



**US Army Corps
of Engineers**

Construction Engineering
Research Laboratories

USACERL Technical Report 98/121
September 1998

Management of Cowbird Traps on the Landscape: an Individual-based Modeling Approach for Fort Hood, Texas

by
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The presence of brown-headed cowbirds (BHCO) affects local songbird populations, including breeding populations of black-capped vireos (BCVI) and golden-cheeked warblers (GCWA), across large distances on Fort Hood, Texas. Due to the impact of BHCO parasitism on these two endangered species, Fort Hood personnel have conducted a BHCO control program since 1991, which includes live-trapping and shooting individual BHCO throughout the breeding season. The objective of this study was to develop a model that simulates BHCO breeding and feeding habitats across the Fort Hood landscape, daily BHCO

movement behavior, and the placement and management of BHCO traps. The model generates predictions of sites most likely to receive frequent visitation by feeding BHCOs, and compares the capture success among different trapping strategies. Output suggests that the model is fairly stable to variation in several input variables, and the model accurately captures current knowledge about BHCO movement and locations on Fort Hood. Ongoing efforts will include improved mapping of nearby feeding habitat across the installation boundary, and validation of BHCO visitation output.

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1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE September 1998	3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Management of Cowbird Traps on the Landscape: an Individual-based Modeling Approach for Fort Hood, Texas		5. FUNDING NUMBERS MIPR 7DCER00399 and 8DCER00242	
6. AUTHOR(S) Ann-Marie Trame, Steven J. Harper, and James Westervelt			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) P.O. Box 9005 Champaign, IL 61826-9005		8. PERFORMING ORGANIZATION REPORT NUMBER TR 98/121	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) III Corps and Fort Hood ATTN: AFZF-PW-ENV-NR Natural Resources Branch, Bldg 1939 Fort Hood, TX 76544-5057		10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The presence of brown-headed cowbirds (BHCO) affects local songbird populations, including breeding populations of black-capped vireos (BCVI) and golden-cheeked warblers (GCWA), across large distances on Fort Hood, Texas. Due to the impact of BHCO parasitism on these two endangered species, Fort Hood personnel have conducted a BHCO control program since 1991, which includes live- trapping and shooting individual BHCO throughout the breeding season. The objective of this study was to develop a model that simulates BHCO breeding and feeding habitats across the Fort Hood landscape, daily BHCO movement behavior, and the placement and management of BHCO traps. The model generates predictions of sites most likely to receive frequent visitation by feeding BHCOs, and compares the capture success among different trapping strategies. Output suggests that the model is fairly stable to variation in several input variables, and the model accurately captures current knowledge about BHCO movement and locations on Fort Hood. Ongoing efforts will include improved mapping of nearby feeding habitat across the installation boundary, and validation of BCHO visitation output.			
14. SUBJECT TERMS Fort Hood, TX birds cowbirds		modeling natural resource management	15. NUMBER OF PAGES 60
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

Foreword

This study was conducted for III Corps and Fort Hood under Military Interdepartmental Purchase Request (MIPR) Numbers 7DCER00399 and 8DCER00242; Work Units "Brown-headed Cowbird Simulation Model" and "Improvement/Validation of the Individual Cowbird Behavior Model (ICBM)." The technical monitor was John Cornelius, Fort Hood Endangered Species Branch.

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 Ann-Marie Trame; Jim Westervelt was Assistant Investigator. Steven J. Harper was a Research Fellow with the Oak Ridge Associated Universities post-graduate program. Dr. Harold E. Balbach is Acting Chief, CECER-LL-N; and Dr. John T. Bandy is Operations Chief, CECER-LL. The USACERL technical editor was Gloria J. Wienke, Technical Information Team.

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1 Introduction

Background

The presence of brown-headed cowbirds (BHCO; *Molothrus ater*) affects local songbird populations across large distances. The BHCO is an obligate brood parasite; females lay their eggs in the nests of other species. Over 200 species of birds are known to be parasitized by BHCOs (Friedmann and Kiff 1985), including two endangered species that breed on Fort Hood, Texas: the black-capped vireo (BCVI; *Vireo atricapillus*) and the golden-cheeked warbler (GCWA; *Dendroica chrysoparia*). A parasitic strategy allows the BHCO to use breeding sites that are not closely coupled with their foraging requirements; since they do not have a nest or offspring to protect, their daily movements can be extensive (up to 7 km/day; Rothstein, Verner, and Stevens 1984). The spatial arrangement of feeding areas and breeding habitats on the landscape strongly influences the population and breeding ecology of the BHCO. Agricultural land use, especially feedlots and overgrazed grasslands, provides 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 (Gates and Gysel 1978, Brittingham and Temple 1983, Robinson et al. in press). The landscape of Fort Hood supports large numbers of BHCOs, although the breeding population has not been counted.

In many cases, host adults raise the BHCO young instead of their own, so brood parasitism can have a substantial impact on host populations (May and Robinson 1985). 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 an 11-day period in the BHCO (Friedmann 1963). This 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 than in unparasitized nests. This strategy leads to lower nest success in parasitized nests (Hayden et al. in press). After nest desertion, BCVIs often reneest, but the overall low productivity due to BHCO parasitism has been identified as a major reason for the endangered status of the species (U. S. Fish and Wildlife Service [USFWS] 1991). With the expansion of BHCO foraging

habitat over the past century, an increase in BHCO populations has been documented (Mayfield 1965; Brittingham and Temple 1983). This increase has been implicated in the decline of a large number of passerines (Robinson and Wilcove 1994; Robinson et al. 1995).

Due to the impact of BHCO parasitism on endangered species, Fort Hood personnel have conducted a BHCO control program since 1991 (reviewed by Hayden et al. in press). Experience demonstrated that trapping female BHCOs from endangered species nesting habitat was not as successful as trapping in BHCO feeding areas, especially in areas frequented by cattle. Increased understanding of large-scale BHCO movements has improved capture rates in the control program. Currently, a BHCO telemetry project, led by The Nature Conservancy of Texas, is underway on Fort Hood (Cook, Koloszar, and Goering 1995).

Computer-based landscape simulation modeling can be used to evaluate the effectiveness of alternative land management strategies. This report documents the design and development of a simulation model that focuses on the behavior of the BHCO. The Individual Cowbird Behavior Model (ICBM) simulates a landscape of BHCO breeding and foraging habitats, cattle herd movements, BHCO movements, and the placement and management of BHCO traps, over the course of one breeding season (April, May, and June). The input variables and trapping strategies can be altered between different runs, and the resulting outcomes compared, to assess which trap management strategies lead to the highest rates of BHCO removal.

The ecology and management of BHCOs is well-suited to landscape simulation since (1) the BHCO responds to landscape level patterns in foraging and breeding habitats, and affects passerine populations across large areas, and (2) management of BHCOs is best accomplished by targeting control across the landscape. The 87,890 hectare landscape of Fort Hood has been influenced by the presence of human activity and livestock grazing over the past century. Cattle grazing is currently an important consideration in the ecology of the BHCO and endangered species management. Landscape features of Fort Hood, combined with an understanding of BHCO behavior, have been captured in a simulation model to identify trapping practices most likely to maximize removal of female BHCO that breed within endangered species areas.

Objectives

The objectives of the study were to: (1) develop the ICBM in consultation with Fort Hood endangered species biologists and with ecologists from The Nature Conservancy on Fort Hood and (2) apply it in order to compare the efficacy of various BHCO trapping strategies through simulation modeling. To accomplish this, researchers summarized and incorporated available information about the Fort Hood landscape and knowledge of BHCO movement behavior into an individual-based model. The modeling objectives were (1) to develop a model structure that captured the movement dynamics of female BHCOs on Fort Hood, and (2) to capture information about the landscape, cattle, and BHCOs, as available from input maps and literature review.

Approach

This work evolved from development of the Fort Hood Avian Simulation Model (FHASM; Trame et al. 1997), a simulation tool for evaluating changes in BCVI and GCWA habitat and populations. According to FHASM simulations, the most effective management activity for increasing the fecundity of the BCVI was to trap BHCOs. This suggested that development of a relatively simple model focusing on the decisions of individual female BHCOs might improve BHCO trapping and BCVI reproduction.

Development of the ICBM began with an assessment of known and available information on female BHCO behavior. Literature on individual modeling approaches, BHCO biology, cattle movement patterns, and predator-prey relationships was reviewed. The results of the literature review revealed the important processes that formed the structure of the model. The model was built in two stages:

1. using Geographic Information Systems (GIS) analysis, in Geographic Resources Analysis Support System (GRASS) 4.2, to capture spatially explicit habitat characteristics and initial locations of cattle, BHCOs, and traps, and
2. using an individual simulation modeling environment to program dynamic interactions among the cattle, BHCOs, and traps.

Scope

The ICBM simulates the landscape of Fort Hood and all adjacent areas within 7 km of the installation boundary. The ICBM simulates changes occurring during the months of April, May, and June, the breeding season of the endangered species of concern, and incorporates a time-step of 1-day intervals. The model includes BHCO breeding and feeding habitat types; habitat variables affecting cattle forage behavior; the movements and interactions between habitat types, cattle, and BHCOs; the occurrence and management of BHCO traps; and the trapping of BHCOs through time. Behavior of cattle and BHCOs is captured at a 750-m X 750-m resolution, representing approximately 56 hectare-sized sections of land. This scale is consistent with data on cattle behavior and estimates of BHCO breeding territory size (Bailey, Walker, and Rittenhouse 1990; Cook, Koloszar, and Goering 1995).

Mode of Technology Transfer

The product of this work effort (including a summary of the results of comparative modeling simulation runs) will be transferred to the Fort Hood Endangered Species Branch. The relative efficacy of various trapping strategies (e.g., how many traps to use, which types of traps, how often to move them, etc.), in capturing female BHCOs with potential for parasitizing endangered species, will be reported.

The ICBM is available for further development. The occurrence and behavior of cattle outside the installation boundary will be improved in Fiscal Year 98 (FY98). A World Wide Web (WWW) user interface for running the ICBM and retrieving output will also be developed during FY98. Other development possibilities include applying simulated cattle or BHCO occurrences to other management concerns or extending the model to other locations at which BHCO or livestock behavior is a management consideration.

This report is available on the USACERL web page at <http://www.cecer.army.mil>

2 Modeling Approach

Conceptually, the ICBM consists of two components: the BHCO behavior component and the BHCO trapping component. The behavior component generates maps of cumulative visitation by cattle and BHCOs, providing a foundation for the trapping component. The trapping component simulates management decisions about trap placement and trap movement rules, and monitors captures of BHCO in traps. Both components were developed using a combination of GIS analyses/input, and dynamic modeling within the simulation environment. Development and execution of the ICBM model was accomplished on machines running versions of the UNIX operating system: Solaris 5.0 on a Sun UltraSparc computer and Redhat Linux running on an IBM-compatible PC.

Introduction to GIS

The researchers used GRASS to perform a number of GIS data development and analysis steps. GRASS commands were combined with standard UNIX commands in shell scripts to create efficient analysis steps. Various digital maps in a pre-existing Fort Hood database were analyzed to evaluate habitat for cattle, BHCO, GCWA, and BCVI. Input maps included streams, roads, and the installation boundary. Analysis steps generated habitat quality index maps for cattle and BHCOs. The GRASS GIS was also used to generate scenarios reflecting random placement of varying densities of birds and cattle corrals.

The ICBM is controlled through an integrated set of UNIX shell scripts that process user options through GIS analyses, and ultimately generate simulation model input files. Once the initial state of the landscape is defined through GIS analyses, the simulation component of ICBM, developed in Swarm (a dynamic simulation modeling environment) is initialized and run. Details of this process are described below.

GRASS is a public-domain GIS, which allowed direct access to GRASS data layers during the Swarm ICBM simulation. During Swarm simulation runs, GRASS raster maps were read and written. Once written, the output maps were then analyzed and displayed using the GIS software.

Introduction to the Simulation Modeling Environment

For this project, the researchers adapted the Swarm dynamic simulation modeling environment, which is a programming environment for modeling individual, discrete entities and events (Santa Fe Institute). The object-oriented modeling approach simulates independent entities (“agents”) interacting via discrete events. This simulation uses agents to represent individual organisms. Simulations consist of groups of many interacting agents. For example, an ecosystem simulation could consist of agents representing individual predators and their prey. The fundamental component that organizes the agents of a Swarm model is an object called a “swarm.” A swarm is a collection of agents associated with activity schedules. For example, a swarm could be a collection of 15 predators, 50 prey, and a simple activity schedule: the prey hiding and the predators eating the prey. An activity schedule is a sequence of actions to be performed. Swarm objects can also be swarms, which provides a hierarchical structure to the model (Figure 1).

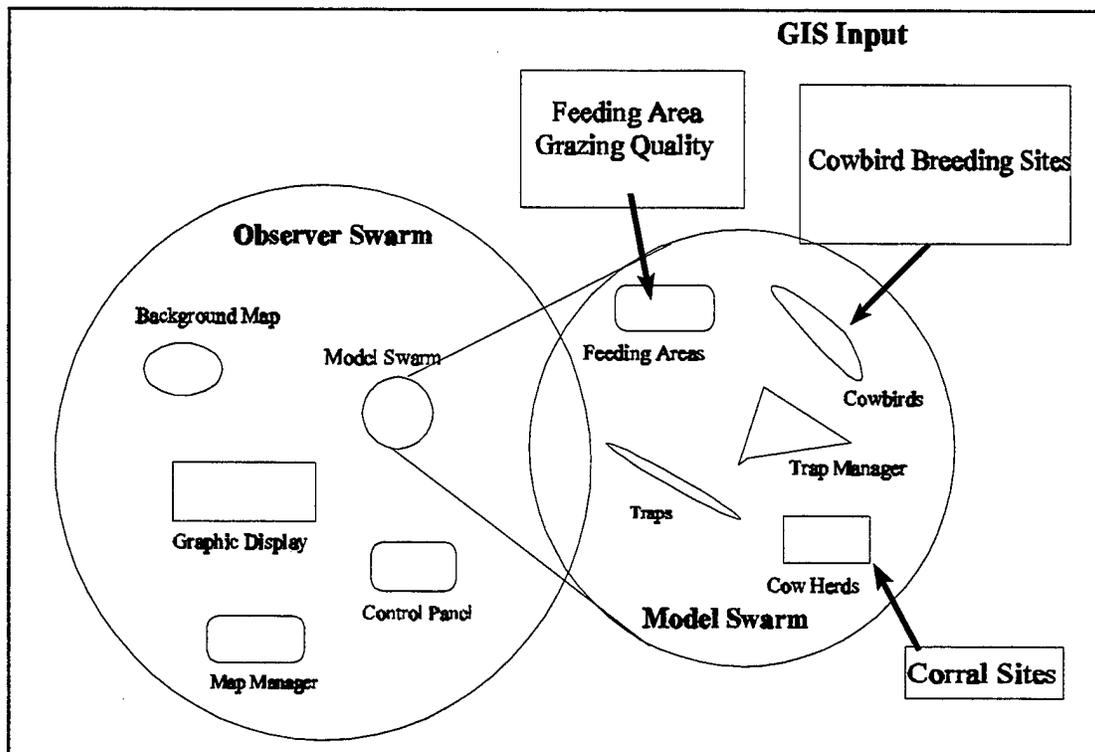


Figure 1. An overview of the ICBM model structure.

