	1.14	0.44	40.0
Indian ricegrass	1.9	0.26	0.11	30.0
Sandberg bluegrass	2.0	1.14	0.44	40.0
Squirreltail	1.0	0.51	0.98	30.0
Needle-and-thread	2.5	0.20	0.13	30.0
Yarrow	0.4	1.14	0.44	40.0
Russian knapweed	0.4	1.14	0.44	40.0
Buckwheat milkvetch	0.4	1.14	0.44	40.0
Diffuse knapweed	0.6	1.14	0.30	20.0
Shaggy daisy	0.4	1.14	0.44	40.0
Evening primrose	0.4	1.14	0.44	40.0
Longleaf phlox	0.4	1.14	0.44	40.0
Cheatgrass	0.6	0.84	0.85	30.0
Storksbill	0.4	1.14	0.44	40.0
Pepperweed	0.4	1.14	0.44	40.0
Tumble mustard	0.4	1.14	0.80	40.0

This matrix provides four physiological control factors that are used by EDYS to 1) keep above- and belowground biomass within reasonable limits and 2) provide for seedling development.

The growing-season maximum root:shoot ratio value is used to prevent an imbalance occurring between above- and belowground biomass. If the root:shoot ratio exceeds this value, no growth allocation to roots takes place that month. This allows aboveground biomass to increase in relation to root biomass. The value for each species is set at twice the cumulative root:shoot ratio value (Matrix 01) for that species.

The growing-season green-out shoot:root ratio has a similar function, but it provides for a rapid readjustment between above- and belowground biomass. This can become necessary when a stressor (e.g., grazing, fire, mowing) causes a sudden removal of aboveground biomass. This is the green-out trigger mechanism between green-out month and winter dormancy (Matrix 10). If the shoot:root ratio becomes less than this value, green-out is triggered. The value for each species equals half of the inverse of the maximum root:shoot ratio.

Maximum one-month seed germination is the proportion of the seed bank for a particular species that can germinate in any single month of the seed germination months (Matrix 10). Most of the values were taken from, or estimated from Vories (1981), Fulbright et al. (1982), and Redente et al. (1982).

Maximum first-month seedling growth determines the maximum amount of biomass seedlings of each species can produce in the month of germination. The value in Matrix 18 is multiplied by the biomass of seeds of the respective species that germinate in that month (i.e., biomass in seed bank x maximum 1-month germination value). These values are estimates based on conceptual models of the relationships between 1-month-old seedling weights and the weight of the seed that produced the seedling.

19. END OF GROWING SEASON DIEBACK

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	0.03	0.15	0.02	0.10	0.50	1.00
Rubber rabbitbrush	0.10	0.20	0.10	0.40	0.95	1.00
Crested wheatgrass	0.10	0.21	0.05	1.00	1.00	1.00
Western wheatgrass	0.10	0.21	0.05	1.00	1.00	1.00
Bluebunch wheatgrass	0.10	0.21	0.05	1.00	1.00	1.00
Indian ricegrass	0.10	0.20	0.05	1.00	1.00	1.00
Sandberg bluegrass	0.10	0.21	0.05	1.00	1.00	1.00
Squirreltail	0.25	0.40	0.15	1.00	1.00	1.00
Needle-and-thread	0.15	0.30	0.10	1.00	1.00	1.00
Yarrow	0.25	0.40	0.15	1.00	1.00	1.00
Russian knapweed	0.25	0.40	0.15	1.00	1.00	1.00
Buckwheat milkvetch	0.25	0.40	0.15	1.00	1.00	1.00
Diffuse knapweed	0.70	0.80	0.80	0.95	0.95	1.00
Shaggy daisy	0.25	0.40	0.15	1.00	1.00	1.00
Evening primrose	0.25	0.40	0.15	1.00	1.00	1.00
Longleaf phlox	0.25	0.40	0.15	1.00	1.00	1.00
Cheatgrass	1.00	1.00	1.00	1.00	1.00	1.00
Storksbill	1.00	1.00	1.00	1.00	1.00	1.00
Pepperweed	1.00	1.00	1.00	1.00	1.00	1.00
Tumble mustard	1.00	1.00	1.00	1.00	1.00	1.00

This matrix provides the values for EDYS to calculate how much of each plant part component for each species dies at the end of each growing season. All (1.00) tissue of all parts of annuals die each year. For most herbaceous perennials, 100% of the leaves and stems die at the end of the growing season. Data used to calculate root survival was taken from Weaver (1954:160-162).

20. DIEBACK FATE

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Big sagebrush	-1	-1	7	7	0	0
Rubber rabbitbrush	-1	-1	7	7	0	0
Crested wheatgrass	-1	-1	0	7	8	0
Western wheatgrass	-1	-1	0	7	8	0
Bluebunch wheatgrass	-1	-1	0	7	8	0
Indian ricegrass	-1	-1	0	7	8	0
Sandberg bluegrass	-1	-1	0	7	8	0
Squirreltail	-1	-1	0	7	8	0
Needle-and-thread	-1	-1	0	7	8	0
Yarrow	-1	-1	0	7	8	0
Russian knapweed	-1	-1	0	7	8	0
Buckwheat milkvetch	-1	-1	0	7	8	0
Diffuse knapweed	-1	-1	0	7	8	0
Shaggy daisy	-1	-1	0	7	8	0
Evening primrose	-1	-1	0	7	8	0
Longleaf phlox	-1	-1	0	7	8	0
Cheatgrass	-1	-1	0	7	8	0
Storksbill	-1	-1	0	7	8	0
Pepperweed	-1	-1	0	7	8	0
Tumble mustard	-1	-1	0	7	8	0

The purpose of this matrix is to designate which pool dead material from each plant part is initially placed. A designation of -1 places the dead material into the soil organic matter of the layer in which the material existed at the time of death. A designation of 0 places the material in surface litter, a value of 7 places the material in the standing dead stems compartment, and a value of 8 places the material into standing dead leaves.

