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A Functional Description of the Ecological Dynamics Simulation (EDYS) Model, With Applications for Army and Other Federal Land Managers

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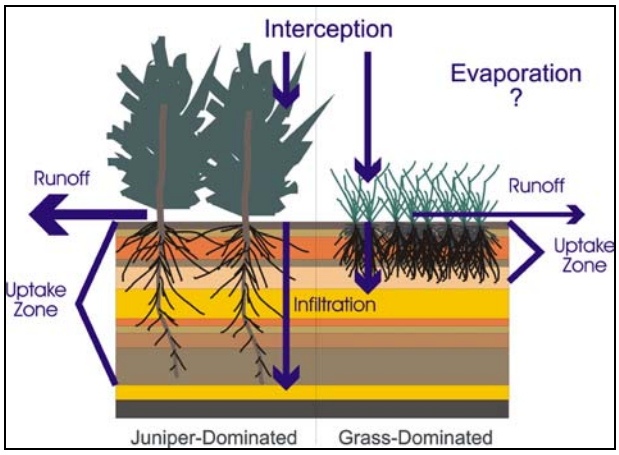

In FY95, USACERL initiated the "Land Based Carrying Capacity" capability package. The impetus behind this research and development package was the coincidence of needs from the Office of the Deputy Chief of Staff for Operations (ODCSOPS), the Office of the Directorate of Environmental Programs (ODEP) and several installations, to address the requirement of sustainable training and testing land carrying capacity. A key component of this capability package is the Ecological Dynamics Simulation (EDYS) model. The model provides the capability to predict responses of training lands to both military and non-military stressors and facilitates linking the cost of training and testing land maintenance to the actual level of training.

We provide here a functional description of the EDYS model with applications for several Army installations, the U.S. Air Force Academy, and the National Water Management Center of the USDA Natural Resources Conservation Service. We also have included appendices that describe system implementation, and data requirements and structure. The EDYS model will be incorporated into the Land Management System (LMS) and will be available to users via the Corps' Engineer Research and Development Center web site.

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THIS IS A PLACEHOLDER PAGE FOR A MANDATORY GOVERNMENT FORM.

Foreword

This study was conducted for Office of the Directorate of Environmental Programs (DAIM), Assistant Chief of Staff (Installation Management) (ACS[IM]) under project 4A162720A896, "Environmental Quality Technology," Work Unit EN-TK-7, "Land-based Carrying Capacity." The technical monitor was Dr. Victor Diersing, DAIM-ED-N.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. David L. Price. Dr. Harold E. Balbach is Chief, CECER-CN-N, and Dr. John T. Bandy is Operations Chief, CECER-CN. The technical editor was Gloria J. Wienke, Information Technology Laboratory. The Director of CERL is Dr. Michael J. O'Connor.

Drs. Terry McLendon, W. Michael Childress, and Cade L. Coldren are Vice President, Ecological System Scientist, and Ecological Modeller, respectively, of Shepherd Miller Inc., Department of Ecological Systems, Fort Collins Colorado, and developed the Army's and other applications of the Ecological Dynamics Simulation (EDYS) model under contract to CERL.

Mr. Brett Russell and Mr. Kevin Vonfinger, Directorate of Environment, Fort Bliss, Texas; Mr. Don Jones, Land Rehabilitation and Management Coordinator, Fort Hood, Texas; Mr. Craig Phillips, Land Rehabilitation and Management Coordinator, Fort Riley, Kansas; Mr. Pete Nissen, Chief of Natural Resources, Yakima Training Center, Washington; and Mr. T. Gene Gallogly, Environmental Division Manager, U. S. Air Force Academy, Colorado Springs, Colorado all provided site-specific technical expertise and data, reviews of early versions of the EDYS model, and funding to leverage the Land Based Carrying Capacity capability. In particular, Fort Bliss' internal carrying capacity research program heavily leveraged the military impacts component of the Land Based Carrying Capacity capability and provided essential databases for the EDYS model regarding tracked and wheeled vehicle impacts and impacts of wildfires.

Drs. Terry Atwood and David Moffit, staff scientists of the National Water Management Center of the USDA Natural Resources Conservation Service, provided technical expertise, reviews of the EDYS model, and funding (Military Interde-

partmental Purchase Request [MIPR] #677103712) to leverage the development of the water dynamics module of the EDYS model. This was done in conjunction with the demonstration and validation of the EDYS model at Fort Hood, Texas, that was partially funded by the U.S. Army Environmental Center (MIPR #5617). The technical monitor was Ms. Kim Michaels.

Mr. William Beavers, formerly staff scientist of the Plant Materials Center, U.S. National Park Service, provided technical expertise and data, reviews of the EDYS model, and funding for several applications of the EDYS model specific to National Park needs. These applications were a direct leverage of Army and National Park Service funds, a direct effort to share land management information, and in practice an interagency partnership.

The military impacts component of the EDYS model was partially funded by the Office of the Directorate of Environmental Programs (DAIM), Assistant Chief of Staff (Installation Management) (ACS(IM)) under Project 40162720A896, "Environmental Quality Technology," Work Unit LL-T08, "Installation Capacity Factors." The technical monitor was Dr. Victor E. Diersing, DAIM-ED-N. The principal investigator was Mr. Alan B. Anderson.

The military impacts component of the EDYS model was partially funded by the Strategic Environmental Research and Development Program (SERDP) Office under Funding Authorization Document (FAD) 0400-98-8141-08, work unit EL8, "Improved Units of Measure For Training and Testing Area Carrying Capacity Estimation." The technical monitor at the beginning of this work was Dr. Femi Ayorinde, Conservation Program Manager. The current technical monitor is Dr. Robert Holst. The principal investigator was Mr. Alan B. Anderson.

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1 Introduction

This report contains an understandable functional description of the Army's version of the Ecological Dynamics Simulation (EDYS) model. To accomplish this we use examples of applications specifically for Army training as a stressor, developed in conjunction with Forts Hood and Bliss, Texas, as well as examples of other applications developed for other federal land managers. We address our approach to scaling the model, provide diagrams and pseudo code for module structure, module programs, module linkages, database design and plans for Internet access. For those readers who are so inclined, we have included appendices that describe system implementation (Appendix A), and data requirements and structure (Appendix B). For a complete discussion on the theoretical background, conceptual approach (Figure 1), technical approach, and approaches for technology transfer plans for the EDYS model, see McLendon, Childress, and Price 1996; Childress, McLendon, and Price 1999; and Price et al. 1997.

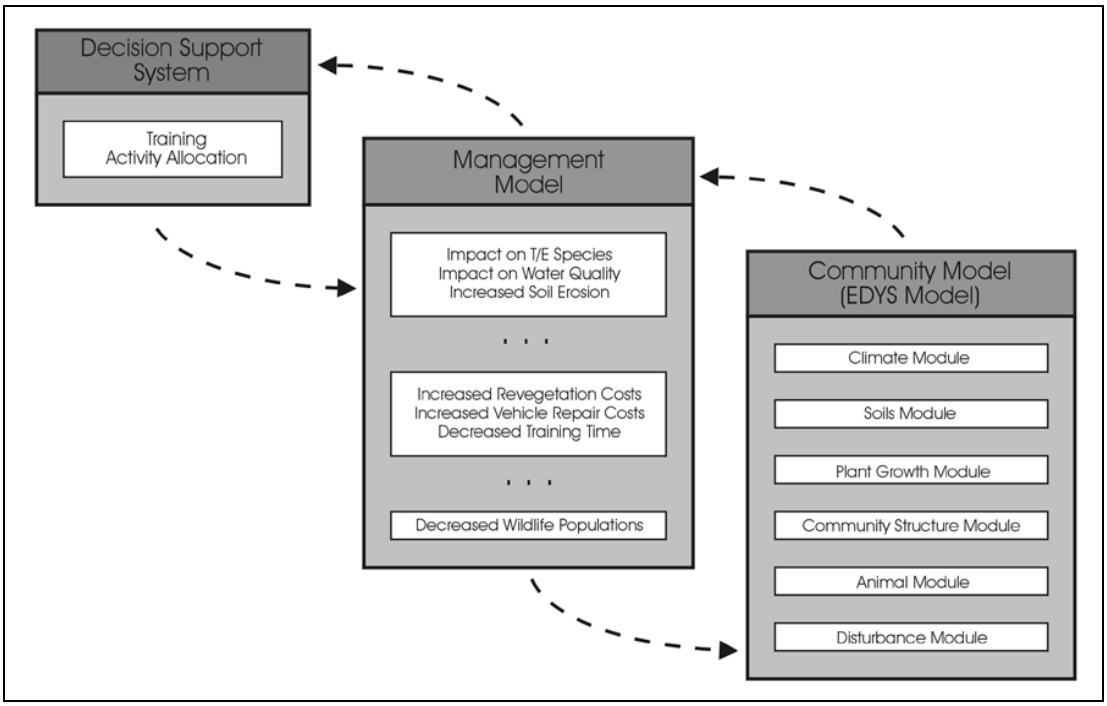

Figure 1. Army Training Decision Support System.*

* The Management Model produces all projections of anticipated effects of different training scenarios. EDYS provides projections of dynamics of all ecosystem components under these scenarios.

The impetus behind the research and development of the EDYS model was the coincidence of needs from the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS), the Office of the Directorate of Environmental Programs (ODEP), and several installations, to address the requirement of sustainable training and testing land carrying capacity (U.S. Army Environmental Center 1996). We also have executed the research and development of the EDYS model within the context of the Department of Defense (DOD) guidance for implementation of an "Ecosystem Management" approach to military land management (DOD 1994 and Goodman 1996), and the DOD Instruction 4715.3, "Environmental Conservation Program" (DOD 1996). Although the term "Ecosystem Management" and the associated concepts (e.g., ecological thresholds) remain controversial, the core themes are generally well accepted by the public and professionals. The primary contact with ecosystem management for most people, including DOD land managers, is vegetation management (see Brown, Herrick, and Price 1999). In the Army's case, vegetation management is where we strive to maintain a realistic training and testing environment on a sustained basis. The EDYS model is one of several useful tools to achieve this end.

Background

The principal program used by the Army to manage its training lands is the Integrated Training Area Management (ITAM) program (Macia 1996). The Land Condition Trend Analysis (LCTA) component of ITAM provides an estimate of the status of the installation's land and natural resources and trends in those resources. ODCSOPS is currently responsible for the ITAM program and has initiated actions to improve the utility of LCTA data and day-to-day management of the Army's land assets within the context of ITAM. One of these initiatives is to develop methods to link the cost of training land maintenance to the actual level of training activity and the subsequent trend in condition of the resource (U.S. Army Concepts Analysis Agency [CAA] 1996). Over the past 15 years these efforts have enhanced the Army's ability to be good stewards of their training lands and associated resources.

Despite these efforts, increasing public concern about the environment continues to generate new legal and regulatory restrictions on training land use. In particular, training impacts on vegetation integrity, threatened and endangered species habitat, soil stability, and water quality/quantity are of major concern. The traditional approach to addressing these types of concerns has been to acquire the necessary data to make a judgment regarding the status and trend of the resources in question. The cost of acquiring the necessary data to determine status and trend and then design and implement a restoration or rehabilitation effort is

often prohibitive until the issue becomes a regulatory or compliance problem. Therefore, in practice, training land management has become management by prioritized level of compliance problems rather than preventative.

In an effort to help training land managers deal with this situation the Deputy Under Secretary of Defense for Environmental Security has initiated an effort to develop and use modeling and simulation technologies within the context of ecosystem management (Goodman 1996). The idea is to use currently available data with knowledge of management oriented ecological thresholds (Brown, Herrick, and Price 1999) and ecological simulation modeling (McLendon, Childress, and Price 1996; Childress, McLendon, and Price 1999; Price et al. 1997) in a risk-based approach to predict outcomes of planned training land use. This approach will reduce data acquisition and its cost to only the data necessary to develop a good a priori decision or management strategy. However, until recently there has been only limited research with the specific objective of developing quantitative vegetation dynamics models that are temporally and spatially explicit enough to lend themselves to practical land management decisions (Brown, Herrick, and Price 1999).

In Fiscal Year 1995, the U.S. Army Construction Engineering Laboratory (CERL) initiated an applied research project to develop a mechanistic-based ecological dynamics simulation model. We planned to incorporate into the model, current knowledge of military impacts and management scenarios on training lands to predict carrying capacity for training lands and facilitate linking the cost of training to land and resource maintenance. An initial evaluation of simulation models then in the public domain for land management resulted in the following conclusions. The models suffer from one or more of the following shortcomings: (1) overly general and of little practical value in evaluation of specific management scenarios, (2) overly specific and therefore, limited to only one or a few sites, (3) very complex and require extensive calibration with site-specific data that are not available, and (4) the endpoints they evaluate, such as soil erosion, are important but the endpoint is only one of several important aspects of ecological dynamics (McLendon, Childress, and Price 1996). However, as a result of this evaluation we found in the private sector an existing simulation model that did not suffer from the above constraints (Childress, McLendon, and Price 1999 and Price et al. 1997). Therefore, CERL determined that it would be most cost effective to partner with the private sector and several key installations to develop applications of this existing ecological simulation model. The core model is generally applicable Army-wide but can easily be made applicable to any installation with only minimum site-specific data requirements.

Objectives

The first objective of this research was to develop military applications of an ecological dynamics simulation model that are applicable to most terrestrial ecosystems but easily calibrated for site-specific applications with only data from the literature and currently available field data from installations. A second objective was to develop the simulation model so that it would stand alone as a PC-based system. The next phase will be to link EDYS with GIS and GIS-based landscape process models such as CASC2D.

Approach

Our approach has been to develop a general hierarchical model, EDYS, in a modular design to quantitatively simulate small- to large-scale ecological dynamics. Modules with linkages at the quadrat (1x1 m), community (1 ha), and landscape-level (thousands ha) have been developed. We present here the design for each module, the functional linkages, results from preliminary simulation runs, code for each module and link, and results thus far from field studies designed to provide calibration, testing, and validation of EDYS. We have also explicitly incorporated the mechanistic approach and ecological processes into the EDYS model. The purpose is to increase the predictive capability and realism and allow consideration of a broad cross section of stressors, including the complex interaction between natural stressors and management actions. Current thinking and application support this approach of simulating the underlying mechanisms that drive ecological processes to more accurately predict ecological dynamics or trajectories, based on management-specified requirements (see Childress et al. 1999 and Brown et al. 1999).

Mode of Technology Transfer

The EDYS model described in this report is or can be linked with other appropriate simulation technologies and decision environments being developed for the Army, DOD, and other Federal and private land managers. EDYS is also being developed as a stand-alone PC-based program for other applications leveraged by other Federal agencies. This report is available in color on the CERL web site at www.cecer.army.mil.

2 Model Design

The EDYS model is a PC-based, mechanistic simulation model developed by Drs. Terry McLendon and W. Michael Childress. EDYS simulates changes in all components of ecological systems resulting from natural and anthropogenic ecological stressors. It can be applied to a wide variety of ecosystems and numerous disturbance and management scenarios.

EDYS consists of Climate, Water, Nutrient, Contaminant, Soil, Plant, Animal, Spatial, Stressor, and Management Units. Climatic inputs can be historical or stochastically generated, or a combination of these. The Water, Nutrient, and Contaminant Units simulate transport, fates, and effects of these materials in all parts of the ecosystem. The Soil Unit is subdivided into layers (horizons, subhorizons, or artificial layers), the characteristics of which are specified for each site. The Plant Unit includes above- and below-ground components for each individual species within a user-defined suite. Plant growth is dynamic in relation to plant components (roots, trunk, stems, leaves, seeds, and standing dead material), season, resource availability, and stressors. The Animal Unit consists of basic population parameters and diets for each species (e.g., insects, small mammals, large mammals, livestock). The Stressor Unit includes drought, nutrient availability, competition, herbivory, fire, trampling (foot and vehicle), contaminants, and control activities. The Spatial Unit implements processes ranging across multiple ecological scales: fine scale (1 m^2 or smaller), patches (e.g., 100 m^2), communities (e.g., 1 to 10 hectares), and landscape 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., plant growth, species composition) to year and longer (e.g., climatic cycles).

The EDYS core model is parameterized with data for each application. For a first approximation, these data can consist entirely of literature or other currently existing values. A large database incorporating ecological data for a great variety of plant and animal species and sites is currently being developed to facilitate fast initial parameterization and testing. However, increased accuracy in EDYS projects can be achieved, if desired, by collection and use of site-specific data.

EDYS is currently being used to simulate responses to 17 ecological and management stressors in 33 different ecological communities at 14 sites. The stressors include contaminants (metals), cultivation, drought, erosion, fire, herbivory (insects, rodents, deer, elk, bison, cattle), hunting, logging, military training, mining, non-native plant invasion, nutrient availability, revegetation, road construction and abandonment, secondary succession, trampling, and weed control (biological, chemical, fire, mechanical). The sites include: Fort Bliss, Texas; Fort Carson, Colorado; Fort Hood, Texas; Fort Riley, Kansas; Yakima Training Center, Washington; U.S. Air Force Academy, Colorado; Acadia National Park (NP), Maine; Big Bend NP, Texas; Glacier NP, Montana; Grand Tetons NP, Wyoming; Lake Mead National Recreation Area (NRA), Nevada; Rocky Mountain NP, Colorado; Yellowstone NP, Wyoming; and Midnite Mine, Washington. Ecological communities at these sites include freshwater wetlands, riparian shrublands, creosote bush desert, sagebrush shrubland, desert grassland, shortgrass plains, bluestem prairie, fescue prairie, ponderosa pine forest, lodgepole pine forest, and subalpine fir/alpine tundra.

EDYS applications for three US military installations are now well underway. The Fort Hood project involves modeling the impacts of military training, fire, grazing, and juniper control on the vegetation dynamics, soil erosion, and water yield of a 3-community landscape/ecotone in central Texas. The Fort Bliss application addresses similar impacts in a black grama grassland in the Chihuahuan Desert. The U.S. Air Force Academy project addresses the impacts of 10 management scenarios (e.g., cadet training, grazing, hunting, weed control) on a 7-community landscape in the 3000-acre Jack's Valley Training Area. Other EDYS applications consider: (1) revegetation of abandoned roadways in Grand Tetons NP and Lake Mead NRA, (2) purple loosestrife invasion of wetlands in Acadia NP, (3) ecological effects of fire in pinyon-juniper-oak woodlands in Big Bend NP, (4) impacts of fire and grazing by bison and elk on sagebrush shrubland in Yellowstone NP, (5) road cut erosion control and revegetation in Big Bend NP, and (6) rangeland recovery following cultivation in blue grama grassland in Colorado.

Because EDYS uses explicit representations of all components of terrestrial ecosystems and all important ecological processes in these systems, it can be adapted for almost any terrestrial system, ranging from small plots to an entire landscape. Because processes are simulated mechanistically, indirect effects, long-term cumulative effects, and ecological thresholds can be evaluated to fully assess impacts of stressors and management strategies.

Multiple Scales

EDYS contains three major modules that correspond to three major scales in ecosystems: Quadrat, Community, and Landscape. The Quadrat Module is the basic unit in the Community Module, and the Community Module is the basic unit in the Landscape Module (Figure 2).