The primary swarm in the ICBM is the Observer Swarm. It provides a map display, several point-and-click dialog boxes that allow the user to alter initial parameter settings (Figure 2; Appendix A), and dynamic output during simulation runs (see Appendix B for details about output). The main simulation is captured inside the Observer Swarm as the Model Swarm.

The Model Swarm is composed of object classes that represent the different ecological entities on Fort Hood. The objects representing each cattle herd and individual BHCO model the behavior of the organisms based on their characteristics and their locations on the map. Each of the individual cattle herds or BHCOs accumulates its own unique history throughout the simulation. Other objects represent feeding areas, corrals, and traps, each of which is characterized by (x,y) coordinates in the input files. An object called the "region manager" maintains spatial information about each object, and about the spatial relationships between objects. These properties are maintained throughout the simulation. As the objects interact, they can query and use information about other objects.

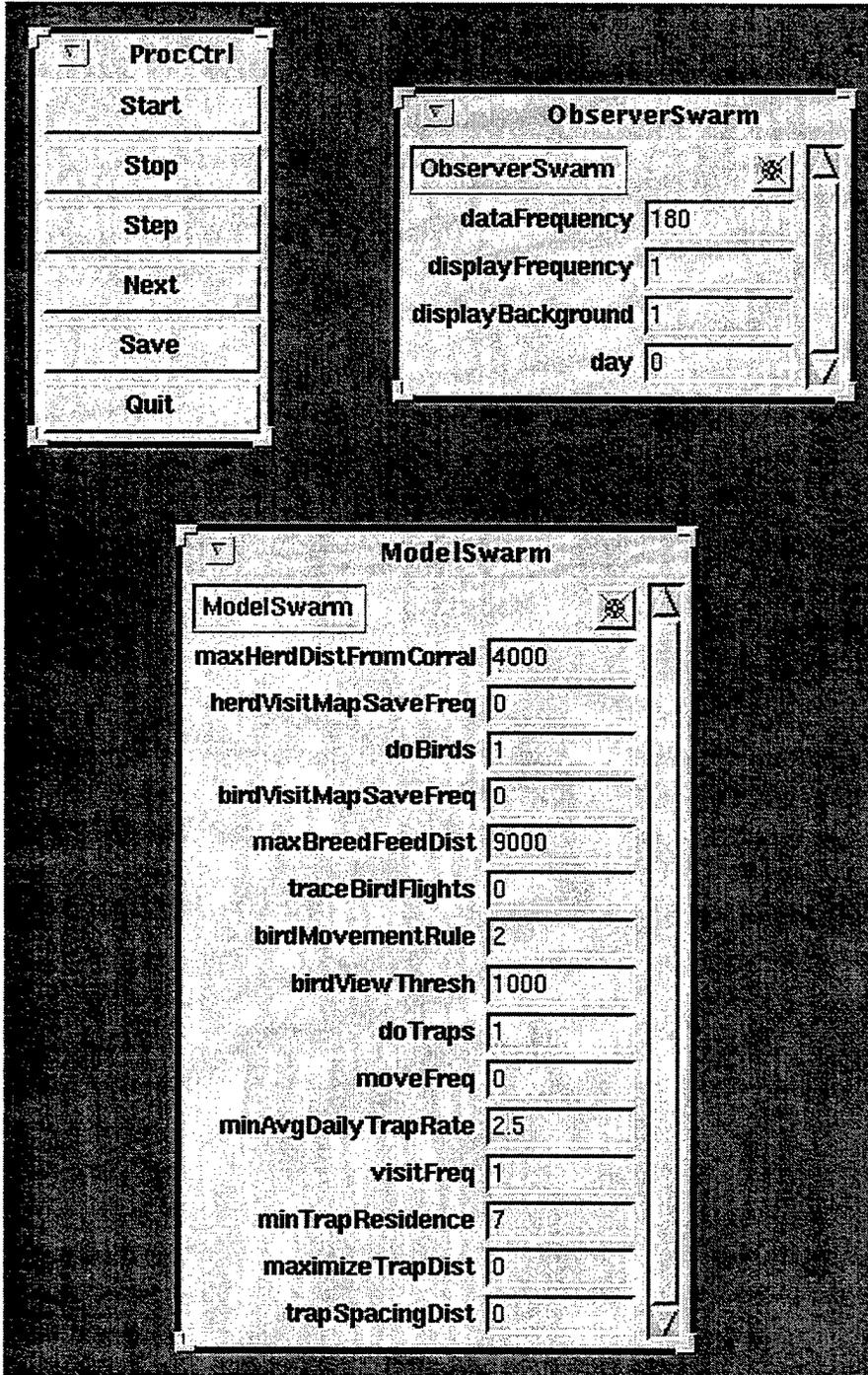


Figure 2. User dialog boxes available through the Observer Swarm component of the ICBM.

3 Cowbird Behavior Component

Input Development

Bands from April 1996 Landsat TM (thematic mapping) imagery were used to generate a map containing unsupervised classification of vegetation types. This map was then categorized into BHCO breeding habitat types and cattle grazing habitat types. Additional GIS analyses provided the following inputs to the dynamic simulation model: locations of female BHCOs in breeding territories, locations of potential cattle grazing areas and their associated grazing quality values, and present-day corral locations. Details of the analyses are provided below. The Swarm modeling environment is not map-based. Spatial inputs were provided to the dynamic Swarm model as lists of (x, y) coordinates with associated identities and characteristics. Swarm provides a tool for keeping track of the characteristics, histories, and interactions of many individual entities, which may include their site coordinates. Thus, model output can be mapped. For this reason, Swarm was linked to GRASS 4.2 to display a background image during simulation, and to visualize and process spatial output.

Evaluation of Habitat Quality

The landscapes of Fort Hood and adjacent lands within 7 km were represented in a GRASS map of two vegetation types known to influence BHCO behavior (Figure 3). The two vegetation categories, grassland and non-grassland, were determined from April 1996 Landsat TM imagery through neural network classification.* The neural network was trained with 152 Land Condition Trend Analysis (LCTA) points from 1995. Ninety-one points were known to be grassland communities; 61 points were known to be non-grassland communities,

* Results of two neural network calculations were combined to create the final vegetation map. Only cells classified as grassland in both calculations were considered grasslands in the ICBM. Settings for the two calculations were: percent trained: 0.75, 0.75; learn: 0.20, 0.60; momentum: 0.90, 0.50; epochs: 100, 100; iterations: 100, 1000. The error for the two calculations was: 0.0979 and 0.0094.

based on the PCC (Plant Community Classification) methodology (Tazik et al. 1992). The output consisted of grassland and non-grassland cells at 50-meter (m) resolution.

The ICBM simulation cell size was 750-m X 750-m, so there were 225 smaller (50-m) cells within each ICBM cell on the background habitat map. To maintain as much information as possible at the larger cell size, the smaller imagery cells were summarized using GRASS; those summary values were associated with the larger cells. Each 750-m cell had a value (range: 0-225) for the number of 50-m cells classified as grassland, and a value (range: 0-225) for the number of 50-m cells classified as non-grassland. These values were important in determining habitat quality for both the BHCO and cattle herds. Each ICBM cell had associated values for landscape context as well. The 50-m grassland cells were processed into contiguous patches using GRASS. Each 750-m cell had a value (range: 0-17) for the number of unique patches, which represented the fragmentation of grasslands at that scale (i.e., larger values resulted from greater fragmentation). This value was important in determining grazing quality of the cell for cattle. The mean distance of all 50-m non-grassland cells from their nearest grassland neighbors was also calculated for each 750-m cell. This value (range: 1-42, with each number representing an additional 50-m in distance) represented an index of edge habitat in each larger cell. This value was important in determining the BHCO breeding habitat quality of the cell. Hereafter, "ICBM cells" refers to the 750-m cells; "smaller cells" refers to the 50-m cells.

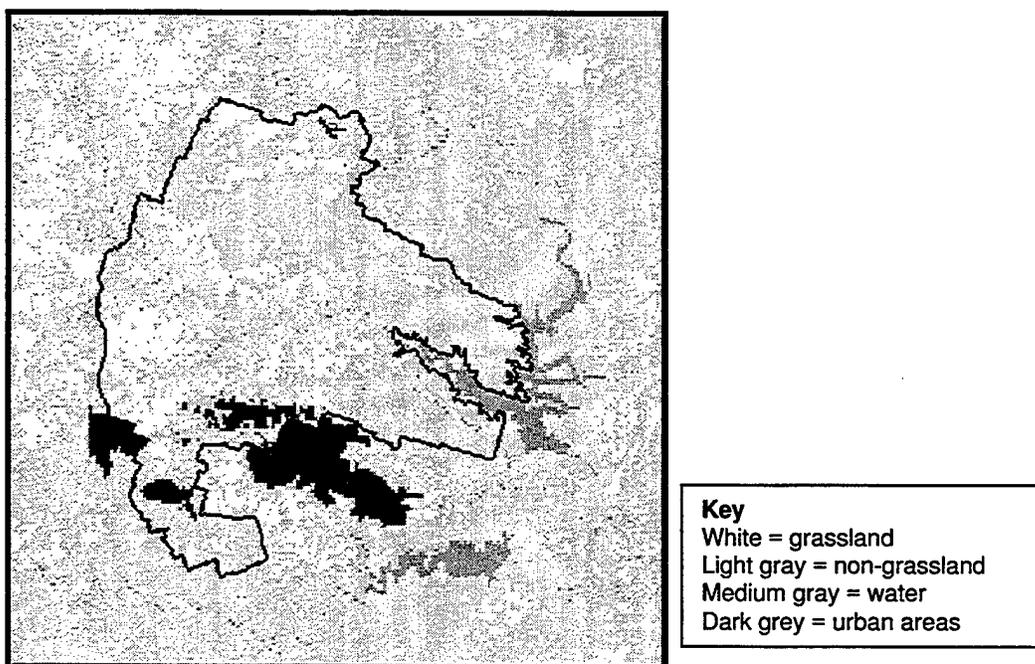


Figure 3. GRASS map depicting grassland and non-grassland cells classified from 1996 Landstat™ imagery using a neural network approach.

Cowbird Choice of Breeding Habitat

The ICBM was designed to assess trapping strategies for removal of female BHCOS with the potential to parasitize the BCVI and the GCWA. For this reason, breeding BHCOS were placed into ICBM cells consisting of at least 70 (out of 225) smaller cells of non-grassland vegetation; this was found to be the lower range of non-grassland cover in endangered species restricted areas (of both species). Three levels of BHCOS breeding habitat quality were incorporated into the ICBM. Breeding BHCOS have been shown to prefer host nests within 100 m of the boundary between forested areas and grasslands (Brittingham and Temple 1983). ICBM cells with a value less than or equal to 100 m for mean distance between non-grassland and grassland cells were considered high quality due to a high edge component. ICBM cells with a value greater than 300 m for mean distance between non-grassland and grassland cells were considered low quality (Brittingham and Temple 1983), while intermediate mean distance values were considered of intermediate quality. Female BHCOS were randomly allocated to these cells based on relative habitat quality. The weighting of the three habitat types was: low quality cells = 1.0; intermediate quality cells = 2.3, and the highest quality cells = 3.6. These values were based on Brittingham and Temple's (1983) results that the proportion of nests parasitized in edge habitats is 3.6 times higher than the proportion of nests parasitized in non-edge habitats (65% vs. 18%). These weights can be altered by the user through the Observer Swarm interface.

The model's Cowbird Object was populated with a GIS input map (see Appendix A, input script "3) Initial BHCOS Locations") of a user-defined, initial number of individuals,* which were placed in breeding territories during ICBM initialization. Breeding territory locations of individuals were static thereafter. Each ICBM cell was 56.25 ha. This value approximated the median (50 ha) and mean (65 ha) size of BHCOS breeding territories from 1995 telemetry studies on Fort Hood (Cook, Koloszar, and Goering 1995). Thus, each ICBM cell represented the breeding territory of one female.

* The user defines the proportion of total possible number of female BHCOS, based on the number of ICBM cells that are potential breeding habitat. If the number of BHCOS is the maximum (= 1.0), all cells with more than 70 smaller non-grassland cells become occupied; at lower proportions, high quality cells are most likely to be occupied, according to their relative weights.

Cowbird Feeding Habitat Preferences

Choice of afternoon feeding habitat by BHCOS is strongly influenced by the presence of cattle on short grass range (J. Cornelius, Wildlife Biologist, Endangered Species Branch, Fort Hood, TX, professional discussion, 14 May 1997 [hereafter referred to as J. Cornelius 14 May 1997]; T. Cook, The Nature Conservancy of Texas, Fort Hood, TX, professional discussion, 14 May 1997 [hereafter referred to as T. Cook 14 May 1997]). Telemetry studies of BHCOS on Fort Hood, conducted during the breeding seasons of 1995 and 1996, revealed that more than 90% of the afternoon sightings of feeding BHCOS were of birds in the presence of at least 30 cattle (T. Cook 14 May 1997). Because of this relationship, the presence of cattle strongly influenced the feeding locations selected by BHCOS in the ICBM; it was crucial to understand and predict cattle movement. The ICBM determined the location of cattle herds (30 or more individuals) on a daily time step, based on their expected behavior for a majority of time in the afternoon (grazing, resting, and drinking combined), since this is the period of time when feeding by BHCOS is strongly associated with cattle.

