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Predicting Northern Goshawk Dynamics Using an Individual-based Spatial Model

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PREDICTING NORTHERN GOSHAWK

DYNAMICS USING AN

INDIVIDUAL-BASED SPATIAL MODEL

By

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The northern goshawk (*Accipiter gentilis*) is a US Forest Service Region 2 Sensitive Species, requiring the Black Hills National Forest to manage for its viability. Previous studies have suggested that a model integrating goshawk population demographics, habitat availability, and territoriality would have the ability to predict population dynamics including goshawk locations, population size, and population viability. An individual-based spatial model was created for the Black Hills goshawk population. This project focused on evaluating our current understanding of goshawk dynamics, and making individual- and population-level predictions as appropriate following model validation. The model simulated demographics and behavior of individuals and usage patterns of selected habitat types. Data sources included published literature (demographic information) and GIS analysis of 50 Black Hills National Forest nest locations (habitat information). Model performance was assessed by comparing input data to the modeled data, and model validation compared observed data not used to build the model to results. Parameters were estimated for which no known published data exists, including: carrying capacity of the Black Hills National Forest, lifespan of adults, proportion of the population made up of juveniles, and age structure of the adult population. Raster maps from 100 simulations were used to create probability surfaces predicting nest site, post-fledging area, and territory occurrences, although 10,000 or more simulations would produce more reliable probability surfaces. The modeled population was based on demographic data from studies in the Kaibab National Forest, and depicted a declining trend. This outcome was not expected, as the observed population is assumed to be stable. Nest surveys in areas not related to proposed timber sales, and local estimates for adult survival and proportion of breeding pairs laying eggs annually would greatly improve the model. Future versions of the model should assess population stability by varying input parameters such as adult and juvenile survival and parameters contributing to fledging success. Suggestions for future research include a better understanding of goshawk movements such as dispersal, immigration, emigration, and seasonal migration. Future applications model include testing for a population threshold response to habitat loss and evaluating potential impacts of proposed management activities. If sufficient data existed, this model could be adapted for other forests, or other similar raptor species.

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1. Introduction

The northern goshawk (*Accipiter gentilis*) is a large raptor found in forest ecosystems in mid to northern latitudes of North America, Europe, and Asia. This species is of interest due to its status as a Sensitive Species, designated by multiple US Forest Service (USFS) Regions, which requires biological evaluations to determine impacts from proposed management activities (Squires and Reynolds 1997). USFS Southwest Region 3 was first to respond to population concerns by creating the Goshawk Scientific Committee that produced *Management Guidelines for the Northern Goshawk in the Southwestern Region* (Reynolds et al. 1992). In 1996, Region 3 issued a Record of Decision amending all regional Forest Plans to include the Reynolds et al. (1992) guidelines.

The US Fish and Wildlife Service (USFWS) listed the goshawk a Category 2 (Candidate) species under the Endangered Species Act in 1991, meaning that additional information was needed to determine listing status; in 1996 the Category 2 designation was removed (Squires and Reynolds 1997) due to lack of evidence of population decline (Kennedy 1997). Today the northern goshawk is a species of concern under the South Dakota Natural Heritage Program; South Dakota Game, Fish, and Parks; and is a Sensitive Species in the USFS Rocky Mountain Region 2 Black Hills National Forest. Due to population viability concerns, the goshawk was an important consideration in the revision process for the Black Hills National Forest Land and Resource Management Plan (USDA 1996) and subsequent Plan amendment process (USDA 2005).

The common USFS method of goshawk management involves conducting nest searches and protecting a minimum area around the nest from timber-harvest-related activities where nest sites are detected. This method results in many missed nest sites for several reasons: 1) as is the case in the Black Hills, most nest searches take place in proposed timber sale areas (Bartelt 1977; Staab pers. comm.); 2) goshawks are known to nest in areas other than mature timber, so the cohort of nesting adults in peripheral habitat is most likely underrepresented; 3) and the methodology for Black Hills National Forest in particular results in a small number of person-days (1 to 2) searching for nest sites (Staab pers. comm.), which may be inadequate for proper detection. Missed nests can be a problem for land managers since knowing only a portion of the territories on a Forest makes it more difficult to estimate size of the breeding population, recruitment, and population viability. Extrapolating habitat quality from an incomplete sample may bias the description of factors influencing habitat selection (Van Horne 1983); systematic surveys are preferable but not always necessary (Daw et al. 1998). Currently the Black Hills manages for goshawks by retaining 73 ha of suitable habitat within 805 m of historically and currently active nests. Stands must be preserved in > 12 ha blocks (Black Hills National Forest 2005).

Habitat preferences at one scale may be extrapolated at that resolution but may be inaccurate at other scales (Wiens 1989) because breeding, foraging, and hiding cover often have different habitat requirements. In response to the common observation of habitat variability over different scales, researchers have suggested that choice of scale in analysis should be related to the habitat needs of the individual, grain and extent of the study area, the ecological process, time scale related to the process, and an organism's activity during that time (Addicott et al. 1987; Wiens 1989; Turner et al. 2001). Several authors have tested which scales best predict goshawk habitat selection by comparison to random sites (McGrath 1997; Clough 2000; Daw and DeStefano 2001; McGrath et al. 2003). Daw and DeStefano (2001) suggest that dense mature forest is important to have for approximately 24 ha surrounding the nest. McGrath et al.

(2003) found that an 83 ha area around the nest was the best for predicting nests sites from random points (75% accuracy). Four scales are recommended for understanding goshawk biology (Reynolds et al. 1992; Reynolds et al. 2006; Reynolds and Joy 2006): nest stand (up to 12 ha), post-fledging area (PFA; approximately 170 ha), defended territory (approximately 1195 ha), and home range (570 to 3500 ha).

Previous modeling efforts have focused on understanding a single population-level attribute, such as nest-site selection or territoriality (McGrath 1999; Clough 2000; Daw and DeStefano 2001; McGrath et al. 2003; Reich et al. 2004). McGrath (1997) and McGrath et al. (2003) modeled goshawk habitat by studying nest-stand metrics in several western states, then testing how well a model could predict nest locations based on metrics analysis. Reich et al. (2004) modeled the territoriality among nest locations and between nest locations and the environment. Hillis et al. (2002) modeled goshawk habitat availability in a Geographic Information System (GIS) using multiple criteria analysis of landscape characteristics by watershed. Kennedy (1998) suggested that once goshawk habitat was well-defined and demographic data available, a model that predicted the relationship between nesting habitat and population trends could be developed. To date, no studies have used spatially explicit models to simultaneously describe the spatial dynamics among goshawks and between goshawks and their environment (Reich et al. 2004).

The purpose of this project was to create an individual-based spatial model for a northern goshawk population; to evaluate the usability of such a model for estimating population parameters; and, as appropriate, to make predictions from the modeled data. This study was designed as a modeling exercise to help biologists understand the current state of our knowledge of goshawk dynamics, and to point out gaps in that understanding that need more research and clarification. In its current form, the model is not meant for making management recommendations, although this may be accomplished in future efforts. The Black Hills National Forest was chosen as the study area, and the Spatially Explicit Landscape Event Simulator (SELES), a language for building dynamic spatial models, was used to build the model.

2. Background

2.1. *Study area description*

The study area is the Black Hills National Forest, which covers 629,000 ha in southwestern South Dakota and northeastern Wyoming (Figure 2-1), an area approximately 200 km long and 100 km wide. Approximately 20% of the lands within the forest boundary are not owned by the USFS, leaving 505,000 ha managed by the Black Hills National Forest. The Black Hills is an island mountain range, rising from the vast Great Plains short-grass prairie and badlands ecosystem.

The Black Hills have a rich cultural history. Archaeologists believe that the area was occupied as early as 10,000 to 12,000 years ago—historically by the Arapaho, Cheyenne, Kiowa, Kiowa-Apache, Crow, and Shoshone, and most recently the Sioux (Black Hills National Forest

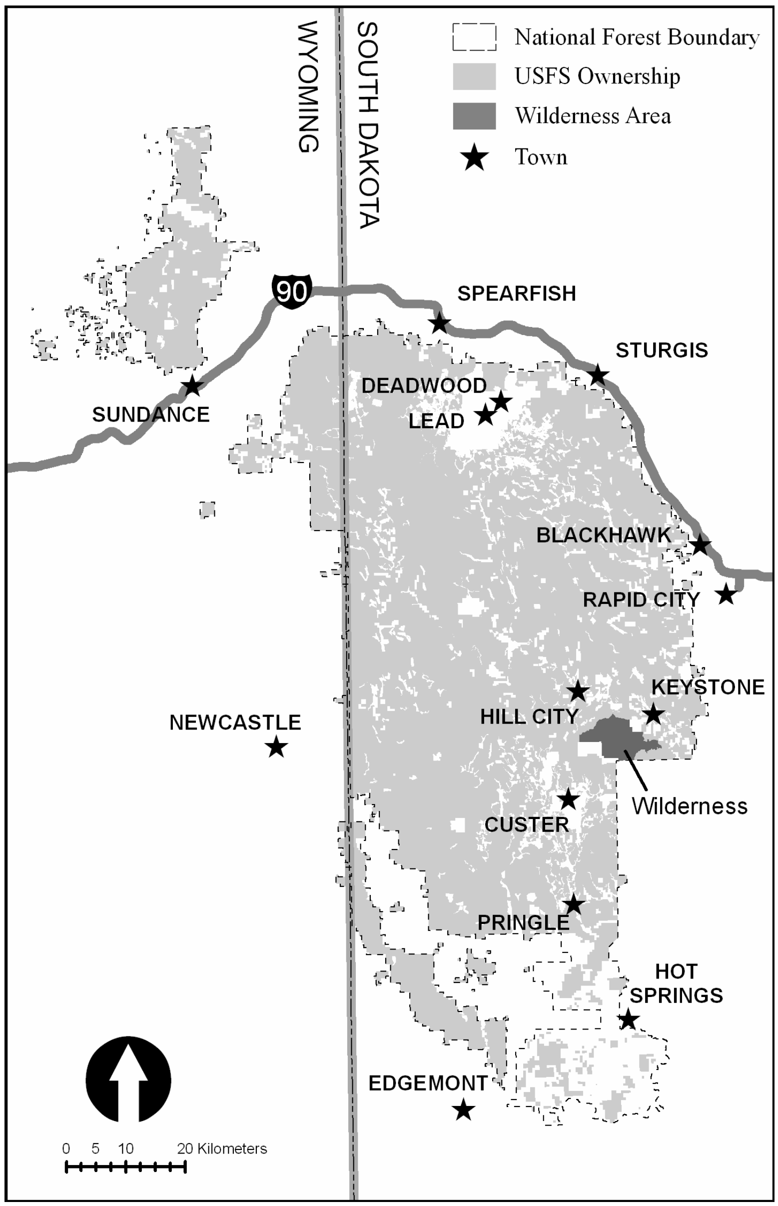

Fig. 2-1 – Black Hills National Forest study area.

1997). The Teton (Lakota) Sioux, who still occupy the area in much smaller numbers, traditionally used the Black Hills seasonally to gather poles for lodges, to hunt, and to hold ceremonies.

The California gold rush of 1848 brought prospectors west and Lieutenant Colonel George Custer's 1874 expedition to the Black Hills, which validated the occurrence of Black Hills gold, created a gold rush there as well. At that time white settlers moved in, ending control of the area by the Teton Sioux, who were moved to Indian reservations. The Black Hills has since been used for mining, oil, timber, ranching, farming, recreation, and tourism.

The first substantial logging occurred to satisfy the needs of miners. In part to protect the forest, President Grover Cleveland established the Black Hills Forest Reserve in 1897. The land was transferred to the USFS in 1905. Contrary to President Cleveland's intention to protect the area, the Black Hills produced a vast amount of timber. Large regions of the Forest were completely harvested. All but approximately 800 ha of the Forest has been cut at least once. Early in the 20^{th} century, the forest was extensively seeded with ponderosa pine, and seed tree, shelterwood, and selections cuts were employed to maximize timber regeneration and output. More than 5 billion board feet of timber have were harvested in 120 years (USDA 1996). Currently about 60% of the forest is composed of trees (primarily ponderosa pine) greater than 23 cm in diameter; 20% is shrubs, seedlings, and trees 2 to 23 cm; 10% is grassland; and 10% is other (rock, water, stand not measured, etc.).

Fire suppression began early in the 20^{th} century and increased fire risk by heightening fuel loading. Prior to 1983, a mean of 1,000 acres burned annually. The 34,000 ha Jasper fire of 2000 was indicative of the growing threat of catastrophic fires in the Black Hills National Forest. Since the year 2000, 14% of the Forest has burned (USDA 2005). There is concern that a series of large catastrophic fires would seriously alter habitat conditions for Species of Concern, including goshawks.

The topography is primarily large rolling hills covered by homogenous ponderosa pine forest with some areas of grassland and natural high-elevation meadow within the USFS boundary. The landscape ranges from 931 to 2196 m elevation with a mean elevation of 1635 m. Private land fragments the forest boundary, with pieces of USFS land scattered across the prairie along the periphery of the Black Hills (Figure 2-1). The Forest includes one 5,500 ha Wilderness area.

The Forest released its Land and Resource Management Plan and Final Environmental Impact Statement in 1997, which was followed by a two-phased amendment process concerning species viability and diversity, fire and insect hazard, and Research Natural Areas. The Record of Decision for the Phase II Amendment was signed in October 2005.

2.2. *Northern goshawk ecology*

Even though numerous studies over large areas using a variety of methodologies have been conducted across the US and Europe, factors influencing goshawk habitat selection are not clearly understood. Habitat preferences appear to differ by landscape and scale (Clough 2000; Daw and DeStefano 2001; Kennedy 2003; McGrath et al. 2003). McGrath (1999) found that nest sites could not be accurately (57% accuracy) predicted at a regional scale across multiple states, indicating that habitat preference varies locally. Erickson (1987) found that goshawks within the Black Hills National Forest tended to nest in large, old-aged, multi-storied ponderosa pine stands with canopy cover of 60 to 85%. A table presented by McGrath et al. (2003) summarizes differences of observed goshawk nest-stand metrics from studies across the western US. Basal area and canopy cover are especially variable from region to region, yet biologists cite both of these attributes as among the best indicators of local suitable habitat. A general pattern does emerge of preference for large mature trees with higher basal areas, canopy cover >50%, use of nest stands > 12 ha, use of a concentrated PFA, and territorial behavior throughout an area approximately 1195 ha in size (Erickson 1987; McGrath 1999; Clough 2000; McGrath et al. 2003; Kennedy 2003; Reich et al. 2004; Reynolds and Joy 2006).