21. PLANT PART LOSSES TO FIRE EVENTS

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Big sagebrush	0.00	0.00	0.50	0.80	0.95	0.95	0.90	1.00	0.00	1.00	0.50
Rubber rabbitbrush	0.00	0.00	0.70	0.90	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Crested wheatgrass	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Western wheatgrass	0.05	0.00	0.30	0.90	1.00	0.95	1.00	1.00	0.00	1.00	0.50
Bluebunch wheatgrass	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Indian ricegrass	0.00	0.00	0.40	0.95	0.95	0.95	1.00	1.00	0.00	1.00	0.50
Sandberg bluegrass	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Squirreltail	0.00	0.00	0.30	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Needle-and-thread	0.00	0.00	0.20	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Yarrow	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Russian knapweed	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Buckwheat milkvetch	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Diffuse knapweed	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Shaggy daisy	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Evening primrose	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Longleaf phlox	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Cheatgrass	0.00	0.00	0.60	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.10
Storksbill	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Pepperweed	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50
Tumble mustard	0.00	0.00	0.90	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.50

This matrix designates how much of the biomass of each plant part of each species is lost in a moderate fire event, i.e., a relatively cool fire. A moderate fire event is defined as one in which the fuel load is 200 g/m^2 (1784 lbs/ac)(Scifres 1980). The fuel load for this calculation is defined as the sum of the litter plus the non-trunk aboveground biomass of all herbaceous species.

22. FUEL COMBUSTIBILITY FACTOR

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Big sagebrush	0.00	0.00	0.75	1.50	2.00	1.00	2.00	4.00	0.00	2.00	1.00
Rubber rabbitbrush	0.00	0.00	0.75	2.00	2.00	1.00	3.00	4.00	0.00	2.00	1.00
Crested wheatgrass	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Western wheatgrass	0.00	0.00	1.00	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Bluebunch wheatgrass	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Indian ricegrass	0.00	0.00	1.00	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Sandberg bluegrass	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Squirreltail	0.00	0.00	1.00	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Needle-and-thread	0.00	0.00	1.00	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Yarrow	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Russian knapweed	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Buckwheat milkvetch	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Diffuse knapweed	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Shaggy daisy	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Evening primrose	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Longleaf phlox	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Cheatgrass	0.00	0.00	1.00	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Storksbill	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Pepperweed	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00
Tumble mustard	0.00	0.00	0.50	1.00	1.00	1.00	1.50	1.50	0.00	1.00	1.00

The effectiveness of a material in contributing to the fuel load is dependent on a number of factors, including 1) size of the material, 2) moisture content, 3) compaction, and 4) chemical composition (e.g., volatile oil content). Matrix 22 provides a measure of these factors in adjusting the effect of the fuel loads calculated using Matrix 21.

In Matrix 22, a value of 1.00 is typical of green fine fuel, such as grass leaves. A value of 1.50 is typical of dry fine fuel, such as dead grass leaves. Woody, or particularly lush herbaceous, materials have values less than 1.00. Material containing volatile oils, have values of 2.00, or greater, depending on moisture content.

23. PLANT LOSS TO TRAMPLING OR A SINGLE VEHICLE PASS

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Big sagebrush	0.00	0.00	0.80	0.80	0.85	0.85	0.90	0.90	0.25	0.90	0.00
Rubber rabbitbrush	0.00	0.00	0.70	0.70	0.80	0.80	0.80	0.90	0.25	0.90	0.00
Crested wheatgrass	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Western wheatgrass	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Bluebunch wheatgrass	0.00	0.00	0.50	0.95	0.95	0.95	0.98	0.95	0.20	0.80	0.00
Indian ricegrass	0.00	0.00	0.50	0.95	0.95	0.95	0.98	0.95	0.20	0.80	0.00
Sandberg bluegrass	0.00	0.00	0.40	0.80	0.80	0.90	0.90	0.90	0.20	0.80	0.00
Squirreltail	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Needle-and-thread	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Yarrow	0.00	0.00	0.40	0.80	0.60	0.80	0.90	0.80	0.10	0.70	0.00
Russian knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buckwheat milkvetch	0.00	0.00	0.40	0.70	0.60	0.70	0.85	0.75	0.10	0.70	0.00
Diffuse knapweed	0.00	0.00	0.50	0.80	0.70	0.80	0.90	0.85	0.20	0.80	0.00
Shaggy daisy	0.00	0.00	0.50	0.80	0.70	0.80	0.90	0.85	0.20	0.80	0.00
Evening primrose	0.00	0.00	0.50	0.80	0.70	0.80	0.90	0.85	0.20	0.80	0.00
Longleaf phlox	0.00	0.00	0.40	0.80	0.70	0.80	0.90	0.85	0.20	0.80	0.00
Cheatgrass	0.00	0.00	0.50	0.80	0.70	0.80	0.85	0.85	0.10	0.70	0.00
Storksbill	0.00	0.00	0.40	0.70	0.50	0.60	0.75	0.75	0.10	0.60	0.00
Pepperweed	0.00	0.00	0.40	0.80	0.60	0.80	0.80	0.75	0.20	0.80	0.00
Tumble mustard	0.00	0.00	0.30	0.60	0.40	0.60	0.80	0.70	0.10	0.60	0.00

The values in Matrix 23 represent estimates of the physical impact of a single trampling event. A value of 0.50, for example, indicates that 50% of the biomass of that plant part is removed and transferred to the litter compartment. This matrix does not address whether or not the plant is killed by the trampling event. Survivability is simulated by the response of the plant to the tissue loss over time.