The Quadrat Module simulates ecological mechanisms and dynamics at the small scale (1 m^2 to 100 m^2). Most of the mechanisms in the EDYS model related to plants (growth, water and nutrient uptake, and competition) and soils (water and nutrient transport through the profile, decomposition) are implemented in this module.

The Community Module focuses on spatial patterns and dynamic from the patch (100 m^2) to the community (1 to 10 hectares) scales. These include spatial heterogeneity in soils, plants, and stressors among quadrats within the community, stressors such as fire propagation, grazing, and lateral flow of surface and subsurface water and materials, and important spatial patterns such as vegetation cover, habitats, and topography.

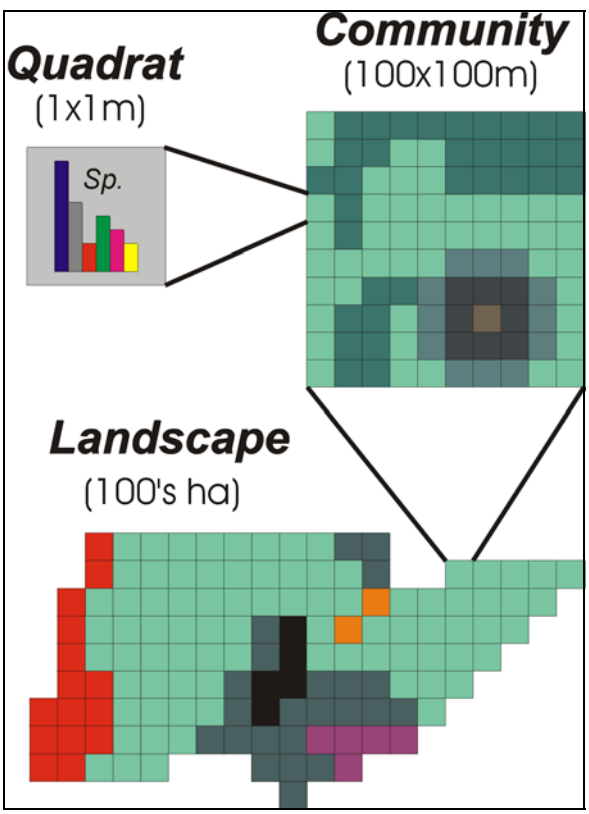

Figure 2. Quadrat-Community-Landscape Module linkages in EDYS.*

* Multiple Quadrats are included within each community to represent small-scale ecological heterogeneity. Similarly, multiple communities are included in the landscape to represent medium-scale ecological heterogeneity.

The Landscape Module focuses on ecological processes operating at large spatial scales (1 km^2 and larger). These include fire initiation regimes, climatic regimes, watershed-level water movement and transport of materials, and management practices such as training scheduling, grazing operations, and weed control.

Quadrat Module

The Quadrat Module comprises the core of the EDYS Model. All the small-scale components of terrestrial ecosystems are explicitly represented by state variables in this module (Figure 3). The spatial extent of each Quadrat is set to be the smallest unit that contains reasonably uniform vegetation and soil profile. Most EDYS applications to date have set the Quadrat scale at 1 m^2, although in one application Quadrats of 150 x 150 m were used to correspond with available ecological data. The Soil Unit in the Quadrat Module represents the vertical depth, water content and holding capacity, nitrogen content, organic matter content, contaminant content, microbial activity, and decomposition rates in each horizon of the soil profile. Precipitation events cause movement of water through the profile and transport of nitrogen, organic matter, and contaminants between horizons. The Plant Unit implements the structural components of all selected plant species, including root biomasses in each of the soil horizons. Plant production algorithms in this unit calculate uptake of water, nitrogen, and contaminants from each horizon, and allocation of new growth among the different structural components. The Animal Unit incorporates important herbivore, omnivore, and predator species in the model. Diet preferences of all animal species are used to simulate herbivory losses of all plant species and transport of contaminants in the food web. Trophic energetics and habitat availability and preferences are used as bases for projecting population dynamics.

Different processes implemented in the Quadrat Module operate at different time scales, and are therefore incorporated into different calculation loops corresponding to different time steps (Figure 4). For example, most of the hydrological, soil profile, and herbivory operations are conducted on a daily basis, and are included in the Daily Loop. Plant growth operations are conducted in the Monthly Loop, using as inputs the cumulative daily uptake of water and nutrients in the Daily Loop.

These different time loops provide great flexibility in adapting EDYS to different management and stressor scenarios. For example, calculations for consumption of plant parts by animals is conducted daily; however, the herbivore population response to plant consumption is conducted monthly. Effects of human disturbances such as military training activities or park visitation activities can be

simulated on daily or monthly bases, depending on the time interval and intensity of these stressors as well as on characteristics of available data. Because EDYS uses essentially all ecosystem components and processes at multiple spatial and temporal scales, complex ecological effects of almost any type of stressor can be addressed with suitable definition of parameters and calibration.

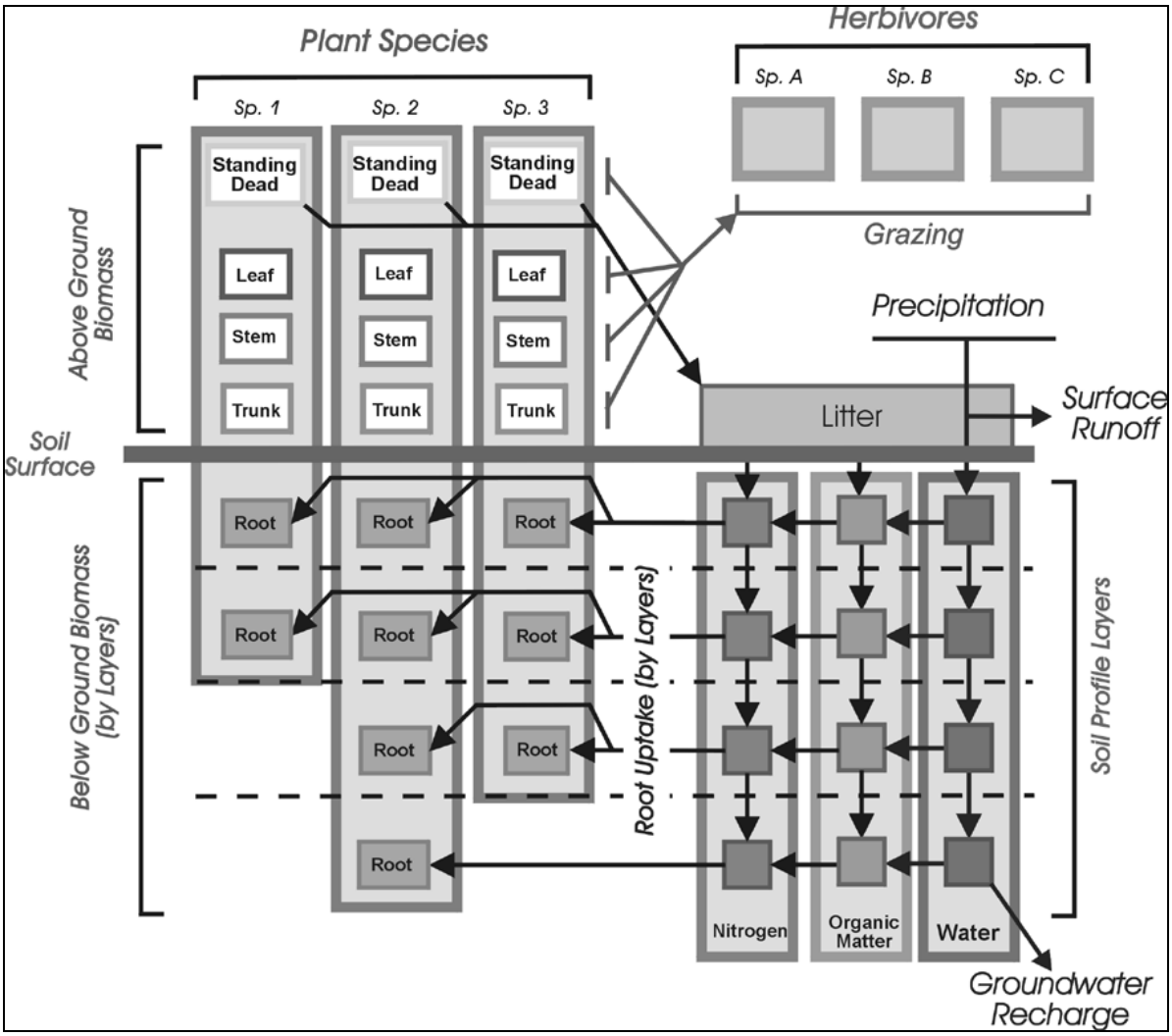

Figure 3. Ecosystem representation in the EDYS Quadrat Module.*

* The dynamics of all depicted elements in the ecosystem are calculated in various EDYS Units to provide a mechanism-based projection of overall ecosystem dynamics.

Community Module

Although the Quadrat Module provides detailed simulations of small-scale ecological dynamics, there can be considerable heterogeneity in small-scale soil profiles and vegetation within a plant community. This heterogeneity is explicitly represented in the EDYS Community Module in a grid-based representation of this spatial variability (Figure 5). The dynamics of Quadrats with similar vegetation and soils are simulated by a single version (a "Quadrat Type") of the Quadrat Module. Quadrats with different vegetation or soils are simulated by different Quadrat Types. The spatial pattern of where these different Types occur within the Community is then represented by a grid of Quadrat cells arrayed within the Community. In this manner, EDYS is able to implement important small-scale processes such as soil hydrology and plant growth within each Quadrat Type, without the computational intractability of independently simulating every cell in the Community grid. Instead of simulating potentially several hundred Quadrats independently in the Quadrat Module, typically 2 to 10 representative Quadrat Types are simulated and their results applied to corresponding cells in the grid.

The Community Module coordinates the dynamics of the Quadrat Types, represents their locations in the Community Grid, and simulates community-level processes such as fire propagation, grazing, surface and subsurface lateral flow of water and materials, and small-scale disturbances such as trails and roads.

Certain disturbances such as fire can cause changes in the vegetation composition of affected Quadrats, therefore requiring new Quadrat Types in the EDYS model to reflect the effects of such stressors. The Community Module coordinates the creation of new Quadrat Types to reflect the impacts of quadrat to community-scale disturbance, and the merging of Quadrat Types when their structural components become sufficiently similar again, such as when vegetation fully recovers after fire.

Landscape Module

Land management usually involves larger spatial scales than Quadrats or Communities. For example, land management objectives, planning, and activities at U.S. military installations typically focus on training areas on the order of 1000's of acres in spatial extent. Certain ecological and hydrological processes, such as animal population dynamics, natural fire regimes, and surface runoff can only be adequately considered at this same scale. The Landscape Module in

EDYS is specifically designed to represent these processes and to accommodate addressing management issues at the same scale considered by land managers.

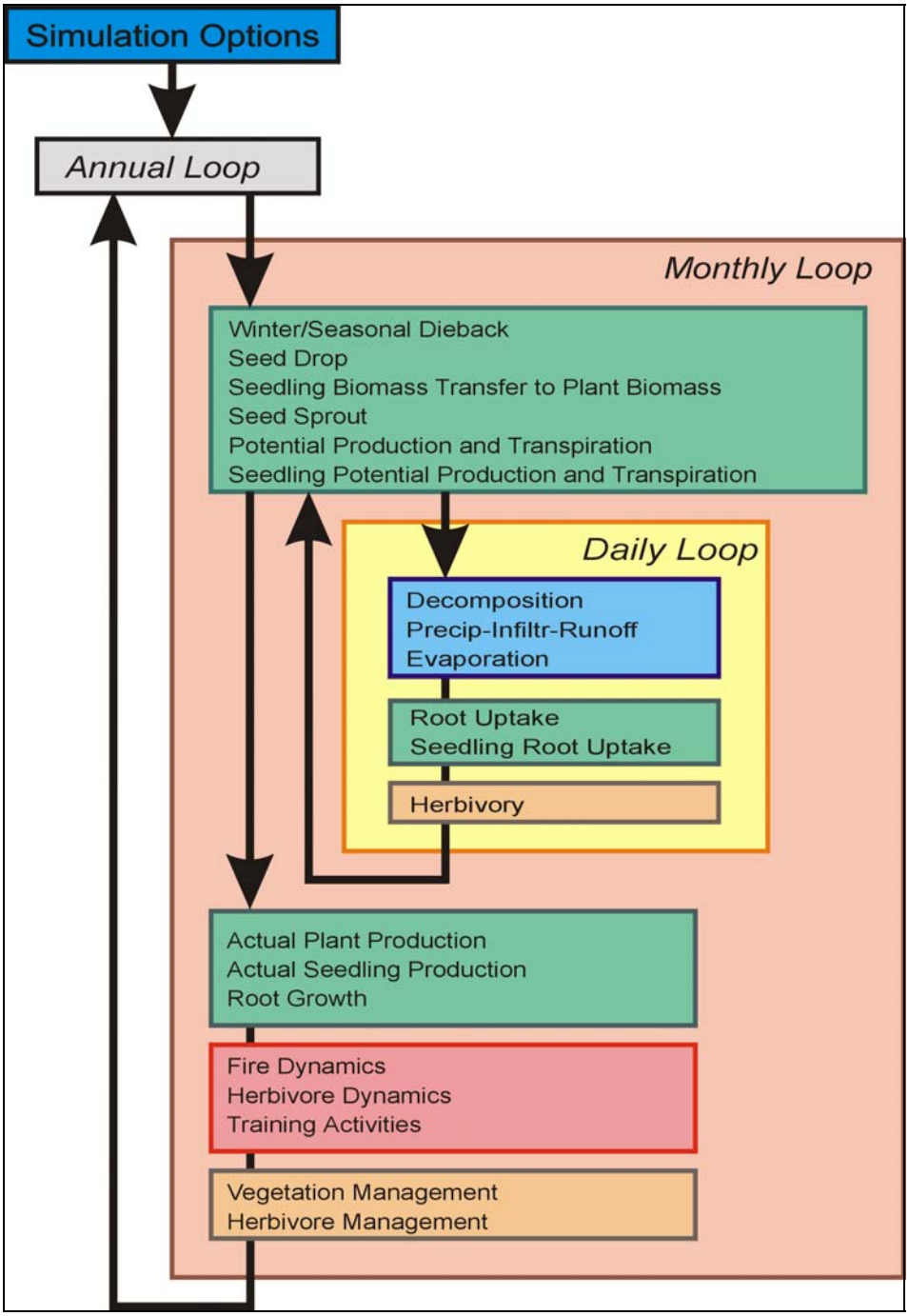

Figure 4. Computational structure in the EDYS Quadrat Module.*

* The various ecological processes simulated in EDYS are computed at different time scales to more realistically reflect the appropriate rate of change for each process.

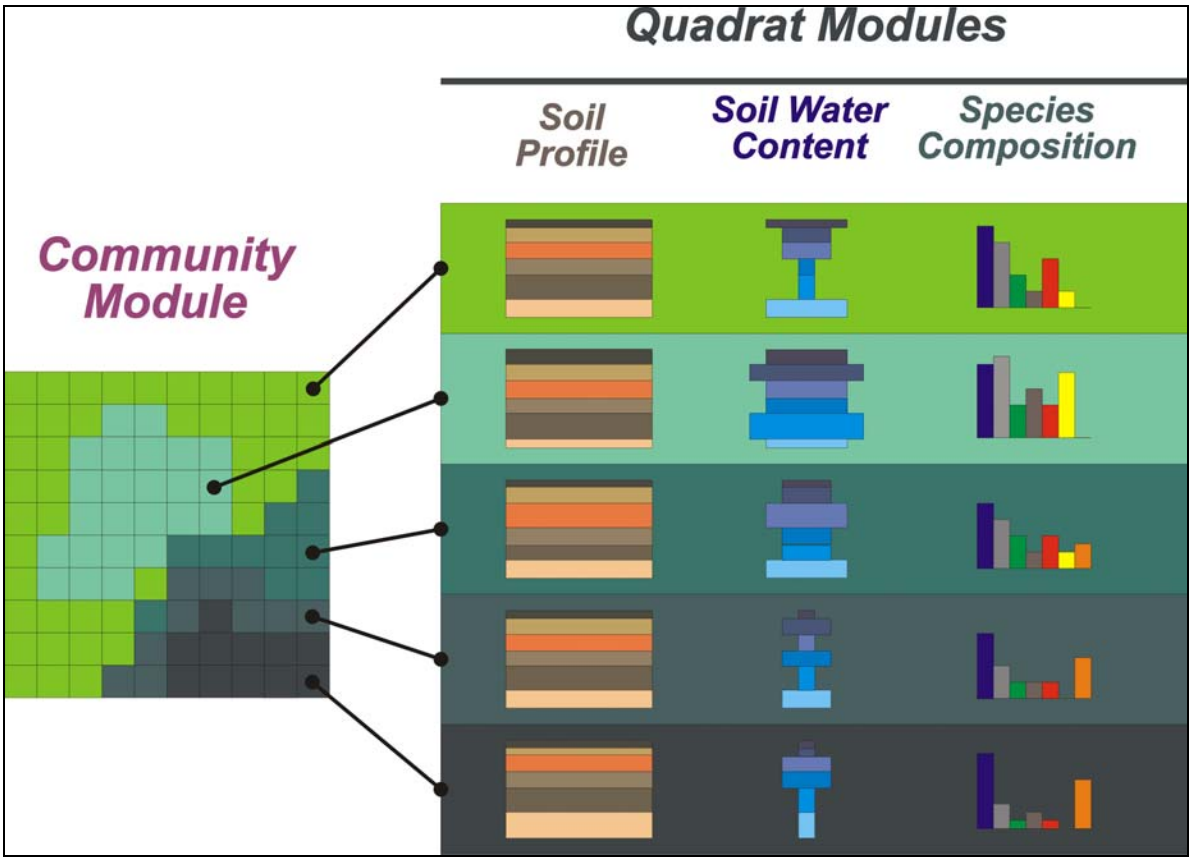

Figure 5. Quadrat-Community Module linkages in EDYS.*

* Each Quadrat type is simulated independently in the Quadrat Module, and the results then applied to those cells in the community grid with corresponding soil profiles and plant species composition.

The Landscape Module centers on three grid-based representations of the entire area of concern for the particular EDYS application: Quadrats and Communities (Figure 6), elevations, and disturbance and management units. This grid is designed to incorporate the entire area of concern for the particular EDYS application. The grid mapping of vegetation is important in representing fuel loads for fire events, habitats for different wildlife species, and pathways for surface runoff and transport of sediments during heavy precipitation events. An example of Landscape grids and dynamics is presented in the following chapter for Jack's Valley Training Area at the U.S. Air Force Academy.

