FINAL REPORT

A Decision Support System for Identifying and Ranking Critical Habitat Parcels on and in the Vicinity of Department of Defense Installations

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List of Acronyms

ASC II	American Standard Code for Information Exchange
BRAC	Base Realignment and Closure program
CD	Compact Disc
DOD	Department of Defense
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
DSS	Decision Support System
DTM	Digital Terrain Model
ERDC-CERL	Engineering Research and Development Center – Construction Engineering Research Laboratory
ESRI	Environmental Systems Research Institute
GAP	Gap Analysis Program
GIS	Geographic Information System
HA	Hectare
KM	Kilometer
LIDAR	Light Detection and Ranging
M	Meter
MCOE	Maneuver Center of Excellence
MCBCL	Marine Corps Base Camp Lejeune
MARS	Merrick Advanced Remote Sensing
NLCD	National Land Cover Data
NCFMP	North Carolina Floodplain Mapping Program
PI	Principal Investigator
RCW	Red-cockaded Woodpecker, *Picoides borealis*
SON	Statement-of-Need
USFWS	United States Fish and Wildlife Service
UTM	Universal Transverse Mercator

Key words

Red-cockaded woodpecker, RCW, *Picoides borealis*, Fort Bragg, Camp Lejeune, Fort Benning, Sandhills, Onslow Bight, decision support systems, DSS, GIS, LIDAR, spatially explicit model, individual based population model, longleaf pine

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Abstract

Our objective was to develop a user-friendly GIS-based spatially-explicit decision support system (DSS) from red-cockaded woodpecker (*Picoides borealis*) (RCW) habitat and population information that will help Department of Defense personnel identify and prioritize habitat parcels on and in the vicinity of DOD installations in the Southeastern United States. We accomplished this by linking a previously existing spatially-explicit, individual-based, RCW population model to the landscape through habitat suitability requirements, in a user-friendly form that operates as a toolbar within ESRI ArcMap. The DSS provides two options for classifying habitat as suitable or unsuitable for RCWs, land cover and habitat quality index, and three options for the amount of suitable habitat required per territory. Testing of the DSS included both model validation and model verification. Validation exercises indicated that the model simulates population dynamics well, but is conservative in its habitat requirements, that is, RCW groups can sometimes persist on fewer acres of suitable habitat than required in the model. We performed two additional modeling exercises to demonstrate the utility of the DSS, the first an assessment of the potential of private lands being considered for purchase to contribute to the RCW population at Marine Corps Base Camp Lejeune, the second an assessment of the impact of new range construction on the RCW population at Fort Benning. The DSS allows users to project the impact of any change in land use or management within their existing land base, or additions to or subtractions from that land base, on their RCW population.

Objective

The objective of this project was to develop a user-friendly GIS-based spatially-explicit decision support system (DSS) from red-cockaded woodpecker (*Picoides borealis*; RCW) habitat and population information that will help DOD personnel identify and prioritize habitat parcels on and in the vicinity of DOD installations in the Southeastern United States. With this system users can assess the effects of landscape fragmentation, habitat loss, habitat restoration, and no management action on RCW populations, at present and into the future. This research is innovative in that it links RCW population dynamics with landscape dynamics to evaluate the importance of individual land parcels.

Background

Statement of Need and DOD Need

This project addresses the SERDP Sustainable Infrastructure Statement-Of-Need (SON) entitled "Examination of Endangered and Threatened Species Habitat Fragmentation on and in the Vicinity of Department of Defense (DOD) Installations". This SON recognizes the increasing pressures military installations face in trying to integrate training and conservation needs. The Base Realignment and Closure (BRAC) program results in increased training intensity on many bases, creating a need to devote more land to ranges and developed cantonments and thus reducing the available acres on which to recover endangered and threatened species. At the same time, development increasingly encroaches on the borders of many installations, making the installations increasingly vital to conservation efforts and reducing opportunities to include habitat off base in those efforts. As habitat is lost and fragmented it becomes increasingly important to be able to identify the most critical habitat parcels to protect both on and off the installation. This ability is necessary to locate and design new ranges to minimize impacts on threatened and endangered species, and to identify habitat parcels for protection and purchase off base that maximize the conservation gain per scarce resource dollars. Research directed at this need can inform critical management decisions with regard to endangered species habitat and population management while complimenting related DOD issues such as training and readiness planning and compatible use buffers surrounding installations. We addressed this need by linking endangered species habitat requirements and population parameters at the landscape level, specifically for the purpose of identifying and ranking critical habitat parcels on and in the vicinity of target installations.

DOD and the RCW

Our project focused on the red-cockaded woodpecker (*Picoides borealis*) (RCW) for two reasons. First, because of its endangered status and large area requirements, the RCW drives habitat management on most military installations in the Southeast, and recovering the species to a point where it no longer places a burden on training activities is a high priority within DOD. Second, for no other species within its ecosystem were sufficient data available to support our technical approach. Our approach relied heavily on existing information and the vast amount of available data regarding RCW habitat requirements, population parameters, landscape function, and management options. Each of these research areas has been explored, but the results have not previously been synthesized in a management tool that can readily be applied to conservation activities. We developed a geographic information system (GIS)-based, spatially-explicit decision support system (DSS) that couples a previously existing, validated, and peer-reviewed spatially-explicit RCW population model (Letcher et al. 1998, Walters et al. 2002a) with actual landscape features on, and in the vicinity of, military installations. The DSS will help DOD personnel identify and prioritize habitat parcels according to their importance to RCW population dynamics, and/or parcels in which existing RCW groups are at highest risk of being lost, on installations and their surrounding landscapes in the Southeast. It can be used to assess

the effects of landscape fragmentation, habitat loss, habitat restoration, and no management action on RCW populations. Examples of specific research and management questions that can be answered using the DSS include: 1) given no management action, how many RCW groups will be present on the installation in 20 or 50 years?; 2) In order to grow the RCW population to the recovery objective population size, what land parcels need to be acquired and restored?; 3) Where is the best location to place a new range that will have the smallest effect on RCW population growth? 4) Given the choice of N off installation parcels, which parcel is likely to contribute the most to RCW population growth? The DSS allows for examination of management actions through time and produces realistic population projections for various management regimes.

The RCW is highly dependent on DOD lands for its recovery. Fifteen installations harbor RCWs, and all or part of six Primary Core Populations (of 12 such populations region-wide) exist on military installations (Camp Mackall, Eglin Air Force Base, Fort Benning, Fort Bragg, Fort Polk, Fort Stewart, and Marine Corps Base Camp Lejeune) (USFWS 2003). These include five of the seven largest remaining populations of the species. DOD has been the clear leader in efforts to recover the RCW, fostering dramatic increases in population size on most installations (Costa 2004), a result that has not been consistently achieved on other public lands. DOD is responsible for the only two instances in which a population has been increased beyond the recovery objective of 350 potential breeding groups (Fort Bragg, Eglin Air Force Base). To continue this record of success in the face of increasing pressures on the land will be challenging. The DSS is designed to help DOD managers meet that challenge.

The RCW has an enormous impact on military training activities on installations in the Southeast. Typically a 200 foot buffer is marked around the set of cavity trees belonging to a woodpecker group (termed a cavity tree cluster), and within that buffer a number of activities are prohibited, including vehicular traffic, digging foxholes, bivouacking or establishing other fixed positions, girdling trees with wire, burying cable, firing artillery within 600 feet and using anything that produces excessive disturbance (e.g., noise simulators, smoke). Military trainers feel that these restrictions detract from realism of training, and make execution of some training exercises difficult in some areas, causing shifts in location of training. Given that a single cavity tree cluster can occupy 10 acres or more, the impact of a large RCW population on the spatial restrictions on training can be significant. That the Army Guidelines enable these restrictions to be lifted when a population reaches the recovery standard of 350 potential breeding groups provides an incentive for managers to increase populations to recovery. One way in which the DSS can support the military mission is in helping managers achieve this goal.

Another way in which the DSS can support the military mission is in facilitating new range construction. Construction that involves clearing of forest habitat often conflicts directly with provisions of The Endangered Species Act. Cutting of cavity trees is considered “take” of RCWs by the U.S. Fish and Wildlife Service (USFWS). Also, USFWS requires that each RCW group be provided with 120-200 acres of mature pine as foraging habitat (USFWS 2003). The DSS can be used to identify locations where forest clearing will result in minimum loss of RCW foraging and nesting habitat, but many other previously existing, GIS-based tools have this capability to assess these immediate impacts. The value of the DSS lies in its capability to project how this habitat loss will affect the dynamics of the RCW population over time. Being able to

demonstrate future impacts and thus effects on recovery objectives, and show that range location and configuration has been designed to minimize these, is invaluable in consultations with USFWS on range construction. This in fact is why USFWS has been so receptive to use of the DSS (see below).

RCW Biology

The red-cockaded woodpecker is endemic to mature pine ecosystems of the southeastern United States. Once common throughout its range, which stretched from New Jersey to Texas, it had reached critically low numbers by the 1960's and was placed on the Endangered Species List in 1970. Extensive habitat loss and degradation are largely responsible for the species' decline (USFWS 2003) . In particular, the longleaf pine (*Pinus palustrus*) ecosystem, once covering more than 37 million hectares (ha), has been reduced by 95% and much of what remains bears little resemblance to pre-colonial conditions. Specifically many tracts are second growth stands, having been cut over in the early 1900s, and contain very little or no old growth (longleaf pine can reach 350-400 years of age). In addition much longleaf habitat has been degraded by fire suppression, which allows a dense hardwood midstory to form and results in suppression of the normally lush, species-rich groundcover. However, large tracts of mature, fire-maintained pine communities remain on DOD lands.

The RCW and its associated habitat provided an ideal case for our modeling effort for several reasons. (1) No other species affects military training and management of DOD land more than the RCW. (2) Though many installations with RCWs are facing increasing encroachment pressure from urbanization, in many cases potentially suitable habitat exists beyond installation boundaries. If acquired these lands could help relieve military training restrictions. (3) The RCW, because of its large area requirements and sensitivity to habitat quality, may act as an "umbrella species", and thus successful RCW management may benefit other species of concern, such as the gopher tortoise (*Gopherus polyphemus)*, and may alleviate potential training restrictions. (4) The RCW is well-studied, being the focus of over 1000 articles and/or books and 4 symposia. For no other species in its ecosystem are demographic data sufficient to support a complex, individual-based, spatially-explicit model of the sort we employ available currently.

Because of the wealth of existing information, habitat suitability for RCWs is readily assessed, and management techniques to convert habitat from unsuitable to suitable condition are well developed. As a result, habitat suitability can be well described in terms of availability of sufficient foraging habitat and nesting habitat, as a function of the age and current condition of pine forest stands (James et al. 1997, James et al. 2001, Walters et al. 2002b, USFWS 2003). Open pine stands containing large, old canopy trees, relatively little hardwood midstory and a lush groundcover rich in grasses and forbs constitute high quality RCW habitat.

In addition to habitat quality requirements, USFWS has developed explicit standards for the amount of habitat that must be provided: depending on the properties of a site (primarily site index), each RCW group must be provided with 120, 150 or 200 acres of suitable habitat (USFWS 2003). We used these requirements to link RCW population dynamics to habitat in the

DSS by restricting formation of new groups for population expansion to locations with a sufficient amount of suitable habitat not already assigned to previously existing groups.

The population dynamics of RCWs are unusual. In most bird species population dynamics involve the demography of territorial pairs and the dispersal of the young they produce each year. In RCWs and other cooperative breeders, however, some of the young, especially males, remain in their natal groups as non-breeding helpers rather than dispersing after fledging (Figure 1). This is the process responsible for formation of the family groups that characterize this species' social system. Helpers can remain on the territory, assisting the breeders in raising young, for up to 11 years (Walters, unpublished data). Helpers often become breeders by inheriting their natal territory upon the death of the breeder (Figure 1). They also disperse to become breeders, but their dispersal range is highly restricted: nearly all movements are to breeding positions only one or two territories away from the natal territory (Walters 1990). Individuals that disperse after fledging have a more typical dispersal range, but they are fewer in number than in most species since a large fraction of juveniles become helpers rather than dispersing early. Thus breeding vacancies on existing territories (and unoccupied habitat) within dispersal range of many helpers have a much higher probability of being filled compared to a more typical bird species, while vacancies beyond dispersal range of helpers have a much lower probability of being filled. Due to this fact, the dynamics of RCW populations cannot be accurately portrayed using conventional models.

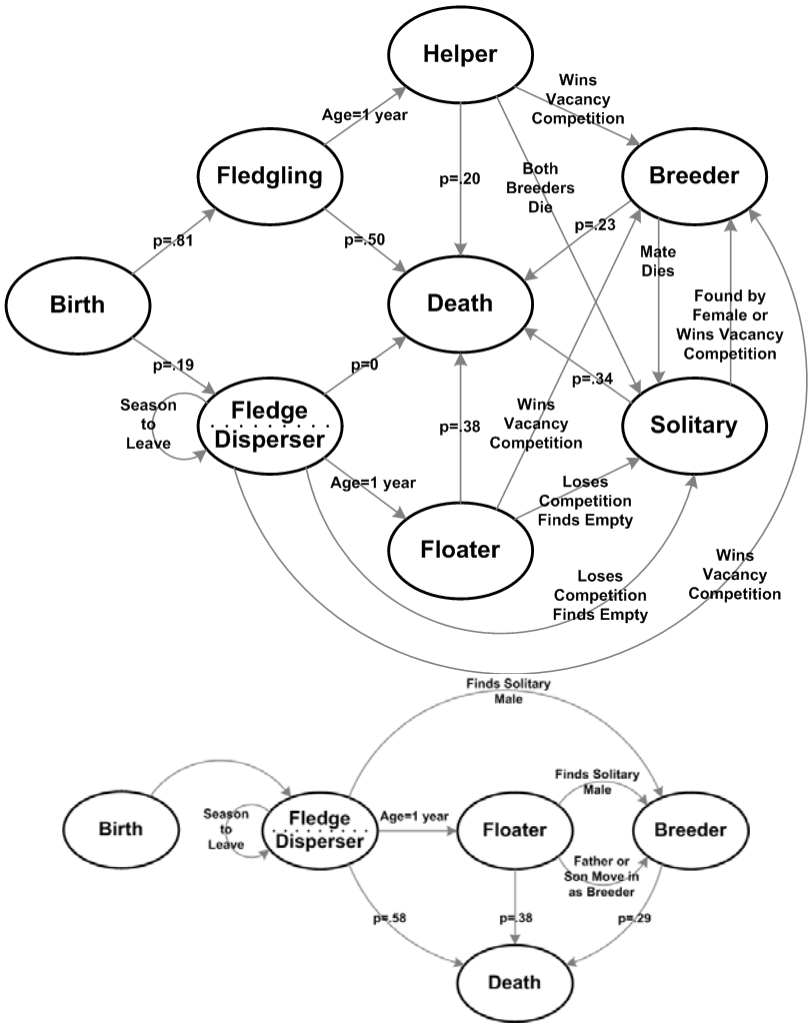


Figure 1. Structure of the underlying model for male (top) and female (bottom) birds in the DSS reflects the demography of RCWs.

The population dynamics of RCWs revolve around their cavity trees (Walters et al. 1992). RCWs are unique in excavating their cavities in living pines, rather than in dead trees or dead limbs in live trees as other woodpeckers do. RCW cavities take years to excavate, but can be used for a decade or more, whereas in other woodpeckers cavities typically take only weeks to excavate but are used for only a single breeding season (Harding and Walters 2002). As a result a set of cavities is a highly valuable resource, and population dynamics are mostly a matter of competing for breeding positions on existing territories with existing cavity tree clusters (Walters 1991). New RCW groups create new territories through two processes: (1) budding, in which one group splits into two and divides its existing cavity trees; and (2) pioneering, in which birds move into unoccupied habitat and create new cavity tree clusters (Hooper 1983). Both processes are rare, but pioneering is much less common than budding. As a result, annual population growth through these natural processes is generally limited to 1-2% (Walters 2004). Much higher rates of annual population growth of 10% or even more can be stimulated by constructing artificial cavities to create new territories, termed recruitment clusters, to induce the birds to occupy

habitat as it becomes suitable (Copeyon et al. 1991, Walters 1991). The DSS incorporates budding and allows use of recruitment clusters, but does not include pioneering.