24. HERBIVORE PREFERENCE AND COMPETITION (P, C)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Insects											
Big sagebrush	0,1	0,1	0,1	0,1	6,1	5,1	0,1	11,1	0,1	3,1	0,1
Rubber rabbitbrush	0,1	0,1	0,1	0,1	6,1	4,1	0,1	11,1	0,1	3,1	0,1
Crested wheatgrass	0,1	0,1	8,1	7,1	3,1	4,1	0,1	9,1	0,1	2,1	6,1
Western wheatgrass	0,1	0,1	8,1	7,1	3,1	4,1	0,1	9,1	0,1	2,1	6,1
Bluebunch wheatgrass	0,1	0,1	8,1	7,1	3,1	4,1	0,1	9,1	0,1	2,1	0,1
Indian ricegrass	0,1	0,1	8,1	7,1	3,1	4,1	0,1	9,1	0,1	2,1	0,1
Sandberg bluegrass	0,1	0,1	8,1	7,1	3,1	4,1	0,1	9,1	0,1	2,1	0,1
Squirreltail	0,1	0,1	8,1	7,1	4,1	6,1	0,1	10,1	0,1	2,1	0,1
Needle-and-thread	0,1	0,1	8,1	7,1	4,1	6,1	0,1	10,1	0,1	2,1	0,1
Yarrow	0,1	0,1	6,1	6,1	2,1	3,1	0,1	8,1	0,1	1,1	0,1
Russian knapweed	0,1	0,1	9,1	8,1	7,1	6,1	0,1	12,1	0,1	4,1	0,1
Buckwheat milkvetch	0,1	0,1	6,1	5,1	1,1	2,1	0,1	8,1	0,1	1,1	0,1
Diffuse knapweed	0,1	0,1	9,1	8,1	7,1	6,1	0,1	12,1	0,1	4,1	0,1
Shaggy daisy	0,1	0,1	6,1	5,1	1,1	2,1	0,1	8,1	0,1	1,1	0,1
Evening primrose	0,1	0,1	7,1	5,1	1,1	2,1	0,1	8,1	0,1	1,1	0,1
Longleaf phlox	0,1	0,1	7,1	6,1	1,1	2,1	0,1	8,1	0,1	1,1	0,1
Cheatgrass	0,1	0,1	8,1	7,1	4,1	5,1	0,1	10,1	0,1	2,1	8,1
Storksbill	0,1	0,1	6,1	6,1	2,1	4,1	0,1	8,1	0,1	1,1	0,1
Pepperweed	0,1	0,1	8,1	7,1	5,1	4,1	0,1	9,1	0,1	2,1	0,1
Tumble mustard	0,1	0,1	7,1	6,1	1,1	3,1	0,1	8,1	0,1	1,1	0,1
Rabbits											
Big sagebrush	0,2	0,2	0,2	0,2	7,2	5,2	0,2	9,2	0,2	4,2	0,2
Rubber rabbitbrush	0,2	0,2	10,2	9,2	8,2	4,2	0,2	10,2	0,2	4,2	0,2
Crested wheatgrass	0,2	0,2	8,2	7,2	4,2	3,2	10,2	8,2	0,2	3,2	5,2
Western wheatgrass	0,2	0,2	8,2	6,2	3,2	2,2	9,2	7,2	0,2	2,2	5,2
Bluebunch wheatgrass	0,2	0,2	8,2	6,2	3,2	3,2	9,2	7,2	0,2	2,2	0,2
Indian ricegrass	0,2	0,2	8,2	6,2	3,2	3,2	9,2	7,2	0,2	2,2	0,2
Sandberg bluegrass	0,2	0,2	8,2	6,2	3,2	2,2	9,2	7,2	0,2	2,2	0,2
Squirreltail	0,2	0,2	8,2	7,2	5,2	6,2	10,2	8,2	0,2	3,2	0,2
Needle-and-thread	0,2	0,2	8,2	7,2	4,2	6,2	10,2	8,2	0,2	3,2	0,2
Yarrow	0,2	0,2	6,2	3,2	2,2	2,2	7,2	5,2	0,2	1,2	0,2
Russian knapweed	0,2	0,2	10,2	10,2	9,2	6,2	12,2	11,2	0,2	6,2	0,2
Buckwheat milkvetch	0,2	0,2	5,2	1,2	1,2	1,2	7,2	5,2	0,2	1,2	0,2
Diffuse knapweed	0,2	0,2	10,2	10,2	9,2	6,2	12,2	11,2	0,2	6,2	0,2
Shaggy daisy	0,2	0,2	5,2	1,2	1,2	1,2	7,2	5,2	0,2	1,2	0,2
Evening primrose	0,2	0,2	3,2	1,2	1,2	1,2	7,2	5,2	0,2	1,2	0,2
Longleaf phlox	0,2	0,2	3,2	1,2	1,2	1,2	7,2	5,2	0,2	1,2	0,2
Cheatgrass	0,2	0,2	8,2	7,2	5,2	5,2	11,2	9,2	0,2	4,2	0,2
Storksbill	0,2	0,2	4,2	2,2	2,2	3,2	9,2	6,2	0,2	2,2	0,2
Pepperweed	0,2	0,2	9,2	8,2	5,2	3,2	9,2	7,2	0,2	3,2	0,2
Tumble mustard	0,0	0,2	5,2	4,2	3,2	3,2	8,2	6,2	0,2	3,2	0,2