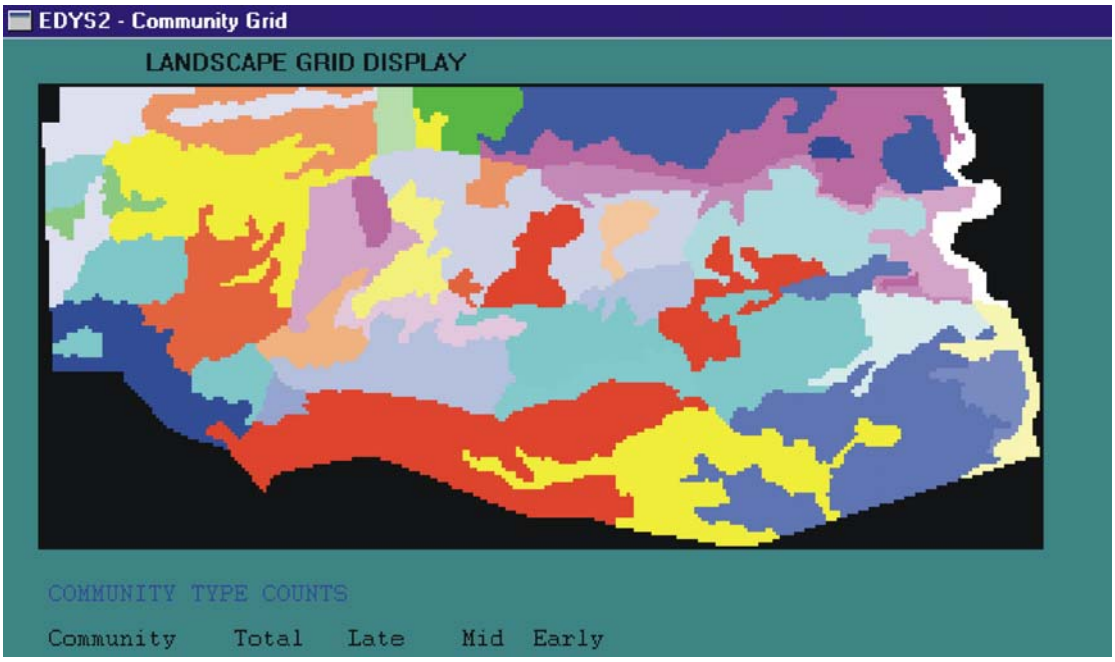

Figure 6. Landscape Vegetation Grid in the EDYS Landscape Module for Jack's Valley Training Area.*

* In this example, each cell in the Landscape Grid corresponds to a single 20m x 20m quadrat. Quadrats are further organized into Community Type as indicated by different shades of gray. Spatial Vegetation Patterns are derived from available vegetation maps and aerial photography.

Hydrological Dynamics

Water dynamics are major components in the Quadrat, Community, and Landscape Modules. EDYS explicitly represents water and materials transport vertically within each Quadrat, among Quadrats in the Community, and among Communities in the Landscape. Effects of stressors and disturbance on vegetation directly influences water dynamics at all scales, and is therefore usually of concern to land managers.

The Quadrat Module focuses primarily on 1-dimensional movement of water up and down in the soil profile (Figure 7). Precipitation events deliver water to each Quadrat; the water then percolates down into different horizons in the profile. Evaporation removes water from the top horizons, and uptake by plant roots in each horizon is then transpired as plants grow.

The Community Module allows excess precipitation water to move along the soil surface among different Quadrats in the Community (Figure 7). These flows are influenced by vegetation and litter cover within each Quadrat and by slope and topology within the Community. Similarly, water in excess of the wetting capacity of each horizon can move down in the profile as groundwater recharge, or

horizontally to adjacent Quadrats as Subsurface Flow downslope, depending on permeability of the different soil horizons.

All water movement has the potential for transporting nutrients, sediments, and contaminants within and among Communities. The EDYS model can therefore explicitly represent fate and effects of contaminants as well as plant community response to nutrient and contaminant additions in a variety of temporal and spatial patterns. Because spatial patterns and elevations of Quadrats and Communities are explicitly represented in the Landscape Module, small to large-scale locations of water movement and material transport is simulated for all precipitation events producing surface runoff (Figure 8).

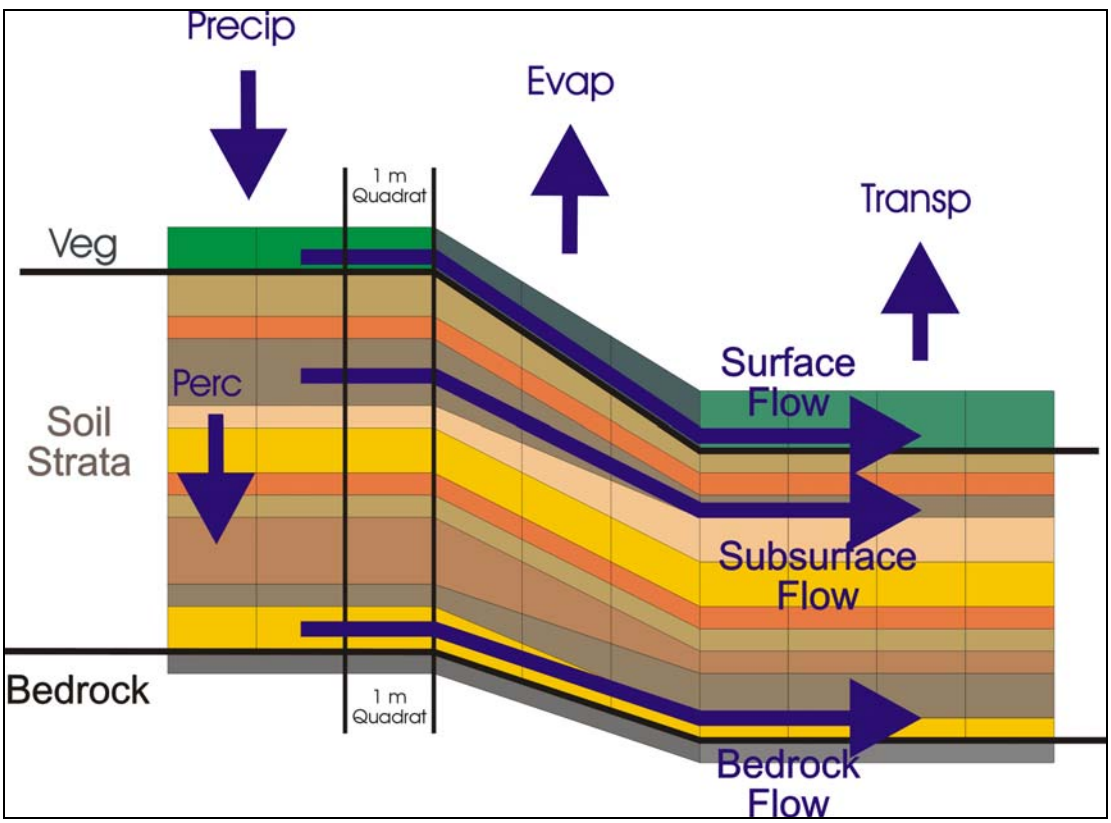

Figure 7. Hydrological dynamics in the EDYS Community Module.*

* Water dynamics at Quadrat, Community, and Landscape scales are crucial in EDYS simulations, so all relevant above and below-ground processes are explicitly represented (Precip - precipitation; Evap – evaporation; Transp – transpiration; Perc – percolation; Veg – vegetation).

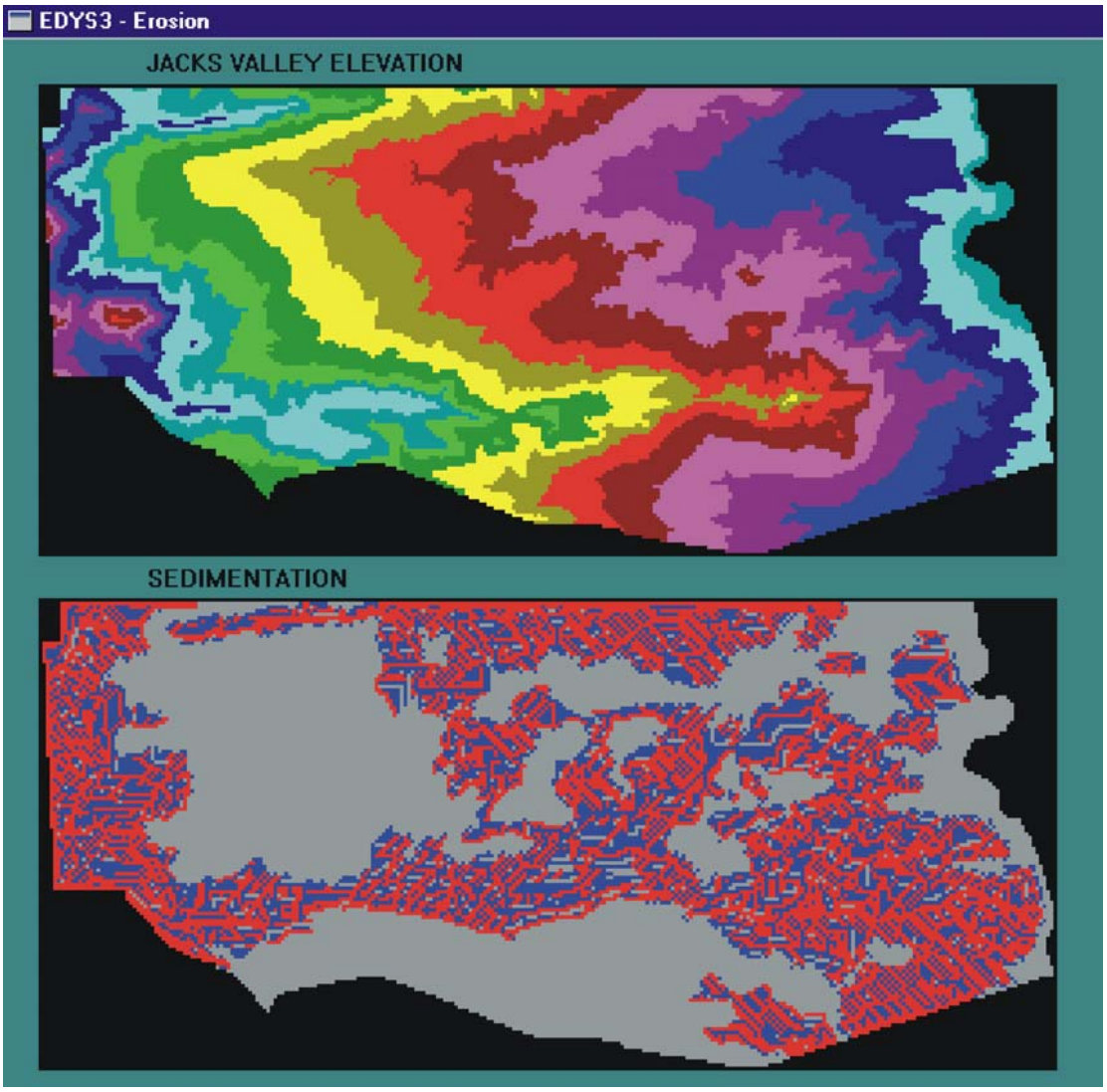

Figure 8. Simulated sediment transport resulting from surface runoff in the EDYS Landscape Module for Jack's Valley Training Area.*

* Gray areas indicate quadrats with no net change in the soil profile, red indicates quadrats with a net loss of soil sediment, and blue indicates quadrats with a net gain of sediments from surface runoff.

The hydrological calculations for surface runoff implemented in EDYS are simplified to ensure computation tractability and reasonably short computation time for long-term simulations. For certain management situations, detailed runoff projections are crucial for management planning and decision-making. A special version of EDYS has been developed specifically for linking with a new grid-based rainfall-runoff modelling system, CASC2D (Dr. Fred Ogden, University of Connecticut) (Figure 9). This linkage is facilitated by the Watershed Management System (WMS) software (U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi), which transfers parameters between EDYS and CASC2D, sends simulation control parameters to each, and provides graphical displays for results from both simulations. This combined package has great potential for use by land managers because it combines strengths of all three pack-

ages: multiple-scale ecological dynamics from EDYS, large-scale hydrological dynamics from CASC2D, and GIS compatibility and visualization tools in WMS. This package comprises the initial component of a larger Land Management System (LMS) which will link a wide variety of software packages via Internet to assist in decision-making procedures for land managers at Army installations.

Current Status

EDYS has been developed in a sequence of versions for major enhancements and specific applications (Table 1). The most current version is EDYS - 3, which incorporates a complete Landscape Module and all the associated spatial representations required to simulate ecological and hydrological dynamics at multiple spatial and temporal scales. This version is now being applied at Jack's Valley Training Area at the U.S. Air Force Academy to assist environmental and training managers in making ecologically-sound decisions about training and other human activities and management practices in this area. Version 4 is currently under development for Jack's Valley, and will incorporate a graphical user interface so that EDYS can be readily used by land managers. This version is scheduled for delivery in April 1999.

EDYS Versions 1 through 3 have been developed in Pascal for Windows (Inprise Corporation) for PC computers using any Microsoft Windows operating system. Version 4 will be implemented in Delphi 4 (Inprise Corporation), an advanced version of Pascal with full 32-bit processing capabilities (i.e., much faster processing and larger data set capabilities) and rapid application development tools for user interface design (i.e., menus and high-resolution graphics). This version will be constrained to PCs with Pentium-equivalent or more advanced processors. It is anticipated that Version 2a will be implemented in the C programming language to facilitate linkages with CASC2D and WMS, and should therefore be applicable for essentially any Windows or Unix systems.

EDYS is also undergoing validation testing at two Army installations: Forts Bliss and Hood, Texas. These projects involve testing projected vegetation dynamics in a number of field plots against field data gathered in 1998 and 1999 from these plots (McLendon, Childress, and Coldren 1999). Results for the black grama grassland at Fort Bliss indicate that projected total aboveground biomass over one growing season is within 4.4% of field-measured biomass (Table 2). Further validation testing involves EDYS projections using literature data for initial vegetation communities (specifically LCTA field plots), precipitation records from nearby long-term monitoring stations, and experimental manipulations of water and nitrogen availability in the field plots. Validation testing will continue for a

second year at both Forts Bliss and Hood to provide additional time for vegetation responses to experimental manipulations.

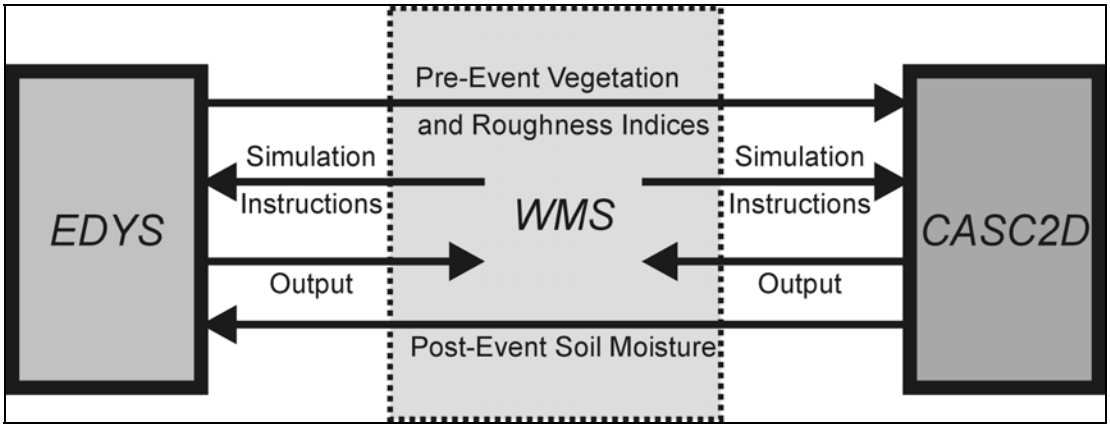

Figure 9. Linkages among EDYS, CAS2D, and the Watershed Management System (WMS).*

* CAS2D is a grid-based rainfall-runoff simulation model. WMS mediates transfer of spatial data between EDYS and CAS2D, sends simulation control commands to each model, and provides graphical displays for output from each model.

Table 1. EDYS Model versions, key features, and current DOD applications.

Version	Features and Major Enhancements
EDYS - 1	- Core Quadrat Module
EDYS - 2	- Multiple Community Module - Quadrat-Community Module Linkages - Simple Runoff Procedure - Simple Landscape Module *Applications:* Ft. Bliss and Ft. Hood Dem-Val Validation Testing
EDYS - 2a	- LMS/WMS/CASC2D Data Transfer Interface - Simplified Input/Output Procedures *Applications:* Land Management System (LMS)
EDYS - 3	- Complete Landscape Module - Revised Runoff and Sediment Transport Procedures - Management Endpoint Procedures *Applications:* U.S. Air Force Academy Jack's Valley Training Area
EDYS - 4 (under development)	- Conversion to Windows Environment - Initial End-User Interface *Applications:* U.S. Air Force Academy Jack's Valley Training Area

Table 2. Summary of EDYS validation testing results for a Black Grama desert community at Fort Bliss, Texas.

Input Data		Simulation Accuracy*			
Vegetation	**Precipitation**	**Total Above-ground**	**Shrubs**	**Perennial Grasses**	**Species Weighted Average**
Feb 98 Site Samples	1998 Site	1.044	0.223	1.184	0.674
Feb 98 Site Samples	1998 El Paso	0.697	0.138	0.797	0.693
Feb 98 Site Samples	1948 El Paso	0.687	0.185	0.762	0.660
1989 LCTA 7 Plots	1998 Site	1.010	0.682	1.065	0.769
1989 LCTA 7 Plots	1998 El Paso	0.680	0.524	0.723	0.606
1989 LCTA 7 Plots	1948 El Paso	0.661	0.579	0.686	0.582
1989 LCTA 34 Plots	1998 Site	0.594	0.867	0.503	0.083
1989 LCTA 34 Plots	1998 El Paso	0.373	0.558	0.329	0.240
1989 LCTA 34 Plots	1948 El Paso	0.472	0.545	0.319	0.135

* The accuracy measures are based on October 1998 aboveground biomass. Different vegetation inputs reflect initial simulation biomasses obtained from 48 sample sites, from 7 nearby LCTA plots, and from all 34 Black Grama LCTA plots on Fort Bliss. Different precipitation inputs reflect different monitoring locations and dates. Perfect accuracy of the simulation results is indicated by 1.0.

3 Applications

The EDYS Model is designed to make accurate, long-term ecological projections for different disturbance and management scenarios to assist land managers in making ecologically sound decisions. The Model and its projections must therefore fit into a management context for each specific application. The following sections present an overall strategy for land management that makes use of simulation models such as EDYS, and also presents examples of EDYS applications at three DOD installations. In addition, we describe two areas for future development of EDYS to increase its broader utility to both public and private land managers.

Strategy for Land Management

Sustainable land management must take into account the multiple uses and values of the multiple aspects of ecological systems. This requires explicit specification of these different values and uses so that management objectives can be assigned to each. Alternative management practices can only be assessed in terms of how they meet the specified management objectives. Successful assessments require some means of expressing both the objectives and the anticipated effects of alternative practices in quantitative, measurable terms so unambiguous results can be derived.

We propose a strategy for land management that focuses on management objectives and selecting management practices that best advance these objectives (Childress and McLendon 1998). This strategy involves a process for specifying objectives, projecting effects of management alternatives using simulation models, quantitatively assessing these effects specifically in light of the objectives, and thereby facilitating the decision-making process (Figure 10). This strategy involves two major steps. First, Management Objectives are specified by all stakeholders and managers. These Objectives determine criteria against which all formally described Management Alternatives will be judged. Second, the Alternatives are assessed in a Decision-Making Process in which the effects of each Alternative are projected using simulation models. The effects are then assigned relative benefits and costs in terms of the Management Objectives. This second

step is repeated iteratively with revised Management Alternatives and under different environmental scenarios until a satisfactory Alternative is selected.

