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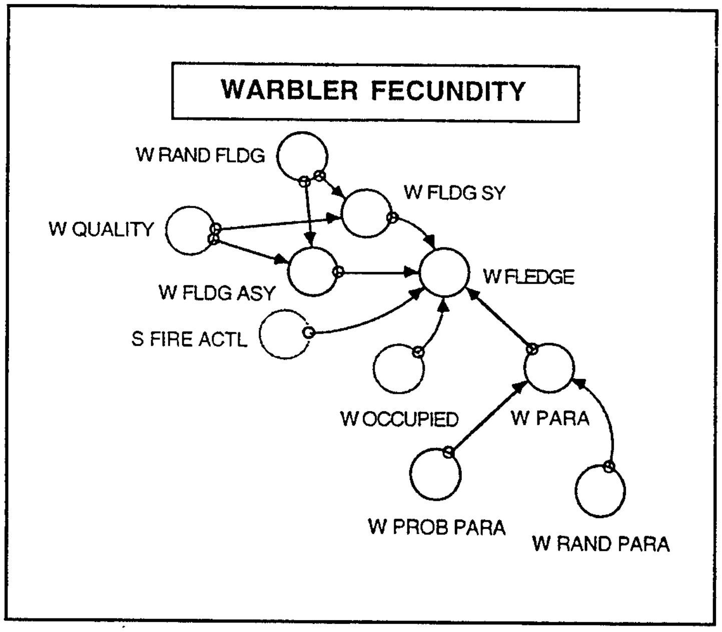
The Fort Hood Avian Simulation Model

A Dynamic Model of Ecological Influences on Two Endangered Species

by
Ann-Marie Trame, Steven J. Harper, Jocelyn Aycrigg, and Jim Westervelt

The endangered golden-cheeked warbler (GCWA) and black-capped vireo (BCVI) breed at Fort Hood, Texas. Both populations are influenced by management activities, military impacts, and land use policies, especially those pertaining to cattle grazing and fire suppression. In addition, the reproductive success of individuals in these populations is adversely affected by brood parasitism by the brown-headed cowbird (BHCO), a species whose distribution and abundance are also influenced by land use policies.

To protect breeding habitat and reduce the impact of cowbird parasitism, natural resource managers must incorporate large-scale processes into their management decisions. Because it is difficult and expensive to conduct large-scale experiments to study the responses of species to land use policies or management actions, computer models can be developed to simulate changes for large regions over time.



This report discusses development and use of the Fort Hood Avian Simulation Model (FHASM), a dynamic, spatially-explicit model of ecosystem processes and population dynamics of BCVI and GCWA at Fort Hood. Using FHASM to simulate different scenarios of management decisions and land use policies, managers may discover improved strategies for control of BHCO and for enhancement of suitable habitat for BCVI and GCWA. The model provides information exchange among six submodels: Management, Accidental Fire, Habitat, Avian, Map Input, and Simulation. Ultimately, FHASM may assist in developing a management plan that will ensure the viability of both endangered species over long periods of time.

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13. ABSTRACT (Maximum 200 words)

The endangered golden-cheeked warbler (GCWA) and black-capped vireo (BCVI) breed at Fort Hood, Texas. Both populations are influenced by management activities, military impacts, and land use policies, especially those pertaining to cattle grazing and fire suppression. In addition, the reproductive success of individuals in these populations is adversely affected by brood parasitism by the brown-headed cowbird (BHCO), a species whose distribution and abundance are also influenced by land use policies.

To protect breeding habitat and reduce the impact of cowbird parasitism, natural resource managers must incorporate large-scale processes into their management decisions. Because it is difficult and expensive to conduct large-scale experiments to study the responses of species to land use policies or management actions, computer models can be developed to simulate changes for large regions over time.

This report discusses development and use of the Fort Hood Avian Simulation Model (FHASM), a dynamic, spatially-explicit model of ecosystem processes and population dynamics of BCVI and GCWA at Fort Hood. The model provides information exchange among six submodels: Management, Accidental Fire, Habitat, Avian, Map Input, and Simulation. Ultimately, FHASM may assist in developing a management plan that will ensure the viability of both endangered species over long periods of time.

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Executive Summary

Background

Two endangered passerine birds, the golden-cheeked warbler (GCWA) and the black-capped vireo (BCVI), breed at Fort Hood, Texas. The relative abundance and spatial pattern of breeding habitat are important considerations for maintaining populations of both species. Both populations are influenced by management activities, military impacts, and land use policies, especially those pertaining to cattle grazing and fire suppression. In addition, the reproductive success of individuals in these populations is adversely affected by brood parasitism by the brown-headed cowbird (BHCO), a species whose distribution and abundance are also influenced by land use policies.

To protect breeding habitat and reduce the impact of cowbird parasitism, natural resource managers must incorporate large-scale processes into their management decisions. It is difficult, if not impossible, to conduct experiments to study the responses of species to land use policies or management actions at large scales; manipulations have logistical problems, and replication of such experiments is expensive. To overcome these limitations, computer models can be developed to simulate changes for large regions over time. Simulations can capture and integrate information about the ecosystem processes at Fort Hood and thereby contribute to ongoing efforts to conserve BCVI and GCWA populations.

Fort Hood Avian Simulation Model

The Fort Hood Avian Simulation Model (FHASM) is a dynamic, spatially-explicit model of ecosystem processes and population dynamics of BCVI and GCWA at Fort Hood. Using FHASM to simulate different scenarios of management decisions and land use policies, managers may discover improved strategies for control of BHCO and for enhancement of suitable habitat for BCVI and GCWA. Ultimately, FHASM may assist managers in developing a management plan that will ensure the viability of both endangered species over long periods of time. FHASM simulates processes believed to influence populations of BCVI and GCWA. The model provides information exchange among six submodels: Management, Accidental Fire, Habitat, Avian, Map Input, and Simulation.

The *Management* submodel simulates the location and timing of activities designed to benefit endangered species and to maintain the suitability of other areas for military training. Efforts to control BHCO, also simulated in the Management submodel, influence the probability of parasitism for nests of endangered species. The *Accidental Fire* submodel simulates the ignition and spread of fires caused by training activities and lightning strikes. Information from these two submodels is incorporated into the *Habitat* submodel, which simulates changes in plant communities resulting from management activities and accidental fires. In addition, the submodel simulates changes in vegetation due to natural succession, training activities, and grazing by cattle. Information about plant communities from the Habitat submodel is incorporated by the *Avian* submodel, which determines the quality of the habitat for breeding by adult BCVI and GCWA. In addition to habitat quality, the history of occupancy by breeding adults influences selection of breeding sites by both species. The Avian submodel also determines the productivity of both species from measures of habitat quality and the probability of parasitism by BHCO. The *Map Input* submodel provides initialization values for parameters in other submodels. This submodel also stores maps that depict various land use scenarios that can be simulated by FHASM. The *Simulation* submodel stores spatial variables generated each time step (and thus changing through time) within a simulation run, so that dynamic spatial variables are available to FHASM when needed.

Models, including FHASM, are best applied within an adaptive management framework. Adaptive management is conducted by planning and executing management activities as if they were experimental treatments in a research study, allowing results from different management strategies to be evaluated statistically. Ultimately, this approach may identify the most effective strategies to be used. Models can assist in this approach by identifying those processes that strongly influence factors of interest. By generating predictions of how complex ecosystems function, FHASM can be validated in the field. As a tool used by resource managers, FHASM may contribute toward ensuring the continued viability of two endangered species.

Foreword

This study was conducted for the U.S. Army Corps of Engineers (USACE) under Project 4A161102BT25, "Environmental Research—Corps of Engineers"; Work Unit LLJ07, "Spatial Simulation Modeling Applications for TES." The technical monitor was Lewis E. Link, Jr., CERD-ZA.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Jim Westervelt and Ann-Marie Trame was assistant investigator. Steven J. Harper and Jocelyn Aycrigg are Research Fellows with the Oak Ridge Associated Universities post-graduate program. Dr. David J. Tazik is Acting Chief, CECER-LL-N, and Dr. William D. Severinghaus is Operations Chief, CECER-LL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

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1 Introduction

Background

Fort Hood, Texas provides breeding habitat for two endangered passerine birds, the golden-cheeked warbler (GCWA; *Dendroica chrysoparia*) and the black-capped vireo (BCVI; *Vireo atricapillus*). The two species have narrow, but conflicting, habitat requirements for breeding. The BCVI requires early successional, scrubby vegetation, while the GCWA requires mature oak (*Quercus* spp.)-ashe juniper (*Juniperus ashei*) forests. High quality sites for these species develop on limestone escarpments, and GCWA habitat frequently succeeds BCVI habitat after 20 or more years. The relative abundance and spatial pattern of habitat types on the landscape are important considerations for maintaining populations of both species. In addition, BCVI, and possibly GCWA, productivity are impacted by the brood parasitism practiced by the brown-headed cowbird (BHCO; *Molothrus ater*). The distribution and abundance of the BHCO are influenced on a large scale by land use policies, especially cattle grazing and fire suppression.

To protect important habitat and reduce the impact of cowbirds, natural resource managers conduct management activities across the entire landscape of Fort Hood. Currently, three general management approaches are used: (1) vegetation is altered through prescribed burns or mechanical clearing in order to create future BCVI habitat, (2) prescribed burns are used to reduce fuel loads near occupied GCWA habitat to avoid accidental habitat destruction, and (3) livetraps and shotguns are used to reduce the number of cowbirds. Monitoring of BCVI and GCWA populations suggests that these approaches are producing additional breeding sites and reducing BHCO parasitism. Additional success may be possible by optimizing the locations of BHCO traps and by optimizing the location and dispersion of suitable habitat for the BCVI and GCWA.

Computer modeling can capture and integrate environmental parameters of Fort Hood, thereby contributing to efforts to conserve BCVI and GCWA populations through landscape management. The Fort Hood Avian Simulation Model (FHASM) is a dynamic, spatially explicit model of ecosystem processes and the population dynamics of the BCVI and GCWA on Fort Hood. The model simulates changes in vegetation and avian populations across the installation (approximately 88,000 ha) over 100-yr intervals (although shorter or longer runs are easily accommodated). The user designates management policies for each simulation run, and the model produces output maps and other data representing simulated BCVI and GCWA abundances and distributions. By comparing the results of different scenarios in FHASM, managers may improve strategies for ensuring the viability of these endangered species.

Objective

The objective of this research was to develop a dynamic, spatially explicit model designed to simulate the effects of management activities and land use practices on the BCVI and GCWA. A future report will evaluate applications of FHASM to important management questions.

Approach

Specific modeling goals were identified through consultation with John Cornelius (Wildlife Biologist, Endangered Species Branch, Fort Hood, professional discussions, January to August 1996), and Timothy J. Hayden (Research Ecologist, USACERL, professional discussion, January 1996). Accordingly, FHASM development was guided by the following questions:

1. Where should potential GCWA habitat be converted to potential BCVI habitat to maintain the greatest numbers of both species?

2. What would the habitat and population consequences be for different fire management zones on the installation (e.g., one or more No Burn Zones and one or more Let Burn Zones)?

3. To what extent is BHCO foraging habitat and behavior impacted by military training and cattle grazing?

4. What is the current carrying capacity for the two species on Fort Hood? How do spatial characteristics of the habitat (e.g., fragmentation, connectivity, patch size) affect carrying capacity?

5. What is the optimal spatial configuration of BCVI habitat given a fixed quantity of habitat?

6. Where could BHCO traps be placed to maximize the efficiency of control efforts?

Further details of FHASM development are given in Chapter 3.

Overview of FHASM

FHASM is a landscape simulation model of endangered BCVI and GCWA on Fort Hood, which occupies 87,890 ha in Bell and Coryll counties, Texas (Figure 1). Within the Lampasas Cutplains physiographic region, the landscape of Fort Hood has alternating flat valleys and limestone escarpments, which rise as high as 379 meters above the plains. Long, hot summers and short, moderate winters are typical climate for the area. Average monthly temperatures range from a low of about 8 °C in January to a high of 29 °C in July. Average annual precipitation is 81 cm (Tazik, Gryzbowski, and Cornelius 1993). FHASM models change in vegetation and BCVI and GCWA populations across the installation over time. The landscape of Fort Hood is divided into 21,540 square grid cells, each representing a 4-ha area (200m x 200m; Figure 2). Most of the simulation algorithms run independently

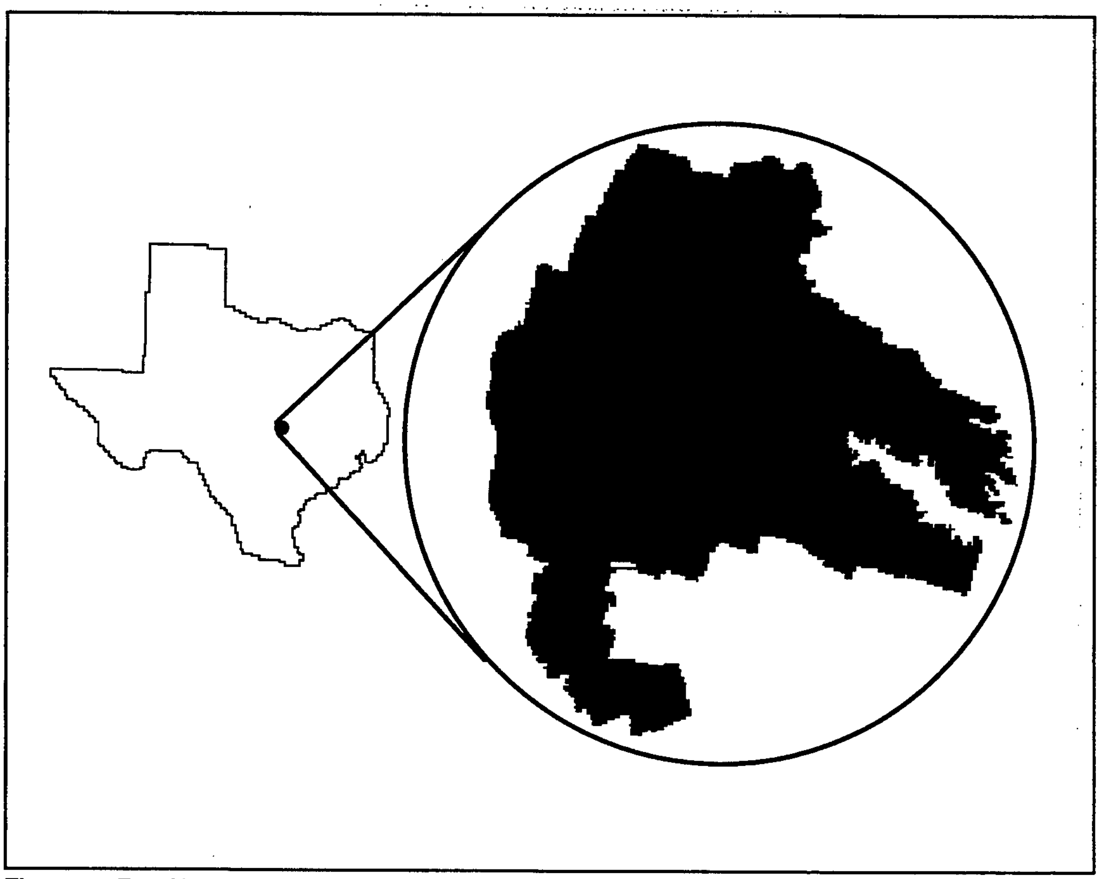
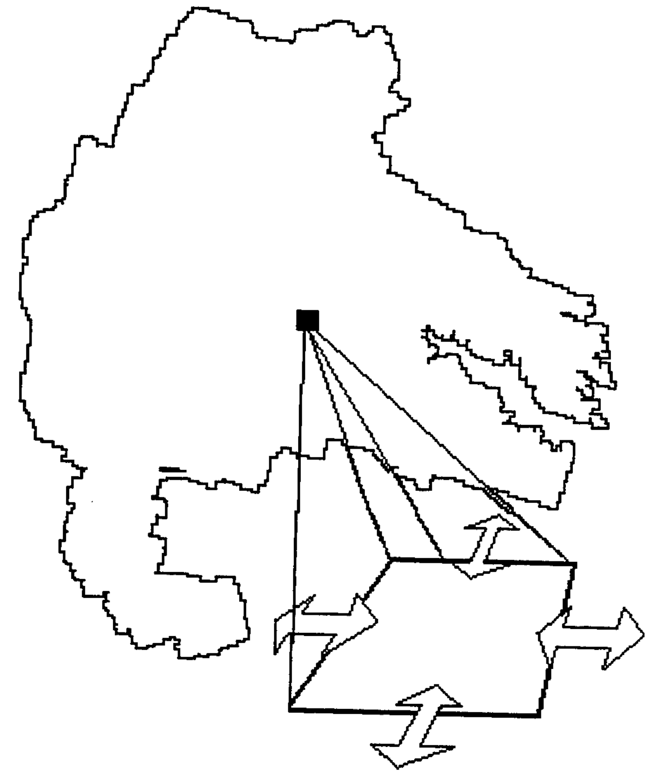


Figure 1. Fort Hood, Texas, is located in Bell and Coryll counties.



Each grid on the larger map represents 25 cells in FHASM; each cell is 200 m by 200 m.

Figure 2. Fort Hood is divided into 21,540 grid cells for landscape simulation in FHASM.

within each cell during a simulation run. In some cases, information is exchanged across multiple cells, as detailed under *Technical Approach* sections in Chapter 4. Mapped parameters for each cell are initialized through geographic information system (GIS) layers, while parameters for nonspatial variables are initialized with constant values defined by mathematical functions. Spatially explicit variables that change throughout a simulation run are input back into the model from the GIS through the Simulation submodel. FHASM simulates processes believed to influence populations of BCVI and GCWA. The model provides information exchange among six submodels: Management, Accidental Fire, Habitat, Avian, Map Input, and Simulation (Figure 3).

The Management submodel simulates the location and timing of activities designed to benefit endangered species and to maintain the suitability of other areas for military training. Efforts to control BHCO, also simulated in the Management submodel, influence the probability of parasitism for nests of endangered species. The Accidental Fire submodel simulates the ignition and spread of fires caused by training activities and lightning strikes. Information from these two submodels is

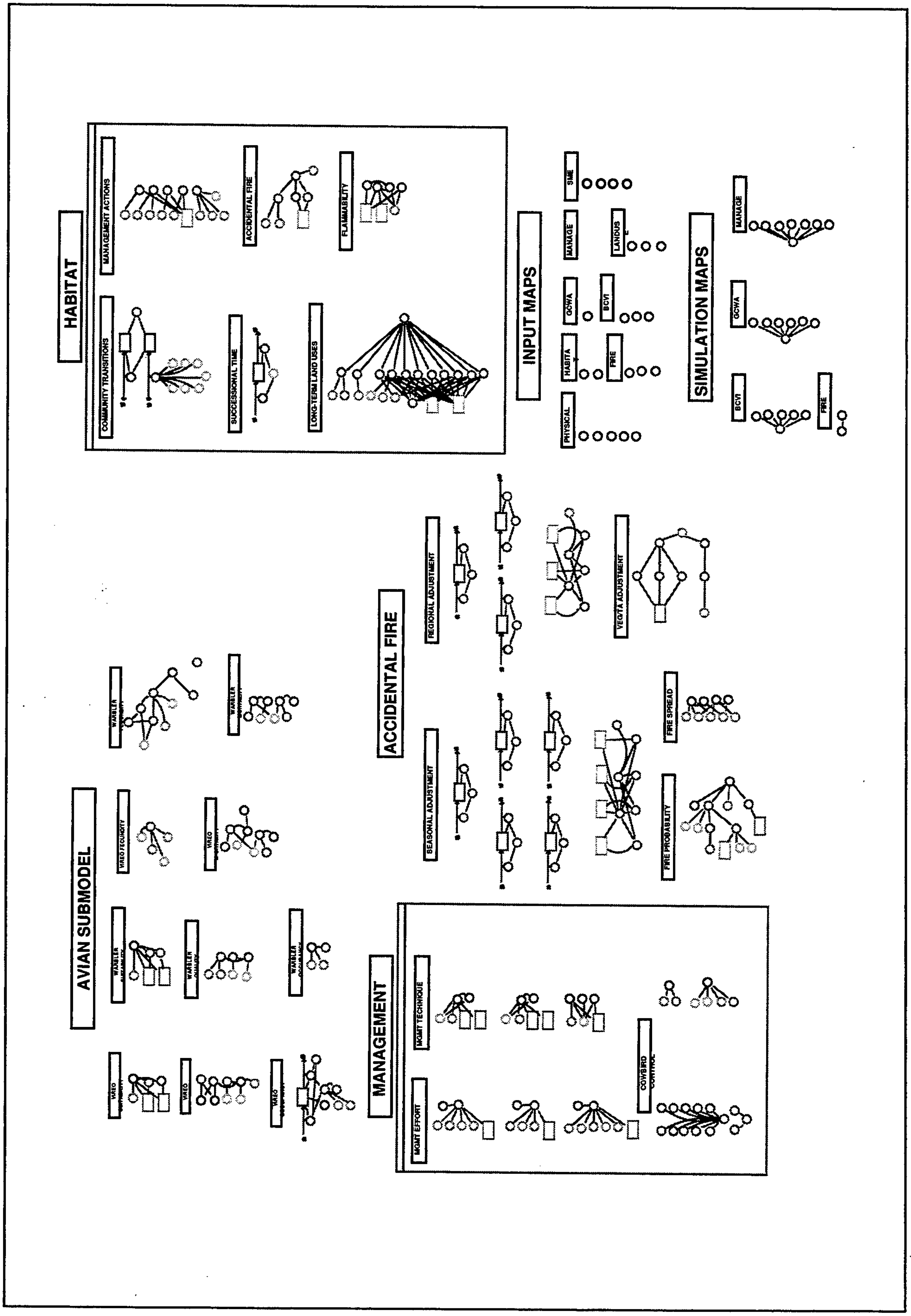


Figure 3. Overview of the six submodels in FHASM.

incorporated into the Habitat submodel, which simulates resultant change in 15 plant communities. The Habitat submodel also simulates changes in vegetation due to natural succession, training activities, and grazing by cattle. Information about plant communities from the Habitat submodel is incorporated by the Avian submodel. This model determines the quality of the habitat for breeding by adult BCVI and GCWA. In addition to habitat quality, the history of occupancy by breeding adults influences selection of breeding sites by both species. The Avian submodel also determines the productivity of both species from measures of habitat quality and the probability of parasitism by BHCO. The Map Input submodel provides initialization values for parameters in other submodels. This submodel also stores maps that depict various land use scenarios that can be simulated by FHASM. The Simulation submodel stores spatial variables generated each time step (and thus changing through time) within a simulation run, so that dynamic spatial variables are available to FHASM when needed.

Overview of Document

This report introduces FHASM and documents its development. The second chapter provides a brief review of spatially explicit population models (SEPMs), their uses, their limitations, and several examples of SEPMs used in a management context. It is important to apply such a general perspective when evaluating any specific model. The remainder of this report documents model development and provides the mathematical functions of FHASM, so that the usefulness and limitations of its application to a Fort Hood management context can be assessed. FHASM users should be familiar with the general strengths and weaknesses of SEPMs as they make their assessments.

A model's usefulness depends partly on the quality of the modeling approach. Were specific modeling objectives identified? How did developers ensure that the structure of the model will capture the relevant ecological relationships? Who was involved in model design? How were decisions made regarding model scale and scope? Chapter 3 presents an interdisciplinary development approach to SEPMs, including the steps that follow documentation (these are steps for future work on FHASM). Chapter 3 also outlines the FHASM development process and may serve as an example for other modeling efforts.

The value of a model is directly related to the quality of its underlying structure, data, and algorithms, which are described in Chapter 4. The background ecology of each submodel or map is reviewed, and the technical approach is presented. The casual reader can acquire an understanding of Fort Hood ecology by reading the

Background sections of Chapter 4. To aid in complete evaluation of the model, the *Technical Approach* sections are written in detail. The *Issues* sections discuss limitations to and concerns about the modeling approach and available data. Figures and Appendices A through E illustrate model construction, define variables, and present equations and shell scripts.

Model documentation is the process by which ecological knowledge is formalized and communicated among model users, managers, and researchers. Formalized documentation has two benefits: (1) it aids in evaluation of the model, and (2) it promotes communication among managers about their own knowledge base, assumptions, and professional judgement about model components and relationships.

Mode of Technology Transfer

This report documents the application of modeling and simulation technologies to natural resources management and endangered species conservation on a military installation. The demonstration model, FHASM, will be accessible to Fort Hood personnel through an interface on the World Wide Web. An electronic form allows users to specify simulation parameters and to remotely launch simulation runs. The interface program will also notify users when output is available for retrieval via FTP.

2 The Uses and Limitations of Spatially Explicit Population Models for Management

Ecologists have recognized that processes can operate at very large temporal and spatial scales (Johnson 1993). However, it is difficult to study the responses of species to large-scale environmental parameters or management actions because large-scale manipulations have inherent logistical problems and replication is expensive (Turner et al. 1995). In contrast, computer models can represent large regions and simulate change over long periods of time, but are abstractions of natural systems.

By definition, a model is a simplified representation of an object or system but may yield information beyond that available by examining the model components alone. Spatially explicit population models (SEPMs) model a population's response to spatially explicit changes in the environment and provide a technique for studying large-scale processes, such as management actions (Dunning et al. 1995). Thus, SEPMs can provide comparative and qualitative statements about population responses to landscape scenarios (Dunning et al. 1995) and allow evaluation of different management possibilities (Turner et al. 1995).

The dynamic nature of SEPMs makes them more applicable than simple habitat suitability models (Turner et al. 1995). This applicability is critical when managers need to understand processes taking place over long time periods (Holt et al. 1995). For example, rare species that rely on ephemeral habitat may appear secure at any moment in time; however, their habitat may disappear quickly through natural succession if new habitat is not generated through periodic disturbance. Population models of such species must consider shifts in the areal extent and arrangement of suitable habitat over many generations (Holt et al. 1995). Even if different scenarios result in identical final landscapes, changes throughout each simulation may vary, and that variation may be critical to a species (Dunning et al. 1995). Dynamic models can also incorporate time lags inherent in some systems. For example, site fidelity in birds can cause lags in response to habitat change (Wiens et al. 1986).

SEPMs are being applied by managers to assist in decisionmaking. The Bureau of Land Management (BLM) compared simulated effects of six land management plans on the northern spotted owl (*Strix occidentalis caurina*) to identify optimal amount and distribution of timber harvests over 100 years (McKelvey et al. 1992 in Turner et al. 1995). Another model output considered competition between an endangered wallflower (*Erysimum menziesii*) and an invasive exotic lupine (*Lupinus arborea*) to assist the evaluation of strategies for removing lupine (Turner et al. 1995). A SEPM also has been developed to assess the effects of pine harvesting options, habitat management through thinning and burning, and different pine species on Bachman's sparrow population size and extinction probability (Pulliam et al. 1992, Liu et al. 1995). By identifying three influential processes (habitat abundance and arrangement, habitat-specific survival and reproductive success, and factors that determine dispersal behavior), results of this model have guided field research and conservation strategies (Pulliam et al. 1992).

Applying output produced by SEPM to species management has some important limitations. Models may not accurately predict the number of individuals on a particular landscape. Predictive capability is reduced by limitations in the information on which the model was built (Turner et al. 1995) and by errors in the structural design of a model (Conroy et al. 1995). SEPMs are particularly susceptible to propagation of error due to their complexity (e.g., many spatially explicit values must be included in addition to demographic parameters; Conroy et al. 1995). The spatial scale, resolution of existing data, and type of functional relationships that drive the natural systems of interest should be reflected in the model. Parameter values must be biologically meaningful and observable (Conroy et al. 1995). SEPMs have demanding data requirements; spatially explicit demographic and dispersal information is necessary, and preferably these data have been collected from the site where the model is to be applied (Pulliam et al. 1992). Based on such cautions, SEPMs should be carefully evaluated before such output is used by managers to guide their decisions.

3 FHASM Approach and Specifications

FHASM was developed at the University of Illinois at Urbana-Champaign (U of I) in collaboration with the U.S. Army Construction Engineering Research Laboratories (USACERL). The first phase of the work was conducted by students in an Advanced Biological Modeling course (Geography 495C). To simplify and justify the original FHASM model, a second phase was conducted by USACERL personnel over several months after the course ended. Both phases are discussed in the numbered paragraphs below. The entire process consisted of eight steps.

1. Identify requirements and objectives of end user. A modeling effort is most successful if developers identify the end users and their requirements at the beginning of model development, because this encourages realistic model objectives. This process requires a great deal of open communication between users and developers. FHASM developers were able to spend several hours discussing user requirements with John Cornelius* at the beginning of the course. Communication continued throughout model development through phone conversations, faxes, and a trip to Fort Hood in Phase II.

2. Identify the hardware and software requirements. FHASM was developed on hardware and software systems that were used in previous USACERL modeling projects (e.g., Westervelt et al. 1995; Westervelt et al. *in press*). A low level of software development (in C++) continued throughout FHASM development, as requirements for new capabilities emerged. Simulations in FHASM are compiled and run on UNIX workstations. The model was developed using a suite of three interacting software packages: STELLA II (High Performance Systems, Inc.), Geographic Resource Analysis Support System (GRASS, version 4.2; Open GRASS Foundation 1993) and Spatial Modeling Environment (SME version 3; Costanza and Maxwell 1991). STELLA is Macintosh software that provided the initial dynamic, single-cell modeling environment. GRASS provided GIS capabilities and was used to generate initialization maps. SME applied the dynamic STELLA model simultaneously to every cell, simulated changes through time, and provided model output.

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* Wildlife Biologist, Endangered Species Branch, Fort Hood, Texas.

3. Identify human resources. Phase I was conducted during a geography class at the U of I. Class instruction was provided by USACERL researchers Dr. Steve Harper (ecologist) and by Dr. Bruce Hannon (U of I geography professor). Students from different departments (i.e., ecology, biology, geography, mathematics, and engineering) formed an interdisciplinary development team. Interdisciplinary efforts can be weakened if individuals are not assigned responsibilities closely related to their skills or their fields of expertise. However, the potential benefits are significant when perspectives are exchanged among people with diverse backgrounds. After the course was completed, Phase II was conducted by Dr. Harper and Ann-Marie Trame (USACERL conservation ecologist) under the direction of Dr. Westervelt.

4. Formalize the scale and scope of the project. To provide reasonable output to assist decisionmaking, a model must be designed at spatial and temporal scales that reflect the ecological processes of interest (Conroy et al. 1995). Science seeks to simplify the natural world and create models based on "just enough" connection and complexity to answer the questions at hand (Holt et al. 1995) while avoiding extraneous details that can inflate model error (Conroy et al. 1995). In addition, models are built with available data. The development of FHASM sought a balance between realistic temporal and spatial scales and the scale of available data.

The time step (dT) in FHASM was originally set at 1 week, but during Phase II, researchers established a time step of 3 months or "quarters" (defined as 1 = Jan-Mar, 2 = Apr-Jun, 3 = Jul-Sep, and 4 = Oct-Dec). This change was an attempt to simplify the model to reflect lack of knowledge of some ecological processes on a weekly basis. For example, the Phase I model simulated nesting activities of breeding birds for each week of the breeding season, a level of resolution that could not be supported with available data. In the Phase II model, each breeding season is captured in a single time step, so summary statistics that describe recruitment by breeding birds over the season can be incorporated.

The spatial scale of FHASM matches the typical minimum territory size of both species, approximately 4 ha in area. Square grid cells are a fixed size of 200 m by 200 m. FHASM encompasses all cells within the boundaries of Fort Hood. Simulations are run for 100-yr intervals, a timeframe typically simulated by population viability models.

5. Conceptualize the model. Course instructors developed the overall concept for FHASM and identified important elements to be included in the model during Phase I. The model content was driven by user output requirements and model

objectives. It was important to include the most important variables determining changes in output, without unnecessarily complicating the model.

6. Develop submodels. Efficient model development was accomplished by dividing the full model into submodels. Each submodel encompassed a portion of the full model and was relatively independent of the other submodels, except via input and output exchange. In Phase I of FHASM, four submodels were proposed: Target Species, Habitat, Impacts, and Map Input submodels. The geography class was divided into three teams, each of which was assigned one of the first three submodels. The Target Species team consisted of Leonardo Chapa (team leader), Robert Diehl, Tracy Galarowicz, Benjamin Halperin, and Mosheh Wolf. The Habitat team was composed of Denny Park (team leader), Ryan Lindberg, Teresa Johnson, and Georgia Sebesta. The Impacts team included Ann-Marie Trame (team leader), Becky Zerlentes, Ben Wang, and Robert Getz. The Map Input submodel was developed by Jocelyn Aycrigg (GIS analyst, postgraduate fellow at USACERL).

The FHASM development teams coordinated to ensure that individual submodels would connect to form a full model. After an initial survey of literature to understand the ecology of their submodel topic, teams specified input and outputs that would be required for each submodel. Cooperation is essential, because output from one submodel plays a critical role as an input variable for at least one other submodel. Submodels are conceptualized through iterative determination of the most important variables. As development proceeds within each team, frequent communication among teams is needed. As teams familiarize themselves with the data available for modeling their submodel, input requirements and assessment of realistic output will likely change. The FHASM teams discussed such issues at least once a week as a large group and communicated more frequently as needed.

7. Integrate submodels into a full model. Because each submodel was completed in coordination with all other submodels, integration was not a problem. However, difficulties did arise, including (1) the inconsistent use of units, (2) two or more submodels using a common variable name, but having different meanings, and (3) unused information in submodels that unnecessarily complicated the full model. Each team produced full documentation for their respective submodels and provided instructions for identifying when submodel output was beyond an acceptable range of values. An iterative debugging process was needed to reduce chaotic behavior in the newly integrated full model. This was conducted by first combining only two submodels, and once they functioned properly, adding a third submodel. When the full model functioned as intended, it was demonstrated to the end users. Further refinement or redevelopment was influenced by changes in user needs, perceived

usefulness and flexibility, and time and financial constraints. It was important to document model development and content, which is the function of this report.

8. Post-development steps. Important work still remains after a model has been constructed and is running. Sensitivity analysis is needed to evaluate model response to component variables and to determine how stable the model is with respect to uncertain data. If a parameter is particularly influential in model results, additional research may be justified to establish a solid relationship between that variable and model output, so the model is more accurate. If deemed appropriate, additional details may be built into the model structure to improve accuracy. Development of a user interface leads to greater application of the model by the user and assists them in comparing management scenarios. Future activity on FHASM is discussed in the final chapter of this report.

4 Ecological Characteristics of Fort Hood and the Technical Approach to Development of FHASM

Avian Submodel Background

The Black-capped Vireo

The BCVI is a small passerine bird listed as Federally endangered in 1987. Its breeding range once extended over much of the south-central United States but recently has been restricted to a few sites in Oklahoma, central Texas, and northern Mexico. The birds winter on the western coast of Mexico. The BCVI arrives on Fort Hood in mid- to late March and leaves for winter ranges during August and September (Tazik, Cornelius, and Abrahamson 1993).

The BCVI is a habitat specialist that requires early- to mid-successional habitat to breed. On Fort Hood, this habitat is comprised of hardwood scrub and mixed forest with patchy shrubs and thickets interspersed with dead trees. Preferred habitats consist of 35 to 55 percent woody cover, including about 11 percent conifer species (ashe juniper) and the remaining deciduous oak species (Grzybowski, Tazik, and Schnell 1994; Grzybowski 1995). Dense deciduous cover from ground level to 2 m in height is characteristic of breeding territories (Grzybowski 1995).

The BCVI is vulnerable to loss of breeding habitat through natural plant succession or through human activities such as large-scale and consistent fire suppression, brush clearing, overgrazing, and urbanization (Campbell 1995). In addition, the BCVI is impacted by reduced productivity caused by brood parasitism. BHCOs are listed by the Fish and Wildlife Service (FWS) as a major reason for the endangered status of the species (Hayden et al. *in press*).

The Golden-cheeked Warbler

The GCWA was listed as endangered in 1990 (Campbell 1995). Fort Hood is an important factor in the conservation of this species because breeding habitat is restricted to the state of Texas. The birds winter in mountainous areas of Central

America. They arrive in Texas in March and depart for winter ranges during June and July (Pulich 1976).

GCWAs are habitat specialists that require mature mixed forests of ashe juniper and oak species. Early accounts suggested that the GCWA utilized edges between grasslands and scrubby, juniper-oak "cedar brakes" (Kroll 1980), and that it preferred forests composed of 14 to 50 percent juniper and 20 to 70 percent oaks (Huss 1954). Sites with a ratio of oak to juniper of 1:1.35 were consistently used for breeding (Kroll 1980). A sizable proportion of the juniper trees must be at least 20-yr old (Kroll 1980), because the peeling bark from trees after this age is required by the GCWA as nesting material (Pulich 1976).

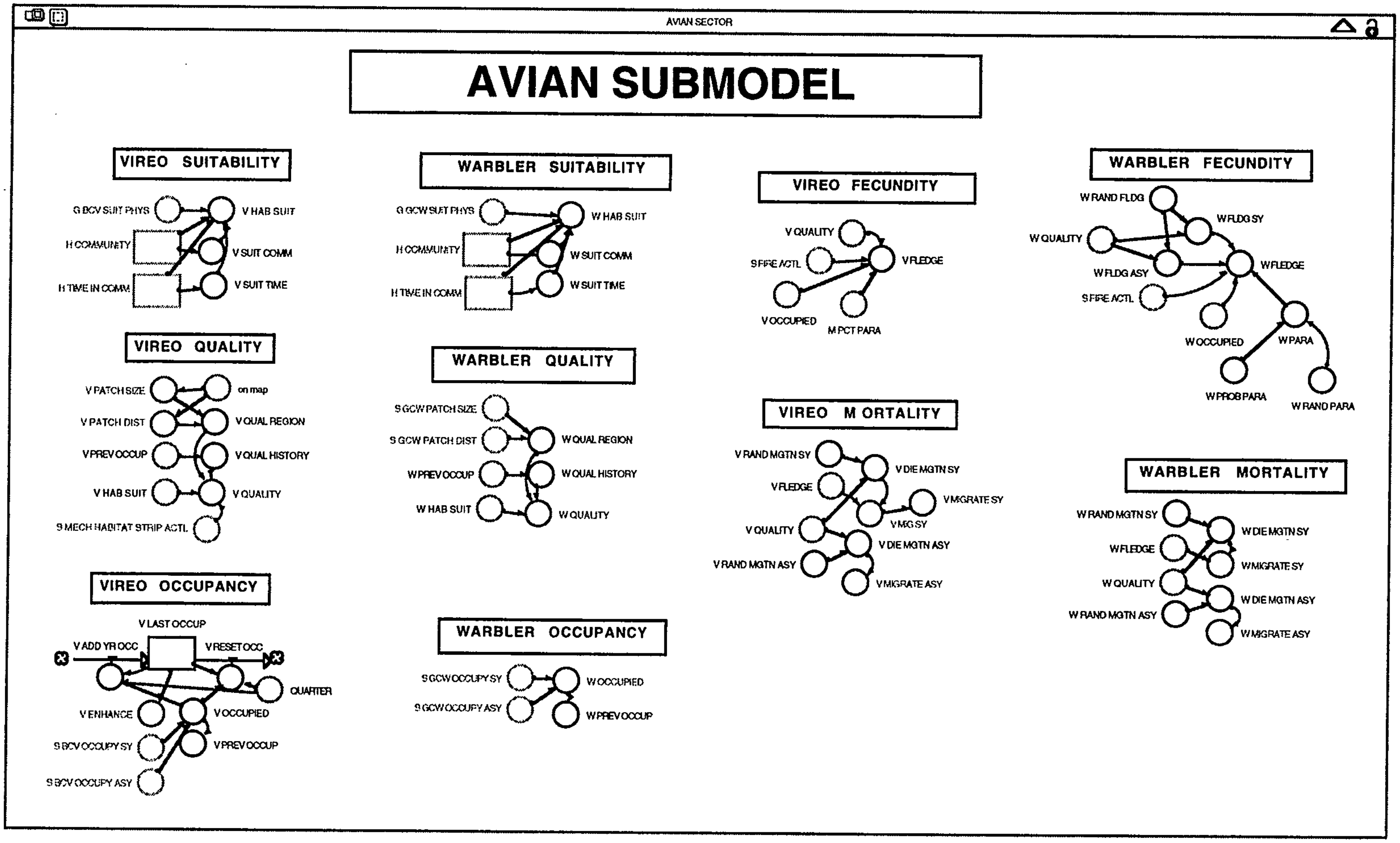
Habitat loss and fragmentation pose the most serious threat to the GCWA. Historically, juniper clearing for fenceposts and range improvement for livestock were significant impacts, but presently, urbanization and river impoundments are greater threats. Parasitism by BHCOs may decrease productivity of the CGWA, but it is not well documented.