24. HERBIVORE PREFERENCE AND COMPETITION (P, C) (Continued)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
<u>Horses</u>											
Big sagebrush	0,3	0,3	10,3	0,3	5,3	2,3	0,3	6,3	0,3	2,3	0,0
Rubber rabbitbrush	0,3	0,3	10,3	9,3	6,3	3,3	0,3	7,3	0,3	3,3	0,0
Crested wheatgrass	0,3	0,3	2,3	2,3	1,3	1,3	4,3	4,3	0,3	2,3	0,0
Western wheatgrass	0,3	0,3	2,3	2,3	1,3	1,3	4,3	3,3	0,3	1,3	0,0
Bluebunch wheatgrass	0,3	0,3	2,3	1,3	1,3	2,3	3,3	3,3	0,3	1,3	0,0
Indian ricegrass	0,3	0,3	2,3	2,3	1,3	1,3	4,3	3,3	0,3	1,3	0,0
Sandberg bluegrass	0,3	0,3	1,3	1,3	1,3	1,3	2,3	2,3	0,3	1,3	0,0
Squirreltail	0,3	0,3	3,3	3,3	2,3	4,3	4,3	3,3	0,3	2,3	0,0
Needle-and-thread	0,3	0,3	2,3	2,3	1,3	4,3	4,3	3,3	0,3	2,3	0,0
Yarrow	0,3	0,3	2,3	2,3	2,3	2,3	4,3	3,3	0,3	1,3	0,0
Russian knapweed	0,3	0,3	0,3	0,3	0,3	7,3	0,3	0,3	0,3	0,3	0,0
Buckwheat milkvetch	0,3	0,3	3,3	2,3	2,3	1,3	3,3	3,3	0,3	1,3	0,0
Diffuse knapweed	0,3	0,3	0,3	0,3	0,3	7,3	0,3	0,3	0,3	0,3	0,0
Shaggy daisy	0,3	0,3	5,3	4,3	3,3	1,3	5,3	4,3	0,3	2,3	0,0
Evening primrose	0,3	0,3	5,3	4,3	3,3	1,3	5,3	4,3	0,3	2,3	0,0
Longleaf phlox	0,3	0,3	5,3	4,3	3,3	1,3	5,3	4,3	0,3	2,3	0,0
Cheatgrass	0,3	0,3	5,3	5,3	4,3	5,3	7,3	6,3	0,3	2,3	0,0
Storksbill	0,3	0,3	5,3	4,3	4,3	7,3	7,3	6,3	0,3	2,3	0,0
Pepperweed	0,3	0,3	7,3	6,3	5,3	4,3	7,3	6,3	0,3	2,3	0,0
Tumble mustard	0,3	0,3	8,3	7,3	6,3	5,3	8,3	7,3	0,3	4,3	0,0
<u>Cattle</u>											
Big sagebrush	0,4	0,4	0,4	0,4	7,4	6,4	0,4	8,4	0,4	6,4	0,0
Rubber rabbitbrush	0,4	0,4	0,4	11,4	10,4	7,4	0,4	0,4	0,4	9,4	0,0
Crested wheatgrass	0,4	0,4	4,4	2,4	2,4	2,4	3,4	3,4	0,4	1,4	0,0
Western wheatgrass	0,4	0,4	4,4	1,4	1,4	1,4	2,4	2,4	0,4	1,4	0,0
Bluebunch wheatgrass	0,4	0,4	4,4	1,4	1,4	1,4	2,4	2,4	0,4	1,4	0,0
Indian ricegrass	0,4	0,4	4,4	1,4	1,4	1,4	2,4	2,4	0,4	1,4	0,0
Sandberg bluegrass	0,4	0,4	4,4	1,4	1,4	1,4	1,4	1,4	0,4	1,4	0,0
Squirreltail	0,4	0,4	5,4	3,4	3,4	3,4	4,4	4,4	0,4	2,4	0,0
Needle-and-thread	0,4	0,4	4,4	2,4	2,4	2,4	3,4	3,4	0,4	1,4	0,0
Yarrow	0,4	0,4	5,4	4,4	4,4	4,4	5,4	5,4	0,4	4,4	0,0
Russian knapweed	0,4	0,4	0,4	0,4	0,4	11,4	0,4	0,4	0,4	0,4	0,0
Buckwheat milkvetch	0,4	0,4	5,4	4,4	4,4	4,4	5,4	5,4	0,4	4,4	0,0
Diffuse knapweed	0,4	0,4	0,4	0,4	0,4	11,4	0,4	0,4	0,4	0,4	0,0
Shaggy daisy	0,4	0,4	9,4	6,4	6,4	5,4	8,4	8,4	0,4	6,4	0,0
Evening primrose	0,4	0,4	7,4	6,4	6,4	4,4	8,4	8,4	0,4	5,4	0,0
Longleaf phlox	0,4	0,4	7,4	6,4	6,4	4,4	8,4	8,4	0,4	6,4	0,0
Cheatgrass	0,4	0,4	6,4	5,4	5,4	5,4	8,4	8,4	0,4	4,4	0,0
Storksbill	0,4	0,4	9,4	8,4	8,4	8,4	9,4	9,4	0,4	7,4	0,0
Pepperweed	0,4	0,4	0,4	9,4	9,4	8,4	10,4	10,4	0,4	8,4	0,0
Tumble mustard	0,4	0,4	0,4	10,4	10,4	9,4	11,4	11,4	0,4	9,4	0,0