Management Objectives must first be established before any management schemes can be adequately assessed. For land units with multiple users and uses, it is important to develop a consensus among all stakeholders for uses and values for which the unit will be managed. Priorities can be assigned to different Objectives in the event that there are conflicting uses and Objectives.

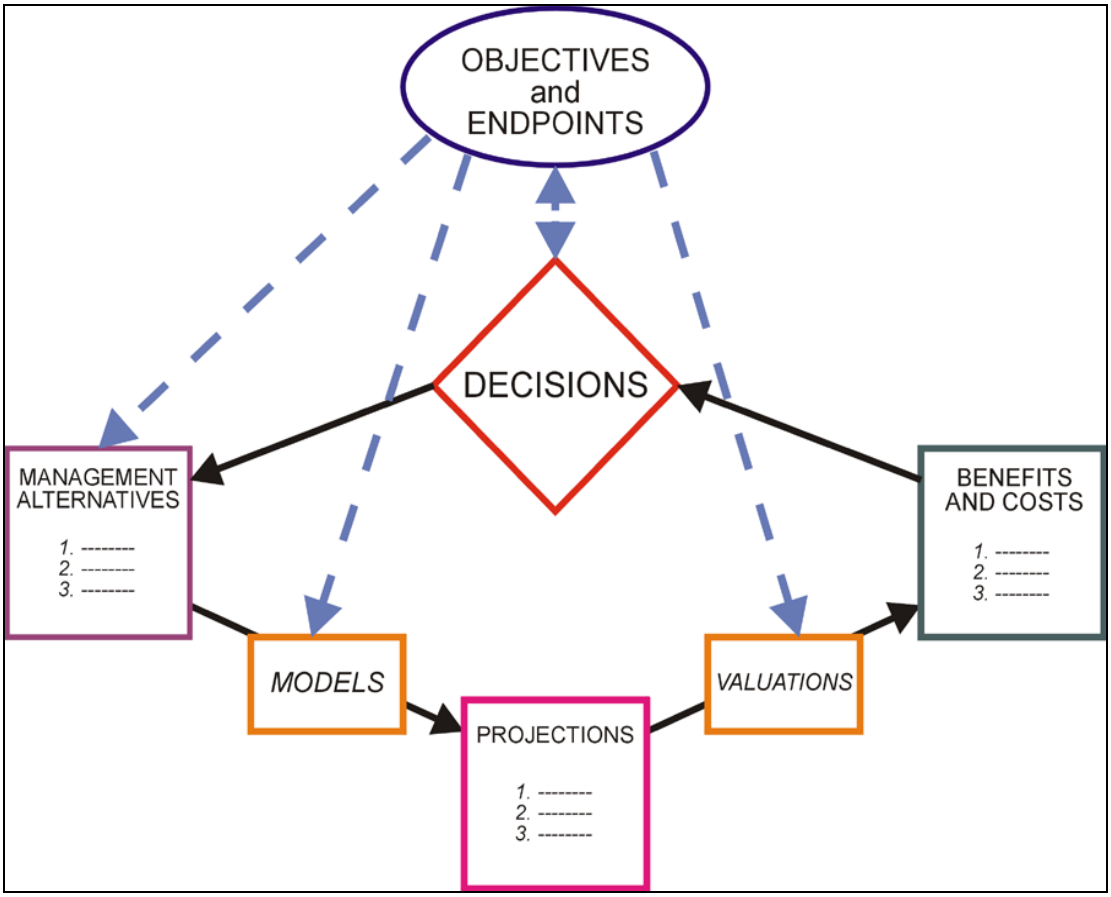

Figure 10. Iterative decision-making strategy for land management.*

* This strategy allows indentification of cost-effective management alternatives which meet all specified management objectives and endpoints. EDYS is used specifically to make projections of anticipated ecological and environmental effects of each alternative for subsequent evaluation.

The second Step is a Decision-Making Process for selecting Management Alternatives that best meet Management Objectives and Endpoints. There are a number of steps in this process, some of which are performed with the assistance of computer tools. Management Alternatives are first specified for consideration in the Process. Each Alternative will include a suite of practices that are considered potentially useful in meeting one or more Objectives. EDYS would then be used to project ecological effects of each Management Alternative. These projections would include a series of runs in which various environmental inputs, such as precipitation, are varied to give a more complete picture of possible outcomes for each Alternative. The various Alternatives would then be assigned valuations based on how well the projections for each Alternative meet specified Management Endpoints. The Alternatives are then ranked according to each of the Endpoints to indicate total Benefits and Costs anticipated if the Alternative was implemented.

Finally, a decision is made by the land unit managers about which, if any, of the Management Alternatives adequately conform to the Endpoints. All of the Alternatives that do conform to the Endpoints are then deemed "Green Light" Alternatives, and can be implemented with confidence that the Management Objectives will be met. Those that only partially conform to the Endpoints are considered "Yellow Light" Alternatives. These would not ordinarily be implemented without further study or revisions. Finally, those that fail to conform to Endpoints are labeled "Red Light" Alternatives, and would not be adapted without major revision. If none of the Alternatives is rated as "Green Light" then some or all of the Alternatives can be revised and run through the process repeatedly until an acceptable Alternative is found. This iterative process can also be used to compare a number of "Green Light" Alternatives to select the best one, or to iteratively revise and improve a single Alternative to find the best overall suite of management practices.

Successful management of larger land units such as landscapes, watersheds, and installations, is best approached using a formal strategy such as the one proposed here. As a rule, such areas will have multiple uses and concerns, multiple stakeholders, multiple Management Objectives at multiple spatial scales, and a wide variety of possible management practices. The strategy we propose should greatly assist land managers in objectively assessing all the considerations in such complex scenarios to more successfully achieve Management Objectives.

Fort Hood, Texas

Land management at Fort Hood in central Texas is complicated by a variety of uses (e.g., training by armored units and cattle grazing) and environmental concerns (e.g., endangered species, water quality in the watershed, and fire hazards). The application of EDYS to land management at this installation has proceeded in an incremental fashion, with parameterization (definition of parameters) and validation testing for 48 research plots located at 3 little bluestem sites to be completed in Spring 1999.

An initial proof-of-concept adaptation of EDYS has been completed for a simple landscape incorporating three grass-dominated communities: a higher-elevation, shallower-soil community dominated by Texas wintergrass; a high-slope, thin-soil community dominated by woody plants; and a lower-elevation, deeper-soil community dominated by little bluestem. These communities are arranged in a 50 x 50 m grid of 1 x 1 m quadrats, with an elevation gradient from top to bottom. Figure 11 is a typical monthly display from the EDYS simulation. This figure depicts location and counts of each Community and Quadrat Type in this simple landscape, along with a table listing biomass of each major plant species in each Quadrat Type. This particular example depicts the aftermath of a simulated natural burn that in the previous year consumed most of the little bluestem community and some of the slope community. Wherever the fire burned, the vegetation in the quadrats was largely consumed, so EDYS automatically created a new Quadrat Type for those cells. In this example, Quadrat Type “101 LBStm” indicates the little bluestem community quadrats that were not burned, and “102 LBStm” those that burned. The differences in the plant biomasses in these quadrats is also evident in the Total Biomass table.

EDYS records vegetation biomasses for each Quadrat Type each month throughout the simulation for later display and printouts. Figure 12 is a graphical display for the aboveground biomass of each major plant species in one of the little bluestem community Quadrat Types. In this particular simulation run, disturbances such as fire, herbivory, and training activities did not occur within this Quadrat Type, resulting in rapid dominance of little bluestem (LBStm) and decline of all other species.

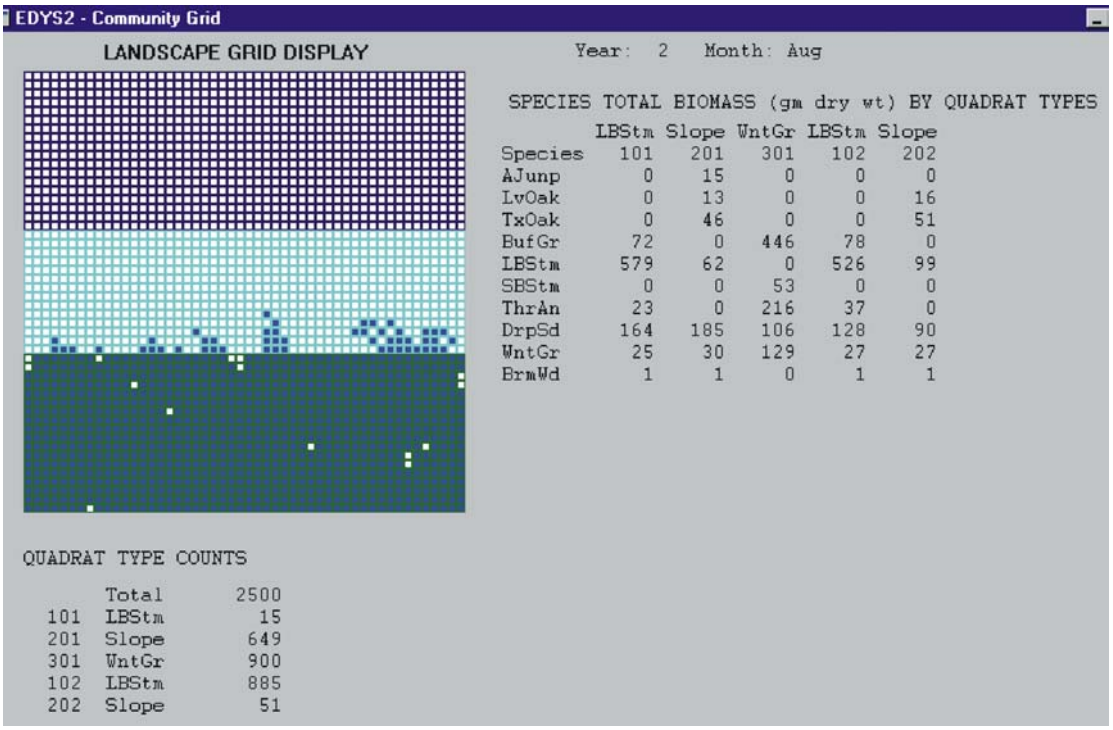

Figure 11. Monthly graphical display during the EDYS simulation of a simple Little Bluestem landscape at Fort Hood.*

* The landscape is a 50m x 50m grid of 1m x 1m Quadrats organized into three communities (WnGr - hilltop wintergrass community; Slope - slope community dominated by shrubs; LBStm - lower Little Bluestem community) along an elevational gradient. Biomasses of each dominant plant species in each community are displayed in one table, with number of Quadrats in each Community displayed in another.

Further development of the EDYS application for Fort Hood will proceed in several directions. Data are now available describing timing, location, and local effects of training activities across the installation; these will be used to revise the training disturbance calculations in the Stressor Unit. A second year of validation testing in the field plots will facilitate further calibration of ecological processes in all Units in EDYS. Two endangered birds species found on the installation have been studied in detail by a variety of ecological researchers. Adding population dynamics and habitat preference and use modules for these species will provide another validation test for the Animal Unit in EDYS. Of particular interest will be a planned demonstration application of the EDYS-CASC2D-WMS package to the Henson Creek watershed at Fort Hood. This demonstration should provide impetus to develop an installation-wide EDYS-CASC2D-WMS system for projecting effects of various land management plans on total watershed water quality and quantity.

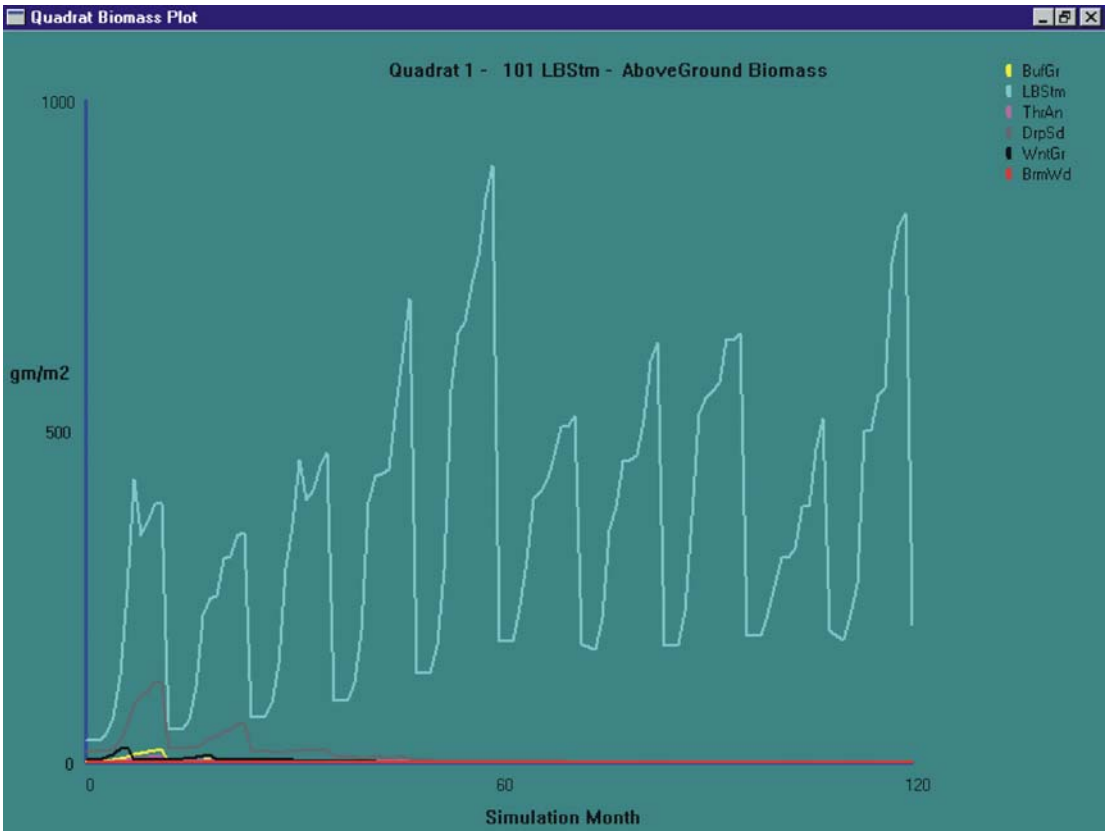

Figure 12. Simulated aboveground biomass of dominant plant species in one Quadrat Type in a little Bluestem community at Fort Hood.*

* In this simulation natural fires, herbivory, and other disturbances were excluded so that little bluestem quickly dominates the Quadrat and the community.

Fort Bliss, Texas

Application of EDYS to land management at Fort Bliss in far West Texas has also proceeded incrementally. The first year of validation testing of EDYS projections for 48 field plots in a black grama desert grassland have been recently completed (McLendon et al. 1999). Results of this first year indicate that, on average, EDYS predicts total plant biomass in each plot within 4.4% of the actual end-of-year biomass (Table 2). EDYS was also run using precipitation data from another nearby site and a different year, and using data from other LCTA black grama sites to provide a measure of the benefit of site-specific data for projection accuracy. The site-specific data for biomass and precipitation produced better accuracy than the alternative data sets, but at a significantly higher cost because of the expense of field surveys. Validation testing will continue at these same plots for a second year in 1999, along with experimental manipulations of soil moisture and nitrogen in selected field plots for further EDYS calibration in this community.

Validation data was then used to recalibrate the EDYS model for the black grama grassland at Fort Bliss and was then used to make some preliminary projections of the effects of different intensities of cattle grazing in this community (Figure 13). Results of 40-yr alternative simulations with no, light, and heavy grazing indicated only incremental shifts in plant species composition over the first 30 years, but a collapse in blue grama by year 40 under the heavy grazing alternative. This preliminary example indicates a primary utility of well-calibrated, mechanistic simulation models: projections of long-term cumulative effects of stressors and management activities on ecosystem structure and function. Field studies over such a long time frame (40 years) are not feasible, nor cost-effective, in evaluating a variety of management alternatives, and short-term studies may not adequately indicate long-term cumulative effects nor thresholds leading to ecological collapse.

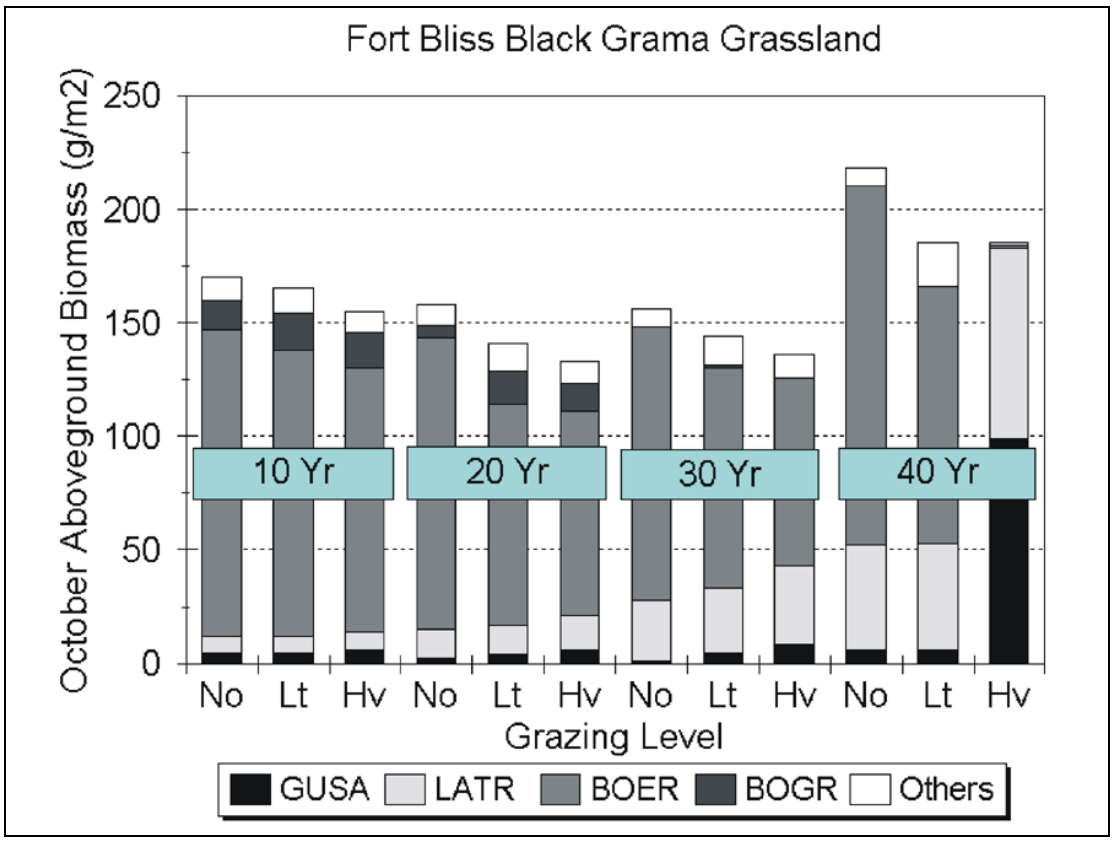

Figure 13. Simulated aboveground biomass of dominant plant species in Black Grama grassland community at Fort Bliss.*

* Results of three different simulations under different intensities of cattle grazing (No - none, Lt - light, Hv - heavy) are plotted at 10-year intervals. After 40 years of heavy grazing, black grama (BOER) collapses and is replaced by snakeweed (GUSA) and creosote bush (LATR).