Technical Approach: General

BCVI and GCWA populations are modeled in the Avian submodel of FHASM (Figure 4) by modeling female birds of both species. Available demographic data, such as fecundity and survival rates, are assumed to be equal between males and females (in some cases, only male-specific data are available from field studies). The fledgling sex ratio is also assumed to be 1:1. The cell size of 4 ha represents an approximation of GCWA and BCVI territory sizes, so FHASM places one breeding female of either species into appropriate habitat and calculates the number of offspring produced. It is assumed that all returning females become successfully mated if sufficient habitat is available for breeding. No adult mortality is assumed during the breeding season. In the event of a fire during the breeding season, fecundity equals zero within burned cells. At the end of the breeding season (QUARTER = 2), all adults and fledglings migrate to wintering grounds. A number of survivors return the following year at the beginning of the breeding season and occupy appropriate habitat. The prefix "V_" indicates BCVI variables; "W_" indicates GCWA variables. The suffix "SY" indicates "Second Year" birds (yearlings) while "ASY" indicates "After- Second Year", older adults.

Technical Approach: Habitat Suitability and Quality

The habitat requirements of the BCVI and the GCWA are modeled in FHASM at two levels, suitability and quality (Figure 5). The suitability value includes edaphic



Habitat suitability and quality affect the productivity of both species. Production from each year plus overwintering losses generate the number of birds returning the following spring. Variables pertaining to BCVI have a V_ prefix, while variables pertaining to GCWA have a W_ prefix.

Figure 4. Overview of the Avian submodel.

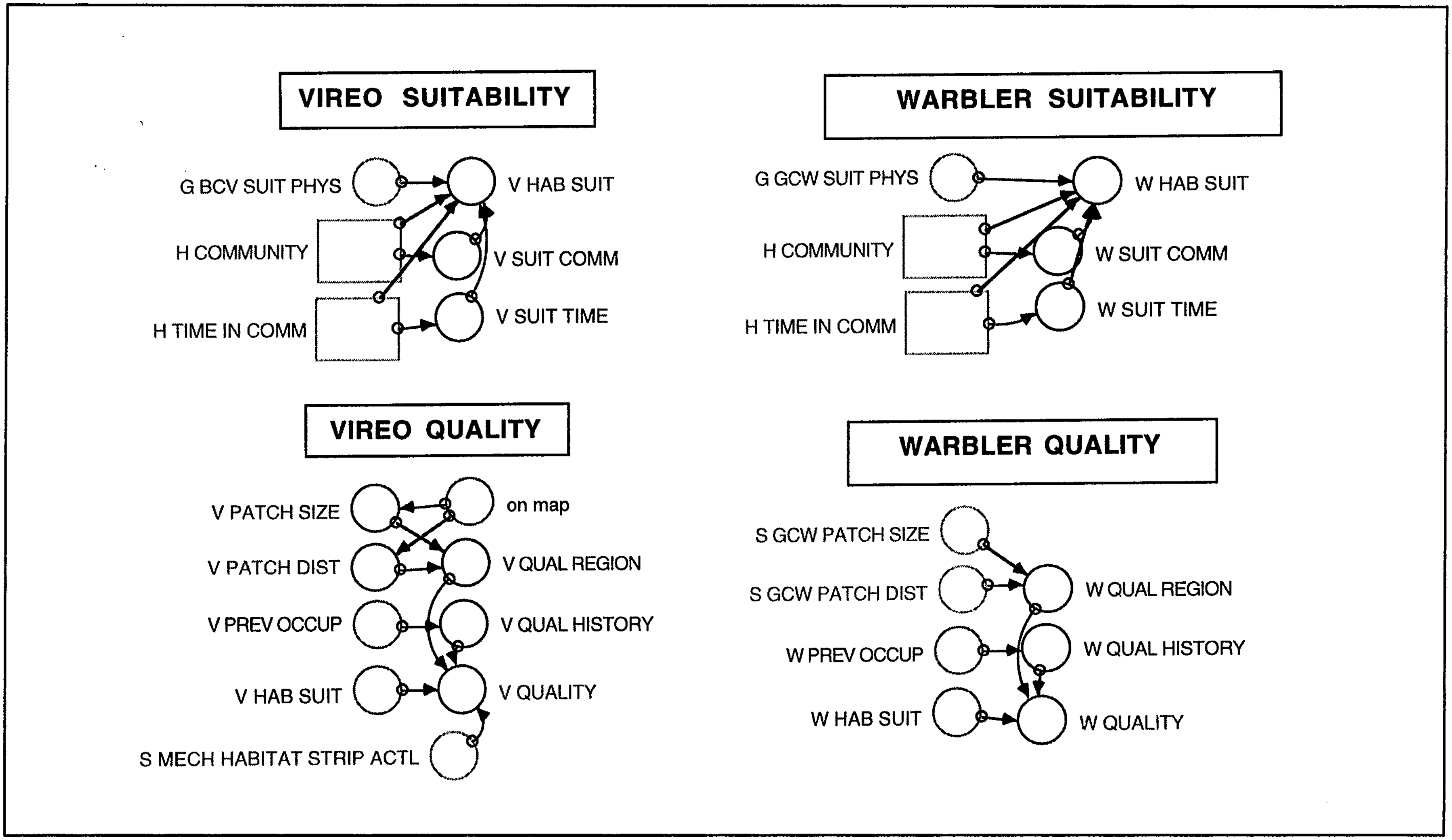


Figure 5. Habitat suitability is based on physical features, community type, and time in community, while habitat quality is based on landscape measures such as patch size, distance to habitat patches, habitat suitability, and previous occupancy of the site for breeding.

factors (e.g., slope, elevation, soil type, geology, and aspect) and plant community factors (e.g., community type and length of time in community) that are core characteristics of habitat. Overall values range from 0 = unsuitable to 3 = high suitability (Tables 1 and 2; Equations A-12 and A-15 [see Appendix A]). Habitat quality incorporates additional influences and affects distribution of the birds upon their arrival each spring (see below). For the GCWA, habitat suitability, previous occupancy of the cell, habitat patch size, and distance to other GCWA habitat patches are equal and additive effects on the quality value (Equation A-21). For the BCVI, habitat suitability, previous occupancy, and whether the habitat was created via stripcutting are equal and additive effects on the quality value (Equation A-18). It is assumed that by conducting stripcutting, managers create a special subtype of community type 6 (see *Habitat Submodel* and *Management Submodel* discussions later in this chapter), and these areas should provide higher quality habitat than other occurrences of community type 6. The Avian submodel tracks previous occupation (Figure 6) in order to evaluate the influence of site fidelity between consecutive years. A value of 1 indicates that a cell was occupied the previous breeding season, and it increases the likelihood that the cell will be occupied in the current breeding season as well. Site fidelity and repeated use of breeding grounds have been observed in both species (Jette, Hayden, and Cornelius in prep; Weinberg, Hayden, and Cornelius in prep).

Table 1. Ecological factors that determine habitat suitability rankings for BCVI and GCWA on Fort Hood.

Edaphic Factors[1]	rank	Community Type[2]	rank	Successional Age in Community	rank
VIREO					
limestone geology slope between 15-25% Eckrant-Real Rock soils western aspect elevation > 309 m	3	9,10	2	7-25 years	2
not documented	2	11,12	1	5-6, 26-30 yrs	1
not documented	1	all others	0	0-4, > 30 years	0
elevation < 271 m	0				
WARBLER					
limestone-derived soils	1	5	2	31+ years	2
all other soil types	0	4,6	1	25-30 years	1
		all others	0	<25 years	0

[1] Values for edaphic factors affecting BCVI habitat suitability were available on a 1990 GRASS map that was not well documented when it was created. Information to explain values was gleaned from the discussion within Tazik et al. 1992, but is not complete.
[2] Community types are referred to by a code number. Definitions and codes can be found in Table 4.

Table 2. Overall habitat suitability ranks for BCVI and GCWA on Fort Hood.

Edaphic Factors	Community Type	Successional Factor *	Overall Suitability Ranking
VIREO			
1	1	1	1
1	1	2	1
1	2	1	1
1	2	2	2
2	1	1	1
2	1	2	2
2	2	1	2
2	2	2	3
3	1	1	2
3	1	2	3
3	2	1	2
3	2	2	3
WARBLER			
1	only comm 6	any age	1
1	1	1 or 2	1
1	2	1	2
1	2	2	3
* Time in community.			

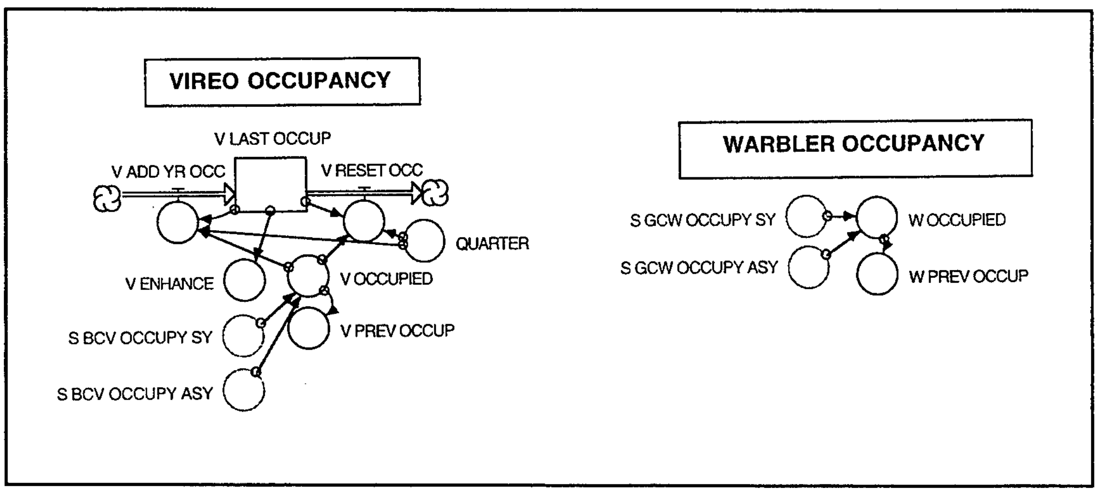


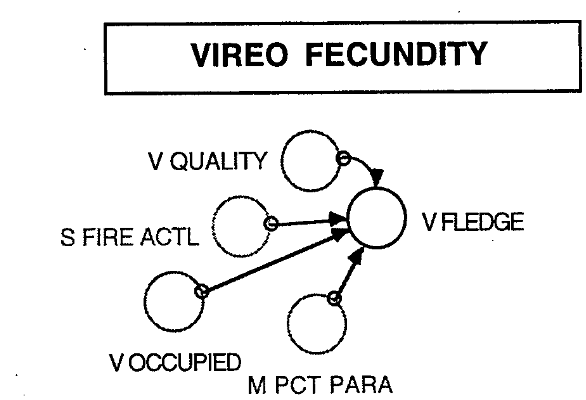
Figure 6. Because both species show evidence of site fidelity, previous occupation of a cell is monitored and is used to increase the chance that a cell will be occupied in the following year.

Technical Approach: Occupation of Habitat Upon Spring Arrival

A shell script, utilizing the GRASS program "r.birds," distributes one female bird per cell at the end of the first quarter of each simulation (see Appendix E, p 129). The number of females returning from winter ranges is found in the variables V_MIGRATE _SY, W_MIGRATE_SY, V_MIGRATE_ASY, and W_MIGRATE_ASY (Equations A-36, A-42, A-34, and A-41; see below for description of how these variables are generated). Females are distributed sequentially in the following order: ASY GCWA, SY GCWA, ASY BCVI, and SY BCVI, which matches observed patterns of arrival on Fort Hood (L. Jette, Oak Ridge Postgraduate Research Fellow, USACERL, professional discussion, December 1996). The distribution confers advantage to ASY individuals in securing the best habitat patches. The r.birds program considers current habitat quality (see previous section) and the relative importance of habitat quality levels to site selection as it places individuals on the landscape, generally allowing higher quality sites to become occupied before lower quality sites. The resulting distribution is moved into the Simulation submodel as four separate maps: S_BCV_OCCUPY_SY, S_BCV_OCCUPY_ASY, S_GCW_OCCUPY_SY, and S_GCW_OCCUPY_ASY.

Technical Approach: Determining Productivity

Productivity of BCVIs and GCWAs is modeled with different approaches in FHASM (Figures 7 and 8). The nesting ecology of BCVIs is complex. A pair may attempt more than one clutch of young, especially if losses occur due to predation, weather events, or abandonment after BHCO parasitism. The probability of successful renesting may be related to past nest fates (was it depredated? was it parasitized? was it successful?) and how late in the nesting season a new attempt begins. Most available field data are gathered and analyzed as per-nest-attempt rates (e.g., parasitism rate per nesting attempt, predation rate per nesting attempt, etc.). Calculations of seasonal fecundity (number of fledglings per breeding female per year) from such data are provided by Pease and Grzybowski



The number of female offspring produced in each cell is output (this equals zero if the cell burns).

Figure 7. BCVI productivity is based on habitat quality and parasitism rates, using data provided by a seasonal fecundity model.

(1995), using BCVI data as one example. Data from this model, provided in the 1995 BCVI Population and Habitat Viability Assessment Report (USFWS 1995), was used to relate parasitism rate and habitat quality to seasonal fecundity (Figure 7). Constant variables in the model included:

- fecundity of successful unparasitized nests = 3.1 fledglings
- fecundity of successful parasitized nests = 0.2 fledglings (due to one nest in which the BHCO eggs did not hatch and the vireos fledged)
- the first day of the nesting cycle on which a nest could be initiated = day 68.

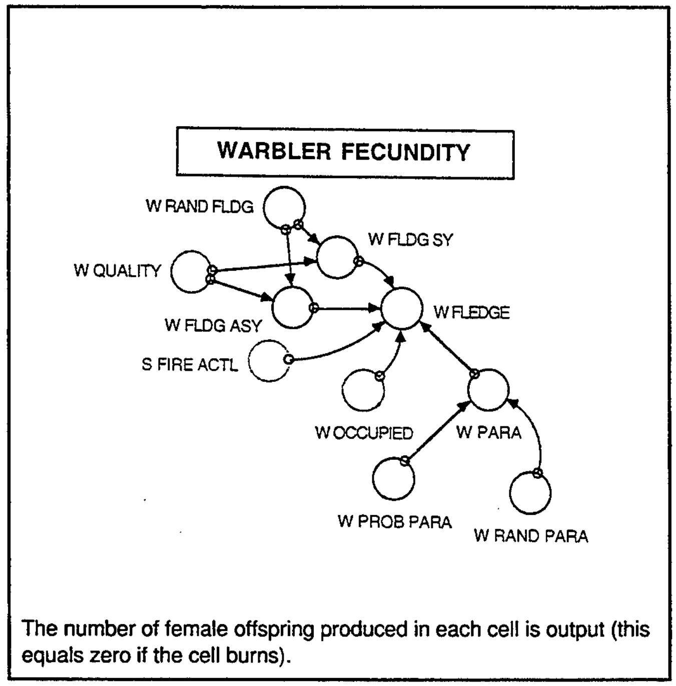
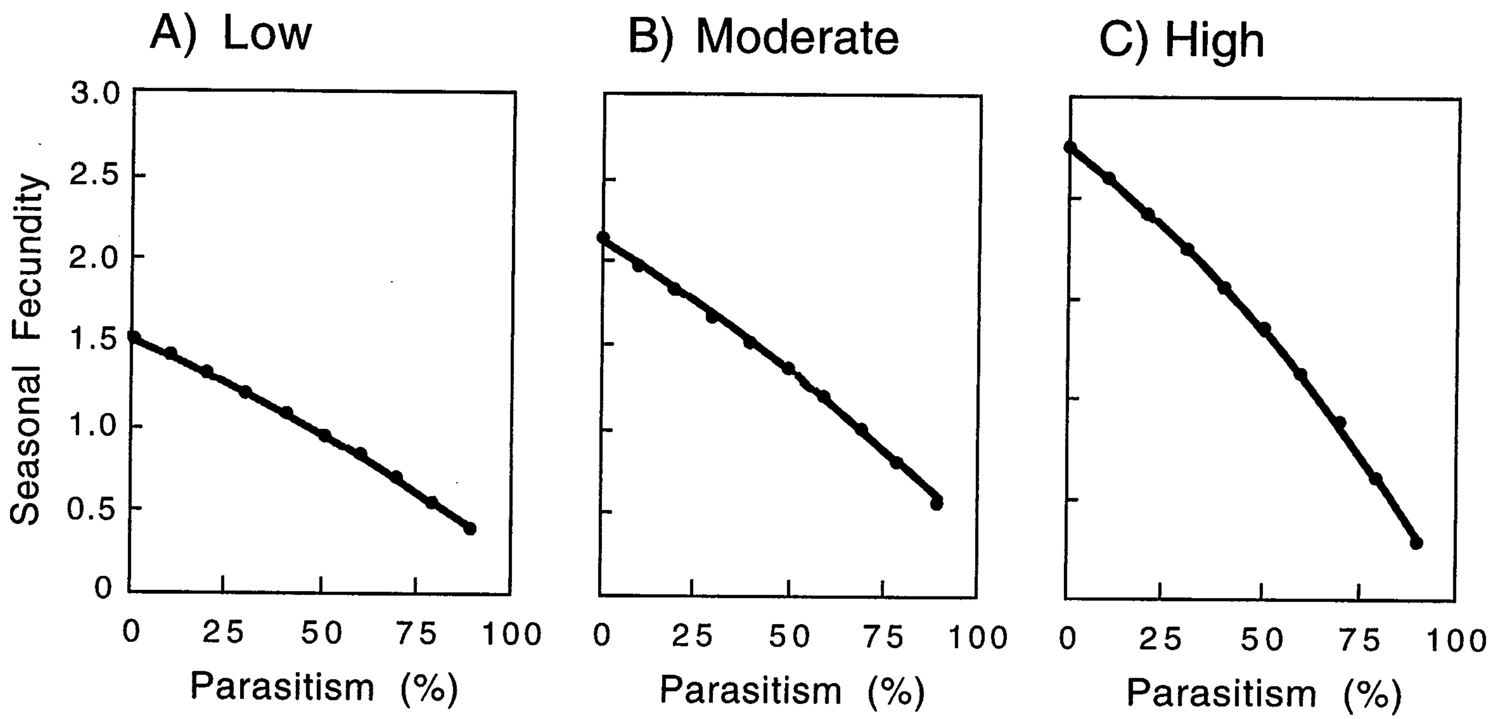


Figure 8. GCWA productivity is based on the probability of parasitism and age-specific differences in seasonal fecundity.

Nest attempt-specific parasitism and predation rates, each ranging from 0 to 90 percent, affect seasonal fecundity. Pease and Grzybowski (1995) labeled any loss of a clutch that was not due to BHCO parasitism as "depredated," even though it could have been lost as a result of abandonment, death of a parent bird, or death from disease or weather events, etc. FHASM links these depredation (or nonparasitism-related loss of offspring) rates with habitat quality levels calculated by other sections of the Avian submodel. Nest attempt-specific losses of 20 percent are modeled for high quality habitat sites, losses of 50 percent are modeled for moderate quality habitat sites, and losses of 70 percent are modeled for the lowest quality sites. Analysis in Statview produced strong relationships (R^2 values > 0.98 for all three analyses) between parasitism rates and fecundity for each level of habitat quality (Figure 9; Equation A-22). This approach allowed results of the Pease and Grzybowski model to be incorporated directly into FHASM, without incorporating the detailed equations used by the model. Thus, parasitism rates generated in the Management submodel and habitat quality levels calculated by the Avian submodel influence the fecundity value assigned to BCVI territories. The value assigned is the average number of female fledglings produced in all territories with the same habitat quality level and facing the same risk of parasitism.



A: relationship in low quality habitat, B: relationship in moderate quality habitat, C: relationship in high quality habitat. Graphs show leveraged plots, in which the distance of a point from the solid, sloped line represents the residual of the effect in the model, and the distance of a point from the dashed, horizontal line represents the residual if the effect was not included in the model. Notice that the x axes are not consistent.

Figure 9. Average number of female offspring produced per territory over the breeding season is related to parasitism rate and differs by habitat quality (which represents nonparasitism reductions in fecundity).

The nesting ecology of GCWA led to a different approach in modeling fecundity (Figure 8). BHCO parasitism is not well understood because nests are rarely located by researchers; however, one expert opinion was that a constant probability of 0.005 be used (Equation A-24) and that productivity be reduced by one GCWA offspring in the event of parasitism (L. Jette, personal communication). Available data for GCWA breeding included only three occurrences of renesting, so it was possible to directly calculate seasonal fecundity rates. These rates were divided in half to reflect the number of female fledglings produced. Age-specific differences in fecundity have been recorded and were incorporated (Equations A-27 and A-28).

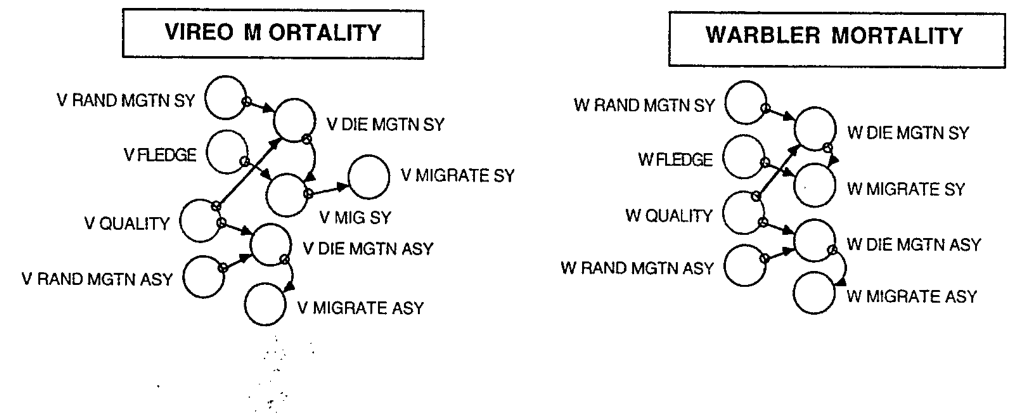
Technical Approach: Migration and Overwintering Losses From Fort Hood

The contribution of each breeding territory to the following year's population is calculated by subtracting the number of offspring and adults that die while not on Fort Hood (including migration in both directions and winter mortality) from the number of female fledglings and adults at the end of the previous breeding season (Figure 10). The probability of a single fledgling or adult returning to Fort Hood has been determined through recapture studies of both the GCWA and BCVI. It is unknown whether losses are due to mortality or permanent emigration from the installation; FHASM uses the simplifying assumption that losses represent mortality, and immigration and emigration from Fort Hood are both negligible. The probability of a single fledgling not returning to Fort Hood is multiplied by two to calculate the probabilities of an additional death per territory (Equations A-33 and A-40). The resulting number is subtracted from the number fledged and is called W_ or V_ MIGRATE_SY (Equations A-35, A-36, and A-42), since the birds will be SY birds the following year. The number of adults calculated to die (0 or 1) is subtracted from 1 (female adult) per cell and is called W_ or V_MIGRATE_ASY (Equations A-34 and A-41). These values are used by r.birds to allocate individuals on the landscape the following year (see *Occupation of Habitat Upon Spring Arrival*).

Habitat Submodel: Vegetation and Land Use Policies

Vegetation Background

The vegetation on Fort Hood is characteristic of three vegetation areas recognized by Gould (1975, cited in Tazik, Gryzbowski, and Cornelius 1993): Edward's Plateau, Blackland Prairie, and Cross-Timbers and Prairie.



FHASM calculates age-specific losses by comparing a random number to field-based probabilities that individuals do not return to Fort Hood.

Figure 10. Losses in both adults and fledglings occur during the nonbreeding season.

The Edward's Plateau is characterized by broad, fertile valleys between limestone hills. The uplands have thin soils overlying hard, unweathered limestone, which limits plant growth to a few hardy species such as shin oak (*Quercus sinuata*), scrub liveoak (*Quercus fusiformis*), and ashe juniper; warm-season grasses dominate the valleys (Tharp 1939).

The Blackland Prairie vegetation occurs on clay and silt soils containing a large amount of calcium carbonate. Areas with deep soils can support dense, scrub timber, but more often these soils are associated with tallgrass prairie dominated by Indiangrass (*Sorghstrum nutans)* and little bluestem (*Schizachyrium scoparium*; Tharp 1939).

The Cross-Timbers and Prairie native vegetation is characterized by an overstory of post oak (*Quercus stellata*) and blackjack oak (*Quercus marilandica*) that ranges from open savannah to dense stands. The understory is composed of tallgrass prairie species (Gould 1969).

The native plant communities of central Texas were structured by regular fires before European settlers and cattle ranching influenced the landscape (Bray 1904, in Rasmussen and Wright 1989; Huss 1954). Fire suppression and grazing have led to changes in the plant communities over time; today there are fewer prairies and savannahs, and more scrubby woodlands, due to increased woody encroachment (Dyksterhuis 1948, West 1988). Following a long history of grazing and mechanized military activity, grasslands on Fort Hood presently are dominated by Texas wintergrass (*Stipa leucotrichia*) and prairie dropseed (*Sporobolus asper*) instead of the original species (Tazik, Gryzbowski, and Cornelius 1993).

The vegetation of Fort Hood is a critical factor affecting the survival and reproduction of the endangered GCWA and BCVI. Thus, it is important to model the existing vegetation and changes in vegetation accurately in FHASM. Both of these efforts are hampered by lack of ecological data on abundance and distributions of individual plant species on Fort Hood, and on individual species responses to long- and short-term impacts. Therefore, vegetation dynamics in FHASM are determined on a plant community basis instead of a species-specific basis. Information about BCVI and GCWA habitat use is available at the community level, so modeling avian population parameters based on plant communities does not result in a serious deficiency.

Land Use Background: Cattle Grazing

Cattle grazing is incorporated into FHASM through its long-term effect on vegetation dynamics in the Habitat submodel. Cattle grazing leases have had a significant influence on the landscape of Fort Hood since the military took control of the land in 1942. Today, the Central Texas Cattlemen's Association holds a permit to graze 3500 animal units (AU) on the Fort Hood open range. Cattle are not evenly distributed across the landscape. They prefer to rest and feed on elevated, breezy, flat areas with trees that provide shade and a nearby water supply (G. Eckrich, Cowbird Control Technician, Fort Hood, professional discussion, 25 June 1996). Cattlemen provide supplemental hay and salt blocks in areas that historically were homesites before Federal land ownership, so cattle tend to concentrate near these sites (J. Cornelius, personal communication).

Land Use Background: Military Training

Military training is incorporated into FHASM through its influence on vegetation dynamics in the Habitat submodel. Fort Hood provides facilities and land for the III Corps, consisting of two active divisions—the 4th Infantry Division and the 1st Cavalry Division—and a logistic support unit the size of a division. The division is the Army's largest fixed organization to train and fight as a tactical team and is a self-sustaining force capable of independent operations. Fort Hood currently supports 800 tanks, 500 Bradleys, another 800 tracked vehicles, 5000 wheeled vehicles, and 300 aircraft (J. Paruzinski, Fort Hood Integrated Training Area Management [ITAM] Coordinator, Fort Hood Directorate of Plans, Training, and Mobilization [DPTM] Range Division, professional communication, 10 January 1997). Although units of all sizes train at Fort Hood, the focus is on training the battalion. To facilitate realistic, challenging experiences for troops, Fort Hood training is conducted in areas (Figure 11) used in the following ways (J. Paruzinski, Tazik et al. 1992, J. Cornelius):

East Ranges: Training Areas (TAs) 1-3 are used for a wide variety of training activities, including logistic, bivouac, maneuver, live fire, and helicopter gunnery practice. TAs 4 and 5 primarily support dismounted infantry training.

West Ranges (TAs 31-53): This area is divided into four training locations that support the majority of vehicle maneuver training: large-scale tactical exercises and emergency deployment training. The west ranges include drop

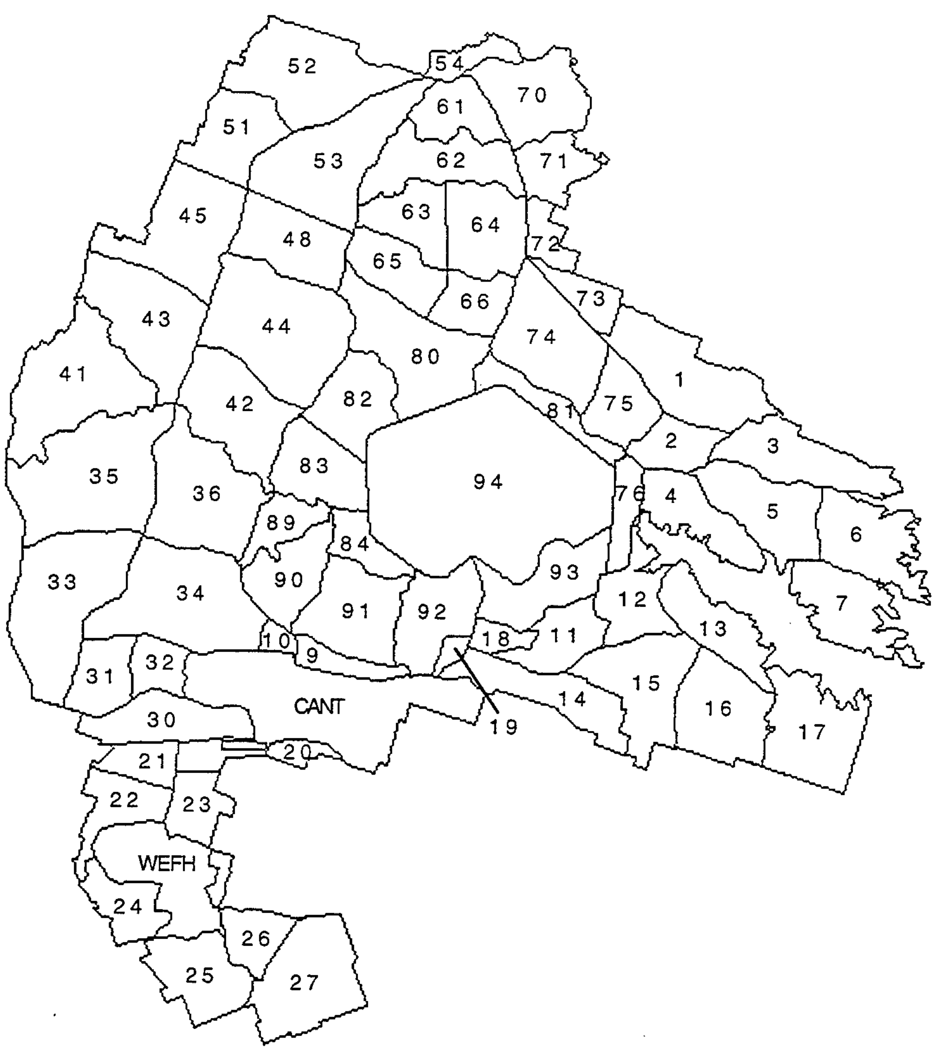


Figure 11. Fort Hood is divided into 94 training areas plus three cantonment areas.

zones and a landing strip for airborne operations. The area commonly supports cross country exercises by armored and mechanized infantry units.

West Fort Hood (TAs 21-27): Small materiel testing, Signal Corps, Medical Corps, intelligence operations, and land navigation training. This area has some use by maneuver units, and an air field is located here.

SE area (TAs 4, 11-17): Supports cross country armored and mechanized infantry units, logistic support, track gunnery range practice, and dismounted training.

TA 8: Used for engineer exercises, logistic and repelling practice, and dismounted training.

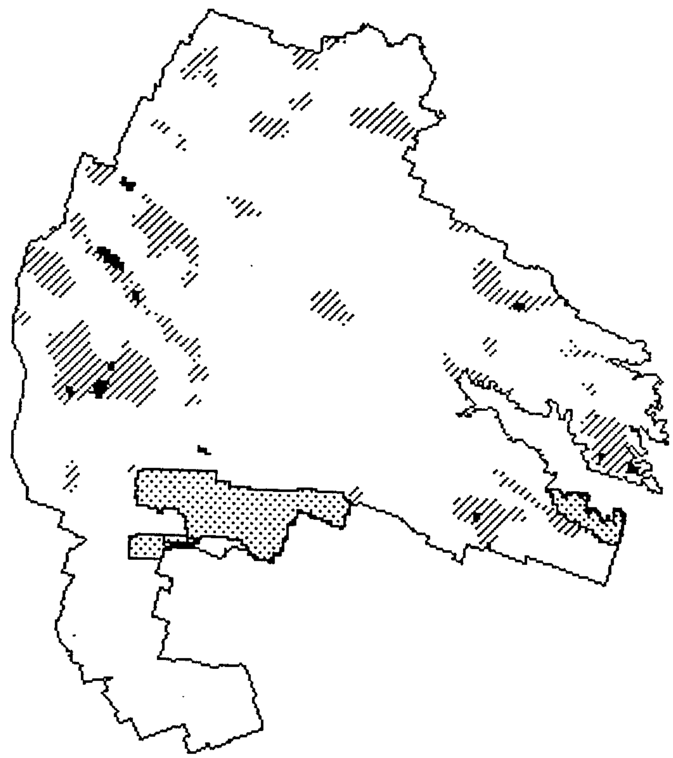
Impact Area and Live Fire Zone: The impact area is used by tanks, Bradleys, artillery, small arms, crew-served weapons, anti-aircraft, and other weapons systems stationed around the perimeter (TAs 61-66, 74-94) for firing practice. It is also used for helicopter door gunnery and high performance aircraft bombing runs with inert munitions. The live fire zone offers a protective buffer so personnel are not injured by off-target live rounds.

Technical Approach: Cattle Grazing

A digital map of concentrations of cattle was made from a hand-drawn map provided by Gil Eckrich. This map has four grazing levels: no grazing (in cantonment and recreational areas), open range, moderate concentrations of cattle, and high concentrations of cattle (G_GRAZING; Figure 12). Cells with moderate and high levels of grazing influence the vegetation dynamics in FHASM. Grazing levels are static in FHASM simulations, because spatially explicit information about cattle distributions and movement through time is not available.

Technical Approach: Military Training

Military training is modeled in two ways. A static GRASS map (G_TRAINING) is used to initialize areas affected by mechanized vehicle training. The map is used by the Long-term Land Use transition matrix (see *Technical Approach: Vegetation Dynamics*), where it influences successional patterns. Secondly, the user has the option of creating a map with the title G_INCR_TRAINING that affects short-term changes in vegetation in the Management Actions transition matrix (see *Technical Approach: Vegetation Dynamics*).



Legend: white = open range, stripe = moderate concentrations of cattle, black = high concentrations of cattle.

Figure 12. G_GRAZING depicting four levels of grazing intensity.

G_TRAINING (Figure 13) depicts disturbed areas that are presumed locations of intensive training. It is assumed that land that supports intensive training is visible on satellite imagery due to loss of vegetation and soil disruption. Areas that attract cattle may also experience vegetation losses and soil disruptions, so areas were removed that were believed to be disturbed from cattle instead of military training.

A disturbance map was created based on SPOT* imagery from 1988-1990 and thematic mapping (TM) imagery from 1991-1993. Because SPOT imagery is composed of three bands at 20-m resolution and TM imagery consists of seven bands at 30-m resolution, the 6 years of imagery were not directly comparable. GRASS programs "i.group," "i.cluster," and "i.maxlik" were used to perform a maximum likelihood, unsupervised classification that resulted in the combination of multiple bands into a single map for each year. The bands were iteratively segregated into 35 classes based on idealized intervals** (Open GRASS Foundation 1993). To identify which categories would be considered to represent disturbance, the final classes of

* SPOT = Systeme Probatoire pour l'Observation de la Terre

** i.cluster settings for all maps: cats = 35, convergence = 98, separation = 0, min_size = 17, iterations = 75, and sample intervals = 22.

Legend: white = low intensity, stripe = moderate intensity, black = high intensity.

Figure 13. G_TRAINING depicting three levels of mechanized training intensity.

each year's categorized map were plotted in a frequency histogram. The frequency distributions were visually inspected for consistent groups of categories that might represent areas of high reflectance (i.e., low vegetative cover, which is likely to be heavily disturbed). Subjective classification of disturbance was conducted by displaying groups of imagery classes (the highest reflectance bands first were displayed alone, then additional bands of the next lowest classes were sequentially added). The resulting images were compared with the image of an airstrip and the main cantonment area until the areas appeared as similar as possible (these two areas consistently have high reflectance values over time, which makes them suitable as reference sites). Using this approach, a category of either "disturbed" or "undisturbed" was assigned to each cell in every year, resulting in maps referred to as "annual disturbance maps" (Table 3).

To produce a map indicating the intensity of military training, the six annual disturbance maps with the GRASS program "r.mapcalc" were combined to make a new map with category values equivalent to the number of years cells were disturbed (range: 0-6). Those values were used to subjectively categorize the intensity of disturbance regime over the long term (0 yr = no/low disturbance regime; 1-3 yr = moderate disturbance regime; and 4-6 yr = intense disturbance regime; Figure 13).

Table 3. Development of six annual disturbance maps for FHASM.

Year	Imagery	Categories of the Original 35 Classified as "Undisturbed"	Categories of the Original 35 Classified as "Disturbed"
1988	SPOT	1-27	28-35
1989	SPOT	1-27	28-35
1990	SPOT	1-26	27-35
1991	TM	1-25	26-35
1992	TM	1-26	27-35
1993	TM	1-25	26-35

Areas with high cattle concentrations may also experience vegetation losses and soil disruptions, so these areas were excluded from G_TRAINING. Sites with low military use (Tazik et al.1992) but with moderate or high levels of cattle grazing and trampling (G. Eckrich; G_GRAZING) were assumed to be more influenced by cattle than by training. All other disturbances were presumed to be related to military training and are included in G_TRAINING (Figure 13).