The Classic Model

Spatially-explicit, individual-based models, because they track the performance and fate of individual organisms (Judson 1994) and their locations (Dunning et al. 1995), can incorporate constraints on movement such as the unusual dispersal behavior of RCW helpers, as well as the unusual population dynamics resulting from group living (Walters 2004, Grimm et al. 2005, Grimm and Railsback 2005). To model RCW population dynamics, the Principal Investigator (PI) and colleagues developed a spatially-explicit, individual-based model that incorporated the unusual dispersal behavior of this species (Figure 1). A major limitation of complex simulation models such as this is the amount of data required for parameter estimation (Murdoch et al. 1992, Conroy et al. 1995, Beissinger and Westphal 1998, Morris and Doak 2002). For the RCW a demographic data set extensive enough to support such a model exists as a result of two long term studies of individually-marked birds by the PI and his colleagues, a 30-year study of 225 groups involving lifetime demographic records of over 12,000 individual RCWs in the North Carolina Sandhills (Carter et al. 1983, Walters et al. 1988, Brust et al. 2004), and a 24-year study of 50 groups with lifetime demographic records of over 1700 individual RCWs at Marine Corps Base Camp Lejeune (MCBCL) (Walters 2004). These data drove construction of the model and, to a large extent, dictated its structure. Simulations using this model indicate that spatial distribution is as important as population size in predicting the dynamics of RCW populations (Letcher et al. 1998, Schiegg et al. 2002, Walters et al. 2002a), including habitat fragmentation effects (Schiegg et al. 2002). Thus a spatially-explicit model is essential to accurately project RCW population dynamics.

This model has been widely employed to simulate the dynamics of theoretical (Letcher et al. 1998, Schiegg et al. 2002, Walters et al. 2002a) and real populations (Crowder et al. 1999, Walters et al. 2001, Walters and Priddy 2005), including Fort Bragg (Walters et al. 2000b), MCBCL (Schiegg et al. 2005, Walters and Priddy 2005) and Eglin Air Force Base (Walters et al. 2000a). The model has been validated through comparisons between simulated and real population behavior (Schiegg et al. 2005). Although widely employed and much in demand, the model's use was limited by its technical inaccessibility to users beyond those who created it. Through its incorporation into the DSS we have made the model available to managers in a user-friendly form for the first time. Also, the model previously was not linked to habitat so could not project effects of changes in habitat over time on RCW populations. Instead it operated under the assumption that all existing habitat was suitable and would remain so indefinitely. Linkage of the RCW model to the habitat on the landscape is another way in which the DSS represents advancement over the "classic" model.

DSS Modeling Approach

In order to meet the DOD objective of identifying the parcels of land with the highest conservation value, we view both the installation and the surrounding areas as a "functional habitat surface" with respect to a single species. We define a "functional habitat surface" as a

spatially explicit representation of the space available to a species to fulfill all of its needs at both the population and organism levels. The functional habitat surface is more than a "habitat map" because it is able to capture multiple parameters required to truly define habitat in the "N-dimensional hypervolume" sense proposed by Hutchinson (1957). These parameters include not only the physical characteristics of specific parcels (e.g., forest age, pine basal area, vertical stratification), but also those related to juxtaposition, size, and connectivity (i.e., typically referred to in the context of landscape ecology). These parameters must work cooperatively with detailed population information in order to develop realistic models of population changes within a given landscape. Further, specific information as to how populations respond to changing landscapes and habitats over time are especially important. These features are often missing from traditional estimates of habitat suitability or population modeling efforts.

The uniqueness of this approach is in the focus on incorporating both population and habitat factors for the purpose of effective management action in the form of land acquisition, habitat restoration, or the wise placement of training activities. Typically, parcels are evaluated based upon their availability and the physical vegetation characteristics found there. This, however, is an incomplete assessment as more critical factors such as landscape function and dispersal are seldom considered, but greatly influence the probability of management success. Van Horne (1993) conveys this concept well and demonstrates that habitat quality (i.e. parcel importance) should be defined in terms of the survival and production characteristics of an animal occupying that habitat, and not by vegetation characteristics or even population density. Thus, in reality, the biological value of two seemingly identical habitat patches may differ greatly based upon their adjacency to or isolation from other suitable habitat parcels. The distance between parcels is not the only variable that may affect parcel isolation and value – the vegetation characteristics between parcels may affect their suitability. Ricketts (2001), for example, demonstrated the variable 'resistance' imposed by differing habitats encountered by migrating butterflies. His research illustrates that the landscape matrix surrounding habitat parcels affects the degree of isolation and thus parcel suitability. These and similar issues are the foundation of the emerging science of landscape ecology. Landscape ecologists are concerned with the affects of scale, adjacency, connectedness, and landscape heterogeneity on ecological processes. Though ecologists and modelers have often ignored these spatial realities because of the complexity of their consideration, research suggests that doing so is often an unacceptable oversimplification of reality (Tilman and Kareiva 1997). Traditional models based solely on measured habitat suitability are of limited value to real population management actions. Meaningful models must incorporate the size, shape, proximity, and spatial arrangement of the landscape (Temple and Wilcox 1986).

We have followed the functional habitat surface approach in incorporating habitat suitability criteria in the DSS and capturing effects of spatial configuration of habitat on movement in the RCW model. In addition, we have incorporated new field data that reveal effects of the matrix on movement to re-parameterize dispersal in the RCW model.

Materials and Methods: Development of the DSS

Construction of the DSS

From a technical perspective, the design and implementation of the DSS was driven by three goals. The first goal was to harness the spatial libraries and inherent capabilities of an existing GIS software package developed by Environmental Systems Research Institute (ESRI) called ArcGIS. This software package allowed us to significantly shorten the development time and increase the capabilities of the DSS. In addition, by operating the population model within this application, the user is able to extend the capabilities of the DSS in a customized way by combining other spatial and non-spatial data and conducting additional separate spatial analyses available to them within the GIS environment.

The second goal was to combine the latest research about RCWs into the underlying population model, specifically new information about movement of female RCWs including matrix effects (see below). The final goal was to develop an interface that was user-friendly and easier to learn than the original model. The intent of this goal was to encourage active technology transfer and ensure widespread use by managers and biologists who are actively engaged in RCW management and habitat restoration.

To achieve these goals, a Dynamic Linked Library wrapper was built around the original code base in VB6. It was decided early on that the best way to maintain the integrity of the original code base was to develop the Dynamic Linked Library using the same language as the original code base, VB6. Minimizing modification to the original code base also minimized potential errors in code that was already tested and peer reviewed. As a Dynamic Linked Library, the code no longer runs as a stand-alone application but as a toolbar within ESRI ArcMap. The code was also developed to adhere to principles of object oriented design wherever feasible and did not interfere with the original code base such that future modifications of the new code would be easier to implement.

Inclusion of Coastal Parameter Set

Our previously existing RCW model was based on the Sandhills RCW study (see above), that is, all parameter values in the model were based on Sandhills data (Letcher et al. 1998). However, demography varies among RCW populations in accordance with typical geographic patterns, with higher survival and lower productivity in coastal and more southern areas compared to inland and more northern areas (Walters, unpublished data). Within the range of the RCW the Sandhills is an inland, northern location. To capture the range of variation in RCW demography, we created an alternate version of the model termed the coastal model in which all survival and fecundity parameter values were based on Marine Corps Base Camp Lejeune (which is coastal in location) rather than Sandhills data. The coastal version of the model also includes a higher rate of retention of juvenile males as helpers than the Sandhills. The other parameters, including all movement parameters, are the same in the two models. The user can choose which version of the

model to use based on the location (inland, northern versus coastal, southern) of their study population. The demography of any population within the range of the RCW will be very close to that of one of the two versions of the model. Users will lack adequate data from their own population to accurately parameterize the model and therefore the DSS does not provide this capability. We believe that the parameter values of the appropriate version of the model will be closer to the true values in a given population than estimates from that population will be, due to sampling error.

Changes in Dispersal Parameters

Helpers monitor territories in their neighborhood for breeding vacancies (Walters 1990). This behavior is captured in the model by allowing helpers to compete for any breeding vacancies within their dispersal range (3 kilometers (km)). At the outset of this study little was known about juvenile dispersal other than the fact that they disperse farther than helpers on average and move variable distances, including long distances (i.e., 20 km or more) occasionally (Walters 1990, Cooper et al. 2008). In the previous version of the RCW model dispersing juveniles moved in a straight line in a random direction from their natal territory at a fixed speed and competed for any breeding vacancy that arose within 3 km of their current position. Birds continued on that line until: 1) the bird found an available territory, 2) the bird left the study area, or 3) the bird died. Movement was unaffected by the landscape. The extent to which this reflected the actual behavior of dispersing juveniles was unknown.

We used two sources of data to develop new parameters for juvenile dispersal. First, as part of this project, we examined historical dispersal data from the Sandhills to determine if landscape features affected the frequency of dispersal between territories (Kesler and Walters, unpublished data). Second, we used results obtained in another SERDP study involving the PI (RC-1471, “Mapping habitat connectivity for multiple rare, threatened, and endangered species on and around military installations”) in which behavior of dispersing juvenile female RCWs was documented through radiotelemetry.

In the first analysis, for each territory we determined potential dispersal destinations (i.e., territories on which appropriate breeding vacancies occurred within the range of distances of observed dispersals from that territory) and compared the habitat along the straight line path to those territories to which dispersal occurred (used paths) to habitat along those paths to territories to which birds did not disperse (unused paths) (Kesler and Walters, unpublished data). We found no differences between used and unused paths in forest type (pine versus hardwood) or forest habitat quality (high quality pine habitat versus low quality pine habitat). Juveniles of both sexes moved readily through all types of forest. However, we found that female but not male movement was inhibited by forest gaps, regardless of status (i.e., juvenile or helper). That is, females appear to be reluctant to cross large openings. The likelihood that a path was used was reduced by the presence of gaps 150 meters (m) or more across, increasingly so with increasing gap size (Figure 2). There was some movement across even the largest gaps however.

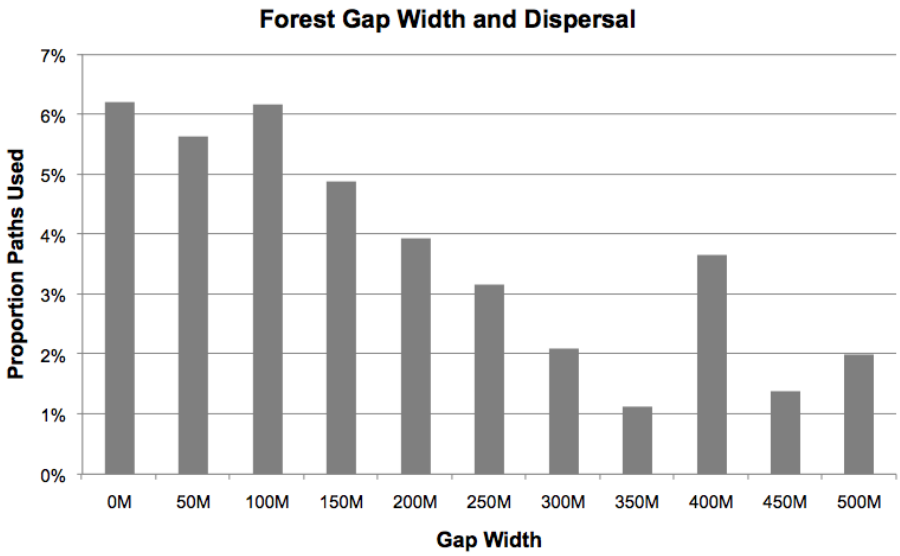


Figure 2. Proportion of travel paths used by dispersing juvenile female RCWs in the Sandhills between 1996 and 2005. Data represent the width of the largest forest gap crossed by travel path.

The RC-1471 telemetry study revealed the surprising result that juvenile females engage in foraying behavior rather than departing the natal territory and searching for breeding vacancies as the model previously had portrayed them to do (Kesler et al. 2010). Females leave their family group to visit other territories up to 6 km away (Figure 3), interact with the groups on those territories, and then return home to forage with their natal group and roost on their natal territory. They do this for several weeks, and dispersal finally occurs when the bird remains at a foray destination rather than returning home.

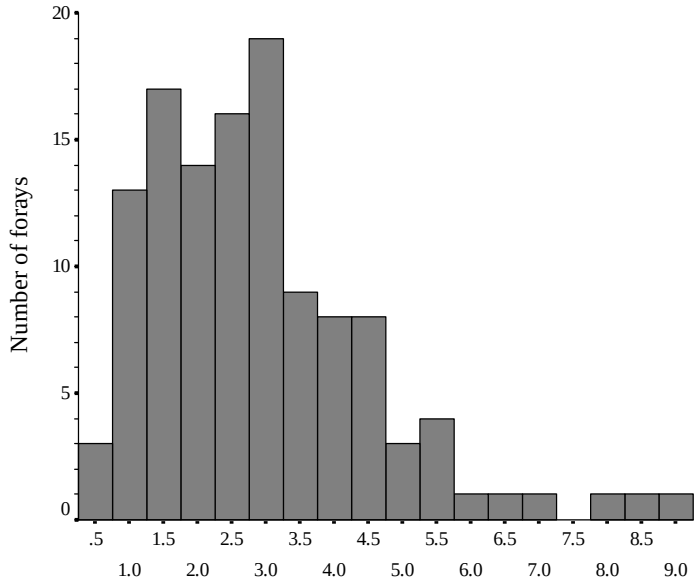


Figure 3. Foray distances (km) of 21 juvenile female RCWs observed on western Fort Bragg using radiotelemetry, February-May 2006. From SERDP project RC-1471 (Kesler et al. 2010).

A second surprising result obtained in RC-1471 was that although many juvenile females dispersed to locations within their previous foraying range, some moved much longer distances (Kesler et al. 2010). These “jumpers” departed the natal territory one day and relocated to a new destination well beyond the area in which they had been foraying (Figure 4). As a result, the dispersal distances of the sample birds was bimodal, one group moving within foraying range and the other jumping to distant locations (Figure 5).

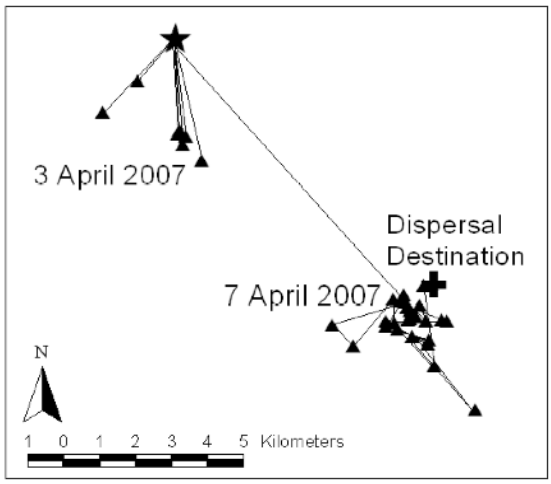


Figure 4. Example of a jumper from eastern Fort Bragg in April 2007. The line between the two clusters indicates the jump, and the lines within clusters represent forays from the home territory (star) to neighboring territories (triangles). From SERDP project RC-1471 (Kesler et al. 2010).

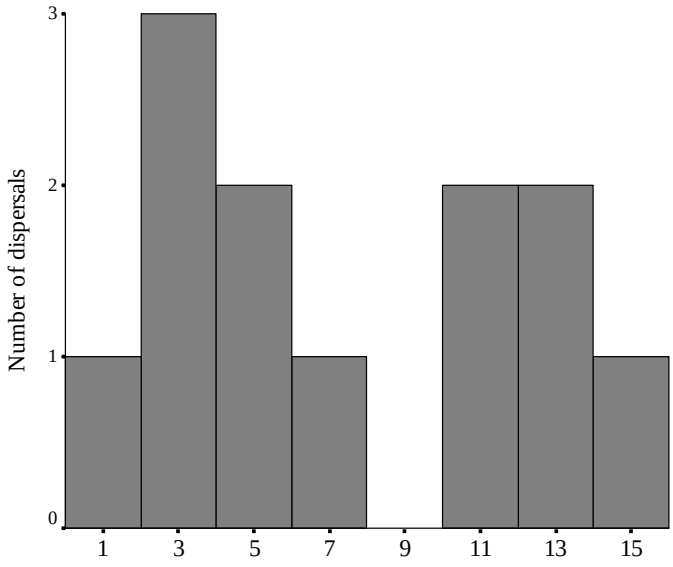


Figure 5. Dispersal distances of juvenile female RCWs observed on western Fort Bragg using radiotelemetry, February-May 2006. Left group are female dispersing within foraying range, right group are jumpers. From SERDP project RC-1471 (Kesler et al. 2010).

These findings indicate that the movement rules in the previously existing model were overly simplistic. We therefore altered movement rules to better reflect actual behavior. Specifically we altered juvenile dispersal behavior to make it similar to that of helpers, reflecting a reliance on forays rather than departing and searching. In the DSS juveniles compete for breeding vacancies within foray range (6 km) until reaching age one. We also incorporated an effect of forest gaps larger than 150 m on both juvenile female forays and movement of floater females. Finally, we incorporated jumping by allowing a portion of floater females to cross gaps of any size.

Description of Model Changes

Both high and low-level model modifications to the original base code were necessary to construct the DSS. High-level changes involve changes in the way the user interacts with the underlying models. These changes include a new interface for both input and output and most are readily apparent to the user familiar with the original model. Low-level changes involve model implementation and design and focus on incorporating new research into the overall population dynamics model. Low-level changes are not always readily apparent to the user. However, through all stages of the DSS design, particular care was devoted to maintaining the low-level integrity and results of the original base code.