U.S. Air Force Academy, Colorado

A recent application of EDYS has been in development of a management system for Jack's Valley Training Area at the U.S. Air Force Academy in central Colorado. This 3000-acre area, located at the junction between the Great Plains and the Rocky Mountains, is used for a variety of training activities, including basic cadet training each summer for incoming Academy freshmen. The specifications for the EDYS application for Jack's Valley include 8 community types, 6 different ecological stressors, 10 alternative management activities, and 18 different management end points to be used as indicators of environmental/ecological quality in Jack's Valley (Table 3). The initial outcome of this application in Spring 1999 will be a software package delivered to land managers at the Academy to be used in assessing outcomes of different management scenarios planned for 1999 training activities in Jack's Valley.

Table 3. EDYS application specifications for U.S. Air Force Academy Jack's Valley Training Area.

Eight Community Types	Six Ecological Stressors
1. Ponderosa pine woodland	1. Foot traffic
2. Pine-oak woodland	2 Vehicle traffic
3. Gambel oak woodland	3. Drought
4. Bluestem grassland	4. Fire
5. Stipa grassland	5. Nitrogen availability
6. Brome grassland	6. Herbivory
7. Riparian shrubland	
8. Roads and buildings	**Eighteen Management End Points**
	1. No increase in soil erosion overall
Ten Management Activities	2. No increase in soild erosion in BCTA
1. Training	3. No successional decline in BCTA
2. Fire control and fuel reduction	4. No change in habitat proportions in BCTA
3. Chemical and weed control	5. No change in habitat proportions overall
4. Timber thinning and harvesting	6. No bareground except in road/building areas
5. Rehabilitation and revegetation	7. Maintain or improve successional status overall
6. Wildlife watering facilities	8. Maintain habitat types and diversity
7. Reforestation	9. Reduce abundance of exotic plant species
8. Boundary line maintenance	10. Maintain riparian community structure
9. Road and trail closures	11. Shift from smooth brome to native grasses
10. Deer hunting	12. Maintain western areas in best habitat
	13. Maintain 200 m buffer strips around boundaries
	14. Maintain hunting habitat for peregrine falcon
	15. Protect spotted owl habitat
	16. Maintain deer population
	17. Maintain elk population
	18. Maintain wild turkey population

This application requires landscape-level spatial information about community types (Figure 6), elevations (see Figure 8), soil types, waterways and watersheds (see Figure 8), and human use areas (Figure 14). These data have been incorporated into a grid-based representation system with resolution down to 20 x 20 m quadrats. Forty field plots have been established in different communities across Jack's Valley to provide parameterization data for plant biomasses and soil profiles and for ground-truthing of existing vegetation maps for the Academy. These plots will be surveyed through 1999 to provide validation tests of small-scale ecological dynamics in the various ecosystems.

Preliminary EDYS simulation runs concur with Academy land managers that natural fires present a significant risk to management of habitats in the Valley. Simulated burns can propagate rapidly across different community types in the landscape (Figure 15), especially under dry fuel conditions, making fuel management to protect training facilities a high priority. However, most of the Valley is relatively undisturbed by human activities, so that potential habitat is available for a wide variety of wildlife, including threatened and endangered species such as the spotted owl, peregrine falcon, and Preble's meadow jumping mouse.

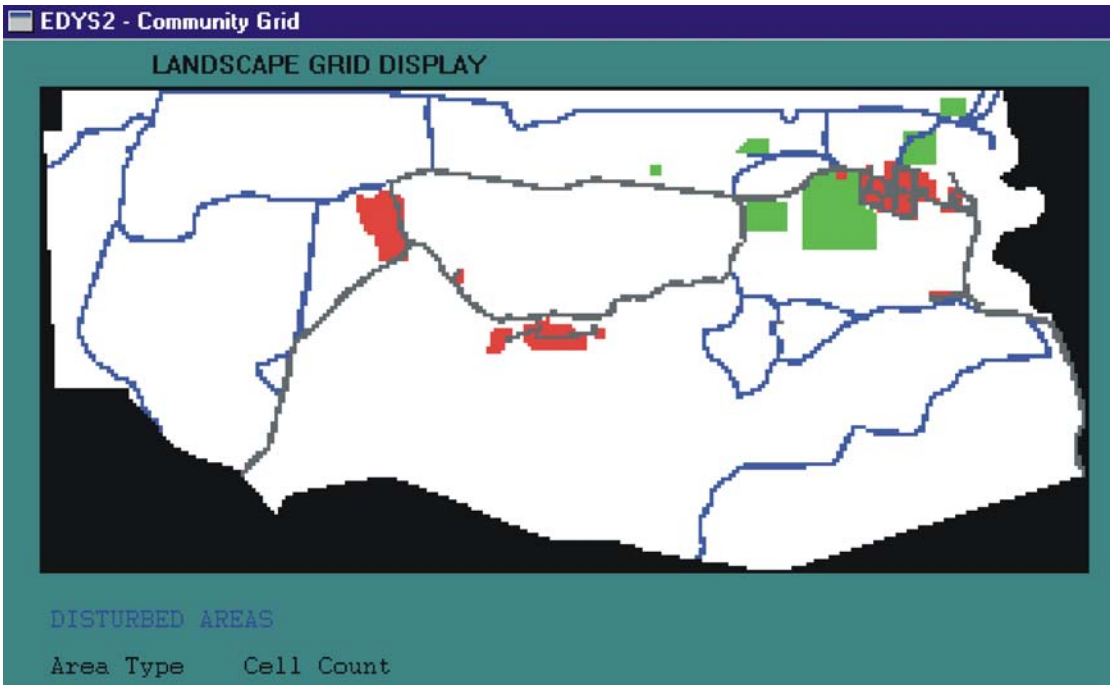

Figure 14. Human use disturbed areas grid for the EDYS adaptation for Jack's Valley Training Area.

* These areas include roads (gray lines), permanent use areas and structures (dark gray/orange areas), and seasonal training areas (light gray/green areas).

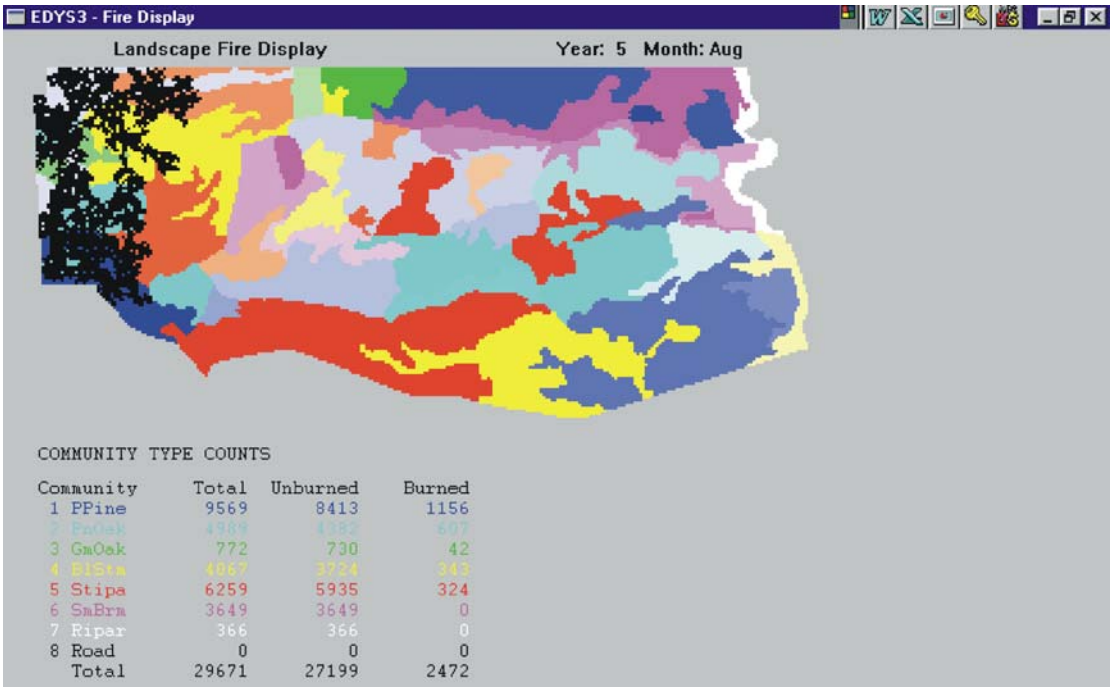

Figure 15. Simulated natural fire in the EDYS Landscape Vegetation Grid for Jack's Valley Training Area.*

* Burned Quadrats are indicated by black. Simulated natural fires propagate across the EDYS Landscape using a stochastic process which considers vegetation type, fuel load, and moisture content in calculating probabilities of spread into each Quadrat from adjacent burning Quatrats. New Quadrat Types are automatically created in EDYS for each burned Quadrat type to reflect change in vegetation structure in those cells.

Even though these species may not be present in the Valley, maintenance of appropriate habitat for them ensures compliance with regulatory environmental constraints (e.g., National Environmental Policy Act [NEPA] and Endangered Species Act [ESA]), another high priority for Academy land managers. For example, song birds in the Valley provide a potential prey base for peregrine falcon, so the dynamics of different guilds are explicitly simulated in the EDYS application for Jack's Valley as an indicator (i.e., a management "endpoint") for falcon habitat quality (Figure 16). It is by including appropriate endpoints for all areas of concern listed in the application specifications (Table 3) that EDYS will have maximum utility for land managers in deriving an appropriate land management strategy.

Because an EDYS simulation package will be delivered to the Academy for specific use by land managers, a graphical user interface is now under development. This interface makes use of menus and graphical displays to assist users in selecting simulation options for different management scenarios, and for designating outputs (graphical or tabular) for monitoring different components of the landscape and communities for each scenario (Figure 17). EDYS developers will provide training and user manuals to Academy managers, and will monitor use of this application and the new interface to identify areas for improvement and

further development. It is anticipated that a successful outcome for this EDYS application will result in expansion to the entire Academy, and eventual application for other installations, as well as for a wide variety of public and private land managers in the United States and elsewhere.

Hydrological Applications

As noted earlier, EDYS has great potential utility in assessing linkages between ecological dynamics and water quantity and quality in small- to large-scale systems. EDYS can be used alone to make these projections, or in conjuction with CASC2D and WMS to make highly accurate runoff quantity and quality projections for landscapes and watersheds.

A recent application of EDYS as a stand-alone simulation model is investigating the effects of invasion of junipers in grasslands of the western United States on water resource quality and quantity. These effects are likely to be complex and highly site-specific (Figure 18).

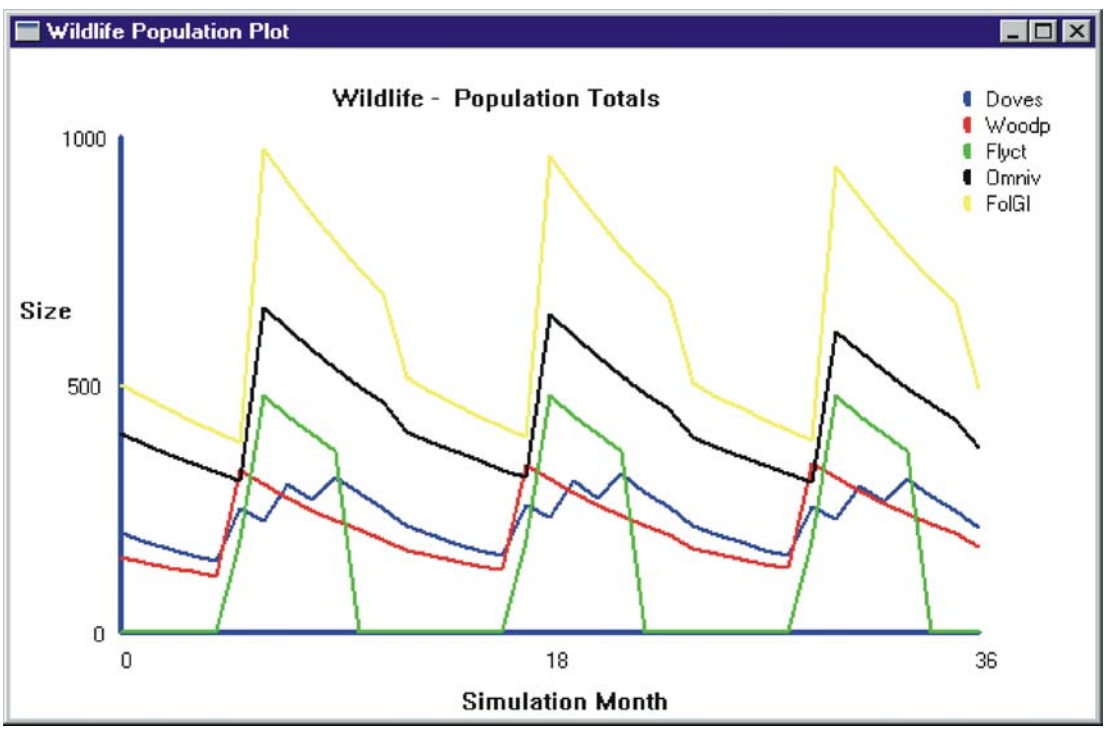

Figure 16. Simulated bird guild dynamics for the EDYS implementation at Jack's Valley Training Area.*

* Each guild represents several species with similar feeding habits. (Doves - granivores such as mourning dove and rock dove; Woodp - bark-foraging insectivores such as woodpeckers, sapsuckers, and flickers; Flyct - aerial insectivores such as swallows, wood peewees, and flycatchers; Omniv - omnivores such as magpies, robins, and tanagers; FolGl - foliage-gleaning insectivores such as vireos, chickadees, and warblers.)

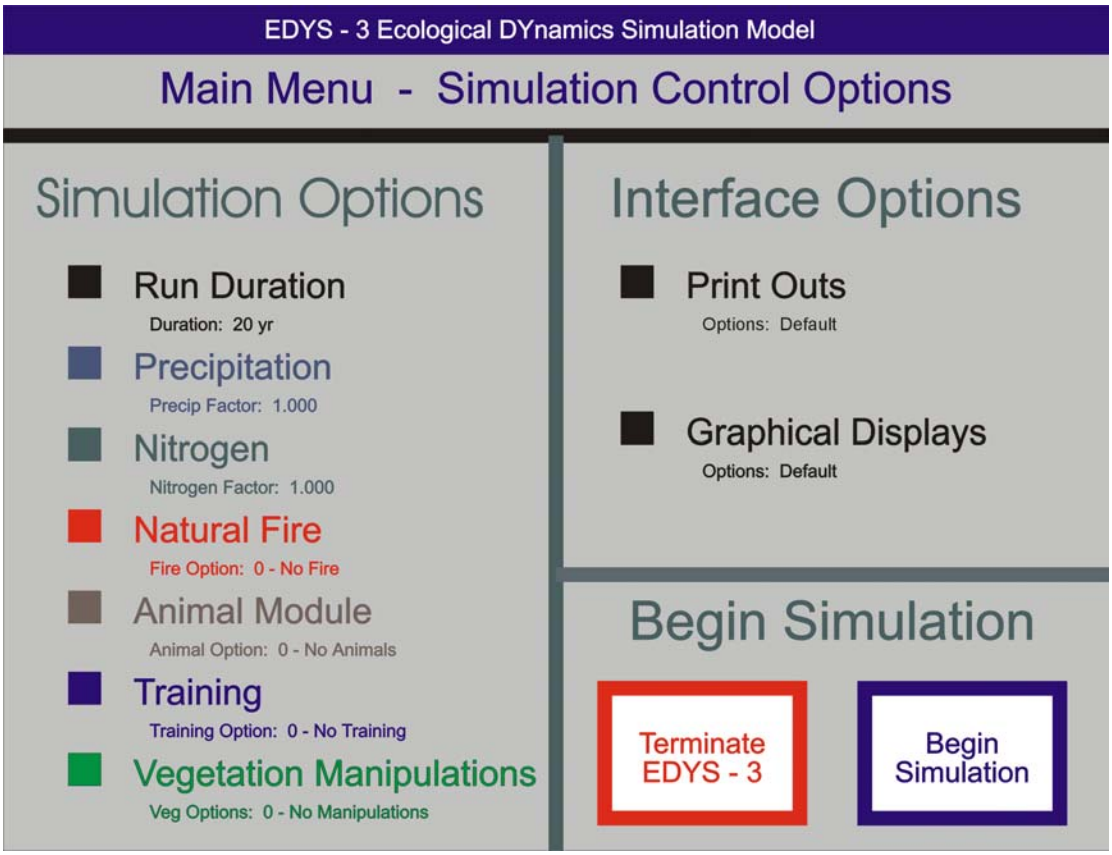

Figure 17. Menu-based user interface design for the EDYS implementation at Jack's Valley Training Area.*

* The management user specifies simulation duration, details of disturbance and management options, and graphical and printed output options for each simulation run using a series of menus for each EDYS Module.

Junipers have dense canopies and secondary compounds in roots and leaf litter that effectively exclude all other plant species. Juniper canopies have substantially greater interception of precipitation than grasses, resulting in a significant decrease in the amount of water that reaches the soil surface. Evaporation of water from the surface is highly site specific, depending on amount of bare ground, height and density of vegetation, and water-holding capacity of the top soil layers. Because the ground is essentially bare under the junipers, there is little biomass to slow surface runoff of water and allow it to enter the soil profile. This high energy flow picks up substantial quantities of sediment, resulting in considerable erosion. In dense grasslands, however, the dense plant material litter substantially slow any sheet flow, allowing the water time to infiltrate, thereby reducing erosive power and sediment-carrying capacity of remaining runoff.

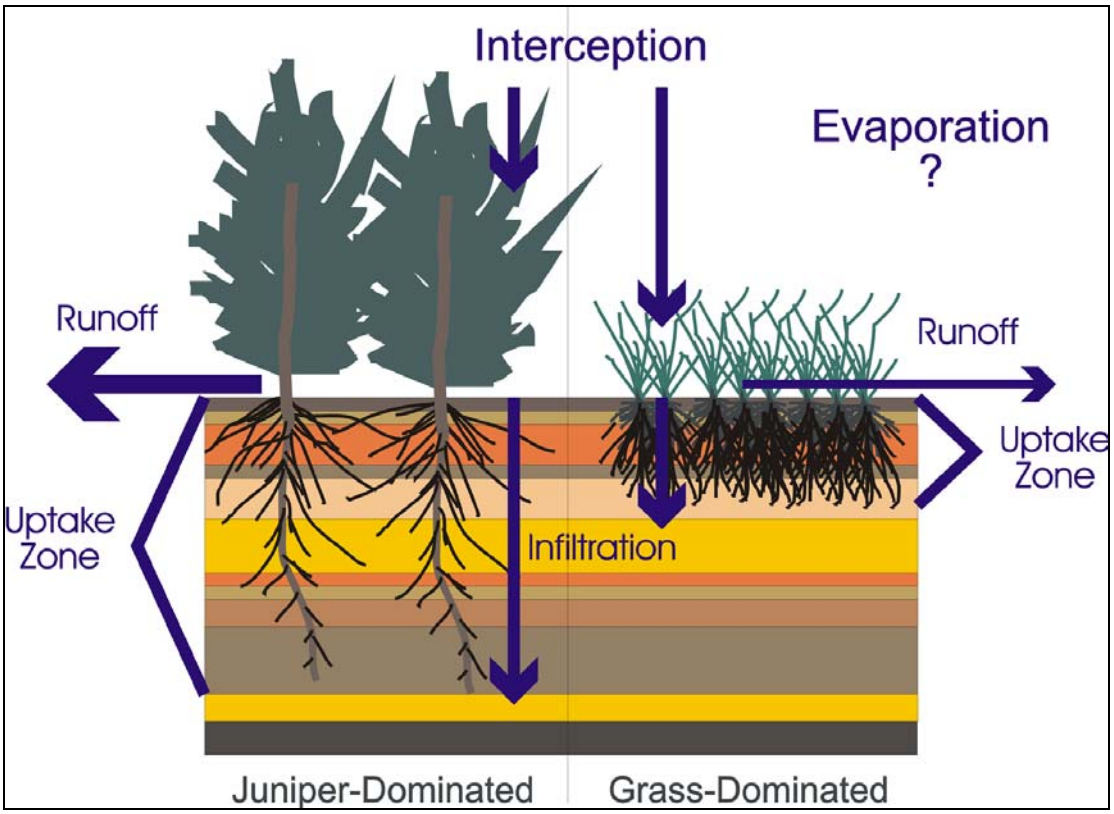

Figure 18. Conceptual effects of juniper invasion of grassland on EDYS Community hydrology.*

* Juniper can influence essentially all hydrological processes, including interception, transpiration, evaporation, subsurface percolation, and runoff energy.