Field work was not conducted as part of this project. The model presented here combines population-based and individual-based demographic (survival, reproduction) and behavioral (territoriality) information from published literature with habitat information (nest site, PFA, and territory selection) obtained from GIS analysis of Black Hills National Forest nest sites to assess the adequacy of our knowledge of goshawk dynamics when collected in a modeled environment.

2.3. *Individual-based modeling and SELES*

Models are indispensable for their ability to simplify reality to a manageable complexity, test our assumptions, identify weak links in understanding, fill in knowledge gaps, compare alternative management scenarios, assess impacts, and predict outcomes (Baird and Wilby 1999; Fall and Fall 2001; Fall 2003; Canham et al. 2003; Peck 2004; Grimm and Railsback 2005).

> It is a widely held myth that a model cannot be developed before we have sufficient data and a comprehensive understanding of the system. The opposite is true: our knowledge and understanding are always incomplete, and this, exactly, is the reason to develop models (Grimm and Railsback 2005).

Models that do not consider both population and habitat dynamics may give an incomplete assessment of landscape carrying capacity, population viability, and landscape connectivity. Spatially explicit individual-based population models combining species behavior, demographics, and habitat maps are becoming more widely used as an effective way to package, track, and quantify a complicated decision process at the landscape scale (Dunning et al. 1995; Matsinos et al. 2000; Akcakaya et al. 2004; Wiegand et al. 2004; Grimm and Railsback 2005; Breckling et al. 2006; McIntire et al. in press).

This model uses a static raster layer of Habitat Structural Stage (HSS) codes that represent a combination of vegetative life form and canopy cover. Modeled individuals interact with the layer by assessing habitat suitability and determining whether to select areas for a nest site and PFA. Habitat suitability decisions are based on a "search" image in the model, which was determined through GIS analysis of habitat types and patterns surrounding observed nest locations on the Black Hills National Forest. At the same time, the model tracks a set of individual states related to population parameters in the model, so that the model counts how many new breeding adults are recruited into the population and are searching for a territory. A simple flowchart (presented in the next section) becomes a complex decision process in the modeled environment. The model results can be used to compare simulated population dynamics with known population dynamics for model validation (Wiegand et al. 2004).

The individual-based modeling and ecology approach (Grimm and Railsback 2005) suits this project for a number of reasons:

1. The model is built to depict relationships based on individual behavior. This allows population-level phenomena to emerge from the system rather than being programmed into the system.
2. The model considers variation in individual behavior by incorporating stochasticity (random chance), which is important to characterizing a range of possible population-level outcomes.

3. Where relationships in a static model/layer are localized and unchanging, individual-based modeling can be portable to other landscapes because it can consider adaptive species behavior using state variables.
4. A dynamic model of this type can be used as a forum for exploring population sensitivity to varying demographic and habitat-based inputs.
5. The model can be used to associate mechanistic data with habitat layers to see whether our current understanding makes sense as a whole. An example in the case of goshawk populations would be testing for the amount of immigration necessary to stabilize a population in which juvenile recruitment is not great enough to compensate for adult mortality.
6. Models can be used to explore landscape "experiments" not possible using animals and habitats in the real world.

SELES is a mid-level modeling language, providing a balance between a general-purpose programming language and parameterizing an existing model with built-in assumptions. Functions are built into the language that help the user describe initial agent locations, numbers of individuals, movement, survival, and reproduction.

A SELES model consists of two components. The first component is comprised of a set of raster layers and global variables that together define the landscape state. This component includes layers and parameters that either remain static or change during the simulation. Second, landscape event files define model behavior (Fall 2001). Interaction and feedback between different processes results in changes to raster maps and state variables, which are reported as results to the user's specification.

3. Methods

3.1. *Data collection*

Data for model input was gathered from published literature and GIS analysis of observed nest locations on the Black Hills National Forest.

3.1.1. *Use of literature*

Population input variables were primarily found in two sources: literature published by Reynolds and his colleagues over the last three years, and Kennedy's USFS Region 2 Goshawk Assessment (2003). Reynolds and his colleagues have studied the Kaibab National Forest goshawk population for nearly two decades, establishing population demographics, behavioral attributes, and life history traits based on large sample sizes. Although many other works were referenced, only these were used as inputs to the model since Kennedy's assessment is the most locally focused, while Reynolds studies have the longest study period and largest sample sizes.

Data from the well-studied goshawk population on the Kaibab National Forest was used because there was not sufficient demographic data available for the study area. Although vital rates have been estimated for other western US populations, the choice was made to use all rates from one population, rather than mixing vital rates from several populations into what could be an unrealistic coupling of data. Subsequent modeling efforts that focus on population management recommendations should utilize a range of demographic input from populations other than the Kaibab National Forest, and include a sensitivity analysis of those rates. Section 3.2 further describes knowledge gaps and assumptions of the model.

3.1.2. *Use of GIS analysis*

GIS analysis was used to characterize the habitat selection of Black Hills National Forest goshawks based on vegetation maps from 2006 and active nest locations observed over the last 10 years, both acquired in ESRI® shapefile format from the National Forest in spring 2006. Limitations of these datasets are discussed in Section 3.2.

3.1.2.1. *Vegetation classification*

Vegetation information was obtained from the Rocky Mountain Resource Information System (RMRIS) forest inventory database for 2006. This database contains stand attributes describing a combination of vegetative life form, tree size, and canopy cover, known in USFS Region 2 as "HSS codes." Polygons were delineated through aerial photo interpretation, of which about 50% had an accompanying stand exam to verify the accuracy of the classification (Staab pers. comm.). HSS attributes were determined from the aerial photos, while several others were not determined until a stand exam had taken place. Thus, the HSS is the most complete of all fields in the database. HSS was used to characterize the search image of the goshawk because tree size and canopy cover are often more indicative of preferred goshawk habitat than vegetation communities (McGrath et al. 2003). Table 3-1 below displays the meaning of each code and its relative abundance in the study area.

Because SELES is a raster-based model, stand polygons were dissolved based on the HSS attribute and converted to a raster layer with a pixel size of 1 ha using ESRI's ArcInfo 9.2 Spatial Analyst extension. This pixel size corresponds to the approximate minimum mapping unit of the vector polygons.

Table 3-1
HSS classification of vegetation information

Code	Life form	Tree size class	Diameter range for most trees	Crown cover (%)	Hectares
None[a]	No data	None	None	0	140,048
1	Grass-forb	Nonstocked	None	0 to 10	61,245
2	Shrub-seedling	Established	<2 cm	11 to 100	13,800
3A	Sapling-pole	Small, medium	2 to 23 cm	11 to 40	23,908
3B	Sapling-pole	Small, medium	2 to 23 cm	41 to 70	33,781
3C	Sapling-pole	Small, medium	2 to 23 cm	71 to 100	19,763
4A	Mature	Large, very large	23+ cm	11 to 40	130,058
4B	Mature	Large, very large	23+ cm	41 to 70	138,599
4C	Mature	Large, very large	23+ cm	71 to 100	57,780
5	Old growth	Large, very large	Varies	Varies	797

[a]None refers to areas of private ownership (non-classified by the USFS); non-classified areas within the National Forest; water; rock outcrop; or gravel. Of this category, 82% is private lands.

Table 3-2
Goshawk territories analyzed for habitat search image

Last year territory known to be active	Number of territories analyzed [a]
1996	1
1997	5
1998	3
1999	4
2000	1
2001	1
2002	5
2003	8
2004	8
2005	14
Total number of samples	50

[a] These are independent samples, i.e. each space on the landscape is represented and analyzed only once.

3.1.2.2. *Analysis of habitat selection*

Goshawk nest locations were provided by the Black Hills National Forest from their FAUNA database. Reflecting goshawks propensity to use alternate nests in different years, the nest site point layer contained multiple nests grouped by territory. The data was accompanied by a spreadsheet naming each territory and which of the alternate nests within that territory was the most recently active. The point layer was reduced to only nests that were active within the last ten years (Table 3-2). This resulted in 51 samples; one was discarded because it occurred in HSS 2 (shrub-seedling type) and was thought to be misclassified, resulting in 50 samples total.

The most recently active nest site was assumed to be the center of each territory. For purposes of this study, the territory was defined as the defended portion of the foraging area, which includes the nest stand and the PFA. Territories are approximately 1195 ha, a circular area with a 3.9 km diameter (Reynolds and Joy 2006). Vegetation within 1 ha (56 m radius) of each nest site was examined to determine in what HSS habitat types goshawks were nesting. This data was then compared to the amount of each HSS type available within by calculating a use-versus-availability index. Anywhere the index was greater than 1.0 was deemed preferential use. Nest sites were modeled at 1 ha because it corresponded to the pixel size of the input raster layer (100 × 100 m cells).

Next, this approach was used to determine preferential use at 24 ha, 83 ha, and 170 ha. GIS was used to buffer the nests by radii of 276, 514, and 736 m respectively, and summarize the habitat within those circular buffers. No metrics were calculated beyond 170 ha because larger areas have been less successful at predicting goshawk nest sites (McGrath 1999; McGrath et al. 2003). Where the indices (based on all nest sites grouped) showed preferential use, this habitat type was utilized in the model as the "search image" for the modeled individuals for that area. However, for nest sites only (the 1 ha area), modeled individuals were allowed to choose from any HSS type with an index value greater than 0. For those HSS types that evaluated to less than 1.0, the observed probability of selecting that type was used. This was done because goshawks are known to nest in micro-sites (small pockets of suitable habitat different from the larger stand), that would be lost at the 1-ha pixel size. Utilizing the observed probability meant that less desirable HSS types would not be completely prohibited.

An alternate method for creating a search image is setting the highest used-versus-available value to 1, the lowest to 0, and rescaling the other values between with a logistic model representing probability of selecting each HSS type. The method used here allows individuals to choose from any type, and pass over non-preferential habitat, leaving some portion of the PFA to consist of whatever non-preferential HSS types may lie between. This created a less restrictive search image to meet the assumption that goshawks are more forest generalists than the 50 samples may suggest. A logistic model could be tested in future iterations of the model. Tables 3-3 to 3-6 show the results of the use-versus-availability analysis.

Table 3-3
Habitat within 1 ha of nest location

HSS code	Hectares within 1 ha	Percent within 1 ha	Hectares available	Percent available	Used vs available	Model value
1	0.0	0%	61,245	13%	0	0.00
2	0.0	0%	13,800	3%	0	0.00
3A	0.6	1%	23,908	5%	24%	0.24
3B	3.3	7%	33,781	7%	94%	0.94
3C	2.1	4%	19,763	4%	102%	1.00
4A	7.8	16%	130,058	27%	58%	0.58
4B	18.0	36%	138,599	29%	125%	1.00
4C	17.0	34%	57,780	12%	283%	1.00
5	1.0	2%	797	0%	1209%	1.00

Table 3-4
Habitat within 24 ha of nest location

HSS code	Hectares within 24 ha	Percent within 24 ha	Hectares available	Percent available	Used vs available	Model value
1	20.8	2%	61,245	13%	14%	0
2	3.5	0%	13,800	3%	10%	0
3A	16.6	1%	23,908	5%	28%	0
3B	71.7	6%	33,781	7%	86%	0
3C	45.8	4%	19,763	4%	94%	0
4A	206.0	17%	130,058	27%	65%	0
4B	447.0	38%	138,599	29%	131%	1
4C	333.2	28%	57,780	12%	235%	1
5	32.7	3%	797	0%	1672%	1

Table 3-5
Habitat within 83 ha of nest location

HSS code	Hectares within 83 ha	Percent within 83 ha	Hectares available	Percent available	Used vs available	Model value
1	107.9	3%	61,245	13%	21%	0
2	26.7	1%	13,800	3%	24%	0
3A	108.0	3%	23,908	5%	55%	0
3B	217.0	5%	33,781	7%	78%	0
3C	208.5	5%	19,763	4%	128%	1
4A	741.3	19%	130,058	27%	69%	0
4B	1478.6	37%	138,599	29%	130%	1
4C	959.8	24%	57,780	12%	202%	1
5	100.3	3%	797	0%	1529%	1

Table 3-6
Habitat within 170 ha of nest location

HSS code	Hectares within 170 ha	Percent within 170 ha	Hectares available	Percent available	Used vs available	Model value
1	269.9	3%	61,245	13%	27%	0
2	87.2	1%	13,800	3%	38%	0
3A	255.2	3%	23,908	5%	65%	0
3B	486.0	6%	33,781	7%	87%	0
3C	402.4	5%	19,763	4%	123%	1
4A	1642.6	21%	130,058	27%	76%	0
4B	2923.5	37%	138,599	29%	128%	1
4C	1717.7	22%	57,780	12%	180%	1
5	144.6	2%	797	0%	1098%	1

3.2. *Knowledge gaps and assumptions*

Little is known about the Black Hills National Forest goshawk population in comparison to the Kaibab National Forest population. For purposes of this project only, it was assumed that the Black Hills goshawks respond to their environment similarly to the Kaibab goshawks, surviving and reproducing at similar rates. Future applications of the model should integrate data from other western US goshawk populations before using the model to make management recommendations.

Limitations to the GIS datasets used exist. First, the vegetation information is only updated annually, and those updates focus on stand exams or areas of known change (timber sales, natural or prescribed fire), while unmanaged stands experiencing natural succession may not have changes in stand density recorded between yearly database updates. Secondly, the choice was made to use nest information only from those nest sites active within the last 10 years, assuming forest change over a longer period might not reasonably represent stand conditions the goshawk was selecting for at the time of last use of the territory.

As described earlier, nest searches were conducted in response to proposed timber sales. Therefore this data largely represents a cohort of adults whose nesting preferences are associated with mature timber. There is a potential bias of this data to show that goshawks require more forested habitats than they may actually need. Therefore, the model could result in fewer overall territories and underpredict breeding, resulting in a more modest population size because non-forested areas (grass, forb, and shrub types) are not sought out as suitable PFA habitat in the model. The extent to which goshawks are nesting outside of mature forest areas in what is often considered marginal habitats is unknown, and, where present in the dataset, is likely underrepresented.

It was assumed that each year each breeding pair returned to the same territory with the same mate and attempted breeding. Goshawks have high territory (95%) and mate (98%) fidelity (Wiens et al. 2006). Still, there is not enough recruitment in the modeled population presented here to compensate for mortality, causing the modeled population to decline, while the observed Black Hills goshawk population appears stable (Reynolds pers. comm.). Ongoing research by Reynolds and his colleagues (unpublished) is looking into rates of immigration and emigration and using population-viability-analysis to determine what minimum population size is needed for a self-sustaining population. It is also not known what winter habitat is used by the population or what the condition is of that habitat (Kennedy 2003). For this study it was assumed that winter mortality was included in the yearly survival rate, and that explicit modeling of winter migration and habitat was unnecessary.