High- level changes

Interface

As mentioned previously, the model no longer runs as a stand-alone application, but now requires ArcMap 9.3 to run. ArcMap is the most popular and capable GIS in use throughout North America. Access to the DSS is through a toolbar that is installed within ArcMap. This toolbar provides access to three different functional groups of processes, a scenario builder (The Wizard, Figure 6), a results display (Scenario Manager, Figure 7), and a recruitment cluster tool (Recruitment Cluster Manager, Figure 8). Each of these tools will be discussed in detail below. Also, all interactive display of DSS progress is shown within ArcMap via the status bar, a message form, and limited spatial changes (representing budding) to the Map. Detailed spatial display changes during the course of the model runs would significantly impact the performance and stability of the DSS. Therefore we decided to limit spatial changes to the Map while the DSS was running.

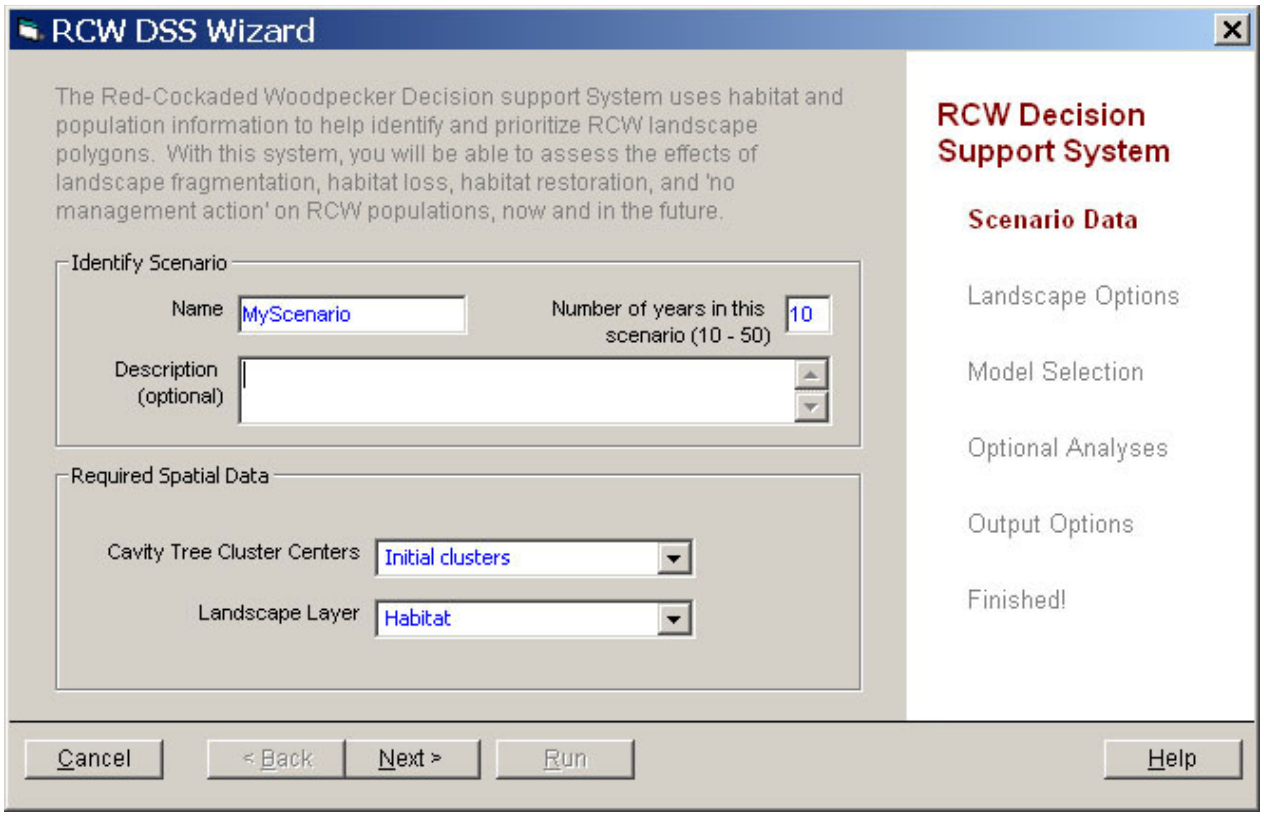


Figure 6. The Wizard interface.

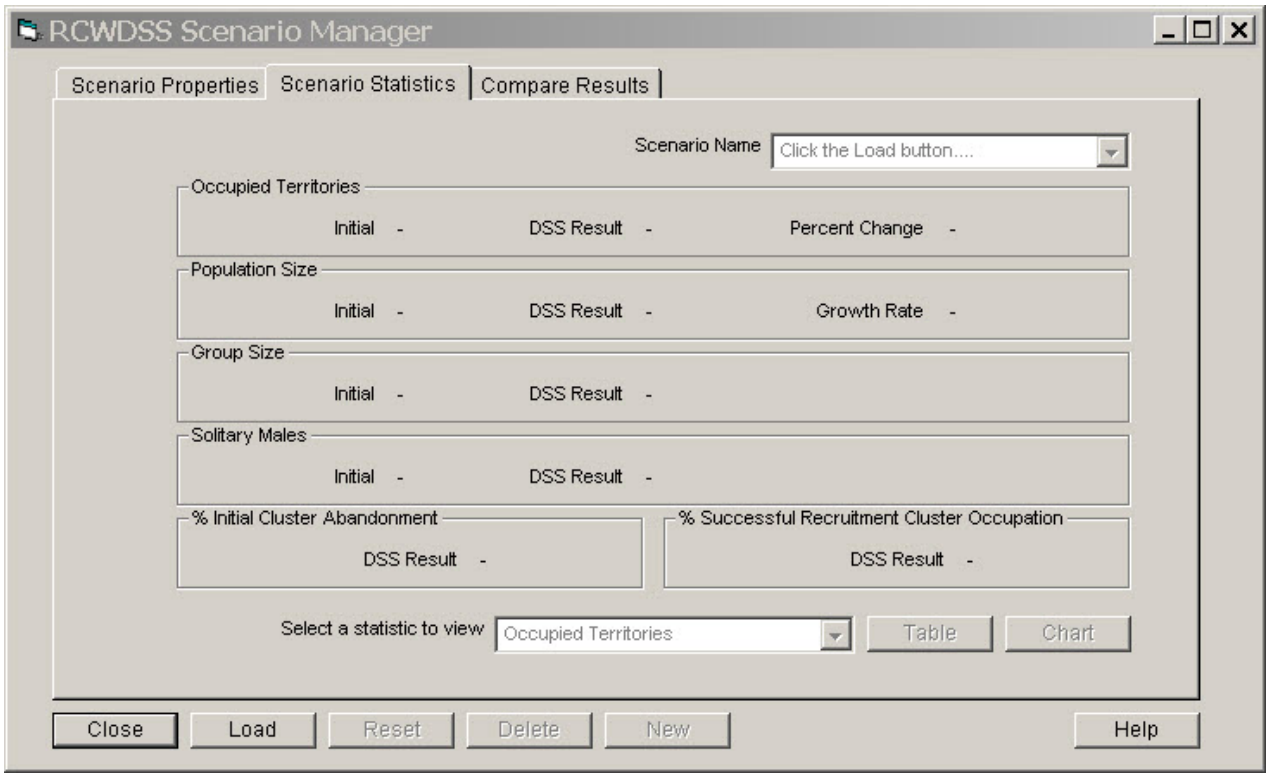


Figure 7. The Scenario Manager interface.

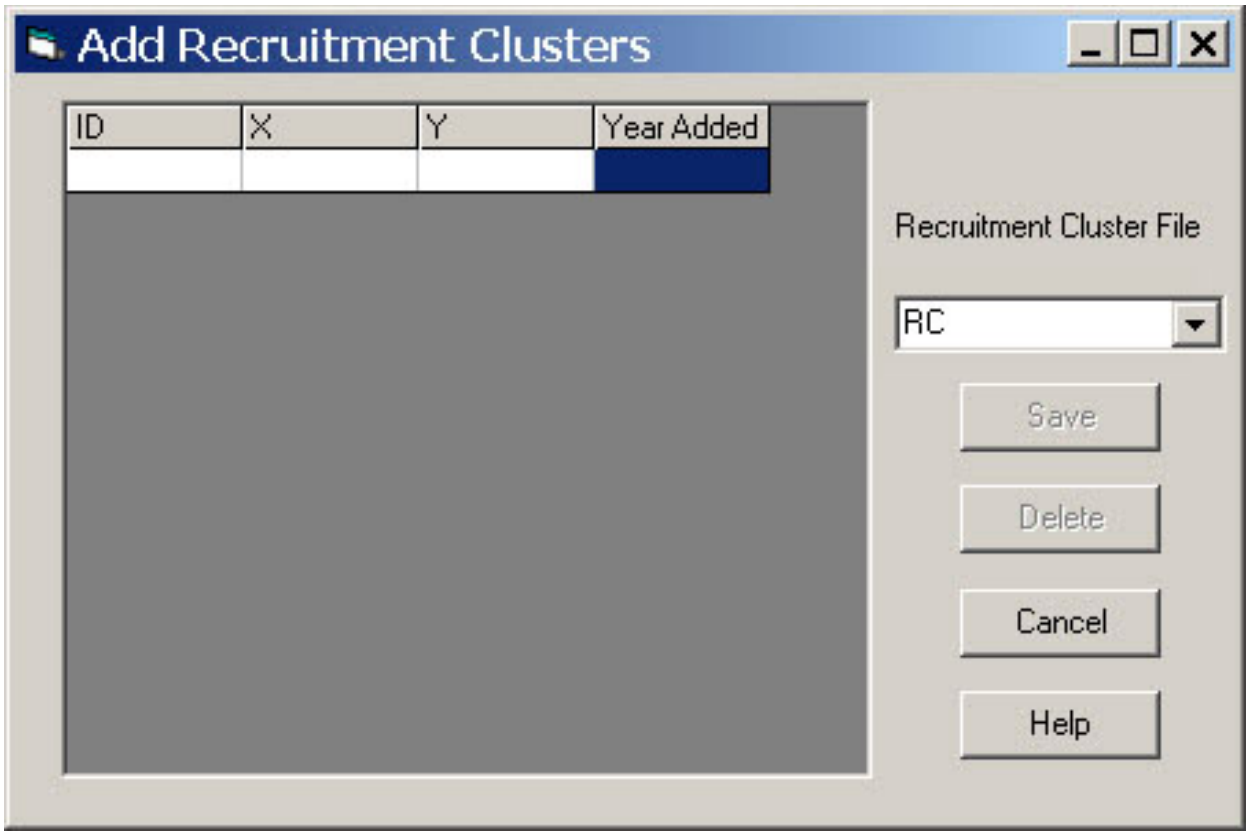


Figure 8. The Recruitment Cluster Manager interface.

Input

A major enhancement was a reduction in the number and complexity of the user inputs required by the model. The original code base required up to 14 input files in order to access all of its available functionality. These input files were not in a standard format and were difficult to parse and understand. The DSS reduces that number to three (one optional) spatial files: initial territory / cavity tree cluster centers, habitat, and optional recruitment cluster centers (Figure Figure 9). Detailed discussion about these input files is provided in the Description of the DSS section below.

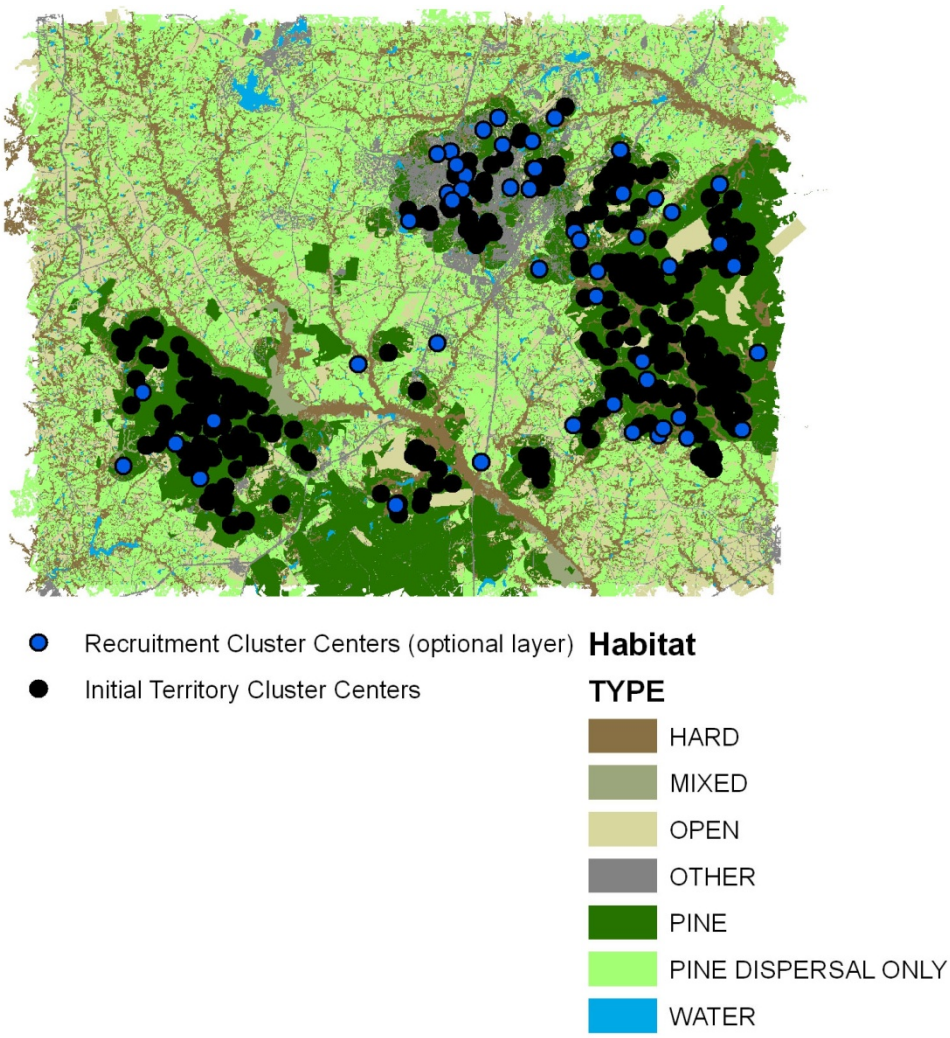


Figure 9. Sample map showing the three user input files: habitat, initial territory centers and optional recruitment cluster centers.

Output

The complexity of the output was also a factor we considered when making changes to the original model. The DSS version of the model was built to support the endeavors of managers and biologists, rather than researchers. For this reason, ease of use and interpretation of results was a primary concern. The default output of the DSS is less detailed than that of the original model. However, tables of summary statistical data (*.DBF files) and spatial datasets (rasters, Shapefiles) are available in special output directories. If the user wishes to conduct their own analysis of the results, they can use the DBF tables and Shapefile attributes to extend the results in a customized manner. Scenario Manager will display the most relevant results to the user in an organized manner that requires no action by the user. The spatial output datasets provided to the user describe initial cluster abandonment, recruitment cluster success, budding density, and dispersal tracking. Each dataset is detailed in its own section below.

Initial cluster abandonment

The Initial Cluster Abandonment layer (Figure 10) shows the propensity of specific initial territories to be abandoned within the scenario. The initial cluster abandonment statistic is calculated as the total number of times that a territory is permanently abandoned within a scenario (70 simulations). Abandonment occurs when a territory has not been occupied for 5 continuous years. The model does not allow a cluster to be reoccupied once it meets the abandonment criterion, mimicking natural behavior (Doerr et al. 1989).

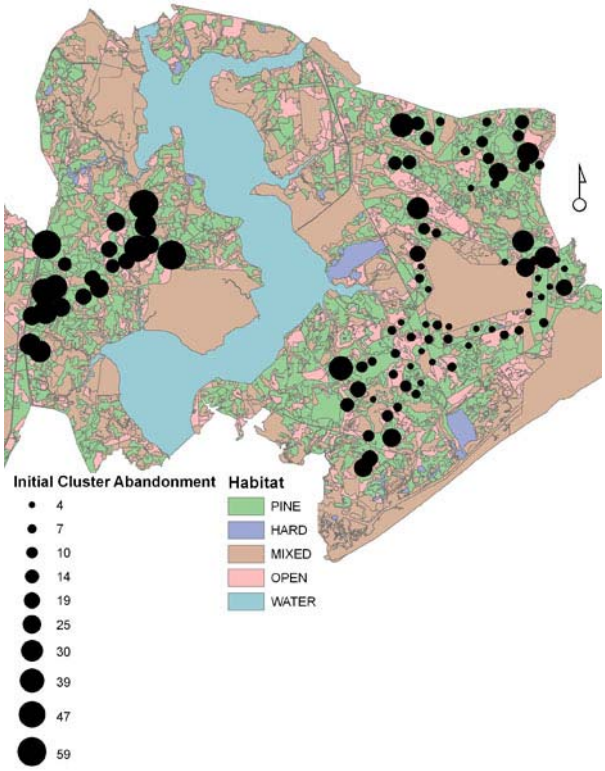


Figure 10: Initial cluster abandonment layer. The initial cluster abandonment statistic is calculated as the total number of times that a territory is permanently abandoned within a scenario (70 simulations). Abandonment occurs when a territory has not been occupied for 5 continuous years. Landscape is Marine Corps Base Camp Lejeune, North Carolina.