EDYS is now being applied to little bluestem grassland communities at Fort Hood, Texas, most of which are subject to invasion by Ashe juniper. In addition to hydrological effects, junipers create a highly flammable fuel for potential wild fires, and their canopies interfere with training activities. Another potential project is to project effects of invasion of Utah juniper in the 90,000-acre Clover Creek watershed in northern Utah. This invasion has been associated with decrease in both water quality and quantity for domestic water supply, agricultural use, wildlife use, and aquatic and riparian habitats.

The root zones under grasses are filled with fibrous roots, which can take up considerably more water for transpiration than the less dense root zones under the junipers. However, any water that does pass below the grass root zone escapes transpiration, and moves laterally as subsurface flow or down into the groundwater recharge zones. Although more water initially enters deeper soil horizons under the junipers, this water is still accessible for uptake by the considerably deeper roots of the junipers. The actual difference in subsurface recharge under each community type therefore greatly depends on the profile depth and age and root depth of the juniper stand.

4 Future Development and Applications

EDYS capabilities will continue to be developed and tested in the future for application in new and expanded land management situations. Two specific areas of current development are described in the following sections.

Internet Access

The linkage among EDYS, CASC2D, and WMS to provide enhanced ecological/hydrological simulation capabilities is only the first step in the development of a comprehensive Land Management System (LMS) specifically for use at DOD installations (Figure 19). This system will be designed to allow land managers to link a wide variety of management tools and data sources by means of Internet-capable software. This is an important strategy for all land managers to make use of the rapidly increasing availability of ecological, climatic, hydrological, and geological data, much of which is spatially represented, on various sites on the Internet. Additional models that are proposed for incorporation into this system are weather predictors from the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service (NWS), models such as the Army Training and Testing Area Carrying Capacity (ATTACC) for predicting characteristics and direct effects of different kinds of training activities, and complementary ecological models such as those for assessing habitat suitability for threatened and endangered plant and animal species, and complementary hydrological models such as groundwater dynamics simulators.

Other federal government agencies such as U.S. Department of Agriculture, National Resource Conservation Service, U.S. Forest Service, U.S. Geological Survey, Bureau of Land Management, and National Park Service have begun to recognize the value of establishing Internet modeling and data resources for use by public as well as private land managers. It is very likely that in the near future there will be collaborative efforts among these and agencies from state and local governments to provide these resources in user-friendly, yet powerful formats such as the prototype LMS. We anticipate that EDYS, CASC2D, and other modeling tools that can make ready use of a variety of available data, especially in scaleable grid-based format, will have wide-spread applications in these systems.

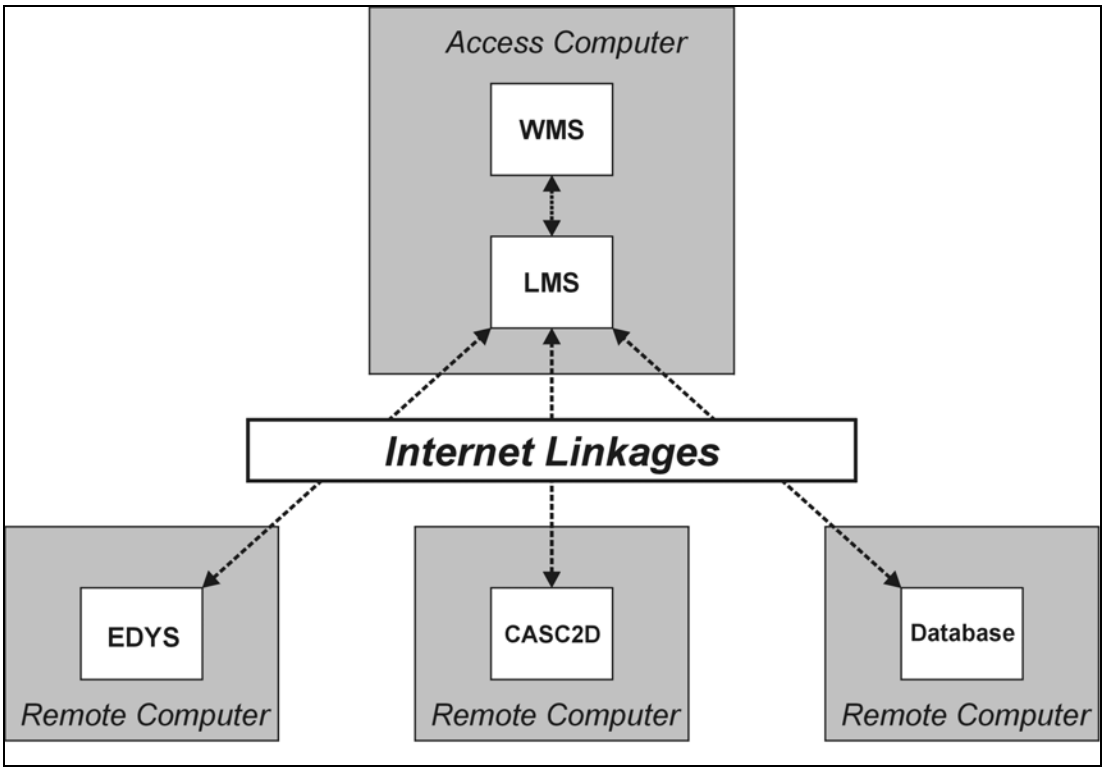

Figure 19. Conceptual Land Management System (LMS).*

* LMS coordinates simulation commands and control, data transfers, and outputs among various simulation models (including EDYS and CAS2D), databases, and interface software (WMS), all of which may be remotely linked via Internet.

EDYS Database Development

EDYS is designed to be calibrated using either literature or site-specific data (or a combination of the two) about plant and animal species, soil profiles, and climatic conditions. There is an obvious trade-off in using one source versus the other in parameterizing EDYS: literature values can be obtained cheaply and quickly, but do not provide the precision and accuracy in projections that can be obtained with site-specific data; however, site-specific data usually require expensive and time-consuming field surveys. A cost-effective strategy for parameterizing EDYS is to develop a “first pass” application using almost entirely literature information specifically to assess the benefits to model projections and the survey costs of obtaining site-specific data. This assessment approach will be facilitated by validation testing now being conducted at Forts Bliss and Hood.

A significant effort in subsequent EDYS development will be to create and maintain a large database system for archiving information and data sources which can be used in EDYS simulations (Figure 20). In this overall system, the core database would be an archive of data processed and tabularized in formats directly accessible by EDYS for all simulation runs. Sources for this data can be

categorized as ecological literature (journals, books, and research reports), Internet resources (especially climatic data), existing site data (e.g., U.S. Army's LCTA field survey data), and new field data collected specifically for EDYS simulations. Each application of EDYS to a particular site will provide additional data about the site and plant and animal species found there; this data will be incorporated into the database. It is anticipated that over time, the database should accumulate sufficient information to accommodate rapid development for first pass applications for any ecosystem in the continental United States, and other locations throughout the world where EDYS has been applied.

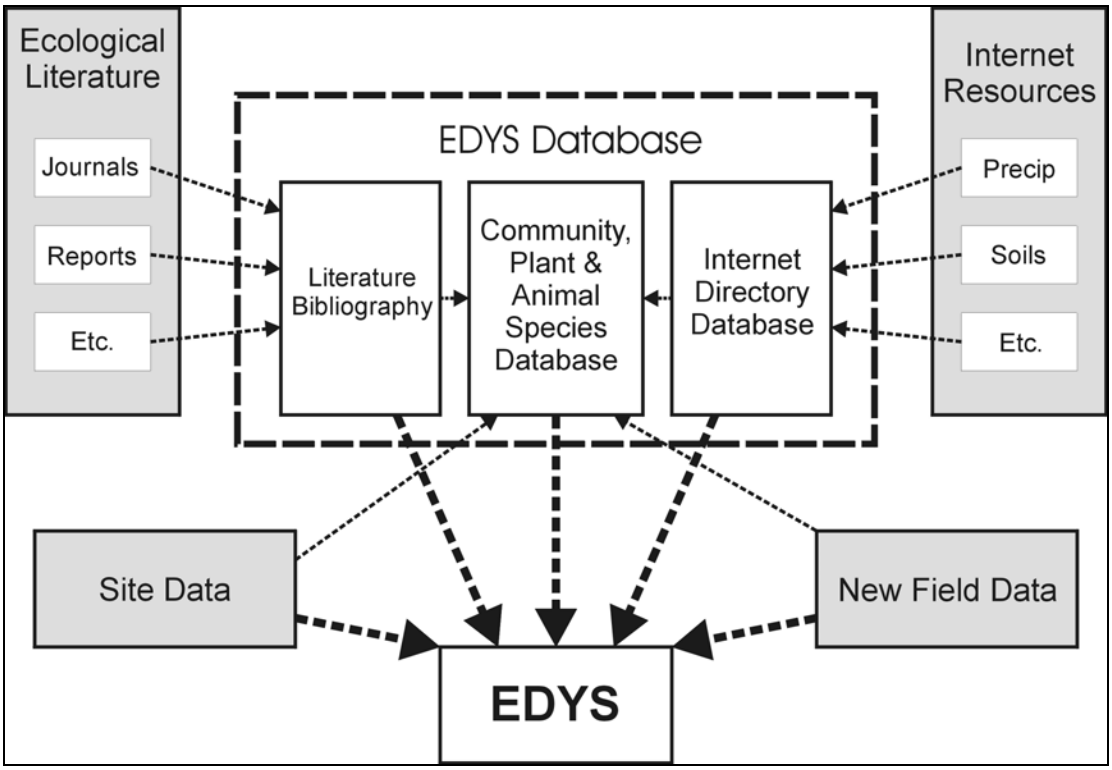

Figure 20. EDYS database system.*

* EDYS is a general ecosystem model which can make use of a great variety of data sources in providing process parameters, initial state values, and validation data. The EDYS Database is a large system of general and site-specific ecological information designed for fast access and rapid development of EDYS applications.

5 Summary

We have provided a functional description of the EDYS model, including system implementation, and data requirements and structure with examples of applications for Army and other federal land managers. The EDYS model can accurately predict (1) responses or trajectories of ecological communities on training lands to military disturbance and land management actions in conjunction with natural stress (e.g., drought, fire); (2) responses of disturbed communities to rehabilitation/restoration efforts; and (3) maximum sustainable use with management-specified requirements under various scenarios and ecological conditions.

The model is designed to assist in real land management scenarios. We believe this works in practice because we have (1) based the model on ecological mechanisms controlling ecosystem dynamics; (2) calibrated a general core model to site-specific conditions for each ecological community; (3) tested the model with field validation experiments; and (4) adapted the model to multiple scales to accommodate realistic training and testing activity scales.

The EDYS model is a key component of the Land Based Carrying Capacity capability and will facilitate linking the cost of training and testing land maintenance to the actual level of training. We have leveraged the research and development of EDYS with other DOD installations as well as other federal agencies. The EDYS model will be incorporated into the Land Management System and will be available in the future to Army users via a Corps' Engineer Research and Development Center internet web site.

Literature Cited

Brown, J.R., J. Herrick, and D.L. Price. 1999. "Managing Low-output Agroecosystems Sustainably: The Importance of Ecological Thresholds." *Canadian Journal of Forest Research*. 98-370- Special Issue (In Press).

Childress, W. M., and T. McLendon. 1998. *Strategies for land management*. Technical Report SMI-ES-005. Shepherd Miller Inc., Fort Collins, Colorado. 11 pp.

Childress, W. M., T. McLendon, and D.L. Price. 1999. "A Multi-scale Model for Allocation of Training Activities on U.S. Army Installations." Pages 80-108 in J.M. Klopatek and R.H. Gardner (eds.), *Landscape Ecological Analysis: Issues, Challenges, and Ideas*. Ecological Studies Series. Springer-Verlag. New York.

Department of Defense (DoD). 1996. "Environmental Conservation Program, " Instruction 4715.3, 8 May 1996.

DoD. 1994. "Guidance for Implementation of an Ecosystem Management Approach to Military Land Management." DUSD[ES]EQ-CO memo, 8 August 1994.

Goodman, S. W. 1996. "Ecosystem Management at the Department of Defense." *Ecological Applications*. 6:706-707.

Macia, T.E. 1996. "Army Reinvents Training Land Protection, Operators Take the Lead." In: *Proceedings of the 22nd Environmental Symposium and Exhibition of the American Defense Prepardness Association*. Orlando, Florida.

McLendon, T., W.M. Childress and D.L Price. 1996. "Use of Land Condition Trend Analysis (LCTA) Data to Develop a Community Dynamics Simulation Model as a Factor for Determination of Training Carrying Capacity of Military Lands." In: *Proceedings of the 5th LRAM/ITAM Workshop*. LaCrosse, Wisconsin. 26-28 August 1996.

McLendon, T., W.M. Childress, and C. Coldren. 1999. "EDYS - 2: First-year validation results for a black grama desert grassland community - Fort Bliss, Texas." Progress Report submitted to U.S. Army Construction Engineering Laboratory, Champaign, Illinois. Technical Report SMI-ES-008. Shepherd Miller Inc., Fort Collins, Colorado.

Price, D.L., A.B. Anderson, P.J. Guertin, T. McLendon, and W. M. Childress. 1997. *The Army's Land-Based Carrying Capacity*. USACERL Technical Note 97/142, September 1997.

U.S. Army Concepts Analysis Agency (CAA). 1996. *Evaluation of Land Values Study*. USACAA Technical Report CAA-SR-96-5.

U.S. Army Environmental Center. 1996. "Land Condition Trend Analysis II (LCTA II): Workshop Report." 29 March 1996.

Appendix A: EDYS Version 2 System Implementation

This is a listing of all Programs, Units, and Procedures used in the EDYS-2 model. It includes short descriptions and general outlines for each of the modules used. All code was written in Turbo Pascal, version 7.

PROGRAM EDYS2 - This is the main source code for the Ecological Dynamics Simulation model.

Steps: Read user options for length of simulation, precipitation factor, soil nitrogen factor, biomass adjustment factor, fire regime, herbivory regime, training regime, print file options, and display options (Procedure UserOptions).
Read quadrat data inputs (Procedure BuildInitialQuadratRecords)
Read plant species data inputs (Procedure BuildSpeciesRecords)
Real animal species data inputs (Procedure BuildAnimalRecords)
Tally the number of grid cells in each quadrat type (Procedure QuadratTally)
Initialize data records for each species (Procedure InitializePlantData)
Calculate burnability factors for each quadrat type (Procedure CalculateBurnability)
Set initial rates for dynamic herbivory (Procedure SetHerbRate)
Set up animal population dynamics variables (Procedure InitializeAnimalPopulation)
Set up training variables (Procedure InitializeTraining)
Set up results files (Procedures TableHeadings and MonthlyDisplayData)
Start annual simulation
- Initialize precipitation data
- Start monthly simulation
  - Initialize nitrogen and hydrological records (Procedure InitializeTableRecords)
  - Initialize herbivory variables (Procedure ResetHerbivory)
  - Initialize monthly plant dynamics
    - Determine monthly levels of dieback (Procedure MonthlyDieBack)
    - Drop seeds (Procedure DropSeeds)
    - Transfer seedling biomass to plant biomass (Procedure SeedlingTransfer)
    - Sprout seeds (Procedure SeedSprout)
  - Load precipitation data
  - Estimation of monthly potential plant production and transpiration
    - Estimate daily potential transpiration of plants (Procedure DailyPotentialTranspiration)
    - Estimate seedling daily potential transpiration (Procedure SeedlingDailyPotentialTranspiration)
  - Start daily simulation

Calculate levels of decomposition (Procedure Decomposition)
Determine levels of water available from precipitation
(Procedure Precipitation)
Perform infiltration (Procedure Infiltration)
Determine levels of runoff (Procedure Runoff)
Calculate amounts of evaporation (Procedure Evaporation)
Perform plant transpiration (Procedure Transpiration)
Perform seedling transpiration (Procedure SeedlingTranspiration)
Conduct daily herbivory (Procedure DailyHerbivory)
Conduct daily herbivory based on animal population dynamics
(Procedure AnimalPopulationHerbivory)

Calculation of monthly plant production
Perform plant production (Procedure PlantProduction)
Perform seedling production (Procedure SeedlingProduction)
Determine root biomass reallocation (Procedure RootReallocation)

Fire operation
Perform spatial fire process (Procedure FireProcess)
Display fire effects (Procedure FireDisplay)
Perform quadrat dynamics for burned quadrats (Procedure ReconcileQuadrats)
Determine burnability of each quadrat type (Procedure CalculateBurnability)

Training operations
Perform training operations (Procedure Training)

Herbivory
Perform monthly herbivory for herbivory regimes 2-7 (Procedure MonthlyHerbivory)
Perform herbivory for regime 8 (Procedure HerbivoreAdjustment)

Animal populations
Perform monthly animal population dynamics (Procedure AnimalPopulationDynamics)

Print Monthly Results

<u>UNIT Options</u>
PROCEDURE DurationOptions - sets the number of years for the simulation to run.
PROCEDURE PrintOptions - coordinates the designation of print out files by the user.
PROCEDURE DisplayOptions - coordinates designation of graphical displays by the user.
PROCEDURE FireRegimeOptions - coordinates designation of the fire regime by the user.
PROCEDURE HerbRegimeOptions - coordinates designation of the herbivory regime by the user.
PROCEDURE TrainingRegimeOptions - sets the training disturbance regime options.
PROCEDURE PrecipAdjustmentOptions - sets the precipitation options.

PROCEDURE SoilNAdjustmentOptions - sets the soil nitrogen adjustment options.
PROCEDURE BiomassFactorOptions - sets the biomass factor options.
PROCEDURE UserOptions - coordinates input of simulation options from the user.