Little is known about the time required daily or monthly by goshawks for particular tasks or how quickly they move across the landscape. For instance, data about juvenile dispersal distance are based on small sample sizes and somewhat incidental data sources (e.g. a banded individual is found three years later 80 km from its natal nest site). In this model no individual could leave the modeled Black Hills area.

Forest structural conditions at multiple spatial scales largely influence population productivity by affecting abundance and accessibility of prey (Safalsky et al. 2005; Wiens et al. 2006; Reynolds et al. 2006). Due to the lack of data about goshawk prey, this information was implicitly considered within the habitat choices made by Black Hills National Forest goshawks. Here, the model was meant to recreate a scenario similar to the present day goshawk population and did not incorporate a vegetation growth model. This too could be integrated into future versions of the model if needed to address an ecological hypothesis.

Table 3-7
The seven elements of the ODD protocol (reproduced from Grimm et al. 2006)

Blocks	Elements
1. Overview	a. Purpose b. State variables and scales c. Process overview and scheduling
2. Design concepts	a. Design concepts
3. Details	a. Initialization b. Input c. Submodels

3.3. *Model methodology*

Methodology for creating the dynamic spatial model is presented following the Overview, Design Concepts, Details (ODD) protocol (Grimm et al. 2006). This standard protocol was developed and tested by a group of 28 ecological modelers to aid in communication of the often cumbersome amount of information needed to adequately describe an individual-based model.

The ODD protocol follows seven steps shown in Table 3-7.

Overview gives the reader an idea of the purpose and complexity of the model. Design concepts provide information a modeler would need to be able to reproduce the model. Details are the finest level of information, including initialization values and description of submodels.

3.3.1. *Overview*

This section describes the overall purpose and structure of the model.

3.3.1.1. *Purpose*

The purpose of this project was to create a model representing our knowledge of goshawk dynamics, to evaluate the usability of the individual-based modeling method for predicting population parameters given the current knowledge, and, as appropriate, to predict population parameters from the model. SELES, a language for building dynamic spatial models, was used.

3.3.1.2. *State variables and scales*

"State variables" are defined here as dynamic ecological variables that have the capacity to change their value in response to the modeled environment. Tables are presented that have state variables organized by entity represented (e.g. individual, population, habitat). This section describes the full set of state variables used in the model which provides an overview of model structure, resolution, and level of detail in representing female individuals. Male individuals are not explicitly represented.

Low-level state variables

Low-level state variables are the elementary properties of modeled entities (Grimm et al. 2006). Modeled goshawks are characterized by a number of low-level variables that describe their age, breeding status, and success at finding a nest site and territory. The model consists of three submodels that interact: Population, Movement, and Habitat. Population (Table 3-8) describes how individuals survive, age, and breed. Movement (Table 3-9) describes how individuals move around the landscape and search for a potential nest site, or territory center. Habitat (Table 3-10) describes how individuals evaluate habitat and establish territories. These events are described in more detail in Section 3.3.1.3. Each variable is described, and its source cited. If the variable is implemented to track information but is not directly from data, it is denoted as a tracking variable.

Table 3-10 describes low-level state variables in the Habitat landscape event file. The subroutine uses a spreading function where agents search a cluster of neighboring cells and choose whether to spread to those cells for a territory. Each variable below describes a prospective individual habitat that is represented by a cluster of cells.

High-level state variables

High-level state variables are those that describe the entire population of individuals, subpopulations of individuals, or landscapes. They also include variables that are aggregated from low-level variables. Such variables are categorized by individual-level or population-level and are described in Tables 3-11 and 3-12.

Table 3-13 describes dynamic landscape variables, which in SELES are portrayed as raster maps. Maps that are saved as output are described.

Scales

The broadest area is the model extent, which covers the Black Hills National Forest boundary and a buffer of approximately 4 km. Territories are modeled at a number of nested scales: 1 ha (56 m radius; nest site), 24 ha (276 m radius), 83 ha (514 m radius), 170 ha (736 m radius; PFA), 1195 ha (1950 m radius; territory), and 4778 ha (3900 m radius; territory buffer). The smallest resolution in the model is 1 ha, which is the pixel size of all raster layers.

In the model, habitat selection criteria were nested, such that an individual would evaluate suitable habitat at 1 ha, then evaluate the number of suitable habitat pixels within 24 ha, within 83 ha, and within 170 ha. The individual had to pass each criterion successfully in order to search the next largest area. This "spreading" function in the model takes place in a fraction of a time step. Failure to find enough suitable habitat within any of the thresholds resulted in the modeled individual abandoning the area and moving somewhere else to try again.

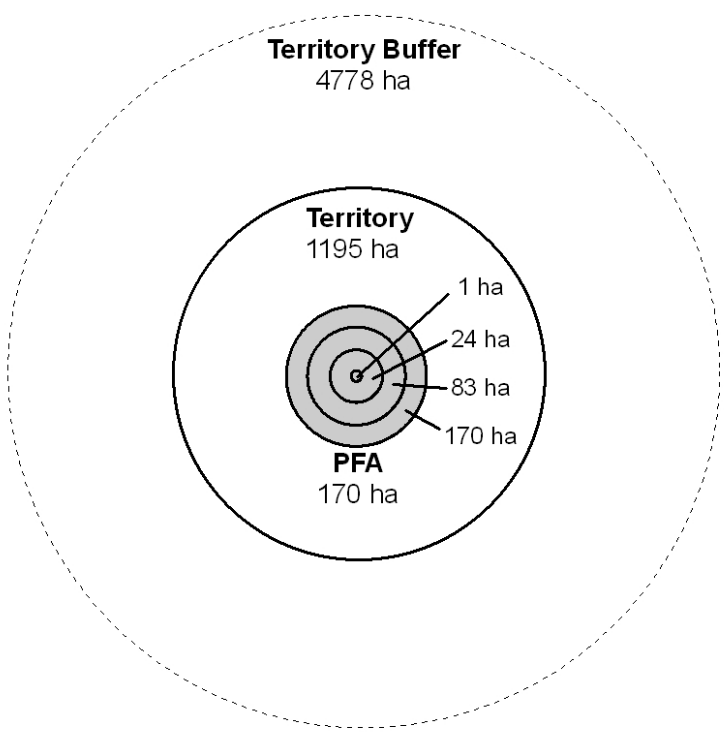

Fig. 3-1 – Areas used in the model.

Table 3-8
Low-level state variables in the Population submodel

State variable	Value	Description
Age	Non-negative integer; begins at age 0 when born and adds 1 per year [b].	For individuals that are seeded by model initialization, starting age is equal to the breeding age; for all new births age begins at 0.
BreedingAge	Rounded value pulled from a normal distribution (μ=3.5, ± 0.32; range 2-8; Wiens and Reynolds 2005).	Age at which individuals make their first attempt at breeding.
BirdType[a]	200=first year juvenile, 100=adult; numbers are arbitrary, simply representing a state [b].	Tracked for purposes of evaluating first year juvenile survival differently than adult survival.
BreedingAdult	1 or 0 [b].	If Age ≥ BreedingAge then 1 else 0.
NeedPFA[a]	1 or 0 [b].	If bird is a breeding adult but does not have a territory, then 1 else 0
HasPFA[a]	1 or 0 [b].	If bird has a territory, then 1 else 0.
Survive	1 or 0; Probability of adult survival: μ=0.75, ± 0.02 (Reynolds et al. 2004). Probability of juvenile survival: μ=0.71 ± not reported (Wiens et al. 2006).	If individual dies, Survive evaluates to 0 and all properties for the individual are removed from the maps.
SexOfOffspring	0, 0.5, or 1 [b].	Number fledged (2) is multiplied by the SexOfOffspring value to determine how many of the young are female. In the model there is a 0.25 probability of having 0 females (SexOfOffspring = 0), a 0.50 probability of having one female (SexOfOffspring = 0.5), and a 0.25 probability of having 2 females (SexOfOffspring = 1).
ProportionOfBreedingPairs	Pulled from a uniform distribution from 0.22 to 0.87 (Reynolds and Joy 2006).	Number of breeding pairs with active territories (laying eggs) in a given year.
BreedingThisYear	1 or 0 [b].	Not all territorial females breed each year; this represents whether the individual is in the proportion of breeders with active nests.

State variable	Value	Description
WillFledgeYoung	1 or 0; Probability of fledging young in an active nest $\mu = 0.805 \pm$ not reported (Wiens and Reynolds 2005).	Tests whether a breeding adult with an active nest is in the proportion of those that successfully fledge young.
Fledged	0, 1, 2 (Wiens and Reynolds 2005).	Each breeding adult may fledge up to 2 female young per year.

[a] Represents a global variable, for which values are available among all submodels.
[b] Used as a tracking variable to relate information about individuals.

Table 3-9
Low-level state variables in the Movement submodel

State variable	Value	Description
JuvMovedOnce	1 or 0 [b].	Evaluates to 1 once a juvenile disperses from the natal nest site; individual continues movement later when searching for a territory.
NeedToMove	1 or 0 [b].	Equals 1 if: a bird is searching for a nest site, is in another's occupied territory, or is outside of the forest boundary (unsatisfactory nesting habitat).
LastDirection	0 to 359; randomly chosen from a uniform distribution [b c].	Tracks the last direction an individual moved as part of a correlated random walk.
MoveDirection	0 to 359; chosen from a normal distribution, μ= LastDirection, $\sigma = 40$ [b c].	Next direction an individual will move calculated as part of a correlated random walk.
MoveDistance	0 to 10,000 [b c].	This is the distance in meters an individual will move. Individuals move 300 m in each step when searching for a nest; individuals (both adults and juveniles) move 3900 m when in another's territory (based on nearest neighbor distance between territory centers); individuals move farther when outside the forest boundary—1000 m when < 10 km away, and 10,000 m when > 10 km for model efficiency (i.e. no data source regarding movement).
FoundSite [a]	1 or 0 [b].	If an individual found a potential nest site then 1 else 0; probability of choosing a habitat pixel as a potential nest site shown in Table 3-3 above.
TryAgain [a]	1 or 0 [b].	Evaluates to 1 If an individual searches for a territory and finds unsatisfactory habitat in Habitat.lse.

[a] Represents a global variable, for which values are available among all submodels.
[b] Used as a tracking variable to relate information about individuals.
[c] Values estimated for modeling purposes; not from published literature.

Table 3-10
Low-level state variables in the Habitat submodel

State variable	Value	Description
GoodHab24	0 to 24; A rounded number pulled from a skewed normal distribution (μ=24, σ of left side =7.6, σ of right side =0.01; range 0 to 24) based on GIS analysis.	Number of cells of suitable PFA habitat an individual needs to pass the 24 ha area.
GoodHab83	6 to 83; A rounded number pulled from a skewed normal distribution (μ=61, σ of left side =17.4, σ of right side =7.4; range 6 to 83) based on GIS analysis.	Number of cells of suitable PFA habitat an individual needs to pass the 83 ha area.
GoodHab170	17 to 166; A rounded number pulled from a skewed normal distribution (μ=108, σ of left side =30.6, σ of right side =16.9; range 17 to 166) based on GIS analysis.	Number of cells of suitable PFA habitat an individual needs to pass the 170 ha area.
AreaUsed24	0 to 24 [b].	Number of cells within 24 ha that are suitable PFA habitat.
AreaUsed83	0 to 83 [b].	Number of cells within 83 ha that are suitable PFA habitat.
AreaUsed170	0 to 170 [b].	Number of cells within 170 ha that are suitable PFA habitat; if enough suitable pixels are found, the territory is established.
AreaSearched	0 to 1195 [b].	Total number of cells in the cluster.
AbandonThisPFA	1 or 0 [b].	If "AreaUsed" < "GoodHab" for any area, then 1 else 0; this will stop an individual from establishing a territory in an area of unsuitable habitat.

[a] Represents a global variable, for which values are available among all submodels.
[b] Used as a tracking variable to relate information about individuals.

Table 3-11
High-level state variables for modeled breeding individuals

State variable	Description
NumYearsAtBreedingAge	Counts the number of years each individual lives after reaching breeding age.
NumYearsFloatingBreeder	Counts the number of years each individual spends searching for a territory.
AgeFoundTerritory	Age at which a breeding individual established a territory.
NumYearsWithTerritory	Counts the number of years each individual lives after establishing a territory.
AgeFirstBred	Age at which an individual first successfully fledged young.
NumYearsSuccessfulBreeder	Counts the number of years each individual successfully fledged young.
NumYoungFledged	Counts the number of young fledged by an individual.
HSS1, HSS2, HSS3A, HSS3B, HSS3C, HSS4A, HSS4B, HSS4C, HSS5	Total number of cells in the PFA made up each each HSS type.

Table 3-12
High-level state variables for the modeled population

State Variable	Description
PopulationSize	Total number of female individuals in the model including adults and juveniles.
BreedingAdultCounter	Number of living female adults in the population that have reached breeding age.
NumJuvsDied	Number of juveniles that have died throughout the simulation.
NumJuvsAlive	Number of juveniles currently alive.
NumAdultsDied	Number of adults that have died throughout the simulation.
NumAdultsAlive	Number of adults currently alive.
NumAdultsDiedPerYear	Number of adults that died in the current year.
NumAdultsLivedPerYear	Number of adults that survived in the current year.
NumJuvsDiedPerYear	Number of juveniles that died in the current year.
NumJuvsLivedPerYear	Number of juveniles that survived in the current year.
AdultsWithPFAs	Number of adults in population that found a territory.
SuccessfulBreeder	Number of adults in a year that successfully fledge young (whether male of female, e.g. even if SexOfOffspring variable evaluates to 0).
NumWithActiveTerritory	Number of breeding pairs with established territories that are laying eggs in a given year.
Age1, Age2, Age3, Age4, Age5, Age6, Age7, Age8, Age9, Age10, AgeGreater	Number of individuals in the population in each age category.

Table 3-13
Landscape variables (raster map layers)

State Variable	Description
PFA	Map that shows pixels used in each individual's PFA.
PermNestSite	Once a territory is established, the center pixel (nest site) is recorded.
Territory	Map that shows territory for each individual that has established one.

3.3.1.3. *Process overview and scheduling*

The model proceeds annually, running for 30 years total, a time long enough to allow two complete generations of individuals to be modeled so that results are not based on the same individuals that initialized the model. Within each year, time occurs in 1/10,000 increments. The Population submodel occurs once per year, the Movement submodel occurs up to 10,000 times per year, and Habitat submodel occurs once for every ten time steps in Movement (i.e. up to 1,000 times per year). Movement and Habitat processes within each year continue until all individuals searching for a territory have found one or time runs out.