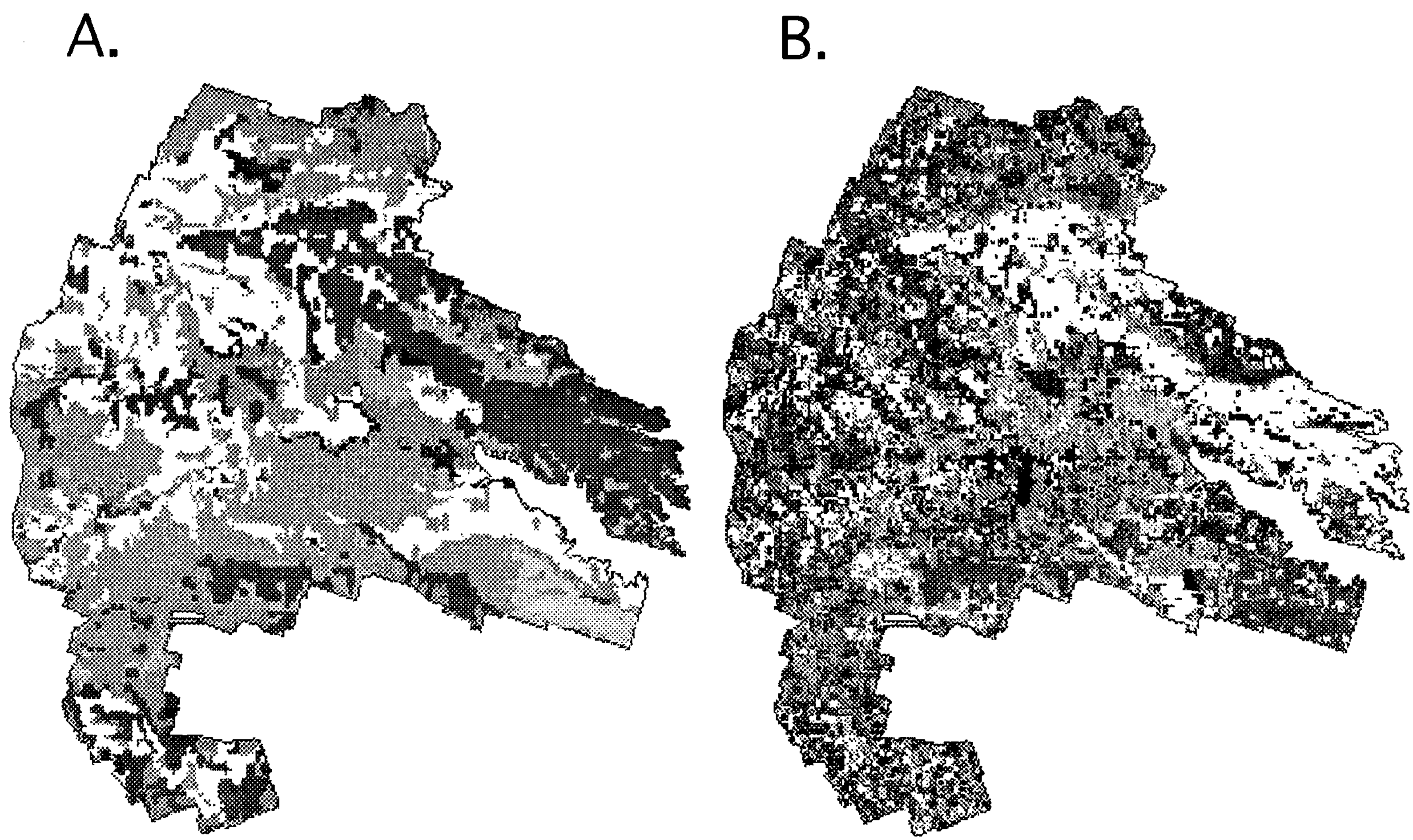
Issues: Military Training

Information needed to simulate military training activities through space and time was unavailable. The available imagery allowed quantification of patterns of disturbance in a crude manner, which was assumed to be similar to the typical pattern of training through time. As an alternative to this highly subjective method, future efforts to define disturbed areas may be quantitative (e.g., categorizing a fixed proportion of cells with the highest reflectance as disturbed). Areas of high reflectance may be unrelated to military training or cattle grazing. For example, rocky outcrops on ridge-tops could be included in these high reflectance areas.

Technical Approach: Vegetation Types

FHASM is initialized with a slightly modified, 1987 terrain analysis (vegetation) map provided as a GRASS data layer by the Fort Hood Environmental Division (G_COMMUNITY; Figure 14a). These community types have been slightly altered* for the purposes of FHASM. Each plant community type is identified by a unique number code (1-15) as shown in Table 4. Each cell also is given an initial value for length of time in community (G_TIME_IN_COMM). This initialization map was built by identifying the length of time each community persists on different soil types (in the absence of disturbance) and then randomly assigning a value within

* Original categories #13 (short grass) and #14 (tall grass) were merged for FHASM. Also created was community #15 = oak and sumac regeneration after catastrophic disturbance to mixed forests.



A new random number within realistic bounds was generated to represent the time a cell has had the initialized community type for each unique combination of community type and soil type.

Figure 14. (A) G_COMMUNITY depicting 15 plant community types used to initialize simulations, and (B) GRASS map initializing the variable H_TIME_IN_COMM.

Table 4. Names, code numbers, definitions, and conditions under which the community is not modeled, for each plant community type in FHASM.

Code Number	Community Type Name	Definition of Community Type	Conditions Under Which the Community Is Not Modeled
1	Coniferous Forest > 50% canopy	Mature, dense ashe juniper forest, found on south- and west-facing slopes of mountains, or on invaded old pastures in the absence of fire.	Moderate or high training on any soils Soil 3
2	Coniferous Forest < 50% canopy	Pastures invaded by young ashe junipers, but not yet mature.	Soil 3
3	Deciduous Forest > 50% canopy	Young or mature broad-leaf forests along rivers and washes, dominated by elm, pecan, hackberry, sugarberry.	Moderate or high training on any soils
4	Deciduous Forest < 50% canopy	Post oak or blackjack oak savannahs, young or mature.	--
5	Mixed Forest > 50% canopy	Mature juniper-oak woodlands on ridgetops and slopes of mountains.	Moderate or high training on any soils
6	Mixed Forest < 50% canopy	Young juniper-oak woodlands, or mature juniper-oak woodlands that have an open canopy due to human influences; also occur scattered on flat pasture lands.	--
7	Coniferous Scrub > 50% canopy	Young or mature juniper-dominated scrub on ridgetops or slopes with rock outcrops.	Moderate or high training on any soils Grazing on Soil 2 Soil 3
8	Coniferous Scrub < 50% canopy	Same as above but with less canopy cover, possibly due to harsher edaphic conditions or more rock outcrops.	Soil 3
9	Deciduous Scrub > 50% canopy	Mature oak-dominated scrub on ridgetops or slopes with rock outcrops.	Moderate or high training on any soils
10	Deciduous Scrub < 50% canopy	Young oak-dominated scrub on ridgetops or slopes with rock outcrops.	--
11	Mixed Scrub > 50% canopy	Mature juniper-oak scrub on ridgetops or slopes with rock outcrops, young or mature.	Moderate or high training on any soils Soil 2
12	Mixed Scrub < 50% canopy	Young juniper-oak scrub on ridgetops or slopes with rock outcrops, young or mature.	Soil 2 with grazing or successional patterns alone
13	Grasslands	Prairies, degraded and managed grasslands of any height or composition, also includes barren areas within grasslands.	--
14	Barren areas	Areas devoid of vegetation because of fire, especially relevant on south-facing slopes with crown-fires.	--
15	Oak and Sumac Regeneration	Root-sprouting oak and sumac which remain after fires in mixed forests and mixed scrubs.	--

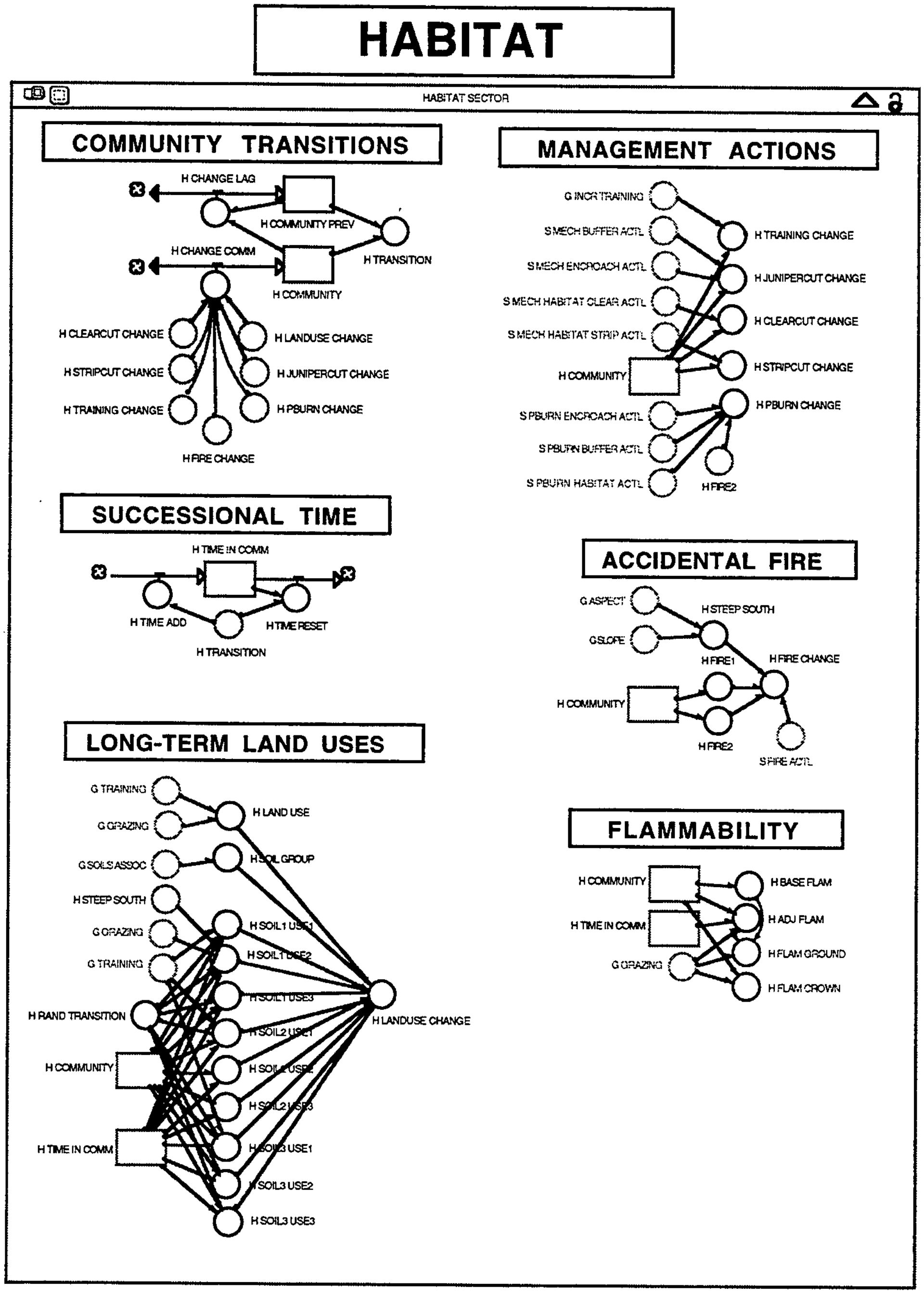
NOTE: Names and code numbers are slightly modified from 1987 GRASS map; definitions are based on professional discussions with John Cornelius, Laura Sanchez*, and Gil Eckrich, as well as A. Trame, pers. obs. 24-25 June 1996. Conditions under which a community is not modeled allow the community to persist if its presence is initialized, but FHASM will not create additional occurrences.
*Senior Field Botanist, professional discussion, 24 June 1996.

that range. To mimic a patchy mosaic of past succession, blocks of communities are broken up by calculating a new random number for each unique combination of plant community type and soil type (Figure 14b; see Appendix E, p 134 for script of program).

Technical Approach: Vegetation Dynamics

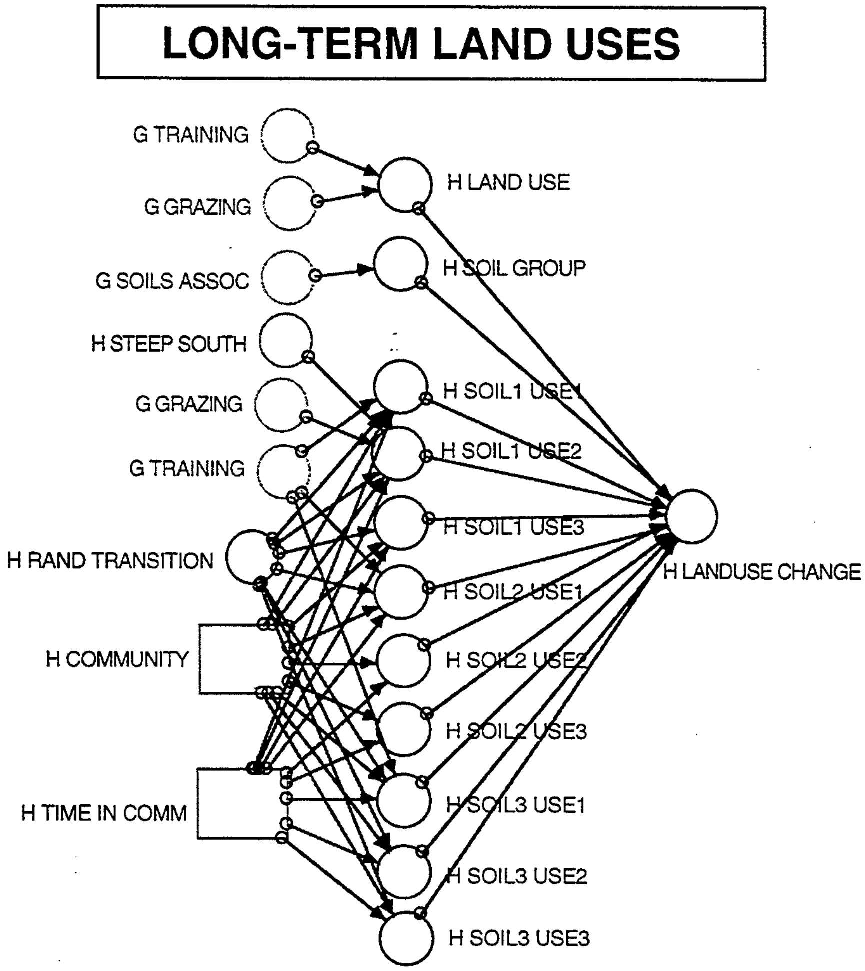
An overview of the Habitat submodel of FHASM is shown in Figure 15. The triggers for vegetation change are found in three transition matrixes: the Long-term Land Uses matrix, the Management Actions matrix, and the Accidental Fire matrix. Input variables designated as "ACTUAL," (e.g., M_PBURN_ACTUAL or F_FIRE_ACTUAL) indicate that another submodel generated the event. Additional inputs are GRASS maps (e.g., G_GRAZING and G_TRAINING). The three matrixes within the Habitat submodel then produce output that is designated as "CHANGE" (e.g., H_PBURN_CHANGE or H_FIRE_CHANGE). These parameters move into the Community Transitions section, where a new plant community category is calculated and a community transition occurs.

Community development and change were estimated based on natural succession, management activities, land use policies, and natural disturbances, primarily through a literature review and discussions with Fort Hood personnel. The Long-term Land Uses matrix (Figure 16) defines the progression of community types based on soil type, time in community type, and long-term land use regimes (grazing and military training; Table 5). The soils of Fort Hood were divided into three groups of soil associations (the following information taken from U.S. Department of Agriculture [USDA] 1985). Eckrant-Real Rock soils (Soil 1 in FHASM; see Figure 16) are most common on ridges and hillsides and are associated with limestone bedrock. These soils are often droughty and poor in nutrients, which allows invasion of and, in some cases, domination by ashe juniper. The prevalence of ashe juniper on Eckrant-Real Rock sites is reflected in FHASM through invasion by juniper into young plant communities and increased juniper canopy cover in the absence of disturbance. The second soil association (Soil 2 in FHASM) is comprised of a broad group of prairie and floodplain soils (Nuff-Cho, Bosque-Frio-Lewisville, Doss-Real-Krum, and Slidell, Topsey-Brackett). Different successional patterns were estimated for these areas, reducing the importance of juniper because it has less of a competitive advantage in more fertile soils. Bastil-Minwells soils (Soil 3 in FHASM) support post-oak savannah communities, which appear more resistant to juniper invasion and domination than other communities (G. Eckrich, A. Trame, pers. obs.). In FHASM, mature post oak savannahs that occur on Bastil-Minwells soils do not experience juniper invasion. However, other communities experience juniper invasion and develop into mixed forests. Soil type is provided by a GRASS



Long-term changes are modeled according to soil type, land use policies, and time. "ACTL" management actions or fire events are input from shell script functions that lead to "CHANGE" variables which describe resultant changes to plant communities. The variables related to the Habitat submodel are designated by the prefix "H".

Figure 15. Overview of the Habitat submodel.



Changes in plant communities related to natural succession, long-term land use policies, soil type, and topology are influenced by this section of the Habitat submodel.

Figure 16. Overview of the Long-term Land Uses section of the Habitat submodel.

map called G_SOILS_ASSOC and then categorized into the three types with the variable G_SOIL_GROUP (Equation B-13 [see Appendix B]).

Vegetation dynamics are also influenced by topology. The south-facing slopes of the escarpments have extremely dry soils that sometimes support 100 percent ashe juniper scrub or forests. Within the Long-term Land Uses matrix (Figure 16), succession of plant community 6 (mixed forest < 50 percent cover) on soil 1 with grazing will be unique on steep, south-facing slopes (Equation B-14). Under these conditions, plant community 6 will convert to plant community 2 (conifer forest > 50 percent cover) whereas, under most conditions, it will succeed to become plant community 5 (mixed forest >50 percent cover; Equations B-17, B-18, B-21, and B-24).

Table 5. Transitions in community types due to long-term successional patterns and long-term training and grazing policies.

Community Type	Land Use Conditions	Soil type*	Time (yr)	Transition Into Community Type
1 Coniferous forest > 50% cover	This community persists under all long-term conditions and soil types.			
2 Coniferous forest < 50% cover	Grazing	1,2,3	5	1
	Successional	1	30	1
	Successional	2	15	1
3 Deciduous forest > 50% canopy	This community persists under all long-term conditions and soil types.			
4 Deciduous forest < 50% canopy	Grazing	1	10	6
	Successional	3	20	3
	Most intense training level	3	50	13
5 Mixed forest > 50% canopy	This community persists under all long-term conditions and soil types.			
6 Mixed forest < 50% canopy	Most intense training level	1,2	5	13
	Most intense grazing level	1	30	2
	Grazing, Successional	1	10	5
	Successional	2,3	10	5
7 Coniferous scrub > 50% canopy	This community persists under all long-term conditions and soil types.			
8 Coniferous scrub < 50% canopy	This community persists under all long-term conditions and soil types.			
9 Deciduous scrub > 50% canopy	Grazing	1	13	5
		2,3	15	5
	Successional	1,2,3	11	5
10 Deciduous scrub < 50% canopy	Training	1,2,3	15	6
	Grazing	1,2,3	4	9
	Successional	1,2,3	2	9
11 Mixed scrub > 50% canopy	Grazing	1	13	5
		3	15	5
	Successional	1,3	11	5
12 Mixed scrub < 50% canopy	Training	1,2,3	15	6
	Grazing	1,3	4	11
	Successional	1,3	2	11
13 Grassland	Grazing	1,2,3	5	2
	Successional	1,2,3	10	6
14 Barren	Grazing Successional	1,2,3	50	2
15 Oak and sumac regeneration	Training	1	5	60%= 10 40%= 12
		2,3	10	60%= 10 40%= 12
	Grazing	2	5	10
		1,3	5	50%= 10 50%= 12
	Successional	2	3	10
		1,3	3	60%= 10 40%= 12

Note: If a land use condition or soil type is not represented for a given community, that means no transitions occur under those conditions (e.g., the community persists indefinitely).
*Soil type by association: 1 = Eckrant-Real Rock, 2 = Nuff-Cho, Bosque-Frioo-Lewisville, Doss-Real-Krum, and Slidell-Topsey-Brackett, 3 = Bastil-Minwells.

The Long-term Land Uses matrix (Figure 16) includes the influence of long-term grazing and training policies. Concentrated grazing reduces the biomass of grasses, which increases the invasion rates of woody species, especially juniper (J. Cornelius, pers. obs.). Over the long term, grazing may significantly reduce or eliminate hardwood regeneration and lead to a change in community type (Dyksterhuis 1948; West 1988). Similarly, long-term mechanized training may also reduce woody vegetation and convert woodlands into grassland (Trame 1997). The variable "Use 1" in FHASM refers to a policy of moderate or intense military training, the equivalent of categories 2 and 3 on the military disturbance map (Figure 13; Equation B-15). "Use 2" refers to a policy of moderate or intensive grazing, the equivalent of categories 3 and 4 on the grazing map (Figure 12), but with low military training activity (Equation B-15). "Use 3" refers to negligible levels of both grazing and training, the equivalent of category 1 on the training map and categories 1 and 2 on the grazing map (Equation B-15). G_TRAINING and G_GRAZING are GRASS maps that are input to the Habitat submodel at the beginning of each simulation and do not change over time within a simulation.

For each Soil (1-3) and Use (1-3) combination, a unique transition matrix defines changes in vegetation type according to the ecological information shown in Table 5 (Equations B-16 through B-24). This output is captured in the H_LANDUSE _CHANGE parameter (Equation B-12). See Appendix B for details.

The second matrix is the Management Actions matrix (Figure 17), which incorporates management activities that have immediate effects on the plant community, including juniper clearing and habitat enhancement (J. Cornelius). Increases in military training (from low intensity to moderate or high intensity) also are included in this matrix. The impact of these activities is influenced by community type but not by soil type or topology (Table 6). The occurrence of any of these activities has an immediate impact on the vegetation that temporarily overrides the long-term land use transitions discussed above. Management activities are provided by the Simulation submodel as binary (i.e., yes/no) flags (e.g., S_MECH_ ENCROACH_ACTL), which serve as inputs to the Management Actions matrix and are translated into vegetation change parameters (Equations B-29–B-33). Increases in military training intensity are controlled through the G_INCR_ TRAINING map, which triggers a flag for the H_TRAINING_CHANGE variable (Equation B-32). In the absence of field data, and according to the best judgement of the model developers, an increase in military training will reduce all canopy cover to less than 50 percent (Equation B-32). Juniper clearing converts coniferous forests into grasslands (Equation B-30). Habitat enhancement can either reduce canopy cover to less than 50 percent with stripcutting (Equation B-31) or convert mature mixed forests into early-successional shrublands dominated by root-sprouting oaks and

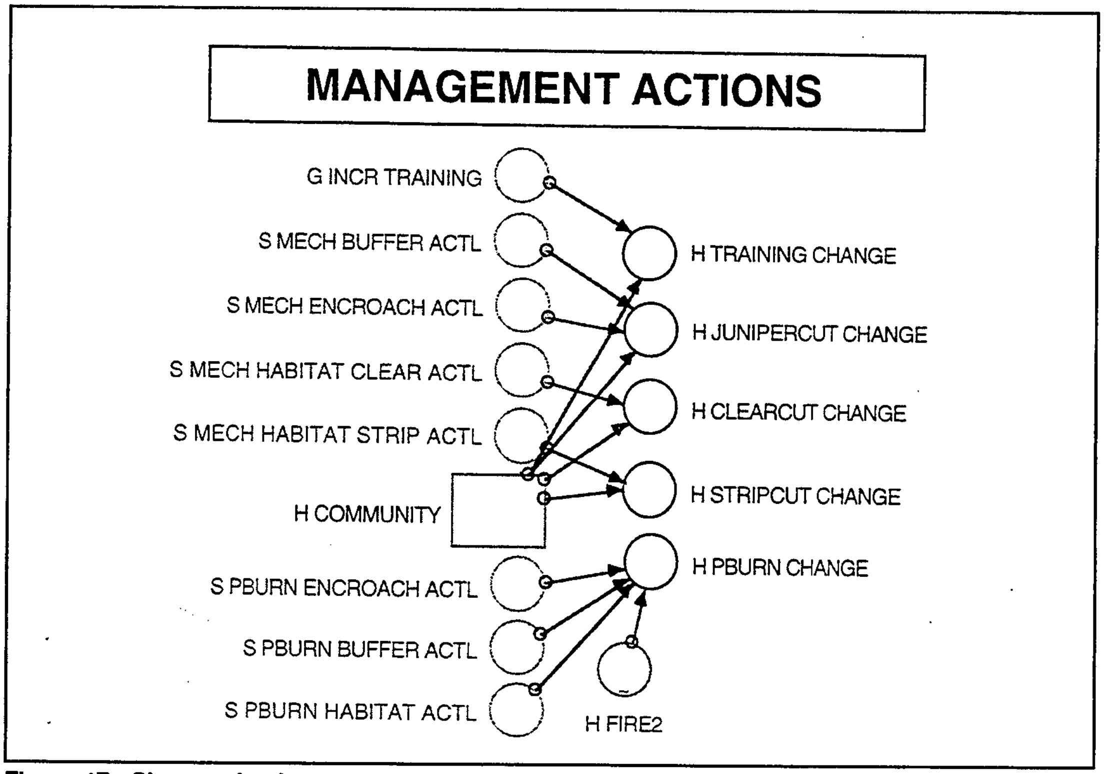


Figure 17. Changes in plant communities related to specific management actions are influenced by the Management Actions section of the Habitat submodel.

Table 6. Transitions in community types due to management practices (prescribed burns or juniper clearing), accidental fires, or an increase in military training intensity.

Initial Community Type*	Transition to Community Type
Hydroaxing: Clearcut	
5,6	15
Hydroaxing: Stripcut	
5	6
Juniper Cut	
1,2	13
Increase in Military Training	
1	2
3	4
5	6
7	8
9	10
11	12
Fire	
1,2,3,4,6	13
7,8	14
5,9,10,11,12	15

*If a community type is not included, that means the community does not receive management.

sumacs if clearcutting is conducted (Equation B-29). Prescribed fire is triggered for three different reasons (Equations C-3, C-6, and C-10), but the effect on plant communities of any prescribed burn is controlled in Equation B-33.

A third transition matrix in the Habitat submodel models the influence of accidental fire on vegetation (Figure 18). The occurrence of fire is generated in the Accidental Fire and Simulation submodels (see *Accidental Fire Submodel*), and then is provided to the Habitat submodel as a binary (i.e., yes/no) flag called S_FIRE_ACTL. When this flag is triggered, it alters community type by the transition variable H_FIRE_CHANGE in the Accidental Fire section of the Habitat submodel (Figure 18a; Equation B-34). If a cell covered with a mature, juniper-dominated community (community types 1, 5, 7, or 11) is ignited by S_FIRE_ACTL, the fire is

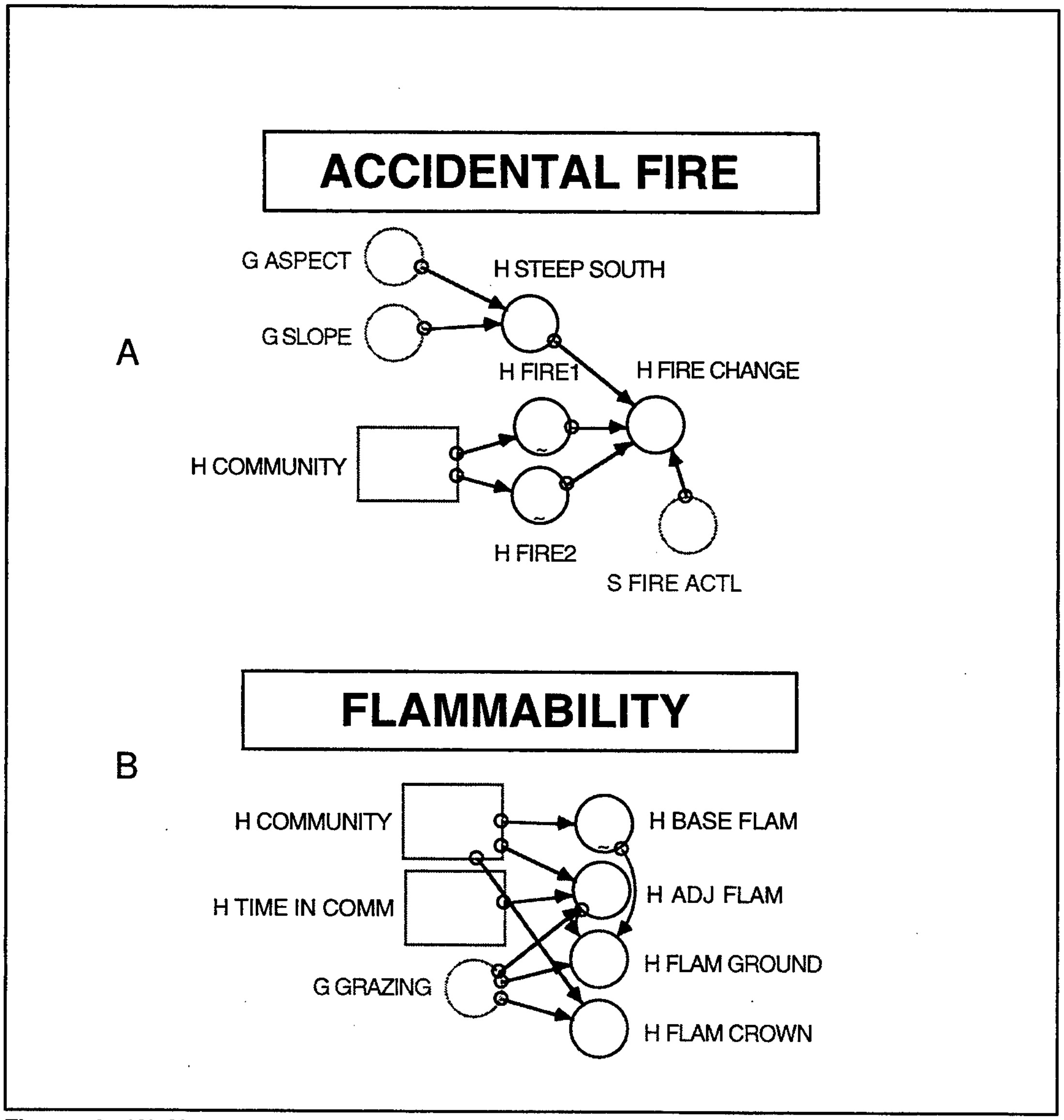


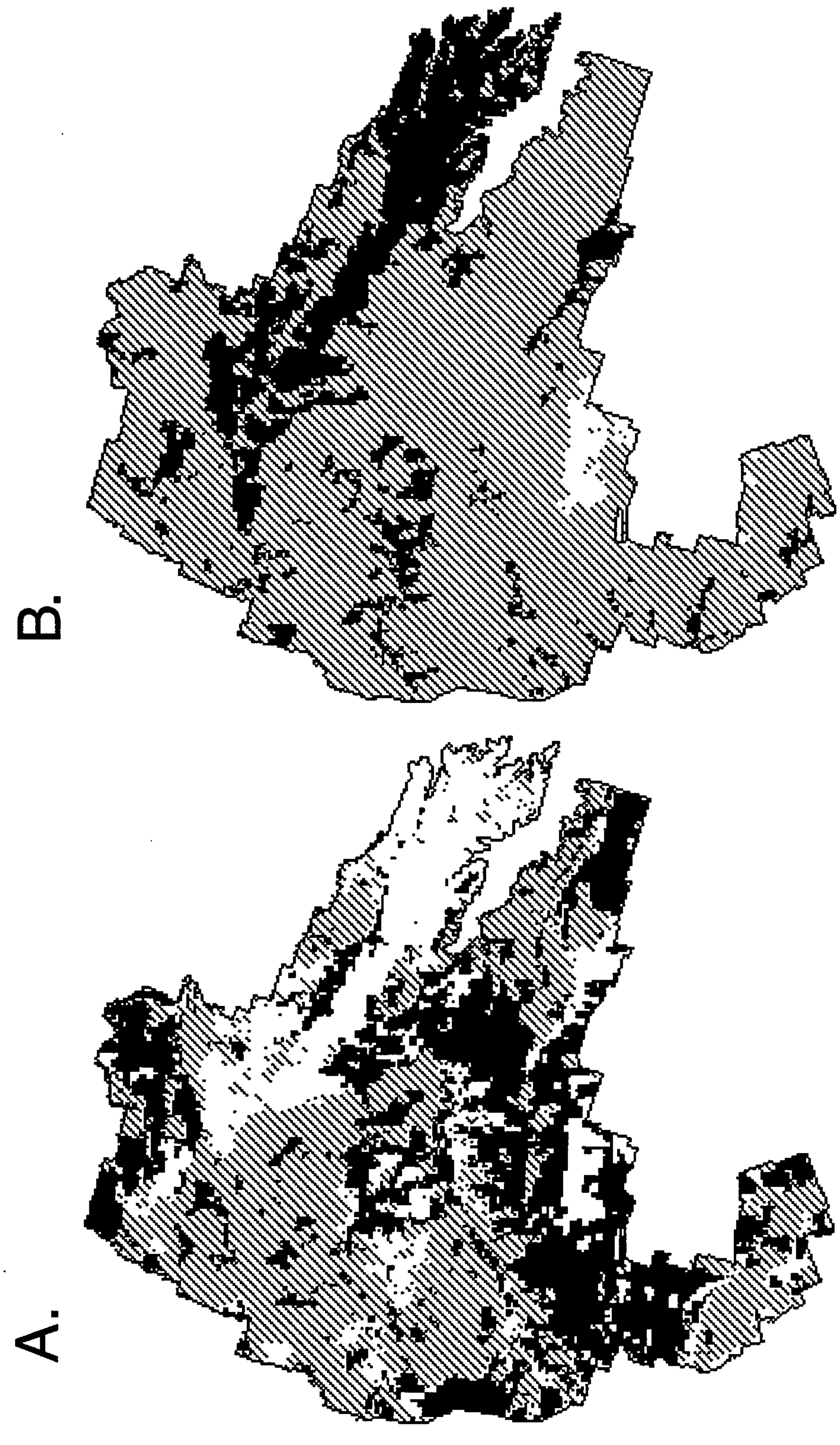
Figure 18. (A) Changes in plant communities related to accidental fire events, and (B) the flammability of each community type is determined for ground fire and crown fire conditions.

designated as a crown fire. For all other communities, the simulated fire is a ground fire. Slope and aspect influence vegetation response to fire. South-facing slopes are so droughty that they are generally covered by 100 percent ashe juniper scrub or forest. When these slopes are burned (by a crown fire), the entire community is lost, along with the organic soil layer and any seed bank, so it is considered a barren area. The recovery time for these slopes is very long, and the resultant community is uncertain (L. Sanchez). This possibility is included in a variable called FIRE1, which represents a fire on a south-facing slope and has a unique formula for vegetation dynamics (Equation B-35). All other fires are represented by equations in the variable FIRE2 (Equation B-36).

Each plant community is assigned a qualitative ranking of flammability under ground fire conditions and crown fire conditions (H_FLAM_GROUND and H_FLAM _CROWN; Figures 18b and 19; Equations B-27 and B-28). These values influence the spread of fires in the Accidental Fire submodel. These rankings, which range from 0-3, and the conditions under which they occur, are shown in Table 7.

The Successional Time section (Figure 20) records the number of time steps a cell remains in the same vegetation type (Equations B-8, B-10, and B-11). When a change in vegetation occurs, the H_TIME_IN_COMM parameter is reset to zero during that time step. Each subsequent time step in which no transition occurs incrementally increases the counter by a value of one. By monitoring the time in community type, the rate of vegetation change can be considered under different circumstances. For example, FHASM models a transition from community type 2 to type 1 after 30 yr on Soil 1, but after only 15 yr on Soil 2 (Table 5; Equations B-18 and B-21).

Although the three transition matrixes determine the direction and timing of vegetation change, the Community Transitions (Figure 21) section actually calculates the change between community types. Throughout the Habitat submodel, community types are represented as state variables, equal to the code number shown in Table 4, so transitions occur through the addition or subtraction of the value needed to change to the new community code. This occurs via the H_CHANGE_COMM flow (Equation B-3), which feeds into the H_COMMMUNITY stock (Figure 21; Equation B-1). By comparing the previous community code to the current community code, a transition is identified and used to reset the H_TIME_IN_COMM counter (Figure 20; Equations B-4, B-10 and B-11).

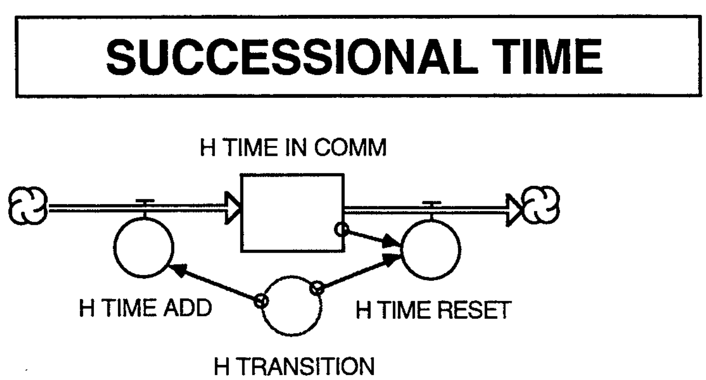


A - flammability under ground fire conditions; B - flammability under crown fire conditions. Legend: white = low flammability, striped - moderate flammability, black = high flammability.

Figure 19. GRASS maps of flammability levels of the community types on Fort Hood.

Table 7. Flammability indexes for Fort Hood vegetation types and the grazing and successional conditions under which they occur.

Community Type	Grazing Regime	Time in Community	Flammability Index
GROUND FIRE CONDITIONS			
ALL	most intense (G_GRAZING = 4)	--	0
1,5,7,11,14	ALL	--	0
2,6,8,12	moderate (G_GRAZING = 3)	> 5 years	1
2,6,8,12	low (G_GRAZING < 3)	> 10 years	1
3,9,15	ALL	--	2
4,10,13	moderate (G_GRAZING = 3)	--	2
2,6,8,12	moderate (G_GRAZING = 3)	< = 5 years	2
2,6,8,12	low (G_GRAZING < 3)	< = 10 years	2
4,10,13	low (G_GRAZING < 3)	--	3
CROWN FIRE CONDITIONS			
14	ALL	--	0
2,4,6,13	most intense (G_GRAZING = 4)	--	1
2,4,6,13	moderate and low (G_GRAZING < = 3)	--	2
3,8,9,10,12,15	ALL	--	2
1,5,7,11	ALL	--	3
Note: 3 = most flammable, 1 = least flammable.			



This section counts cumulative time that a cell has been in the same community type.

Figure 20. Successional Time section of the Habitat submodel.