UNIT LoadData
PROCEDURE DisposeGrid - This procedure removes the spatial grid from Pascal dynamic memory storage.
PROCEDURE BuildSpeciesRecords - This procedure inputs plant species data from the *.DAT file and builds species records for input into EDYS2. 'yyyyy' is a five letter abbreviation for each species and 'xx' represents the site location.

Steps: Input plant species integer data from yyyyyixx.DAT
Input plant species real data from yyyyyrxx.DAT

PROCEDURE DisposeSpeciesRecords - This procedure removes plant species records from Pascal dynamic memory storage.
PROCEDURE BuildAnimalRecords - This procedure inputs animal data from the *.DAT files and builds animal records for input into EDYS2. 'yyyyy' is a five letter abbreviation for each species and 'xx' represents the site location.

Steps: Input animal species integer data from yyyyyixx.DAT
Input animal species real data from yyyyyrxx.DAT

PROCEDURE DisposeAnimalRecords - This procedure removes animal species records from Pascal dynamic memory storage.
PROCEDURE BuildInitialQuadratRecords - This procedure inputs quadrat and species data from the Data file and builds quadrat records for input into EDYS2.

Steps: Input data from Integer.DAT
Input data from Text.DAT
Input data from Biomass.DAT
Input data from Seedbank.DAT
Input data from Seedling.DAT
Input data from Root.DAT
Input data from Litter.DAT
Calculate initial bare ground percentage
Input data from Soil.DAT
Input data from Soilname.DAT
Reset values for : Infiltration and runoff data
Burnability factor
Transpiration data
Production data
Seedling transpiration and production data
Initial soil moisture data
Input data from Color.DAT

PROCEDURE DisposeAllQuadratRecords - This procedure removes all quadrat records from Pascal dynamic memory storage.
PROCEDURE BiomassTally - This procedure calculates total living and standing dead biomasses.
PROCEDURE OldBiomassTally - This procedure calculates total old biomass.
PROCEDURE SeedlingBiomassTally - This procedure determines total seedling biomass.
UNIT Quadrats - This unit handles most of the real-time quadrat dynamics.
PROCEDURE TransferQuadratData (N, O : Integer) - This procedure transfers data from one quadrat to another. Two input values are required: the old quadrat number (O) to transfer data from and the new quadrat number (N) into which the data is transfered.

Steps: Transfer all the quadrat position data.
Transfer all the quadrat hydrology data.
Transfer all the quadrat nitrogen data.
Transfer all the biomass table data.
Transfer all the soil moisture table data.

PROCEDURE QuadratTally - This procedure tallies the number of grid cells for each quadrat type.

UNIT Soil - This unit handles soil and precipitation dynamics.
PROCEDURE Decomposition - This procedure conducts decomposition of litter, standing dead biomass, and material within the soil.

Steps: Litter decomposition
- Litter microbial decomposition
- Litter organic matter decomposition

Standing dead biomass decomposition
- Decomposition of stems
- Decomposition of leaves
- Recalculate total standing dead nitrogen

Soil profile decomposition
- Organic matter decomposition
- Soil microbial decomposition of nitrogen
- Revise soil nitrogen totals

PROCEDURE Precipitation - This procedure calculates runoff and infiltration values for each quadrat type from the precipitation data.

Steps: Revise precipitation data for interception of precipitation by foliage
- Calculate canopy cover based on all above-ground components
  - Interception is set to a maximum of 1 mm H_2O for each 100% of total cover

Find current top soil layer in case layer one has been lost

Loop through rain segments
- Wet litter and send on excess
- Wet soil layers one at a time and send excess moisture to the next layer
- Saturate soil layers one at a time and send excess to the next layer
- Any excess moisture beyond saturation becomes runoff
- Calculate infiltration as (Precipitation - Interception - Runoff)

PROCEDURE Infiltration - This procedure conducts infiltration through the soil profile.

Steps: Percolation through the litter
- Checks for sufficient precipitation to pass through the litter after wetting it
- Movement of nitrogen and organic matter

Wet soil infiltration
- Wet each soil layer and pass excess precipitation on to the next layer
- Movement of nitrogen and organic matter

Soil saturation
- If sufficient water is available, saturate each soil layer from the bottom up
- Revise nitrogen and organic matter content
- Excess precipitation now becomes runoff and is removed before evaporation

Tally soil nitrogen and organic matter levels

PROCEDURE Runoff - This procedure conducts runoff across the grid.

Steps: Revise bare ground calculation for all quadrat types

Scan all quadrat types to see if there is any runoff

Loop through the spatial grid, calculating water and material movement by rows
- Calculate the sediment and litter carrying capacity for the cell's runoff
- Mobilize/demobilize sediment and litter to meet the capacity

Revise quadrat types for erosion losses to the profile

Calculate sediment and litter loss/gain per quadrat

PROCEDURE Evaporation - This procedure conducts daily evaporation if no precipitation is occurs on that day.

Steps: Remove daily evaporation from litter and top soil layer

Remove evaporation from litter first

If more evaporation is needed, remove moisture from the top profile layer

Tally evaporation and precipitation levels

PROCEDURE Transpiration - This procedure conducts daily plant transpiration.

Steps: Calculate initial root demand

Calculate daily potential transpiration based on two estimates

1st estimate is the portion of total monthly transpiration demand

2nd estimate is the residual monthly transpiration demand

Use the smaller estimated value

Conduct transpiration for each plant species at each soil layer

Calculate allocation as species proportion of functional biomass

Calculate nitrogen uptake

Tally actual root uptake

Calculate the empirical transpiration loss

Tally the total profile nitrogen and organic matter content

PROCEDURE SeedlingTranspiration - This procedure conducts water uptake for any seedlings present.

Steps: Calculate daily potential transpiration for each species

1st estimate is the portion of total monthly transpiration demand

2nd estimate is the residual monthly transpiration demand

Use the smaller estimated value

Conduct transpiration for each species

Calculate total root allocation for each species by root biomass

Allocate water based on effective root biomass and water levels available

Tally actual uptake and allocate uptake by soil layer

Transfer nitrogen and soil water

<u>UNIT Plants</u> - This unit handles all plant dynamics.

PROCEDURE InitializePlantData - This procedure initializes plant biomass data for January conditions.

Steps: Adjust biomass levels for biomass factor

Put seeds into the seed bank for each species

Transfer biomass to litter or standing dead biomass as appropriate for each growth form

PROCEDURE DropSeeds - At the beginning of the month after seed month, this procedure drop all seeds.

Steps: Put seeds into the seedbank in the month AFTER seed production

Revise seedbank tallies, by species

PROCEDURE MonthlyDieBack - This procedure conducts potential die-back of plants each month.

Steps: Find the current maximum leaf biomass over prior 12 months, by species

Is root : leaf ratio skewed, by species?

Calculate maximum allowable root biomass and how much current root biomass exceeds that

Transfer root materials to organic matter

Transfer trunk materials to litter

Once a year dieback of above ground biomass for each species

Calculate dieback losses by components

Transfer biomass and nitrogen to appropriate fates, either litter or standing dead material

PROCEDURE SeedlingTransfer - This procedure transfers seedling biomass to main plant biomass.

Steps: Transfer seedling below ground biomass to plant below ground biomass
Allocate seedling above ground biomass to plant above ground biomass

PROCEDURE SeedSprout - This procedure conducts seed sprout and transfer of biomass to seedlings.

Steps: Check for adequate precipitation for seed sprout
For each species, check if this is greenout month or the next month
Conduct seed sprout if conditions are appropriate
Put seeds into the seedling biomass
Estimate seed sprout and transfer biomass to seedlings
Take seeds out of the seedbank

PROCEDURE DailyPotentialTranspiration - This procedure calculates daily potential transpiration for each species.

Steps: Calculate maintenance and production estimates for each species
Calculate light competition factor
Check for green out month and greenout conditions
Calculate monthly potential production for greenout conditions or for normal production for each plant component
Conduct monthly transpiration based on new production
Conduct monthly maintenance transpiration for current new biomass
Conduct monthly maintenance transpiration for old biomass

PROCEDURE SeedlingDailyPotentialTranspiration - This procedure determines daily potential transpiration for seedlings.

Steps: Determine if seedlings are present for this species this month
Calculate seedling monthly maintenance transpiration
Calculate seedling potential production
Calculate seedling potential production transpiration
Calculate seedling total potential transpiration
Calculate starting residual potential transpiration

PROCEDURE PlantProduction - This procedure performs the actual plant production for the EDYS2 model.

Steps: Make up old biomass water deficit for each species, if a deficit exists
Determine old biomass maintenance for each species
If sufficient transpiration is not available, then old biomass maintenance loss is a direct loss of water weight
Calculate and deduct maintenance for this component proportionally to old biomass
Conduct negative production for old biomass
Test each component for each species to determine if water loss is too great to maintain old biomass
If so, calculate old biomass losses and transfer the loss to litter
Determine new biomass maintenance for each species
If sufficient transpiration is not available, then new biomass loss is proportional to the transpiration shortfall
If seeds are available, remove biomass loss from seeds
If seed biomass is not sufficient to cover losses, remove loss from leaf and stem biomass
Transfer biomass loss to litter
Determine production by species
Calculate actual production as the smaller of two estimates: one based on transpiration and the other based on nitrogen limitations

Select allocation pattern for production
If seed month, then annuals produce seeds
If greenout month, then use greenout allocation
Revise root allocation based on the root-to-shoot ratio
Allocate production among plant components

PROCEDURE SeedlingProduction - This procedure calculates actual production for seedlings.

Steps: Check whether seedlings are present for each species
Calculate seedling production
If transpiration sufficient, then positive production
If transpiration is not sufficient, then negative production
Loss is proportional to transpiration shortfall
Transfer biomass losses to litter

PROCEDURE RootReallocation - This procedure adjusts root percentages in each layer according to the prior month's uptake of water.

Steps: Calculate percent root increase for each species
Tally proportions of prior monthly uptake in each soil layer
Allocate increase among root levels according to uptake

UNIT Fire - This unit handles all fire dynamics.

PROCEDURE CalculateBurnability - This procedure calculates the burnability factor for each quadrat. Burnability is used in estimating fire spread probabilities.

Steps: Calculate burnability by plant component for each species
Average the burnability for the extent of each quadrat type

PROCEDURE FireProcess - This procedure handles the spatial fire dynamics.

Steps: Pick a random quadrat where a fire might start
Test to see if a fire is to be started this month (for the Fixed Fire Regime)
Make the random cell burn
Test to see if there will be a fire (for the Stochastic Fire Regime)
Make the random cell burn
If a cell has burned, conduct fire spread around the burned cell
Scan the grid repeatedly for burning cells
Search through the neighborhood looking for new cells to ignite
If a cell is within the neighborhood extent, not burned, not currently burning, and burnable, then fire spreads to this cell

PROCEDURE BurnQuadrat - This procedure calculates the effect of a burn on the quadrat type's biomass.

Steps: Calculate fire loss and fire nitrogen loss for each component of each species
All fire nitrogen loss goes into free nitrogen in the top soil layer
Burn the litter
All litter nitrogen go to the top soil layer
Completely remove water from the litter

PROCEDURE ReconcileQuadrats - This procedure handles quadrat dynamics for disturbed quadrats.

Steps: Check for burned or disturbed quadrats
Setup a new quadrat record for this disturbed quadrat
Create a new quadrat type
Transfer all the old quadrat data to the new
Conduct disturbance in this quadrat type (call of Procedure BurnQuadrat)
Revise the grid with the new quadrat type
Tally the number of cells for each quadrat type

UNIT Training - This unit handles all training operation dynamics.

PROCEDURE InitializeTraining - This procedure designates a training activity path across the landscape and creates new quadrat types in the specified paths.

Steps: Spatially place the training pathway in a path starting at a given X-coordinate, of a width as specified by the variable TrainingZone, and extending through all the extent of the grid along the Y-axis.
Reconcile quadrats in this pathway as new quadrat types
Check for all training pathway quadrats
Setup a new quadrat record for this disturbed quadrat
Create a new quadrat type
Transfer all the old quadrat data to the new quadrat
Revise the grid with the new quadrat type
Tally the number of cells for each quadrat type

PROCEDURE Training - This procedure conducts training activity disturbances in the training activity pathway.

Steps: Search the training pathway quadrats looking for undisturbed cells
Disturb all components of each plant species
Deduct living biomass losses
Deduct standing dead biomass losses
Deduct seedling losses
Transfer species losses to litter
Convert all disturbed quadrats back to normal quadrat types

UNIT Animal - This unit handles herbivory and animal population dynamics.

PROCEDURE ResetHerbivory - This procedure resets the herbivory variables at the beginning of each month.

PROCEDURE MonthlyHerbivory - For fixed herbivory regimes 2-7, this procedure conducts herbivory losses each month. For these regimes, herbivory is at fixed rates and calculated at the end of each month.

Steps: For cow herbivory
Calculate biomass loss and add to herbivore gain
Calculate nitrogen loss and add to herbivore gain
For insect herbivory
Calculate biomass loss and add to herbivore gain
Calculate nitrogen loss and add to herbivore gain

PROCEDURE DailyHerbivory - For dynamic herbivory regime 8, this procedure conducts daily herbivory by three animal types.

Steps: Check whether the herbivore is hungry
Check whether the plant component and species are of the correct preference priority
Calculate biomass available for this herbivore as the balance of biomass after prior herbivory this month
Calculate the portion of available biomass that can be taken in one day
Calculate nitrogen loss
Tally herbivore gains and biomass losses (both old and new biomass)
Calculate herbivore gains
Calculate herbivore nitrogen gains

PROCEDURE SetHerbRate - For dynamic herbivory regime 8, this procedure sets the maximum herbivory rate at the beginning of each simulation.

PROCEDURE HerbivoreAdjustment - For dynamic herbivory regime 8, this procedure adjusts the forage demand for each herbivore on a monthly basis.

Steps: For grasshoppers
- Demand is reset each January to maximum rate
- Demand is adjusted by deficit in uptake in the current month

For cottontails
- Adjust demand based on rabbit demand trigger values

For cattle
- Cattle demand does not change over time

PROCEDURE InitializeAnimalPopulations - This procedure sets up initial conditions for the animal population dynamics.

PROCEDURE AnimalPopulationDynamics - This procedure handles the population dynamics and predator-prey interactions on a monthly basis for age class structured animal populations.

Steps: Adjust population sizes for migratory species

Check whether this is the end of the year or species with generation time of less than one year
- Move cohorts from one age class to the next. Those in the last age class die.

Check whether the current month is the birth month for any species
- If good conditional state, then young are born
- Sex ratio is adjusted if conditional state impacts sex ratio for this species

Conduct monthly mortality

Check whether the current month is during hunting season for legally hunted species
- Remove members from the population

Check whether any species are migratory
- Save population sizes for return from migration

Tally population totals

Calculate total food demand for each species

For predators
- Calculate demand on each prey class
- Check to see whether enough prey biomass exists to satisfy the demand
  - If not, reallocate prey demand among other prey classes
- Adjust predator body masses based on availability of prey and intrinsic growth rates
- Consume prey (Procedure Depredate)

PROCEDURE Depredate - This procedure handles all predation events.

Steps: For each predator
- Find available prey species
- Translate food demand biomass into numbers of prey items
- Remove prey items from populations
- Tally biomass of prey consumed

PROCEDURE AnimalPopulationHerbivory - This procedure handles herbivory based on the actual animal population levels. This is conducted on a daily basis.

Steps: Tally population sizes to ensure they are correct

Calculate food demand

Allocate food demand by plant growth form

Loop through plant species
- Check for correct preference rank and competition class
- Check whether sufficient biomass exists to satisfy the herbivore's demand

If not, re-allocate the demand among other species and growth forms
Implement biomass losses
Tally herbivore gains
Tally herbivore nitrogen gains
Adjust body mass and conditional states based on food availability and intrinsic growth rates
PROCEDURE AnimalPopulationTally - This procedure determines the total population size and total population for each sex for each species.

UNIT PrntData - This unit handles all text file printing.
PROCEDURE InitializeTableRecords - This procedure initializes all the variables in the quadrat hydrology and quadrat nitrogen data records.
PROCEDURE NCalculations - This procedure calculates the total grid nitrogen pools.

PROCEDURE BiomassCalculations - This procedure calculates total grid biomasses.
PROCEDURE TableHeadings - This procedure prints table headings for the six possible results tables.
PROCEDURE MonthlyPrintOuts - This procedure processes all monthly printouts.
PROCEDURE AnnualPrintOuts - This procedure processes all annual printouts.

UNIT Display2 - This unit contains all EDYS2 graphics display procedures.
PROCEDURE GridDisplay - This is the master procedure for the grid display operations. It is called only in August of each year.
PROCEDURE FireDisplay - This is the master procedure for the fire display operations. It is called only after a fire.
PROCEDURE BiomassGraphsDisplay - This is the master procedure for the biomass graphs display operations. It is called only at the end of the simulation.
PROCEDURE RunoffDisplay - This is the master procedure for the runoff graphs display operations. It is called only at the end of the simulation.
PROCEDURE MonthlyDisplayData - This procedure saves monthly biomass, soil water, and runoff data for display at the end of the simulation.
PROCEDURE MonthlyDisplay - This procedure coordinates displays at the end of each month.
PROCEDURE AnnualDisplay - This procedure coordinates displays at the end of each year.
PROCEDURE EOSDisplay - This procedure coordinates displays at the end of the entire simulation.

Prior to running a model simulation, several data programs must be executed to build the data files used as input for the model. These data programs contain all site-specific information as detailed in Appendix B. The data files are then read by the LoadData Unit of the EDYS-2 model during a simulation run, allowing the model to be written for a generalized soil-plant-disturbance-animal system. The data programs are called Dataxx.pas and yyyyy.pas with ‘xx’ corresponding to a specific site location and ‘yyyyy’ corresponding to a five letter abbreviation for each plant and animal species.

PROGRAM Dataxx - This program is contained in the Dataxx.pas file and produces all site-specific information that varies by quadrat type. It builds the following set of data files for input into the EDYS-2 model:

Integer.DAT - contains several integer values as to the number of communities, number of quadrat types, number of plant species, and the initial grid setup.
Text.DAT - contains text headings, such as site location of the simulation, the names of the community types, and names plant and animal species.
Biomass.DAT - contains biomass data and plant nitrogen levels.

SeedBank.DAT - contains data on seedbank biomass and nitrogen.
Seedling.DAT - contains data on seedling biomass and nitrogen.
Root.DAT - contains data on root proportions.
Litter.DAT - contains information on litter, including biomass, nitrogen, organic matter, microbial nitrogen, and water content.
Soil.DAT - contains data on the soil profile, including water content, horizon depth, nitrogen, organic matter, and microbial nitrogen levels.
SoilName.DAT - contains the names of the soil profile layers.
Animal.DAT - contains a animal community preferences.
Color.DAT - contains information for the visual displays.

PROGRAM yyyyy - This program is contained in the yyyyy.pas file and produces all site-specific information that does not vary by quadrat type. It builds the following set of data files for input into the model:

yyyyyixx.DAT - For plants, it contains integer values about the plant species, including the number of species, growthforms, and months for greenout, seed production, and dieback. For animals, it contains all the integer data as outlined in Appendix B.

yyyyyrxx.DAT - For plants, it contains all the data on fire and herbivory and the remainder of the information about plants, including the dry weight proportions, canopy factor, bare ground factor, plant nitrogen concentration, water use, growth rates, production allocations, light competition matrix, root-to-shoot ratios, greenout triggers, seed sprout properties, dieback properties, and root uptake capacities. For animals, it contains all the real data as outlined in Appendix B.