In theory, model processes were basic, although coding and process scheduling to implement the model was more complex. Figure 3-2 shows the submodels, scheduling, and how processes are nested within one another. The goshawk model has three submodels that work together: Population, Movement, and Habitat.

Population. The population is initialized once at the beginning of the simulation. In this process 50 agents are created and placed at observed nest site locations that correspond to the 50 observed samples. Each agent is stochastically assigned a breeding age and is seeded at that age. All state variables described in Tables 3-8, 3-11, and 3-12 are initialized.

Next, survival is evaluated once per year. Juvenile and adult survival is evaluated with different probabilities (Table 3-8). Individuals that survive age one year, and juveniles become adults. If an individual dies, its presence on output maps is erased. Finally, reproduction occurs. In order to fledge young, an individual must have an established territory, be in the proportion of pairs active and laying eggs in the current year, and successfully fledge those young. If so, the number of female offspring is stochastically selected and added to the population as juvenile females of age 0, with a predetermined breeding age.

Movement. Information about agents is relayed between submodels using maps and variables. Once agents are established, the model evaluates whether they need to move their location. There are four reasons an agent will move: 1) it is a juvenile dispersing from the natal nest site; 2) it is within another goshawk's territory; 3) it is a breeding adult that has not yet established a territory; or 4) it is outside of the forest boundary. Next, the distance and direction of the move is calculated as described in Table 3-9, and the new location is preserved for input into the Habitat submodel.

Juveniles that disperse from their natal nest site will exist as floaters (individuals that do not have a territory) until one year prior to breeding age, at which time they will begin searching for a territory. This representation was a modeling decision, but did not come from published data. For each adult, the pixel that is "landed on" is evaluated for nest site suitability. If the pixel is suitable the individual does not move again. Once all individuals have found potential nest sites, or after ten tries, whichever is less, all that have found a suitable site move on to the Habitat submodel. If individuals do not successfully implement a territory in Habitat, they return to Movement again. This continues until all individuals have established territories, or until time runs out.

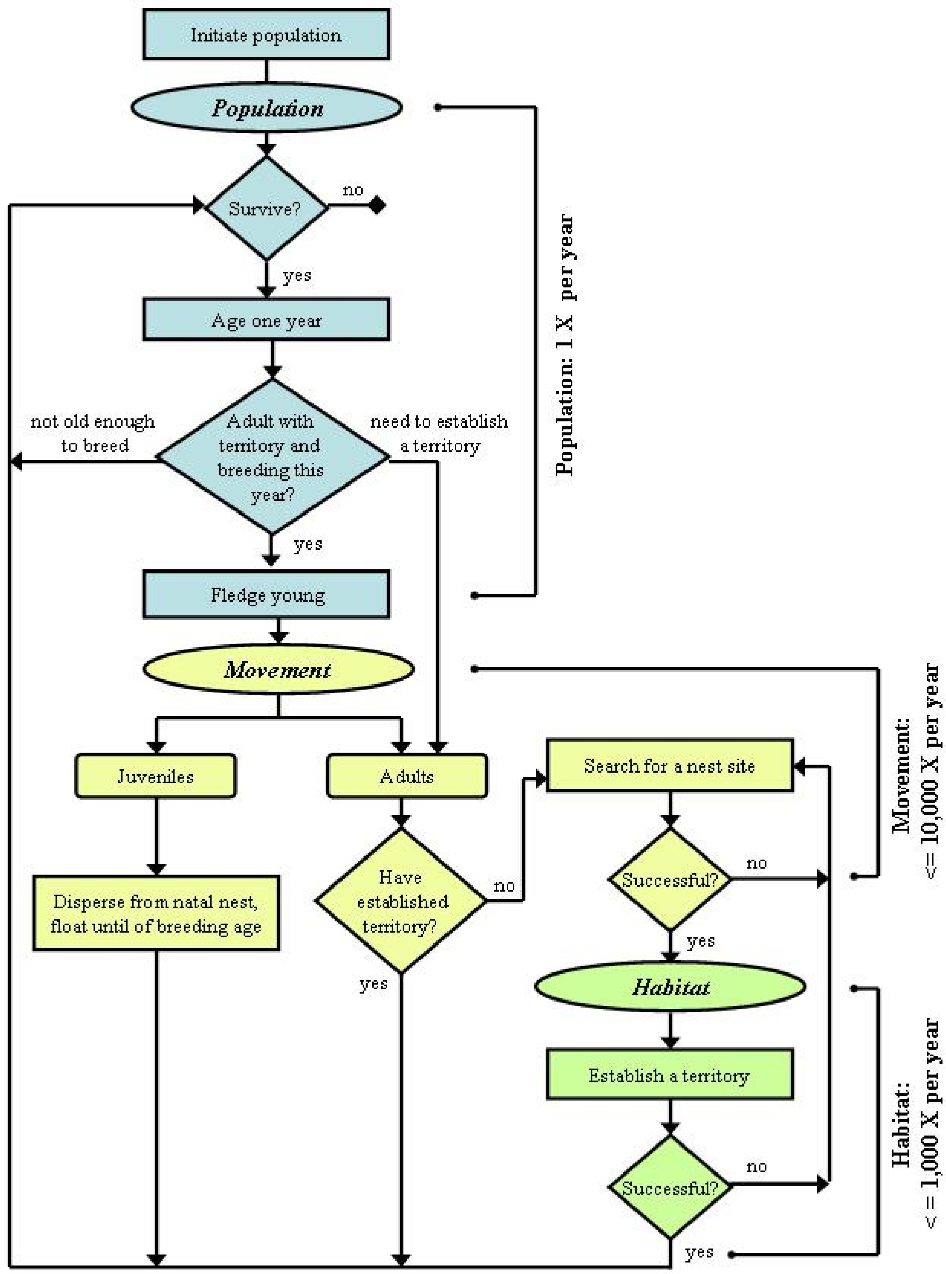

Fig. 3-2 – Model flowchart showing submodels and scheduling of processes.

Habitat. The Habitat submodel uses a spreading function where agents search a cluster of neighboring cells and choose whether to spread to those cells as part of their territory. The submodel tests whether the individual has found adequate habitat within each area in order to stay and use the area as their territory (Table 3-10). If there is not enough suitable habitat the area is abandoned. After all individuals have either established a territory or abandoned the area the process ends, and those still in need of a territory return to the Movement submodel. When all juveniles have dispersed and adult agents have established territories or run out of attempts, the year ends and all agents return to the Population submodel once again.

3.3.2. *Design concepts*

Design concepts communicate the conceptual framework of how the model represents processes (Grimm and Railsback 2005; Grimm et al. 2006).

3.3.2.1. *Emergence*

Some system-level processes emerge from the model, while others are imposed. The act of searching for a territory is imposed on individuals of breeding age; however, establishing a territory is emergent from the satisfaction of several conditions including being a breeding adult, finding a suitable nest site, and finding suitable PFA habitat (Tables 3-8 to 3-10). The act of breeding is also emergent from several attributes. An individual must be of breeding age, have an established territory, be in the proportion of breeding pairs laying eggs in the current year, and successfully fledge their young (Tables 3-8 to 3-10).

3.3.2.2. *Sensing*

Modeled individuals are assumed to know and consider certain elements of their environment. Individuals sense themselves as breeding adults, sense other breeding adults and their territory boundaries, and sense the forest structure around them. Only females are explicitly modeled, and are therefore assumed to sense and pair with a male when breeding age is reached.

The sensing of forest structure (HSS) is explicitly simulated in the Movement submodel while searching for a potential nest site, and in the Habitat submodel while evaluating the 170 ha PFA. An individual also senses when it has left the forest and entered non-nesting habitat. Individuals move in longer flights until they have returned to the forest.

3.3.2.3. *Fitness*

Suitable habitat implicitly provides for individual fitness by providing foraging opportunities and protection for breeding individuals and their young. The model assumes that preferred habitat provides critical fitness components, particularly food availability and forest structure, which are the most ubiquitous factors limiting goshawk productivity (Safalsky et al. 2005; Reynolds et al. 2006; Wiens et al. 2006).

3.3.2.4. *Interaction*

Territorial behavior is modeled as an interaction. When an individual lands in an established territory it is sent away 3900 m (the nearest neighbor spacing of territory centers) in a random direction. Under the umbrella of breeding, other interactions between a pair implicitly take place but are not explicitly modeled. Those include: courtship, egg laying, feeding, foraging, raising and fledging young, and defending the territory.

3.3.2.5. *Stochasticity*

Stochastic processes introduce randomness, or chance, into the model to represent the uncertainty of natural processes. Each simulation will have a different output, reflecting an outcome from a range of variation in the system. Parameters were varied stochastically to match available data. If error around the mean was presented in the literature then the statistical model used was the normal distribution. Not all modeled vital rates included variance, as not all data presented in the literature included that information. For data collected from GIS analysis (i.e. habitat preference), the statistical model that best fit the data was used, which was the skewed normal distribution.

3.3.2.6. *Collectives*

Individuals are collected into groups based on their age. Their first year (Age 0 to < Age 1) the modeled individuals are considered juveniles and their survival rate is calculated separately from adults (Table 3-8). At Age 1 individuals become adults. All individuals in the model are a collective of females, as male goshawks are not explicitly represented.

3.3.3. *Details*

This section contains model details about initialization and input that are not already described above. These details would be needed to implement the model in another context.

3.3.3.1. *Initialization and input*

Three raster maps are used as input layers, but only the Territories50 map is used for initialization (Table 3-15). The model initializes one adult individual at each of 50 territory centers. Initialization of agent locations was the same for every simulation. The only stochastic variable used during initialization was BreedingAge. Table 3-16 depicts all variables that are initialized with a starting value. Any variables not shown begin with a value of 0. Other details regarding input data are in Section 3.1 above.

3.3.3.2. *Submodels*

Three submodels, Population, Movement, and Habitat interact within the goshawk model. The submodels are described in detail in Section 3.3.1.3.

Table 3-15
Raster maps used as model input

Map	Description
Initial territories	Map of 50 territory centers used as initial locations of agents.
HSS	Map of HSS codes from the 2006 forest inventory layer.
Distance to forest	Map that buffers the National Forest boundary by 0 km, 10 km, and > 10 km; used in making movements outside of the forest farther and faster to save model processing time.

Table 3-16
Initialization values for simulation start up

State variable	Start value	Description
InitialPopSize	50.	Number of individuals initialized at simulation start up.
PopulationSize	50.	Total number of female individuals in the model including adults and juveniles.
NumAdultsAlive	50.	Number of female adults currently alive.
BreedingAdultCounter	50.	Number of living female adults in the population that have reached breeding age.
BreedingAge	Rounded value pulled from a normal distribution (μ=3.5, ±=0.32; range 2-8; Wiens and Reynolds 2005).	Age at which individuals make their first attempt at breeding.
Age	Equal to BreedingAge.	For individuals that are seeded by model initialization, starting age is equal to the breeding age.
NeedPFA	1.	Individuals begin by attempting to establish a territory.
Survive	1.	All initially survive.

3.4. *Simulations*

One hundred model simulations were run. The number of simulations was not greater due to the intense computational time required to run the model; if possible for future exercises, approximately 10,000 simulations would be more adequate for producing probability maps. Simulations were initiated with 50 individuals, each starting in one of 50 nest locations used in the GIS analysis (Section 3.1.2). Reproduction began in Year 2, allowing one preceding year for the model initialization to take place (i.e. seeding of breeding adults and establishment of territories).

The model ran the first 15 years without mortality in order to build a large population of breeding adults with established territories. According to Reich et al. (2004), territoriality sets the upper limit to the population, and according to Reynolds and Joy (2006), a stable population will likely have floating adults waiting for an available territory. Both are true at year 15: the number of breeding pairs with established territories becomes stable and approximately the same number that have found territories are searching for territories. Data from year 15 was used to estimate carrying capacity of the Forest, as well as the number of territorial pairs and calculation of the modeled nearest-neighbor-distance between territory centers.

Mortality was allowed after year 15. Immediately the population began a declining trend because juvenile recruitment was not great enough to compensate for adult mortality. The model was run until year 30, which was chosen as a time long enough to allow an entire second generation of goshawks to be modeled, and to allow the individuals alive during the first 15 years (with a superficially lengthened life span) to die. This allows the population age structure to naturally emerge within the model.

The remaining variables were examined at year 30. Population-level output parameters were written to a text file at the end of each simulation, resulting in 100 data values to analyze. For individual-level and habitat usage outputs, a random subset of 100 values was analyzed. Model results from 100 stochastic simulations were categorized into population-level, individual-level, and habitat usage outputs.

At the time the model structure was completed for this study there was one known problem. The issue was that occasionally when individuals died, their territories were not deleted from the output maps, and therefore not available to any other individual throughout the simulation. The problem did not affect these results. The carrying capacity of the Forest was assessed as the number of breeding pairs with established territories at year 15. Since no territories were deleted until after year 15, the carrying capacity output was not affected. All other outputs at year 30 were not affected because the declining population left ample vacant habitat for establishment of territories (even though some areas incorrectly appeared to be claimed).

4. Results and Discussion

The model results and discussion are presented following 100 model simulations. Results were summarized by the mean, standard deviation, a 95% confidence interval around the mean, the range, and figures depicting simulated parameter distributions. Statistics that are sensitive to sample size are not appropriate for analyzing results of simulation models since the number of simulations can be arbitrarily chosen to achieve a desired range of variation. Thus, summary statistics used for modeled data were not sample size dependent. The ideal comparison to observed data would include all data values, depicting the distribution of the full dataset; however, most often only the mean, standard error, and range were available, and those values were compared to modeled data to approximate similarity of distributions.

Confirming model input verifies that the model system is treating data appropriately and functioning properly at a basic level. The model was evaluated for satisfactory performance by comparing results to input data, and validation was accomplished by comparing results to data not used to build the model. As appropriate based on model performance and model validation, population predictions are presented for those parameters estimated by the model for which no known published data exists. For population- and individual-level results, model performance and model validation were satisfactory if results correctly predicted input data, judged by whether observed data fell within the 95% confidence limits of the mean of the modeled data (McIntire et al. in press).

The most forthcoming result of running the model was that the modeled population is a sink (using demographic data from the Kaibab National Forest, and habitat information from the Black Hills National Forest). This outcome was not expected because both the Kaibab and Black Hills populations are assumed stable (Reynolds, pers. comm.). This informative finding is a prominent and compelling reason to use the individual-based modeling method to evaluate goshawk dynamics.

Due to the modeled population decline, several parameters estimated by the model which are density-dependent do not meet expectations associated with the stable population situation assumed to occur in the Black Hills. Density-dependent results presented here display shortcomings of the model in its current form; these results should be interpreted with caution, and should not be considered applicable to management recommendations at this time. Model predictions that are not density-dependent are the best known estimate for those parameters.