Livestock pastures and corrals located on neighboring lands (within 7 km of the installation boundary) may have influenced the behavior of BHCOS on Fort Hood, since birds that breed on post may have flown over the fenceline to feed on private lands nearby. The ICBM included livestock, and BHCOS feeding decisions, on private land.

Cattle Grazing Habitat Preferences

Prior to federal ownership in 1942, the land of Fort Hood was divided into private cattle ranches; this history influences grazing management decisions today. Currently, the Central Texas Cattlemen's Association holds a permit to graze 3500 animal units (AU) on the Fort Hood open range. At any given time, 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 hereafter referred to as G. Eckrich 25 June 1996). Cattlemen maintain corrals and provide supplemental hay and salt blocks at former ranch and homestead sites, so cattle tend to concentrate in these locations (J. Cornelius 14 May 1997). These factors contributed to the habitat quality of grazing areas in the ICBM.

Abiotic factors, including the location of water, are recognized as primary determinants of cattle movement over large areas (Senft et al. 1987, Coughenour 1991). The importance of water to cattle feeding behavior has been recognized

for decades. Valentine (1947) recommended that stocking rates be adjusted for distance to water, since vegetation far from water was underused compared to vegetation near water. The influence of distance to water on cattle grazing also was found to be highly significant by numerous other researchers (Cook 1966, Stafford Smith 1988, Senft, Rittenhouse, and Woodmansee 1983). Other factors may influence the relationship between water location and grazing preferences, such as time of year, breed and age of livestock, grazing system, temporary availability of outlying water (ephemeral sources), snow, succulent forage, salting locations, presence of roads or trails, resistance of forage to grazing and trampling, and topography (Valentine 1947, Stafford Smith 1988). However, because the effects of these factors have not been mapped nor measured for the landscape of Fort Hood, they were not included in the ICBM.

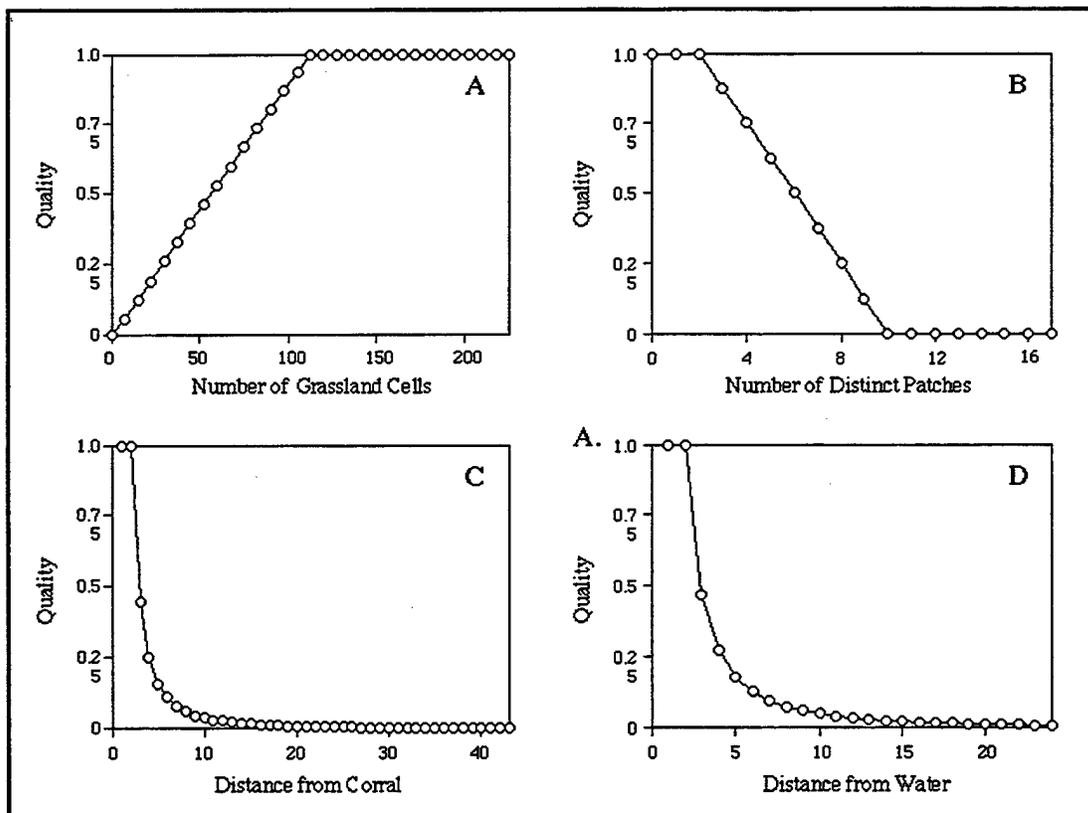


Figure 4. Mathematical relationships used to calculate grazing quality of Feeding Area in the ICBM.

The quality of habitat for grazing by cattle was calculated using four factors: number of smaller cells designated as grassland within each ICBM cell, number of patches of grassland within each ICBM cell (an index of fragmentation), distance to nearest permanent source of water, and distance to nearest corral (see Figure 4). Habitat quality was represented with a value from 0 to 1 for each of these factors, and the product of these was used as the measure of grazing habitat quality. While each factor currently contributes equally to the final value, individual factors could be weighted to alter their relative importance. The resulting GIS map of grazing quality was used to initialize the Feeding Area Object in the Swarm dynamic model.

For this work, the authors developed mathematical relationships to describe how the quality of the grazing habitat was influenced by each of the four components. For distance to water, we used a negative exponential equation after the approach documented in Senft, Rittenhouse, and Woodmansee (1983) and Stafford Smith (1988). We modified this relationship such that at distances of 0, 1, and 2 cells (0 to 1.50 km) away from water, habitat quality was maximized (value = 1), but after that point, habitat quality declined. Habitat quality reached an extremely low value at a distance of 24 cells (18 km; Figure 4). This relationship resulted in most cattle (96.4%) remaining within 5 cells of water (5 cells = 3.75 km), consistent with results of other researchers (Valentine 1947, Hodder and Low 1978, Squires 1982, Holechek, Pieper, and Herbel 1989).

No quantitative information was available to describe cattle foraging response to location of supplemental feeding, although it is believed to be significant (McDougald, Frost, and Jones 1989). Personnel at Fort Hood believe the majority of cattle remain within 2 km of corrals most of the time. The effect of distance to corrals on cattle grazing habitat quality was characterized using a negative exponential equation. Again, within a distance of 0, 1, or 2 cells (up to 1.5 km), the habitat quality remained at a maximum, and then declined exponentially (Figure 4). Although we had no information regarding the relationship between corrals and livestock movement on nearby private lands, we assumed that the same mathematical relationship applied.

The effects of vegetation type and quality are less clear. Work in Australia showed that vegetation type influenced movements; cattle went farther from water to stay in preferred vegetation (Hodder and Low 1978). However, another study suggested that cattle spent time on different vegetation types in proportion to the area represented (neither seeking nor avoiding different areas). Dwyer (1961) compared the proportion of three Oklahoma vegetation types, based on soil type, to cattle occurrence: (1) loamy prairie made up 70% of the study site; cattle spent 77.1% of their grazing time there; (2) shallow soils covered 12% of

the pasture; cattle occurred on these areas 8.3% of the time; and (3) rocky breaks were 18% of the pasture area; cattle spent 14.6% of their grazing time there. In the ICBM, grazing habitat quality was affected by both amount of grassland and fragmentation of grassland. Quality increased linearly from 0 to 1 as the number of smaller grassland cells increased from 1 to 112, out of a maximum of 225 (up to 50% grass cover). ICBM cells containing 112 to 225 smaller grassland cells (over 50% grass cover) were assigned a maximal quality value of 1 (Figure 4). Greater habitat quality values were assigned to areas of contiguous grassland compared with areas containing numerous disjunct patches of grassland. A habitat quality value of 1 was assigned to ICBM cells with only 1 or 2 patches of grass; this value decreased linearly as the number of unique patches (fragmentation) increased. ICBM cells with 10 or more grassland patches were assigned a quality value of 0 (Figure 4).

Swarm Model

Cattle Movement

Cattle movement in the ICBM was largely based on day-to-day movement patterns measured by Bailey, Walker, and Rittenhouse (1990) in a 248-ha Texas pasture of fairly homogenous forage. The pasture was initially divided into 63 units, but the final analysis grouped the units into 5 large sections, to calculate transition probabilities among different areas on a daily time scale. Their observations suggested that location early in the morning is a good indication of 24-hr grazing locations at this spatial scale. This was corroborated by Low, Dudzinski, and Muller (1981), who found that at daybreak, most cattle were found in the plant community in which they spent most of their grazing time. For the ICBM, we assumed that morning location results are a good predictor of cattle location during the afternoon feeding period of BHCOS on Fort Hood. The majority of the cattle in Bailey, Walker, and Rittenhouse's (1990) study remained in the same pasture section two mornings in a row in 29.4% of the observation sets during March-May-June observations. This is very close to the rate at which they moved to neighboring areas or more distant areas (35.3% and 29.4% of the time, respectively). They moved between farthest areas only once out of 17 times (about 5.9% of the time). Bailey, Walker, and Rittenhouse concluded that

The average area of the five sections was 49.6 ha, approximated in the ICBM by a cell size of 56.25 ha.

cattle display a "win-switch" strategy when foraging. Rather than stay in a productive area until the value drops, as predicted by optimal foraging theory (Charnov 1976), they switch grazing areas before forage quality drops. This may allow for increased replenishment between foraging bouts (but see Squires 1982 for different results from Australia). In addition, cattle may use spatial memory (Bailey 1995, Bailey et al. 1996) to avoid recently grazed areas, which would lead to the low community selectivity seen in this and other studies (e.g., Bailey 1995). Behavioral research has shown that cattle recall locations of food depletion for at least 8 days (Bailey et al. 1996). Such mechanisms may be important in homogenous environments; studies in heterogenous landscapes may show different patterns arising from alternative mechanisms (Bailey, Walker, and Rittenhouse 1990). For the ICBM, we assumed that forage quality across feeding areas is relatively homogenous.

The ICBM initialized 30 corrals within the installation boundary at locations specified by Fort Hood personnel (G. Eckrich, June 1997; see Appendix A, input script "5) Corral Locations"). The average density of corrals on the Fort Hood landscape was calculated. The same density of corrals was randomly placed on the landscape outside the installation boundary, to allow for the influence of agricultural lands nearby. This process resulted in 86 corrals being placed in random positions off-post. The Map Manager registered each corral location and assigned a specified number of cattle herds (representing about 30 cattle each) to each corral. To match current grazing policy on Fort Hood, 4 cow herds were associated with each corral, for a total of 3,600 cattle in 120 unique herds on the Fort Hood landscape, and a total of 10,320 cattle in 344 unique herds offpost. Each Cow Herd Object identified the feeding areas within a fixed distance (3.75 km) from its associated corral, and created cow-memory objects for each (see Appendix A, input script "4) Initial Cattle Grazing Quality"). To minimize computational overhead during simulations, cow herds only considered moving to these feeding areas. Although cattle were placed on both sides of the installation boundary, movement did not occur across the border (which is fenced).

During simulation, each Cow Herd Object chose which feeding area to occupy each day (Figure 5). The choice was based on a calculated attractiveness value for each associated Feeding Area, composed of three factors: (1) its grazing quality (see **Cattle Grazing Habitat Preferences**), (2) time since first occupied by the herd, and (3) distance from the object's current location.

When a cow herd visited a Feeding Area, it was registered with the Feeding Area Object and the Cow Herd Object itself. Following this initial visit, the grazing quality of the cell was adjusted to match observed behavior that cattle rarely

occupied the same feeding area for more than 1 or 2 days, and avoided areas that they recently visited (Bailey, Walker, and Rittenhouse 1990). The value of the visited Feeding Area decreases daily through the 5th day following initial visitation. By that day the probability of re-visiting dropped to zero. The value of the Feeding Area increased over the next 8 days. No reduction in value was created due to recent occupation by a different herd, since avoidance is thought to be based on memory of the cattle's own occupation, not environmental cues.

When a cow herd visited a Feeding Area, the Cow Herd Object recorded the herd's location. This influenced the choice of feeding area during the next time step, since cattle are more likely to move to adjacent or nearby feeding areas, rather than distant areas. Attractiveness was not reduced for the Feeding Area occupied, nor for immediately adjacent Feeding Areas, but the value declined in a linear fashion for Feeding Areas at distances of 2, 3, and 4 cells. Beyond distances of 4 cells, the attractiveness of a Feeding Area dropped to zero.

Each of these three attractiveness factors (grazing quality, distance from the previous herd location, and time since first occupied) was represented by values ranging from 0 to 1, which were multiplied together to calculate the overall attractiveness value. At $t = 1$, each of the cattle herds moved to the first randomly selected Feeding Area. For each time step of the simulation, the process was repeated. Percent of cattle herds moving 0, 1, 2, and 3-or-more cells distance is output in a moving strip chart at each time step (Figure 6). Average distances moved by the ICBM cattle herds was captured and compared to values reported in the literature (in Bailey, Walker, and Rittenhouse 1990), as one form of model validation. This comparison is provided in the chapter titled **Application and Results**.