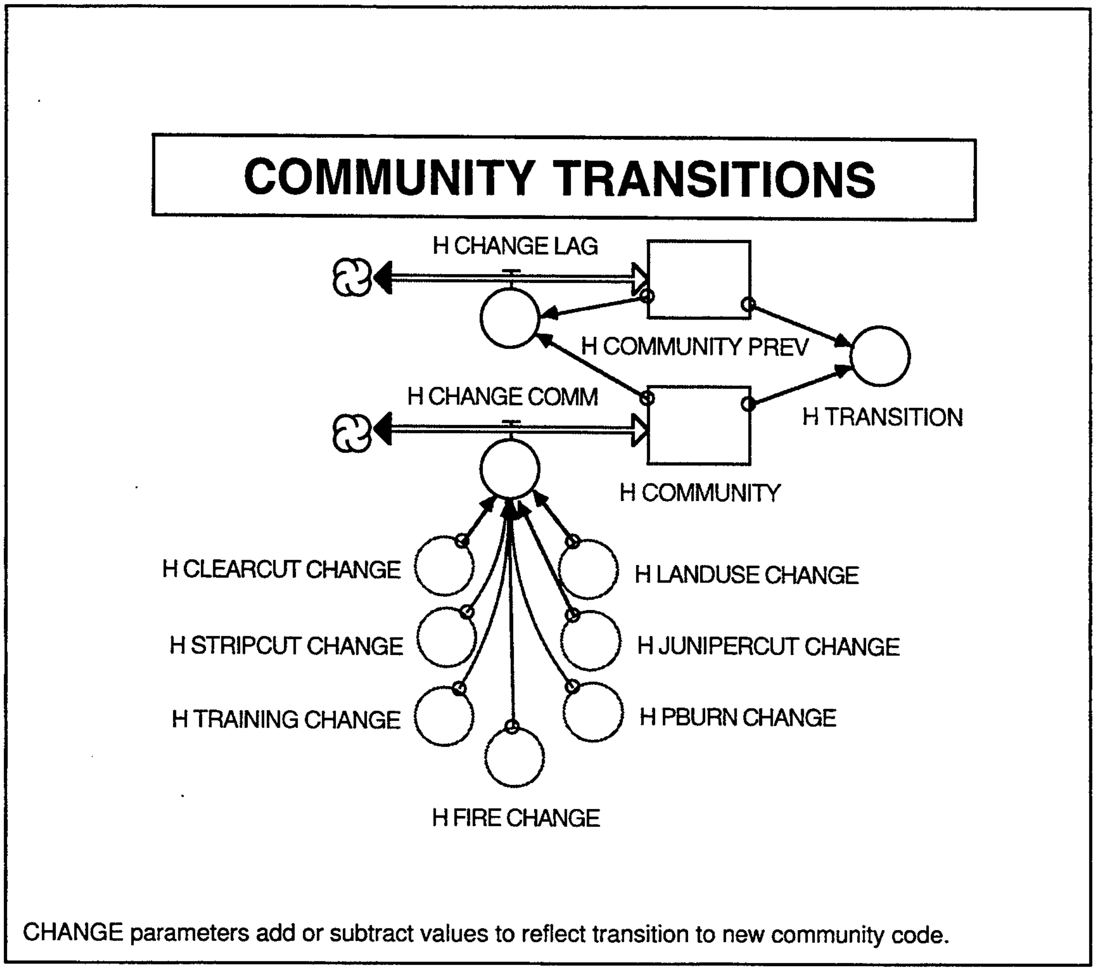


Figure 21. Changes among types of plant communities in Community Transitions section of the Habitat submodel.

Issues: Vegetation

Although general knowledge about plant community composition exists, specific relationships driven by soil types, topology, weather, land uses, and management decisions are unknown (not to mention interspecific competition, seed predation, and germination requirements). FHASM simulates changes among community types based on available (limited) knowledge. For example, the relative growth rates of oak and juniper on different soil types are unknown. Realistically, changes in soil conditions at a fine scale probably determine the relative abundance of oak and juniper within a mixed forest, therefore determining the different levels of habitat quality for the GCWA.

The lack of a field-validated vegetation map for use during the FHASM development phase and for SME initialization leads to serious shortcomings in FHASM. The existing 1987 vegetation map appears to be incorrect (e.g., communities are mapped in locations where they do not exist; J.Cornelius; Terry Cook, State Conservation Scientist, The Nature Conservancy, Fort Hood, professional discussion, 24 June 1996). At best, it predates the available data on management, fire history, and GCWA/BCVI biology. During FHASM development, attempts were often made to analyze the relationship of ecological processes to vegetation, but confidence in the results was low because of the quality of the vegetation map. For example, our background development analyses concluded that BHCO parasitism rates were unrelated to vegetation, when they most likely are related, and this may be demonstrable if accurate vegetation data were available. If a more recent vegetation map was available, it could be used to improve the equations underlying FHASM simulations.

Management Submodel: Management Actions and Cowbird Control Efforts

Management Actions Background

Land managers on Fort Hood manipulate plant communities to generate future BCVI habitat, maintain firebreaks, and create suitable environments for military training. To generate future BCVI breeding habitat, periodic disturbance, such as prescribed fires or mechanical clearing, is required on appropriate sites. These techniques are planned for sites where vireos have bred in the past, but appear to no longer use the site due to successional changes in vegetation structure (J. Cornelius). Mature mixed forests that require such disturbance are resistant to fire. Juniper sap and needles contain oils and resins that eliminate herbaceous plant growth under juniper canopies, thus eliminating fine fuels that would otherwise carry fire up to the base of the trees. In addition, junipers in closed canopy forests lose their lower branches, so there is no fuel near ground level. Under conditions that allow mature junipers to ignite, a fire tends to be a catastrophic crown fire that destroys all above-ground vegetation (only root-sprouting oaks and sumac [*Rhus* spp.] can survive; L. Sanchez; A. Trame, pers. obs.). The uncontrolled nature of such fires makes prescribed burning to create BCVI habitat difficult (J. Cornelius). When conducted, such prescribed burns are attempted during late December to early February under weather conditions that permit catastrophic fire (e.g., wind speed greater than 15 mph and relative humidity less than 20 percent; J. Cornelius).

As alternatives, bulldozing and hydroaxing may mimic the effects of fire and create future BCVI habitat. Hydroaxing is a new, experimental approach that has an unknown effectiveness. Two methods of hydroaxing have been attempted: (1) clear-cuts of areas to reduce vegetation to short stubble across the entire site or (2) strip-cuts of areas to remove vegetation in a cross-hatch pattern of 40-ft wide north-south strips and 20-ft wide east-west strips (J. Cornelius). The latter approach may increase plant recruitment rates in the regenerating strips, thus reducing the time needed to create BCVI breeding habitat. In addition, stripcutting could immediately create suitable BCVI habitat by creating a patchy pattern of vegetation. It is not known how the vegetation will respond through time to these management actions, nor whether the BCVI will nest in these sites (J. Cornelius). In FHASM, mechanical clearing through hydroaxing or bulldozing will have similar effects and will mimic the effect of fire. Stripcutting converts the vegetation to the mixed forest <50 percent cover plant community.

A second land management objective is to remove encroaching juniper from grasslands valued for military training. Ashe juniper is an aggressive invader of most sites on Fort Hood, particularly in areas where intensive cattle grazing has reduced grass biomass. These sites must be cleared of juniper on a regular basis through prescribed burning or mechanical cutting (J. Cornelius). Prescribed burning every 3 to 5 yr is the preferred (less expensive) technique. Burns are typically conducted with light winds (<10 mph) and relative humidity of 25 to 35 percent. Under these conditions, grasslands and young juniper will burn easily, but mature woodlands will not. However, if grazing significantly reduces grass biomass, or if burns are not conducted within 10 yr, the vegetation will no longer carry fire, and mechanical cutting is necessary. Neither method of clearing is allowed on sloped land nor within 100 m of potential GCWA habitat (J. Cornelius).

A third management objective is to reduce fuel loads adjacent to GCWA habitat because it can be destroyed by crown fire and is potentially at risk from ignitions caused by military training. Fort Hood personnel use prescribed burns to reduce fuel loads and eliminate encroaching juniper on areas adjacent to (and especially along the southern edge of) potential GCWA habitat (J. Cornelius). The prescribed burning protocol is similar to that used when clearing juniper from other grasslands. If a rotation of less than 10 yr is maintained, these areas can be successfully burned. If grass biomass is very low or the encroaching juniper begins to eliminate all herbaceous growth under its canopy, then mechanical clearing is necessary.

Cowbird Control Background

The BHCO is an obligate brood parasite, meaning that females lay their eggs in the nests of other species. Over 200 species of birds are known to be parasitized by cowbirds (Friedmann and Kiff 1985), including the BCVI and the GCWA. A parasitic strategy allows the cowbird to utilize breeding sites that are not closely coupled with their foraging requirements. They do not have a nest or offspring to protect, so their daily movements can be extensive (up to 7 km/day; Rothstein, Verner, and Stevens 1984). Agricultural land uses, especially feedlots and overgrazed grasslands, provide ideal foraging habitats for BHCOs. Research has found higher parasitism rates in landscapes with forest openings, clearcuts, small tracts of forests, and edges, compared to landscapes of large, continuous forest tracts, especially if foraging habitat is abundant (Robinson et al. 1995). The landscape of Fort Hood supports large numbers of cowbirds, although the population has not been quantified.

In many cases, host adults raise the BHCO young instead of their own, so brood parasitism can have substantial impact on host populations (Robinson et al. 1995). The BHCO parasitizes both the BCVI and GCWA, but the BCVI seems particularly vulnerable. The incubation period for BCVI is 14 to 17 days (Graber 1961) compared to 11 days for the BHCO (Friedmann 1963). This difference gives the BHCO a developmental advantage over the smaller BCVI young, so BCVI rarely fledge from nests that also contain BHCOs. The only defense demonstrated by BCVIs is nest desertion, which is much more common in parasitized nests compared to unparasitized nests. This strategy leads to lower nest success in parasitized nests (Hayden et al. in press). After nest desertion, BCVIs often renest, but the overall low productivity due to BHCO parasitism is listed by the FWS as a major reason for the endangered status of the species (Hayden et al. in press).

The probability for BHCO parasitism is modeled in the Management submodel through mathematical relationships between control efforts and measured parasitism rates on Fort Hood. Starting in 1988, the population of cowbirds on Fort Hood has been artificially reduced through the use of large live traps. Traps were constructed of lumber and poultry mesh (Hayden et al. in press). Each trap was populated with a dozen or more individuals to help attract additional birds; food and water were available inside. In 1988 and 1989, only a few (3 and 7, respectively) traps were installed within occupied BCVI breeding habitat. From 1991-1994, traps were located in BHCO foraging areas, in an attempt to capture more birds. Captured females were killed in all years.

In 1989, and from 1991-1996, female cowbirds also have been killed by attracting them with a taped playback of female chatter calls and then shooting them. In the earlier years, shooting efforts were conducted on an *ad hoc* basis and were not recorded. Since 1993, locations of cowbirds have been recorded (Hayden et al., in press). Shooting is now focused within occupied vireo habitat, in order to remove females that have a very high probability of parasitizing the nests of endangered species (G. Eckrich).

BHCO parasitism also is reduced by BCVI research technicians, who addle, remove, or kill BHCO eggs and nestlings found in parasitized nests monitored for research purposes. FHASM incorporates this management activity by reducing the parasitism rate in consistently studied locations (G_STUDY_AREAS) by the proportion of all nesting attempts in which nests are located. This reduction is assumed to reflect the proportion of all nests that are manipulated to remove BHCOs.

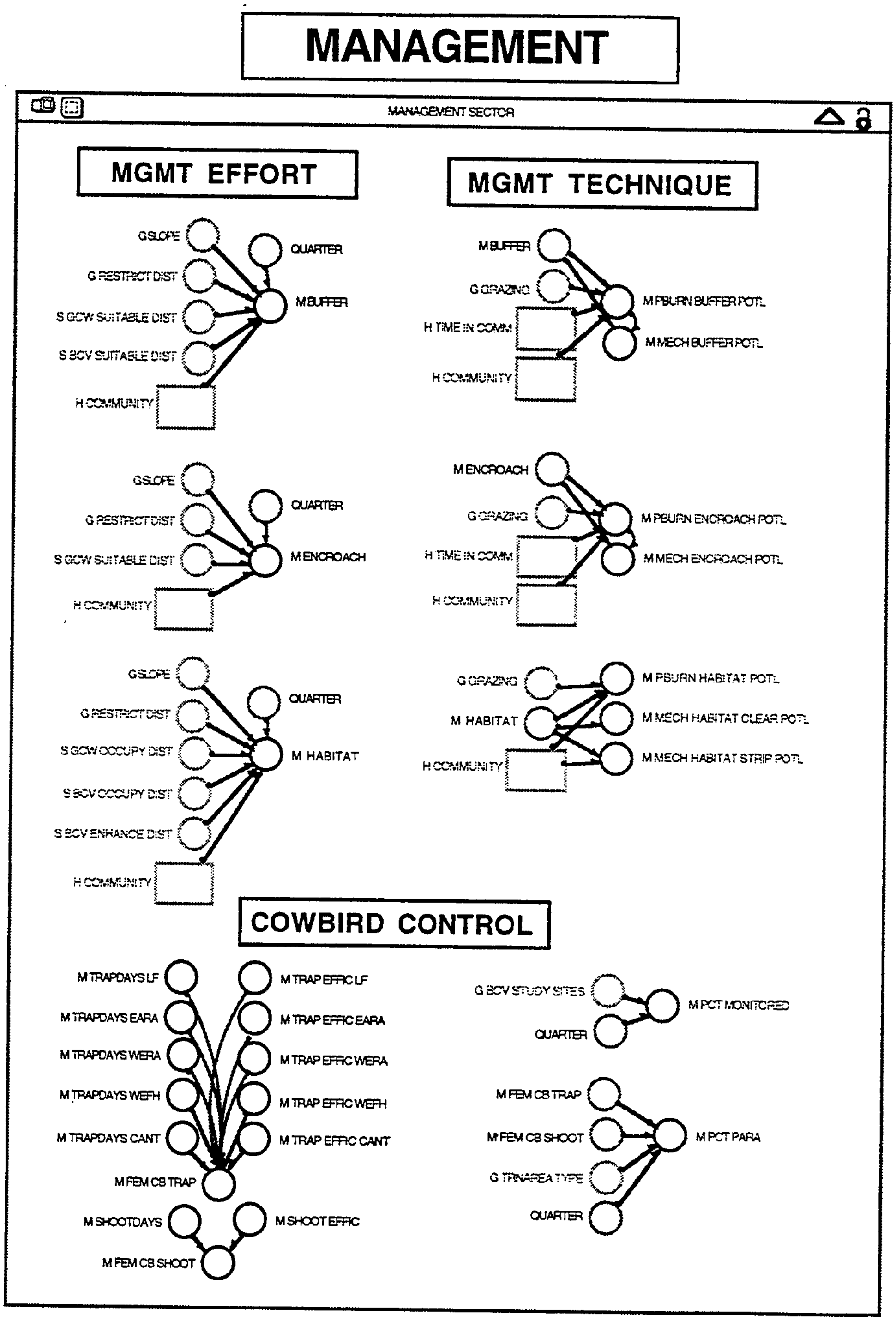
Technical Approach: Management Action Flags

An overview of the Management submodel is shown in Figure 22. Once criteria for each management purpose are met, the technique (e.g., mechanical clearing or prescribed burning) for management is determined. STELLA equations determine whether or not individual cells meet the criteria for management actions and, if so, trigger a binary switch that functions as a flag (Equations C-2, C-3, C-5, C-6, C-8, C-9, and C-10 [see Appendix C]). All of these binary variables can be recognized by the term "POTL" ("potential"; e.g., M_MECH BUFFER_POTL and M_PBURN_HABITAT_POTL).

A cell is flagged as having potential to be managed for juniper encroachment (M_ENCROACH) if: (1) slope is less than or equal to 4 percent, (2) it is the first or fourth quarter of the year (October through March), (3) it is more than 200 m from potential GCWA habitat, (4) it is not within protected endangered species (GCWA or BCVI) habitat, and (5) the cell has plant community type 1 or 2 (grasslands being encroached by 100 percent juniper; Figure 23; Equation C-1).

A cell is flagged as having the potential for buffer zone clearing (M_BUFFER) if: (1) slope is less than or equal to 4 percent, (2) cell is not in protected endangered species habitat, (3) it is not the second quarter of the year (April through June, breeding season), (4) the cell has plant community type 1 or 2 (grasslands being encroached by 100 percent juniper), and (5) the cell is 200 m from potential endangered species habitat (Figure 23; Equation C-4).

A cell can be cleared of juniper through prescribed burn or mechanical means, depending on the successional stage of the vegetation and the grazing regime. Prescribed burns do not occur in >50 percent juniper forests or in areas of intensive grazing, but young juniper forests of <50 percent canopy cover can be considered according to their age and grazing intensity (see Equation C-3 for details). Mechanical clearing is flagged if the cell is flagged by M_ENCROACH or M_BUFFER but not flagged for prescribed burning (Figure 24; Equations C-2 and C-5).



First the need for management efforts is evaluated (M_BUFFER, M_ENCROACH and M_HABITAT) and then the management techniques are evaluated ("POTL"). A subset of these cells ("ACTL") is managed according to shell script programs. The cowbird control section calculates a probability of parasitism for each cell based on user-defined level of control efforts and geographic area. All variables related to the Management submodel are designated by the prefix "M".

Figure 22. Overview of the Management submodel.

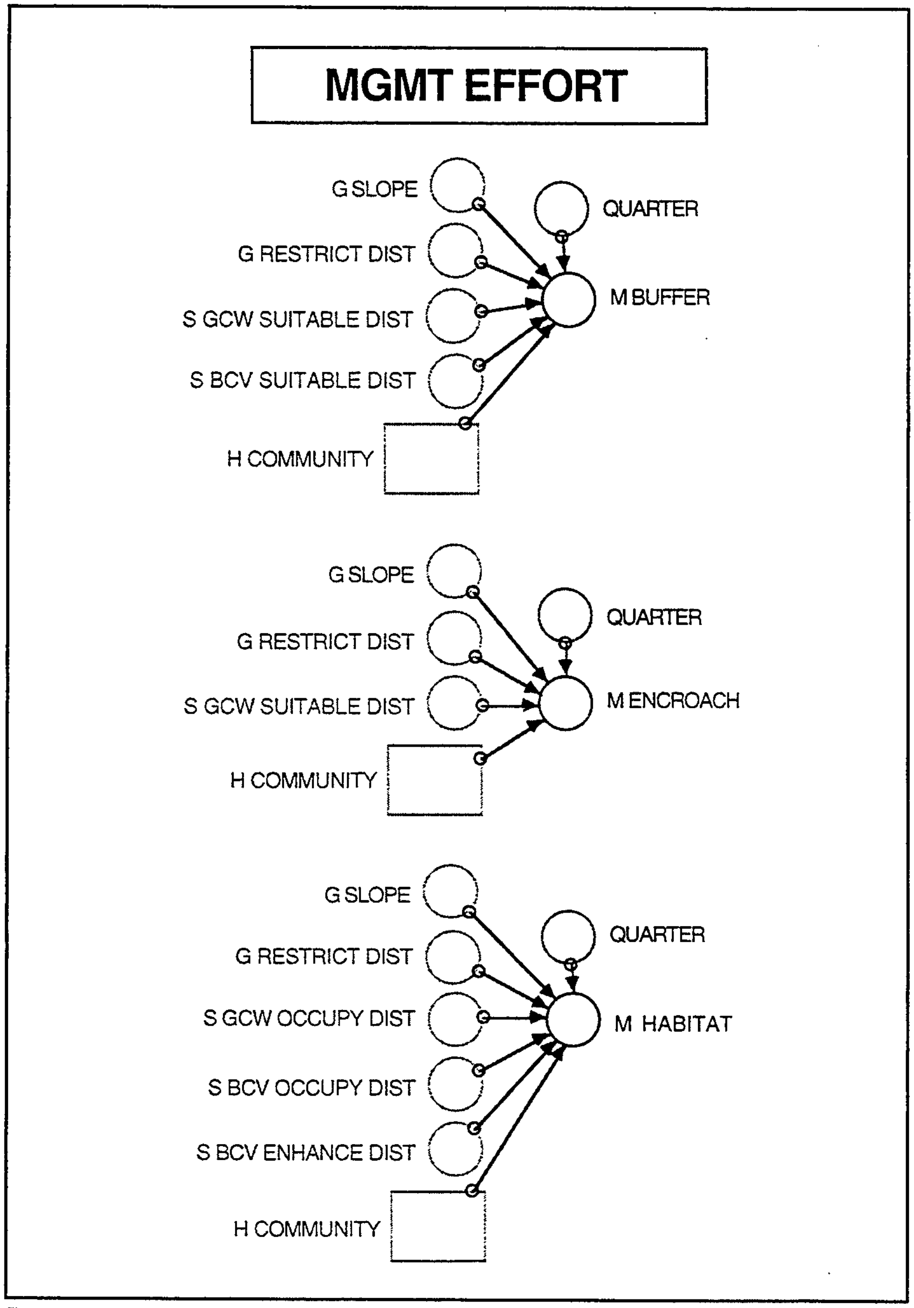


Figure 23. The suitability of a site for management activity is determined by slope, the potential for disrupting endangered species, and community type.

A cell is flagged for the potential for BCVI habitat enhancement (M_HABITAT) if the following criteria are met: (1) slope is less than or equal to 4 percent, (2) it is the first or fourth quarter of the year (October through March), (3) BCVIs bred in the cell in the past, but it has not supported breeding BCVIs for at least 5 yr, (4) the cell is within recognized endangered species habitat, (5) GCWAs did not inhabit the cell in the preceding breeding season, and (6) the cell has plant community type 5 or 6 (mixed oak-juniper forest; Figure 23; Equation C-7). All cells that are flagged for M_HABITAT are also flagged as M_PBURN_HABITAT_POTL (eligible for prescribed burns) and M_MECH_HABITAT_CLEAR_POTL (eligible for clear-cutting). Those cells that are flagged as M_HABITAT and are also community type 5 (>50 percent canopy mixed forest) are flagged as M_MECH_STRIP_POTL (eligible for stripcutting; Figure 24; Equations C-8 through C-10). Although M_HABITAT cells will be flagged for more than one technique, the user will designate how many management events per year will be executed with each technique (see next section).

Technical Approach: Spatial Context of Management Actions

A map of cells flagged for management potential is output to GRASS (Figure 25a). GRASS identifies clumps that are larger than a user-specified critical size (which may be equal to or larger than final management units) and then randomly selects

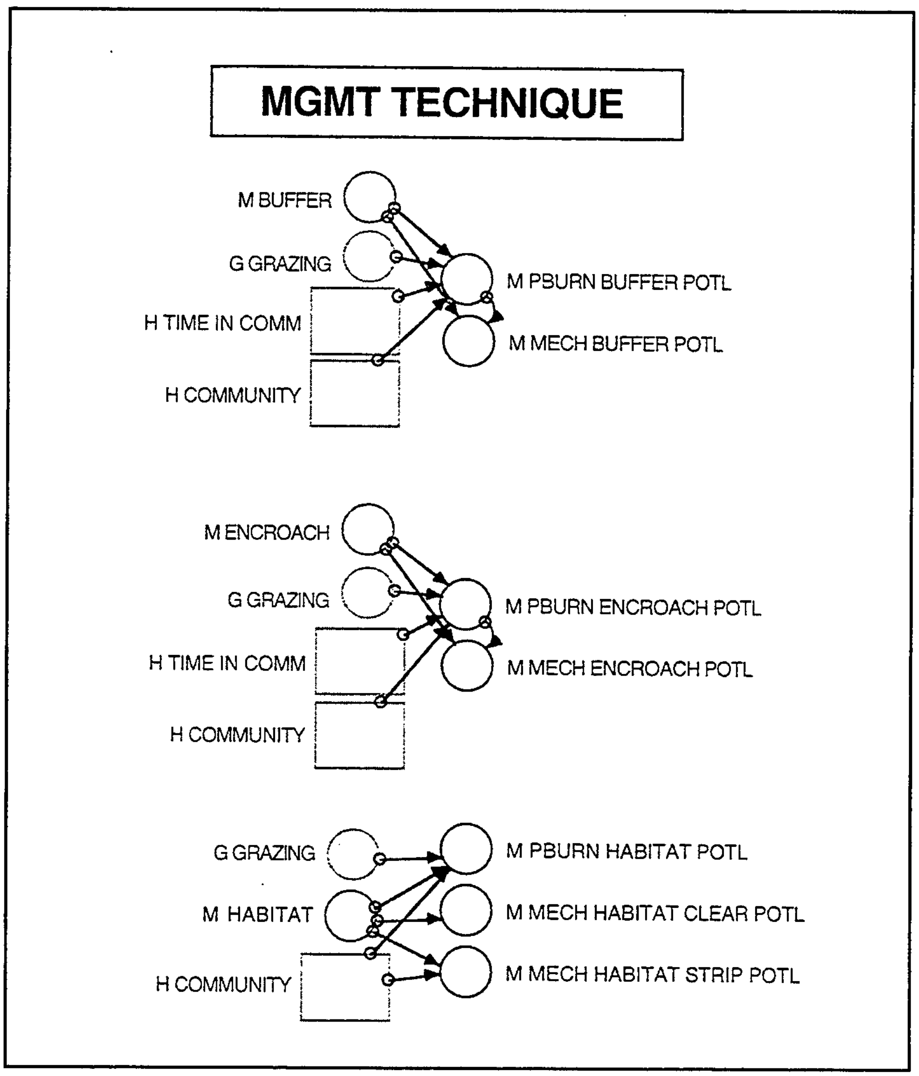
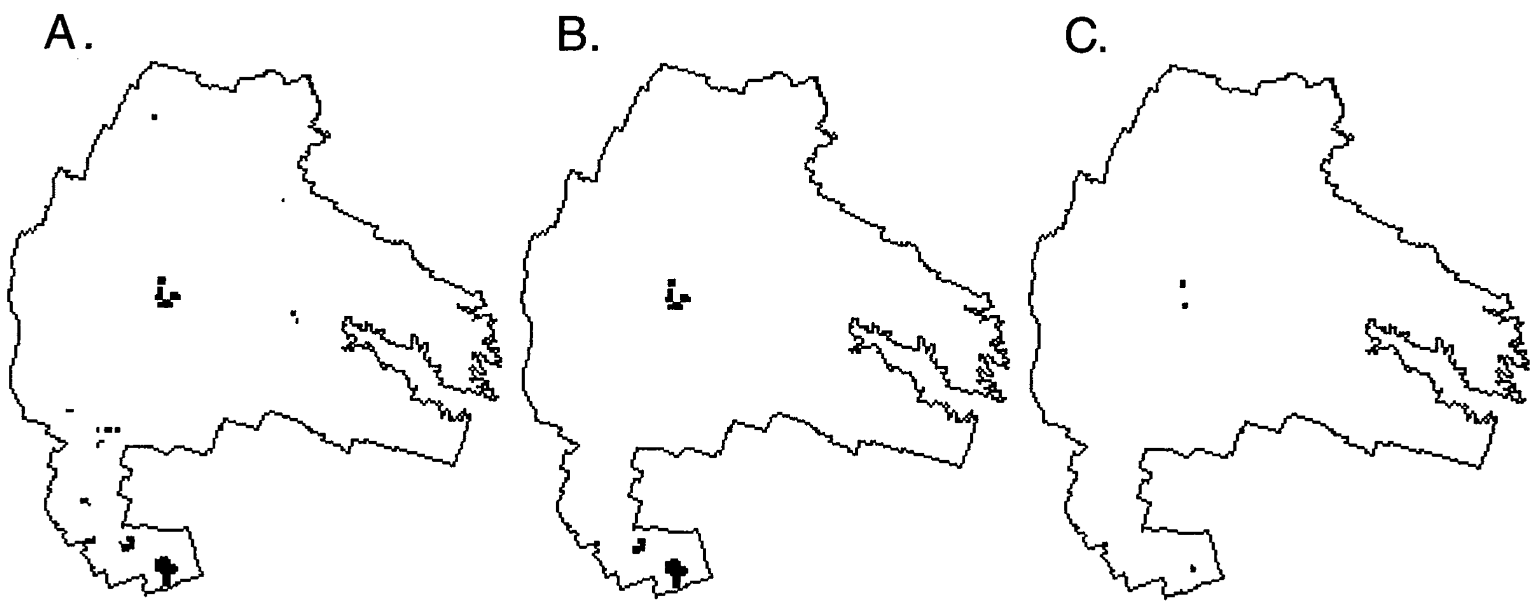


Figure 24. The decision to use prescribed burning vs. mechanical techniques for management is based on the flammability of the vegetation (which is related to community type, time in community, and the intensity of grazing).



A: Cells with potential for juniper cutting identified by the Management submodel. B: Clumps of potential cells of a minimum size are identified. C: To reflect financial and manpower constraints experienced by land managers, a random subset of clusters (in this case three), are actually cleared.

Figure 25. Regional analysis is used to identify which cells with potential for management are actually managed, as illustrated here for juniper clearing.

a subset of those clumps to be managed (see Appendix E, p 137, for the script of this program). Management actions are triggered at the appropriate scale in FHASM: habitat enhancement occurs in 15-cell clusters (simulating a total area of 60 ha), while juniper clearing occurs in 9-cell clusters (total area of 36 ha; Figure 25b). The total number of management events in any given year is also limited to match real-life constraints (e.g., money, time, personnel) of land management decisionmaking on Fort Hood. Typically, 3 to 5 juniper clearing events are conducted per year, while only 1 to 2 habitat enhancement events occur per year. The user designates which technique (prescribed burn, clearcutting, or stripcutting) is used to conduct the two habitat enhancement events, so although cells may be flagged with the potential for two or three techniques (see previous section), FHASM output will reflect user-designated techniques (see program script in Appendix E). Figure 25c shows the final cell clusters that actually are managed by juniper cuts in the simulated time step. These cells are flagged with a value of 1 on maps that are stored in the Simulation submodel. These variables can be identified by the prefix "S" and the name "ACTL" (e.g., S_MECH_ENCROACH_ACTL). These variables are sent to the Habitat submodel where they influence vegetation dynamics (in Equations B-29 through B-33). Once cells have been flagged as "ACTUAL," they become ineligible for further management by other techniques or for other purposes. M_BUFFER_POTL cells are processed into ACTUALs before M_ENCROACH_POTL cells, and M_MECH_HABITAT_POTL cells are processed into ACTUALs before M_PBURN_HABITAT_POTL cells, conferring priority on the earlier management option.

FHASM allows manipulation of certain management criteria to simulate the effects of different management strategies. The following factors can be defined by the user:

1. Upper limit of area managed for BCVI habitat enhancement or juniper clearing
2. Upper limit of how many management events can occur in 1 yr
3. Decision to stripcut vs. clearcut when using the hydroaxe for BCVI habitat enhancement
4. Decision to use prescribed burning vs. mechanical clearing for BCVI habitat enhancement
5. Number of days per year of cowbird control, both trapping and shooting.

Issues: Management Actions

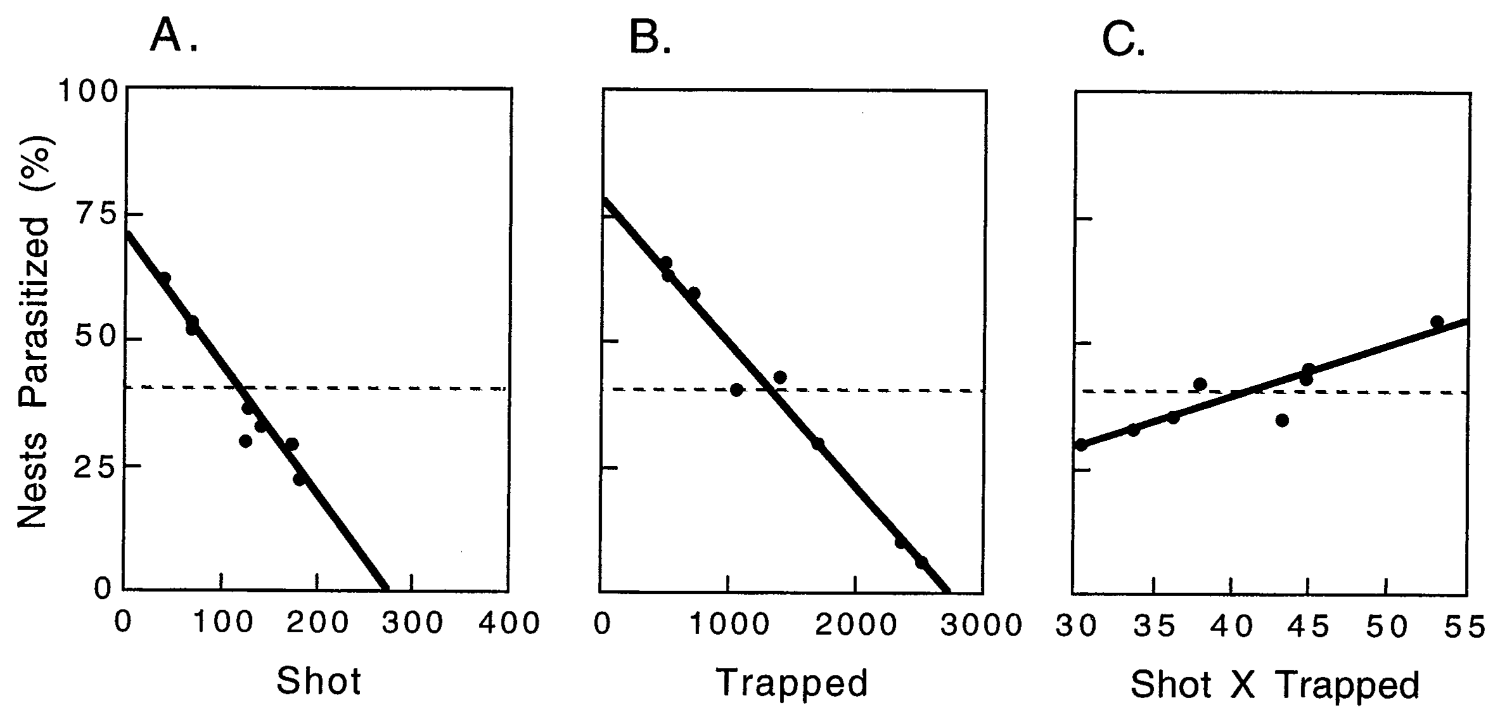
Because mechanical clearing with a hydroaxe is a new, experimental technique, it is difficult to model the decision rules used to determine sites for its application. As experience reveals the proper use of hydroaxing, FHASM could be updated to reflect more refined decisions, especially the decision to use the hydroaxe to create a clearcut vs. a stripcut.

Currently, weather conditions do not influence the potential for prescribed burning. This is not necessarily a deficit, since the time step in FHASM is 3 months. It is assumed that weather conditions within each quarter will not prevent the execution of desired management practices.

Technical Approach: Cowbird Control

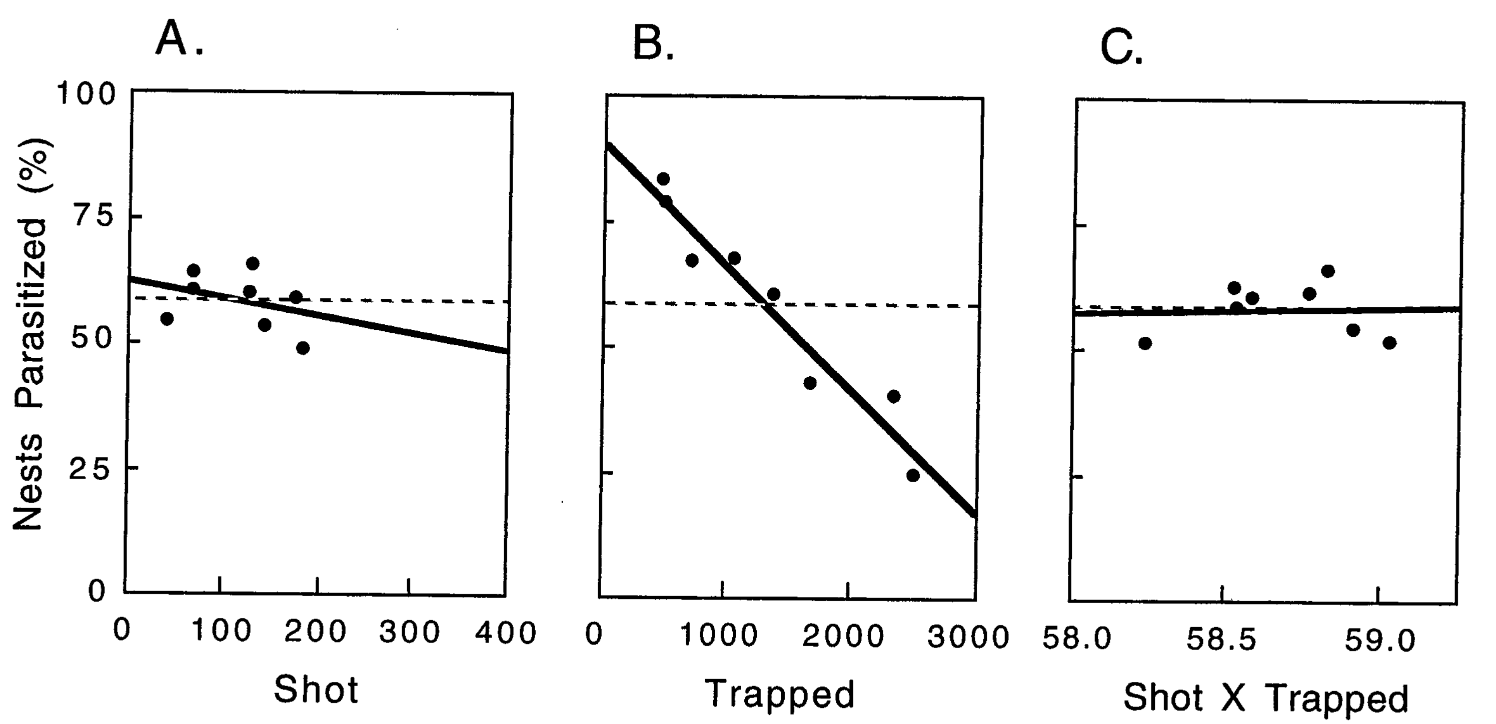
All control and parasitism data used in this section were taken from Hayden and Tazik (1991), Bolsinger and Hayden (1992, 1994), Tazik and Cornelius (1993), Weinberg, Bolsinger, and Hayden (1995), and Weinberg, Jette, and Cornelius (1996). As cowbird control efforts and numbers of females killed increased from 1988 through 1995, installation-wide parasitism rates dropped dramatically from 90.91 percent in 1987 to a low of 12.59 percent in 1994 and 15.17 percent in 1995. Control efforts (i.e., the total number of female cowbirds captured and shot across the entire installation) were used to estimate probability of parasitism according to location (live fire area vs. non-live fire area). Based on historical data (1987-88, 1991-95), it was found that the overall percent of BCVI nests in non-live fire areas parasitized by BHCO was strongly related (adjusted $R^2 = 0.980507$) to the number of females killed by shooting ($F=59.5913$, $df=1$, $P<0.0015$), the number of females captured by trapping ($F=166.2290$, $df=1$, $P<0.0002$), and their interaction ($F=16.8250$, $df=1$, $P<0.0148$; Figure 26; Equation C-11). In the live fire areas, the number of BCVI nests parasitized by BHCO was strongly related (adjusted $R^2 = 0.94839$) to the number of females captured by trapping ($F=129.6201$, $df=1$, $P< 0.0000$; Figure 27; Equation C-11). Parasitism was not related to the number of BHCO females shot or the interaction effect in the live fire area. Parasitism rates were examined at a finer spatial scale (the five regions discussed in the next paragraph), and while parasitism was influenced by numbers of females captured, the relationship did not show a regional effect. This suggests that differences in parasitism rates among the five regions were due to different trapping efforts. The total number of females killed is the sum of the numbers killed in the five regions, according to user-defined trapping and shooting efforts and documented trapping and shooting efficiencies (Figure 28).