4.1. *Model performance*

Model performance was defined as the capability of the model to output data similar to what was input, confirming that the model functioned as intended at a basic level.

Table 4-1 summarizes model performance for individual-level variables. Population-level output from individual-level input data was used to evaluate model performance, as summarized in Table 4-2. Results of the individual- and population-level model validation outputs show that all of the comparison values fell within the confidence interval for the modeled parameters, indicating the model performed satisfactorily.

Table 4-3 presents habitat usage predictions relating to the pattern of the goshawk search image. The model required individuals to find suitable habitat in amounts equal to or greater than the GoodHab variable; therefore, predicted habitat usage values were satisfactory if greater than or equal to the mean suitable habitat value for observed PFAs. Figures 4-1 to 4-3 show the modeled amount of suitable habitat within 24 ha, 83 ha, and 170 ha areas compared with 50 observed and 50 random PFAs. Modeled goshawks that succeeded at establishing a territory had fewer suitable habitat pixels (combination of HSS 4B, 4C, and 5) within 24 ha than the sampled territories (not satisfactory), and had more suitable habitat pixels (combination of HSS 3C, 4B, 4C, and 5) within 83 and 170 ha than observed (satisfactory). Distribution comparisons (Figures 4-1 through 4-3) show that simulations reproduced patterns much more similar to the "search image" than to random PFAs.

The patterns produced by model were mostly satisfactory but would benefit from improvement of the algorithm for predicting habitat closest to the nest (within the 24 ha area). Modeled nearest-neighbor-distance was consistently higher than model input, which should be addressed in a future version of the model. Spacing more similar to the 3.9 km between territory centers suggested by Reynolds and Joy (2006) would likely increase the proposed carrying capacity figure.

4.2. *Validation*

Confirmation of individual, population, and habitat parameters not used to build the model substantiates the system's capability to produce credible results. Model validation was defined as the confirmation of simulated data through comparison to observed data (from published literature or GIS analysis) not used to build the model.

The first output in Table 4-4 did not validate because it was density-dependent. In a stable or increasing population situation, the landscape would be saturated and adults would likely wait 2 to 5 years for a territory to become available (Reynolds and Joy 2006). The declining modeled population yielded ample space for new territories to become established. In this scenario individuals waited 0 years after reaching breeding age to establish a territory.

Table 4-1
Comparison of individual-level inputs to outputs

Variable	Model output [a]	Model input	Source
Breeding age (age at first attempt) [c]	$\mu = 3.5$, $\sigma = 0.50$ $CI_{\alpha=0.05} = 3.4$ to 3.6 range = 3 to 4	$\mu = 3.5 \pm 0.32$ range 2 to 8	Wiens and Reynolds 2005
Number of young fledged per successful nest [bc]	$\mu = 2$, $\sigma = 0.00$ $CI_{\alpha=0.05} = 2$ range = 2	$\mu = 2.0 \pm$ not reported $\mu = 1.8 \pm 0.12$	Wiens and Reynolds 2005 Bartelt 1977

[a] Tables present the mean, 95% confidence interval around the mean, and range of values from 100 simulations.
[b] In the model each successful nest fledges 2 young, with a random probability of 0.5 that an individual is female; the parameter is not stochastically evaluated. Future versions of the model could include a range of young fledged per nest.
[c] Shown in bold are those variables that met the model validation test using the confidence interval around the mean.

Table 4-2
Comparison of population-level inputs to outputs

Variable	Model output	Model input	Source
Proportion of breeding pairs with active territory per year [c]	$\mu = 0.52$, $\sigma = 0.19$ $CI_{\alpha=0.05} = 0.48$ to 0.55 range = 0.22 to 0.87	range = 0.22 to 0.87	Reynolds and Joy 2006
Proportion of breeding pairs with active territory successfully fledging young per year [c]	$\mu = 0.81$, $\sigma = 0.14$ $CI_{\alpha=0.05} = 0.78$ to 0.84 range = 0.33 to 1.00	$\mu = 0.805 \pm$ not reported	Wiens and Reynolds 2005
Proportion of adults surviving [c]	$\mu = 0.74$, $\sigma = 0.04$ $CI_{\alpha=0.05} = 0.74$ to 0.75 range = 0.62 to 0.85	$\mu = 0.75 \pm 0.02$	Reynolds et al. 2004
Proportion of juveniles surviving [c]	$\mu = 0.73$, $\sigma = 0.14$ $CI_{\alpha=0.05} = 0.70$ to 0.76 range = 0.33 to 1.00	$\mu = 0.71 \pm$ not reported	Wiens et al. 2006

[a] Shown in bold are those variables that met the model validation test using the confidence interval around the mean.

Table 4-3
Comparison of habitat usage inputs to outputs

Variable	Model output	Model input	Source
Suitable habitat within 24 ha [b]	$\mu = 14.29$, $\sigma = 1.95$ $CI_{\alpha=0.05} = 13.91$ to 14.67 range = 7 to 16	μ=24 σ of left side =7.6 σ of right side =0.01 range 0 to 24	GIS analysis
Suitable habitat within 83 ha [c]	$\mu = 67.55$, $\sigma = 8.26$ $CI_{\alpha=0.05} = 65.93$ to 69.17 range = 49 to 83	μ=61 σ of left side =17.4 σ of right side =7.4 range 6 to 83	GIS analysis
Suitable habitat within 170 ha [c]	$\mu = 127.44$, $\sigma = 18.97$ $CI_{\alpha=0.05} = 123.72$ to 131.16 range = 82 to 170	μ=108 σ of left side =30.6 σ of right side =16.9 range 17 to 166	GIS analysis
Average nearest neighbor distance in km	$\mu = 4.316$, $\sigma = 0.66$ $CI_{\alpha=0.05} = 4.303$ to 4.329 range = 4.151 to 4.541	$\mu = 3.9 \pm$ not reported $\mu = 4.0 \pm$ not reported	Reynolds and Joy 2006 Bartelt 1977

[a] Defined as the number of ha of HSS 4B, 4C, and 5.
[b] Defined as the number of ha of HSS 3C, 4B, 4C, and 5.
[c] Shown in bold are those variables that met the model validation test using the confidence interval around the mean.

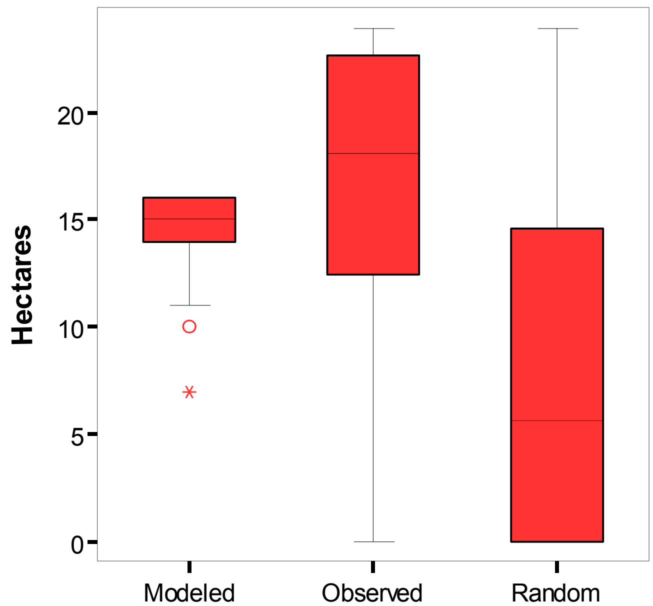

Fig. 4-1 – Suitable habitat within 24 ha for 100 modeled, 50 observed, and 50 random PFAs.

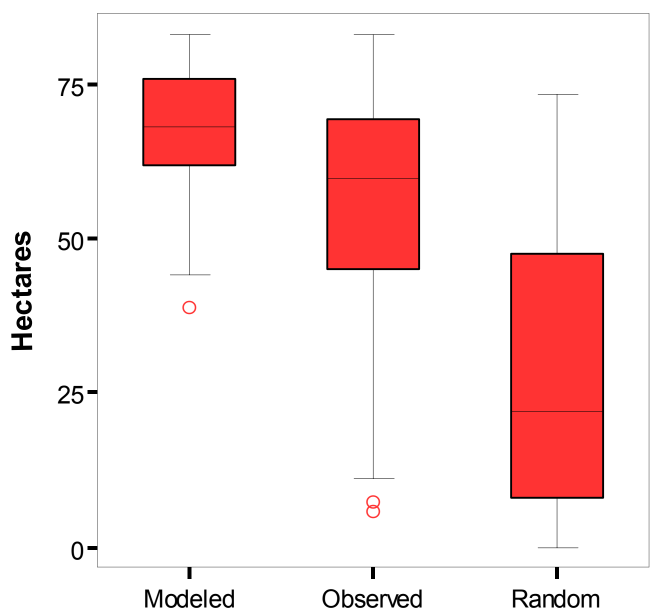

Fig. 4-2 – Suitable habitat within 83 ha for 100 modeled, 50 observed, and 50 random PFAs.

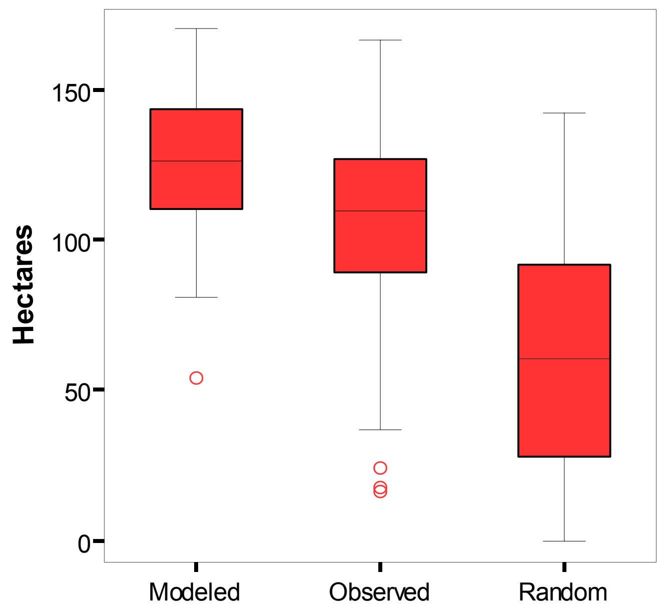

Fig. 4-3 – Suitable habitat within 170 ha for 100 modeled, 50 observed, and 50 random PFAs.

Number of years with an established territory is a function of breeding age and lifespan. This parameter validated, as the confidence interval fell within the range estimated by Reynolds and Joy (2006). Reproductive lifespan was modeled as the number of years an individual successfully fledged young. This parameter met the validation test, compared with data from Wiens and Reynolds (2005).

Surprisingly, the number of young fledged per lifetime (Figure 4-4) did not validate using the confidence interval around the mean, as results were higher than those for observed data. However, and perhaps more importantly, the range and shape of the distribution of values were similar. Field measurements reflected a lower number fledged than is emergent from low-level variables in the model. This finding may suggest that further field research is needed to confirm the observed data.

Results in Table 4-5 depict relative amounts of different habitat types used in the 170 ha PFA. This data acts as a model validation because information regarding amount of individual HSS classes was not considered by the model, only the pattern of a combination of classes. Outputs were within confidence interval targets for HSS None/1, 2, 3C, and 4C/5. Additionally, HSS 4B was modeled in higher amounts than observed. Since the model was instructed to find equal to or greater than a certain amount of suitable habitat, this parameter validated as well. All suitable habitat types (HSS 3C, 4B, and 4C/5) validated, indicating that the model performed very well in predicting habitat types used by goshawks. The mean and 95% confidence interval around the mean for 100 modeled, 50 observed, and 50 random PFAs is shown in Figures 4-5 through 4-12.

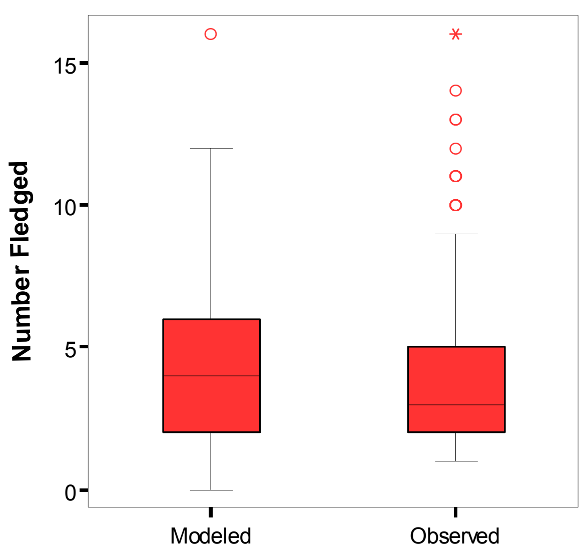

Fig. 4-4 – Young fledged per lifetime for 100 modeled and 260 observed individuals (Kaibab National Forest data reproduced from Wiens and Reynolds 2005).

Table 4-4
Comparison of individual-level inputs to validation data

Variable	Model output	Comparison value	Source
Number of years waiting for territory to become available after reaching breeding age	$\mu = 0$, $\sigma = 0.00$ $CI_{\alpha=0.05} = 0$ range = 0	range = 2 to 5 yr	Reynolds and Joy 2006
Number of years with an established territory [b]	$\mu = 4.6$, $\sigma = 3.00$ $CI_{\alpha=0.05} = 4.0$ to 5.2 range = 1 to 10	range = 1 to 6	Reynolds and Joy 2006
Reproductive lifespan [ab]	$\mu = 2.2$, $\sigma = 1.80$ $CI_{\alpha=0.05} = 1.9$ to 2.6 range = 0 to 8	$\mu = 2.107 \pm 0.11$ yr range 1 to 10	Wiens and Reynolds 2005
Number of male and female young fledged per lifetime	$\mu = 4.5$, $\sigma = 3.70$ $CI_{\alpha=0.05} = 3.7$ to 5.2 range = 0 to 16	$\mu = 3.185 \pm 0.23$ yr range 0 to 15	Wiens and Reynolds 2005

[a] Modeled as the number of years a female successfully fledged young.
[b] Shown in bold are those variables that met the model validation test using the confidence interval around the mean.