Recruitment cluster success

The Recruitment Cluster Success layer (Figure 11) shows the propensity of specific recruitment clusters to produce one or more fledglings during the scenario. The statistic is calculated as the total number of runs (out of 70) in which occupation of a recruitment cluster resulted in a group that subsequently produced at least one fledgling.

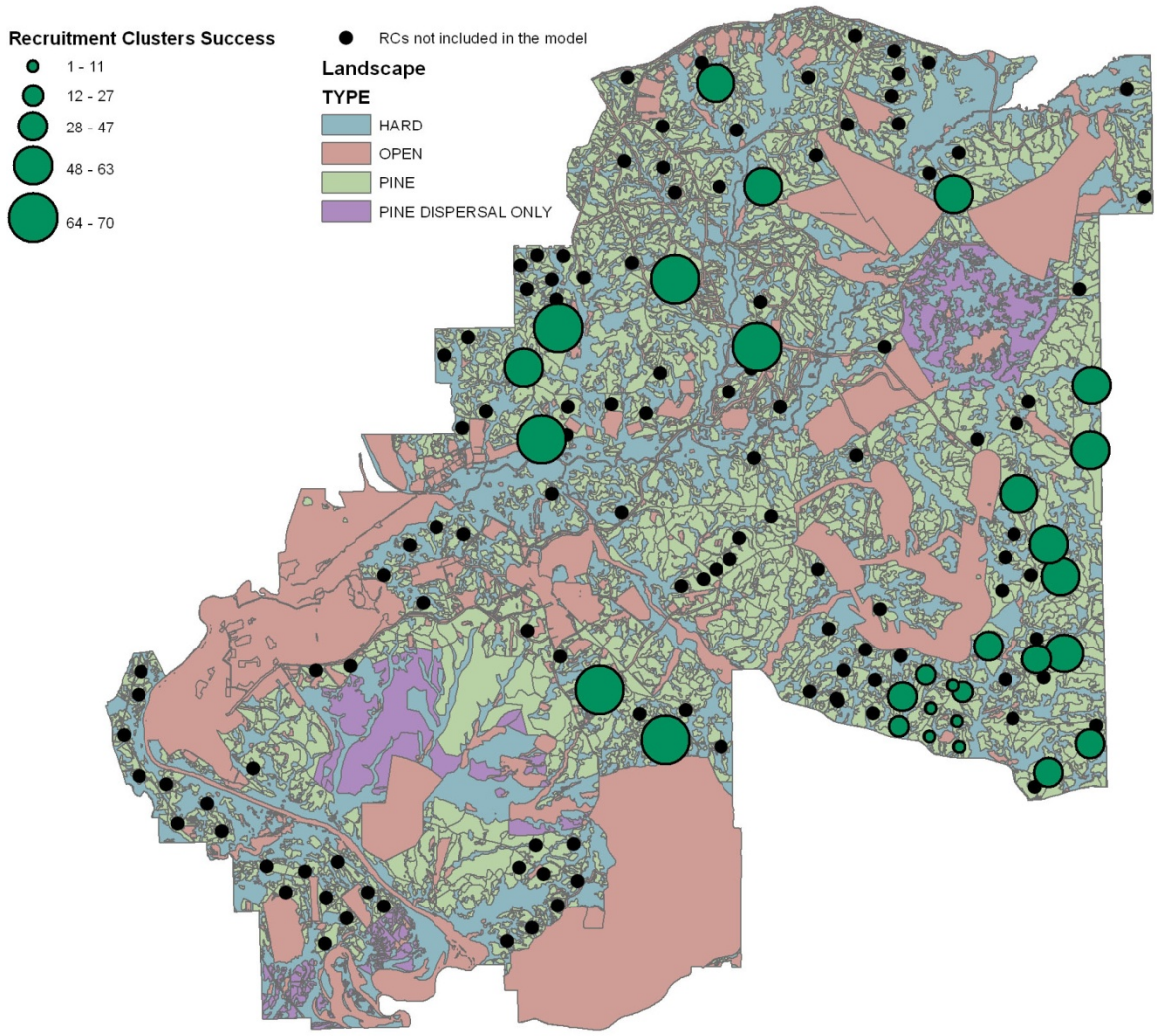


Figure 11: Recruitment cluster success layer. The statistic is calculated as the total number of runs (out of 70) in which a group produced at least one fledgling. The black dots indicate recruitment clusters that were never occupied because of insufficient habitat (see below). Landscape is Fort Benning, Georgia.

<u>Budding density</u>

This functionality illustrates where budding occurred within a scenario. The budding density layer (Figure 12) displays categorical values from low (white) to high (black) indicating the budding density across the landscape. The closer a grid cell on the landscape map is to a budding site center, the higher its value. Each cell accumulates a value for each budding site. The DSS considers a 750 m radius when calculating the cell values and does so using a 10 cell by 10 cell window moving across the landscape, for every instance of budding in all 70 simulations of a scenario. The equation to calculate the cell value is

$$1 - \frac{Distance\ from\ cell\ to\ budding\ site\ center}{750}$$

A value of 1 indicates the budding site is located in the center of the cell.

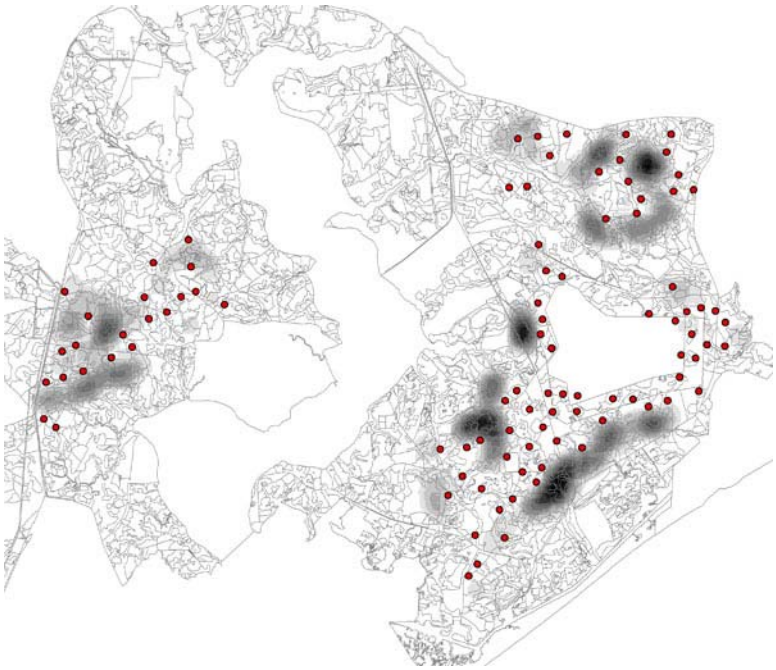


Figure 12: Budding density layer illustrates where budding occurred within a scenario. Darker areas represent locations of higher occurrences of budding within a scenario. Landscape is Marine Corps Base Camp Lejeune, North Carolina.

Dispersal tracking

The dispersal tracking functionality (Figure 13) tracks dispersal from one landscape region to another. The regions are established using an attribute in both the Clusters Center layer and the Recruitment Cluster Center layer (if used). Dispersal tracking tracks both gender and direction. Therefore, any two regions can have the following tracks: A to B Female, A to B Male, B to A Female, and B to A Male. The dispersal tracks are represented as straight lines between the calculated centroids of the regions. The line width is proportional to the number of dispersing birds, the wider the line, the greater the number of dispersal events.

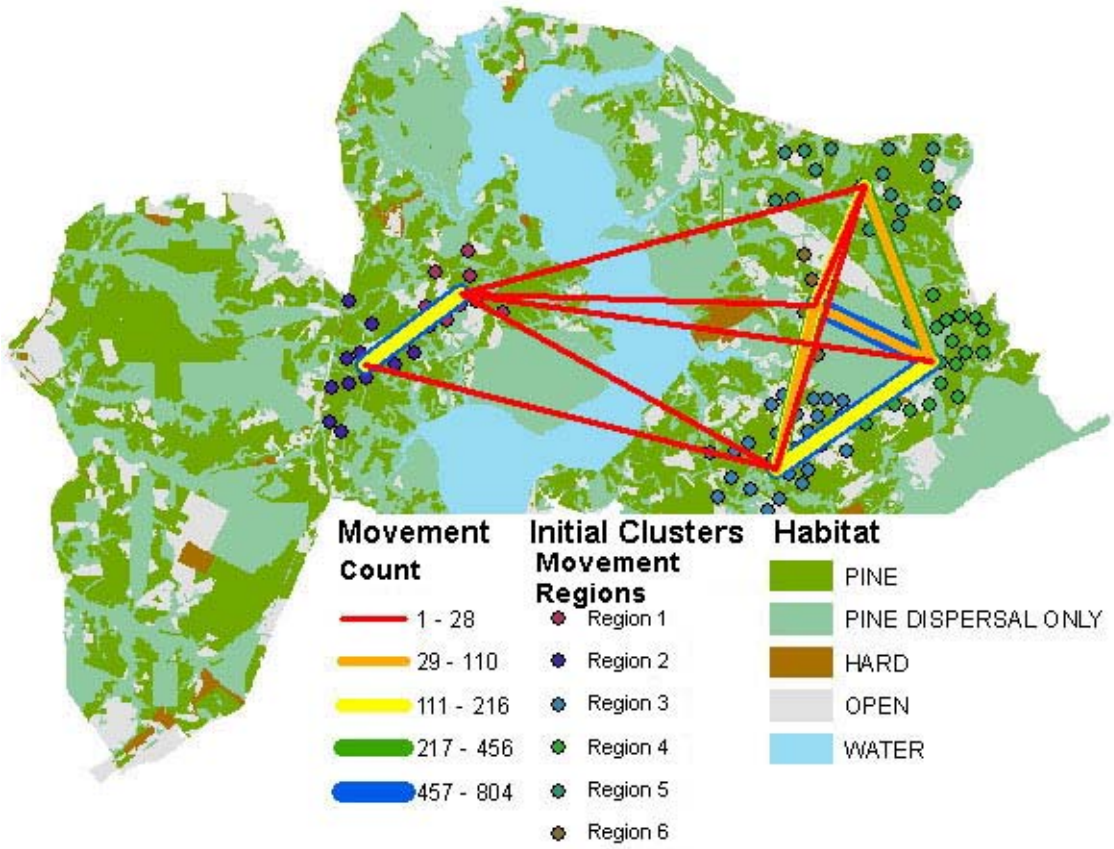


Figure 13: Dispersal tracking layer. Dispersal tracking functionality tracks dispersal of RCWs from one landscape region to another. Landscape is Marine Corps Base Camp Lejeune, North Carolina.

Additional high-level model changes

Two additional features were included with the DSS to facilitate its adoption by new users, and to support continued development (resources permitting) of the existing DSS. The first is an installer/uninstaller program and the second is an optional listserv to which users can post questions and developers can post announcements and updates. The listserv address is rcw_dss@listserv.vt.edu.

Low-level changes

Movement

As discussed above, dispersal parameters were altered in light of new research on RCW movement resulting from SERDP project RC-1471. First, in the DSS those juvenile females that survive to age one remain on their natal territory until the end of their first year, whereas in the old model they departed from the natal territory during the first year. While on their natal territory they compete for breeding vacancies within 6 km of the natal territory, whereas in the old model they competed for vacancies within 3 km of their current position. These changes reflect the discovery that juvenile females engage in forays. Second, new code was developed to incorporate sensitivity of females to landscape gaps. Three of the habitat types in the DSS, open, water and other (which is primarily urban areas), as well as pine habitat less than 10 years of age,

are considered gaps. In the DSS juvenile females do not foray across gaps of 150 m or more, and thus do not compete for breeding vacancies on territories separated from their natal territory by such gaps.

After age one those surviving juvenile females who have not located a breeding vacancy depart the natal territory in a straight line in a random direction (becoming floaters) at a designated speed and compete for breeding vacancies within 3 km of their current position as in the previous model. However, unlike in the previous model they also are sensitive to gaps. For these females, the probability of crossing a gap, p, is a declining function of gap length,

$$p = (-0.00163 * gap\ length) + 1$$

This equation is valid between 150 and 630 meters; gaps less than 150 m are always crossed and gaps larger than 630 have a 10% chance of being crossed by dispersing females. This last feature represents another new addition, the inclusion of jumping behavior, which reflects patterns seen in the new telemetry study.

The improved model simulates movement of floater females in the following way. As the bird moves in its straight-line direction, it searches for gaps in a radial pattern from its current location. If it encounters no gap along its initial direction, it will continue to move in that direction. If it does encounter a gap, the radial search pattern, because it is conducted in a “back and forth” motion, enables the bird to choose a new direction as close to her original direction as possible. The female picks a direction that allows her to proceed for the distance moved in one time step in the DSS, regardless of whether a gap exists beyond that distance. Steps along a specific radial arm are conducted at 100 meter intervals. Figure 14 shows the progression of the search pattern for a bird encountering a gap, and Figure 15 shows the simulated movement of floater females across a landscape resulting from this search routine.

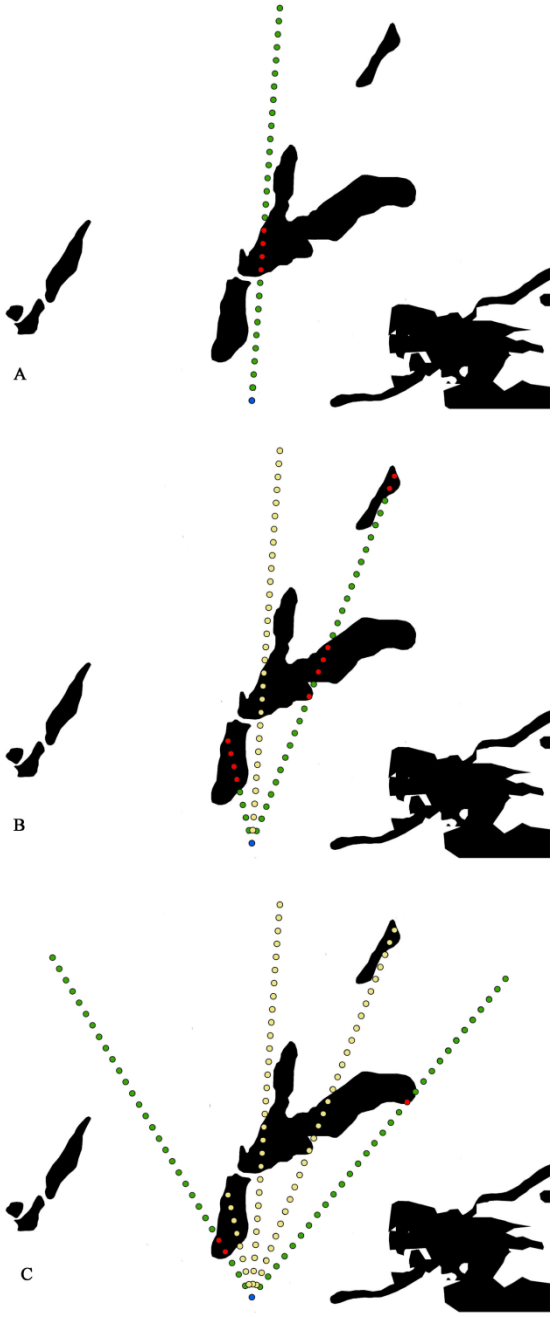


Figure 14. Illustration of female bird movement in relation to habitat gaps. A) First step along original direction. B) Second step fanning out from original position. C) Third step fanning out from original position. Black polygons are habitat gaps, blue dot is original location, yellow dots are previous radial search arms, green dots are current radial search arms, and red dots indicate encountered gaps. Dots indicate each 100 meter step along the arm. The shorter arms are terminated due to gaps not being crossed by the female. In this example, the female's new direction in the next forward movement would be the original direction depicted in A.