The five regions used to model trapping efforts and efficiencies are those recognized by researchers on Fort Hood (Figure 29). Regions have historically been considered separately on Fort Hood because of the differences in control activities, land use practices, and topography (Hayden et al. in press). The West Ranges (WERA) are characterized by rolling grasslands with pockets of scattered woodlands along slopes



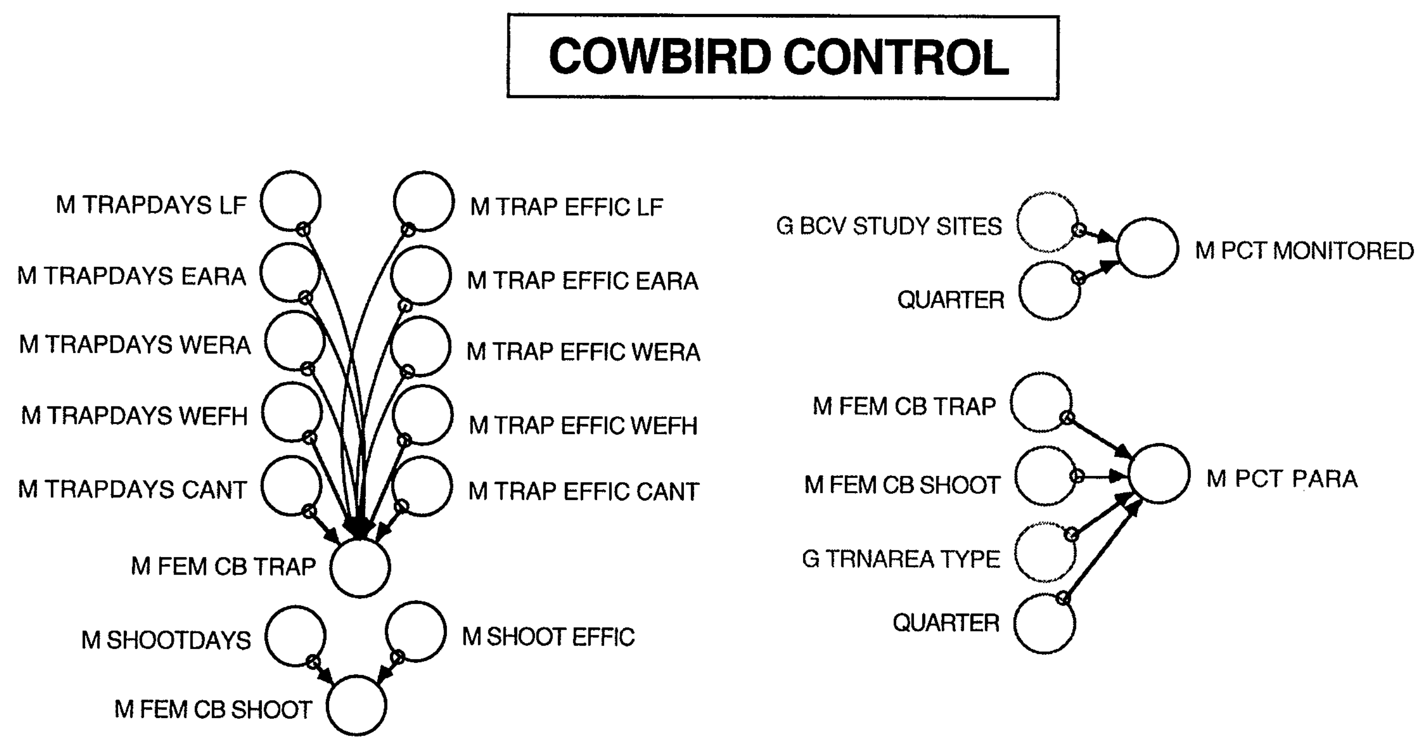
A: Relationship between total numbers of female cowbirds shot and percent of BCVI nests parasitized. B: Relationship between total numbers of female cowbirds trapped and percent of BCVI nests parasitized. C: Relationship between the interactive effects of cowbird trapping and shooting and percent of BCVI nests parasitized.

Figure 26. Parasitism rates are strongly related to cowbird control efforts in non-live fire areas on Fort Hood.



A: Relationship between total numbers of female cowbirds shot and percent of BCVI nests parasitized. B: Relationship between total numbers of female cowbirds trapped and percent of BCVI nests parasitized. C: Relationship between the interactive effects of cowbird trapping and shooting and percent of BCVI nests parasitized.

Figure 27. Parasitism rates are strongly related to cowbird trapping in live fire areas on Fort Hood.



Statistical relationships based on available data are used to calculate probabilities of parasitism in live fire areas and non-live fire areas.

Figure 28. The Cowbird Control section of the Management submodel.

and streams. These training areas support most of the armored vehicle training on Fort Hood. The East Ranges (EARA) are more rugged and have more woodlands than WERA. Small, dismounted units often use these areas, so vehicle traffic is predominantly on roads and trails. The Live Fire Area (LVF, including North = NOLF, South = SOLF, East = EALF and West = WELF units) occupies the center

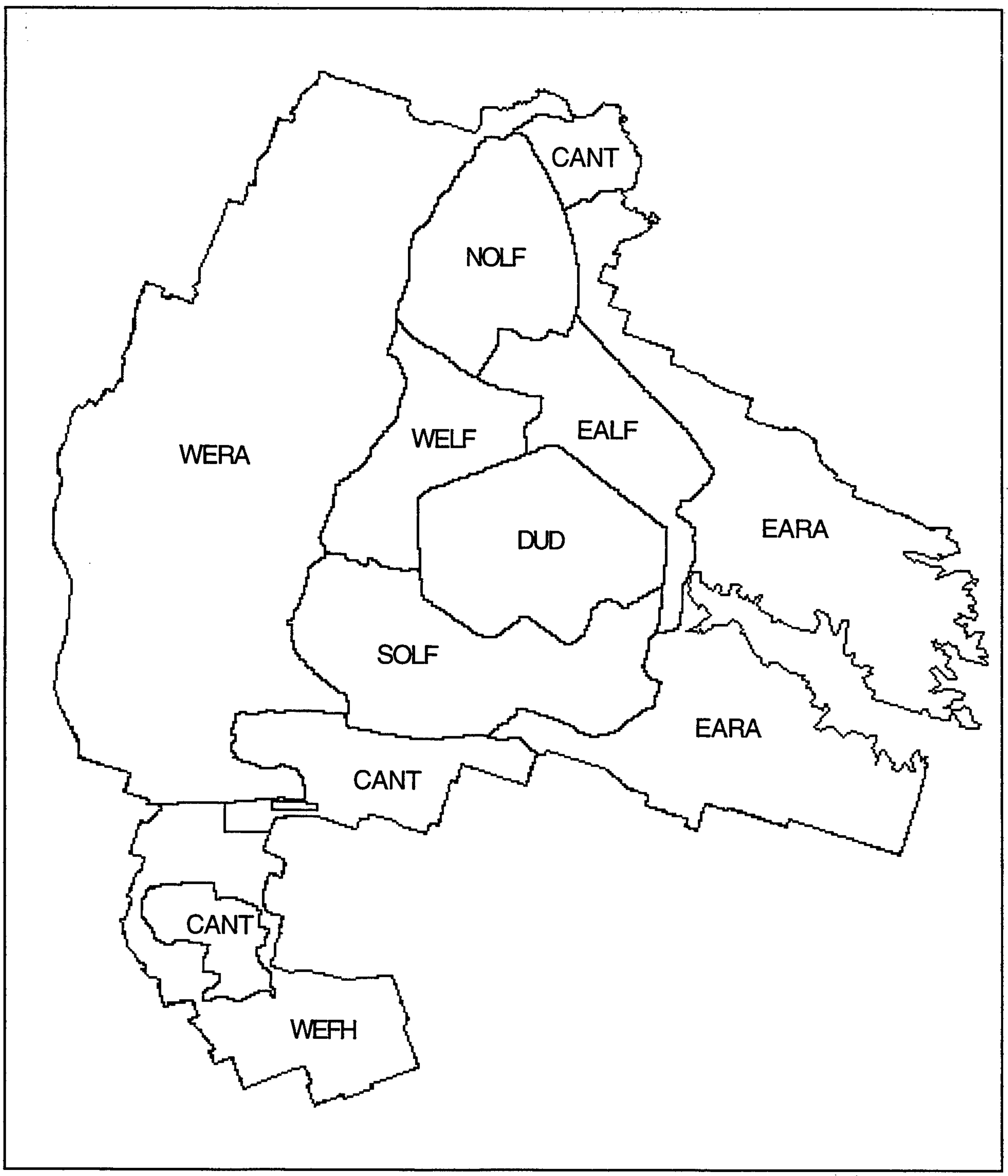


Figure 29. Five regions historically recognized by Fort Hood researchers and used to determine regional trapping efforts and efficiency rates for BHCO capture.

of Fort Hood. The vegetation is undisturbed by vehicle traffic throughout most of this region, but in the central impact zone, fires caused by phosphorus flares or exploding ordnance maintain dense scrubby deciduous vegetation preferred by BCVI for nesting. The NOLF is undisturbed woodlands that serve as a protected buffer zone. West Fort Hood (WEFH) is a peninsula of Army land surrounded by private agricultural and urban properties. A large ridgeline running north to south on the western boundary of WEFH has some prime habitat for both the BCVI and the GCWA. The Cantonment Areas (CANT) do not currently host either of the endangered bird species, but manicured grass areas provide extensive foraging grounds for the BHCO (all information on regions taken from Hayden et al. in press).

The number of females captured and shot is modeled as a function of effort and efficiency. Effort is defined as the number of trap days (Equations in C-12) or shooting excursions (Equation C-13) for the second quarter of each simulation year (the breeding season). Efficiency is defined as the number of females trapped per trap day (Equations in C-14) or the number of females shot per shooting excursion (Equation C-15). The product of these measures gives the number of females killed (Equations C-16 and C-17), which is used in calculating the percent parasitism (Equation C-11). These measures are modeled at the regional scale for trapping, and at the installation-wide scale for shooting, as a result of constraints in available data. Both trapping and shooting efforts are user-controlled variables, but parameters in FHASM are set using trapping effort values from the most recent year (1995; Weinberg, Jette, and Cornelius 1996) and an estimated shooting effort value for 1995 (calculated by a linear regression equation from 1989 data; see next section).

The efficiency of trapping has increased linearly over time (Figure 30a). This indicates that managers have become more efficient at capturing BHCOs through improved placement of traps on the landscape. In addition, this increase in efficiency does not appear to be reaching an asymptote. Efficiency differed among regions (Figure 30b), as female BHCOs were captured more easily in some regions than in others. Parameters in FHASM are also set using regional efficiency values for trapping from the most recent year of data (1995). The efficiency of shooting equals the installation-wide efficiency observed in 1989, the most recent year for which data are available.

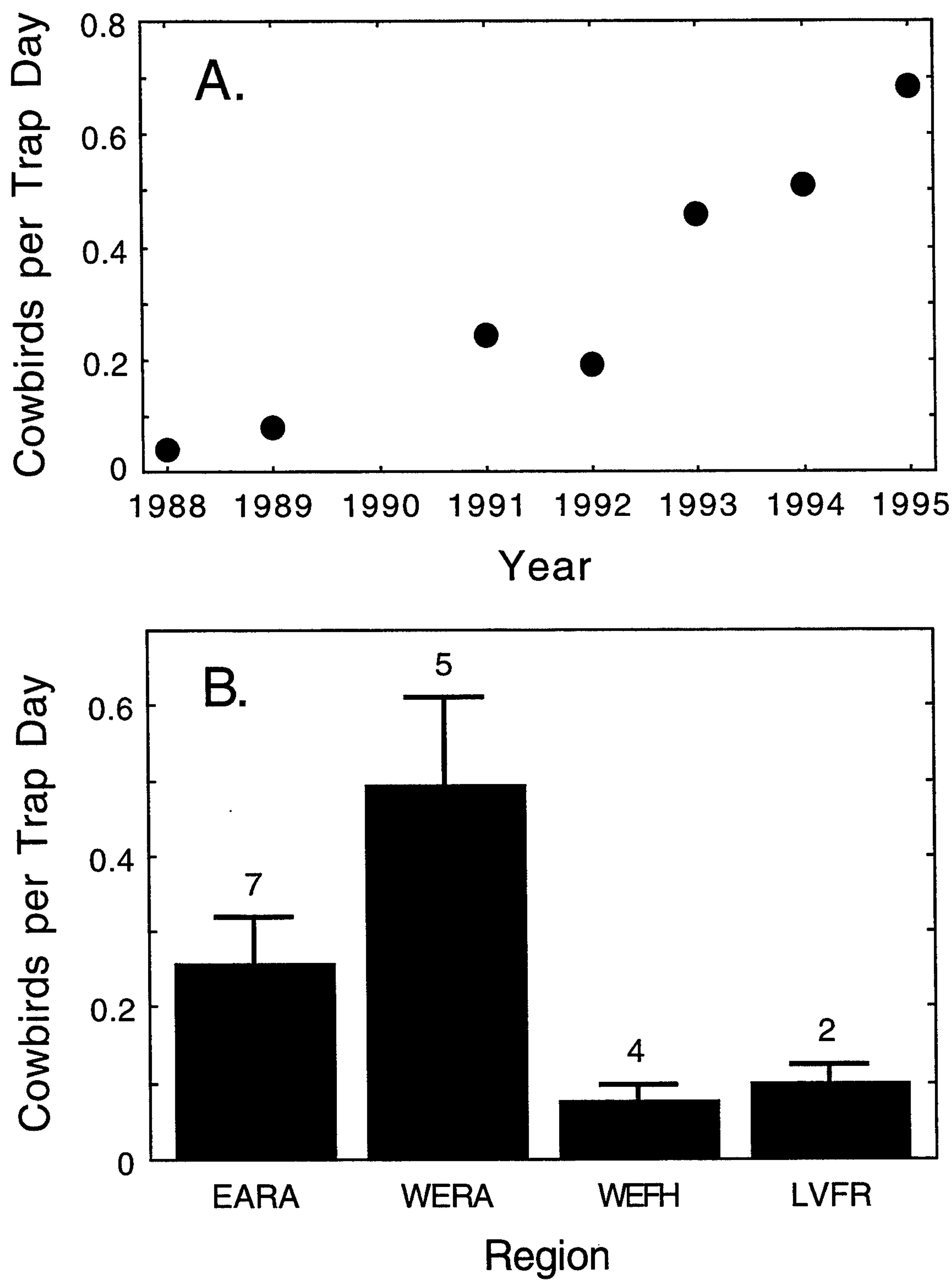


Figure 30. The efficiency of trapping cowbirds (BHCO per trap day ± S.E.) has steadily increased through time (A) and varies by region (B).

Issues: Relationship Used in FHASM

The trapping of cowbirds is assumed to affect parasitism on an installation-wide scale (i.e., the effects of trapping are experienced by nests uniformly across the installation, rather than in the local area surrounding a trap). Although this uniformity is probably not strictly the case, it seems reasonable given the large areas covered by individual cowbirds and the results of the data analysis. When modeling trapping efficiencies on the regional level, the four units from the LVF were pooled as a result of low trapping activity in this restricted zone.

Shooting effort data were only available for 1989. A linear regression to evaluate the relationship between the five regional values of effort in 1989 (plus one null value in 1988) and female kills was highly significant ($P = 0.0019$; $R^2 = 0.9299$). This relationship was applied to the observed numbers of kills in other years to predict the numbers of visits in those years, assuming no change in shooting efficiencies across years. The 1995 value used to set shooting effort parameters in FHASM was calculated from this regression, because actual effort in 1995 was not recorded.

Issues: Failed Analyses

Two alternative approaches for modeling cowbird parasitism were attempted. Relationships were sought between cardinal densities (based on Barber 1993), proximity to disturbed areas, and distances to nearest trap (using 1995 trap locations). This approach failed because the value needed for FHASM was a probability for parasitism, whereas the categorical quality of the individual nest information (parasitized vs. not parasitized) was inappropriate. It was problematic to aggregate individual nests into groups for calculations of probability for parasitism, and then to subsequently compare those groups to the above independent variables.

The second attempt was to generate full maps of cell-specific parasitism probabilities based on existing maps plus the categorical (parasitized vs. not parasitized) nest data. For each cell, the weighted numbers of parasitized vireo nests and total nests in a 5-km radius were used to calculate the percent parasitism. The weighted counts were made with a circular matrix filter using concentric rings of 1 km, weighted according to a normal distribution (e.g., 1 km = 50, 2 km = 30, 3 km = 15, 4 km = 4, and 5 km = 1). The GRASS program "r.mfilter" was used to sum up the weighted counts per ring and then "r.mapcalc" was used to calculate the percent parasitism for the centroid cell. A similar approach was attempted to acquire weighted sums of disturbed cells and weighted sums of traps. Analyses revealed no significant relationship between distance to a trap and percent of nests parasitized.

Accidental Fire Submodel

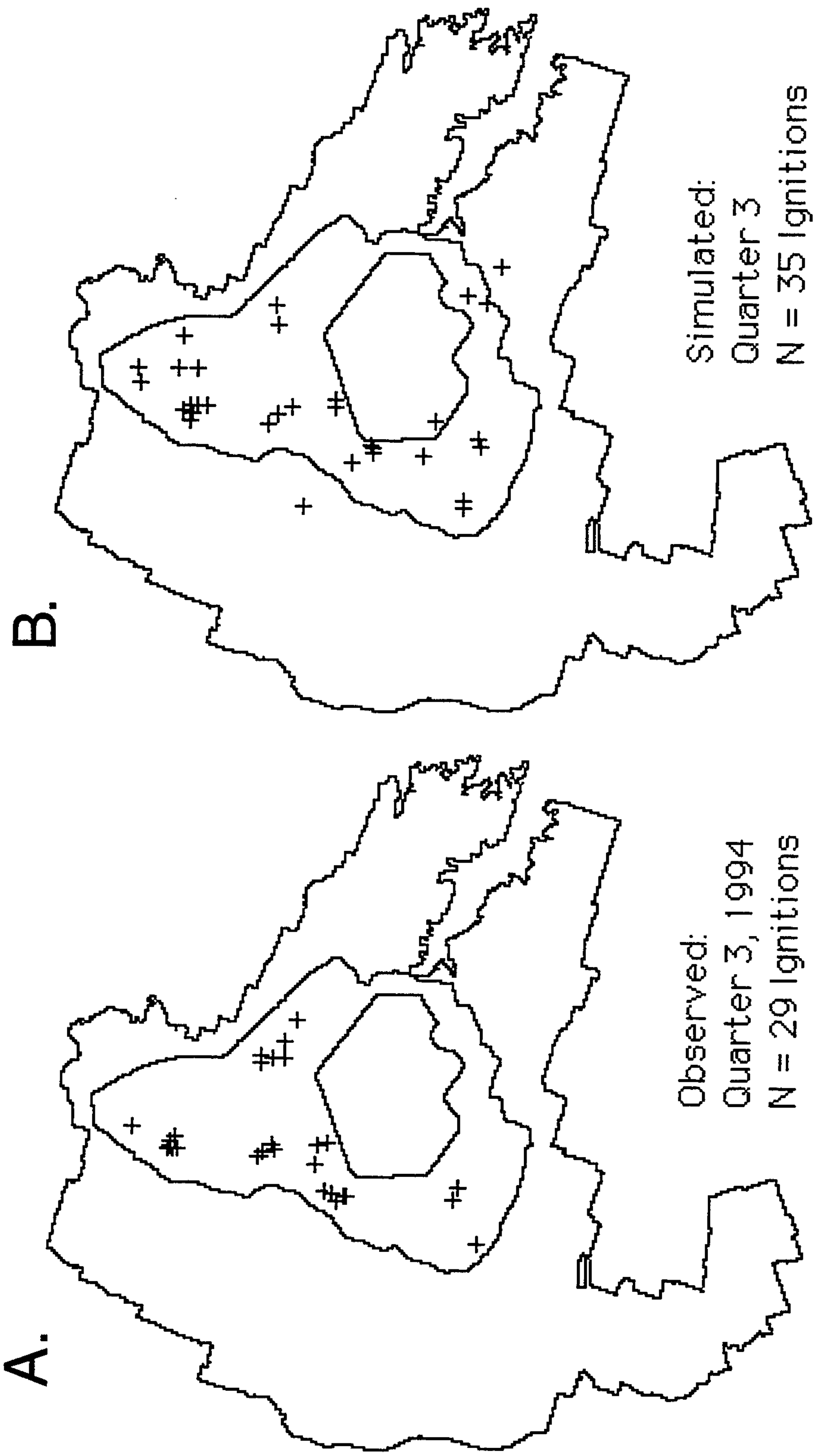
FHASM simulates accidental fires in temporal and spatial patterns that resemble the historical record at Fort Hood (1993 to 1995; Figure 31). The submodel was developed at a coarse resolution, without detailed information about fuel loads, moisture levels, updrafts, etc. A systematic approach was used to assign ignition probabilities according to location, time of year, and vegetation type.

The spread and termination of accidental fires are based on (1) the relative flammability of the vegetation types (Figure 19), (2) the existence of management-designated No Burn Zones and Let Burn Zones (Figure 32), (3) whether the fire is a crown fire or a ground fire, and (4) the presence of roads, waterways, and cantonment areas (Figure 33). A random number, within user-defined bounds, limits the spread of fires to an area less than what the maximum possible size would be if natural features alone determined the termination of fire. This limit mimics the effects of fire-fighting efforts and allows the simulated fire sizes to match the sizes of known fires from the historical record. A fire that is designated as a crown fire or that occurs within a Let Burn Zone will spread farther than a ground fire or fire that ignites within a No Burn Zone.

Technical Approach: Ignitions

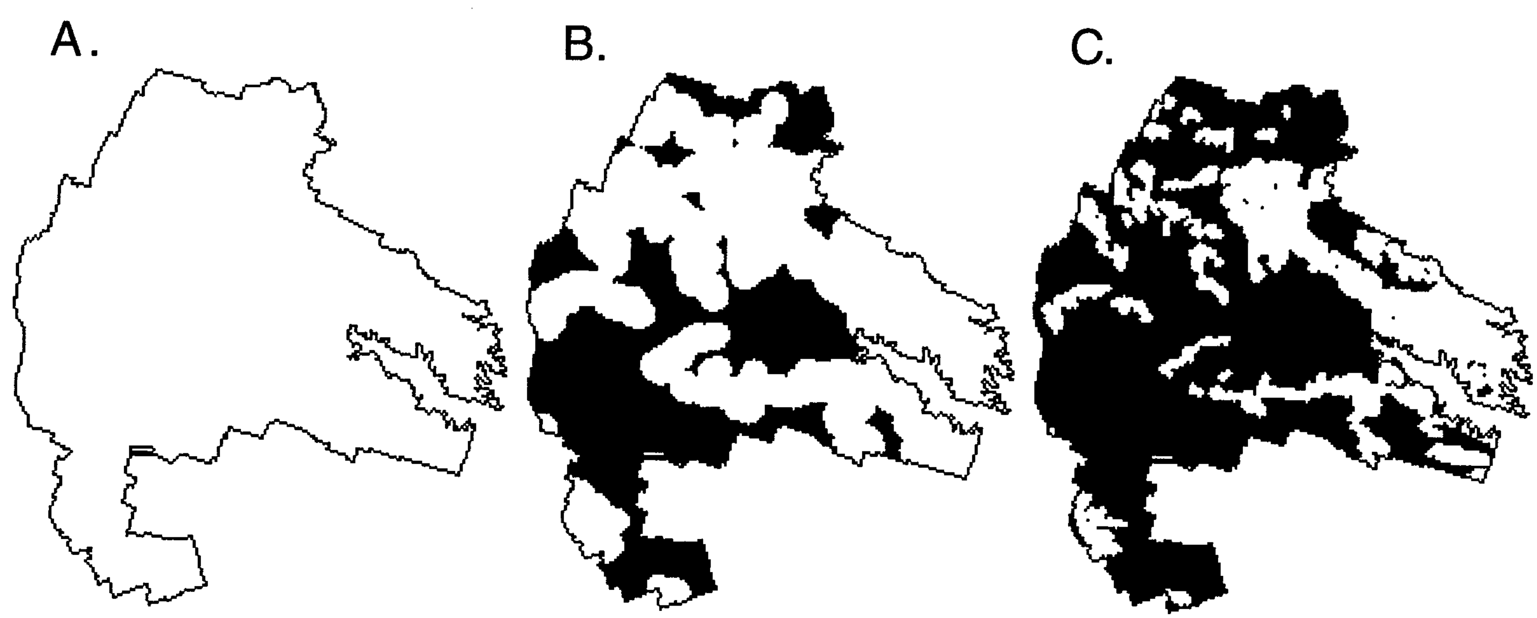
The Accidental Fire submodel (Figure 34) simulates fire across four quarters of each year and across the training areas of Fort Hood. Total annual and quarterly ignition probabilities are first established in the Seasonal Adjustment section. Probabilities for regional patterns are generated in the Regional Adjustment section. Finally, vegetation-specific and training area probabilities are calculated in the Veg/TA Adjustment section. The trigger for fire ignition resides in the Fire Probability section, based on the probabilities generated in the first three sections. Lastly, the Fire Spread section models the cost of fire spread, including fire termination once a maximum cost has been met.

The Seasonal Adjustment section generates a random number (F_ANNUAL_RAND) within the bounds of the historical data (from a low of 45 in 1995 to a high of 123 in 1993) that represents the total number of simulated fires each year (Figure 35; Equation D-1 [see Appendix D]). Next, the annual number of fires is distributed on a quarterly basis. Random numbers (F_QUART_[1-4]_RAND in Figure 35) within historical distributions (Figure 36a) are generated to determine the percent of annual fires that occur in each quarter (Equations D-5, D-9, D-13, and D-17). The random numbers are adjusted to equal a total of 100 percent in Equations D-21 through D-25 (leading to parameter F_PCT_QUART in Figure 35; Equation D-26).



A: Ignitions recorded in the third quarter of 1994 (N=29), (from historical record). B: Ignitions simulated for Quarter 3 of a given year (N=35).

Figure 31. Ignitions of accidental fires on Fort Hood.



Managers may designate No Burn Zones and Let Burn Zones to simulate different fire control policies. A: The current fire control policy on Fort Hood is No Burn across the entire installation. B: One potential scenario would be to allow accidental fires to burn anywhere greater than 1 km from protected endangered species areas. C: An alternative scenario would be to allow accidental fires to burn anywhere greater than 200 m from protected endangered species areas.

Figure 32. Spread of fires is influenced by fire control policies.

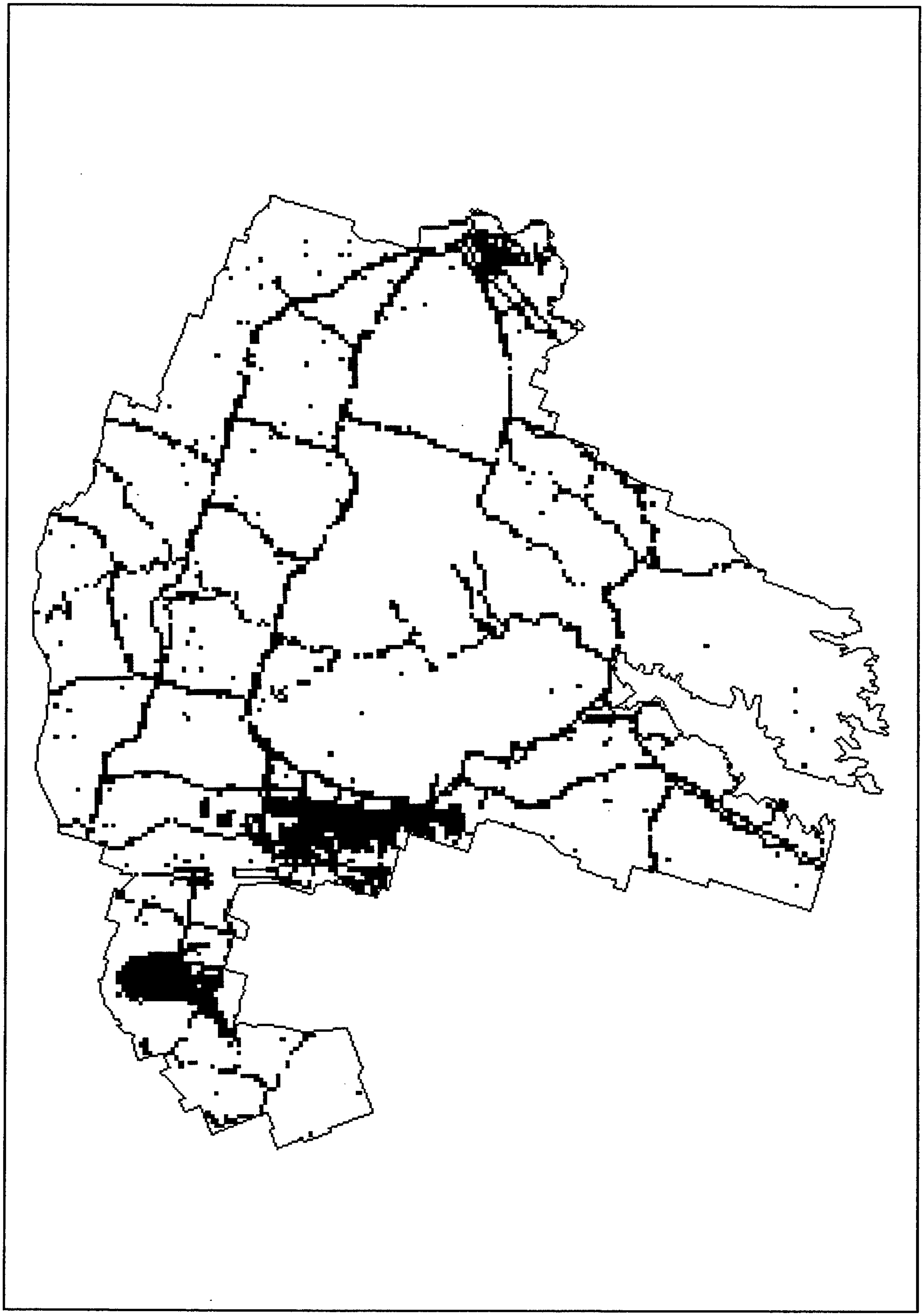
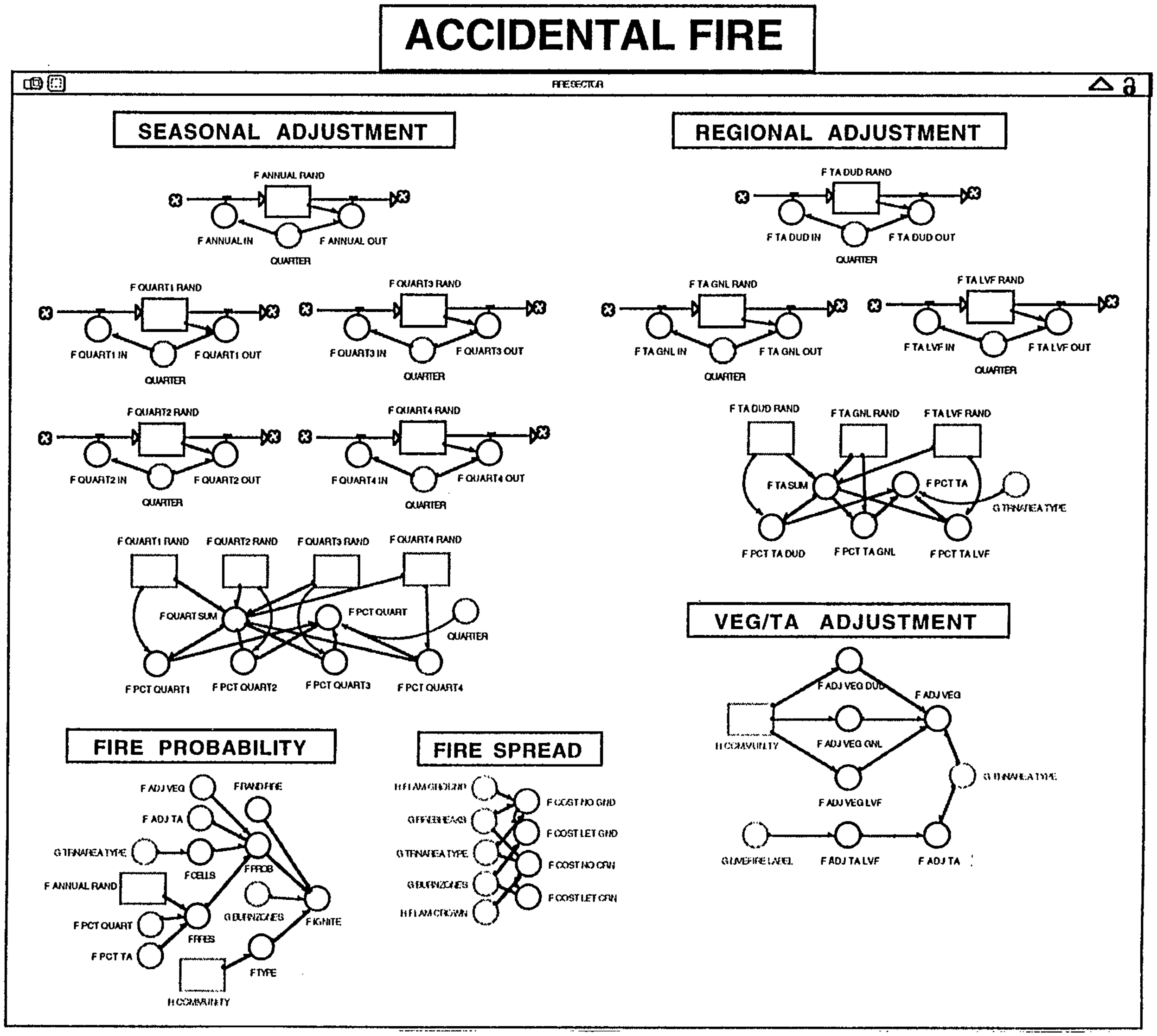


Figure 33. Roads, streams, and cantonment areas serve as firebreaks.



Probabilities for ignition are adjusted according to location, season, and vegetation type; fire spread and termination are controlled by the "cost" of burning a cell. The variables related to the Accidental Fire submodel are designated by the prefix "F".

Figure 34. Overview of the Accidental Fire submodel.

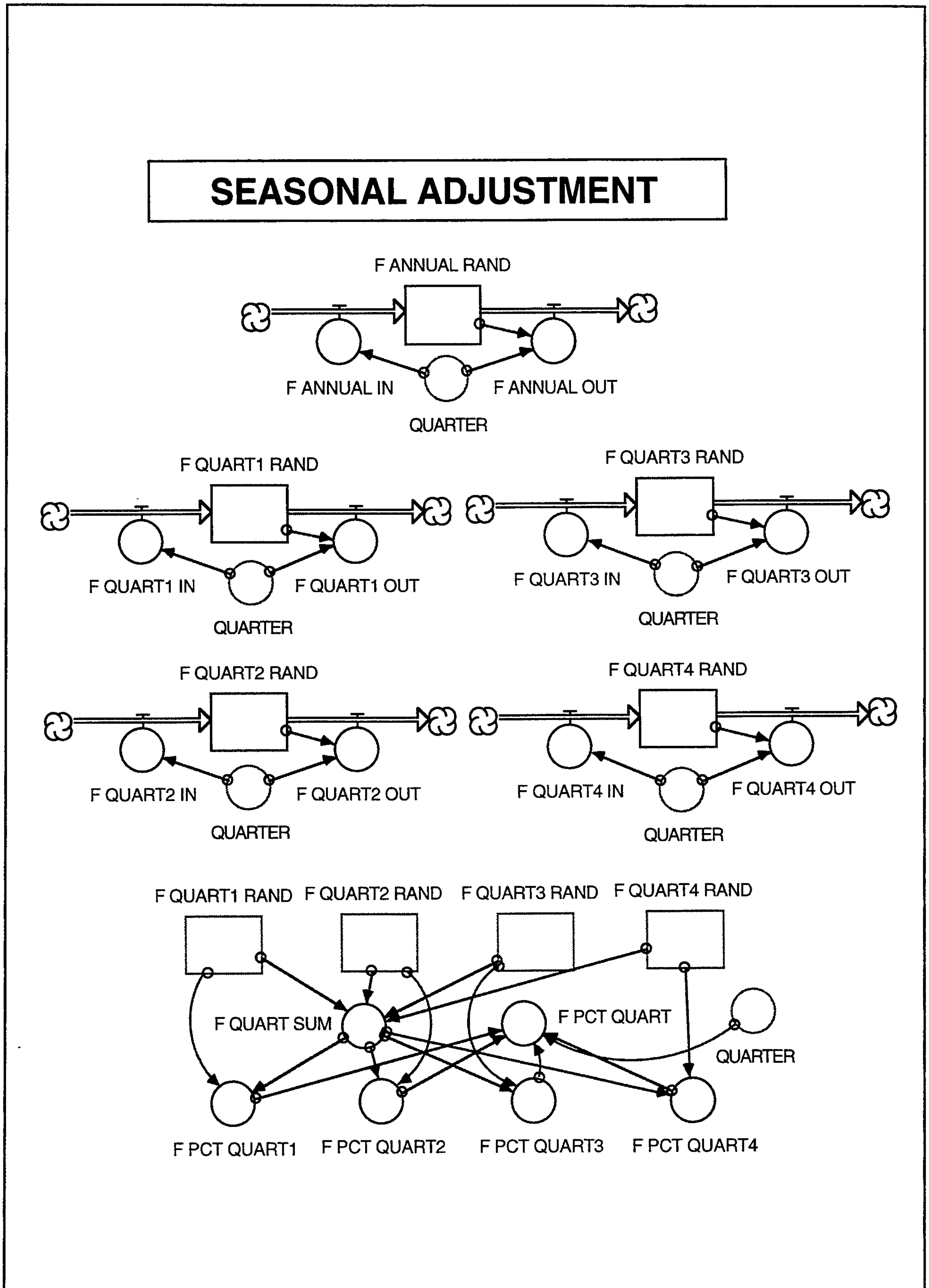
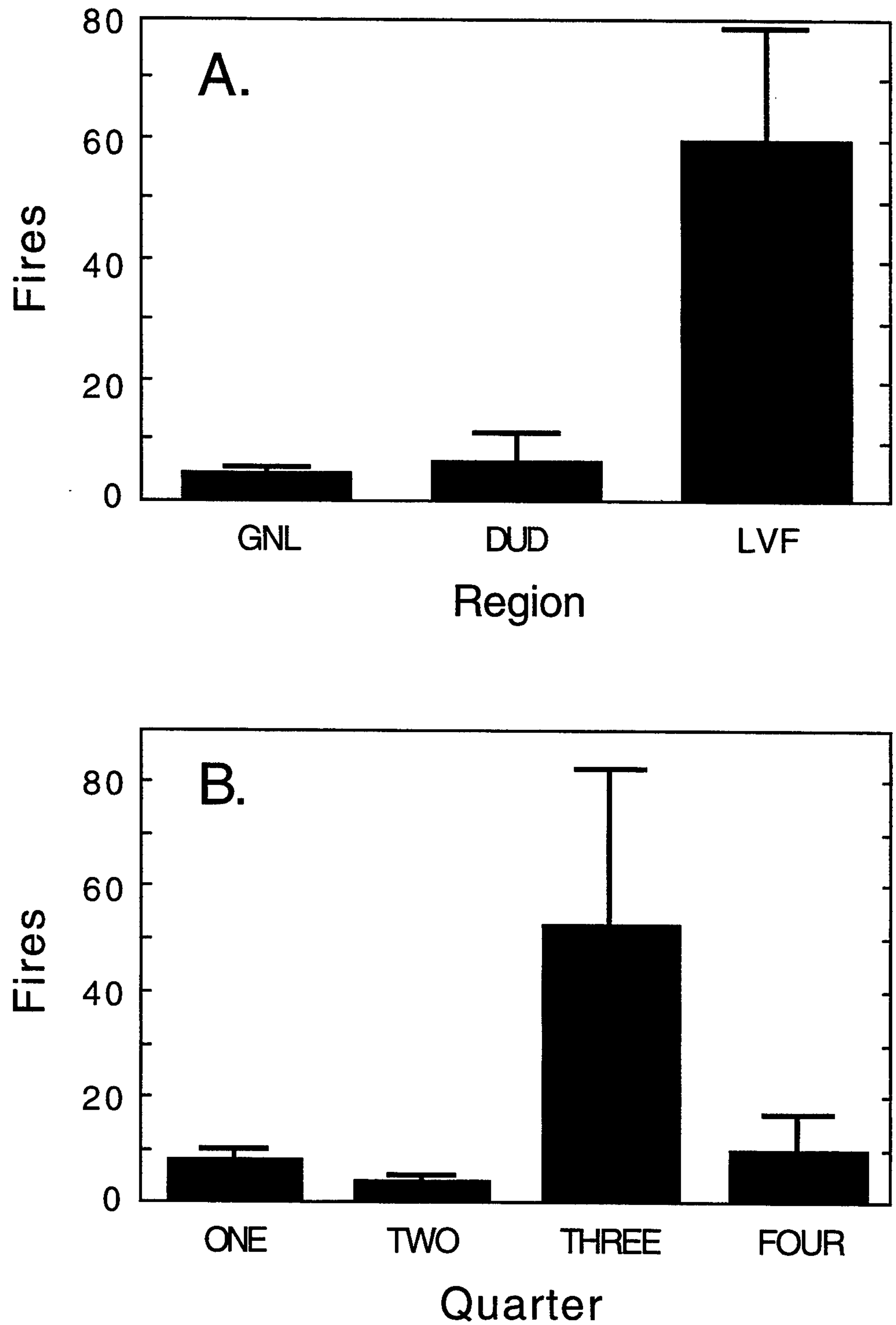


Figure 35. The Seasonal Adjustment section of the Accidental Fire submodel allocates the total number of ignitions per year into four quarters according to historically-based probabilities.