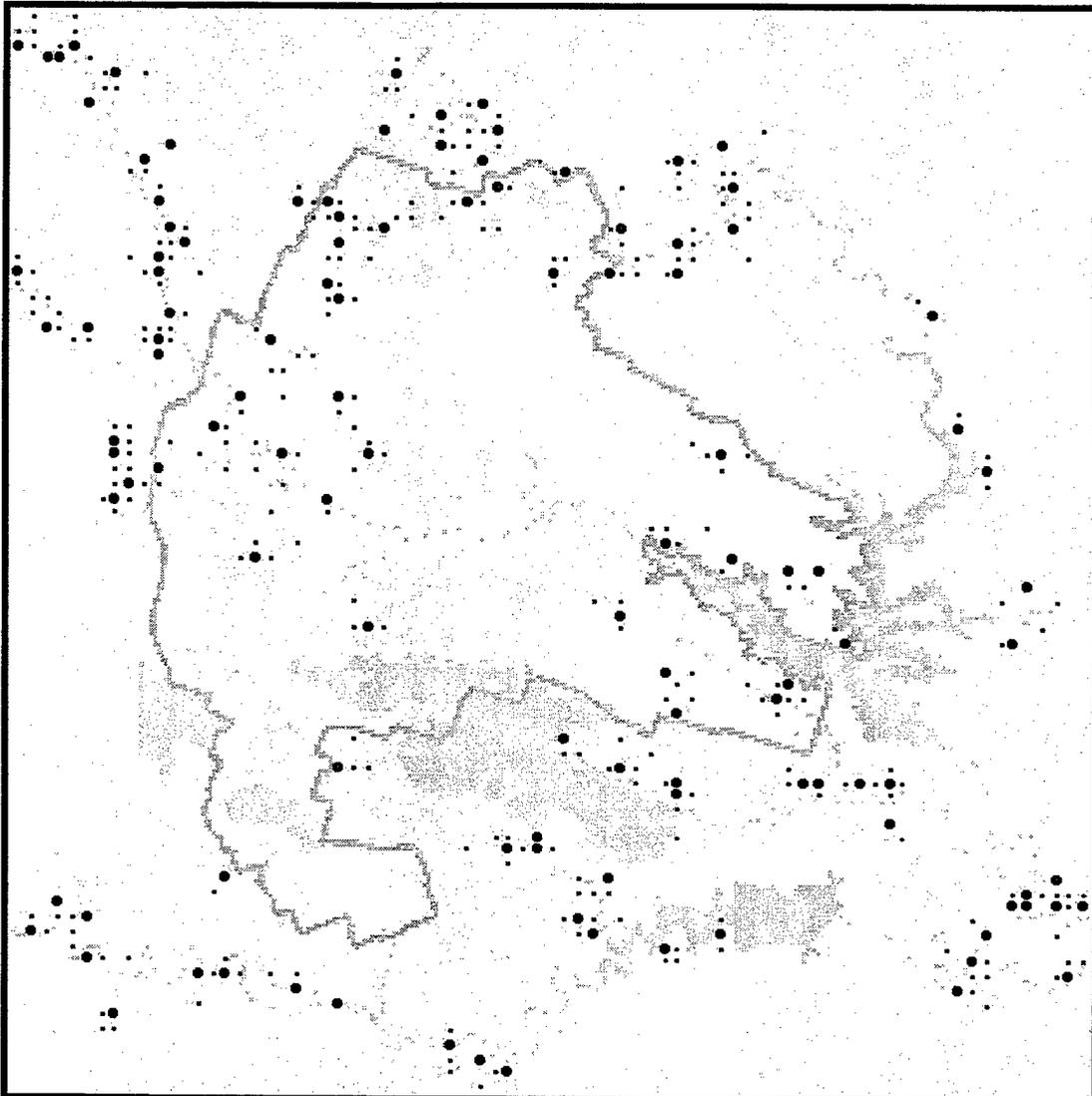


Figure 5. Example depiction of initial location of corrals (circles) and cattle herds (small squares).

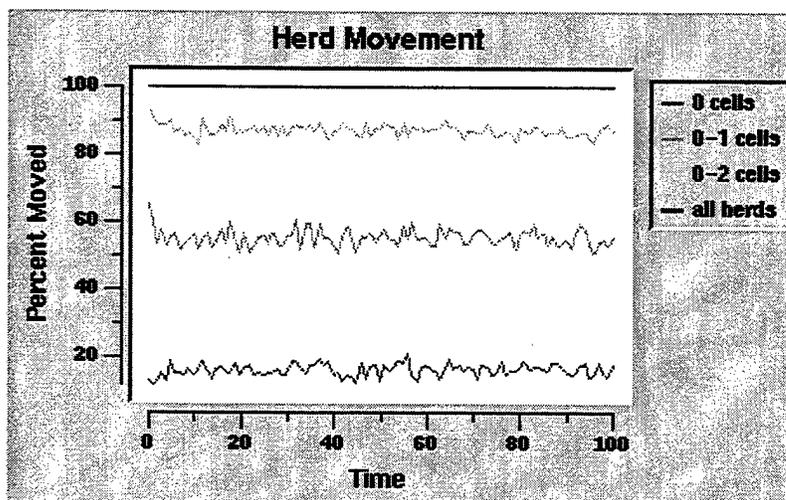


Figure 6. Example output showing the cumulative number of cattle herds moving the equivalent of 1, 2, or more than 2 cells (each cell = feeding area, 56.25 ha in size) on a daily basis.

Cowbird Movement

Daily feeding area movement patterns of BHCOs have not been reported in the literature to date. Four algorithms (rules) were evaluated to model BHCO movement on a daily basis among Feeding Area Objects; each one assumed a different level of knowledge about the landscape. In all cases, BHCO foraging locations were based on the presence of a cow herd.

In rule 0, no previous knowledge was assumed. Each day, each BHCO moved randomly from its breeding site to the nearest Feeding Area, and then to the next nearest Feeding Area, until a Feeding Area occupied by cattle was encountered.

In rule 1, decisions were made based first on memory of previously-used areas, and then based on searches for the next nearest Feeding Areas occupied by cattle. For each time step, each female was placed into a Feeding Area according to the following sequential rules:

- a. If the Feeding Area it last occupied again was occupied by cattle, then it remained there for the day.
- b. If that Feeding Area did not contain cattle, but the second-to-last-visited Feeding Area was occupied by cattle, then it settled into this second location.
- c. If neither of those Feeding Areas were occupied by cattle, it checked the third-to-last-used Feeding Area, and stayed there if cattle were present.
- d. If none of the three previous locations were occupied by cattle, the bird searched other potential Feeding Areas by randomly visiting the next nearest (but as-yet unvisited) Feeding Area, until one occupied by cattle was encountered.

Rule 2 was identical to rule 1, except that BHCOs were capable of using memory to assess the Feeding Areas located between those last visited. If a Feeding Area contained cattle and was found between any of the previously-used Feeding Areas, the BHCO would select that as its feeding site. All Feeding Areas within 1000 meters of the straight-line path between previously-visited sites became potential feeding sites under rule 2. This "perception distance" could be modified by the model user.

Lastly, rule 3 assumed omniscient BHCOS; during each time step, each female traveled directly to the Feeding Area nearest to its breeding site that contained cattle.

To evaluate the results of these four alternatives, 100 runs were conducted using each movement rule. In all runs, the number of BHCOS initialized was held constant, at 25% of saturation densities. Corrals were placed outside the installation boundary, at randomly selected locations, but matching the density of corrals on-post. Each run consisted of 100 time steps.

For each of the four movement rules, the average distances moved each day while en route to feeding sites, and the average straight-line distances between breeding sites to feeding sites were calculated. The latter were compared to available Fort Hood telemetry data (in Cook, Koloszar, and Goering 1995). Details of this comparison are reported in the chapter titled **Application and Results**. The results indicate that rule 2 provides acceptable patterns, while also being logically defensible. Thus, we chose rule 2 for subsequent simulations.

Output from the BHCO behavior component was converted into two maps: one reflecting the cumulative number of visits by cattle herds over the 100-day run, and one reflecting the cumulative number of BHCO visits over the 100-day run, for each Feeding Area. A limited sensitivity analysis was conducted to assess the importance of off-post corral locations and densities, and the importance of initial BHCO densities, on these cumulative cattle and BHCO visitation maps (see chapter titled **Application and Results**). The map of cumulative BHCO visitation was used as a primary input into the BHCO trapping component.

4 Cowbird Trapping Component

The output of the BHCO behavior component was mapped as cumulative visitation counts of both cattle herds and BHCOs to each Feeding Area. This spatial information, combined with additional trap placement rules, was used as input to the BHCO trapping component of the ICBM. This component simulated management decisions about trap numbers, trap types, trap placement, and schedules for moving traps throughout the breeding season. Some of these decisions were captured through GIS analysis, and provided as input to Swarm, while other decisions were modeled dynamically within Swarm. The output of the BHCO trapping component was cumulative numbers of female BHCOs caught in all traps (Figure 7).

GIS Input

The output of the BHCO behavior model, mapped as cumulative visitation counts of both cattle herds and BHCOs to each Feeding Area, was used in combination with trap placement rules to generate a Swarm input file of trap sites. The model can reflect strategies such as dispersing traps evenly across the installation, or encircling the installation boundary. Trap sites can be constrained to areas near paved roads, and traps can be placed on either side of the installation boundary. After GIS processing, the resulting ACSII file of (x,y) coordinates was input into Swarm (Figure 8).

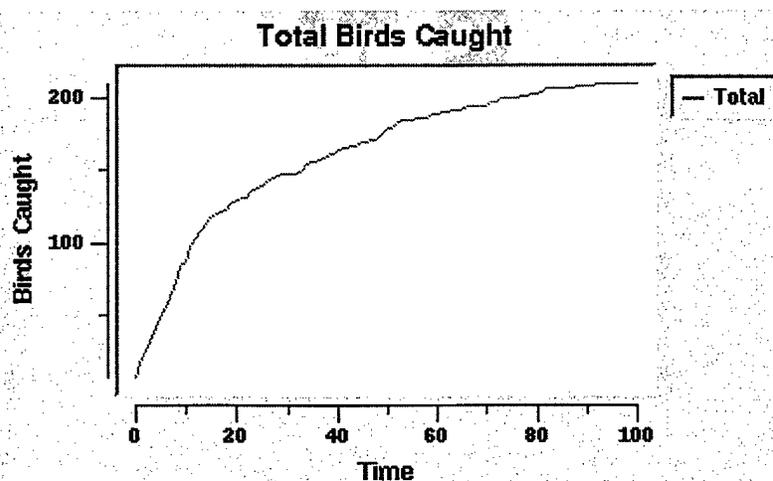


Figure 7. Example output showing the cumulative numbers of BHCO caught in all traps throughout a simulation run.

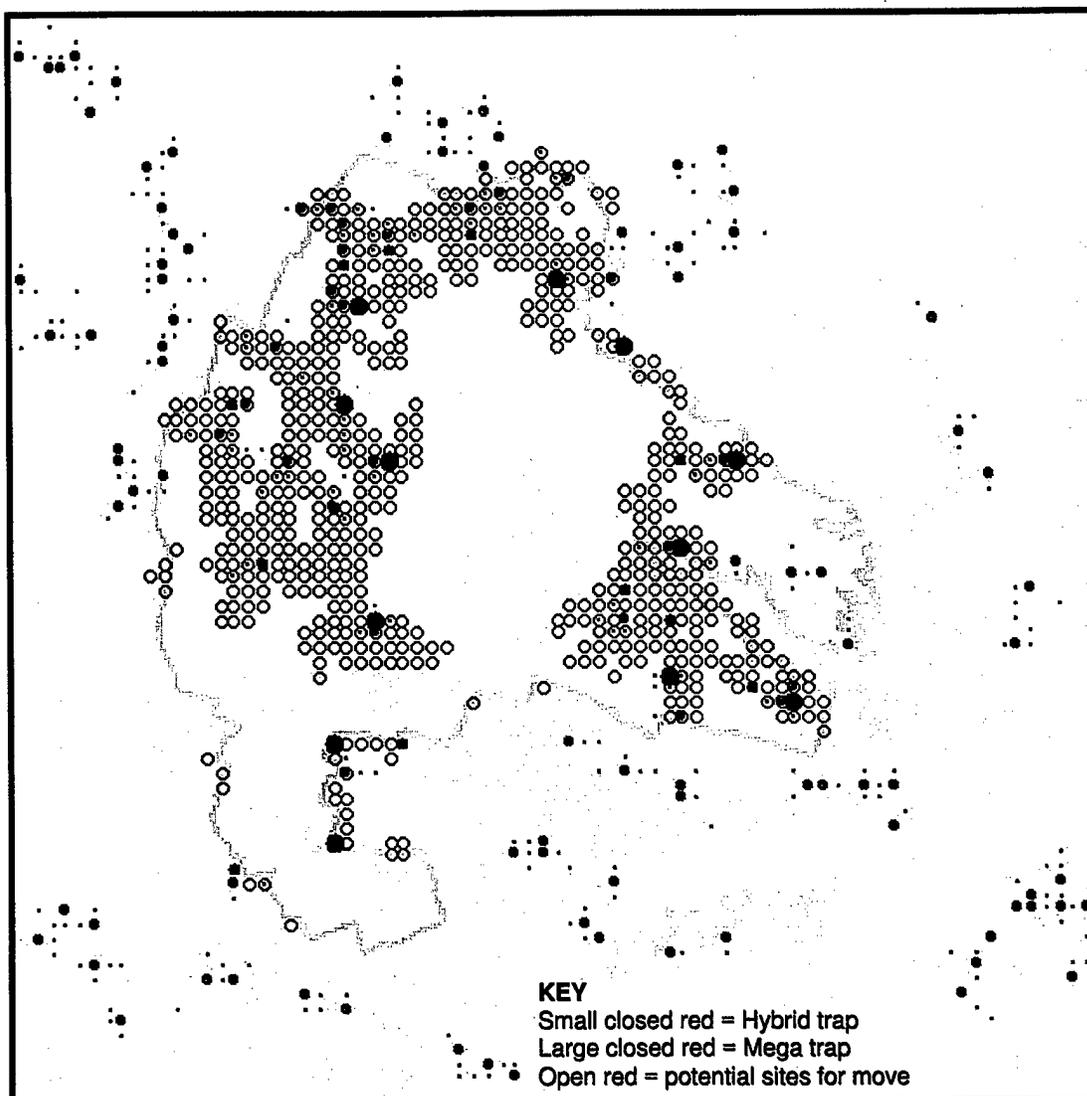


Figure 8. Example depiction of 24 BHC0 traps placed onto the land of Fort Hood according to the 24 sites most likely to have BHC0 visitation.