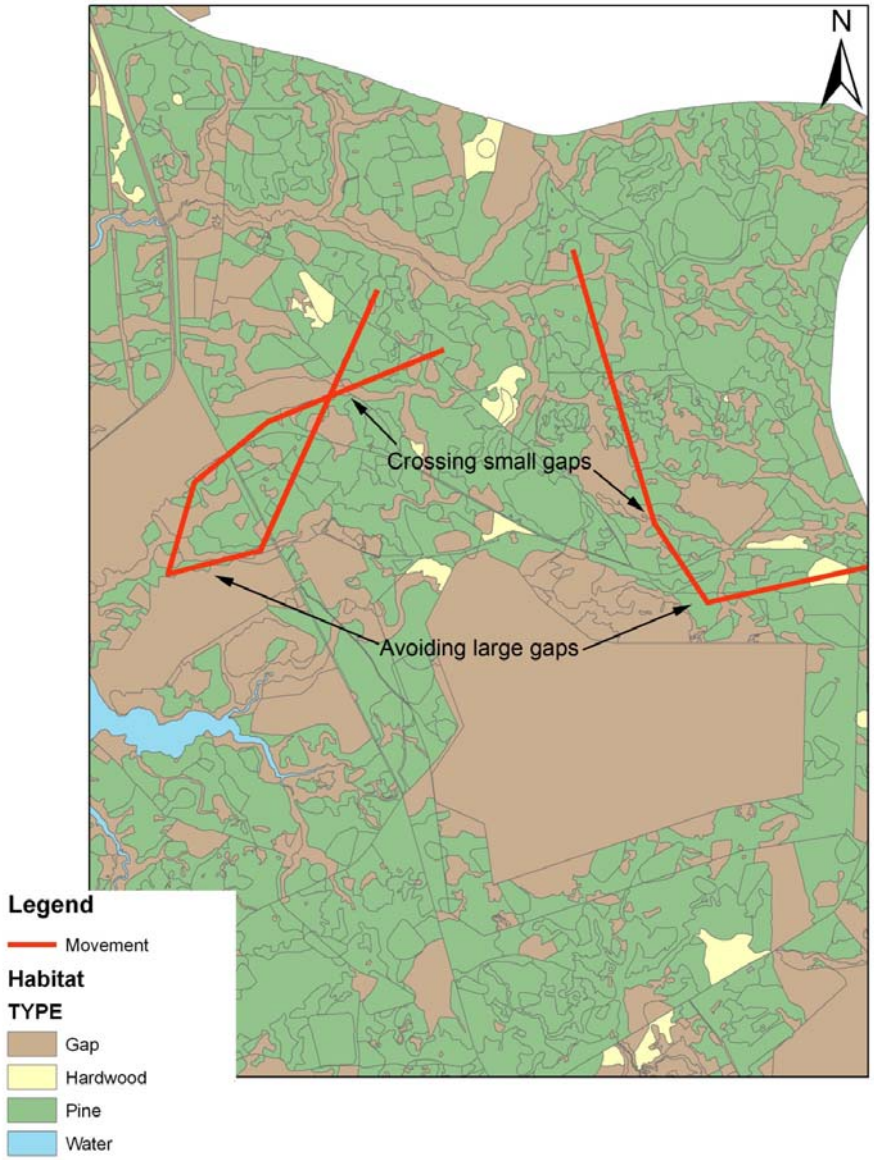


Figure 15. Simulated movement of female dispersers across a landscape. Habitat type is simplified for visual purposes.

Although only radial arms near the direction of movement are used to select a new direction to avoid a gap, the radial arms extend in all directions from the current location as they are also used to locate territories in the vicinity. Along any specific arm, a female will step 100 meters and look for any available territories. Each territory discovered is noted, so that the female may compete for breeding vacancies on any such territories. All territories seen are sorted by distance such that territories closer to the center are evaluated first, as distance to a breeding vacancy is one of the criteria (along with female age) to determine winners of these competitions, and closer females win over farther females.

The discovery of territories by juvenile females occurs by this same process as for dispersing females. The only difference is the juveniles will avoid all gaps greater than 150 meters, thereby never discovering territories beyond those gaps, whereas dispersers are sensitive to but not completely obstructed by gaps greater than 150 meters, thereby providing a probability of discovery inversely proportional to the gap length. In the case of juvenile females, the radial arms extend from the natal territory and represent forays.

A fraction of the juvenile males that survive to age one are designated as helpers and the remainder as dispersers. Only the dispersers compete for breeding vacancies during their first year, and they do so through foraying in the same manner as juvenile females, except that they are not affected by habitat gaps. Males foray in a radial clockwise manner from their current position. This is illustrated in Figure 16. Dispersing males that do not obtain a breeding position also depart the natal territory at the end of the first year and move across the landscape as floaters just as females do, except that again they are not sensitive to gaps. Because of this male floaters always continue to move in straight lines, maintaining their original direction, assigned randomly. The “back and forth” motion used for female movement is not necessary since the direction of movement will never change. Figure 17 illustrates simulated movements across the landscape by floater males.

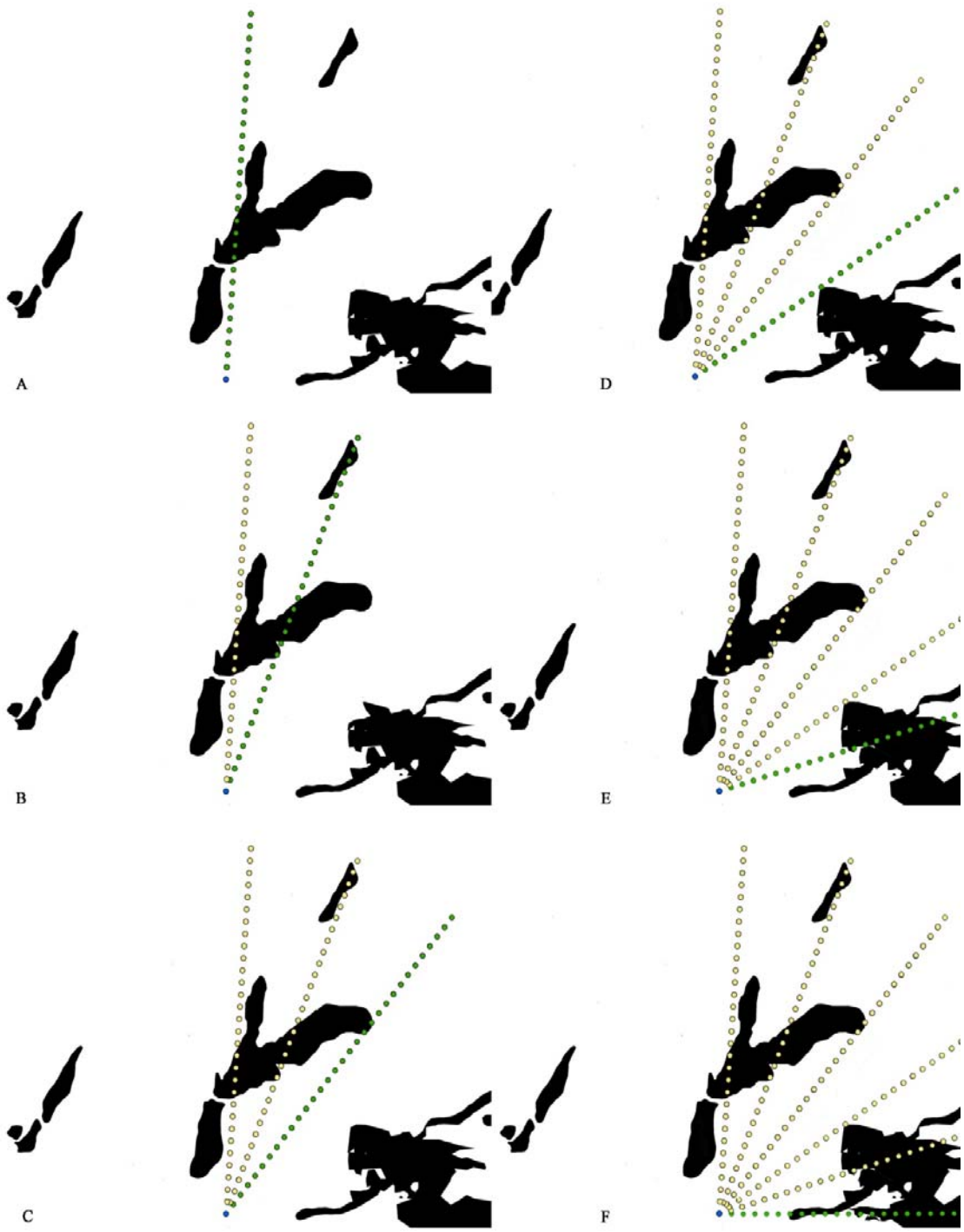


Figure 16. Illustration of male forays in relation to habitat gaps. A) First step along original direction. B) Second step from original position in a clockwise manner. C) Third step from original position in a clockwise manner. D) Fourth step from original position in a clockwise manner. E) Fifth step from original position in a clockwise manner. F) Sixth step from original position in a clockwise manner. Black polygons are habitat gaps, blue dot is original location, yellow dots are previous radial search arms, green dots are current radial search arm. No red dots are present because males are insensitive to gaps. Dots indicate each 100 meter step along the arm.

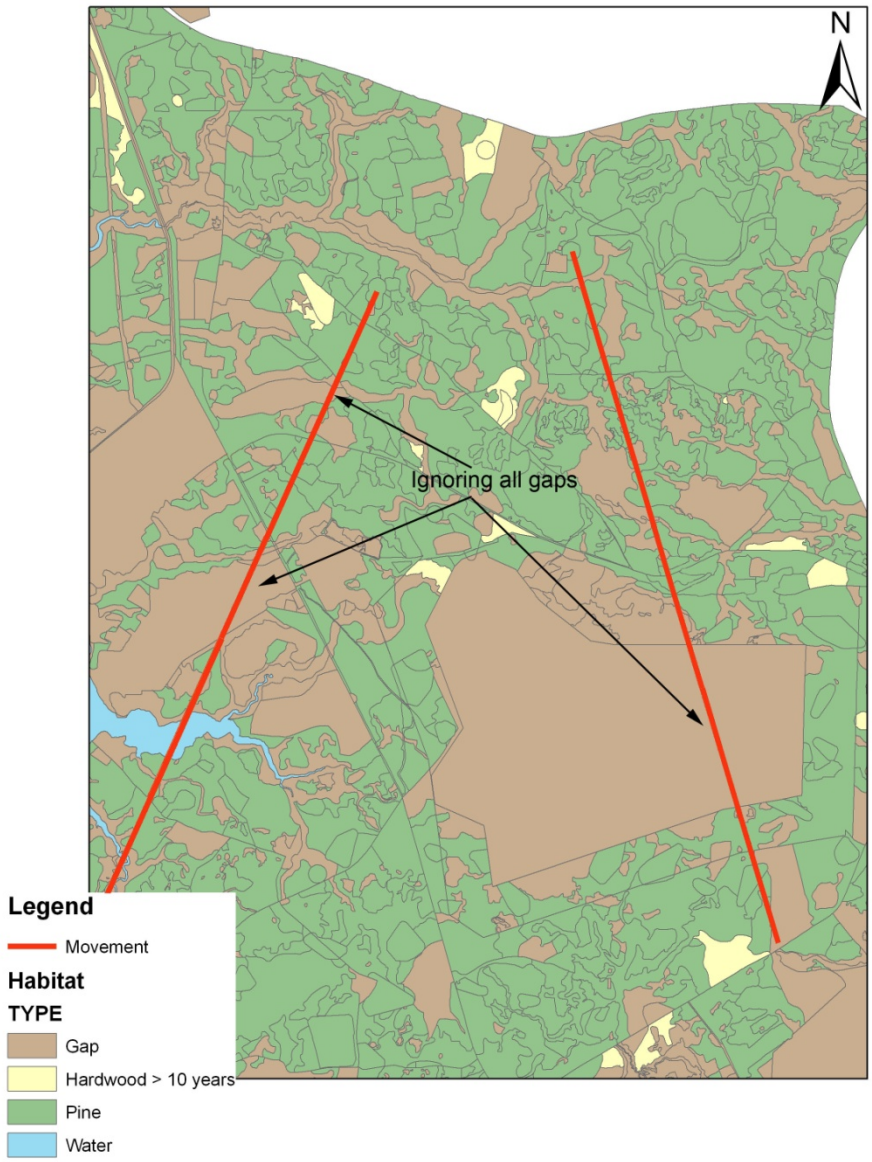


Figure 17. Simulated movement of male floaters across a landscape. Habitat type is simplified for visual purposes.

Habitat

In the original model, habitat was a simple binary construct that defined suitable and unsuitable habitat that was fixed over time. For the DSS additional granularity was defined to represent a closer approximation of RCW habitat. Habitat descriptors such as habitat type, pine stand age and habitat quality index were built into the model. All of these descriptors are used to define nesting and foraging habitat (see below), and type is also used to define movement of females across a landscape. These descriptors are introduced into the model as attributes in the habitat

layer (see Figure 9). In addition, there is a minimum amount of acreage of habitat required to support a new RCW group. This minimum is set by the user in the wizard. Three choices are available: 125, 150, and 200 acres.

Landscape evaluation

The DSS enables the user to evaluate the contribution of specific parts of the RCW landscape to the overall RCW population. This evaluation is done by first running a scenario with all polygons included, then running similar scenarios with selected polygons removed from the landscape. The concept of being "removed" means being rendered unsuitable nesting and foraging habitat or dispersal habitat. In other words, the polygons evaluated are considered gaps. Once this initialization scenario is finished, the scenario is rerun using the same parameters for each unique value found in the attribute table. The only difference between these scenarios and the initial baseline run is that the indicated parts of the landscape are now considered gaps.

Changes in the Landscape Interface and Landscape Processing

The original model treated the landscape in a simplistic fashion—habitat was either suitable or unsuitable—and the model did not account for the effects of landscape composition on many natural processes, such as the quantity of suitable habitat required for budding to occur. The revised model provides for a more realistic treatment of the landscape and the ways in which the landscape affects bird movement and territory configuration, and thus the revised landscape input file is more complex.

The DSS accepts a landscape layer in the form of an ESRI polygon Shapefile. Landscape polygons must be attributed with the following information:

- cover type – pine, hardwood, mixed, open, water, other
- stand age – age of stand (applicable to pine cover type only)
- habitat quality index – relative measure of habitat quality, based on metrics defined by the USFWS RCW Habitat Matrix Application (http://www.fws.gov/rcwrecovery/matrix_download.html, accessed 11/1/2009)

Actual field names, required format, and detailed information on how the DSS uses these data are described in the Help file.

Cover type, stand age, and habitat quality index (optionally) interact to determine whether a polygon is suitable or unsuitable for RCW nesting and foraging habitat, or whether a polygon represents a habitat gap (resistance to movement) to dispersing birds. The DSS provides two options for classifying habitat as suitable or unsuitable, land cover and habitat quality index. The land cover option is based on guidelines provided in the USFWS Recovery Plan (USFWS 2003). Under this option, the DSS classifies habitat as suitable if cover type is pine and the age is greater than 60 years old. The DSS tracks pine stand age, so that young pine stands convert from unsuitable to suitable when they mature to age 60.

Optionally, users can use the habitat quality index field to influence how the model deals with habitat quality. To use this feature, each stand must be attributed with a value between 1 and 5 that represents a relative index of habitat quality; the USFWS RCW Matrix Application provides

this capability if detailed stand metrics are available. The user then chooses a threshold value that represents the minimum score at which a stand is considered suitable. Stands with values less than this threshold are classified as unsuitable, regardless of age and cover type. This functionality is very useful in situations where stand metrics such as basal area, stem counts and groundcover composition can be used to create habitat quality site index values, and where a threshold value below which habitat is generally unsuitable can be determined.

Analysis of Utility of LIDAR Data

Introduction to LIDAR related activities

We also explored the possibility of using traditional multispectral imagery and Light Detection and Ranging (LIDAR) data for characterizing forest metrics that are critical to RCW habitat suitability in order to provide a third alternative for classifying habitat. This is an attractive option because spatially explicit maps that characterize pine species, pine basal area by size class, the spatial distribution of mid-story hardwoods and other features important to RCWs, although often available for military installations, typically are not currently available for privately owned and state lands in the vicinity of those installations.

Large scale assessment of RCW habitat potential with remotely sensed data requires a combination of high posting density, small footprint LIDAR data and high spatial and spectral resolution multispectral imagery. Analysis of high density LIDAR data and high spatial and spectral resolution multispectral imagery does provide some capability for assessing the spatial variability of these critical forest metrics. However, development of spatially explicit maps that characterize these same forest metrics across a regional or landscape scale with LIDAR data is cost prohibitive, in terms of both data acquisition and analysis. Small scale, regional assessment of RCW habitat potential, such as the habitat assessment requirements of this research, must be completed using regional, statewide or national scale remotely sensed data sources. Therefore, assessment of forest structure at regional scales requires the use of larger footprint, lower sampling density LIDAR data and coarser resolution multispectral imagery. Associated with decreased LIDAR sampling density is a reduced capability to assess detailed forest structure parameters. Lower sampling densities do not allow for assessment of individual forest stems and result in significantly fewer LIDAR returns that penetrate the canopy and intercept understory vegetation. Therefore, it is not possible to assess basal area by size class and understory conditions with such data. Similarly, lower spatial and spectral resolution multispectral imagery does not allow for separation of pine species. However, analysis of larger footprint, lower sampling density LIDAR data in combination with multispectral imagery does provide some capability to delineate pine forest and estimate mean stand heights from which stand age can also be estimated. Regional, landscape scale assessment of forest stand height and age are useful for initializing and parameterizing landscape scale habitat models such as the model developed in this research.