Herbivory is simulated in EDYS as a species-specific and a plant part-specific process. Each species of herbivore selects various plant species, based on the preference of that herbivore and the availability of the plant species. In addition, each herbivore also selects individual plant parts of individual species based on preference and availability.

The first number of each pair in Matrix 24 is the relative preference value for that plant part of that species for a specific herbivore. Cattle prefer grasses and deer prefer forbs and shrubs. Therefore, grasses have higher preference values for cattle than they do for deer. However, cattle prefer some grasses over others.

The second number of each pair in Matrix 24 is the relative competition value for each plant part of each species for each herbivore. This value is used to determine which herbivore gets first choice of that plant part, when more than one herbivore attempts to select it and there is insufficient amount to supply both herbivores. In most cases, this value assumes that if the material is limited, insects are most likely to acquire the limited resource, followed by rabbits, and finally cattle.

25. HERBIVORE ACCESSIBILITY

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Insects											
Big sagebrush	0	0	100	100	99	95	100	90	0	99	5
Rubber rabbitbrush	0	0	100	100	98	95	100	85	0	99	5
Crested wheatgrass	0	0	90	100	100	100	100	100	0	95	25
Western wheatgrass	0	0	90	100	100	100	100	100	0	95	25
Bluebunch wheatgrass	0	0	90	100	100	100	100	100	0	95	10
Indian ricegrass	0	0	90	100	100	100	100	100	0	95	10
Sandberg bluegrass	0	0	90	100	100	100	100	100	0	95	5
Squirreltail	0	0	90	100	100	100	100	100	0	95	10
Needle-and-thread	0	0	90	100	100	100	100	100	0	95	10
Yarrow	0	0	90	100	100	100	100	90	0	99	1
Russian knapweed	0	0	90	100	100	100	100	90	0	95	0
Buckwheat milkvetch	0	0	100	100	100	100	100	100	0	99	5
Diffuse knapweed	0	0	90	100	100	100	100	90	0	95	1
Shaggy daisy	0	0	100	100	100	100	100	100	0	99	5
Evening primrose	0	0	100	100	100	100	100	100	0	99	5
Longleaf phlox	0	0	100	100	100	100	100	100	0	99	5
Cheatgrass	0	0	95	100	100	100	100	100	0	95	10
Storksbill	0	0	95	100	100	100	100	100	0	95	5
Pepperweed	0	0	100	100	100	100	100	95	0	95	1
Tumble mustard	0	0	95	100	100	100	100	100	0	99	1
Rabbits											
Big sagebrush	10	0	100	50	50	10	50	45	0	90	0
Rubber rabbitbrush	10	0	100	75	70	25	75	65	0	90	0
Crested wheatgrass	5	0	90	100	95	95	100	90	0	85	10
Western wheatgrass	5	0	90	100	95	95	100	90	0	85	10
Bluebunch wheatgrass	5	0	90	100	95	95	100	90	0	85	0
Indian ricegrass	5	0	90	100	95	95	100	90	0	85	5
Sandberg bluegrass	5	0	90	100	95	95	100	90	0	85	0
Squirreltail	5	0	90	100	95	95	100	90	0	85	0
Needle-and-thread	5	0	90	100	95	95	100	90	0	85	0
Yarrow	10	0	90	100	90	95	100	85	0	85	0
Russian knapweed	10	0	90	100	90	95	100	85	0	85	0
Buckwheat milkvetch	10	0	95	100	95	95	100	90	0	80	0
Diffuse knapweed	10	0	90	100	90	95	100	85	0	85	0
Shaggy daisy	0	0	90	100	90	95	100	85	0	80	0
Evening primrose	10	0	95	100	95	95	100	90	0	85	0
Longleaf phlox	10	0	95	100	95	95	100	90	0	85	0
Cheatgrass	0	0	90	100	95	95	100	90	0	85	5
Storksbill	0	0	90	100	80	95	100	75	0	80	0
Pepperweed	0	0	95	100	90	95	100	85	0	80	0
Tumble mustard	10	0	90	100	80	95	100	75	0	85	0