Two files are input to the trapping component. The first file indicates the total number of Mega and Hybrid traps, and the capture efficiency of each type of trap. Capture efficiency is a value (described in Hayden et al. In press) between 0 and 1 indicating the proportion of birds visiting a Feeding Area that become trapped daily. Since we do not know the probability of a female entering a trap, we fixed a value for all traps of a given type (i.e., one capture efficiency for Mega traps and one capture efficiency for Hybrid traps). The relative capture efficiency of each type of trap is more important than the actual value, since the actual number of females on the landscape is unknown, and the actual number "caught" in the simulations is not predictive except in a relative sense when comparing among different scenarios.

The second file includes the following information:

- Site coordinates (x,y) for trap locations.
- Whether that location is initialized with the trap present or whether it is provided as a potential trap site for possible Hybrid trap placement during simulation.
- Identity of trap type (Mega or Hybrid). All potential sites are characterized as "Hybrid."
- Relative level of expected cattle or BHCO visitation, based on the cumulative visitation map output from the BHCO behavior component.
- Frequency at which trap is moved to a new location (measured in time step units, only relevant for Hybrid trap types) can be given a unique value for each trap, instead of managing all Hybrid traps on the same movement schedule.

Swarm Model

The Trap Object kept track of the information in the two input files, as well as additional trap movement rules set through the Swarm user interface. Mega traps were placed on the landscape through the input files, and did not move. Hybrid traps were initialized onto the landscape through the input files, and then were controlled through several movement rules options (Figure 9). The following possibilities for timing of trap movement were simulated:

1. No movement of any traps,
2. A fixed schedule of movement (in time-step units),
3. Trap movement triggered by the capture rate dropping below a user-provided threshold, and
4. Trap movement triggered by a drop in capture rate, but only after a minimal period of time has passed (e.g., even if capture rates are very low, the trap cannot be moved any more frequently than a specified time interval).

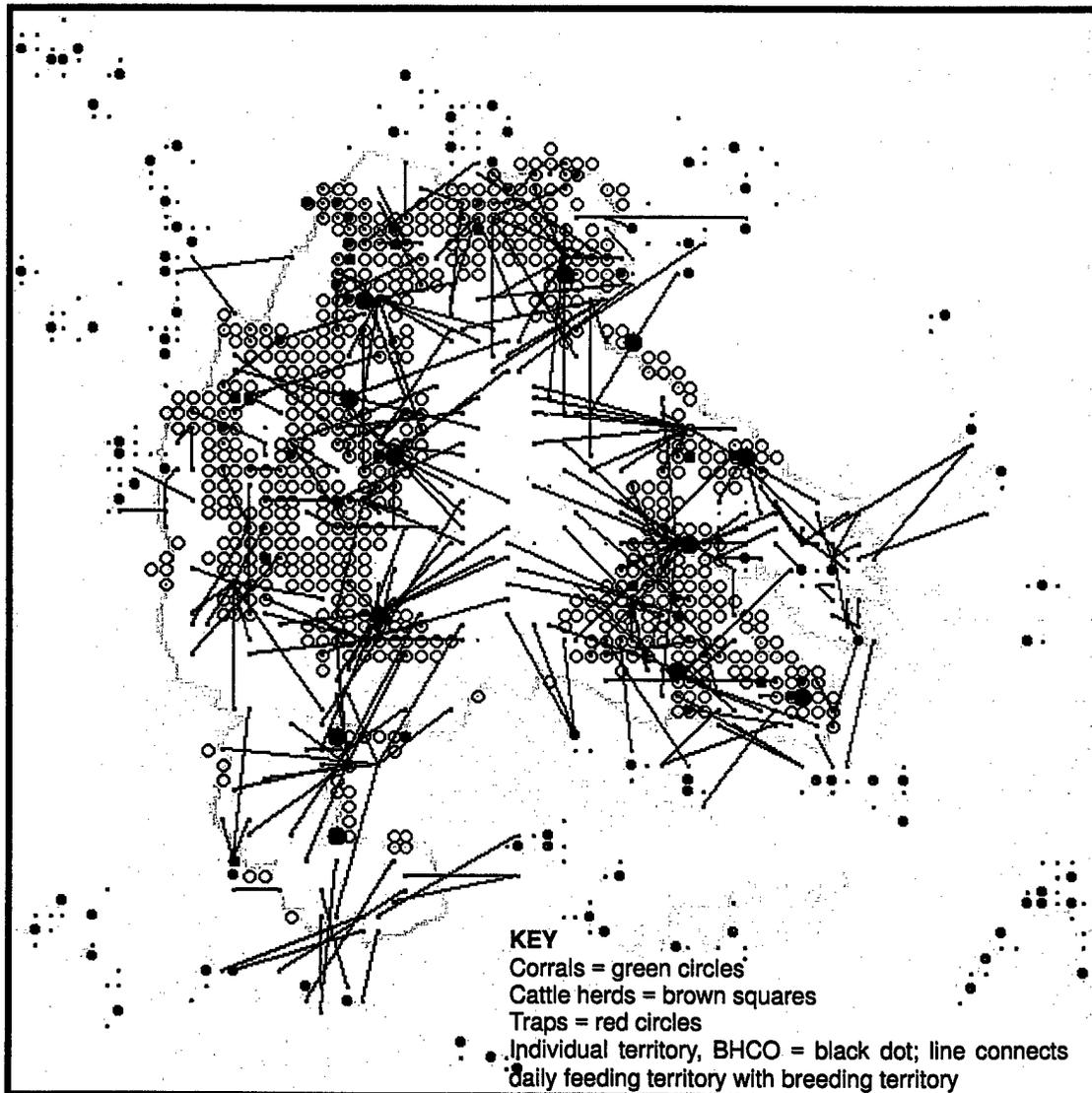


Figure 9. Example depiction of corrals, cattle herds, individual BHCOs, and traps.

Hybrid traps moved according to one or more of the following placement rules:

1. Each trap was placed into the site having the next-highest expected BHCO visitation, as recorded in the input file, but which had not yet had a trap placed in it,
2. An option that increased the distance between subsequent trapping locations. This was accomplished by each potential trap location recognizing the nearest current trap site (in its "neighborhood"), and then each trap being moved to the farthest potential location among these "neighborhood" choices, and

3. An option that moved each trap into the site having the next-highest expected BHCO visitations, but only if the site was located a minimal distance from the current site. This minimal distance moved can be changed through the Swarm user interface.

The number of female BHCOs captured in each trap was counted and the cumulative total number trapped was output in a moving strip chart during simulation.

5 Application and Results

Cattle Distances Moved

ICBM output of daily cattle movement distances was compared to literature values, which served as a validation exercise for the cattle movement algorithm in the model. Values of distances moved by each cattle herd during a simulation were captured in an ASCII output file and then compared to values reported by Bailey, Walker, and Rittenhouse (1990). Results of ICBM simulation approximated reported values, although the model over-predicted movements across three cells and under-predicted the percent of cattle remaining in the same cell for 2 days in a row (Figure 10).

Cowbird Distances Moved

To evaluate the 4 possible BHCO movement rules, 100 runs were conducted using each rule, and output was compared to 1996 telemetry data (Cook, Koloszar, and Goering 1996). In all runs, the number of BHCOs initialized was

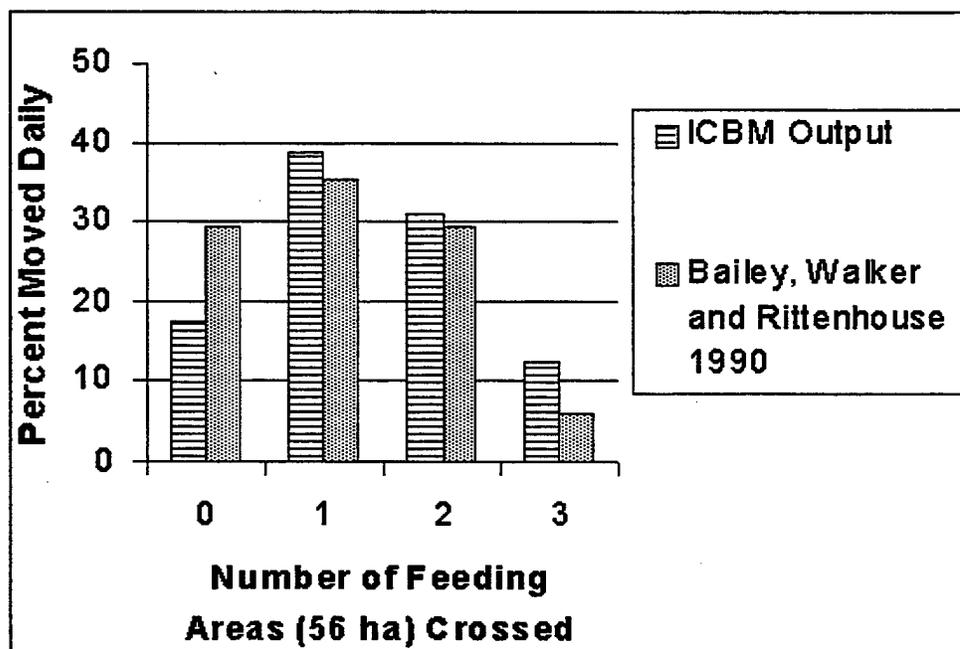


Figure 10. Percent of cattle herds moving across 0,1,2, or 3 feeding areas on a daily basis.

held constant, at 25% of saturation densities ($n=312$). Corrals were placed outside the installation boundary, at randomly selected locations, but matching the density of corrals on-post, for a total of 344 corrals off-post. Each run consisted of 100 time-steps.

For each of the four movement rules, the average distance moved each day while en route to feeding sites, and the average straight-line distance between breeding sites to feeding sites were calculated, and the latter compared to available Fort Hood telemetry data (in Cook, Koloszar, and Goering 1996; Figure 11). Results indicate that rule 2 provided acceptable patterns, and also was logically defensible. Thus, we chose rule 2 for simulations performed for comparison of various trapping scenarios.

Additionally, more detailed distance data from a single run were compared to telemetry data (Table 1). Simulated mean and median distances moved were similar to those measured through telemetry studies on Fort Hood.

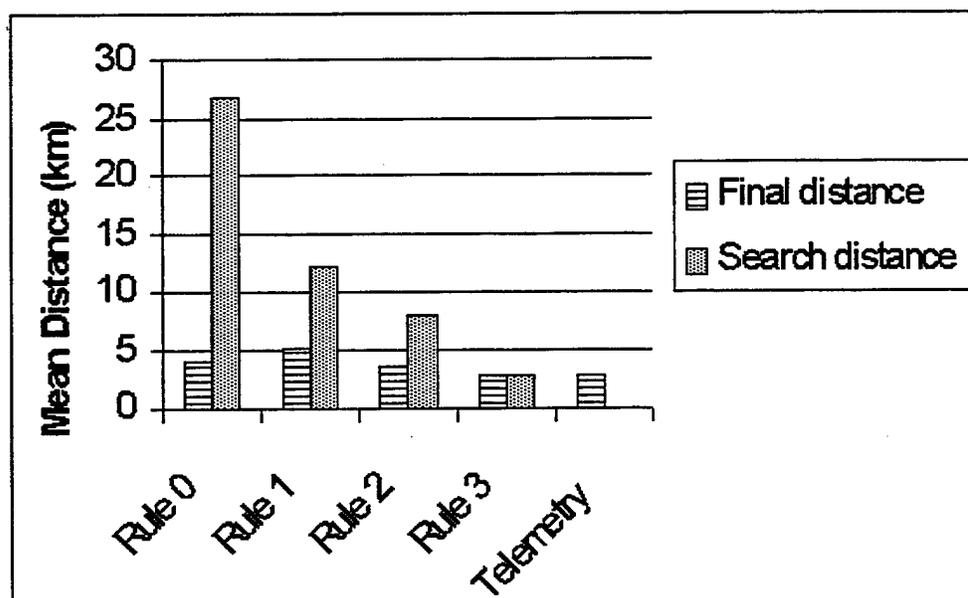


Figure 11. Mean daily searching distances and mean final distances between BHCO breeding sites and afternoon feeding sites, as output from ICBM simulation and as measured by telemetry studies on Fort Hood (Cook, Koloszar, and Goering, 1996).

Table 1. Comparison of final, straight-line distances (d) between breeding and feeding sites on a daily basis.

	Mean d (km)	Median d (km)	Min	Max
ICBM, All Birds	3.08	2.37	0	9.0
ICBM, Birds breeding in BCVI habitat	3.54	3.09	0	9.0
Telemetry, Birds breeding in BCVI habitat	2.68*	2.74*	0.1	13.1

* Values are averaged from the daily movements of 7 individuals

Cumulative Visitation Patterns

Sensitivity analysis was conducted to assess (1) the influence of BHCO initialization densities and off-post corral densities, and (2) the influence of the four BHCO movement rules, on cumulative visitation output from the behavior component. To evaluate the importance of off-post corral densities to cattle movement, 100 runs were conducted with off-post corrals placed in random sites at 50%, 100%, and 150% the density of on-post corrals. Results indicated that variation in off-post corral densities did not significantly affect the cumulative visitation of cattle herds (Appendix C, Figure C1). To evaluate the importance of BHCO densities and off-post corral densities on BHCO movement, 100 runs were conducted for each of the following twelve combinations of settings (for a total of 1200 runs):

- BHCO movement rule 2 for all runs,
- BHCO initialization densities equivalent to 25%, 50%, 75%, or 100% saturation densities, with random, static breeding locations, and
- Off-post corral densities equivalent to 50%, 100%, or 150% on-post densities, with random locations off-post.

Results suggest that neither initialization densities of BHCO nor off-post corral densities qualitatively affect the cumulative visitation patterns of BHCOS (Appendix C, Figures C2-C5). However, consistent differences do appear between visitation patterns of BHCOS breeding in BCVI and GCWA habitats, and between these BHCOS and all BHCOS on post. These results suggest that certain sites with high BHCO visitation may be more likely to contain individuals that threatened BCVI or GCWA populations, and trapping could be focused on these areas for maximum benefit to the two listed species.

The second analysis evaluated the influence of the four BHCO movement rules on cumulative BHCO visitation. These simulations were conducted using BHCO initialization densities of 25% saturation levels, and equal densities of corrals on- and off-post. Movement rule 0 (search next nearest areas until cattle are located) tends to produce more sites with high visitation, whereas rules including memory (rule 1 and rule 2) tend to decrease the number of "hot spots." In all cases, overall patterns of hot spots and even infrequently visited sites are similar (Appendix D, Figures D1-D3).