Bars represent standard error.

Figure 36. The historical record of accidental fires (1993-1995) reveals (A) temporal and (B) spatial variation in accidental ignitions.

The Regional Adjustment section (Figure 37) calculates ignition probabilities based on spatial patterns in the historical data. Three regions were recognized for this purpose: the permanently dudded area (DUD), the live fire (buffer zone) area (LVF), and general training areas that are not part of the impact areas (GNL; G_TRNAREA_TYPE; Figure 38). The percentages of accidental fires occurring in these regions are determined by random numbers (F_TA_[DUD, GNL, LVF]_RAND from Figure 37; Equations D-27, D-31, and D-35) within the bounds of the historical data (Figure 36b). The random numbers are adjusted to equal a total of 100 percent in Equations D-39 through D-42 (leading to parameter F_PCT_TA in Figure 37; Equation D-43). The number of fires that will occur in each region in each quarter for each year (F_FIRES; output in Figure 31b) equals the product of the annual total number of fires, proportion of fires in the region, and proportion of fires in the quarter (Figure 39a; Equation D-50). Table 8 shows an example of these calculations.

The historical fire data did not identify the plant community type at the ignition source. However, the plant community was identified on the vegetation map at the center of each recorded fire. Within each region (GNL, DUD, or LVF), the probability of a fire igniting within any given cell was calculated by dividing the total number of observed fires in that region (from historical data) by the number of cells in that region, giving a "regional baseline probability" for fire. The probability of a fire igniting in any given cell of a certain vegetation type was calculated by dividing the total number of observed fires in the community type (from historical data and vegetation map) by the number of cells of the community type in the region, resulting in the "vegetation-based probability." The proportional differences between the regional baseline probability and the vegetation-based probabilities for each vegetation type equal the dependent values defining F_ADJ_VEG_[DUD, GNL, LVF] for each region (Figure 40; Equations D-44 through D-47). These parameters provide constant regional probabilities adjusted for each vegetation type.

Similarly, an adjustment is made in the probability of fire for the various training areas within the LVF because this region historically has experienced the most accidental fire ignitions (approximately 74 percent of all recorded fires, see Table 8). The approach was identical to that used in adjusting for vegetation type. The regional baseline probability of a fire igniting within any given cell was calculated by dividing the total number of observed fires in that region (from historical data) by the number of cells in that region. The probability of a fire igniting in any given cell of each training area was calculated by dividing the total number of observed fires in each training area (from historical data) by the number of cells in each training area (i.e., training area-based probability). The proportional differences between the regional baseline probability and the training area-based probabilities

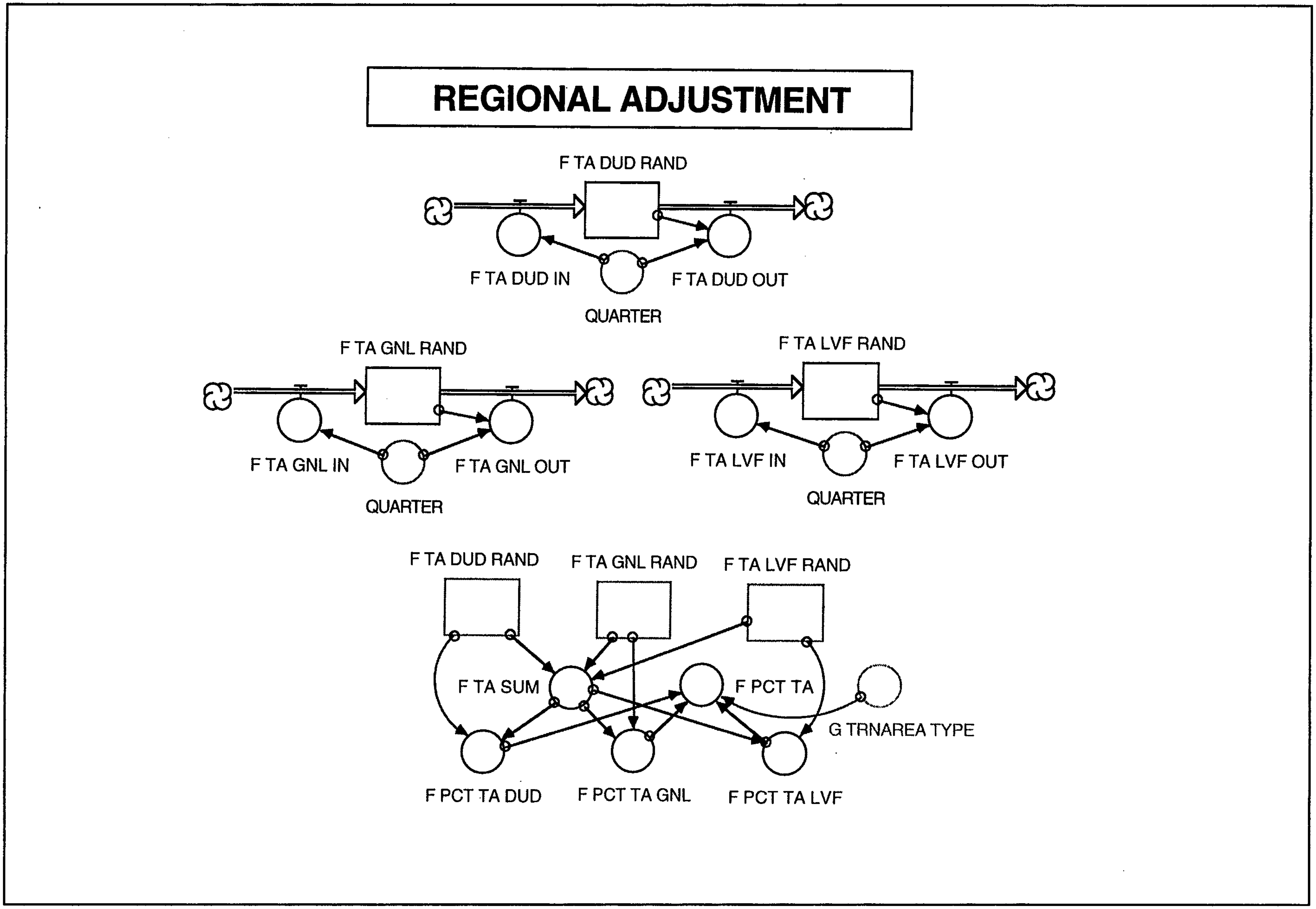


Figure 37. The Regional Adjustment section of the Accidental Fire submodel allocates the total number of ignitions per year into three regions according to historically based probabilities.

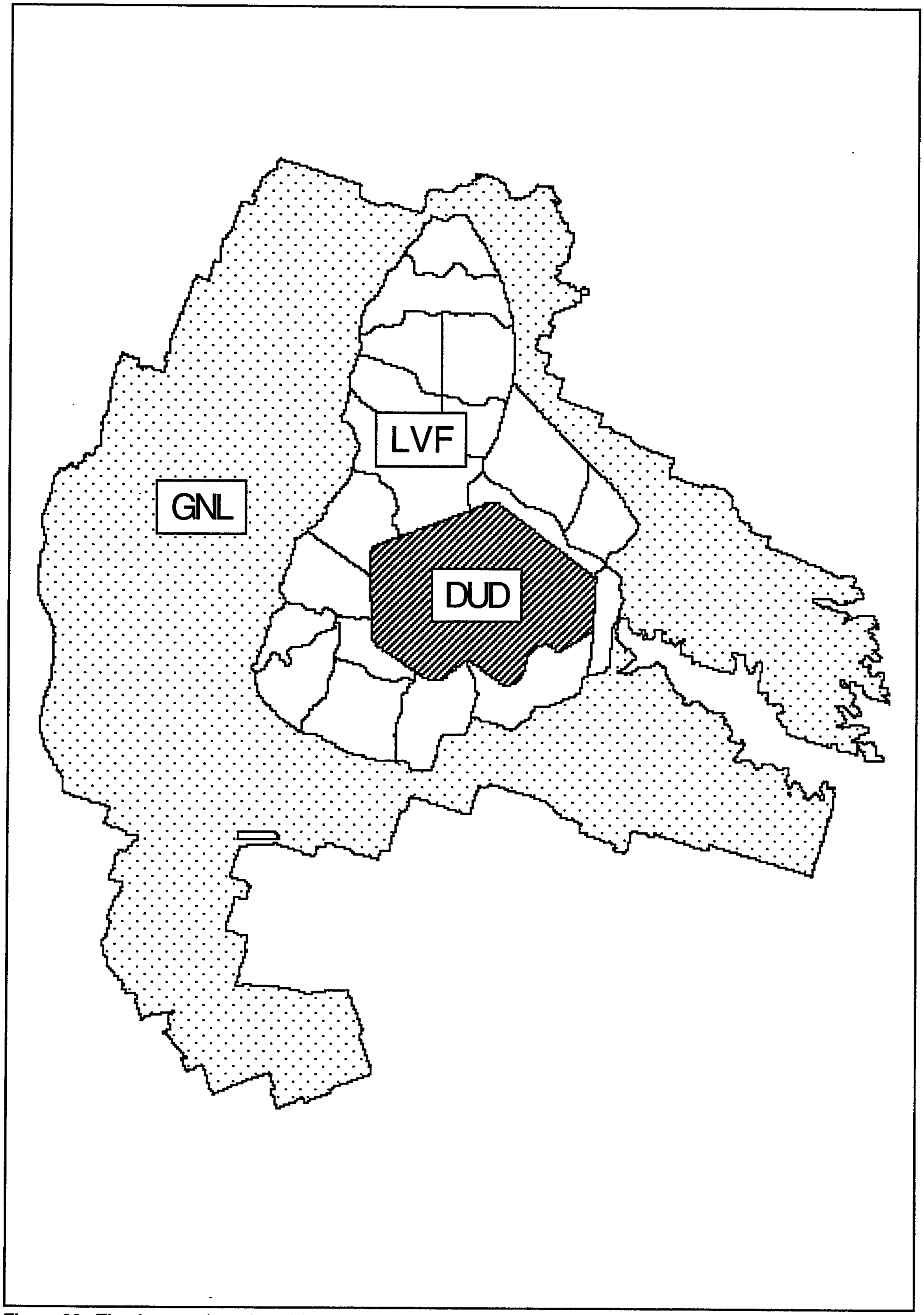
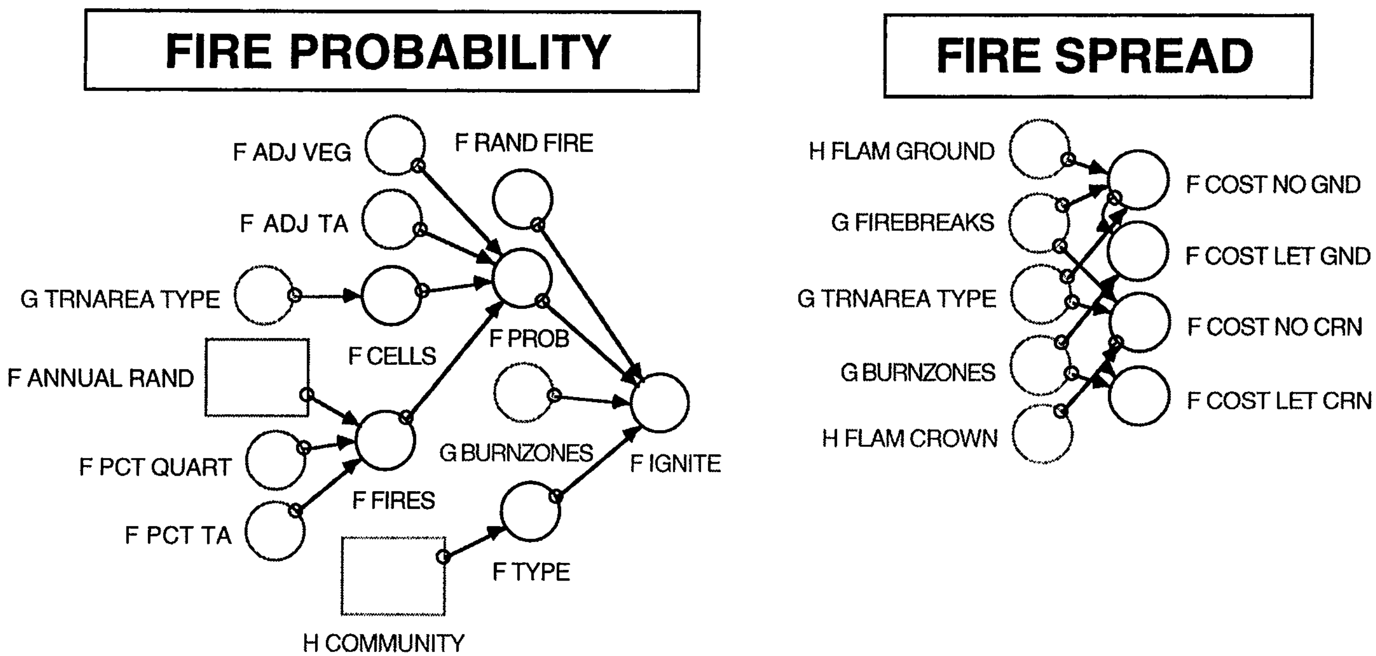


Figure 38. The three regions for which accidental fire ignition probabilities are adjusted.



(A) in the Fire Probability section of the Accidental Fire submodel, for each cell, a probability for ignition is compared to a random number to determine if ignition occurs and (B) the Fire Spread section calculates the cost of fire spreading through each cell, depending on whether the cell is in a No Burn Zone or a Let Burn Zone, and whether the fire is a crown fire or a ground fire.

Figure 39. Simulation of fire ignition and spread.

Table 8. A hypothetical example of the process used in FHASM to determine and allocate the number of fires across time and space.

SIMULATION OF FIRE IGNITIONS IN ONE YEAR
Q.x = quarter (1-4) DUD = dudded region
LVF = live fire area GNL = general training areas

Historical Range		Random Number	Proportion Adjusted to Sum 1.0	Multiply by Total Annual Fires	# of Fires (rounded)
Total number of annual fires :					
45-123		90	n/a		90
To calculate the number of fires in quarters:					
Q.1	3.2520- 26.0869	20	20/ 128 = 0.1562	0.1562 * 90 = 14.06	14
Q.2	2.2222- 10.8695	7	7/ 128 = 0.0546	0.0546 * 90 = 4.91	5
Q.3	35.5557- 91.0569	69	69/ 128 = 0.5391	0.5391 * 90 = 48.52	49
Q.4	0-51.1111	32	32/ 128 = 0.2500	0.25 *90 = 22.50	22
SUMS =		128	0.9999		90
To calculate the number of fires in regions:					
LVF	77.7778- 88.8889	85	85/ 115 = 0.7391	0.7391 * 90 = 66.52	66
GNL	4.4586- 22.2222	20	20/ 115 = 0.1739	0.1739 * 90 = 15.65	16
DUD	0-11.4649	10	10/115 = 0.0870	0.0870 * 90 = 7.83	8
SUMS =		115	1.0000		90

To calculate numbers of simulated fires per region and quarter:

Area	Calculation	# Fires	Area	Calculation	# Fires
Q.1 x LVF	90 * 0.1562 * 0.7391 = 0.1154	11	Q.3 x LVF	90 * 0.539 * 0.7391 = 35.85	36
Q.1 x DUD	90 * 0.1562 * 0.0870 = 0.0136	1	Q.3 x DUD	90 * 0.539 * 0.087 = 04.22	4
Q.1 x GNL	90 * 0.1562 * 0.1739 = 02.44	2	Q.3 x GNL	90 * 0.539 * 0.1739 = 08.44	9
Q.2 x LVF	90 * 0.0546 * 0.7391 = 03.63	4	Q.4 x LVF	90 * 0.25 * 0.7391 = 16.63	17
Q.2 x DUD	90 * 0.0546 * 0.0870 = 0.4275	0	Q.4 x DUD	90 * 0.25 *.0546 = 01.23	1
Q.2 x GNL	90 * 0.0546 * 0.1739 = 0.8545	1	Q.4 x GNL	90 * 0.25 * 0.1739 = 03.91	4

for each training area equal the dependent values defining F_ADJ_TA_LVF (Figure 40; Equations D-48 and D-49). This parameter provides constant probabilities adjusted for the LVF training area, based entirely on historical data. Probabilities of fire are not adjusted according to training area within the DUD region or the GNL region.

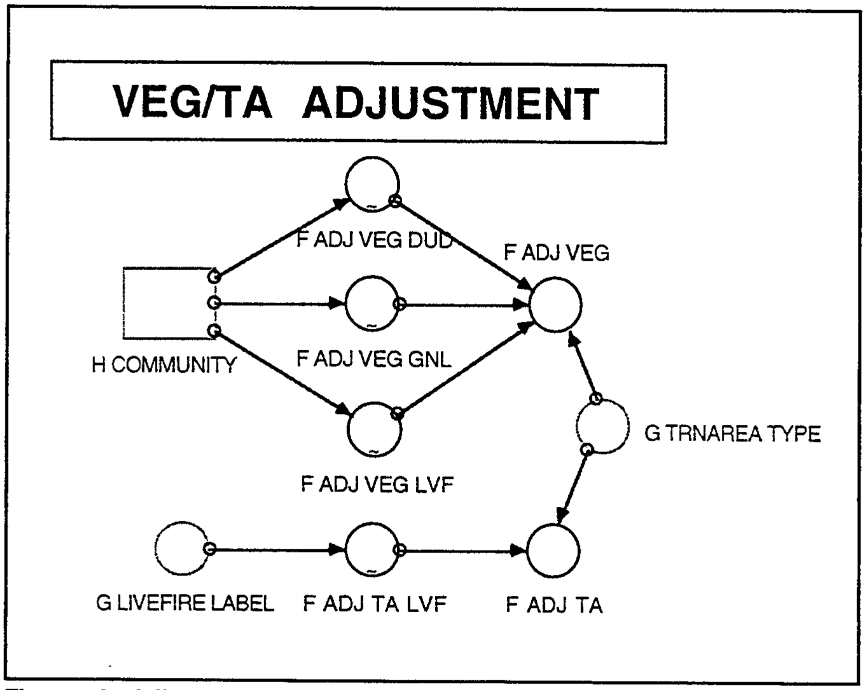


Figure 40. Adjustments to fire ignition probabilities based on vegetation type and live fire training area.

Finally, to allocate potential fire ignitions to the cells within each quarter, vegetation type, training area (where applicable), and region, F_FIRES is divided by the number of cells in the region and multiplied by the appropriate factor from F_ADJ _VEG and F_ ADJ_TA. This probability is called F_PROB (Figure 39a and Equation D-52). Next, a random number (F_RAND_ FIRE; Equation D-53) is selected. An ignition occurs if the random number is equal to or greater than F_PROB (F_IGNITE; Figure 39a). If a fire is ignited, it is categorized as a crown fire or ground fire depending on the vegetation in the ignition cell (Equation D-55). FHASM assumes that, if a fire ignites within a mature juniper-dominated community (vegetation type = 1, 5, 7, or 11), then it is a crown fire. Any other community type supports a ground fire. The ignition variable also considers whether the cell of ignition resides within a No Burn Zone or a Let Burn Zone (Equation D-54).

Technical Approach: Spread and Termination of Fire

The Fire Spread section of FHASM is shown in Figure 39b. The historical fire data did not include information about the spread of fire through different plant communities. However, broad generalizations about the relative "cost" of, or resistance encountered by, a fire moving through each of the 15 FHASM vegetation types can be derived from the flammability index discussed in the Habitat submodel section. The cost of burning is the "mirror image" of the flammability index: if flammability = 1, then cost = 3, and vice versa. Flammability ratings of 0 lead to very high-cost values (e.g., 99). In addition to the influence of vegetation type, natural or man-made firebreaks can halt the spread of fire in FHASM. These firebreaks are shown in Figure 33 (G_FIREBREAKS). Roads (categorized as hard surface, improved dirt, or tank trail), waterways (categorized as river, stream, pre-reservoir river, pre-reservoir stream, lake, or pond), and cantonment areas all have high enough costs that fires will terminate upon contact. The cost of fire movement through a cell is calculated by Equations D-56–D-59, based on G_FIREBREAKS, G_BURNZONES, H_FLAM_GROUND, and H_FLAM_CROWN (Figure 39b). The cost will be higher for crown fires and for fires within No Burn Zones (see program script in Appendix E, p 143). The GRASS function "r.cost" creates a map of the cost incurred by a fire moving outward from each ignition source. Fires spread along paths with least cost. Termination of fire spread occurs when the maximum allowed total cost is met. The maximum is randomly generated for each fire, but it falls within user-specified maxima and minima (the script for this program is found in Appendix E, p 143). Figure 41 illustrates the final boundaries of simulated fires, which are stored as F_FIRE_ACTL in the Simulation submodel.

Issues: Accidental Fire

The historical fire record includes the following information for accidental fires in the years 1993 through 1995: date, size, UTM* of center, training area, and other information. When the UTM points were mapped in GRASS, five were not on Fort Hood at all, seven were duplications, and 23 were in training areas that differed from the training areas stated in the original data. These problematic data were eliminated, which reduced the number of recorded events from 249 to 214.

The relationship of fire ignitions to vegetation type relies on the vegetation map, G_COMMUNITY. This map was created in 1987, whereas the fire record dates from 1993 to 1995.

* UTM = Universal Transmercater

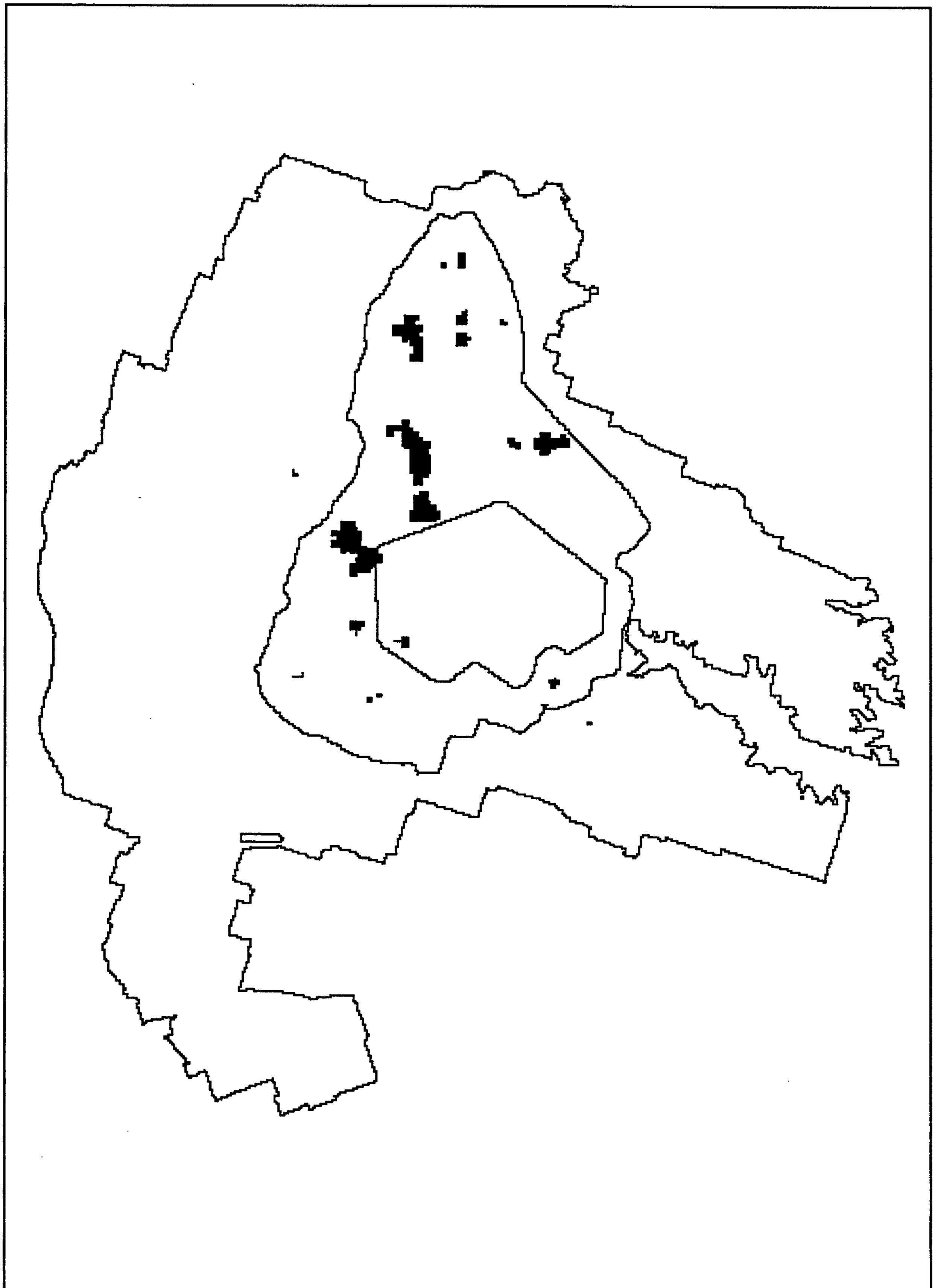


Figure 41. Map output indicating cells burned through ignition and spread of both ground and crown accidental fires under a No Burn policy across the entire installation.

5 Summary and Recommendations

Summary

After determining end-user requirements and objectives, USACERL researchers and students and instructors from the University of Illinois at Urbana-Champaign developed submodels to be included in the Fort Hood Avian Simulation Model. Values in these submodels (Target Species, Habitat, Impacts, and Map Input) were made to be unique so that integration into the full model was as uncomplicated as possible. As each submodel was integrated, problems were resolved and functions modified until the full model was demonstrated to end users. Further refinements were influenced by user needs, perceived usefulness and flexibility, and time and financial constraints.

The final group of submodels (Management, Accidental Fire, Habitat, Avian, Map Input, Simulation) were built with available data and developed using realistic temporal and spatial scales. FHASM's spatial scale matches the typical territory size of both the BCVI and GCWA. Temporal scales were set at 3 months to reflect lack of data on a more refined scale for some ecological processes.

Recommendations

Future work on FHASM could take two paths. First, improvements in the underlying data and the structure of the model are possible. Additional data sources or field studies could lead to more defensible algorithms, as discussed in the *Issues* sections. The most serious deficiency is the lack of an accurate vegetation map; a detailed, ground-truthed vegetation map would allow major improvements in the accuracy of this model. The structure of the cowbird sector could be altered by producing an individual-based model of cowbird behavior. Three years of cowbird telemetry data from Fort Hood are now available and could provide the basis for an individual-based model. Combining the behavior of individual female cowbirds with the chances of being trapped or shot could lead to cell-specific parasitism probabilities. This exercise may lead to novel information about cowbird behavior and ecology, and should provide an interesting comparison between population approaches and individual approaches in modeling organisms on a landscape.

Secondly, regardless of whether FHASM is advanced further, a thorough sensitivity analysis will be conducted. The results will assist land managers in interpreting model output and may point to future research directions and data collection priorities. Sensitivity analysis assesses the relative importance of model variables. It determines whether a given variable has a disproportionate impact on model results. This analysis is important since many parameters are assigned values in the absence of solid data. If one parameter has a large impact on model results, users need to understand the range of results that different values can produce. Additional research on these influential variables may be justified. However, the sensitivity of a model to a particular parameter may not mean that the parameter is critical to the ecology of the system being modeled (Green and Hirons 1991). On the other hand, sensitivity analysis can identify variables for which the model is indifferent. In this case, simulations can be run with a single value without concern (Dunning et al. 1995).

The sensitivity analysis of FHASM should test a wide range of values for all user-defined variables specified in the *Technical Approach* sections. Fort Hood personnel must be included in the design of the sensitivity experiments so that appropriate values are tested for each parameter. Variables about which we have little information, such as the rates of vegetation change in the transition matrix, should be tested as well.

Ideally, FHASM would go through a validation phase in which model output is compared to independent observations that were not used in model development. A tight correspondence between predicted and observed patterns would suggest an accurate model, but the underlying assumptions of the model may still be invalid, since more than one mechanism can lead to any given outcome (Conroy et al. 1995). It is likely that models are more valid in circumstances similar to those under which the model was developed. The threshold of applicability may be established through validation experiments.

Models, including FHASM, are best applied within an adaptive management framework. Adaptive management is conducted by planning and executing management activities as if they were experimental treatments in a research study. The results of different management strategies are statistically comparable and improve knowledge about ecosystem functioning as well as feedback for improving management (reviewed in Trame and Tazik 1995). Models can assist in this approach by generating predictions that then can be compared to real-world observations (Conroy et al. 1995). New information from field studies can be used to improve the model. Many management treatments can be applied by the model during sensitivity analysis and the results can provide insight about future management priorities, if interpreted with caution.

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Appendix A: The Avian Submodel Variables and Equations

Naming Conventions

V or W = variable created in the Avian submodel
H = variable generated in the Habitat submodel
M = variable generated in the Management submodel
F = variable generated in the Accidental Fire submodel
G = map stored in the Map Input submodel
S = variable created by simulation results

Definitions and Equations

Habitat Suitability and Quality, including Previous Occupancy

Definitions.

H_COMMUNITY: A state variable equal to the community type code listed in Table 1; equivalent to one of the 15 recognized plant communities on Fort Hood. This parameter is initialized with the GRASS map "G_COMMUNITY," categories 1-15.

H_TIME_IN_COMM: A state variable that increases by a value of 1 for each time step that no transition in community type occurs, and is reset to 0 following a transition. Represents the number of time steps that a cell has been in the current community type.

G_[BCV, GCW]_SUIT_PHYS: GRASS maps depicting levels of habitat suitability for either BCVIs or GCWAs. The map for BCVIs is based on slope, geology, elevation, aspect, and soils. The map for GCWAs is based on geology. Ranks range from 0 (unsuitable) to 3 (highly suitable).

[V,W]_SUIT_COMM: The influence of community type on habitat suitability. Ranks range from 0 (unsuitable) to 2 (optimal).

[V,W]_SUIT_TIME: The influence of successional stages of a community type on habitat suitability. Ranks range from 0 (unsuitable) to 2 (optimal).

[V,W]_HAB_SUIT: The overall suitability of a cell for BCVI or GCWA breeding. Values range from 0 (unsuitable) to 3 (highly suitable).

[V,GCW]_PATCH_SIZE: The number of cells in the cluster of moderately or highly (ranks of 2 or 3) suitable habitat in which a given cell resides. This value is calculated by a shell script during each run within a simulation. Information is not currently available to model this parameter for the BCVI; for the GCWA, cells within patches of ≥25 cells receive higher habitat quality rankings.

[V,GCW]_PATCH DIST: The distance from a "large" patch of habitat with a suitability rank of 2 or 3. The number of cells required to be considered a large patch is defined within the shell script that produces this value. Currently, information is not available to model this parameter for the BCVI. For the GCWA, a distance of ≤1000 m leads to a higher quality ranking.

V_ADD_YR_OCC: Adds a count of "1" to V_LAST_OCCUP if cell is not occupied by BCVI in breeding season.

V_RESET_OCC: Resets V_LAST_OCCUP to "0" if cell is occupied by BCVI in breeding season.

V_LAST_OCCUP: The number of years since BCVI occupied a cell.

V_ENHANCE: A 0/1 switch, equal to 1 when V_LAST_OCCUP is ≥5 years. Used by the Management submodel to influence habitat enhancement decisions.

S_[BCV,GCW]_OCCUPY_[SY,ASY]: Shell script output map of numbers of BCVI or GCWA individuals (SY or ASY) at the beginning of the breeding season.

[V,W]_OCCUPIED: A 0/1 switch, equal to 1 when the cell is occupied by either an SY or an ASY individual.

[V,W]_PREV_OCCUP: A 0/1 switch, equal to 1 when the cell was occupied the previous breeding season by the same species for which it is evaluated in the current run. A value of 1 leads to a higher habitat quality ranking.

[V,W]_QUAL_REGION: A 0/1 switch, equal to 1 when patch size and patch distance (landscape) factors increase the value of habitat quality of a cell.

[V,W]_QUAL_HISTORY: 0/1 switch, equal to 1 when previous occupancy leads to a higher value of habitat quality of a cell.

S_MECH_HABITAT_STRIP_ACTL: A 0/1 switch, equal to 1 when the cell was managed by stripcutting, and leading to higher habitat quality values for BCVI (see text for additional information).

[V,W]_QUALITY: The overall quality of a cell for BCVI or GCWA breeding. Values range from 0 (unsuitable) to 3 (high quality).

Equations.

INFLOWS:

A-1 V_ADD_YR_OCC = IF (QUARTER = 2 and V_LAST_OCCUP >= 1 and V_OCCUPIED = 0) THEN 1 ELSE IF (QUARTER = 2 and V_LAST_OCCUP = 0 and V_OCCUPIED = 1) THEN 1 ELSE 0

OUTFLOWS:

A-2 V_RESET_OCC = IF (QUARTER =2 and V_OCCUPIED >= 1) THEN (V_LAST_OCCUP -1) ELSE 0

A-3 V_LAST_OCCUP(t) = V_LAST_OCCUP(t - dt) + (V_ADD_YR_OCC - V_RESET_OCC) * dt

A-4 INIT V_LAST_OCCUP = G_BCV_LAST_OCCUPY

A-5 V_OCCUPIED = IF S_BCV_OCCUPY_ASY = 1 then 2 else if S_BCV_OCCUPY_SY = 1 then 1 else 0

A-6 V_PREV_OCCUP = if (delay(V_OCCUPIED,4) >=1) then 1 else 0

A-7 W_OCCUPIED = IF S_GCW_OCCUPY_ASY = 1 then 2 else if S_GCW_OCCUPY_SY = 1 THEN 1 ELSE 0

A-8 W_PREV_OCCUP = if (delay(W_OCCUPIED,4) >=1) then 1 else 0

A-9 V_ENHANCE = IF (V_LAST_OCCUP > 5) THEN 1 ELSE 0

A-10 V_SUIT_COMM = if (H_COMMUNITY <= 8 or H_COMMUNITY >= 13) then 0 else (if H_COMMUNITY = 11 or H_COMMUNITY = 12 then 1 else 2)

A-11 V_SUIT_TIME = IF (H_TIME_IN_COMM < 20 or H_TIME_IN_COMM > 120) then 0 else (if H_TIME_IN_COMM >= 20 and H_TIME_IN_COMM < 28 then 1 else (if H_TIME_IN_COMM > 100 and H_TIME_IN_COMM <=120 then 1 else 2))

A-12 V_HAB_SUIT = if (G_BCV_SUIT_PHYS >= 2) and (H_COMMUNITY = 5 or H_COMMUNITY = 6) and (H_TIME_IN_COMM <= 10) then 1 else if (G_BCV_SUIT_PHYS * V_SUIT_COMM * V_SUIT_TIME = 0) then 0 else if (G_BCV_SUIT_PHYS = 1 and V_SUIT_TIME = 1) then 1 else if (G_BCV_SUIT_PHYS = 2 and V_SUIT_COMM = 1 and V_SUIT_TIME = 1)then 1 else if (G_BCV_SUIT_PHYS = 1 and V_SUIT_COMM = 1 and V_SUIT_TIME = 2) then 1 else if (G_BCV_SUIT_PHYS = 3 and V_SUIT_TIME= 2) then 3 else if (G_BCV_SUIT_PHYS = 2 and V_SUIT_COMM = 2 and V_SUIT_TIME = 2) then 3 else 2

A-13 W_SUIT_COMM = if H_COMMUNITY = 5 then 2 else if (H_COMMUNITY = 4or H_COMMUNITY = 6) then 1 else 0

A-14 W_SUIT_TIME = 0 then 0 else if (G_GCW_SUIT_PHYS = 1 and W_SUIT_COMM = 1) then 1 else if (W_SUIT_TIME = 1) then 2 else 3

A-15 W_HAB_SUIT = if (G_GCW_SUIT_PHYS = 1and H_COMMUNITY = 6 and H_TIME_IN_COMM <= 10) then 1 else if G_GCW_SUIT_PHYS * W_SUIT_COMM * W_SUIT_TIME = 0 then 0 else if (G_GCW_SUIT_PHYS =1 and W_SUIT_COMM = 1) then 1 else if (W_SUIT_TIME = 1) then 2 else 3

A-16 V_QUAL_HISTORY = if (V_PREV_OCCUP = 1) then 1 else 0

A-17 V_QUAL_REGION = if (V_PATCH_DIST >= 0 or V_PATCH_SIZE >= 0) then 0 else 0

A-18 V_QUALITY = if (V_HAB_SUIT = 0) then 0 else if (V_HAB_SUIT + V_QUAL_REGION + V_QUAL_HISTORY + S_MECH_HABITAT_STRIP_ACTL) >= 3 then 3 else (V_HAB_SUIT + V_QUAL_REGION + V_QUAL_HISTORY + S_MECH_HABITAT_STRIP_ACTL)

A-19 W_QUAL_HISTORY = if (W_PREV_OCCUP = 1) then 1 else 0

A-20 W_QUAL_REGION = if (S_GCW_PATCH_DIST <= 5 or S_GCW_PATCH_SIZE >= 25) then 1 else 0

A-21 W_QUALITY = if (W_HAB_SUIT = 0) then 0 else if (W_HAB_SUIT + W_QUAL_REGION + W_QUAL_HISTORY) >= 3 then 3 else (W_HAB_SUIT + W_QUAL_REGION + W_QUAL_HISTORY)

Fecundity

New definitions.