In addition to the work with LIDAR conducted as part of our project, we will discuss a case study that utilized small footprint, high sampling density LIDAR data and high spatial and spectral resolution multispectral imagery to demonstrate the utility of such data for detailed assessment of forest structure parameters at a local scale. The case study was funded by the U. S.

Army Corps of Engineers Engineering Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL) (PI: Scott Tweddale) and is leveraged in this project to document the utility of high resolution LIDAR for local habitat assessment and to contrast and compare with LIDAR based habitat assessment techniques developed in this research, which are suitable for assessment at a landscape or regional scale.

Case study results

LIDAR data with a high posting density (nominally 4.0 returns/m^2) were processed to create both a canopy terrain model and bare earth digital elevation model (0.5m cell resolution) for a 30km^2 area spanning a corridor between Fort Bragg and Camp Mackall in the North Carolina Sandhills. These models, in addition to the multispectral imagery (0.25m resolution), were used to assess species composition, determine locations of individual trees and their associated heights for evaluation of stand structure, and to assess midstory structure.

Separation of pine from hardwood species using multispectral image classification resulted in an overall accuracy of approximately 80%, and when differentiating between longleaf and loblolly (*Pinus taeda*) pine species, overall accuracy was 74%.

Identification of individual stems was accomplished by identifying local maxima in the canopy terrain model in order to estimate height of individual stems and infer diameter based on height - diameter relationships. Mean differences between field and LIDAR-estimated tree heights ranged from 0.5 to 1.0 m for pine species and 1.5 to 2.5 m for hardwood species. For the purposes of assessing RCW habitat suitability, errors in height estimates of this magnitude are acceptable for inferring diameter at breast height (DBH) and then evaluating DBH for three different size classes (large, medium, small) as defined in the RCW recovery plan. On average, approximately 80% of individual stems identified in the field were successfully identified from LIDAR analysis. Generally, most canopy stems were identified and smaller isolated stems were also successfully identified. Errors of omission were biased towards smaller, less isolated trees in the canopy. As a result, estimates of basal area for large and medium size trees were relatively accurate, but estimates of basal area for small trees could not be accomplished using this method.

Quantification of understory/midstory density was evaluated using relative densities of individual LIDAR returns in four distinct height strata. As expected, at the lowest height strata, or the strata nearest to the ground, there was no relationship between relative densities of LIDAR returns and field measured cover. At increasing heights in the understory, relative densities of LIDAR returns explained more of the variation in field measured cover (Table 1).

Table 1. Results of the midstory/understory analysis between field observations of total cover and LIDAR return densities for four midstory/understory height classes at Fort Bragg, North Carolina.

Height Class	R Square
Less than 2.1 meter	0.00
2.1 to 4.6 meters	0.26
4.6 to Height to Live First Branch	0.36
Height to Live First Branch to top of Canopy	0.6

In summary, analysis of LIDAR with high posting density and high spatial/spectral resolution multispectral imagery does provide some capability to assess species composition, basal area by size class, and midstory structure, all of which are key parameters for evaluating RCW habitat suitability. However, such analysis is not feasible for regional or statewide assessment due to data acquisition and analysis costs.

Assessment of species composition with national scale satellite imagery and derived land cover products provides a reasonable method for assessing of pine versus hardwood canopy composition. However, small scale, regional or statewide LIDAR data acquisitions are typically collected at a posting density of one return/5m^2 or less, and therefore, at these coarser posting densities, it is not possible to identify individual stem locations from which one can infer DBH and basal area for different pine size classes. Figures 18 to 21 provide graphical examples of top of canopy terrain developed from high density LIDAR data used in the case study (4.0 returns/m^2) and coarser, statewide LIDAR data used in this research (one return/5m^2). These examples are not for the same area, as statewide all return LIDAR data that corresponds to the case study area were not available. However, the figures do provide a comparison of similar forest conditions. The figures include both 2-D and 3-D perspectives. In the high density data (Figure 19; Figure 21), individual tree canopies can be identified. In the lower density LIDAR data (Figure 18; Figure 20), individual tree canopies are difficult to discern. These examples are taken from relatively open canopy forest. Delineation of individual tree canopies becomes more difficult as canopy closure increases. Therefore, mean predominant canopy height for large geographic regions such as the study areas in this research must be estimated from the LIDAR derived canopy terrain models derived from large footprint, lower sampling density LIDAR data and used as a surrogate measure of mean height of individual stems. Using mean predominant canopy height estimates, it is possible to estimate relative age of stands using height-age relationships for a given site index. However, it is not possible to assess midstory structure with large footprint, lower sampling density LIDAR data, as the proportion of returns that penetrate the canopy will be greatly decreased. Therefore, the primary focus of this research was to develop a method to utilize statewide, larger footprint, lower sampling density LIDAR data and statewide land cover classifications to estimate mean predominant canopy height and age of forest stands in the regions surrounding Fort Bragg and Marine Corps Base Camp Lejeune (MCBCL).

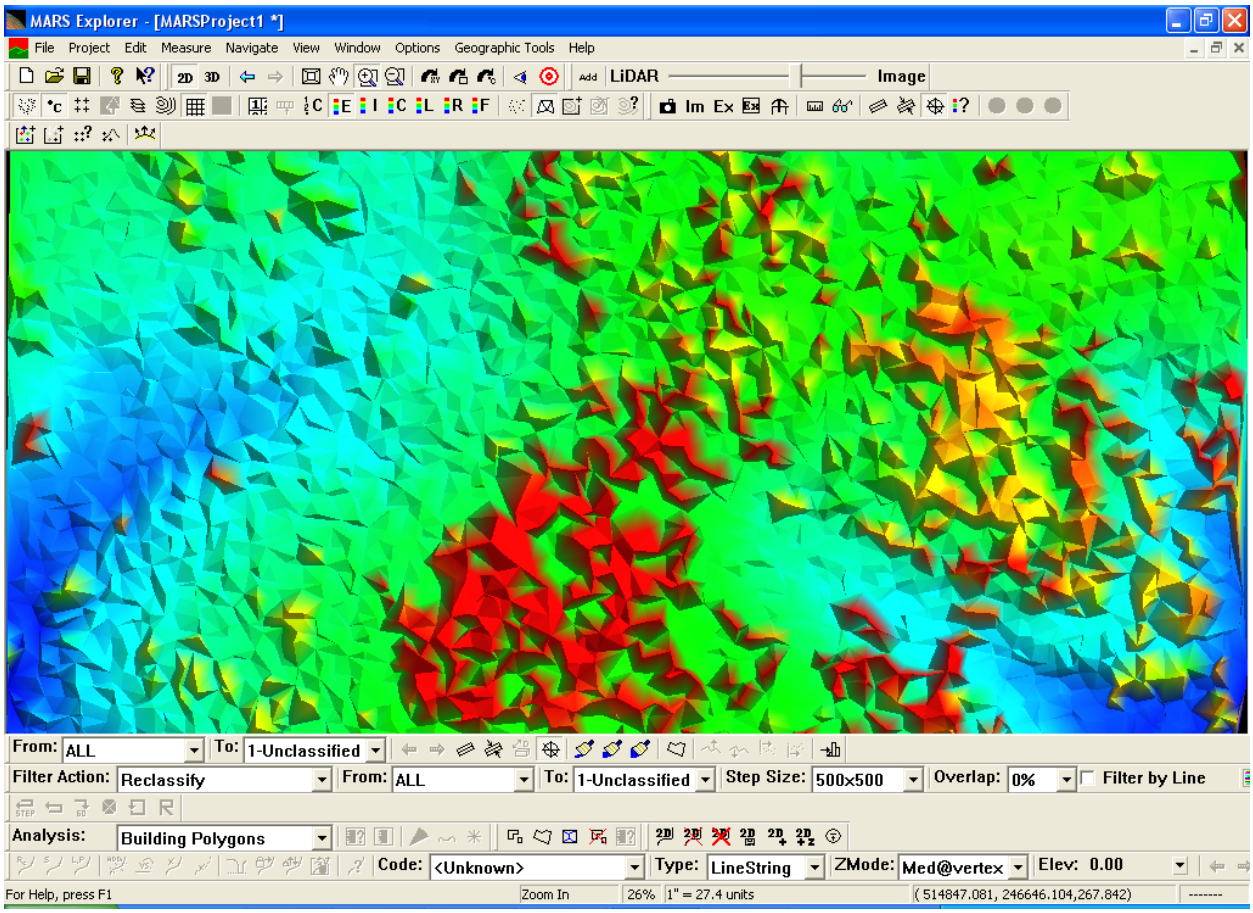


Figure 18. Top of canopy Digital Terrain Model for the North Carolina Sandhills from statewide, large footprint, lower sampling density LIDAR data provided by the North Carolina Floodplain Mapping Program.

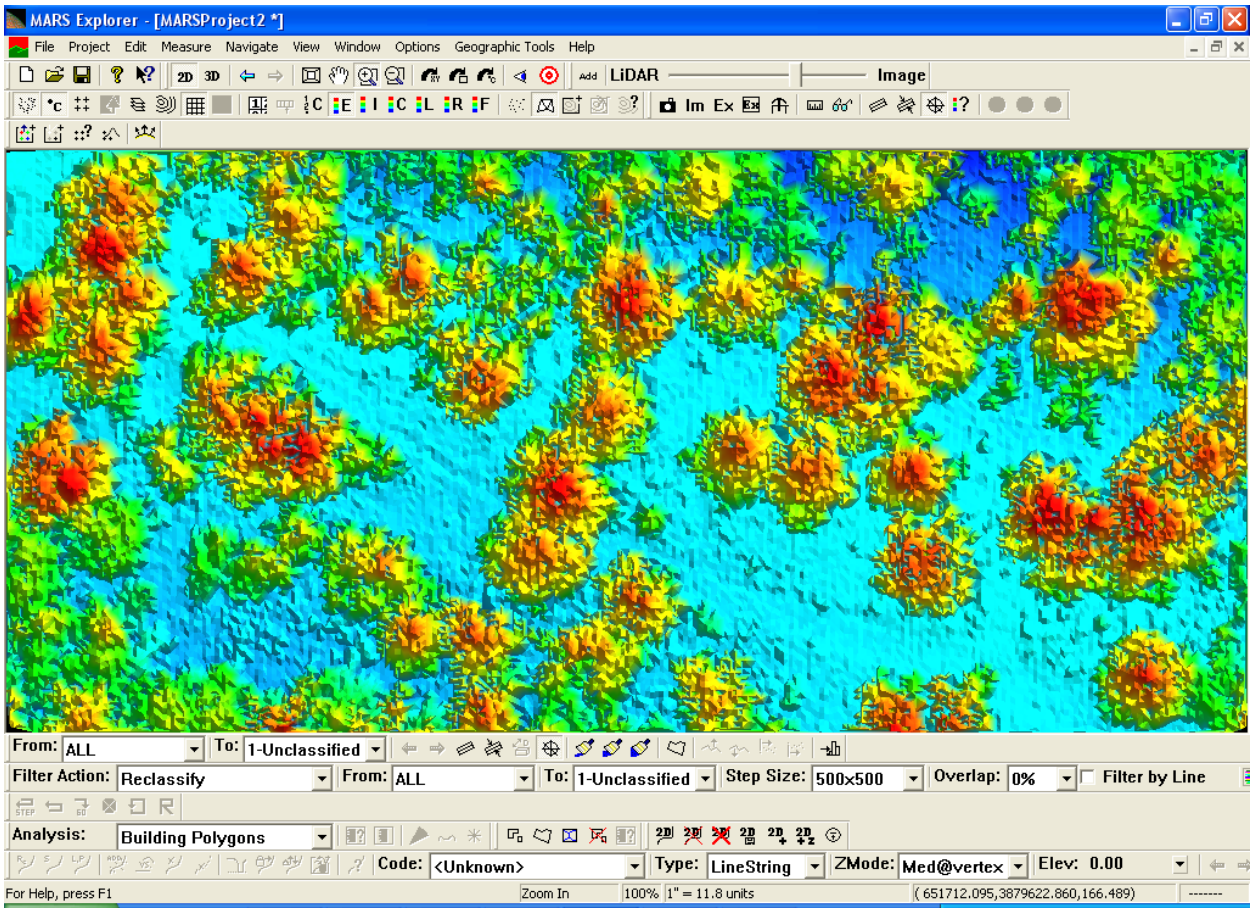


Figure 19. Top of canopy Digital Terrain Model for the North Carolina Sandhills from small footprint, higher sampling density LIDAR data provided by ERDC-CERL and utilized in the case study.

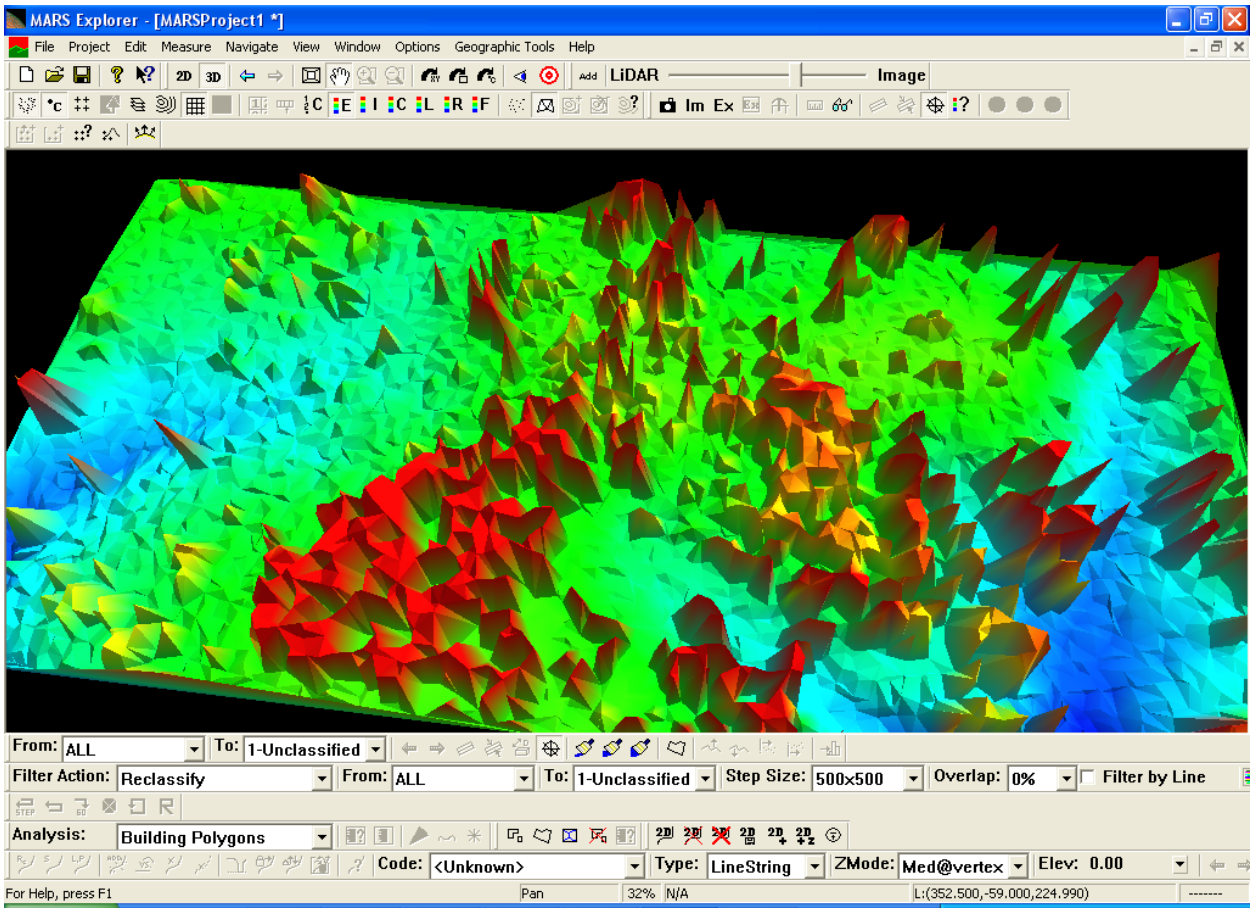


Figure 20. Top of canopy Digital Terrain Model for the North Carolina Sandhills from statewide, large footprint, lower sampling density LIDAR data provided by the North Carolina Floodplain Mapping Program (3-D perspective).