Regardless of movement rule, most birds breeding in BCVI habitat do not select off-post feeding areas, except along the boundary of West Fort Hood (Figure D2).

Current ICBM simulations indicate that BHCOS with the potential to parasitize GCWA may be more likely to feed across the installation boundary (Figure D3). Access to better information about livestock distributions on private adjoining lands will allow further evaluation of the importance of nearby foraging habitat to BHCOS on Fort Hood.

Comparison of Trapping Strategies

The relative effectiveness of varying proportions of Hybrid and Mega traps and different fixed schedules for trap movement were compared through ICBM simulation. For all runs,

- BHCOS were initialized at 25% saturation densities,
- Off-post corral density was equal to on-post density,
- BHCOS movement rule 2 was used, and
- Traps were allowed to be placed outside installation boundaries.

Trap placement was restricted to within 750 m of a road ("road" was defined by categories 1-5 in the GRASS "roads_50" map). Trapping efficiencies were set as follows: Mega traps = 0.3020; Hybrid traps = 0.1836. These values were generated by calculating the relative capture rates of 1995 Mega traps and 1995 Hybrid traps from the raw Fort Hood data, assuming that visitation to the traps was equivalent. These actual capture (and trap efficiency) rates were then increased by the same proportion to allow reasonable capture rates during ICBM simulation, considering the numbers of females simulated by the model. It is only the relative value of the trap efficiencies that is important during simulation, since BHCOS population levels are arbitrarily set upon initialization, and only the relative success of different trapping strategies is intended to be used by land managers.

The first exercise used 12 Hybrid and 12 Mega traps; the Hybrid traps were moved to new locations using 3 different schedules: every 7 days, every 28 days, and every 56 days. Additionally, a minimum distance restriction was applied to control placement of Hybrids in the new locations. These distance restrictions included: 0 km (no restriction to placement), 1 km, 2 km, 3 km, and 4 km. Mean total numbers of BHCOS (+/- SD) trapped were calculated for each combination of trapping strategies. Neither the trap movement interval nor the relocation

distance appear to affect overall capture success within the parameters used in this exercise (Figure 12).

A second exercise compared varying numbers of Hybrid and Mega traps. For these runs, Hybrid traps were moved at a fixed interval of 28 days; there were no distance restrictions on relocation decisions. All other rules and parameters were the same as in the first exercise. As one setting for this exercise, the actual numbers of traps used on Fort Hood during May, June, and July, 1995 (i.e., 8 Mega and 36 Hybrid), were used. Furthermore, to better reflect recent trapping practices on Fort Hood, these 36 Hybrid traps were not moved during the simulation. Mean total numbers (± 1 SD) BHCOS trapped were calculated for each combination of trapping strategies. The use of Mega traps had a larger influence on total BHCOS captured compared to an equivalent number of Hybrid traps. Recent (1995) trapping practices on Fort Hood were found to have intermediate capture success compared to the other trapping regimes simulated in this exercise (Figure 13).

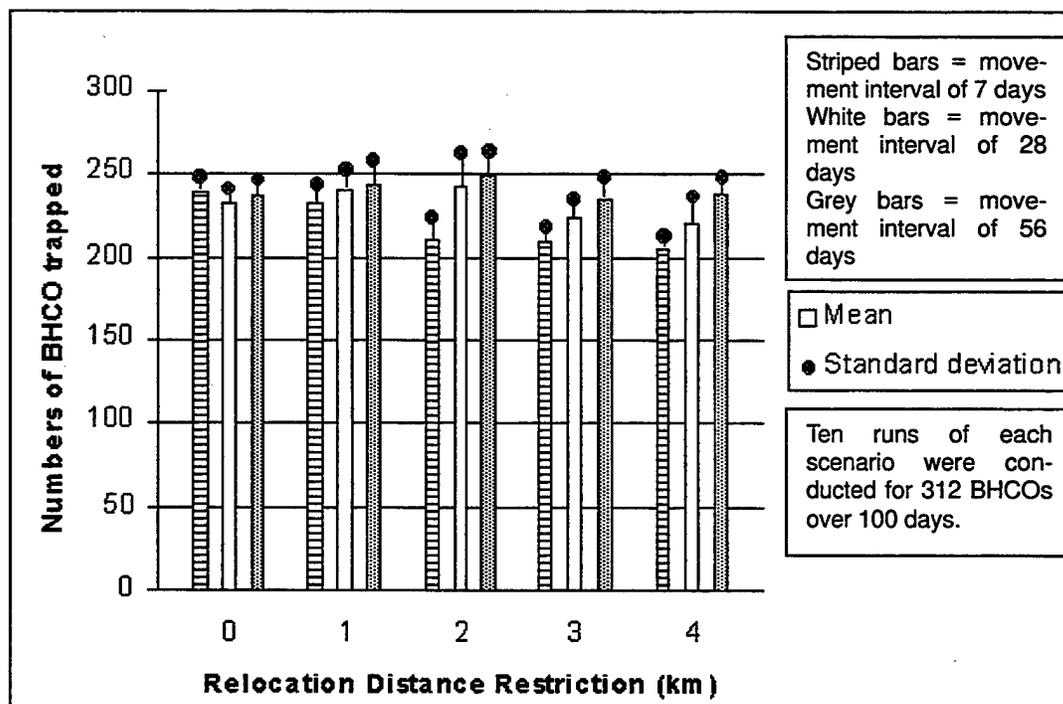


Figure 12. Number of BHCOS removed from Fort Hood land in the ICBM simulation exercise comparing trap movement intervals and relocation distance restrictions.

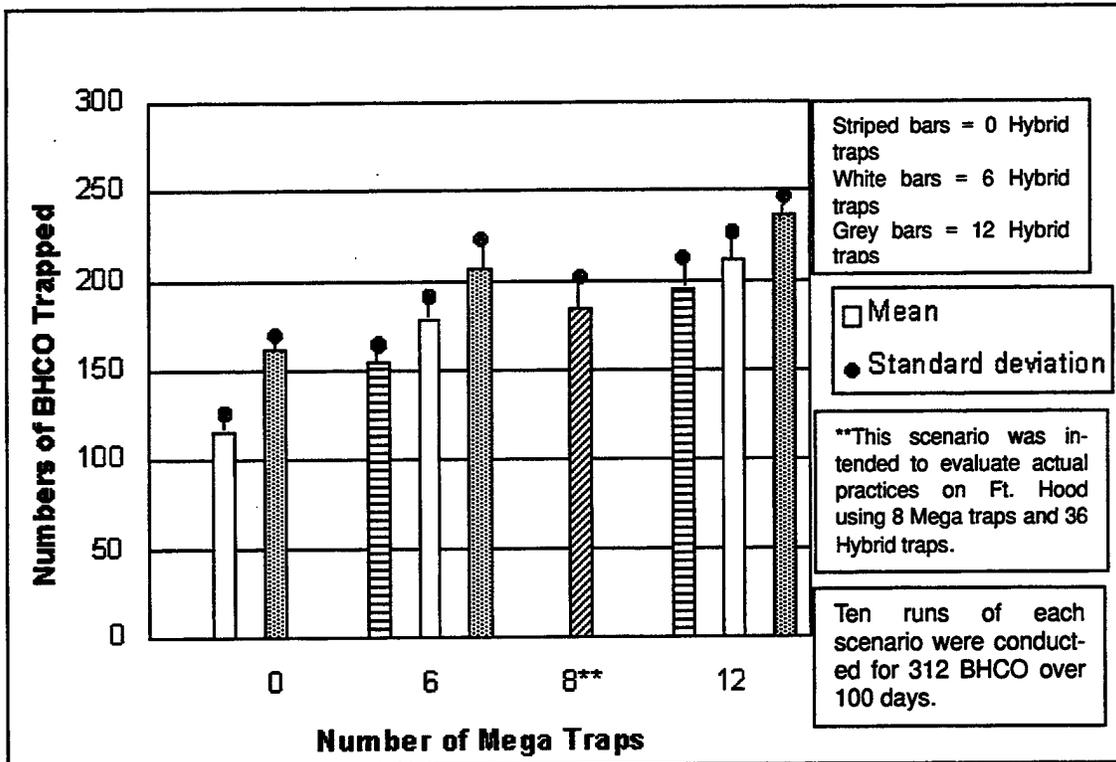


Figure 13. Numbers of BHCO removed from Fort Hood land in the ICBM simulation exercise comparing different numbers of Hybrid and Mega traps.

6 Conclusions and Future Application

The ICBM demonstrates that individual-based modeling technology is applicable to landscape-scale wildlife management concerns, such as the management of BHCOs across a large military installation. Even without full knowledge about the factors that influence BHCO and cattle movement, initial ICBM output compares well to data collected by field biologists. In addition, early output and predictions were reviewed by Fort Hood Endangered Species Branch personnel, who stated that the model appears reasonable, and holds promise for application on landscapes with no previous trapping work (J. Cornelius; G. Eckrich; J. Koloszar, Fort Hood endangered species technician, 16 December 1997). Field work planned for 1998 will improve model input of livestock occurrence outside the boundary of the installation. Additionally, data with which to validate cattle and BHCO movement decisions will be gathered. The potential exists for application of the ICBM by other land management agencies charged with conservation of GCWA and BCVI breeding populations.

List of Abbreviations

AU	animal units
BCVI	black-capped vireo
BHCO	brown-headed cowbird
FHASM	The Fort Hood Avian Simulation Model
GCWA	golden-cheeked warbler
ICBM	Individual Cowbird Behavior Model
USACERL	United States Army Construction Engineering Research Laboratories
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service

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Appendix A: Input to Simulation

User Interface

maxHerdDistFromCorral : The maximum distance, in meters, that a herd is allowed to move away from its associated corral. Range: 750- no max. Current setting: 4000

herdVisitMapSaveFreq : Frequency (in time steps) that a map of cumulative cattle herd visitation is output from the BHCO behavior component. Range: 1-100. Current setting: 100

birdVisitMapSaveFreq : Frequency (in time steps) that a map of cumulative total BHCO visitation is output from the BHCO behavior component. Range: 1-100. Current setting: 100

doBirds : a 0/1 switch that includes birds in the ICBM simulation. Current setting: 1 (yes)

maxBreedFeedDist : The maximum distance, in meters, that a BHCO is allowed to search for and select a feeding site with respect to its breeding site. Range: 750- no max. Current setting: 9000.

traceBirdFlights : a 0/ 1 switch that allows the display to show the pathways of all BHCOs as they search for feeding sites. Current setting: 0

birdMovementRule : User designates which of the 4 BHCO movement rules should be used. Range: 0-3. Current setting: 2.

birdViewThresh : Distance to either side, in meters, that a BHCO can search for cattle herds while travelling en route to previously-used Feeding Areas during movement rules 1 and 2. Range: 0- no max. Current setting: 1000.

doTraps : a 0/1 switch that includes traps in the ICBM simulation. Current setting: 1 (yes)

moveFreq : If the ASCII BHCO trapping component input file does not specify unique values for trap movement intervals for each mobile trap (e.g., the column = 0 for all traps) then this parameter creates a fixed movement interval for all mobile traps, in time- steps. Range 1-100. Current Setting: 28.

minAvgDailyTrapRate : If the ASCII BHCO trapping component input file does not specify unique values for trap movement intervals for each mobile trap (e.g., the column = 0 for all traps), and the moveFreq parameter equals 0, then this parameter specifies the threshold daily capture rate at which mobile traps are moved. Otherwise, it is ignored, and a fixed movement schedule is used. Range: 0- no max. Current setting: N/A.

visitFreq : Interval, in time steps, at which trap managers visit traps and could possibly move mobile traps. If this parameter > 1, then trap movement activity will only occur during time steps when traps are visited as well as when other criteria are met. Range: 1-100. Current setting: 1.

minTrapResidence : The minimum length of time for which mobile traps must remain in a given location (to be used with the minimum capture rate trigger for trap movement, so that traps are not moved every day, or some other unrealistically frequent interval). Range: 0-100. Current setting: 7.

maximizeTrapDist : 0/ 1 switch to consider all possible trapping locations within the vicinity of current or past trap locations, and then relocate each trap into the farthest possible choice, to maximize distance between past and new trap locations. Current setting: 0

trapSpacingDist : Sets the minimum distance (m) between past and new trap locations when mobile traps are relocated. Range: 0- no max. Current setting: N/A.

Input Files

1) Simulation Setup: setup.model

This file captures the user input from the Model Swarm dialog box shown in Figure 2.

BHCO movement rules:

0 = birds fly to next-nearest Feeding Area sequentially, until cattle herd is located

1 = birds fly from breeding site to last three feeding sites in reverse order, then if no cattle have been located, start searching as in Rule 0.

2 = birds fly to last three feeding sites, and can stop at in-between points if cattle are present. If no cattle have been located, search as in Rule 0.

3 = Fly directly from breeding site to nearest Feeding Area with cattle.

2) Simulation Observer: setup.observer

This file captures the user input from the Observer Swarm dialog box shown in Figure 2.