25. HERBIVORE ACCESSIBILITY (Continued)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Horses											
Big sagebrush	0	0	95	95	90	95	95	85	0	90	0
Rubber rabbitbrush	0	0	98	95	90	95	95	85	0	90	0
Crested wheatgrass	0	0	70	98	95	98	98	90	0	80	0
Western wheatgrass	0	0	70	98	95	98	98	90	0	80	0
Bluebunch wheatgrass	0	0	70	98	95	98	98	90	0	80	0
Indian ricegrass	0	0	70	98	95	98	98	90	0	80	0
Sandberg bluegrass	0	0	60	98	90	98	98	85	0	70	0
Squirreltail	0	0	70	98	95	98	98	90	0	80	0
Needle-and-thread	0	0	70	98	95	98	98	90	0	80	0
Yarrow	0	0	50	90	80	98	90	75	0	50	0
Russian knapweed	0	0	80	98	90	98	98	85	0	70	0
Buckwheat milkvetch	0	0	60	90	90	90	90	85	0	60	0
Diffuse knapweed	0	0	80	98	90	98	98	85	0	70	0
Shaggy daisy	0	0	80	98	95	95	98	90	0	70	0
Evening primrose	0	0	80	98	95	98	98	90	0	80	0
Longleaf phlox	0	0	70	98	95	98	98	90	0	70	0
Cheatgrass	0	0	70	98	95	98	98	90	0	75	0
Storksbill	0	0	50	90	80	90	90	75	0	40	0
Pepperweed	0	0	70	98	90	95	98	85	0	50	0
Tumble mustard	0	0	50	98	80	98	98	75	0	40	0
Cattle											
Big sagebrush	0	0	90	90	80	90	90	70	0	50	0
Rubber rabbitbrush	0	0	95	95	90	95	95	80	0	50	0
Crested wheatgrass	0	0	10	90	90	95	90	80	0	25	0
Western wheatgrass	0	0	10	80	80	95	80	70	0	25	0
Bluebunch wheatgrass	0	0	10	90	90	95	90	80	0	25	0
Indian ricegrass	0	0	10	90	90	95	90	80	0	25	0
Sandberg bluegrass	0	0	5	80	70	95	80	60	0	25	0
Squirreltail	0	0	10	90	90	95	90	80	0	25	0
Needle-and-thread	0	0	10	90	90	95	90	80	0	25	0
Yarrow	0	0	5	80	60	90	80	50	0	20	0
Russian knapweed	0	0	20	90	80	90	90	70	0	25	0
Buckwheat milkvetch	0	0	10	60	50	80	60	40	0	20	0
Diffuse knapweed	0	0	20	90	80	90	90	70	0	25	0
Shaggy daisy	0	0	20	90	80	90	90	70	0	25	0
Evening primrose	0	0	20	80	70	80	80	60	0	25	0
Longleaf phlox	0	0	10	80	70	90	80	60	0	25	0
Cheatgrass	0	0	10	90	80	90	90	70	0	20	0
Storksbill	0	0	5	50	50	70	50	40	0	5	0
Pepperweed	0	0	10	90	80	80	90	70	0	10	0
Tumble mustard	0	0	5	90	50	90	90	40	0	10	0

Another important aspect of determining herbivore diets is accessibility. This relates to how much of a particular plant part an herbivore could select if it wanted the plant part. A high value in Matrix 25 does not suggest that the herbivore would actually select that plant part. Selection is largely determined by preference (Matrix 24).

26. INITIAL BIOMASS

Species	C100	C200	C300	C400	C500	C600	C700	C800
Big sagebrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rubber rabbitbrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bluebunch wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indian ricegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sandberg bluegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Squirreltail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Needle-and-thread	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yarrow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Russian knapweed	0.00	17.19	0.00	0.00	0.00	0.00	0.00	0.00
Buckwheat milkvetch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diffuse knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shaggy daisy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evening primrose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longleaf phlox	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	6.70	8.06	4.30	8.10	7.80	11.96	9.44	7.90
Storksbill	0.00	0.53	0.53	0.00	0.08	0.00	0.00	0.00
Pepperweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tumble mustard	3.20	2.50	2.80	3.00	2.60	3.00	3.00	3.00

Species	C900	C1000	C1100	C1200	C1300	C1400	C1500	C1600
Big sagebrush	1.18	0.00	0.00	1.18	0.98	1.96	1.18	1.18
Rubber rabbitbrush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crested wheatgrass	0.61	4.89	0.00	0.00	0.00	0.00	0.37	1.83
Western wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bluebunch wheatgrass	3.96	6.79	4.47	9.36	4.47	4.47	9.36	21.45
Indian ricegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sandberg bluegrass	4.52	4.52	4.04	0.49	2.57	5.26	0.49	2.94
Squirreltail	1.00	1.00	1.33	1.00	4.24	1.33	1.00	4.89
Needle-and-thread	0.00	0.00	0.98	0.00	0.98	2.20	0.00	1.22
Yarrow	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Russian knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buckwheat milkvetch	0.00	0.00	0.66	0.00	0.66	0.53	1.32	10.58
Diffuse knapweed	17.46	19.84	21.43	19.84	21.43	24.34	19.84	31.48
Shaggy daisy	0.00	0.03	0.03	0.03	0.03	0.82	0.03	0.55
Evening primrose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.32
Longleaf phlox	1.56	1.56	1.43	1.56	1.43	1.43	1.56	2.09
Cheatgrass	1.70	1.70	1.64	1.90	3.24	1.64	1.90	1.90
Storksbill	0.34	1.03	1.03	1.03	1.03	1.03	1.03	1.03
Pepperweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tumble mustard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66

These are the initial aboveground biomass values used to begin an EDYS simulation. The values for each community were based on the data collected in the field treatment plots.