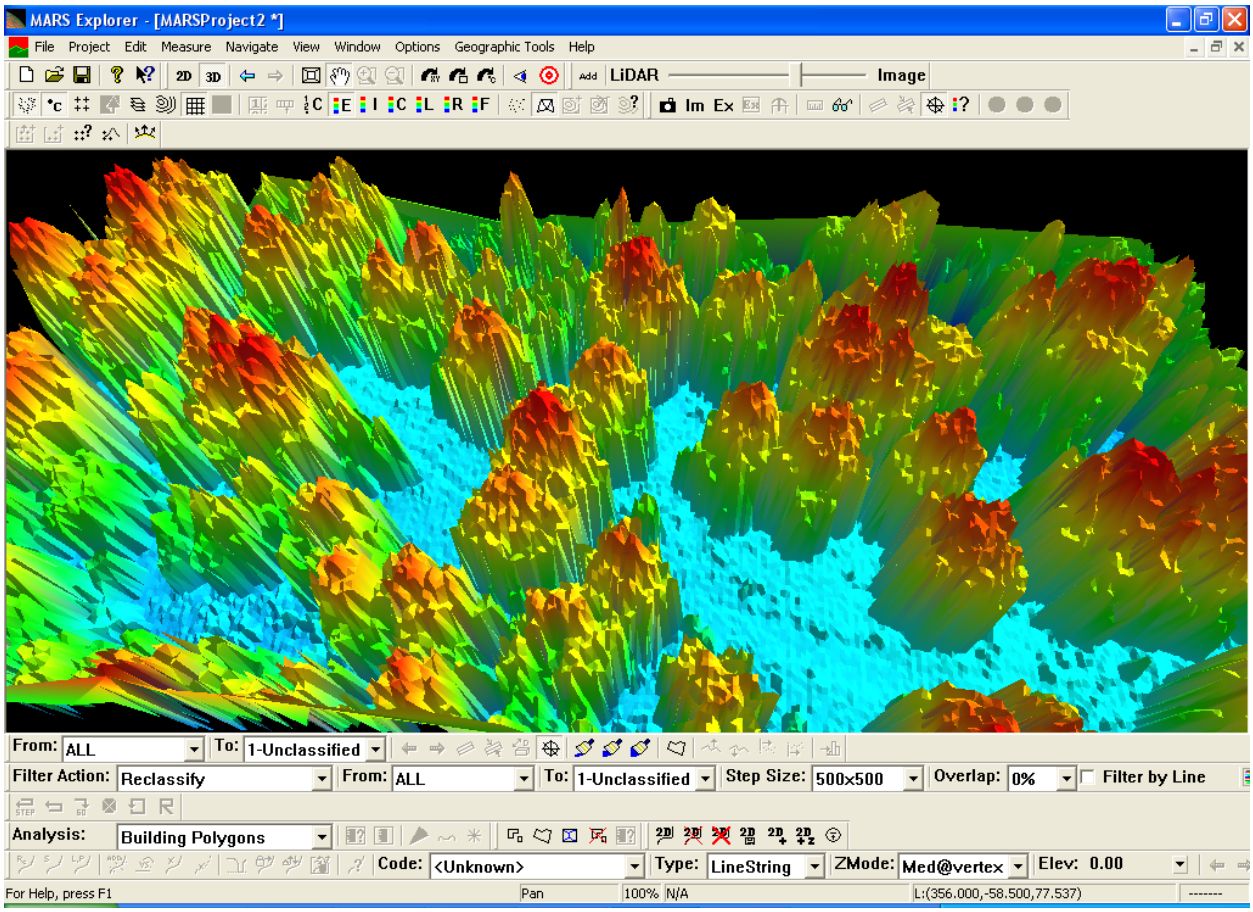


Figure 21. Top of canopy Digital Terrain Model for the North Carolina Sandhills from small footprint, higher sampling density LIDAR data provided by ERDC-CERL and used in the case study (3-D perspective).

Regional assessment of RCW habitat potential

A generalized, landscape-scale RCW habitat classification scheme was developed and applied to regions surrounding Fort Bragg and MCBCL. The habitat classification identified pine forest. For areas identified as pine forest, mean predominant canopy height for individual pine stands was estimated from LIDAR data to predict stand age using established height/age relationships.

Study area

Regional study areas were delineated around Fort Bragg and MCBCL by establishing a 5 km buffer around each installation to include all known locations of active RCW cavity trees. The resulting study area for Fort Bragg was approximately 5484 km^2, and the MCBCL study area was approximately 8,404 km^2 (Figure 22).

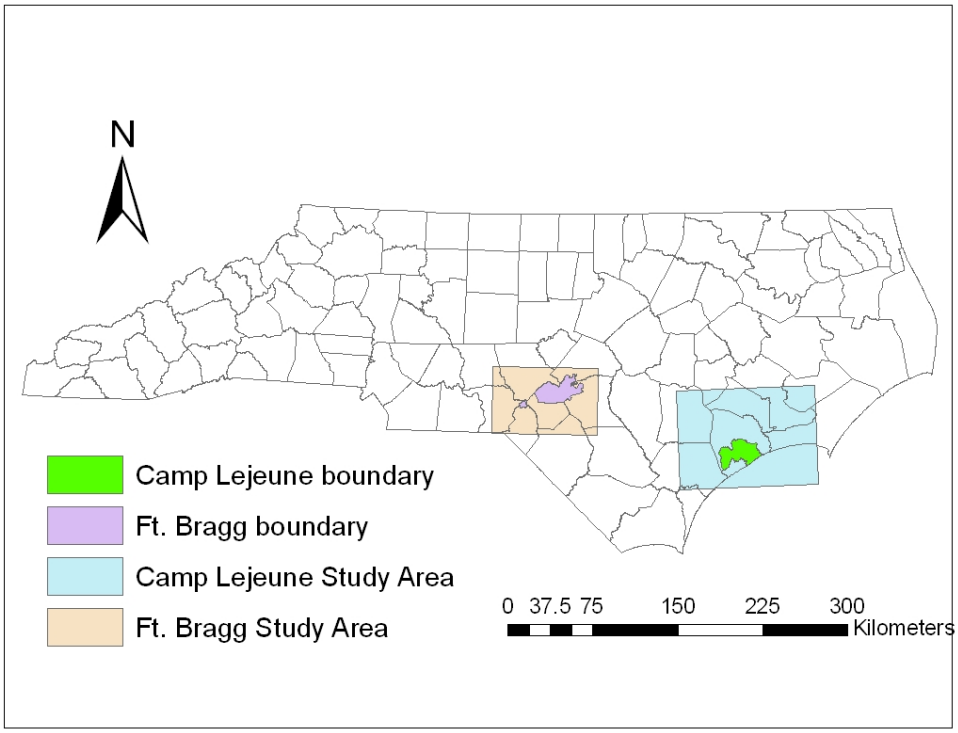


Figure 22. Fort Bragg and Marine Corps Base Camp Lejeune study areas.

Pine forest delineation

National Land Cover Data (NLCD) (2001) (www.epa.gov/mrlc/nlcd-2001.html) and Gap Analysis Program (GAP) land cover data for North Carolina (McKerrow, Wentworth, and Cheshire, in prep), which is a derivative product of the NLCD, were extracted for both study regions and the extent of pine forest was delineated. The GAP land cover data are similar to the NLCD data, but have been altered to reflect local conditions and incorporate local knowledge with respect to land cover conditions. Comparison between NLCD and GAP land cover products indicated that GAP land cover provided a more detailed breakout of pine forest types, and therefore it was selected for analysis.

All pine forest types were extracted from the GAP land cover map for both study areas and individual forest patches less than 0.5 ha were eliminated from the analysis. After removal of forest patches less than 0.5 ha, 62,038 individual forest patches were identified in the Fort Bragg study area (Figure 23) and 38,010 individual forest patches were identified in the MCBCL study area (Figure 24). In the latter case, the base itself (blue area in Figure 24) was not included in the GAP analysis.

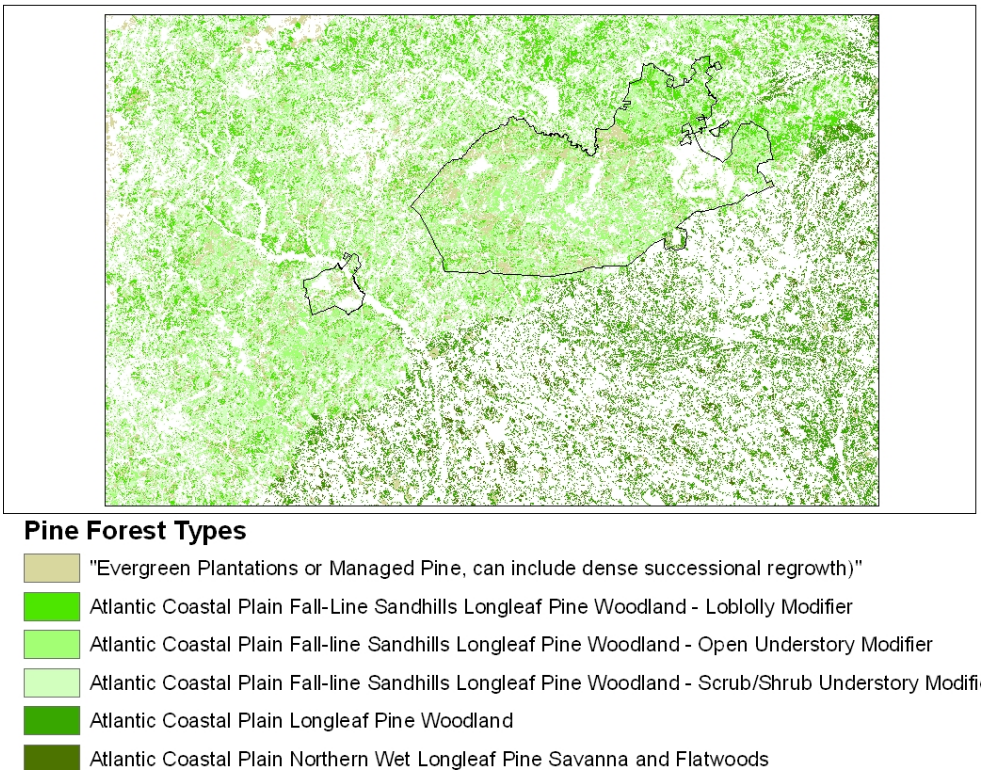


Figure 23. Individual pine forest patches extracted from GAP land cover for Fort Bragg study area.

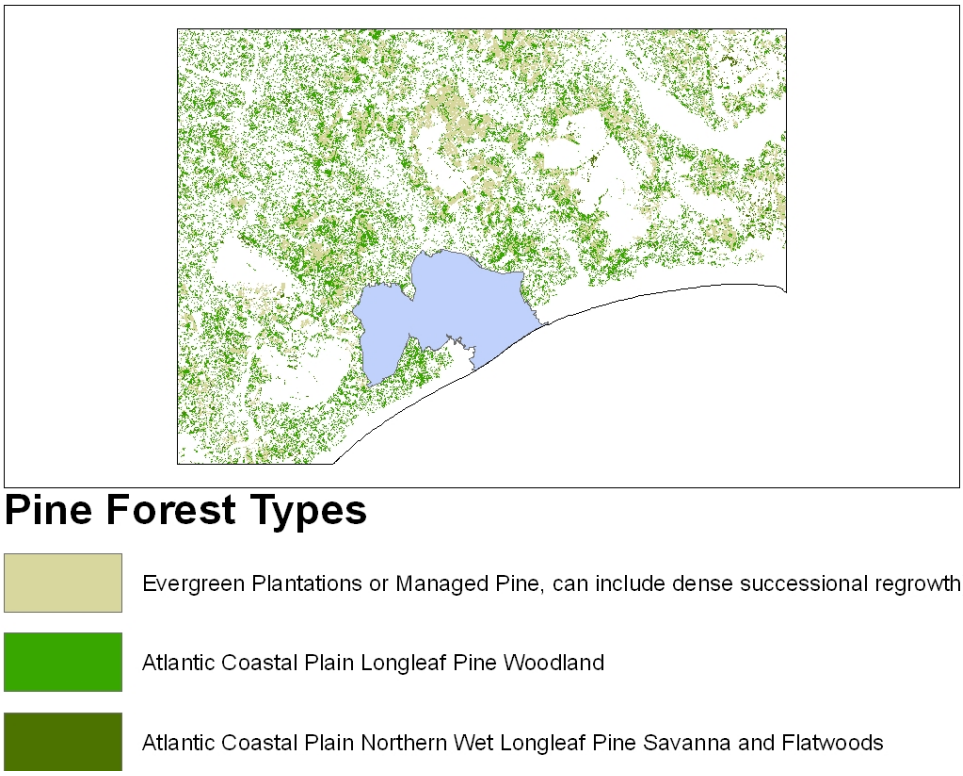


Figure 24. Individual pine forest patches extracted from GAP land cover for MCBCL study area.

LIDAR data

The North Carolina Floodplain Mapping Program (NCDMP) (www.ncfloodmaps.com), which is a partnership and cooperative program with the State of North Carolina and the Federal Emergency Management Agency, was developed to produce updated, accurate, statewide flood hazard data, floodplain mapping, and Digital Flood Insurance Rate Maps. As part of this multi-year effort, statewide coverage of high resolution (6.1 m resolution) and accurate Digital Elevation Models (DEMs) of bare earth terrain have been created from LIDAR data collected in 2001. LIDAR data collection was divided into three phases, with Phase I defined by six eastern river basins, Phase II defined by five central river basins, and Phase III defined by six western river basins. LIDAR data were collected with a nominal point spacing of 5 m.

The primary objective of the LIDAR data collection was to utilize the data to derive high resolution and accurate DEMs of bare earth terrain. Several private LIDAR vendors were contracted to acquire LIDAR data and to post-process the data to identify and differentiate between individual LIDAR returns or pulses that intercepted the ground versus pulses that intercepted features above ground, including natural vegetation and man-made structures. This was an automated process, but automated procedures still result in misclassification of some returns. Therefore, significant manual editing was required by private LIDAR vendors to accurately identify all LIDAR ground returns. Using all LIDAR ground returns as input, surfacing algorithms were used to create a bare earth surface. Statewide coverage of bare earth DEMs have been produced from LIDAR data and are available for download from the NCFMP. The individual LIDAR ground returns used to produce the DEMs are also available.

In addition to these products, all LIDAR returns, including both ground and non-ground, are also available statewide. The all return LIDAR data have not been utilized to produce a Digital Terrain Model (DTM) of the top of canopy surface because this was not a primary objective of the NCFMP. Therefore, a DTM of the top of canopy surface was created in this research.

Bare earth DEMs were stored and made available in tiles of 10,000 X 10,000 feet. There are 649 full or partial bare earth tiles within the Fort Bragg study area and 976 full or partial bare earth tiles within the MCBCL study area. Originally, bare earth DEM tiles were acquired in an American Standard Code for Information Exchange (ASCII) format and were imported to an ESRI grid format. For many of the tiles, multiple versions of the same tile were available. Manual inspection of these tiles was necessary because only one of the versions was the complete and correct version, and it was not possible to determine which version was the correct version from the tile naming scheme.

All return LIDAR data were stored in a variety of spatial configurations, depending on which data collection phase and which LIDAR vendor was used to acquire and process the data. The Fort Bragg study area is located primarily in the Phase I collection area, but the western edge of the study area extends into the Phase II collection area. For the area of Fort Bragg that is located in Phase I, there were 240 tiles of all return LIDAR data. Each tile is 25 km^2. Phase II all return LIDAR data were stored in individual flight lines rather than tiles (Figure 25). Flight lines varied in size and orientation.

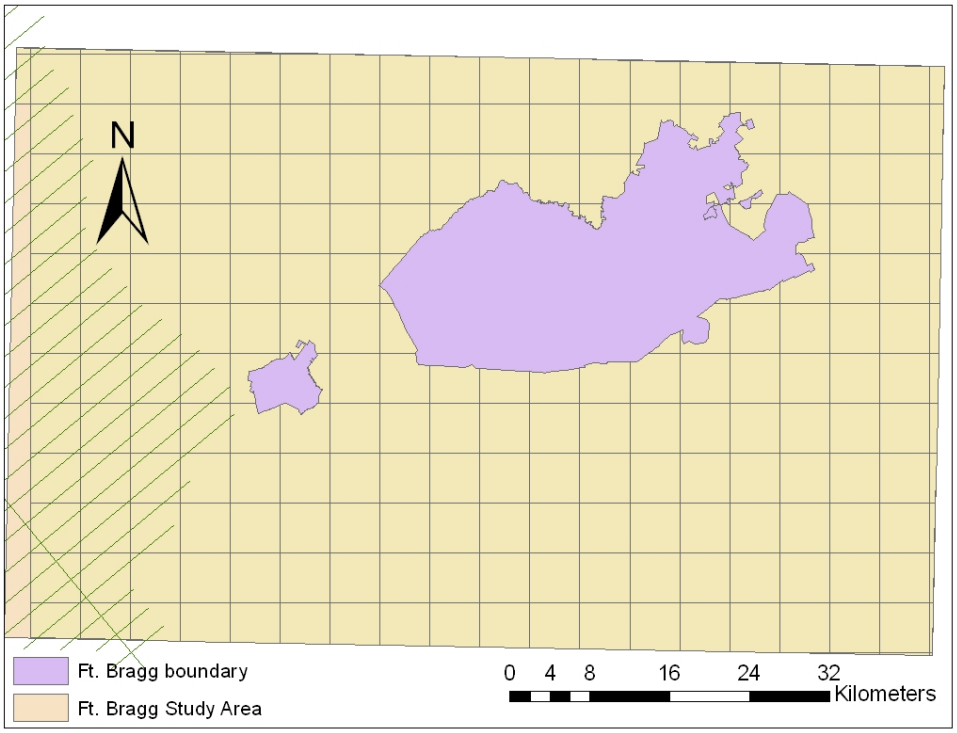


Figure 25. Individual tiles and flight lines containing all return LIDAR data for the Fort Bragg study area.