Table 4-5
Comparison of habitat usage outputs to validation data

Variable	Model output	Comparison value	Source
HSS None or HSS 1 in 170 ha PFA [ac]	$\mu = 13.8$, $\sigma = 16.0$ $CI_{\alpha=0.05} = 10.7$ to 16.9 range = 0 to 72	$\mu = 15.7 \pm 1.7$	GIS analysis
HSS 2 in 170 ha PFA [c]	$\mu = 1.9$, $\sigma = 4.7$ $CI_{\alpha=0.05} = 0.9$ to 2.8 range = 0 to 25	$\mu = 1.8 \pm 0.5$	GIS analysis
HSS 3A in 170 ha PFA	$\mu = 2.1$, $\sigma = 4.6$ $CI_{\alpha=0.05} = 1.2$ to 3.0 range = 0 to 24	$\mu = 5.1 \pm 1.2$	GIS analysis
HSS 3B in 170 ha PFA	$\mu = 5.3$, $\sigma = 8.6$ $CI_{\alpha=0.05} = 3.6$ to 7.0 range = 0 to 35	$\mu = 9.7 \pm 1.5$	GIS analysis
HSS 3C in 170 ha PFA [c]	$\mu = 6.1$, $\sigma = 11.9$ $CI_{\alpha=0.05} = 3.8$ to 8.4 range = 0 to 77	$\mu = 8.1 \pm 1.6$	GIS analysis
HSS 4A in 170 ha PFA	$\mu = 14.9$, $\sigma = 15.6$ $CI_{\alpha=0.05} = 11.6$ to 18.0 range = 0 to 68	$\mu = 32.9 \pm 2.6$	GIS analysis
HSS 4B in 170 ha PFA [c]	$\mu = 76.1$, $\sigma = 37.8$ $CI_{\alpha=0.05} = 68.7$ to 83.5 range = 0 to 165	$\mu = 58.4 \pm 3.3$	GIS analysis
HSS 4C or HSS 5 in 170 ha PFA [bc]	$\mu = 45.6$, $\sigma = 43.6$ $CI_{\alpha=0.05} = 37.1$ to 54.1 range = 0 to 170	$\mu = 37.2 \pm 3.5$	GIS analysis

[a] No data values outside of the forest and for private inholdings were treated as grassland types and combined with HSS 1.
[b] Because there are only 797 ha (0.1%) of HSS 5 on the Forest, output data was combined with code 4C.
[c] Shown in bold are those variables that met the model validation test using the confidence interval around the mean.

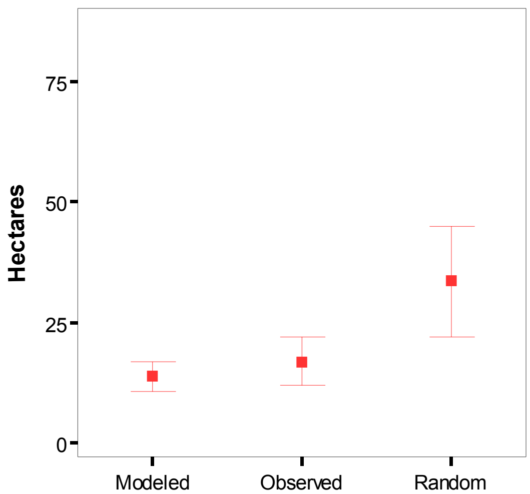

Fig. 4-5 – HSS 1 and None (no data) in 100 modeled, 50 observed, and 50 random PFAs.

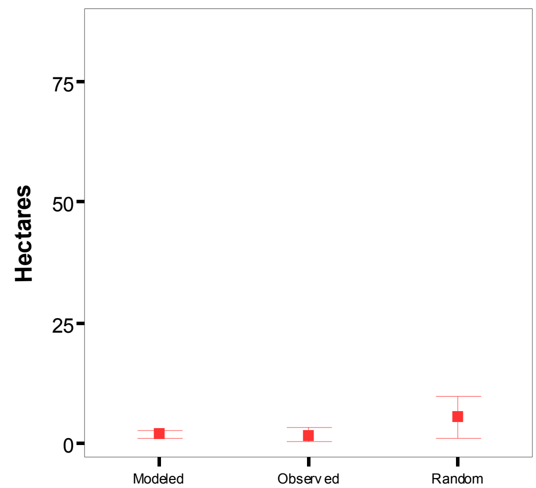

Fig. 4-6 – HSS 2 in 100 modeled, 50 observed, and 50 random PFAs.

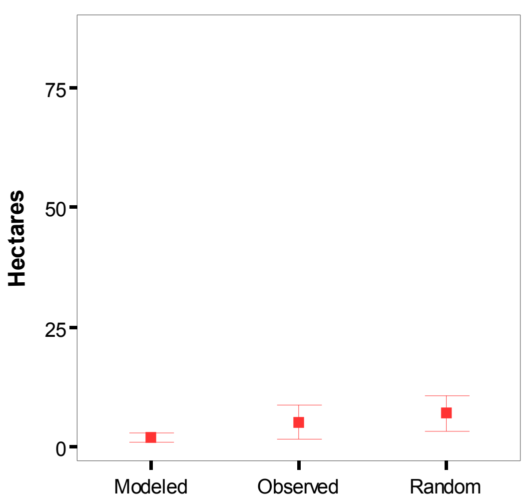

Fig. 4-7 – HSS 3A in 100 modeled, 50 observed, and 50 random PFAs.

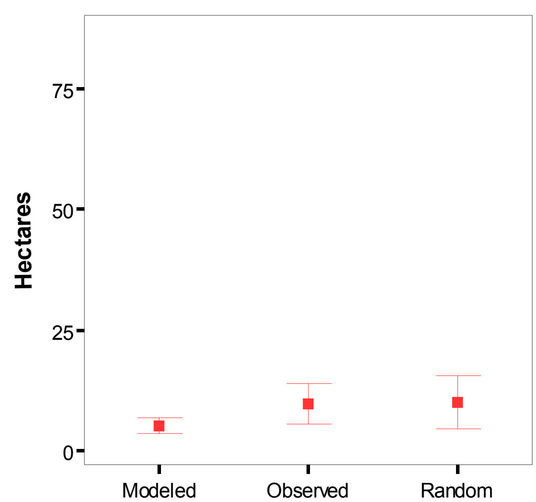

Fig. 4-8 – HSS 3B in 100 modeled, 50 observed, and 50 random PFAs.

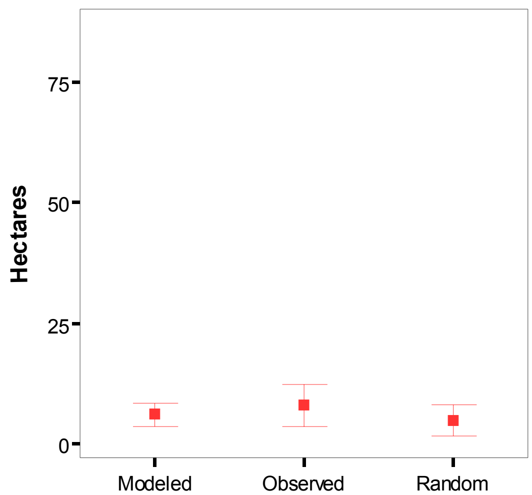

Fig. 4-9 – HSS 3C in 100 modeled, 50 observed, and 50 random PFAs.

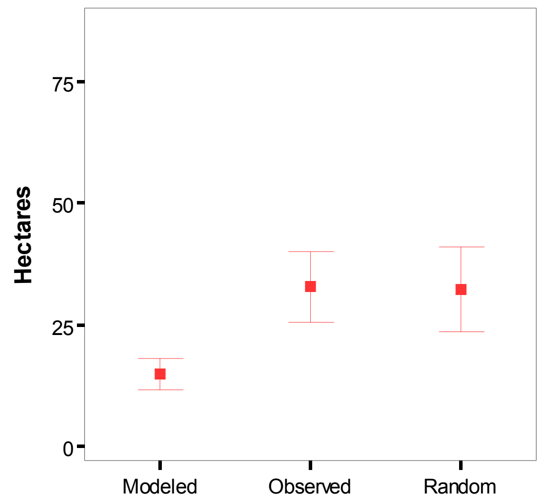

Fig. 4-10 – HSS 4A in 100 modeled, 50 observed, and 50 random PFAs.

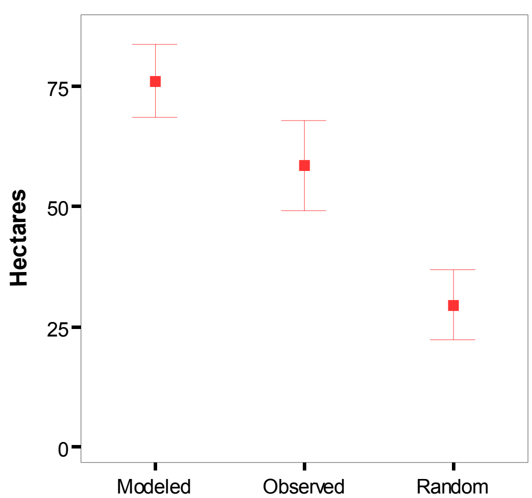

Fig. 4-11 – HSS 4B in 100 modeled, 50 observed, and 50 random PFAs.

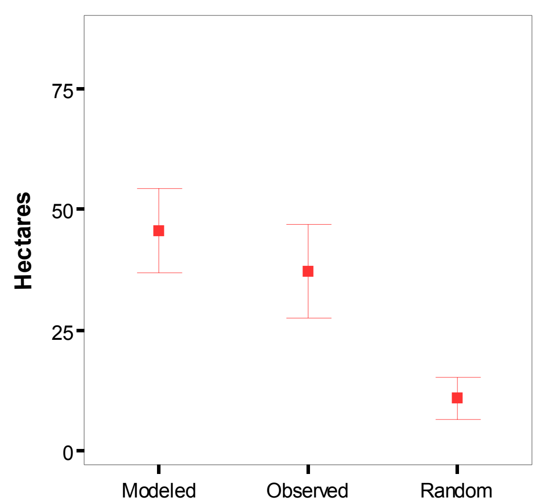

Fig. 4-12 – HSS 4C and 5 in 100 modeled, 50 observed, and 50 random PFAs.

4.3. *Predictions*

Model predictions were defined as those parameters estimated by the model for which no known published data exist against which to validate them. For non-density-dependent results, predictions shown here are believed to be accurate based on the success of model performance and validation tests. Density-dependent predictions, however, will require further investigation prior to claiming accuracy or using information to suggest management techniques. This is with the exception of the carrying capacity result, which was estimated with mortality turned off in the model and was therefore not subject to the issue of population decline.

4.3.1. *Individual-level predictions*

Individual-level outputs are shown in Table 4-6. Lifespan of adults (those who make it to at least 1 year of age) was estimated at 5.3 years with a range of 1 to13 years (Figure 4-13).

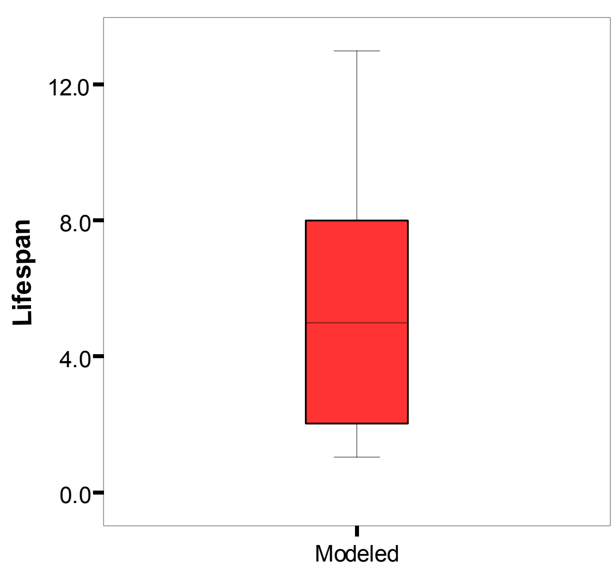

Fig. 4-13 – Lifespan of 100 modeled individuals.

Results for age at first successful breeding and age when territory was established should be regarded with caution. Values for these density-dependent variables are depicted here lower than they would be in a stable population situation where adults waited 2 to 5 years for a territory to become available (Reynolds and Joy 2006) before being able to breed.

Table 4-6
Additional individual-level model predictions

Variable	Modeled output
Lifespan of adults ($\geq$ 1 yr)	$\mu = 5.3$, $\sigma = 3.40$ $CI_{\alpha=0.05} = 4.6$ to 5.9 range = 1 to 13
Age at first successful breeding	$\mu = 4.3$, $\sigma = 1.10$ $CI_{\alpha=0.05} = 4.0$ to 4.5 range = 3 to 8
Age when territory was established	$\mu = 3.5$, $\sigma = 0.50$ $CI_{\alpha=0.05} = 3.4$ to 3.6 range = 3 to 4

Table 4-7
Population-level model predictions

Variable	Modeled output
Carrying capacity of the Forest (number of breeding pairs with established territories at year 15)	$\mu = 206.31$, $\sigma = 5.76$ $CI_{\alpha=0.05} = 205.18$ to 207.44 range = 194 to 222
Age structure of population	Proportion juveniles (0 yr): 0.12 Proportion adults ($\geq$1 yr): 0.88
Number of breeding females in population	$\mu = 48.12$, $\sigma = 8.81$ $CI_{\alpha=0.05} = 46.39$ to 49.85 range = 29 to 66
Number of juveniles successfully fledged per year (both male and female young included)	$\mu = 18.26$, $\sigma = 10.05$ $CI_{\alpha=0.05} = 16.29$ to 20.23 range = 2 to 50
Total population size (both male and female individuals included)	$\mu = 150.98$, $\sigma = 31.08$ $CI_{\alpha=0.05} = 144.89$ to 157.07 range = 82 to 260

4.3.2. *Population-level predictions*

Using simple division, the 619,776 ha Black Hills National Forest landscape has a maximum possible number of territories of 518, given a territory size of 1195 ha (Reynolds and Joy 2006). However, ignoring landscape dynamics gives overly optimistic results compared with a simulation that incorporates landscape dynamics (Akcakaya et al. 2004). The maximum number of territories modeled was 222, while the mean carrying capacity was 206. Density of modeled territories was higher in the northern Black Hills than the southern part of the National Forest, as also observed by Bartelt (1977). The carrying capacity estimated was three times greater than the number of known territorial breeding pairs (70; Staab pers. comm.), yet substantially lower than the number estimated by Reynolds (300 to 400; pers. comm.). This number would likely increase given a modeled nearest neighbor distance closer to that suggested by Reynolds and Joy (2006) or Bartelt (1977). The modeled carrying capacity would also increase if a cohort of goshawks nesting in marginal habitat areas were represented in the input dataset. This would result in lower selectivity coded into the model, and in turn a more broad use of the landscape represented.

Figure 4-14 presents the spatial output of the model as a visual representation of how the carrying capacity might be distributed across the landscape. Depicted is the result of a single simulation, chosen for display because it had 206 territories, the mean of 100 simulations. Note that territories in observed locations were not always reproduced by the model because goshawk selectivity (number of suitable habitat pixels sought by the individual) was not tied to spatial location for those individuals that initialized the model. Therefore, an individual may be initialized in a location with low habitat suitability, and choose to abandon the site and disperse to an area of higher suitability.