S_FIRE_ACTL: Simulation output of areas burned by accidental fires.

M_PCT_PARA: The percent probability of a nest being parasitized by BHCOs. Separate values for live-fire areas and non-live-fire areas are calculated. Range: 0-100.

V_FLEDGE: The number of female fledglings produced in a cell.

W_PROB_PARA: A constant probability that a territory will be parasitized by BHCOs within the breeding season. Currently = 0.005.

W_RAND_PARA: Random number between 0 and 1.

W_PARA: A 0/1 switch, equal to 1 when W_RAND_PARA is less than W_PROB_PARA. It means that the territory is parasitized by BHCOs at least once in the breeding season.

W_RAND_FLDG: Random number between 0 and 1.

W_FLDG_[SY,ASY]: Probability of a cell inhabited by an SY or ASY female producing one or two female fledglings.

W_FLEDGE: The number of female fledglings produced in a cell.

Equations.

A-22 V_FLEDGE = if (V_QUALITY = 0 or S_FIRE_ACTL = 1) then 0 else if (V_OCCUPIED >= 1 and V_QUALITY = 1) then (1.5308182 - (M_PCT_PARA * 0.009531) - (M_PCT_PARA * M_PCT_PARA * 0.000033)) else if (V_OCCUPIED >= 1 and V_QUALITY = 2) then (2.1321818 - (M_PCT_PARA * 0.013273) - (M_PCT_PARA * M_PCT_PARA * 0.000042)) else if (V_OCCUPIED >= 1 and V_QUALITY = 3) then (2.7518182 - (M_PCT_PARA * 0.013748) - (M_PCT_PARA * M_PCT_PARA * 0.000086)) ELSE 0

A-23 W_RAND_PARA = RANDOM(0,1)

A-24 W_PROB_PARA = .005

A-25 W_PARA = IF (W_RAND_PARA <= W_PROB_PARA) THEN 1 ELSE 0

A-26 W_RAND_FLDG = RANDOM (0,1)

A-27 W_FLDG_ASY = if (W_QUALITY >= 1 and W_RAND_FLDG <= 0.0889) then0 else if (W_QUALITY >= 1 and W_RAND_FLDG <= 0.7556) then 1 else if (W_QUALITY >= 1 and W_RAND_FLDG <= 1.000) then 2 else 0

A-28 W_FLDG_SY = if (W_QUALITY >= 1 and W_RAND_FLDG <= 0.1429) then 0 else if (W_QUALITY >= 1 and W_RAND_FLDG <= 0.8929) then 1 else if (W_QUALITY >= 1 and W_RAND_FLDG <= 1.000) then 2 else 0

A-29 W_FLEDGE = if (S_FIRE_ACTL = 1) then 0 else if (W_OCCUPIED = 1 and W_PARA = 1) then (W_FLDG_SY - 1) else if (W_OCCUPIED = 2 and W_PARA= 1) then (W_FLDG_ASY - 1) else if (W_OCCUPIED = 1) then W_FLDG_SY else if (W_OCCUPIED = 2) then W_FLDG_ASY else 0

Migration and Mortality

New definitions.

[V,W]_RAND_MGTN_[SY,ASY]: Random numbers between 0 and 1, generated to determine whether fledgling(s) from a cell die during winter migration.

[V,W]_DIE_MGTN_[SY,ASY]: The number of fledglings from a given cell that die during winter migration.

V_MIG_SY: The actual number of fledglings that successfully migrate to breed in the subsequent year (a floating point number, needs to be rounded off to be allocated to a cell).

[V,W]_MIGRATE_[SY,ASY]: The number of female birds that return to Fort Hood to breed the subsequent year; the number of survivors over winter migration.

Equations.

A-30 V_RAND_MGTN_ASY = RANDOM (0,1)

A-31 V_RAND_MGTN_SY = RANDOM (0,1)

A-32 V_DIE_MGTN_ASY = if (V_QUALITY >= 1 and V_RAND_MGTN_ASY <=0.5500) then 1 else 0

A-33 V_DIE_MGTN_SY = if (V_QUALITY >=1 and V_RAND_MGTN_SY <= 0.7744) then 2 else if (V_QUALITY >=1 and V_RAND_MGTN_SY <= 0.8800) then 1 else 0

A-34 V_MIGRATE_ASY = (1 - V_DIE_MGTN_ASY)

A-35 V_MIG_SY = max (V_FLEDGE - V_DIE_MGTN_SY, 0)

A-36 V_MIGRATE_SY = ROUND (V_MIG_SY)

A-37 W_RAND_MGTN_ASY = RANDOM (0,1)

A-38 W_RAND_MGTN_SY = RANDOM (0,1)

A-39 W_DIE_MGTN_ASY = if (W_QUALITY >= 1 and W_RAND_MGTN_ASY <= 0.4300) then 1 else 0

A-40 W_DIE_MGTN_SY = if (W_QUALITY >=1 and W_RAND_MGTN_SY <= 0.3600) then 2 else if (W_QUALITY >=1 and W_RAND_MGTN_SY <= 0.60) then 1 else 0

A-41 W_MIGRATE_ASY = (1 - W_DIE_MGTN_ASY)

A-42 W_MIGRATE_SY = max (W_FLEDGE - W_DIE_MGTN_SY, 0)

Appendix B: The Habitat Submodel Variables and Equations

Naming Conventions

V or W = variable created in the Avian submodel
H = variable generated in the Habitat submodel
M = variable generated in the Management submodel
F = variable generated in the Accidental Fire submodel
G = map stored in the Map Input submodel
S = variable created by simulation results

Definitions and Equations

Community Transitions

Definitions.

H_COMMUNITY: A state variable equal to the community type code listed in Table 1; equivalent to one of the 15 recognized plant communities on Fort Hood. This variable is initialized with the GRASS map "G_COMMUNITY." It is changed in value by H_CHANGE_COMM.

H_CHANGE_COMM: This variable allows changes in plant community type by changing the state value of H_COMMUNITY. It is equivalent to the transition equations output by management and land use transition matrixes, which are transferred by the following seven variables:

> H_FIRE_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to an accidental fire.
>
> H_PBURN_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to a prescribed burning action.

H_JUNIPERCUT_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to juniper cutting.

H_CLEARCUT_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to clearcutting with a hydroaxe.

H_STRIPCUT_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to stripcutting with a hydroaxe.

H_TRAINING CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to an increase in military training from low levels to either moderate or intensive levels.

H_LANDUSE_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to long-term influences such as grazing and military training land uses, or natural succession.

Equations.

B-1 H_COMMUNITY(t) = H_COMMUNITY(t - dt) + (H_CHANGE_COMM) * dt
B-2 INIT H_COMMUNITY = G_COMMUNITY

INFLOWS:

B-3 H_CHANGE_COMM = IF (H_FIRE_CHANGE > 0) THEN H_FIRE_CHANGE ELSE IF (H_TRAINING_CHANGE > 0) THEN H_TRAINING_CHANGE ELSE IF (H_PBURN_CHANGE > 0) THEN H_PBURN_CHANGE ELSE IF (H_JUNIPERCUT_CHANGE > 0) THEN H_JUNIPERCUT_CHANGE ELSE IF (H_CLEARCUT_CHANGE > 0) THEN H_CLEARCUT_CHANGE ELSE IF (H_STRIPCUT_CHANGE > 0) THEN H_STRIPCUT_CHANGE ELSE IF (H_LANDUSE_CHANGE > 0) THEN H_LANDUSE_CHANGE ELSE 0

Successional Time

New definitions.

H_COMMUNITY_PREV: A state variable for the community type from the previous time step. Initialized with a value of 0.

H_CHANGE_LAG: Identifies the type of community in the previous time step, allowing a comparison to be made to determine whether a transition occurred.

H_TRANSITION: By subtracting the community type value in the current time step from the community type value in the previous time step, this variable reveals whether a transition in community type has actually occurred or not.

H_TIME_IN_COMM: A state variable that increases by a value of 1 for each time step that no transition in community type occurs, and is reset to 0 following a transition. Represents the number of time steps that a cell has been in the current community type. Initialized with G_STAGE_TIME.

H_TIME_ADD: Adds a value of 1 to the H_TIME_IN_COMM variable during each time step that a transition does not occur.

H_TIME_RESET: The number of time steps that must be subtracted from the H_TIME_IN_COMM variable to reset to 0 following a transition in community type.

Equations.

B-4 H_TRANSITION = IF (H_COMMUNITY = H_COMMUNITY_PREV) THEN 0 ELSE 1

B-5 H_COMMUNITY_PREV(t) = H_COMMUNITY_PREV(t - dt) + (H_CHANGE_LAG) * dt

B-6 INIT H_COMMUNITY_PREV = 0

INFLOWS:

B-7 H_CHANGE_LAG = H_COMMUNITY - H_COMMUNITY_PREV

B-8 H_TIME_IN_COMM(t) = H_TIME_IN_COMM(t - dt) + (H_TIME_ADD - H_TIME_RESET) * dt

B-9 INIT H_TIME_IN_COMM = G_STAGE_TIME

INFLOWS:

B-10 H_TIME_ADD = IF (H_TRANSITION = 0) THEN 1 ELSE 0

OUTFLOWS:

B-11 H_TIME_RESET = IF (H_TRANSITION = 1) THEN H_TIME_IN_COMM ELSE 0

Details of the LANDUSE CHANGE Equation

New definitions.

G_TRAINING: GRASS map from the Map Input submodel. Depicts static levels of disturbance due to military training. Category 1 = low, 2 = moderate, and 3 = intense.

G_GRAZING: GRASS map from the Map Input submodel. Depicts static levels of disturbance due to cattle grazing. Category 1 = none, 2 = light, 3 = moderate, and 4 = intensive.

H_LAND_USE: Represents the long-term land use policies regarding military training and cattle grazing. Category 1 = moderate or intense military training, regardless of cattle grazing, 2 = moderate or intensive cattle grazing, but no disturbance due to military training, and 3 = no disturbance due to training and no or light disturbance due to grazing.

G_SOILS_ASSOC: Static GRASS map from the Map Input submodel. Depicts six types of soils associations mapped on Fort Hood, 1 = Eckrant-Real Rock, 2 = Nuff-Cho, 3 = Slidell-Topsey-Brackett, 4 = Doss-Real-Krum, 5 = Bosque-Frio-Lewisville, and 6 = Bastil-Minwells.

H_SOIL_GROUP: A simplified categorization of the six soil groups above. Category 1 = Eckrant-Real Rock, 2 = Nuff-Cho, Slidell-Topsey-Brackett, Doss-Real-Krum, and Bosque-Frio-Lewisville, and 3 = Bastil-Minwells.

G_ASPECT: Static GRASS map from Map Input submodel. Represents the aspect of slope of the land, in degrees from North.

G_SLOPE: Static GRASS map from Map Input submodel. Represents the slope of the land in degrees: ranges from 0 to 27 across the installation.

H_STEEP_SOUTH: Variable that identifies south-facing cells over 4 degrees in slope, with a 0/1 switch.

H_SOIL_*x*_USE_*n*: The formulae for adding and subtracting community type code values to allow community transitions. *x* ranges from 1 to 3 according to the H_SOIL_GROUP variable; *n* ranges from 1 to 3 according to the H_LAND_USE variable.

H_LANDUSE_CHANGE: The formula for adding and subtracting community type code values to allow a change in community type due to long-term influences such as grazing and military training land uses, or natural succession. It selects the appropriate "H_SOIL_*x*_USE_*n*" equation according to soil group and land use policy.

Equations.

B-12 H_LANDUSE_CHANGE = IF (H_SOIL_GROUP = 1) AND (H_LAND_USE = 1) THEN H_SOIL1_USE1 ELSE IF (H_SOIL_GROUP = 1) AND (H_LAND_USE = 2) THEN H_SOIL1_USE2 ELSE IF (H_SOIL_GROUP = 1) AND (H_LAND_USE = 3) THEN H_SOIL1_USE3 ELSE IF (H_SOIL_GROUP = 2) AND (H_LAND_USE = 1) THEN H_SOIL2_USE1 ELSE IF (H_SOIL_GROUP = 2) AND (H_LAND_USE = 2) THEN H_SOIL2_USE2 ELSE IF (H_SOIL_GROUP = 2) AND (H_LAND_USE = 3) THEN H_SOIL2_USE3 ELSE IF (H_SOIL_GROUP = 3) AND (H_LAND_USE = 1) THEN H_SOIL3_USE1 ELSE IF (H_SOIL_GROUP = 3) AND (H_LAND_USE = 2) THEN H_SOIL3_USE2 ELSE IF (H_SOIL_GROUP = 3) AND (H_LAND_USE = 3) THEN H_SOIL3_USE3 ELSE 0

B-13 H_SOIL_GROUP = IF (G_SOILS_ASSOC = 1) THEN 1 ELSE IF G_SOILS_ASSOC = 6 THEN 3 ELSE 2

B-14 H_STEEP_SOUTH = IF (G_SLOPE < 4) THEN 0 ELSE IF (G_ASPECT >=16 AND G_ASPECT <= 22) THEN 1 ELSE 0

B-15 H_LAND_USE = IF (G_TRAINING >=2) THEN 1 ELSE IF (G_GRAZING =3 OR G_GRAZING = 4) THEN 2 ELSE 3

B-16 H_SOIL1_USE1 = IF (H_COMMUNITY = 6) AND (G_TRAINING = 3) AND (H_TIME_IN_COMM >= 20) THEN 7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 40) AND (H_RAND_TRANSITION <= 0.6) THEN -7

ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 40) AND (H_RAND_TRANSITION > 0.6) THEN -5 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 60) THEN -4 ELSE IF (H_COMMUNITY = 12) AND (H_TIME_IN_COMM >= 60) THEN -6 ELSE 0

B-17 H_SOIL1_USE2 = IF (H_COMMUNITY = 2) AND (H_TIME_IN_COMM >= 20) THEN -1 ELSE IF (H_COMMUNITY = 4) AND (H_TIME_IN_COMM >= 40) THEN 2 ELSE IF (H_COMMUNITY = 6 AND G_GRAZING = 4 AND H_STEEP_SOUTH = 1 AND H_TIME_IN_COMM >= 120) THEN -4 ELSE IF (H_COMMUNITY = 6 AND H_TIME_IN_COMM >= 40) THEN -1 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 16) THEN -1 ELSE IF (H_COMMUNITY= 13) AND (H_TIME_IN_COMM >= 20) THEN -11 ELSE IF (H_COMMUNITY = 15) AND (H_TIME_IN_COMM >=200) THEN -13 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 20) AND (H_RAND_TRANSITION <= 0.5) THEN -7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 20) AND (H_RAND_TRANSITION > 0.5) THEN -5 ELSE IF (H_COMMUNITY = 9) AND (H_TIME_IN_COMM >= 52) THEN -4 ELSE IF (H_COMMUNITY = 11) AND (H_TIME_IN_COMM >= 52) THEN -6 ELSE IF (H_COMMUNITY = 12) AND (H_TIME_IN_COMM >= 16) THEN -1 ELSE 0

B-18 H_SOIL1_USE3 = IF (H_COMMUNITY = 2) AND (H_TIME_IN_COMM >= 120) THEN -1 ELSE IF (H_COMMUNITY = 6 AND H_TIME_IN_COMM >= 40) THEN -1 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 8) THEN -1 ELSE IF (H_COMMUNITY = 13) AND (H_TIME_IN_COMM >= 40) THEN -7 ELSE IF (H_COMMUNITY = 15) AND (H_TIME_IN_COMM >=200) THEN -13 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 12) AND (H_RAND_TRANSITION <= 0.6) THEN -7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 12) AND (H_RAND_TRANSITION > 0.6) THEN -5 ELSE IF (H_COMMUNITY = 9) AND (H_TIME_IN_COMM >= 44) THEN -4 ELSE IF (H_COMMUNITY = 11) AND (H_TIME_IN_COMM >= 44) THEN -6 ELSE IF (H_COMMUNITY = 12) AND (H_TIME_IN_COMM >= 8) THEN -1 ELSE 0

B-19 H_SOIL2_USE1 = IF (H_COMMUNITY = 6) AND (G_TRAINING = 3) and (H_TIME_IN_COMM >= 20) THEN 7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 40) AND (H_RAND_TRANSITION <= 0.6) THEN -7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 40) AND (H_RAND_TRANSITION > 0.6) THEN -5 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 60) THEN -4 ELSE IF (H_COMMUNITY = 12) AND (H_TIME_IN_COMM >= 60) THEN -6 ELSE 0

B-20 H_SOIL2_USE2 = IF (H_COMMUNITY = 2) AND (H_TIME_IN_COMMUNITY = 20) THEN -1 ELSE IF (H_COMMUNITY = 13) AND

(H_TIME_IN_COMMUNITY = 20) THEN -11 ELSE IF (H_COMMUNITY = 15) AND (H_TIME_IN_COMM >=200)
THEN -13 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 20)
THEN -7 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 16)
THEN -1 ELSE IF (H_COMMUNITY = 9) AND (H_TIME_IN_COMM >= 60)
THEN -4 ELSE 0

B-21 H_SOIL2_USE3 = IF (H_COMMUNITY = 2) AND (H_TIME_IN_COMM >= 60) THEN -1 ELSE IF (H_COMMUNITY = 6 AND H_TIME_IN_COMM >= 40) THEN -1 ELSE IF (H_COMMUNITY= 13) AND (H_TIME_IN_COMM >= 40) THEN -7 ELSE IF
(H_COMMUNITY = 15) AND (H_TIME_IN_COMM >=200) THEN -13 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 12) THEN -7 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 8) THEN -1 ELSE IF (H_COMMUNITY = 9) AND (H_TIME_IN_COMM >= 44) THEN -4 ELSE 0

B-22 _SOIL3_USE1 = IF (H_COMMUNITY = 4) AND (G_TRAINING = 3) AND (H_TIME_IN_COMM >= 200) THEN 9 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 40) AND (H_RAND_TRANSITION <= 0.6) THEN -7 ELSE
IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 40) AND
(H_RAND_TRANSITION > 0.6) THEN -5 ELSE IF (H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 60) THEN -4 ELSE IF (H_COMMUNITY = 12) AND
(H_TIME_IN_COMM >= 60) THEN -6 ELSE 0

B-23 H_SOIL3_USE2 = IF (H_COMMUNITY = 2) AND (H_TIME_IN_COMMUNITY = 20) THEN -1 ELSE IF (H_COMMUNITY = 13) AND (H_TIME_IN_COMMUNITY = 20) THEN -11 ELSE IF (H_COMMUNITY = 12) AND (H_TIME_IN_COMM >= 16) THEN
-1 ELSE IF (H_COMMUNITY = 15) AND (H_TIME_IN_COMM >=200) THEN
-13 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 20) AND
(H_RAND_TRANSITION <= 0.5) THEN -7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 20) AND (H_RAND_TRANSITION > 0.5) THEN -5 ELSE IF (H_COMMUNITY = 9) AND (H_TIME_IN_COMM >= 60) THEN -4 ELSE IF
(H_COMMUNITY = 11) AND (H_TIME_IN_COMM >= 60) THEN -6 ELSE IF
(H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 16) THEN -1 ELSE 0

B-24 H_SOIL3_USE3 = IF (H_COMMUNITY = 4) AND (H_TIME_IN_COMM >= 80)
THEN -1 ELSE IF (H_COMMUNITY = 6) AND (H_TIME_IN_COMM >= 40)
THEN -1 ELSE IF (H_COMMUNITY = 12) AND (H_TIME_IN_COMM >= 8) THEN -1 ELSE IF (H_COMMUNITY = 13) AND (H_TIME_IN_COMM >= 40) THEN -7 ELSE IF
(H_COMMUNITY = 15) AND (H_TIME_IN_COMM >=200) THEN -13 ELSE IF
(H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 12) AND
(H_RAND_TRANSITION <= 0.6) THEN -7 ELSE IF (H_COMMUNITY = 17) AND (H_TIME_IN_COMM >= 12) AND (H_RAND_TRANSITION > 0.6) THEN -5 ELSE IF

(H_COMMUNITY = 9) AND (H_TIME_IN_COMM >= 44) THEN -4 ELSE IF
(H_COMMUNITY = 11) AND (H_TIME_IN_COMM >= 44) THEN -6 ELSE IF
(H_COMMUNITY = 10) AND (H_TIME_IN_COMM >= 8) THEN -1 ELSE 0

Flammability of Community Types

New definitions.

H_BASE_FLAM: Flammability rankings for ground fire conditions, low to moderate grazing intensity, and short time in community. Flammability rankings range from 0 (inflammable) to 4 (Highly flammable).

H_ADJ_FLAM: Values to adjust ground fire flammability rankings based on more intensive grazing levels, community type, and time in community.

H_FLAM_GROUND: Final flammability rankings for ground fire conditions. Values range from 0 to 3.

H_FLAM_CROWN: Flammability rankings for crown fire conditions, based on community type and grazing intensity. Values range from 0 to 3.

Equations.

B-25 H_BASE_FLAM = GRAPH(H_COMMUNITY) *

(1.00, 0.00), (2.00, 2.00), (3.00, 2.00), (4.00, 3.00), (5.00, 0.00), (6.00, 2.00), (7.00, 0.00), (8.00, 2.00), (9.00, 2.00), (10.0, 3.00), (11.0, 0.00), (12.0, 2.00), (13.0, 3.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 2.00)

B-26 H_ADJ_FLAM = if (G_GRAZING = 3 and H_TIME_IN_COMM > 20 and (H_COMMUNITY = 2 or H_COMMUNITY = 6 or H_COMMUNITY = 8 or H_COMMUNITY = 12)) then -1 else if (G_GRAZING < 3 and H_TIME_IN_COMM > 40 and (H_COMMUNITY = 2 or H_COMMUNITY = 6 or H_COMMUNITY = 8 or
H_COMMUNITY = 12)) then -1 else if (G_GRAZING = 3 and (H_COMMUNITY = 4 or
H_COMMUNITY = 10 or H_COMMUNITY = 13)) then -1 else 0

B-27 H_FLAM_GROUND = if (H_BASE_FLAM = 0 or G_GRAZING = 4) then 0 else max(H_BASE_FLAM + H_ADJ_FLAM, 1)

B-28 H_FLAM_CROWN = if (H_COMMUNITY = 15 or H_COMMUNITY = 16) then 0 else if (H_COMMUNITY = 1 or H_COMMUNITY = 5 or H_COMMUNITY = 7 or

H_COMMUNITY = 11) then 3 else if (G_GRAZING = 4 and (H_COMMUNITY = 2 or H_COMMUNITY = 4 or H_COMMUNITY = 6 or H_COMMUNITY = 13)) then 1 else 2

Effects of Management Activities

New definitions.

G_INCR_TRAINING: A user-developed GRASS map from the Map Input submodel that shows areas in which disturbance from military training is to be increased from none to moderate or intense levels.

S_MECH_BUFFER_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating mechanical juniper clearing for the purpose of buffer zone maintenance.

S_MECH_ENCROACH_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating mechanical clearing of encroaching juniper.

S_MECH_HABITAT_CLEAR_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating mechanical clearcutting for habitat enhancement.

S_MECH_HABITAT_STRIP_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating mechanical stripcutting for habitat enhancement.

S_PBURN_ENCROACH_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating prescribed burning to remove encroaching juniper.

S_PBURN_BUFFER_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating prescribed burning to clear juniper for the purpose of buffer zone maintenance.

S_PBURN_HABITAT_ACTUAL: A 0/1 switch calculated by the Management submodel and triggered by simulation output, designating prescribed burning to clear juniper for the purpose of habitat enhancement.

H_FIRE2: The formula for adding and subtracting community type code values to allow a change in community type due to a typical accidental fire, for all locations except steep, south-facing slopes.

Equations.

B-29 H_CLEARCUT_CHANGE = IF (S_MECH_HABITAT_CLEAR_ACTUAL = 0) THEN 0 ELSE IF (H_COMMUNITY = 5) THEN 12 ELSE IF (H_COMMUNITY = 6) THEN 11 ELSE 0

B-30 H_JUNIPERCUT_CHANGE = IF (S_MECH_BUFER_ACTUAL = 0 AND S_MECH_ENCROACH_ACTL = 0) THEN 0 ELSE IF (H_COMMUNITY = 1) THEN 12 ELSE IF (H_COMMUNITY = 2) THEN 11 ELSE 0

B-31 H_STRIPCUT_CHANGE = IF (S_MECH_HABITAT_STRIP_ACTUAL = 1 AND H_COMMUNITY = 5) THEN 1 ELSE 0

B-32 H_TRAINING_CHANGE = IF (G_INCR_TRAINING = 0) THEN 0 ELSE IF (H_COMMUNITY = 1) THEN 1 ELSE IF (H_COMMUNITY = 3) THEN 1 ELSE IF (H_COMMUNITY = 5) THEN 1 ELSE IF (H_COMMUNITY = 7) THEN 1 ELSE IF
(H_COMMUNITY = 9) THEN 1 ELSE IF (H_COMMUNITY = 11) THEN 1 ELSE 0

B-33 H_PBURN_CHANGE = IF (S_PBURN_BUFFER_ACTUAL = 1 OR S_PBURN_ENCROACH_ACTUAL = 1 OR S_PBURN_HABITAT_ACTUAL = 1) THEN H_FIRE2 ELSE 0

Effects of Accidental Fires

New definitions.

S_FIRE ACTUAL: A 0/1 switch calculated by the Accidental Fire section of the Habitat submodel and triggered by simulation output that designates the occurrence of an accidental fire.

H_FIRE1: The formula for adding and subtracting community type code values to allow a change in community type due to an accidental fire on steep, south-facing slopes.

Equations.

B-34 H_FIRE_CHANGE = IF (S_FIRE_ACTUAL = 0) THEN 0 ELSE IF (H_STEEP_SOUTH = 1) THEN H_FIRE1 ELSE H_FIRE2

B-35 H_FIRE1 = GRAPH(H_COMMUNITY) *

(1.00, 14.0), (2.00, 13.0), (3.00, 12.0), (4.00, 11.0), (5.00, 10.0), (6.00, 9.00), (7.00, 8.00), (8.00, 7.00), (9.00, 6.00), (10.0, 5.00), (11.0, 4.00), (12.0, 3.00), (13.0, 2.00)

B-36 H_FIRE2 = GRAPH(H_COMMUNITY) *

(1.00, 12.0), (2.00, 11.0), (3.00, 10.0), (4.00, 9.00), (5.00, 12.0), (6.00, 7.00), (7.00, 8.00), (8.00, 7.00), (9.00, 8.00), (10.0, 7.00), (11.0, 6.00), (12.0, 5.00), (13.0, 0.00)

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*These graphs are in the following format: (current community type code, new community type code in the event of fire). It is an alternative method for modeling transitions in STELLA.

Appendix C: The Management Submodel Variables and Equations

Naming Conventions

V or W = variable created in the Avian submodel
H = variable generated in the Habitat submodel
M = variable generated in the Management submodel
F = variable generated in the Accidental Fire submodel
G = map stored in the Map Input submodel
S = variable created by simulation results

Definitions and Equations

Management To Reduce Juniper Encroachment

Definitions.

H_COMMUNITY: A state variable equal to the community type code listed in Table 1; equivalent to one of the 15 recognized plant communities on Fort Hood. This parameter is initialized with the GRASS map "G_COMMUNITY," categories 1 to 15.
G_SLOPE: Static GRASS map from Map Input submodel. Represents the slope of the land in degrees, ranges from 0 to 27 across the installation.

G_RESTRICT DIST: GRASS map showing the number of cells a given cell is from areas that are recognized as endangered species habitat. This map is used to identify zones around protected habitat in which to model land use restrictions or management actions.

G_TRAIN_AREA: GRASS map of training areas, by number.

QUARTER: Time of year, divided into four equal units: Value of 1 = Jan-Mar, 2 = Apr-Jun, 3 = Jul-Sept, 4 = Oct-Dec.

S_GCW_SUITABLE_DIST: Simulation output map showing the number of cells a given cell is from suitable GCWA habitat.

G_GRAZING: GRASS map from the Map Input submodel. Depicts static levels of disturbance due to cattle grazing. Category 1 = none, 2 = light, 3 = moderate, and 4 = intensive.

H_TIME_IN_COMM: A state variable that increases by a value of 1 for each time step that no transition in community type occurs, and is reset to 0 following a transition. Represents the number of time steps that a cell has been in the current community type.

M_ENCROACH: A 0/1 switch, equal to 1 when the necessary (cell-specific) conditions exist to conduct juniper clearing. This variable is modeled through STELLA equations. It does not necessarily equal the cells that are actually managed.

M_MECH_ENCROACH_POTL: A 0/1 switch, equal to 1 when the necessary cell-specific and multi-cell conditions are met to conduct juniper cuts through mechanical means.

M_PBURN_ENCROACH_POTL: A 0/1 switch, equal to 1 when the necessary cell-specific and multi-cell conditions are met to conduct juniper cuts through prescribed burning.

Equations.

C-1 M_ENCROACH = if (G_SLOPE > 4 OR G_RESTRICT_DIST = 1 OR QUARTER = 2 OR QUARTER = 3) then 0 else if (H_COMMUNITY <= 2 and S_GCW_SUITABLE_DIST >= 3) then 1 else 0

C-2 M_MECH_ENCROACH_POTL = IF (M_ENCROACH = 1 AND M_PBURN_ENCROACH_POTL = 0) THEN 1 ELSE 0

C-3 M_PBURN_ENCROACH_POTL = IF (G_GRAZING = 4 OR H_COMMUNITY = 1) THEN 0 ELSE IF (M_ENCROACH = 1 AND G_GRAZING = 3 AND H_TIME_IN_COMM <= 20) THEN 1 ELSE IF (M_ENCROACH = 1 AND G_GRAZING <= 2 AND H_TIME_IN_COMM <= 40) THEN 1 ELSE 0

Management for Maintenance of Buffer Zones

New definitions.

M_BUFFER: A 0/1 switch, equal to 1 when the necessary (cell-specific) conditions exist to conduct juniper clearing to reduce fuel loads near GCWA habitat. This variable is modeled through STELLA equations. It does not necessarily equal the cells that are actually managed.

M_MECH_BUFFER_POTL: A 0/1 switch, equal to 1 when the necessary cell-specific and multi-cell conditions are met to clear buffer zones of reduced fuel loads near GCWA habitat through mechanical means.

M_PBURN_BUFFER_POTL: A 0/1 switch, equal to 1 when the necessary cell-specific and multi-cell conditions are met to clear buffer zones of reduced fuel loads near GCWA habitat through prescribed burning.

S_BCV_SUITABLE_DIST: Simulation output map showing the number of cells a given cell is from suitable BCVI habitat.

Equations.

C-4 M_BUFFER = if (G_SLOPE > 4 or G_RESTRICT_DIST = 1 or QUARTER = 2) then 0 else if (H_COMMUNITY <= 2 and (S_GCW_SUITABLE_DIST = 3 or S_BCV_SUITABLE_DIST = 3)) then 1 else 0

C-5 M_MECH_BUFFER_POTL = IF (M_BUFFER = 1 AND M_PBURN_BUFFER_POTL = 0) THEN 1 ELSE 0

C-6 M_PBURN_BUFFER_POTL = IF (G_GRAZING = 4 or H_COMMUNITY = 1) THEN 0 ELSE IF (M_BUFFER = 1 AND G_GRAZING = 3 AND H_TIME_IN_COMM <= 20) THEN 1 ELSE IF (M_BUFFER = 1 AND G_GRAZING <= 2 AND H_TIME_IN_COMM <= 40) THEN 1 ELSE 0

Management for BCVI Habitat Enhancement

New definitions.

M_HABITAT: A 0/1 switch, equal to 1 when the necessary (cell-specific) conditions exist to conduct BCVI habitat enhancement. This variable is modeled through STELLA equations. It does not necessarily equal the cells that are actually managed.

M_MECH_HABITAT_CLEAR_POTL: A 0/1 switch, equal to 1 when the necessary (cell-specific) conditions are met to mechanically clearcut to generate new BCVI habitat. This variable is modeled through STELLA equations. It does not necessarily equal the cells that are actually managed.

M_MECH_HABITAT_STRIP_POTL: A 0/1 switch, equal to 1 when the necessary (cell-specific) conditions are met to mechanically stripcut to generate new BCVI habitat. This variable is modeled through STELLA equations. It does not necessarily equal the cells that are actually managed.

M_PBURN_HABITAT_POTL: A 0/1 switch, equal to 1 when the necessary (cell-specific) conditions are met to do a prescribed burn to generate new BCVI habitat. This variable is modeled through STELLA equations. It does not necessarily equal the cells that are actually managed.

S_BCV_ENHANCE_DIST: The distance from cells that were occupied by BCVI in the past, but have not been occupied for 5 or more years. This captures the concept that habitat enhancement is most effective in sites that were previously chosen by BCVI for nesting, but are no longer appropriate, presumably due to successional changes.

S_BCV_OCCUPY_DIST: Simulation output map showing the number of cells a given cell is from occupied BCVI habitat.

S_GCW_OCCUPY_DIST: Simulation output map showing the number of cells a given cell is from occupied GCWA habitat.

Equations.

C-7 M_HABITAT = if (G_SLOPE > 4 or QUARTER = 2 or QUARTER = 3 or H_COMMUNITY < 5 or H_COMMUNITY > 6) then 0 else if (G_RESTRICT_DIST = 1 and S_BCV_ENHANCE_DIST <= 3 and S_BCV_OCCUPY_DIST > 2 and S_GCW_OCCUPY_DIST > 2) then 1 else 0

C-8 M_MECH_HABITAT_CLEAR_POTL = M_HABITAT

C-9 M_MECH_HABITAT_STRIP_POTL = IF (M_HABITAT = 1 AND H_COMMUNITY = 5) THEN 1 ELSE 0

C-10 M_PBURN_HABITAT_POTL = IF (H_COMMUNITY = 6 AND G_GRAZING = 4) THEN 0 ELSE M_HABITAT

Cowbird Control

New definitions.

M_TRAPDAYS_[LF, EARA, WERA, WEFH, CANT]: Trapping efforts (total sum of the number of days every trap was set within the second quarter) at the regional level. Initial values come from 1995 Fort Hood data but can be altered by users.

M_TRAP_EFFIC_[LF, EARA, WERA, WEFH, CANT]: Trapping efficiencies (number of females trapped per trap day) at the regional level. Initial values come from 1995 Fort Hood data but can be altered by users.

M_FEM_CB_TRAP: Total numbers of female cowbirds trapped.

M_FEM_CB_SHOOT: Total numbers of female cowbirds shot.

M_SHOOTDAYS: Estimated 1995 value for shooting effort (number of shooting excursions during the second quarter); can be altered by users.

M_SHOOT_EFFIC: 1989 value for shooting efficiency (number of females killed per shooting excursion); can be altered by users.

M_PCT_PARA: The percent probability of a nest being parasitized by BHCOs. Separate values for live fire areas and non-live fire areas are calculated. Range: 0-100.

M_PCT_MONITORED: The percent probability that a BCVI nest will be located by researchers and any BHCO eggs or nestlings killed. Based on location and historical nest location rates.

Equations.

C-11 M_PCT_PARA = IF (QUARTER = 2 AND G_TRNAREA_TYPE >= 3) THEN NORMAL(91.807209,11.0650332) - M_FEM_CB_TRAP * NORMAL(0.024825,0.0061658) ELSE IF (QUARTER = 2 AND G_TRNAREA_TYPE <= 2) THEN NORMAL(89.538144,8.96659) - M_FEM_CB_SHOOT * NORMAL(0.2611,0.095657) - M_FEM_CB_TRAP * NORMAL(0.028634,0.006279) + M_FEM_CB_SHOOT * M_FEM_CB_TRAP * NORMAL(0.0001202,0.000085) ELSE 0

C-12 M_TRAPDAYS_CANT = 153
M_TRAPDAYS_EARA = 1890

M_TRAPDAYS_LF = 0
M_TRAPDAYS_WEFH = 0
M_TRAPDAYS_WERA = 2074

C-13 M_SHOOTDAYS = 27

C-14 M_EFFIC_CANT = 1.3660
M_EFFIC_EARA = 0.4894
M_EFFIC_LF = 0.0664
M_EFFIC_WEFH = 0.0614
M_EFFIC_WERA = 0.8120

C-15 M_SHOOT_EFFIC = 1.5682

C-16 M_FEM_CB_SHOOT = M_SHOOTDAYS * M_SHOOT_EFFIC

C-17 M_FEM_CB_TRAP = M_TRAPDAYS_LF * M_EFFIC_LF + M_TRAPDAYS_CANT * M_EFFIC_CANT + M_TRAPDAYS_EARA * M_EFFIC_EARA + M_TRAPDAYS_WERA * M_EFFIC_WERA + M_TRAPDAYS_WEFH * M_EFFIC_WEFH

C-18 M_PCT_MONITORED = IF (QUARTER = 2 and G_BCV_STUDY_SITES = 1) then 75.32 else if (QUARTER = 2 and G_BCV_STUDY_SITES = 2) then 89.10 else 0

Appendix D: The Accidental Fire Submodel Variables and Equations

Naming Conventions

V or W = variable created in the Avian submodel
H = variable generated in the Habitat submodel
M = variable generated in the Management submodel
F = variable generated in the Accidental Fire submodel
G = map stored in the Map Input submodel
S = variable created by simulation results

Definitions and Equations

Seasonal Adjustment

Definitions.

F_ANNUAL_RAND: Total number of accidental fires that will be allocated annually. This is a random number generated within the bounds of available historical data. This value remains the same for all four quarters in a given year.

F_ANNUAL_IN: Inflow to F_ANNUAL_RAND that generates the random number at the beginning of each new year.

F_ANNUAL_OUT: Outflow from F_ANNUAL_RAND. At the end of each year, it removes the value from the previous year so that a new random number takes effect.

QUARTER: Time of year, divided into four equal units: Value of 1 = Jan-Mar, 2 = Apr-Jun, 3 = Jul-Sept, 4 = Oct-Dec.

F_QUART_x_RAND: State variable representing the number of accidental fires allocated to each of the four quarters (x) of the year, randomly generated within historical bounds.

F_QUART_x_IN: Inflow to each F_QUART_x_RAND variable that generates the random number at the beginning of each new year.

F_QUART_x_OUT: Outflow from F_QUART_x_RAND variables. At the end of each year, it removes the value from the previous year so that a new random number takes effect.

F_PCT_QUART_x: Percent of total annual fires calculated for each quarter.

F_QUART_SUM: The randomly generated counts of fires summed over four quarters, summation is equal to F_ANNUAL_RAND.

F_PCT_QUART: The percent of total annual fires associated with the current quarter.

Equations.