Appendix Table 1. Sources of root:shoot ratios used in the EDYS application for Yakima Training Center, Washington.

Species	Source
Big sagebrush	DeLucia et al. (1989), Redente (1992), Sturges and Trlica (1978), Welch (1997)
Rubber rabbitbrush	Donovan and Richards (2000)
Crested wheatgrass	Svejcar (1990)
Western wheatgrass	Burlson and Hewitt (1982), Kemp and Williams (1980), Mack (1986), Mueller and Bowman (1989), Samuel and Hart (1992), Vinton and Burke (1995)
Bluebunch wheatgrass	Aguirre and Johnson (1991), Arrendondo et al. (1998), Blank and Young (1998)
Indian ricegrass	Orodho and Trlica (1990)
Sandberg bluegrass	Blank and Young (1998), Link et al. (1990)
Squirreltail	Arrendondo et al. (1998), Blank and Young (1998), Hironaka and Sindelar (1975), Redente (1992)
Needle-and-thread	Blank and Young (1998), Burleson and Hewitt (1982), Vinton and Burke (1995)
Yarrow	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Russian knapweed	Lowe et al. (2002)
Buckwheat milkvetch	*Astragalus micropterus* – Barbour (1973)
Diffuse knapweed	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Shaggy daisy	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Evening primrose	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Longleaf phlox	*Acroptilon repens* – Lowe et al. 2002
Cheatgrass	Aquirre and Johnson (1991), Arrendondo et al. (1998), Blank and Young (1998), DeLucia et al. (1989), Hinds (1975), Link et al. (1990), Lowe et al. (2002), Sheley and Larson (1994), Svejcar (1990)
Storksbill	Annual – Odum (1971)
Pepperweed	Annual – Odum (1971)
Tumble mustard	Annual – Odum (1971)

Data from the following studies were used to calculate root:shoot ratios:
Aguirre and Johnson 1991, Andersson 1970, Arrendondo et al. 1998, Beaty et al. 1975, Blank and Young 1998, Burlson and Hewitt 1982, Cerligione et al. 1987, Coupland and Johnson 1965, Coyne and Bradford 1986, Davidson 1969, DeLucia et al. 1989, Detling et al. 1979, Duvigneaud et al. 1971, Dwyer and Wolde-Yohannis 1972, Eissenstat 1990, Foster et al. 1980, Ganskopp 1988, Gigon and Rorison 1972, Groot et al. 1998, Haystead et al. 1988, Hellmers et al. 1955, Hetrick et al. 1990, Hinds 1975, Hironaka and Sindelar 1975, Holechek 1982, Hons et al. 1979, Johnson et al. 1989, Kemp and Williams 1980, Kramer 1969, Link et al. 1990, Mack 1986, McDermot 1954, McGinnies and Crofts 1986, McNeill and Wood 1990, Mohammad et al. 1982, Mueller and Bowman 1989, Nadelhoffer et al. 1985, Nasri and Doescher 1995, Orodho and Trlica 1990, Pande and Singh 1981, Patterson 1992, Redente et al. 1992, Samuel and Hart 1992, Santantonio et al. 1977, Sheley and Larson 1994, Shipley and Peters 1990, Smith 1982, Svejcar 1990, Tilman and Wedin 1991, Velagala et al. 1997, Vinton and Burke 1995, Weaver and Zink 1946, White and Van Auken 1996, and Williams et al. 1995.

Appendix Table 2. Sources of root architecture data.

Species	Reference
Shrubs	
Big sagebrush (*Artemisia tridentata*)	Branson et al. (1976), Sturges and Trlica (1978)
Rubber rabbitbrush (*Chrysothamnus nauseosus*)	Melgoza and Nowak (1991), McLendon et al. (2000a)
Grasses	
Crested wheatgrass (*Agropyron cristatum*)	Caldwell and Richards (1990)
Western wheatgrass (*Pascopyrum smithii)*	Weaver and Darland (1949), Hopkins (1953), Weaver (1958)
Bluebunch wheatgrass *(Agropyron*	Caldwell and Richards (1990)
Indian ricegrass (*Achnatherum hymenoides*)	Weaver and Darland (1949)
Sandberg bluegrass (*Poa secunda*)	Weaver and Darland (1949)
Squirreltail (*Elymus elymoides*)	Branson et al. (1976)
Needle-and-thread (*Stipa comata*)	Coupland and Brayshaw (1953), Weaver (1968)
Cheatgrass (*Bromus tectorum*)	Cline et al. (1977)
Forbs	
Yarrow (*Achillea millefolium*)	Lorenz (1977), Holch (1941)
Russian knapweed (*Acroptilon repens*)	Marler et al. (1999)
Buckwheat milkvetch (*Astragalus caricinus*)	Weaver (1977)
Diffuse knapweed (*Centaurea diffusa*)	Marler et al. (1999)
Shaggy daisy (*Erigeron pumilus*)	Weaver (1977)
Evening primrose (*Oenothera pallida)*	Weaver (1977), Holch (1941)
Longleaf phlox (*Phlox longifolia*)	Weaver (1977)
Storksbill (*Erodium cicutarium*)	Weaver (1977)
Pepperweed (*Lepidium perfoliatum*)	Renz et al. (1997)
Tumblemustard (*Sisymbrium altissimum)*	Weaver (1977)

Appendix Table 3. Maximum reported rooting depths (cm).