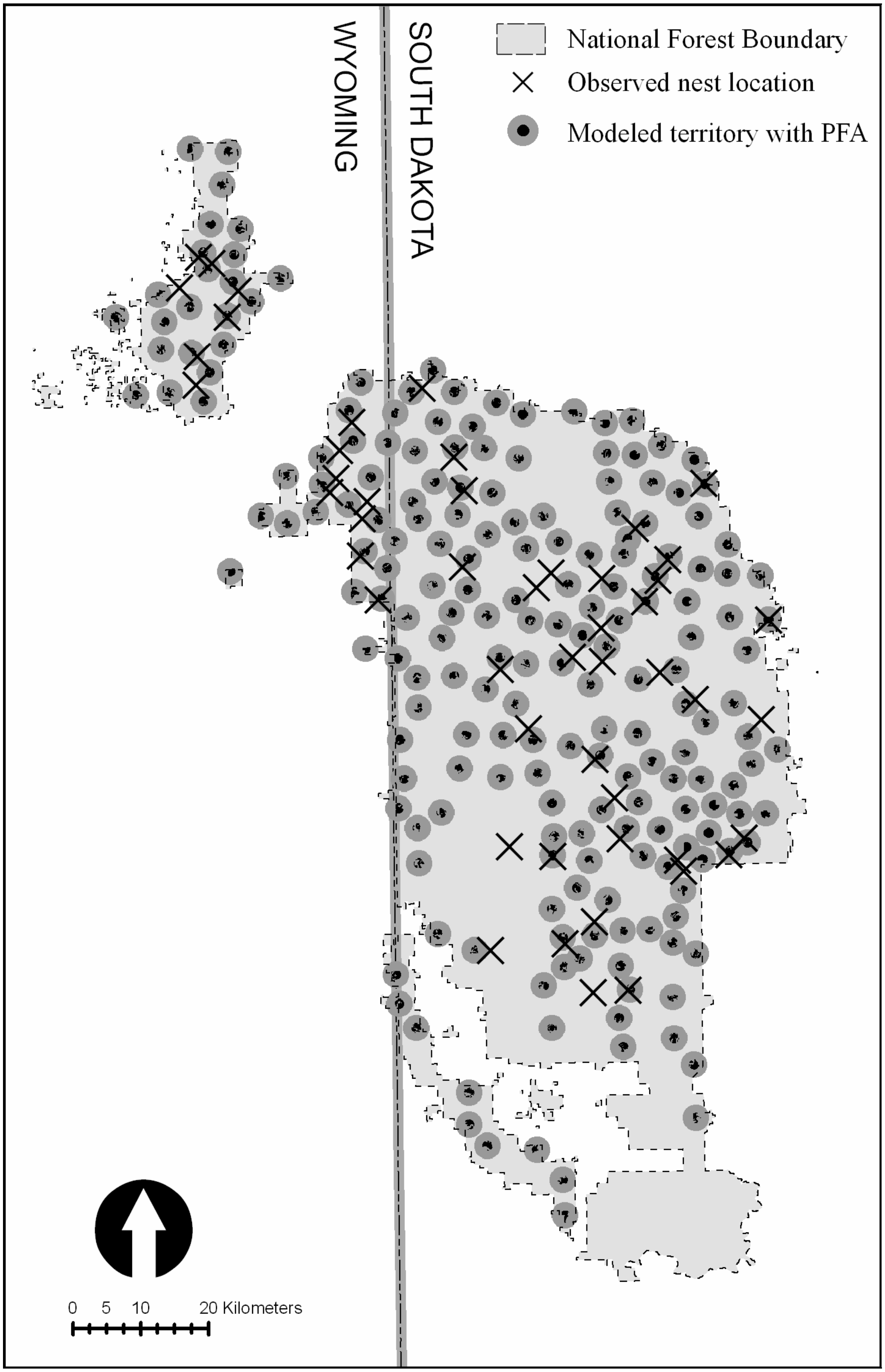

Fig. 4-14 – Sample output from a single simulation with 206 territories modeled. Territory boundaries are shown, with suitable PFA habitat shown darker in the center. Observed nest locations used to initialize model locations are also displayed.

Results regarding age structure of the population show that approximately 12% of the population will consist of juveniles (age 0 to less than 1), while 88% will be adults (age 1 or greater). The adult population was further divided into proportion within several age classes. Figure 4-15 shows the age structure of the adult population, ages 1 to 13.

The last 3 results in Table 4-7 were density dependent. Again, these results should be used with caution, as they were not based on a stable population scenario assumed to occur in the Black Hills. The results were included here to show that the system is capable of estimating the total number of breeding adults (including those that have not established territories), total number of juveniles fledged per year, and the total population size (which is extremely difficult to detect from field observation). Given that the carrying capacity is approximately 206 individuals, the modeled number of breeding females (48; one-fourth of the carrying capacity) would be at least four times higher in a stable population scenario. Following the same logic, the estimated total population size of the Black Hills National Forest is at least four times that reported in Table 4-7, or greater than 600 individuals.

4.3.3. *Habitat usage predictions*

Spatial results from 100 simulations were combined to depict areas of high habitat importance. A map depicting the frequency of nest locations was created (Figure 4-16). Simple map algebra was used for 100 raster outputs depicting PFAs and territories present in year 15. Grids were summed to create probability surfaces ranging from 0 to 100% probability that a goshawk would use an area as part of a PFA or territory. Results are presented in Figures 4-17 and 4-18.

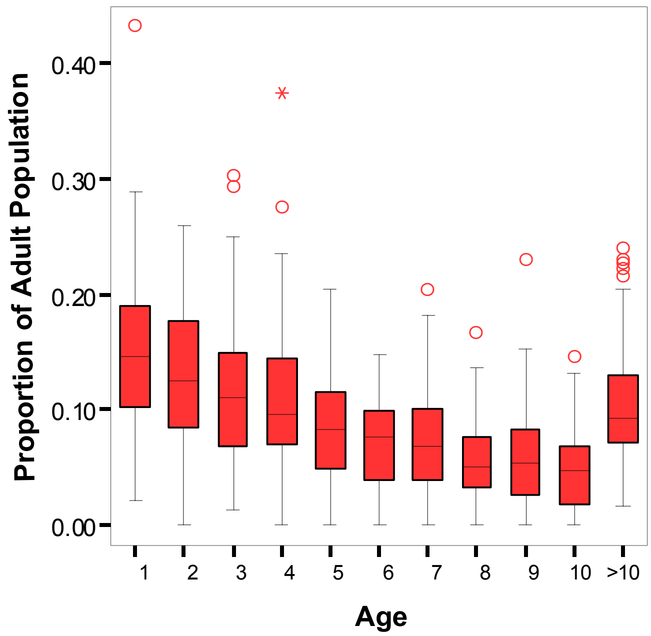

Fig. 4-15 – Age structure of population (based on 100 modeled individuals).

Spatial results presented here could be used as a starting point for nest searches during field surveys. The most accurate predictions expected are of those areas of PFA occurrence with 80 to 100% probability (Figure 4-17). Nest sites were predicted based on one pixel of suitable nest habitat (and were subsequently not abandoned if the model found suitable habitat surrounding the nest site). Nest sites have the greatest amount of variability in the spatial results, and are expected to be less reliable than the PFA results, which were based on a specific search image encompassing 170 pixels. Buffering the PFAs, territories represent occupied space, but were not predicted based on habitat outside of 170 ha. Like nest sites, territories are not expected to be as reliable a spatial result as PFA results. The model found eight PFA pixel clusters in the 80 to 100% probability category.

A fair validation of the probability surfaces would result from comparing observed locations to several thousand simulations using random starting locations for individuals. Unlike the modeled aspatial attributes, which are estimated 100 times in 100 simulations, the probability of each pixel in the model is not estimated 100 times in 100 simulations. A much larger number of simulations (10,000 or more) would be needed in order for each pixel to be visited and evaluated at least 100 times, flushing out the full range of stochasticity built into the spatial part of the model. Due to the intensive computational requirements of the model, several thousand simulations were not possible for this project. Validation of the probability surfaces is not desirable at this time, but this analysis should be conducted before the model is used to predict nest locations for land management recommendations.

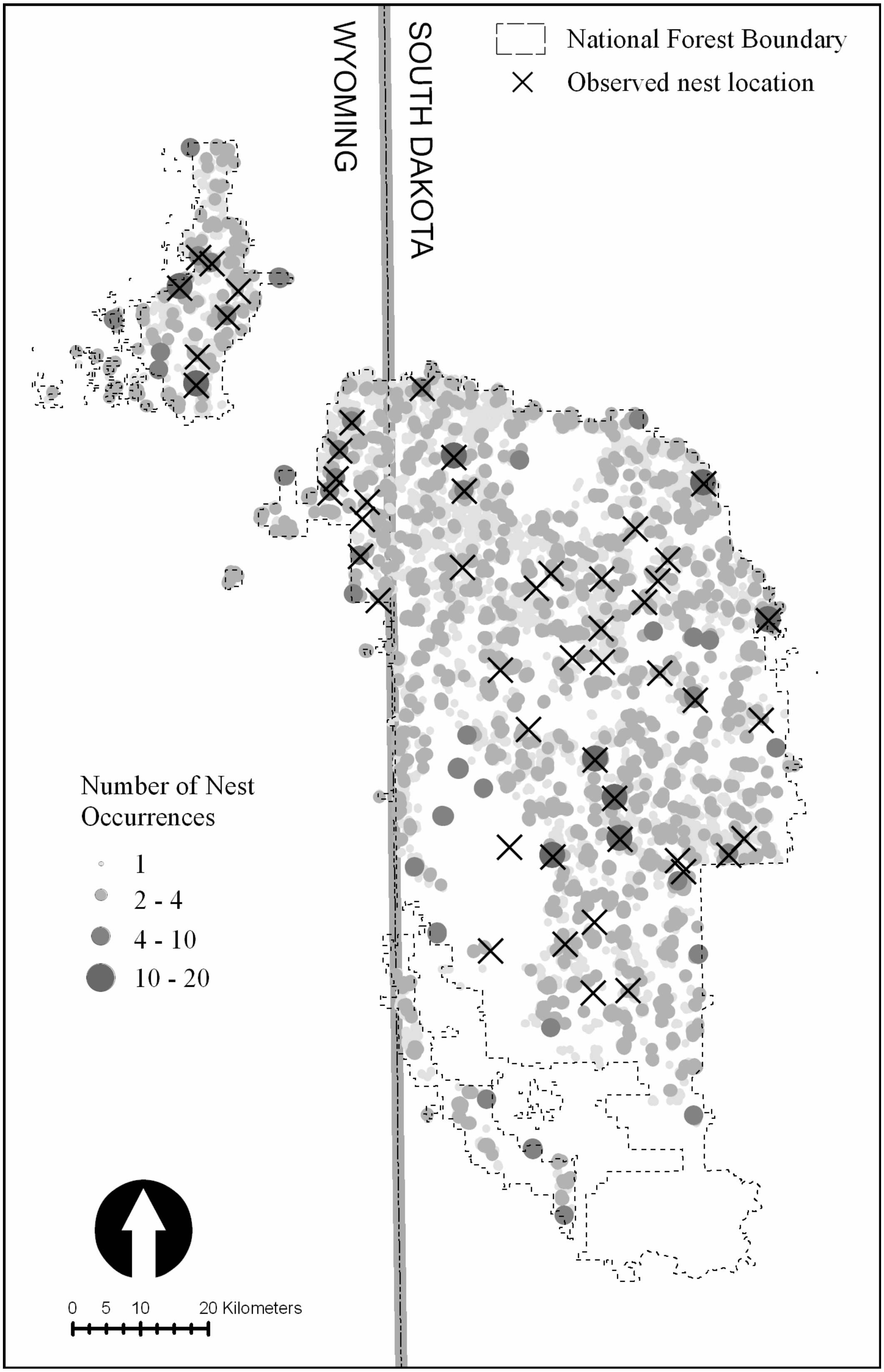

Fig. 4-16 – Frequency of nest site occurrences from 100 simulations.

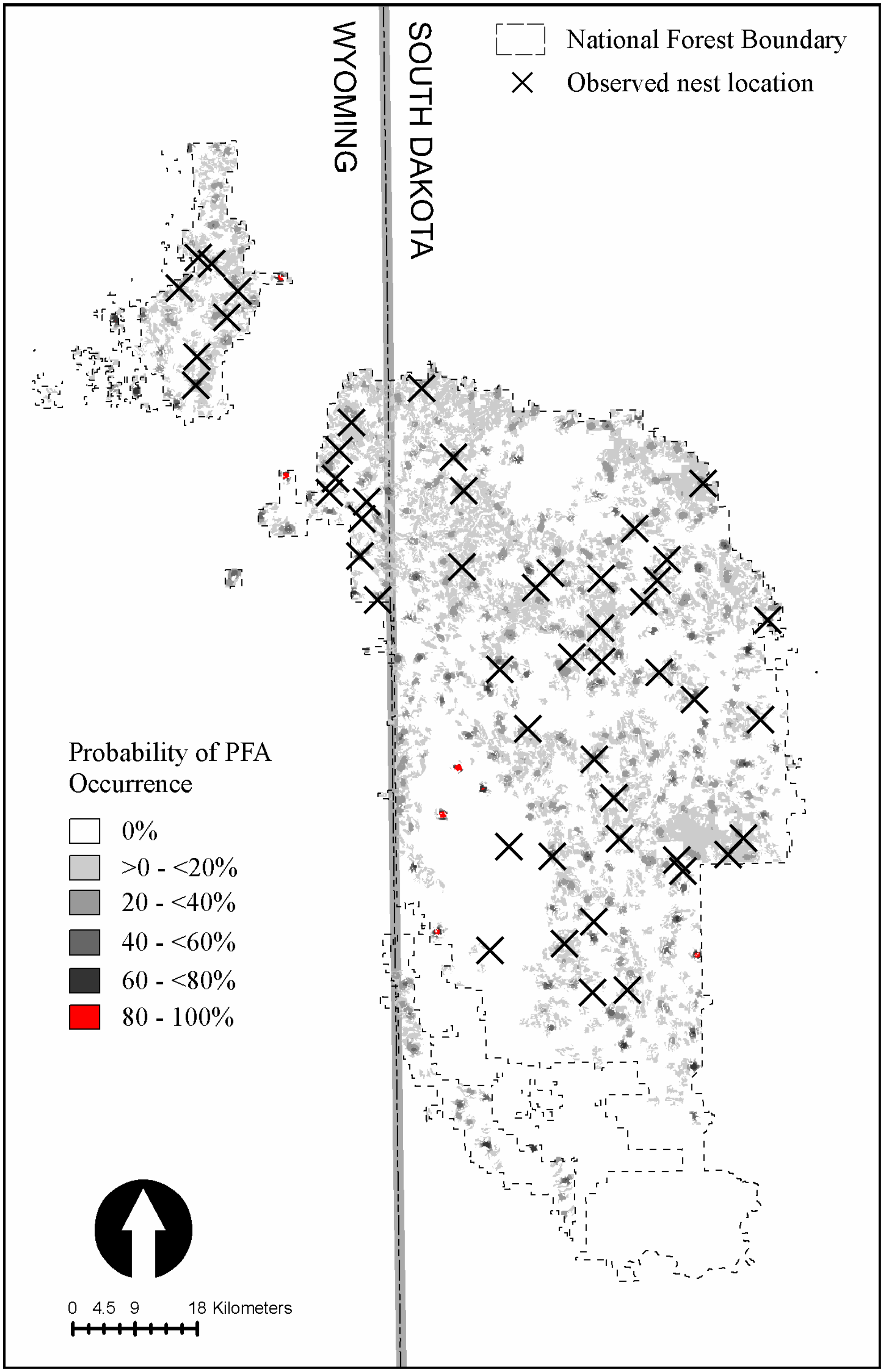

Fig. 4-17 – Probability surface of goshawk PFA occurrences from 100 simulations.