D-1 F_ANNUAL_RAND(t) = F_ANNUAL_RAND(t - dt) + (F_ANNUAL_IN - F_ANNUAL_OUT) * dt

D-2 INIT F_ANNUAL_RAND = 78

INFLOWS:

D-3 F_ANNUAL_IN = if (QUARTER = 4) then random (45,123) else 0

OUTFLOWS:

D-4 F_ANNUAL_OUT = if (QUARTER = 4) then F_ANNUAL_RAND else 0

D-5 F_QUART1_RAND(t) = F_QUART1_RAND(t - dt) + (F_QUART1_IN - F_QUART1_OUT) * dt

D-6 INIT F_QUART1_RAND = 4.5026

INFLOWS:

D-7 F_QUART1_IN = if (QUARTER = 4) then random (3.2520,26.0869) else 0

OUTFLOWS:

D-8 F_QUART1_OUT = if (QUARTER = 4) then F_QUART1_RAND else 0

D-9 F_QUART2_RAND(t) = F_QUART2_RAND(t - dt) + (F_QUART2_IN - F_QUART2_OUT) * dt

D-10 INIT F_QUART2_RAND = 3.2569

INFLOWS:

D-11 F_QUART2_IN = if (QUARTER = 4) then random (2.2222,10.8695) else 0

OUTFLOWS:

D-12 F_QUART2_OUT = if (QUARTER = 4) then F_QUART2_RAND else 0

D-13 F_QUART3_RAND(t) = F_QUART3_RAND(t - dt) + (F_QUART3_IN - F_QUART3_OUT) * dt

D-14 INIT F_QUART3_RAND = 69.2546

INFLOWS:

D-15 F_QUART3_IN = if (QUARTER = 4) then random (35.5556,91.0569) else 0

OUTFLOWS:

D-16 F_QUART3_OUT = if (QUARTER = 4) then F_QUART3_RAND else 0

D-17 F_QUART4_RAND(t) = F_QUART4_RAND(t - dt) + (F_QUART4_IN - F_QUART4_OUT) * dt

D-18 INIT F_QUART4_RAND = 9.3652

INFLOWS:

D-19 F_QUART4_IN = if (QUARTER = 4) then random (0,51.1111) else 0

OUTFLOWS:

D-20 F_QUART4_OUT = if (QUARTER = 4) then F_QUART4_RAND else 0

D-21 F_QUART_SUM = F_QUART1_RAND + F_QUART2_RAND + F_QUART3_RAND + F_QUART4_RAND

D-22 F_PCT_QUART1 = 100 * F_QUART1_RAND / F_QUART_SUM

D-23 F_PCT_QUART2 = 100 * F_QUART2_RAND / F_QUART_SUM

D-24 F_PCT_QUART3 = 100 * F_QUART3_RAND / F_QUART_SUM

D-25 F_PCT_QUART4 = 100 * F_QUART4_RAND / F_QUART_SUM

D-26 F_PCT_QUART = if (QUARTER = 1) then F_PCT_QUART1 else if (QUARTER = 2) then F_PCT_QUART2 else if (QUARTER = 3) then F_PCT_QUART3 else F_PCT_QUART4

Regional Adjustment

New definitions.

F_TA_[DUD, LVF, GNL]_RAND: State variable representing the number of accidental fires allocated to each of the three regions, randomly generated within historical bounds.

F_TA_[DUD, LVF, GNL]_IN: Inflow to each F_TA_[DUD, LVF, GNL]_RAND variable that generates the random number at the beginning of each new year.

F_TA_[DUD, LVF, GNL]_OUT: Outflow from F_TA_[DUD, LVF, GNL]_RAND variables. At the end of each year, it removes the value from the previous year so that a new random number takes effect.

F_PCT_TA_[DUD, LVF, GNL]: Percent of total annual fires calculated for each region.

F_TA_SUM: The randomly generated counts of fires summed over the three regions, summation is equal to F_ANNUAL_RANDOM.

F_PCT_TA: The percent of total annual fires associated with the appropriate region.

G_TRNAREA_TYPE: GRASS map showing the three regions used to allocate fires, categories = DUD, GNL, and LVF regions.

Equations.

D-27 F_TA_DUD_RAND(t) = F_TA_DUD_RAND(t - dt) + (F_TA_DUD_IN - F_TA_DUD_OUT) * dt

D-28 INIT F_TA_DUD_RAND = 5.2456

INFLOWS:

D-29 F_TA_DUD_IN = if (QUARTER = 4) then random (0,11.4649) else 0

OUTFLOWS:

D-30 F_TA_DUD_OUT = if (QUARTER = 4) then F_TA_DUD_RAND else 0

D-31 F_TA_GNL_RAND(t) = F_TA_GNL_RAND(t - dt) + (F_TA_GNL_IN - F_TA_GNL_OUT) * dt

D-32 INIT F_TA_GNL_RAND = 11.2589

INFLOWS:

D-33 F_TA_GNL_IN = if (QUARTER = 4) then random (4.4586,22.2222) else 0

OUTFLOWS:

D-34 F_TA_GNL_OUT = if (QUARTER = 4) then F_TA_GNL_RAND else 0

D-35 F_TA_LVF_RAND(t) = F_TA_LVF_RAND(t - dt) + (F_TA_LVF_IN - F_TA_LVF_OUT) * dt

D-36 INIT F_TA_LVF_RAND = 82.9837

INFLOWS:

D-37 F_TA_LVF_IN = if (QUARTER = 4) then random (77.7778,88.8889) else 0

OUTFLOWS:

D-38 F_TA_LVF_OUT = if (QUARTER = 4) then F_TA_LVF_RAND else 0

D-39 F_TA_SUM = F_TA_DUD_RAND + F_TA_GNL_RAND + F_TA_LVF_RAND

D-40 F_PCT_TA_DUD = 100 * F_TA_DUD_RAND / F_TA_SUM

D-41 F_PCT_TA_GNL = 100 * F_TA_GNL_RAND / F_TA_SUM

D-42 F_PCT_TA_LVF = 100 * F_TA_LVF_RAND / F_TA_SUM

D-43 F_PCT_TA = if (G_TRNAREA_TYPE = 1) then F_PCT_TA_GNL else if (G_TRNAREA_TYPE = 2) then 0 else if (G_TRNAREA_TYPE = 3) then F_PCT_TA_LVF else if (G_TRNAREA_TYPE = 4) then F_PCT_TA_DUD else 0

Vegetation and Training Area (within LiveFire Zone) Adjustment

New definitions.

F_ADJ_VEG_[DUD, GNL, LVF]: Graph functions that adjust baseline probabilities for accidental fire ignition according to plant community type, so that some communities are more likely to ignite than others. The relationships are based on historical fire data.

F_ADJ_VEG: The adjustment in fire probability based on plant community type, for the appropriate region.

F_ADJ_TA_LVF: Graph function that adjusts baseline probabilities for accidental fire ignition according to training area within the LVF region, so that some training areas within this region are more likely to ignite than others. The relationships are based on historical fire data.

F_ADJ_TA: The adjustment in fire probability based on training area, for the appropriate region.

G_LIVEFIRE_LABEL: GRASS map that depicts the training areas within the LVF region.

Equations.

D-44 F_ADJ_VEG_DUD = GRAPH(H_COMMUNITY) *

(1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 1.09), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 2.69), (13.0, 0.645), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00)

D-45 F_ADJ_VEG_GNL = GRAPH(H_COMMUNITY) *

(1.00, 0.00), (2.00, 0.00), (3.00, 1.93), (4.00, 0.00), (5.00, 0.792), (6.00, 1.28), (7.00, 15.5), (8.00, 0.00), (9.00, 0.00), (10.0, 2.01), (11.0, 0.00), (12.0, 0.00), (13.0, 0.8), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00)

D-46 F_ADJ_VEG_LVF = GRAPH(H_COMMUNITY) *

(1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 1.61), (6.00, 0.741), (7.00, 0.82), (8.00, 0.00), (9.00, 0.00), (10.0, 3.75), (11.0, 0.00), (12.0, 1.94), (13.0, 0.761), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00)

D-47 F_ADJ_VEG = if (G_TRNAREA_TYPE = 1) then F_ADJ_VEG_GNL else if (G_TRNAREA_TYPE = 2) then 0 else if (G_TRNAREA_TYPE = 3) then F_ADJ_VEG_LVF else if (G_TRNAREA_TYPE = 4) then F_ADJ_VEG_DUD else 0

D-48 F_ADJ_TA_LVF = GRAPH(G_LIVEFIRE_LABEL) *

(1.00, 1.22), (2.00, 0.169), (3.00, 3.68), (4.00, 1.08), (5.00, 0.00), (6.00, 0.00), (7.00, 1.13), (8.00, 0.779), (9.00, 0.449), (10.0, 2.02), (11.0, 0.00), (12.0, 1.65), (13.0, 0.0986), (14.0, 1.19), (15.0, 0.00), (16.0, 1.38), (17.0, 1.22), (18.0, 0.834), (19.0, 0.343)

D-49 F_ADJ_TA = if (G_TRNAREA_TYPE = 1) then 1 else if (G_TRNAREA_TYPE = 2) then 0 else if (G_TRNAREA_TYPE = 3) then F_ADJ_TA_LVF else if (G_TRNAREA_TYPE = 4) then 1 else 0

Fire Probability

New definitions.

F_CELLS: The number of cells in each of the three regions.

F_PROB: The probability of an accidental fire ignition.

F_RAND_FIRE: Random number generated to determine whether an ignition occurs.

F_IGNITE: 0/1 switch that equals 1 when the F_RANDGEN= > F_PROB, and signifies an ignition. This switch is modeled through STELLA equations. It does not necessarily equal the cells that actually burn.

G_BURNZONES: GRASS map that depicts No-Burn Zones (value of 1), in which fires are extinguished as quickly as possible, and Let-Burn Zones (value of 2), in which fires are allowed to burn out naturally.

F_TYPE: Designates whether the fire is a ground fire (value of 1) or a crown fire (value of 2). Crown fires are limited to ignitions which begin in community types 1, 5, 7, and 11.

Equations.

D-50 F_FIRES = F_ANNUAL_RAND * (F_PCT_QUART/100) * (F_PCT_TA/100)

D-51 F_CELLS = if (G_TRNAREA_TYPE = 1) then 14575 else if (G_TRNAREA_TYPE = 2) then 720 else if (G_TRNAREA_TYPE = 3) then 4749 else 1496

D-52 F_PROB = (F_FIRES / F_CELLS) * F_ADJ_VEG * F_ADJ_TA

D-53 F_RAND_FIRE = random (0,1)

D-54 F_IGNITE = if (F_RAND_FIRE > F_PROB) then 0 else if (G_BURNZONES = 1 and F_TYPE = 1) then 1 else if (G_BURNZONES = 1 and F_TYPE = 2) then 2 else if (G_BURNZONES = 2 and F_TYPE = 1) then 3 else if (G_BURNZONES = 2 and F_TYPE = 2) then 4 else 0

D-55 F_TYPE = if (H_COMMUNITY = 1 or H_COMMUNITY = 5 or H_COMMUNITY = 7 or H_COMMUNITY = 11) then 2 else 1

Spread and Termination of Accidental Fires

New definitions.

G_FIREBREAKS: GRASS map of roads, waterways and cantonment areas that have a very high cost of fire spread, thus functioning as firebreaks.

F_COST_LET_CRN: The numerical representation for the cost of a crown fire spreading through a cell which is in a Let-Burn Zone.

F_COST_LET_GND: The numerical representation for the cost of a ground fire spreading through a cell which is in a Let-Burn Zone.

F_COST_NO_CRN: The numerical representation for the cost of a crown fire spreading through a cell which is in a No-Burn Zone.

F_COST_NO_GND: The numerical representation for the cost of a ground fire spreading through a cell which is in a No-Burn Zone

H_FLAM_GROUND: Flammability rankings for ground fire conditions, based on community type and grazing intensity. Values range from 0 to 3.

H_FLAM_CROWN: Flammability rankings for crown fire conditions, based on community type and grazing intensity. Values range from 0 to 3.

Equations.

D-56 F_COST_LET_CRN = IF (G_BURNZONES = 1) THEN 99 ELSE F_COST_NO_CRN

D-57 F_COST_LET_GND = IF (G_BURNZONES = 1) THEN 99 ELSE F_COST_NO_GND

D-58 F_COST_NO_CRN = IF (G_FIREBREAKS = 1 OR G_TRNAREA_TYPE = 2 OR H_FLAM_CROWN = 0) THEN 99 ELSE (4 - H_FLAM_CROWN)

D-59 F_COST_NO_GND = IF (G_FIREBREAKS = 1 OR G_TRNAREA_TYPE = 2 OR H_FLAM_GROUND = 0) THEN 99 ELSE (4 - H_FLAM_GROUND)

*These graphs are in the following format: (community type code, index for adjusting fire probabilities).

Appendix E: Shell Scripts

Index of Scripts

Birds.sh, birds.bcv.config, and birds.gcw.config

A script and supporting files that assign one female BCVI or one female GCWA to a cell based on habitat quality.

Birds.sh

```
:
if [ $# -ne 0 ]
then
echo "Usage: `basename $0`" >&2
exit 1
fi

# Script uses r.birds GRASS program to sequentially distribute GCW and BCV,
#   so that only 1 female (regardless of species or age) occupies any cell.
#   Female birds allocated to cells in the following order:
#      ASY-GCW, SY-GCW, ASY-BCV, SY-BCV
#
# Requires 4 input maps indicating number of female birds successfully
#   returning from overwintering grounds to post:
#      V_MIGRATE_SY, V_MIGRATE_ASY, W_MIGRATE_SY, W_MIGRATE_ASY
#
# Requires 2 input maps indicating habitat quality for each species:
#      V_QUALITY, W_QUALITY
#
# Requires 2 text config files that indicate relative weights of quality
#   categories and maximum number of female birds per cell:
```

```
#    birds.bcv.config, birds.gcw.config
#
# Produces 4 output maps indicating locations of female birds:
#  V_OCCUPY_SY, V_OCCUPY_ASY, W_OCCUPY_SY, W_OCCUPY_ASY

# count and report number of ASY warblers to be placed
asygcw=`r.sum -q v=W_MIGRATE_ASY | awk '{print $2}'`
echo ""
echo $asygcw "...ASY Golden-Cheeked Warblers being placed"
# place ASY warblers with no restrictions
r.birds -q n=$asygcw out=W_OCCUPY_ASY hab=W_QUALITY
config=birds.gcw.config
# convert floating-point map to integer
r.mapcalc "W_OCCUPY_ASY = int(W_OCCUPY_ASY)" 1>/dev/null 2>/dev/null

# count and report number of SY warblers to be placed
sygcw=`r.sum -q v=W_MIGRATE_SY | awk '{print $2}'`
echo ""
echo $sygcw "...SY Golden-Cheeked Warblers being placed"
# place SY warblers, restricting to cells not occupied by GCW-ASY
r.birds -q n=$sygcw out=W_OCCUPY_SY hab=W_QUALITY
config=birds.gcw.config start=W_OCCUPY_ASY
# convert floating-point map to integer
r.mapcalc "W_OCCUPY_SY = int(W_OCCUPY_SY)" 1>/dev/null 2>/dev/null
# remove GCW-ASY birds from this map (r.birds adds new birds to startmap)
r.mapcalc "W_OCCUPY_SY = W_OCCUPY_SY - W_OCCUPY_ASY" 1>/dev/null
 2>/dev/null

# count and report number of ASY vireos to be placed
asybcv=`r.sum -q v=V_MIGRATE_ASY | awk '{print $2}'`
echo ""
echo $asybcv "...ASY Black-Capped Vireos being placed"
# place ASY vireos, restricting to cells not occupied by GCW's (sum of
# ASY and SY warblers used as startmap)
r.mapcalc "birds.temp = W_OCCUPY_ASY + W_OCCUPY_SY" 1>/dev/null
2>/dev/null
r.birds -q n=$asybcv out=V_OCCUPY_ASY hab=V_QUALITY
config=birds.bcv.config start=birds.temp
# convert floating-point map to integer
r.mapcalc "V_OCCUPY_ASY = int(V_OCCUPY_ASY)" 1>/dev/null 2>/dev/null
# remove previously-placed birds from this map
```

```
r.mapcalc "V_OCCUPY_ASY = V_OCCUPY_ASY - birds.temp" 1>/dev/null
2>/dev/null

# count and report number of SY vireos to be placed
sybcv=`r.sum -q v=V_MIGRATE_SY | awk '{print $2}'`
echo ""
echo $sybcv "...SY Black-Capped Vireos being placed"
# place SY vireos, restricting to cells not occupied by GCW's or ASY-BCV
# (sum of ASY warblers, SY warblers, and ASY vireos used as startmap)
r.mapcalc "birds.temp = W_OCCUPY_ASY + W_OCCUPY_SY +
V_OCCUPY_ASY" 1>/dev/null 2>/dev/null
r.birds -q n=$sybcv out=V_OCCUPY_SY hab=V_QUALITY
config=birds.bcv.config start=birds.temp
# convert floating-point map to integer
r.mapcalc "V_OCCUPY_SY = int(V_OCCUPY_SY)" 1>/dev/null 2>/dev/null
# remove previously-placed birds from this map
r.mapcalc "V_OCCUPY_SY = V_OCCUPY_SY - birds.temp" 1>/dev/null
2>/dev/null

# remove temporary files
g.remove birds.temp 1>/dev/null 2>/dev/null
```

birds.bcv.config

```
# This config file is used by r.birds to place Black-Capped Vireos
# Format: Cat Max Weight (NOTE, incorrect format described in man page)
#   Cat = V_QUALITY category
#   Max = Maximum number of birds per cell (should always be set as 1)
#   Weight = relative weighting factor (user-defined)
#
1 1 1
2 1 29
3 1 70
```

birds.gcw.config

```
# This config file is used by r.birds to place Golden-Cheeked Warblers
# Format: Cat Max Weight (NOTE, incorrect format described in man page)
#   Cat = V_QUALITY category
#   Max = Maximum number of birds per cell (should always be set as 1)
#   Weight = relative weighting factor (user-defined)
```

```
#
1 1 1
2 1 29
3 1 70
```

Vegtime.sh, vegtime.reclass, vegtime.c

A script and two supporting files that produce an initialization map for the variable H_TIME_IN_COMM by generating random "time in community" values for each unique combination of initialized community type and soils type. The random numbers range from zero years to the maximum length of time that a community type would persist before succeeding to a different type (as defined in our transitions matrixes).

vegtime.sh

```
:
if [ $# -ne 2 ]
then
  echo "Usage: `basename $0` Mapset ProjName" >&2
  exit 1
fi

mapset="$1"
# Name of current GRASS mapset
project="$2"
# Name of current ProjName used in SME3 simulation

#!/bin/sh

# Script generates random time in stage for each unique combination of
#   vegetation and soils, ranging from zero to maximum defined by transition
#   matrices used in FHASM.  Can use output as init map for any given run.
#
# three supporting files used:
#   vegtime.c is C program that identifies lookup values and makes random nos.
#   vegtime.out is compiled C program vegtime.c
#   vegtime.reclass identifies reclass of soil associations into soil "groups"
#
# three maps used:
#   G_COMMUNITY@ecomodel is vegetation community map
```

```
#   soils@PERMANENT is detailed soil map
#   G_SOILS_ASSOC@ecomodel is reclass of soil map into six categories
#
# one map produced:
#   G_STAGE_TIME

echo ""
echo "Executing script to create G_STAGE_TIME"

# reclass the G_SOILS_ASSOC map based on the file "vegtime.reclass" to
#   correspond to soil "groups" used in FHASM
r.reclass in=G_SOILS_ASSOC@ecomodel out=soils.groups < vegtime.reclass

# Generate the cross file for vegetation and soils
r.cross-q   in=G_COMMUNITY@ecomodel,soils@PERMANENT   out=cross   >>
/dev/null

# Generate a list of the community and soil association associated with each
#   category in the "cross" file.
# Pipe the result into a C program (vegtime.c) which uses the lookup table to
#   generate a random number based on the community/soil_group pair.  Output
#   results in r.reclass input format.
# Pipe results into r.reclass to reclassify the cross map into output map.
# NOTE, time in stage equals zero for G_COMMUNITY cats 14 (barren) & 16
(urban)
r.stats -cq cross,G_COMMUNITY@ecomodel,soils.groups | vegtime.out | r.reclass
in=cross out=G_STAGE_TIME >> /dev/null

# resample output map because reclass of cross map
r.resample -q in=G_STAGE_TIME out=G_STAGE_TIME >> /dev/null

# change to map2 format and move to correct SME3 directory
r.compress -u G_STAGE_TIME >> /dev/null
cp /datamnt/landsim/hood/$mapset/cell/G_STAGE_TIME
/datamnt/landsim/sme3/Projects/$project/Data/G_STAGE_TIME.BIN

# remove temporary files
g.remove soils.groups >> /dev/null
g.remove cross >> /dev/null

echo "G_STAGE_TIME has been placed in" $project"/Data as MapII format"
```

vegtime.reclass

```
1 = 1
2 3 4 5 = 2
6 = 3
```

vegtime.c

```
#include <stdio.h>

main(argc, argv)
    int argc;
    char **argv ;
{
    char inbuf[256] ;
    int a, b, c ;

    int hival[16][3] =
      {100, 100, 100,
      30, 100, 100,
     100, 100, 100,
     100, 100, 20,
     100, 100, 100,
      30, 10, 10,
     100, 100, 100,
     100, 100, 100,
      13, 15, 15,
       4, 4, 4,
      13, 100, 15,
       4, 100, 4,
      10, 100, 100,
       0, 0, 0,
     50, 50, 50,
      0, 0, 0 } ;
    int lo, hi ;

    srand(getpid()) ;

    while (gets(inbuf))
    {
        if (check_for_asterix(inbuf)) continue ;
```

```
            sscanf(inbuf, "%d %d %d", &a, &b, &c) ;
            printf("%d = %d\n", a, getrand(0, hival[b-1][c-1])) ;
        }

}

int
getrand(lo, hi)
    int lo, hi;
{
    if (hi == 0) return(0) ;
    return(lo + rand() % (hi - lo)) ;
}

check_for_asterix(s)
    char *s ;
{
    char c ;
    c = *s ;
    while (c != 0)
    {
        if (c == '*')
            return(1) ;
        c = *(++s) ;
    }
    return(0) ;
}
```

Manage.sh

A script to identify actual management units.

Filter.sh and Filter.awk: A script and supporting file that create clumps of mapped output (e.g., potential management sites) to be equal to a user-specified size. Reports number of clumps of appropriate size to the user.

Drain.sh and drain.awk: A script and supporting file that constrain the number and size of management events to match user-specified values.

Manage.sh

```
:
if [ $# -ne 6 ]
```

```
then
  echo "Usage: `basename $0` inputmap minevents maxevents patchsize eventsize
outputmap" >&2
  exit 1
fi

inputmap="$1"
# Raster map of cells flagged by STELLA with potential to be mechanically
# cleared for bufferzones

minevents="$2"
# Integer indicating minimum random number of management events

maxevents="$3"
# Integer indicating maximum random number of management events

patchsize="$4"
# Integer indicating number of cells a cluster must include before being
# considered for management

eventsize="$5"
# Integer indicating number of cells managed per event

outputmap="$6"
# Raster map of cells flagged as actually managed

# determine and report random number of events to be attempted
# add 1 to $maxevents because Jim's rand script ranges from min to max-1
maxevents=`expr $maxevents + 1`
# determine random number of events
events=`rand $minevents $maxevents | awk '{print $1}'`
if [ "$events" -eq 0 ]
then
  echo ""
  echo "No management events will be attempted this time...quitting script"
  r.mapcalc "$outputmap = if(boundary@PERMANENT,0)" 1>/dev/null 2>/dev/null
  exit 1
else
  echo ""
  echo $events "...management events will be attempted"
fi
```

```
# count and report cells flagged with potential for management
initial=`r.sum -q v="$inputmap" | awk '{print $2}'`
if [ "$initial" -eq 0 ]
then
  echo "No cells initially flagged with potential...quitting script"
  r.mapcalc "$outputmap = if(boundary@PERMANENT,0)" 1>/dev/null 2>/dev/null
  exit 1
else
  echo $initial "...cells initially flagged with potential for management"
fi

# identify clusters of cells with potential to be managed
nclumps=`r.clump -q i="$inputmap" o=temp.clump | awk '{print $1}'`

# filter to clusters of required size using filter.sh
# Usage: filter.sh inputmap threshold outputmap
filter.sh temp.clump "$patchsize" temp.filter

# count and report number of cells in clusters of required size
nfilter=`r.sum -q temp.filter | awk '{print $3}'`
if [ "$nfilter" -eq 0 ]
then
  echo "No cells in clusters of required size...quitting script"
  r.mapcalc "$outputmap = if(boundary@PERMANENT,0)" 1>/dev/null 2>/dev/null
  g.remove temp.clump > /dev/null
  g.remove temp.filter > /dev/null
  exit 1
else
  echo $nfilter "...cells remain flagged in clusters of required size"
fi

# contrain number and size of management events using drain.sh
# Usage: drain.sh inputmap events size outputmap
# note: drain.sh reports number of cells actually managed for each event
drain.sh temp.filter "$events" "$eventsize" "$outputmap"

# count and report total cells actually managed
actual=`r.sum -q v="$outputmap" | awk '{print $2}'`
echo $actual "...total cells actually managed"

# remove temporary files
```

```
g.remove temp.clump > /dev/null
g.remove temp.filter > /dev/null

# create map depicting both potential and actual cells
r.mapcalc "$outputmap.view = if($outputmap,2,if($inputmap,1))" \
 1>/dev/null 2>/dev/null
```

Filter.sh

```
:
if [ $# -ne 3 ]
then
 echo "Usage: `basename $0` inputmap threshold outputmap" >&2
 exit 1
fi

inputmap="$1"
# raster map with clusters identified.  Typically generated by r.clump

threshold="$2"
# clusters with fewer than this number of cells are removed

outputmap="$3"
# raster map produced after filtering for clumps of certain size.
# each cluster of required size identified with original value, otherwise null


# Count number of cells per cluster, pipe result to filter.awk, which
#   uses $threshold variable to exclude clusters with too few cells
r.stats -cq "$inputmap" | nawk -f filter.awk THRESH=$threshold | r.reclass
in="$inputmap" out="$outputmap" > /dev/null

# resample output map because reclass of inputmap
r.resample -q in="$outputmap" out="$outputmap" > /dev/null
```

filter.awk

```
{if ($1 == "*") continue}
{if ($2 >= THRESH) print $1 " = " $1
else print $1 " = null" }
```

```
# This awk statement is used by filter.sh to identify and include only those
#   clusters that are of a certain critical size.  THRESH must be defined in
#   the awk command issued in script (typically THRESH=$threshold).
```

Drain.sh

```
:
if [ $# -ne 4 ]
then
  echo "Usage: `basename $0` inputmap events size outputmap" >&2
  exit 1
fi

inputmap="$1"
# Raster map indicating cells with potential to be managed.  Clusters of
#   cells with potential identified with unique number, cells without
#   potential as null.  Typically generated by filter.sh

events="$2"
# Integer indicating number of management events per time step.  Represents
#   contraint of not being able to manage isolated cells with potential.

size="$3"
# Integer indicating number of cells managed per event.  Represents
#   contraint of not being able to manage all cells within a cluster.

outputmap="$4"
# Raster map indicating cells actually managed.  Managed cells identified
#   as 1, non-managed cells as 0.  Typically this will be returned to SME3
#   to continue simulation.


# determine if more cells requested than number of cells with potential
expect=`expr $events \* $size`
avail=`r.sum -q "$inputmap" | awk '{print $3}'`
if [ "$avail" -le "$expect" ]
then
  g.copy rast="$inputmap","$outputmap" > /dev/null
  r.null m="$outputmap" null=0 1>/dev/null 2>/dev/null
  echo ""
  echo $avail "...cells managed (all with potential)"
```

```
  exit 0
fi

# create output map to allow accumulation of events, set to values to zero
r.mapcalc "$outputmap = if(boundary@PERMANENT,0)" 1>/dev/null 2>/dev/null

# create temporary map to indicate cells that still have potential
g.copy $inputmap,drain.avail > /dev/null

# convert values of all cells to random numbers
# note, all cells must be included or r.cost will scoot around edges
r.mapcalc "drain.rand = rand(100,150)" 1>/dev/null 2>/dev/null

# spread individual management events to appropriate size
i=1
while [ "$I" -led "$events" ]
do
  # randomly locate event and identify coordinate and cluster of point
  r.random -q in=drain.avail n=1 s=drain.pt 1>/dev/null 2>/dev/null
  clump=`s.out.ascii -d s=drain.pt | awk '{print $3}'`
  coord=`s.out.ascii s=drain.pt fs=, | awk '{print $1}'`

 # calculate cost surface from event location
  r.cost -k in=drain.rand coordinate=$coord out=drain.cost

  # remove cells not within selected cluster and turn selected point
  #   from null to 1
 r.mapcalc "drain.cost = if(drain.avail==$clump,if(isnull(drain.cost),
1,drain.cost),null())" 1>/dev/null 2>/dev/null

 # sum categories until total equals $size using nawk statement
 r.stats -cq drain.cost | nawk -f drain.awk MAX=$size | r.reclass \
   in=drain.cost out=drain.spread >/dev/null

# count and report number of cells managed
managed=`r.stats -cnq drain.spread | awk '{print $2}'` >/dev/null
echo "  " $managed "...cells managed during event" $I

# remove selected cells from further consideration
 r.mapcalc "drain.avail = if(drain.avail,if(isnull(drain.spread),drain.avail,null()))"
1>/dev/null 2>/dev/null
```

```
 # add managed cells to those from other events
 r.mapcalc "$outputmap = $outputmap + if(isnull(drain.spread),0,1)" 1>/dev/null
2>/dev/null

 i=`expr $I + 1`
done

# remove temporary files
g.remove sites=drain.pt >/dev/null
g.remove drain.avail >/dev/null
g.remove drain.rand >/dev/null
g.remove drain.cost >/dev/null
g.remove drain.spread >/dev/null
```

drain.awk

```
BEGIN {
 TOTAL = 0
 }
{if ($1 == "*") continue}
{if ($1 == "0") continue}
{if ( TOTAL >= MAX ) print $1 " = null"
else { TOTAL = TOTAL + $2; print $1 " = 1" }}

# This awk statement is used by drain.sh to sum categories produced by
#  r.cost until the number of cells reaches a critical size.  MAX must
#  be defined in the awk command issued in script (typically MAX=$size).
```

Fires.sh and firespread.sh.

Scripts to simulate the spread and termination of fires based on community flammability values, fire control policies (Let-Burn Zones vs. No-Burn Zones) and type of fire (ground fire vs. crown fire).

Fires.sh

```
:
if [ $# -ne 10 ]
then
   echo "Usage: `basename $0` ignitions cost1 cost2 cost3 cost4 minground
maxground mincrown maxcrown output" >&2
```

```
  exit 1
fi

ignitions="$1"
# raster map of cells flagged as sources of ignition (1=ground fire ignitions
#   in no-burn zones, 2=crown fire ignitions in no-burn zones, 3=ground fire
#   ignitions in let-burn zones, 4=crown fire ignitions in let-burn zones)

cost1="$2"
# raster map indicating cost of ground fire spreading in no-burn zone

cost2="$3"
# raster map indicating cost of crown fire spreading in no-burn zone

cost3="$4"
# raster map indicating cost of ground fire spreading in let-burn zone

cost4="$5"
# raster map indicating cost of crown fire spreading in let-burn zone

minground="$6"
# integer value of minimum random cost for ground fires (regardless of zone)

maxground="$7"
# integer value of maximum random cost for ground fires (regardless of zone)

mincrown="$8"
# integer value of minimum random cost for crown fires (regardless of zone)

maxcrown="$9"
# integer value of maximum random cost for crown fires (regardless of zone)

output="$10"
# raster output map indicating cells that burned (1=yes)


# **** Ground Fires in No-Burn Zones ****

# report type of fire
echo ""
echo "Calculating spread of ground fires in no-burn zones"
```

```
# identify ignitions that cause ground fires in no-burn zones. Note, must
#   round SME values from floats to integers
r.mapcalc "ignite1 = if(round($ignitions)==1,1,0)" 1>/dev/null 2>/dev/null

# execute firespread.sh
# usage: firespread.sh ignitions costmap minrand maxrand output
firespread.sh ignite1 $cost1 $minground $maxground fire1.out

# report number of cells burned in this type of fire
burn1=`r.sum -q fire1.out | awk '{print $2}'`
echo $burn1 "...cells burned in ground fires in no-burn zones"


# **** Crown Fires in No-Burn Zones ****

# report type of fire
echo ""
echo "Calculating spread of crown fires in no-burn zones"

# identify ignitions that cause crown fires in no-burn zones. Note, must
#   round SME values from floats to integers
r.mapcalc "ignite2 = if(round($ignitions)==2,1,0)" 1>/dev/null 2>/dev/null

# execute firespread.sh
# usage: firespread.sh ignitions costmap minrand maxrand output
firespread.sh ignite2 $cost2 $mincrown $maxcrown fire2.out

# report number of cells burned in this type of fire
burn2=`r.sum -q fire2.out | awk '{print $2}'`
echo $burn2 "...cells burned in crown fires in no-burn zones"


# **** Ground Fires in Let-Burn Zones ****

# report type of fire
echo ""
echo "Calculating spread of ground fires in let-burn zones"

# identify ignitions that cause ground fires in let-burn zones. Note, must
#   round SME values from floats to integers
r.mapcalc "ignite3 = if(round($ignitions)==3,1,0)" 1>/dev/null 2>/dev/null
```

```
# execute firespread.sh
# usage:  firespread.sh ignitions costmap minrand maxrand output
firespread.sh ignite3 $cost3 $minground $maxground fire3.out

# report number of cells burned in this type of fire
burn3=`r.sum -q fire3.out | awk '{print $2}'`
echo $burn3 "...cells burned in ground fires in let-burn zones"


# **** Crown Fires in Let-Burn Zones ****

# report type of fire
echo ""
echo "Calculating spread of crown fires in let-burn zones"

# identify ignitions that cause crown fires in let-burn zones.  Note, must
#   round SME values from floats to integers
r.mapcalc "ignite4 = if(round($ignitions)==4,1,0)" 1>/dev/null 2>/dev/null

# execute firespread.sh
# usage:  firespread.sh ignitions costmap minrand maxrand output
firespread.sh ignite4 $cost4 $mincrown $maxcrown fire4.out

# report number of cells burned in this type of fire
burn4=`r.sum -q fire4.out | awk '{print $2}'`
echo $burn4 "...cells burned in crown fires in let-burn zones"

# Create outputmap and report summary of cells that burned
r.mapcalc "$output = if(fire1.out==1 || fire2.out==1 || fire3.out==1 ||
fire4.out==1,1,0)" 1>/dev/null 2>/dev/null
ntotal=`r.sum -q v=$output | awk '{print $2}'`
echo ""
echo $ntotal "...total cells burned in accidental fires"

# Remove temporary maps
g.remove ignite1 1>/dev/null 2>/dev/null
g.remove ignite2 1>/dev/null 2>/dev/null
g.remove ignite3 1>/dev/null 2>/dev/null
g.remove ignite4 1>/dev/null 2>/dev/null
g.remove fire1.out 1>/dev/null 2>/dev/null
g.remove fire2.out 1>/dev/null 2>/dev/null
```

```
g.remove fire3.out 1>/dev/null 2>/dev/null
g.remove fire4.out 1>/dev/null 2>/dev/null
```

firespread.sh

```
:
if [ $# -ne 5 ]
then
  echo "Usage: `basename $0` ignitions costmap minrand maxrand output" >&2
  exit 1
fi

ignitions="$1"
# raster map of cells flagged as sources of ignition (1=yes)

costmap="$2"
# raster map indicating "cost" of fire spreading across post,
#   typically some function of vegetation and fire breaks

minrand="$3"
# integer value of minimum random cost any given fire can spread

maxrand="$4"
# integer value of maximum random cost any given fire can spread

output="$5"
# raster output map indicating cells that burned (1=yes)

# count and report cells flagged as ignition sources
nignite=`r.sum -q v="$ignitions" | awk '{print $2}'`
if [ "$nignite" -eq 0 ]
then
  echo "No cells flagged as ignition sources...quitting firespread script"
  r.mapcalc "$output = if(boundary@PERMANENT,0)" 1>/dev/null 2>/dev/null
  exit 1
else
  echo $nignite "...cells flagged as ignition sources"
fi

# ***Calculate cost surface of fire spread across post***
```

```
# copy ignitions map because r.cost overwrites map
g.copy rast="$ignitions",temp.ignite 1>/dev/null 2>/dev/null

# make cost of cells surrounding study site some large value (e.g., 99)
#  to prevent r.cost from scooting around edges
r.mapcalc "$costmap=if(isnull(boundary@PERMANENT),99,$costmap)" \
   1>/dev/null 2>/dev/null

# set variable for max_cost argument as $maxrand plus a small value (e.g., 3)
maxarg=`expr $maxrand + 3`

# calculate cost surface
r.cost in="$costmap" max="$maxarg" out=temp.ignite 1>/dev/null 2>/dev/null

# convert ignition sources from null to 1
r.mapcalc "temp.ignite=if(isnull(temp.ignite) && $ignitions==1,1,temp.ignite)" \
   1>/dev/null 2>/dev/null

# ***Identify potential fires as unique clusters***

# change cells within maxrand to 1 to allow cluster calculation
r.mapcalc "temp.bound = temp.ignite <= $maxrand" 1>/dev/null 2>/dev/null

# identify clumps.  Note, number of clumps may be greater than
#  number of ignitions if clusters get split (because r.cost works on
#  diagonal but r.clump does not), or less than ignitions if two or
#  more ignitions are located near one another (within maxrand cost).
nclumps=`r.clump -q in=temp.bound out=temp.clump | awk '{print $1}'`
echo $nclumps "...clusters generated if all ignitions spread to maxcost"

# change null to zero to allow fires to be summed below
r.null temp.clump null=0 1>/dev/null 2>/dev/null

# create output map to accumulate summed fires, set to values to zero
r.mapcalc "$output = if(boundary@PERMANENT,0)" 1>/dev/null 2>/dev/null

# ***Spread individual fires to randomly-determined boundaries***

# add 1 to $maxrand because Jim's rand script really goes from min to max-1
maxrand=`expr $maxrand + 1`
```

```
# determine fire-specific random cutoffs
I=1
while [ "$I" -led "$nclumps" ]
do
  # determine fire-specific cutoff cost between user-defined bounds
  cutoff=`rand $minrand $maxrand | awk '{print $1}'`

  # create fire-specific spread map and report size
  r.mapcalc "temp.fire = if(temp.clump==$i,if(temp.ignite<= \
    $cutoff,1,0),0)" 1>/dev/null 2>/dev/null
  ncells=`r.sum -q v=temp.fire | awk '{print $2}'`

# add current fire map to previous fire maps
r.mapcalc "$output = $output + temp.fire" 1>/dev/null 2>/dev/null

# report random cutoff value and size of fire
echo "  cluster" $I": " $cutoff "...random cutoff cost \
   $ncells "...size of fire"

I=`expr $I + 1`
done

# remove temporary maps
# g.remove temp.ignite 1>/dev/null 2>/dev/null
# g.remove temp.bound 1>/dev/null 2>/dev/null
# g.remove temp.clump 1>/dev/null 2>/dev/null
# g.remove temp.fire 1>/dev/null 2>/dev/null
```

Acronyms and Abbreviations

BCVI	black-capped vireo
BHCO	brown-headed cowbird
BLM	Bureau of Land Management
CANT	cantonment area
DUD	permanently dudded area
EALF	eastern live fire area
EARA	East Ranges
FHASM	Fort Hood Avian Simulation Model
FWS	U.S. Fish and Wildlife Service
GCWA	golden-cheeked warbler
GIS	geographic information system
GNL	general training areas
GRASS	Geographic Resource Analysis Support System
LVF	live fire area
NOLF	northern live fire area
SEPM	spatially explicit population model
SME	Spatial Modeling Environment

SOLF	southern live fire area
SPOT	Systeme Probatoire pour l'Observation de la Terre
STELLA	software for dynamic, single-cell modeling (not an acronym)
TA	training area
TM	thematic mapping
U of I	University of Illinois at Urbana-Champaign
USACERL	U.S. Army Construction Engineering Research Laboratories
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transmercater
WEFH	West Fort Hood
WERA	West Ranges

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