Appendix B: EDYS Version 2 Data Requirements and Structure

This is a listing of data parameters necessary to run EDYS version 2. This listing contains a short description of each parameter, followed by the unit of measurement used, data type (integer, real number, or character string), and the data structure used within EDYS-2.

Model Parameters:

Number of community types.
- Units: -
- Data Type: Integer
- Data Structure: Variable

Grid size. Two values required; one for the X-axis and one for the Y-axis.
- Units: -
- Data Type: Integer
- Data Structure: Variable

Precipitation data file with daily precipitation totals. The file is structured as follows:
- Units: inches
- Data Type: Real
- Data Structure: Array [1 to 34]

Timed segment partitioning of rainfall events, used for runoff calculations.
- Units: -
- Data Type: Real
- Data Structure: Array [1 to 5]

Soil Parameters

Number of soil profile layers
- Units: -
- Data Type: Integer
- Data Structure: Variable

Depth of soil profile layers by community type.
- Units: mm
- Data Type: Real
- Data Structure: Array [1 to number of community types, 0 to number of soil profile layers + 1]

Initial soil profile water content, by community type and soil profile layer. This is based on the levels of precipitation in November and December.
- Units: mm H_2O
- Data Type: Real
- Data Structure: Array [1 to number of community types, 0 to number of soil profile layers + 1]

Maximum water wetting capacities of each soil profile layer by community type.
- Units: mm H_2O/ mm layer depth
- Data Type: Real
- Data Structure: Array [1 to number of community types, 1 to number of soil profile layers]

Amount of available nitrogen in each soil profile layer by community type.
Units: g/m^2
Data Type: Real
Data Structure: Array [1 to number of community types, 0 to number of soil profile layers]

Initial soil nitrogen adjustment factor. Currently set to 1.00.
Units: -
Data Type: Real
Data Structure: Variable

Amount of organic matter in each soil profile layer by community type.
Units: g/m^2
Data Type: Real
Data Structure: Array [1 to number of community types, 0 to number of soil profile layers]

Amount of nitrogen contained in organic matter in each soil profile layer by community type.
Units: g/m^2
Data Type: Real
Data Structure: Array [1 to number of community types, 0 to number of soil profile layers]

Amount of nitrogen contained in microbiota in each soil profile layer.
Units: g/m2
Data Type: Real
Data Structure: Array [1 to number of community types, 0 to number of soil profile layers]

Amount of water held by litter by community type.
Units: kg of water/ g of litter
Data Type: Real
Data Structure: Array [1 to number of community types]

Soil nitrogen mobilization rate per day. Currently set to 0.50.
Units: -
Data Type: Real
Data Structure: Variable

Organic matter mobilization rate per day. Currently set to 0.01.
Units: -
Data Type: Real
Data Structure: Variable

Daily potential evaporation by month.
Units: mm H_2O
Data Type: Real
Data Structure: Array [1 to number of months]

Litter bare ground cover factor. Currently set to 0.0001.
Units: $1/(g/m^2)$
Data Type: Real
Data Structure: Variable

Litter decomposition rate, determined as 0.001 decomposition after 30 wet days. Currently set to 0.00003335.
Units: $1/(g/m^2)$
Data Type: Real
Data Structure: Variable

Litter organic matter decomposition rate, determined as 0.001 decomposition after 30 wet days. Currently set to 0.00003335.
Units: $1/(g/m^2)$
Data Type: Real
Data Structure: Variable

Soil organic matter decomposition rate, determined as 0.001 decomposition after 30 wet days. Currently set to 0.0000335.

Units: 1/(g/m^2)
Data Type: Real
Data Structure: Variable

Microbiota decomposition rate, determined as 0.025 decomposition after 30 wet days. Currently set to 0.0008436.

Units: 1/(g/m^2)
Data Type: Real
Data Structure: Variable

Standing dead material decomposition rate, determined as 0.010 decomposition after 30 wet days. Currently set to 0.000335.

Units: 1/(g/m^2)
Data Type: Real
Data Structure: Variable

Allocation proportions for decomposition losses of nitrogen from litter. Allocation is set using three variables: 1. allocation of litter nitrogen to organic matter nitrogen, currently set to 0.50; 2. allocation of litter nitrogen to microbial nitrogen, currently set to 0.50; and 3. allocation of litter nitrogen to free nitrogen, currently set to 0.0.

Units: -
Data Type: Real
Data Structure: Variable

Allocation proportions for decomposition losses of nitrogen from organic matter. Allocation is set using two variables: 1. allocation of organic matter nitrogen to microbial nitrogen, currently set to 0.50; and 2. allocation of organic matter nitrogen to free nitrogen, currently set to 0.50.

Units: -
Data Type: Real
Data Structure: Variable

Slope of each community type.

Units: ^{o} (degrees)
Data Type: Real
Data Structure: Array [1 to number of community types]

Slope factor for calculating sediment load capacity, determined as 100% of water volume at 45 ^{o} slope. Currently set to 1.0/45.

Units: 1/(^{o} [degrees])
Data Type: Real
Data Structure: Variable

Slope factor for calculating litter load capacity, determined as 50% of water volume at 45 ^{o} slope. Currently set to 0.5/45.

Units: 1/(^{o} [degrees])
Data Type: Real
Data Structure: Variable

Plant Parameters:

Names of all plant species found in the communities.

Units: -
Data Type: Character string
Data Structure: Array [0 to number of species]

Growth form for each species. Values are: 1 - annual grass, 2 - perennial grass, 3- annual forb, 4 - perennial forb,
5 - deciduous shrub or tree, 6 - evergreen shrub or tree.

Units: -

Data Type: Integer
Data Structure: Array [1 to number of species]

Names of plant components. Currently uses ‘Total’, ‘Roots’, ‘Trunk’, ‘Stems’, ‘Leafs’, ‘Seeds’, ‘SDStm’, ‘SDLfs’.
Units: -
Data Type: Character string, 5 characters long
Data Structure: Array [0 to total number of plant components]

Initial plant biomass by species in each community. Biomass is separated by plant component (root, trunk, stem, leaf, seed, stem standing dead, and leaf standing dead).
Units: g/m^2
Data Type: Real
Data Structure: Array [1 to number of community types, 0 to number of species, 0 to number of plant components]

Biomass factors for adjusting initial biomasses. Currently set to 1.0 for each value.
Units: -
Data Type: Real
Data Structure: Array [1 to number of plant species]

Initial plant nitrogen concentration in each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of community types, 1 to number of species]

Seedling biomass growth factor. Used to reduce the actual seed biomass so that seedling growth will not have diluted nitrogen levels.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species]

Initial root profile distributions by species, community type, and soil profile layer.
Units: % in each layer
Data Type: Real
Data Structure: Array [1 to number of community types, 1 to number of species, 1 to number of soil profile layers]

Green-out month for each species. Values are: 1 for January, 2 for February, etc.
Units: -
Data Type: Integer
Data Structure: Array [1 to number of species]

Month of seed production for each species. Values are: 1 for January, 2 for February, etc.
Units: -
Data Type: Integer
Data Structure: Array [1 to number of species]

Month when dieback occurs for each species. Values are: 1 for January, 2 for February, etc.
Units: -
Data Type: Integer
Data Structure: Array [1 to number of species]

Dieback fate for each component of each species. Biomass after dieback becomes either litter (value of 0), standing dead stems (value of 6), or standing dead leaves (value of 7).
Units: -
Data Type: Integer
Data Structure: Array [1 to number of species, 1 to number of plant components]

Monthly root dieback rate (% of difference). Currently set to 0.10.
Units: -
Data Type: Real
Data Structure: Variable

Dry weight proportion of living biomass by species.
Units: %
Data Type: Real

Data Structure: Array [1 to number of species]

Biomass to percent canopy cover factor. Used to calculate the amount of precipitation intercepted by the canopy and evaporated.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Bare ground factor used for converting trunk biomass by species to percent ground cover.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Proportion of nitrogen contained in species biomass.

Units: -

Data Type: Real

Data Structure: Array [0 to number of species]

Maintenance water use rate by species.

Units: mm H_2O/ g biomass/ month

Data Type: Real

Data Structure: Array [1 to number of species]

Maintenance water use rate for new growth for each species. This is the proportion of production needed in the month after production occurs.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Water-use ratio for each species. This is the amount of soil water (in mm) needed to produce 1 g of above ground biomass.

Units: mm of soil water/ g of above ground biomass produced

Data Type: Real

Data Structure: Array [1 to number of species]

Monthly maintenance rate adjustment.

Units: -

Data Type: Real

Data Structure: Array [1 to number of months]

Factor for converting proportional light reduction effect on production. Currently set to 0.01.

Units: $1/(g/m^2)$

Data Type: Real

Data Structure: Variable

Initial new growth proportion for each species of the water-use ratio in the first month of production.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Old biomass deficit factor to initiate loss for each species.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Maximum monthly growth rate for each species. This is based on the percent of leaf biomass.

Units: %

Data Type: Real

Data Structure: Array [1 to number of species]

Maximum growth rate in each month for each species. Values are proportions which range from 0 to 1.0.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species, 1 to number of months]

Proportional rate of production per component biomass for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of plant components]
Greenout and drought proportional rate of production per component biomass for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of plant components]
Light competition matrix. Values are proportional light reduction of each species on the other species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of species]
Biomass growth allocation per plant component for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of plant components]
Greenout and drought allocation matrix by plant component for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of plant components]
Allocation of growth by component for each species in the month of seed production.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of plant components]
Root-to-shoot ratio threshold for each species for switching allocation of growth from below ground to above ground biomass.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species]
Leaf and stem biomass to root biomass ratio threshold for producing greenout drought growth conditions.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species]
Proportion of seeds that sprout each year for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species]
Proportional increase in biomass of seeds during seed sprout for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species]
Dieback loss proportions of plant components for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species, 1 to number of plant components]
Root-to-leaf dieback ratio for each species.
Units: -
Data Type: Real
Data Structure: Array [1 to number of species]
Proportion of nitrogen in dieback material that is resorbed by species.
Units: -
Data Type: Real

Data Structure: Array [1 to number of species]

Root biomass adjustment factor for each species, based on root zone competitive strengths.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Root uptake capacity for each species. Values are based on the proportion of monthly potential production water demand that can be taken up daily.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species]

Fire Parameters:

Plant biomass loss. Values are the proportions of plant components for each species that are lost in each fire event.

Units: -

Data Type: Real

Data Structure: Array [1 to number of species, 1 to number of plant components]

Relative burnability, determined as the total quadrat biomass where burnability = 1. Currently set to 500.

Units: -

Data Type: Real

Data Structure: Variable

Fire spread probability. Currently set to 0.10.

Units: -

Data Type: Real

Data Structure: Variable

Fire initiation probability for Fire Regime 2. Currently set to 0.04.

Units: -

Data Type: Real

Data Structure: Variable

Burnability weight adjustment factors for each plant component.

Units: $1/(g/m^2)$

Data Type: Real

Data Structure: Array [0 to total number of plant components]

Proportion of litter burned. Currently set to 1.0.

Units: -

Data Type: Real

Data Structure: Variable

Training Parameters:

Width of training zone.

Units: Number of quadrats

Data Type: Integer

Data Structure: Variable

Matrix of training effects for each training regime, plant species growth form, and plant component.

Units: -

Data Type: Real

Data Structure: Array [1 to number of training regimes, 1 to number of plant growth forms, 1 to number of plant components]

Loss rate of seedlings from training activities.

Units: -
Data Type: Real
Data Structure: Array [1 to number of training regimes]

Herbivory Parameters:

Number of herbivores.
Units: -
Data Type: Integer
Data Structure: Variable
Names of the herbivores.
Units: -
Data Type: Character string, 11 characters long
Data Structure: Array [0 to number of herbivores]
Number of stocking levels of herbivores.
Units: -
Data Type: Integer
Data Structure: Variable
Stocking levels of each herbivore.
Units: -
Data Type: Integer
Data Structure: Array [1 to number of herbivores]
Herbivory rates for each herbivore at each stocking level.
Units: g/day
Data Type: Real
Data Structure: Array [1 to number of herbivores, 0 to number of stocking levels]
Maximum proportion of available component biomass that can be taken in one day. Currently set to 0.01.
Units: -
Data Type: Real
Data Structure: Variable
Herbivory littering rates for each herbivore at each stocking level.
Units: g/day
Data Type: Real
Data Structure: Array [1 to number of herbivores, 0 to number of stocking levels]
Herbivory seasonality as the proportion of each herbivore stocking level available for plant consumption during each month.
Units: -
Data Type: Real
Data Structure: Array [1 to number of herbivores, 1 to number of months]
Rabbit demand level triggers. One trigger is for the minimum demand, currently set to 0.80. Consumption below this proportion causes a loss in demand. One trigger is for the maximum demand, currently set to 0.90. Consumption above this proportion causes a rise in demand.
Units: -
Data Type: Real
Data Structure: Variable
Number of priorities for herbivore plant preferences.
Units: -
Data Type: Integer
Data Structure: Variable
Selectivity of plant components for biomass loss rates by large herbivores. This array is used for fixed rate herbivory.
Units: -

Data Type: Real
Data Structure: Array [1 to number of plant species, 1 to number of plant components]

Selectivity of plant components for biomass loss rates by herbivorous insects. This array is used for fixed rate herbivory.

Units: -
Data Type: Real
Data Structure: Array [1 to number of plant species, 1 to number of plant components]

Matrix of plant component preference and herbivore competition. Values for matrix[x,x,x,1] are plant species and component preferences by herbivores; values for matrix[x,x,x,2] are percent of that component that can be consumed in an entire month and the percent of that amount that can be consumed in one day; values for matrix[x,x,x,3] are herbivore competition classes.

Units: % for matrix[x,x,x,2]; all others are dimensionless
Data Type: Real
Data Structure: Array [1 to number of herbivores, 1 to number of plant species, 1 to number of plant components, 1 to 3]

Animal Parameters:

Names of all animal species found in the communities.

Units: -
Data Type: Character string
Data Structure: Array [0 to number of species]

Number of age classes in the age structured population.

Units: -
Data Type: Integer
Data Structure: Variable

Number of time intervals contained within each age class within the population.

Units: -
Data Type: Integer
Data Structure: Array [1 to number of age classes]

Length of the time interval for the age class structure of the population. Values less than one are for time intervals in months (i.e. 2/12 represents a time interval of 2 months); a value of 1 is for a time interval of one year.

Units: months or years
Data Type: Real
Data Structure: Variable

Length of the time to sexual maturity. Values less than one are for species which mature in less than one year (i.e. 2/12 represents a generation time of 2 months); a value of 1 is for species which require one or more years to reach sexual maturity.

Units: months or years
Data Type: Real
Data Structure: Variable

Initial size of the population, structured by age classes and sex.

Units: number of individuals
Data Type: Real
Data Structure: Array [0 to number of age classes, 0 to number of sexes]

Population seasonality as the proportion of the total population that is resident within the model's landscape during each month.

Units: -
Data Type: Real
Data Structure: Array [1 to number of months]

Community preferences as the proportion of time each community is occupied by each species.

Units: %
Data Type: Real
Data Structure: Array [1 to number of animals, 1 to number of communities, 1 to number of months]

Tropic level. Values are 1 for herbivores, 2 for omnivores, and 3 for predators.

Units: -
Data Type: Integer
Data Structure: Variable

Prey class. Used in allocating prey species to their respective predators.

Units: -
Data Type: Integer
Data Structure: Variable

Migratory status. A value of one indicates this species is migratory while a value of 0 indicates this species is sedentary.

Units: -
Data Type: Integer
Data Structure: Variable

Month when hunting is allowed. Values are: 1 for January, 2 for February, etc.

Units: -
Data Type: Integer
Data Structure: Variable

Month when young are born and enter the population in age class 1. Currently, up to five breeding events per year are allowed.

Units: -
Data Type: Integer
Data Structure: Array [1 to 5]

Fecundity by age class. First value is the number of young produced for each breeding female while the second value is the proportion of females in the population which breed.

Units: number of individuals, %
Data Type: Real
Data Structure: Array [1 to number of age classes, 1 to 2]

Sex ratio of young by conditional state. This value is used if the sex ratio at birth for a species varies with conditional state of the female.

Units: number of males/number of females
Data Type: Real
Data Structure: Array [1 to the number of conditional states]

Monthly mortality rates for each age class. This does not include mortality due to predation.

Units: % of individuals which die
Data Type: Real
Data Structure: Array [1 to number of age classes, 1 to number of sexes, 1 to number of months]

Initial conditional state for each age class and sex within the population. Values are: 3 - good condition, 2 - moderate condition, and 1 - poor condition.

Units: -
Data Type: Integer
Data Structure: Array [1 to number of age classes, 1 to number of sexes, 1 to number of months]

Body mass of males in each age class.

Units: gm
Data Type: Real
Data Structure: Array [1 to number of age classes]

Body mass of females in each age class.

Units: gm

Data Type: Real
Data Structure: Array [1 to number of age classes]

Rate of assimilation of food intake into change in body mass.
Units: gm of body mass change/gm of food intake
Data Type: Real
Data Structure: Variable

Intrinsic growth rates as the potential rate of growth for each age class if food demands are met. Values are proportional increase or decrease in body mass.
Units: -
Data Type: Real
Data Structure: Array [1 to number of age classes, 1 to number of sexes, 1 to number of months]

Ideal intake rates for each individual within each age class.
Units: gm/day
Data Type: Real
Data Structure: Array [0 to number of age classes, 1 to number of sexes, 1 to number of months]

Proportion of the diet made up of plant material for omnivores. Values are: 1 - herbivores, 0 - predators, between 0 and 1 - omnivores.
Units: %
Data Type: Real
Data Structure: Array [1 to number of age classes, 1 to number of sexes, 1 to number of months]

Composition of diet demand by prey class for each predator. The first value is the prey class number, the second is a preference rank for that prey class. A prey class with a preference rank of 2 would be more highly preferred than a prey class with a rank of 3, but less than a prey class with a rank of 1.
Units: -, -
Data Type: Integer
Data Structure: Array [1 to number of prey classes, 1 to 2]

Ideal proportion of the total diet made up of each prey class.
Units: %
Data Type: Real
Data Structure: Array [1 to number of prey classes]

Competitive ability of each predator species. Values are 1 for most competitive, 2 for next most competitive,…
Units: -
Data Type: Integer
Data Structure: Variable

Composition of diet by plant growth forms for herbivores. Values are growth forms consumed by the herbivore.
Units: -
Data Type: Integer
Data Structure: Array [1 to number of plant growth forms]

Ideal proportion of the total diet made up of each plant growth form.
Units: %
Data Type: Real
Data Structure: Array [1 to number of growth forms]

Matrix of plant component preference and herbivore competition by plant growth form. Values for matrix[x,x,1] are plant species and component preferences by herbivores; values for matrix[x,x,2] are herbivore competition classes; and values for matrix[x,x,3] are percent of that component that can be consumed in one day.
Units: % for matrix[x,x,3]; all others are dimensionless
Data Type: Real

Data Structure: Array [1 to number of growth forms, 1 to number of plant components, 1 to 3]

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