Species	Depth	Reference
Shrubs		
Big sagebrush (*Artemisia tridentata*)	335	Weaver and Clements (1938)
Rubber rabbitbrush (*Chrysothamnus nauseosus*)	391	Dittmer (1959)
Grasses		
Crested wheatgrass (*Agropyron cristatum*)	148	Cook and Lewis (1958)
Western wheatgrass (*Pascopyrum smithii)*	360	Hopkins (1953)
Bluebunch wheatgrass *(Agropyron spicatum)*	135	Harris (1967)
Indian ricegrass (*Achnatherum hymenoides*)	45	Dittmer (1959)
Sandberg bluegrass (*Poa secunda*)	45	Spence (1937)
Squirreltail (*Elymus elymoides*)	72	*Elymus canadensis* – Weaver (1958)
Needle-and-thread (*Stipa comata*)	195	Wyatt et al. (1980)
Cheatgrass (*Bromus tectorum*)	152	Hulbert (1955)
Forbs		
Yarrow (*Achillea millefolium*)	120	Spence (1937)
Russian knapweed (*Acroptilon repens*)	77	*Centaurea solsticialis* – Sheley and Larson (1994)
Buckwheat milkvetch (*Astragalus caricinus*)	152	*Astragalus drummondi* – Weaver (1958)
Diffuse knapweed (*Centaurea diffusa*)		*Centaurea solsticialis* – Sheley and Larson (1994)
Shaggy daisy (*Erigeron pumilus*)	275	*Erigeron jamessii* – Weaver (1958)
Evening primrose (*Oenothera pallida)*	61	*Oenothera macrocarpa* ssp. *Fremontii* – Albertson (1937)
Longleaf phlox (*Phlox longifolia*)	86	*Phlox hoodii* – Coupland and Johnson (1969)
Storksbill (*Erodium cicutarium*)	64	*Lepidium virginicum* – Cole and Holch (1941)
Pepperweed (*Lepidium perfoliatum*)	64	*Lepidium virginicum* – Cole and Holch (1941)
Tumblemustard (*Sisymbrium altissimum)*	64	*Lepidium virginicum* – Cole and Holch (1941)

Appendix Table 4. Water-use efficiency (WUE) values (kg of water required to produce 1 g of plant dry-weight biomass).

Species	WUE	Source
Shrubs		
Big sagebrush (*Artemisia tridentata*)	0.66 – 1.25	Delucia and Heckathorn (1989), Downs and Black (1999)
Rubber rabbitbrush (*Chrysothamnus nauseosus*)	0.28 – 1.10	Donovan and Ehleringer (1994), *Artemisia tridentata* – Downs and Black (1999)
Grasses		
Crested wheatgrass (*Agropyron cristatum*)	0.50 – 0.86	Shantz and Piemeisel (1927), Hull (1963), Fairburn (1982), Caldwell et al. (1983)
Western wheatgrass (*Pascopyrum smithii)*	0.45 – 1.03	Fairbourn (1982),
Bluebunch wheatgrass *(Agropyron spicatum)*	0.71	Caldwell et al. (1983)
Indian ricegrass (*Achnatherum hymenoides*)	0.72 – 1.32	*Stipa viridula* – Fairburn (1982), Power (1985)
Sandberg bluegrass (*Poa secunda*)	0.50 – 0.86	*Agropyrum cristatum* – Shantz and Piemeisel (1927), Fairburn (1982), Caldwell et al. (1983),
Squirreltail (*Elymus elymoides*)	0.72 – 1.32	*Stipa viridula* – Fairbourn (1982), Power (1985)
Needle-and-thread (*Stipa comata*)	0.72 – 1.32	*Stipa viridula* – Fairbourn (1982), Power (1985)
Cheatgrass (*Bromus tectorum*)	0.15 – 0.39	Hull (1963), Link et al. (1995), Nasri et al. (1995)
Forbs		
Yarrow (*Achillea millefolium)*	0.27 – 0.65	*Centaurea iberica* – Lof (1976), *Centaurea maculosa* – Blicker et al. (2003)
Russian knapweed (*Acroptilon repens*)	0.27 – 0.65	*Centaurea iberica* – Lof (1976), *Centaurea maculosa* – Blicker et al. (2003)
Buckwheat milkvetch (*Astragalus caricinus*)	0.84	*Astragalus cicer* – Fairbourn (1982)
Diffuse knapweed (*Centaurea diffusa*)	0.27 – 0.65	*Centaurea iberica* – Lof (1976), *Centaurea maculosa* – Blicker et al. (2003)
Shaggy daisy (*Erigeron pumilus*)	0.27 – 0.65	*Centaurea iberica* – Lof (1976), *Centaurea maculosa* – Blicker et al. (2003)
Evening primrose (*Oenothera pallida)*	0.84	*Astragalus cier* – Fairbourn (1982)
Longleaf phlox (*Phlox longifolia*)	0.84	*Astragalus cier* – Fairbourn (1982)
Storksbill (*Erodium cicutarium*)	0.74	McGinnies and Arnold (1939)
Pepperweed (*Lepidium perfoliatum*)	0.27 – 0.65	*Centaurea iberica* – Lof (1976), *Centaurea maculosa* – Blicker et al. (2003)
Tumblemustard (*Sisymbrium altissimum)*	0.27 – 0.65	*Centaurea iberica* – Lof (1976), *Centaurea maculosa* – Blicker et al. (2003)