3) Initial BHCO Locations (Breeding Locations): xy_cowbirds

Easting Northing Area_type

Area_type categories:

1 = breed off- post (currently not used)

2 = breed in protected BCVI habitat

3 = breed in protected GCWA habitat

4 = breed on post but not in protected TES habitat

EXAMPLE:

613745 3472255 4

4) Initial Cattle Grazing Quality: xy_herdsuit

Easting Northing suitability on post = 1/ off post = 0

EXAMPLE:

614495 3473005 0.0442 1

Appendix B: Output and Statistics

Cattle Herd Movement:

Timestep Name Number Northing Easting Move Distance

BHCO Movement:

Timestep Name Number Northing Easting Breed-Feed Dist Travel-
(searching) Distance Bird Type (0-4)

Trap Locations and Capture Rates:

Timestep Name Number Northing Easting Trap Type BirdVisits
BirdCaptures Avg Daily Capture Rate

Cattle Herd Stats:

AvgDist (moved) Standard Deviation (dist moved)

BHCO Statistics:

AvgDistanceMoved Standard DeviationMoved AvgDistanceTravel (searched)
Standard DeviationTravel (distance searched)

Trap Statistics:

Total Captures

Appendix C: Density Output*

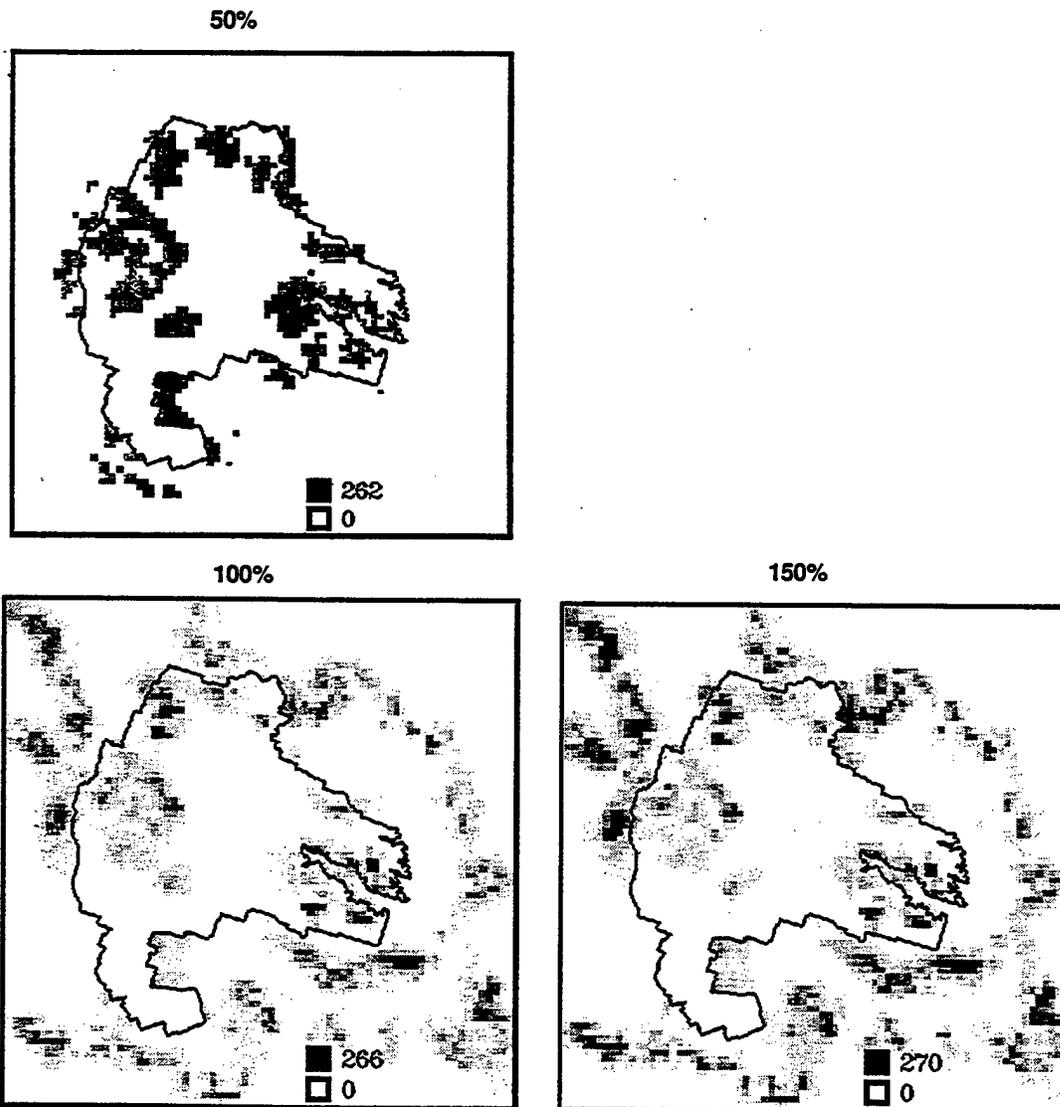
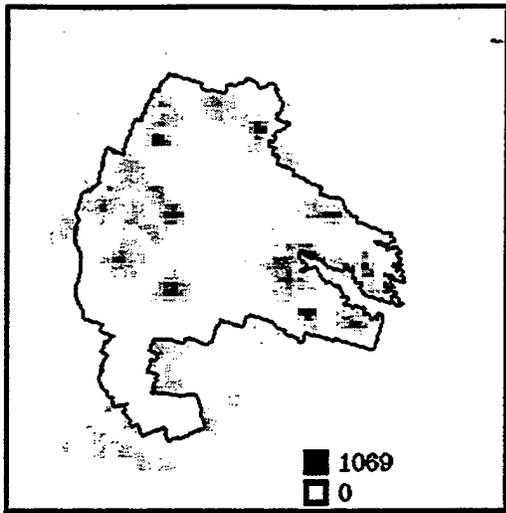
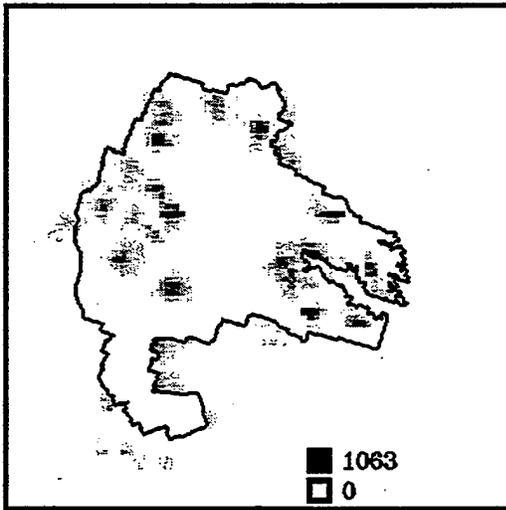


Figure C1. Cumulative visitation counts for cattle herds over 100 runs of 100 time steps each, varying with three levels of off-post corral densities (50%, 100%, and 150% of on-post density).

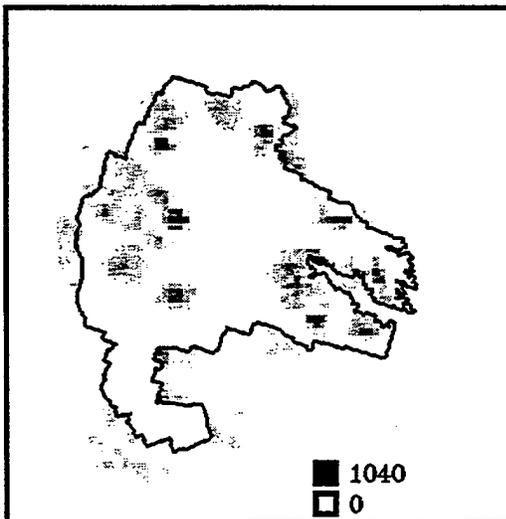
* The intensity of the shading indicates higher cumulative visitation; the upper value is shown in the legend for each map. Note the different absolute scale for each map.



50%



100%



150%

Figure C2. Cumulative visitation counts for all BHCs over 100 runs of 100 time steps each, at 25% saturation levels of BHCs, and three levels of off-post corral densities.

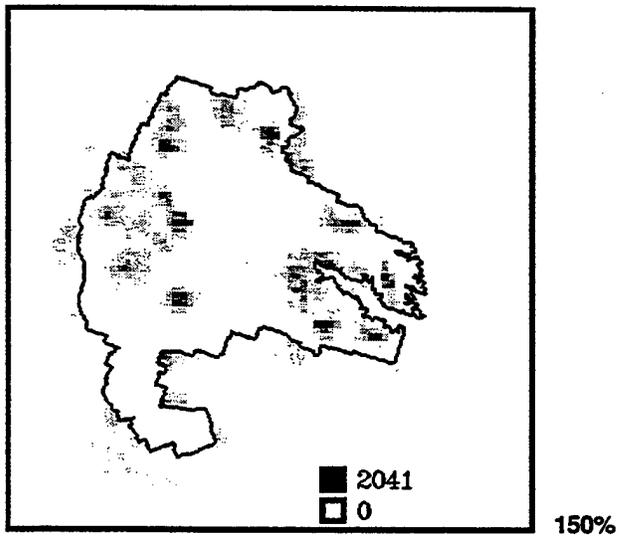
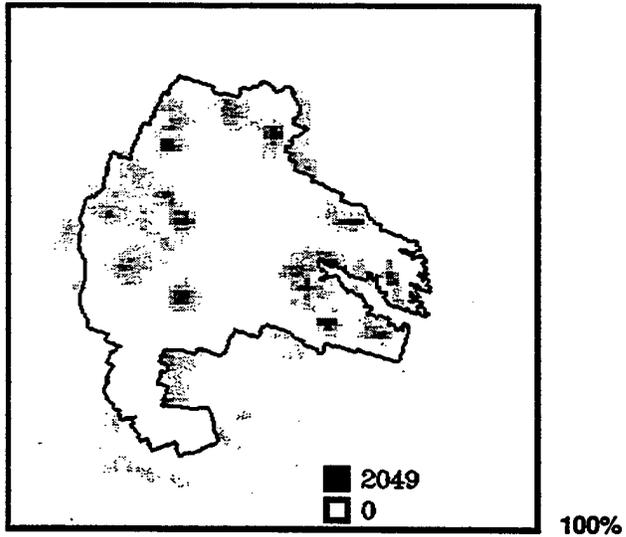
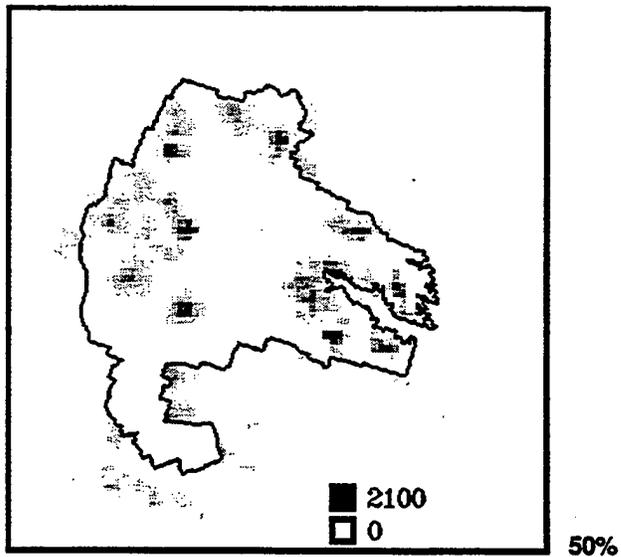
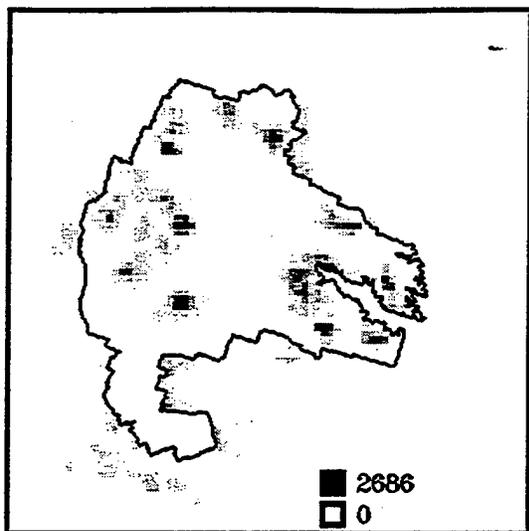
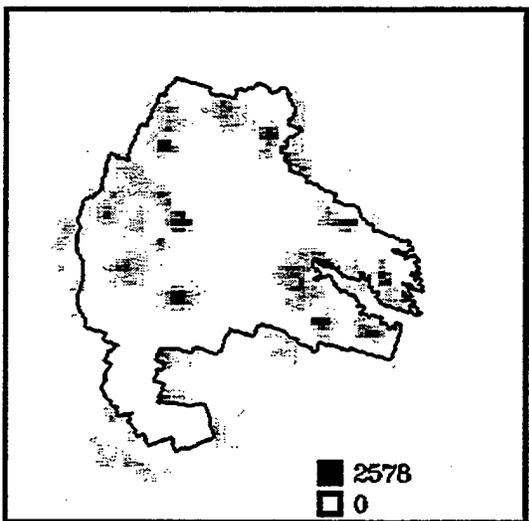


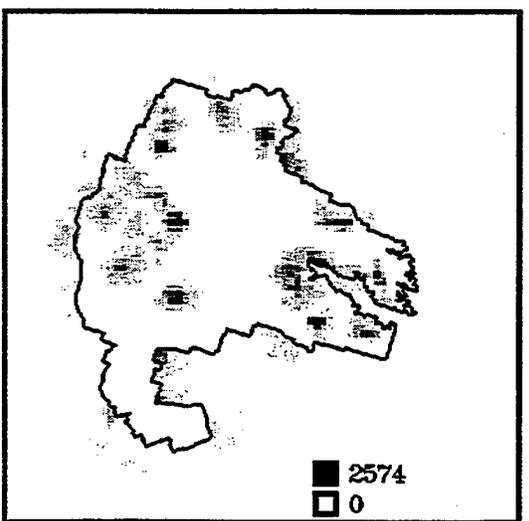
Figure C3. Cumulative visitation counts for all BHCos over 100 runs of 100 time steps each, at 50% saturation levels of BHCos, and three levels of off-post corral densities.



50%



100%



150%

Figure C4. Cumulative visitation counts for all BHCOs over 100 runs of 100 time steps each, at 75% saturation levels of BHCOs, and three levels of off-post corral densities.