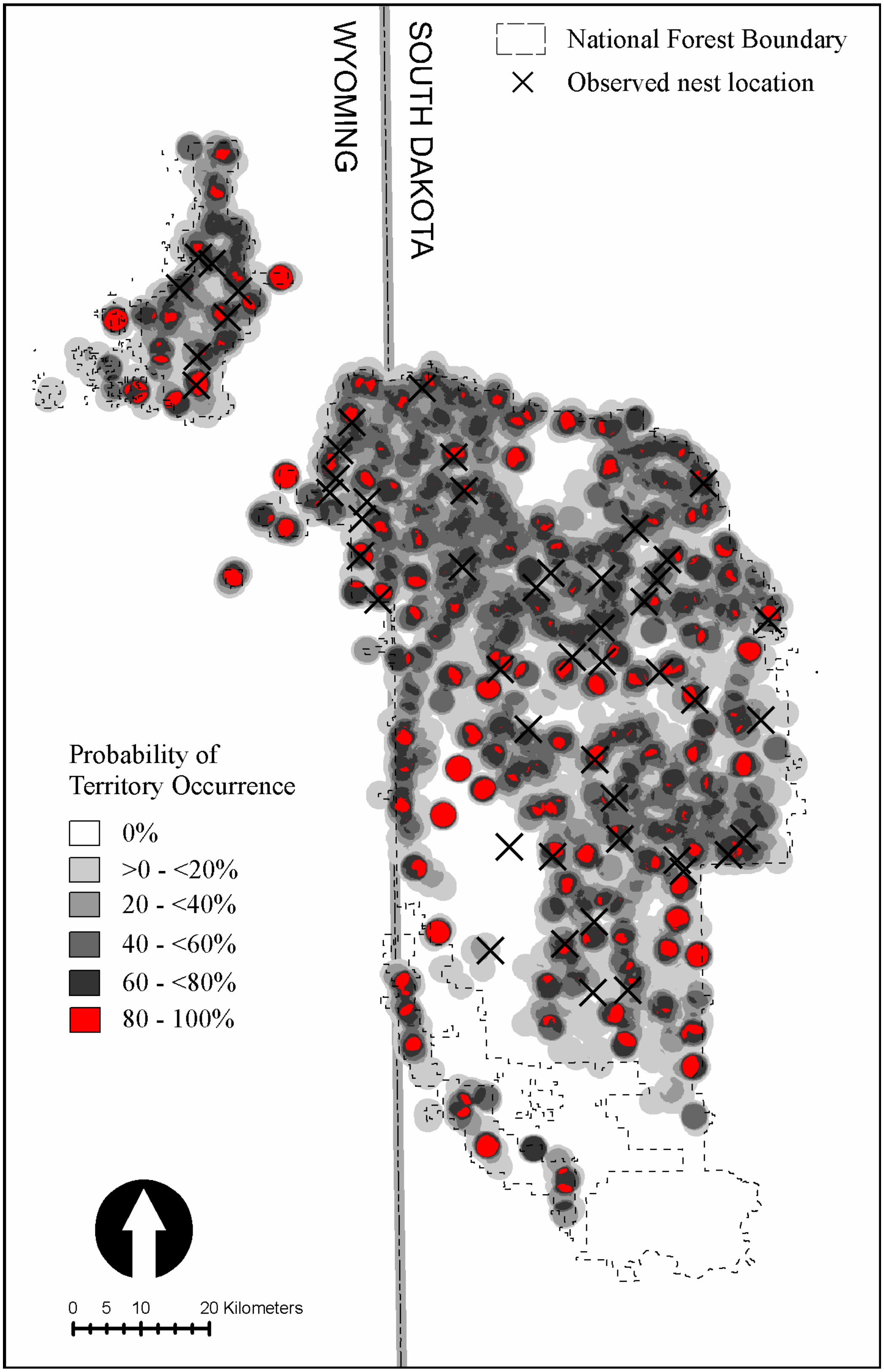

Fig. 4-18 – Probability surface of goshawk territory occurrences from 100 simulations.

5. Further Research

This project has identified several areas where data describing goshawk ecology is missing, or where available data needs improvement. Acquiring such information will allow for better models, and will aid in understanding the viability of this Sensitive Species.

5.1. *Gaps in knowledge of the northern goshawk's life history*

This project was essentially an exercise in compiling ecological knowledge specific to the goshawk, and assembling a complete picture of the goshawk's life history to the extent possible given that knowledge. At several points in the model design, areas were identified where our understanding of the goshawk's life history is lacking. These were exposed due to the individual-based method being used, as more classic population models may simply overlook or not require data of such detail.

The foremost missing piece of knowledge was related to goshawk movement. This included information on how individuals budget their time; juvenile dispersal; seasonal migration; immigration and emigration; and data for the correlated random walk used in the model. Where these data are reported in the literature, most are from incidental sightings, such as for juvenile dispersal estimates from a small number of banded birds found months to years later (Squires and Reynolds 1997).

Of the missing information on movement, the effect of immigration may be most important. Based on demographic data from the Kaibab National Forest, the modeled population was a sink, in decline because juvenile recruitment was not greater than adult mortality. This result was not expected. Reynolds (pers. comm.) suggests that for the stable Kaibab National

Forest population, immigration makes up for this difference. This suggestion is supported by Kennedy's (2003) speculation that USFS Region 2 habitat is relatively continuously distributed and populations are likely not structured as metapopulations. However, given the very isolated nature of the Black Hills National Forest (USFS Region 2), high levels of immigration seem unlikely (Bartelt 1977). It is unknown at this time what role, if any, immigration plays in a landscape as isolated as the study area. This is in need of further study.

Little is known about the daily or monthly time budgets of goshawks, or how quickly they move across the landscape. If more observational studies were available, future versions of the model could improve upon the correlated random walk, make individuals "smarter" about how they direct themselves to unclaimed territories, and relate model time to real time so that time step increments represent seasons, months, or days to more accurately represent goshawk behavior. If data on winter habitat were available, this could be considered as well.

Also helpful would be information about prey density distributions. Goshawk habitat selection and fitness could be correlated with this layer. These types of data are currently not available for the Black Hills National Forest.

Finally, it is clear for this project, that the lack of locally-estimated population parameters based on robust sample sizes limited the ability to model the stability of the Black Hills population specifically.

5.2. *Model improvements*

In addition to a lack of understanding of certain elements of the goshawk's life history, there are several areas where existing data could be improved. While the use of data from one population is still viewed as the best approach because vital rates would presumably be most consistent with each other, there may be crucial differences in some of these rates between the Kaibab and Black Hills.

5.2.1 *Sensitivity analysis*

Future modeling should systematically test demographic parameters from other goshawk populations, exploring the potential to model a stable population without including immigration as a process. In the model, juvenile recruitment is dependent upon 4 variables: being old enough to breed, having an established territory to breed in, being in the proportion of pairs with territories that are laying eggs, and successfully fledging young from the nest. The most variable of these is the proportion of pairs laying eggs, ranging from 22 to 87% annually.

Inclement weather over long time periods reduces food availability, and in turn reduces goshawk productivity (Reynolds et al. 2006). The drought experienced in the region of the Kaibab National Forest for several years is likely reducing productivity estimates, which may not be true for the Black Hills region, which experienced 80 to 100% of normal precipitation between June 2004 and May 2007.

The proportion of pairs laying eggs variable may be driving the success of juvenile recruitment, which in turn may be driving the population stability. A simple sensitivity and elasticity analysis performed by Kennedy (2003) found that adult survival was the most influential parameter on population trend. Foremost, adult survival and proportion of pairs laying eggs should be analyzed through a sensitivity analysis. Secondarily, other demographic parameters should be tested including juvenile survival, number fledged per nest, breeding age, and successfully fledging young given that eggs were laid.

5.2.2. *Improving input datasets*

Missed nests are a problem for land managers since knowing only a portion of the territories on a National Forest makes it difficult to estimate size of the breeding population, recruitment, and ultimately population viability. Reich et al. (2004) suggested that by first describing the spatial distribution among active goshawk nests within a goshawk population and then modeling the interaction between nest locations and forest structure, it may be possible to predict the location of active nests in a given year. The eight pixel clusters with an 80 to 100% probability of occurrence identified in Figure 4-17 may aid in finding nest sites. As available vegetation information increases and more nests are located, especially those in non-mature forest habitat types, the model can be altered to reflect this, thereby improving predictions.

5.2.3. *Updating modeled habitat requirements*

The Black Hills National Forest appropriates a 12 ha or greater buffer surrounding known goshawk nests. Modeling suitable habitat within the 12 ha area was considered during the model-building process but was not included to avoid adding too much complexity to the model. Since nest sites for modeled individuals were surrounded by suitable habitat in14 ha blocks on average, this may indicate that the 12 ha area is more appropriate for the nested search image, and that finding 24 ha of contiguous habitat surrounding nests is not necessary for predicting goshawk

PFA habitat. Future versions of the model should test the prediction success associated with the 12 ha area instead of the 24 ha area.

5.2.4. *Incorporating vegetation change*

The model was meant to recreate a scenario similar to the present day and did not incorporate a vegetation growth projection. This too could be integrated into future versions of the model if needed to address an ecological hypothesis.

5.3. ***Potential applications of the model***

A significant gap in our ecological knowledge of the goshawk identified through this process were the rates of immigration and emigration in the Black Hills area, as well as whether USFS Region 2 goshawks interact as one large population rather than semi-segregated metapopulations. The model could be used to test the influence of immigration by adding adults of breeding age to the population annually, quantify the percent of a stable population made up of immigrants, and assess whether the scenario is realistic given the isolated location of the study area.

A benefit to coding the model for individual-based data and behavior is that it is reasonably portable to other forest landscapes in the West, and other species with similar behaviors (e.g. monogamous territorial raptors). Updating the goshawk model for a different landscape would be best if there were sufficient input data for habitat analysis to update the search image for that area. In order to use the model for a similar raptor species, both habitat usage and population demographics would need to be changed, and some model processes depicting behavior and scale would likely need to be updated.

The model could be used to estimate the population response to various land management activities or planning alternatives. Scenarios could test whether there is a population threshold response of goshawks to habitat loss by changing the input for available habitat on a simulated raster landscape. This could yield information about the amount, type, and pattern of forest vegetation treatments (thinning, logging, fire, etc.) that are compatible with maintaining a viable goshawk population. The modeled effects from varying raster inputs would help land managers relate goshawk population response to land use changes.

6. Conclusions

The ability of computer models (such as the one used here) to quantify otherwise arduous decision processes gives us the opportunity to improve our understanding of entire landscapes and populations in ways not possible previously. The broad application of this project was possible because of the individual-based modeling approach used. The range of information this model can address would conventionally be studied in several different field research or modeling projects.

Organisms are tied to the habitats that support them and integrating habitat considerations with demographic parameters is necessary to attain a complete picture of a population. The individual-based approach allows for individual-level variability to be considered, yielding information not captured by analyzing average population behavior alone. The potential for results to predict population size and individual nest locations makes this approach more attractive than other common approaches.

Models can also be as misleading as they can be informative. If good information is not used to build the model, results can be meaningless. This project explored the ability to create an individual-based model for a northern goshawk population using our current ecological knowledge of the species, evaluated the performance of the model for estimating goshawk population parameters, and discussed further steps needed to refine the model before it can be used for experimentation and management recommendations.

The lack of locally-estimated population parameters limited the ability to model the viability of the Black Hills population specifically since demographic data used from the Kaibab National Forest depicted a population decline. Local estimates for adult survival and proportion of breeding pairs laying eggs annually will greatly enhance the model's predictive capability. Structurally, the model performed well, reproducing all individual-level input datasets within the 95% confidence interval of the modeled population mean, and reproducing 2 of 4 habitat pattern-related parameters. One parameter that did not perform well led to the conclusion that finding 24 ha of contiguous suitable habitat around nest sites was unrealistic, and that the input dataset is likely biased because nest searches are conducted predominantly in proposed timber sale areas. Validation of data not used to build the model was promising, but did not meet every criterion. The model also produced several results for which no known estimate exists. The model predicted the lifespan of an adult goshawk as 5.3 years, with individuals occasionally living up to 13 years. The model also estimated that 12% of the population would be made up of juveniles, while 88% would be made up of adults. Furthermore, extrapolating from the carrying capacity parameter, a Black Hills National Forest total population size was estimated at 600 or more goshawks.

The most evident lack of information missing from available literature and local datasets was information about how individuals move. Dispersal, immigration, emigration, how birds seasonally migrate between areas as part of a larger population, and the boundary of that larger population are important to understanding the viability of goshawks in the Black Hills and elsewhere.

Failure of modeled individuals to find 24 ha of contiguous suitable habitat indicated that 1) the observed data overestimates the selectivity of goshawks because nest searches are conducted in proposed timber sale areas where more mature forest is present or 2) since 24 ha of contiguous suitable habitat is very rare on the landscape, the Black Hills is unable to support a large goshawk population. Data from other studies depicting the goshawk as a forest generalist lead toward the first conclusion.

Increasing the sample size of the observed population and potential inclusion of nest sites in areas with less mature forest may increase the carrying capacity figure in future model simulations, leading toward a higher estimate of goshawk population viability for the Black Hills National Forest.

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