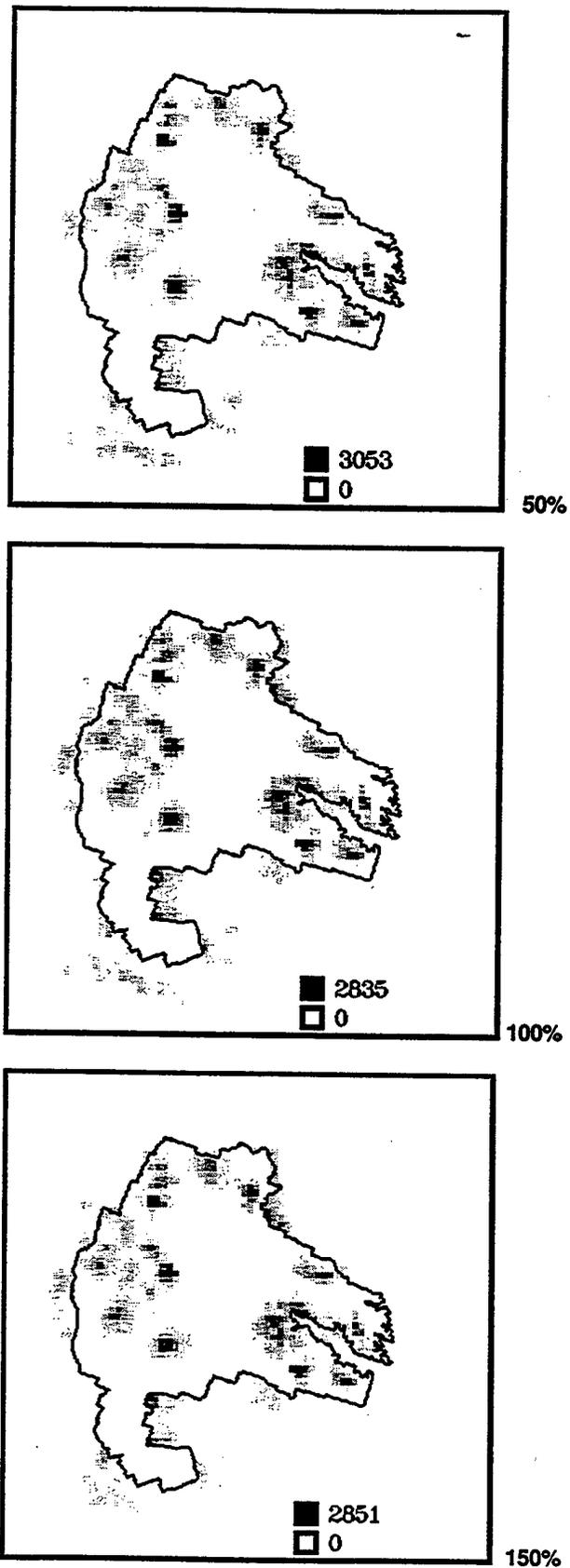


Figure C5. Cumulative visitation counts for all BHCs over 100 runs of 100 time steps each, at 100% saturation levels of BHCs, and three levels of off-post corral densities.

Appendix D: Rule Output

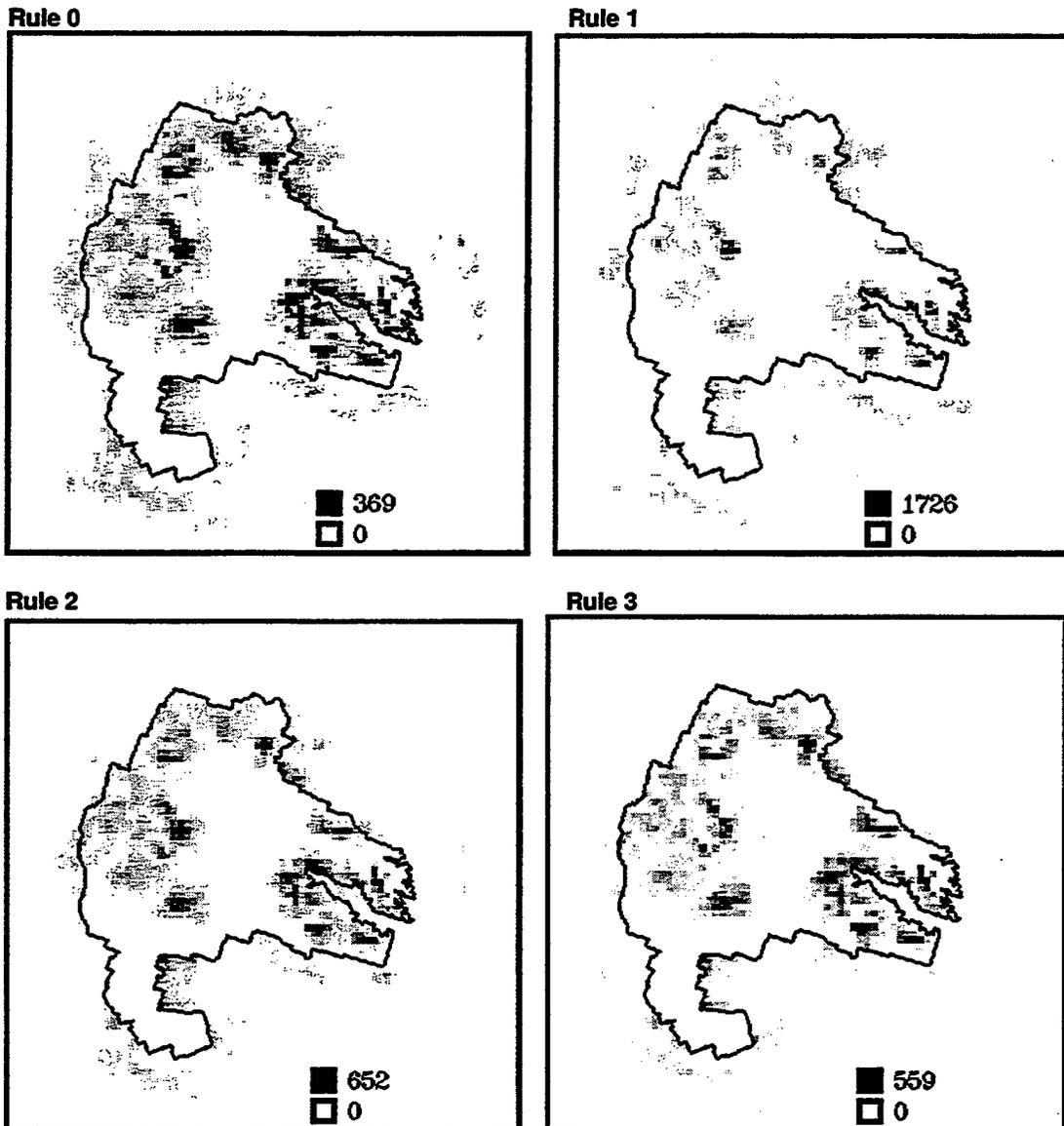
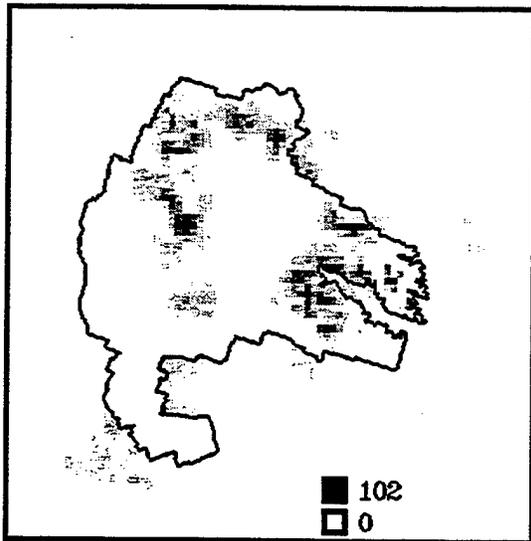
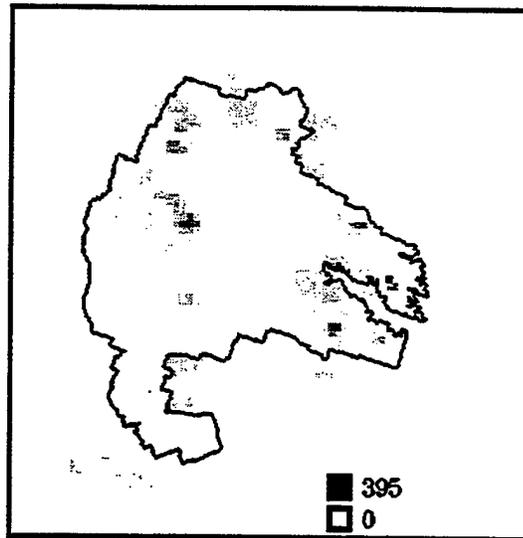


Figure D1. Cumulative visitation counts for all BHCOS over 100 runs of 100 time steps each, at 25% saturation levels of BHCOS, comparing the effects of four BHCOS movement rules.

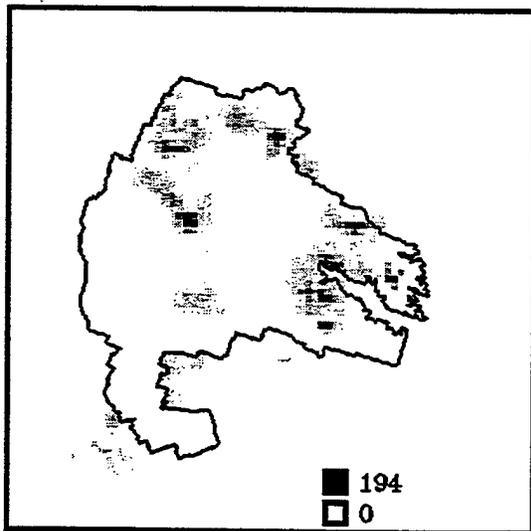
Rule 0



Rule 1



Rule 2



Rule 3

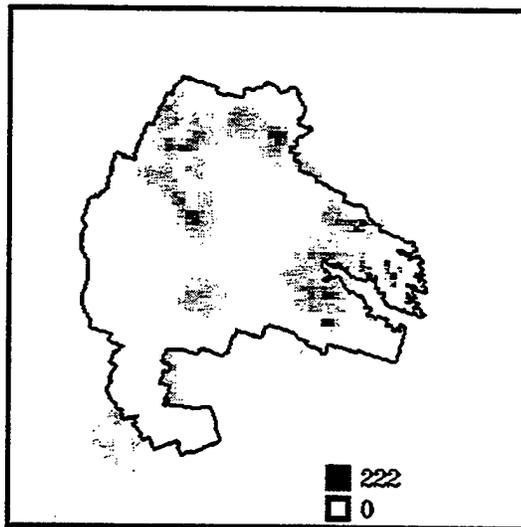
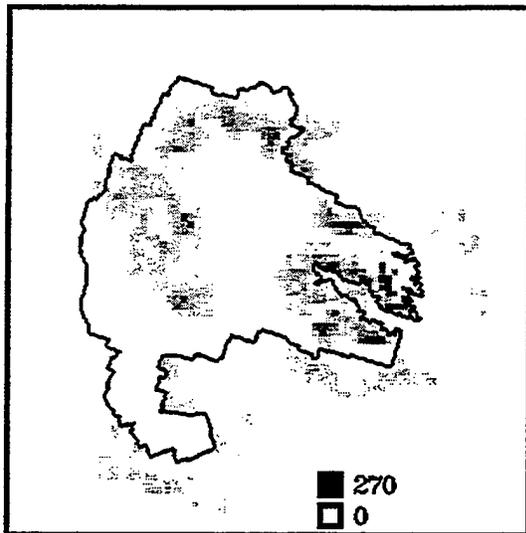
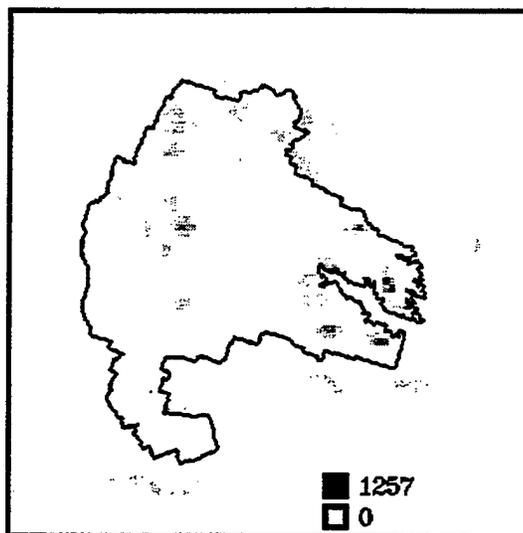


Figure D2. Cumulative visitation counts for BHCOs that breed in designated BCVI habitat, over 100 runs of 100 time steps each, at 25% saturation levels of BHCOs, comparing the effects of four BHCO movement rules.

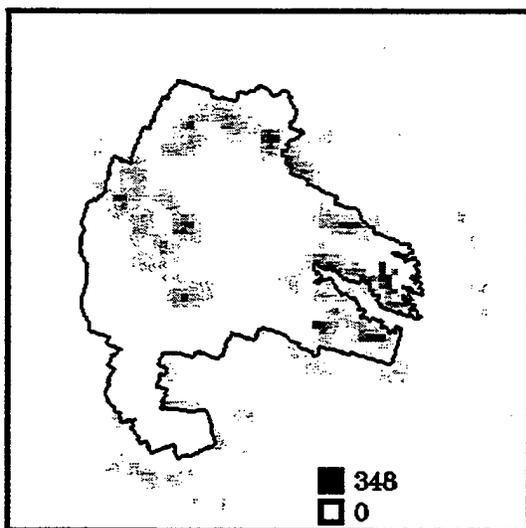
Rule 0



Rule 1



Rule 2



Rule 3

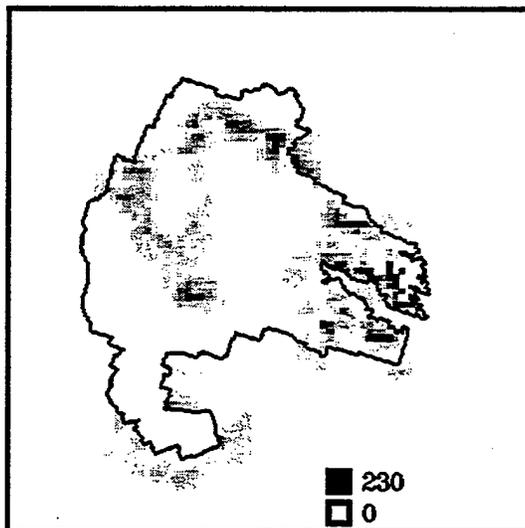


Figure D3. Cumulative visitation counts for BHCOs that breed in designated GCWA habitat, over 100 runs of 100 time steps each, at 25% saturation levels of BHCOs, comparing the effects of four BCO movement rules.

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