The MCBCL study area is located within the Phase I collection area. Some Phase I all return LIDAR data were stored and provided in individual tiles, while some data were stored in flight lines of varying size and orientation. Within the MCBCL study area, there were 167 all return LIDAR tiles and 74 individual all return LIDAR flight lines (Figure 26).

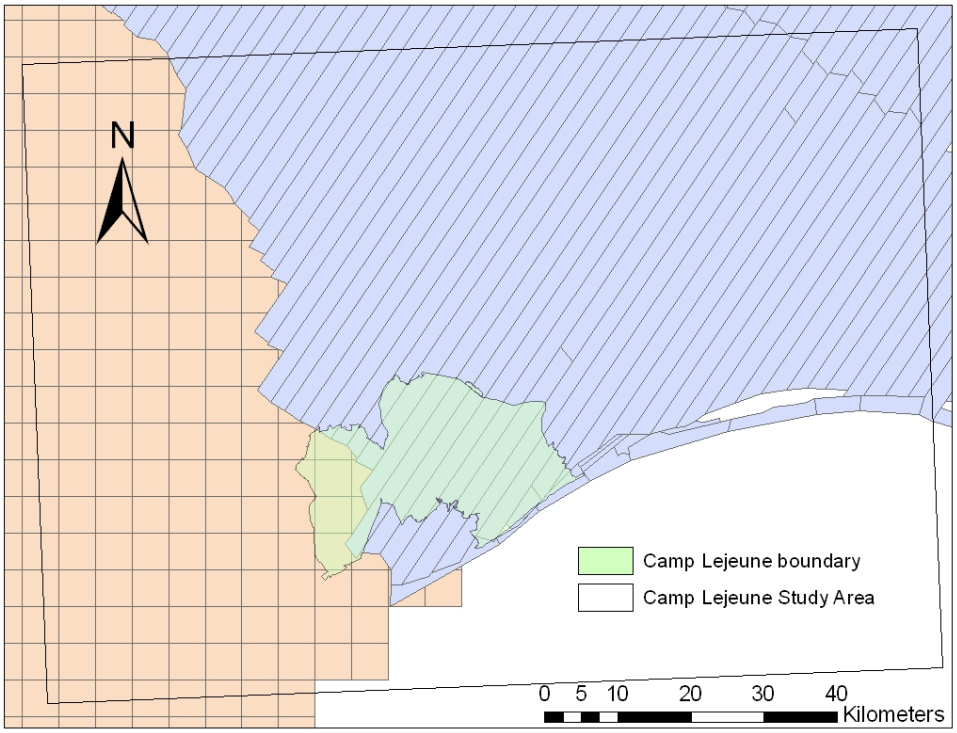


Figure 26. Individual tiles and flight lines containing all return LIDAR data for the Marine Corps Base Camp Lejeune study area.

The primary projection for the statewide NCFMP LIDAR data was North Carolina State Plane Feet. However, for both study areas, some tiles and flight lines used North Carolina State Plane Meters. Therefore, each tile was manually inspected to determine projection and units and all data were ultimately projected to a Universal Transverse Mercator (UTM) projection, NAD83 datum.

Forest height estimation

We estimated canopy height estimates for individual pine forest patches that provide potentially suitable RCW habitat from statewide LIDAR data collected by the NCFMP. Two methods for estimating predominant canopy height from available LIDAR data were evaluated and tested using a test area within Fort Bragg where Fort Bragg forest inventory data were available. The first method utilized a DTM of top of canopy surface which was created from the all return LIDAR data and a matching DEM of bare earth surface that was provided by the NCFMP. The difference in elevation between these two surfaces was used to estimate predominant canopy height. Specifically, bare earth elevations from DEMs were subtracted from elevations of the top of canopy surface DTM. Top of canopy DTMs were created from the all return LIDAR data using surfacing algorithms. The top of canopy DTMs were created at a spatial resolution of 20 feet or 6.1 m to match the spatial resolution of bare earth Deems provided by the NCFMP.

The all return LIDAR tiles and flight lines used to create the top of canopy DTMs were large datasets that contained a record for each individual recorded LIDAR pulse. Standard GIS

software such as ESRI geospatial products is not optimized to analyze extremely large LIDAR datasets. Therefore, specialized software developed to process and analyze LIDAR data efficiently was utilized to create top of canopy DTMs. Both QTModeler from Applied Imagery LLC and Merrick Advanced Remote Sensing (MARS) LIDAR Software System, developed by Merrick & Co. were evaluated for this purpose. Each has similar surfacing algorithms and provides a method to export surfaces to ESRI GRID format. MARS software was selected for final analysis.

Once each tile was surfaced, they were mosaiced to create a single top of canopy DTM for the test study area. Using raster map calculator utilities, the bare earth DEM was subtracted from the top of canopy DTM for the study area to produce a canopy height above ground surface. All canopy heights < 2.0 m above ground were masked from this surface to eliminate low shrub and small saplings. Similar to previous studies, a local maximum filtering algorithm was applied to identify local maximums in the canopy height surface which were presumed to be individual stem locations (McCombs et al. 2003, Popescu and Wynne 2004). In previous studies, small footprint LIDAR data were used to create canopy surfaces, and therefore there was a higher probability that local maximums were representative of individual stem locations. With large footprint LIDAR data such as the data analyzed in this research, it was known that it would be difficult to discern individual stems from local maximums in the canopy height above ground surface. However, a local maximum filter was still applied to eliminate pixels in the canopy height surface that were most likely on the canopy shoulders rather than on crown peaks. For each forest patch identified in the NLCD/GAP land cover classification that was > 0.5 ha in size, mean predominant canopy height was determined by calculating the mean canopy height above ground surface for all canopy height pixels identified as local maximums within the forest patch.

A second method utilized only the original, all return LIDAR data collected by the NCFMP. These data included individual returns that were identified as ground returns and used to create the bare earth DEMs and also individual returns that intercepted above ground vegetation. Instead of creating a separate canopy and bare earth surface, a program in Geographical Resources Analysis Support System was used to overlay an arbitrary 15 m grid over the all return data. For each grid cell, the minimum and maximum individual return heights were subtracted to estimate predominant canopy height. This method eliminated the need to create separate surfaces of bare earth and canopy. Similar methods have been used to estimate forest height at plot and stand scales using higher sampling density LIDAR data for smaller study areas, but such an approach has not been applied to coarser LIDAR data across a study region comparable in size to the study area in this research (Nelson et al. 1988, Naesset 1997a, Naesset 1997b, Magnussen and Boudewyn 1998, Naesset and Bjerknes 2001). A predominant canopy height surface was created for each individual tile or flight line of LIDAR data for both study areas. Each tile and flight line was visually inspected to assess the quality of the LIDAR data and those tiles containing erroneous data were removed from analysis. All remaining individual tiles and flight lines were then mosaiced to create a single canopy height surface for each study area (Figure 27 and Figure 28). Larger gaps in the canopy height surface represent areas of erroneous LIDAR data or large water bodies that do not produce a LIDAR return. Several tiles internal to Fort Bragg were intentionally omitted to reduce data processing time as RCW habitat potential in these areas has already been characterized with field data. However, some tiles within Fort Bragg were processed for validation purposes. Similar to method 1, all canopy heights < 2.0 m above

ground were masked to eliminate low shrub and small saplings. For each forest patch identified in the NLCD/GAP land cover classification that was > 0.5 ha in size, mean predominant canopy height was determined by calculating the mean canopy height above ground surface for all canopy height pixels within the forest patch.

Figure 27. Canopy height DTM for all canopy height pixels > 2.0 m for the Fort Bragg study area.

Figure 28. Canopy height DTM for all canopy height pixels > 2.0 m for the Marine Corps Base Camp Lejeune study area.

Forest height validation

Forest inventory and stand data collected at Fort Bragg in 2001 and 2002 were used to validate estimates of predominant canopy height derived from LIDAR analysis. Mean height for each forest stand within Fort Bragg was calculated using data from the individual stem inventory. However, for many of the stands, individual stem heights were only measured for one or two stems. Therefore, these data were not ideal for validating estimates of predominant canopy height as they did not provide an accurate measurement of predominant canopy height due to the extremely small sample size. It would have been desirable to utilize accepted field measurement protocols for measuring dominant stand height (Naesset 1997a, Naesset and Bjerknes 2001, Naesset 2002). However, the forest inventory data were the only archival field data collected at approximately the same time as the LIDAR data. Hence they were used as the validation data set.

A preliminary assessment of both methods with a limited number of forest stands indicated that both methods provided reasonable estimates of predominant stem height. The first method, which requires significantly more data processing because of the need to create two separate surfaces (bare earth DEM and top of canopy DTM), tended to underestimate heights, while the second method appeared to produce more accurate results. Given the fact that method 2 produced comparable preliminary results and that it was a more efficient method for estimating predominant height that required less data processing, it was adopted as the method for estimating predominant canopy height for stands across the study area.

Standard linear regression of field measured mean height for several stems within stands with LIDAR-derived estimates of predominant canopy height resulted in a coefficient of

determination (R^2) = 0.70 (Figure 29). There was a slight bias that resulted in an underestimation of mean predominant canopy height derived from LIDAR data.

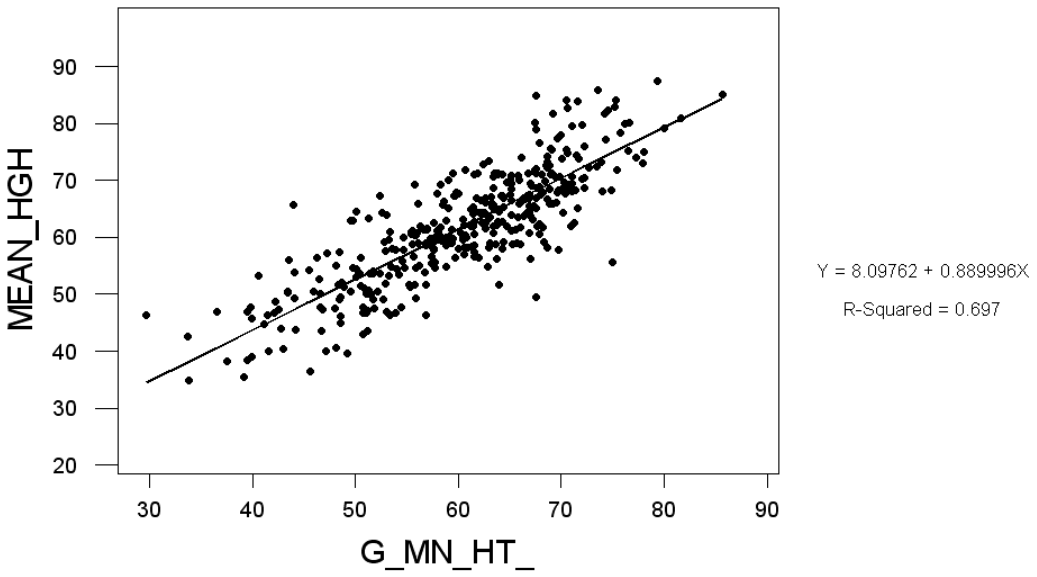


Figure 29. Best fit regression line between LIDAR-derived estimates of predominant canopy height (G_MN_HT) and field measures of mean canopy height (MEAN_HGH).

Relating height estimated from LIDAR to stand age

We assessed the value of using the processed LIDAR data to estimate pine stand age using 800 individual stands at Fort Bragg where both stand age (collected on-the-ground) and height data (estimated from LIDAR) were available. The purpose of this work was to assess whether we could use the LIDAR data to inform estimates of stand age in areas where only cover type was available (i.e., the landscape beyond Fort Bragg and MCBCL proper). To minimize sources of variation in the initial stages of this research, we used only longleaf pine stands in the western part of Fort Bragg. Even within the focus area, the relationship between stand height and stand age was poor, r^2=0.22 (Figure 30). For this reason, we discontinued this line of research and used alternate methods to estimate age in areas where pine age was unknown.

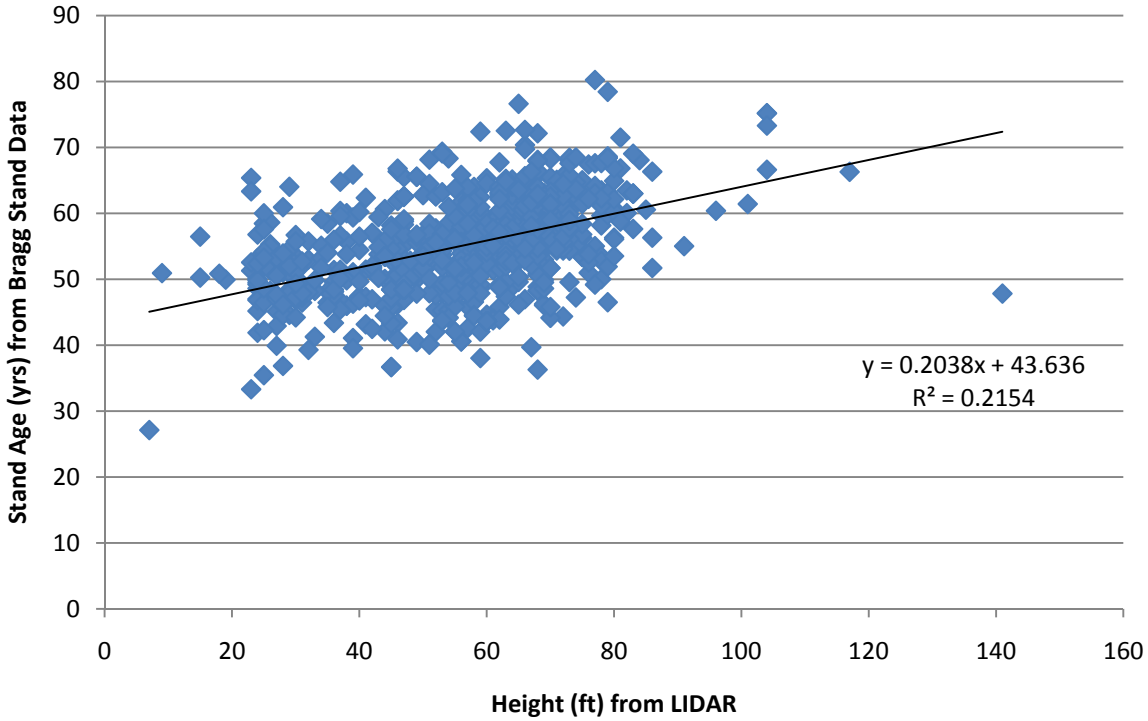


Figure 30. Relationship between longleaf pine stand age and stand height estimated from LIDAR for 800 stands at Fort Bragg, NC.

Discussion of the Utility of LIDAR

LIDAR-derived estimates of predominant stand height were acceptable given the unique limitations associated with the scale of the data analyzed and the extent of the area studied. The LIDAR data acquired from the NCFMP were collected with a larger footprint and lower sampling density, which precludes the ability to identify individual stems. Therefore, the LIDAR data were actually estimating the predominant canopy height surface rather than deriving estimates from the mean height of individual stems. A canopy height surface characterizes the entire canopy profile, including the shoulders of canopies and canopy overlap areas and not just the crown apexes (Nelson et al. 1988, Vega and St. Onge 2008). Although local maximum filters were utilized to eliminate canopy height surface pixels that did not represent stem peaks in method 1, still the larger footprint and lower sampling density LIDAR data were not sufficient to delineate individual crown peaks. Method 2 located the maximum return height within a 15 m cell, and therefore was also functioning as a pseudo local maximum filter, with the assumption that the highest return in each 15 m cell should represent a crown apex or individual stem. Again, because of the LIDAR sampling density, many of these returns were most likely not intercepting the top of stems, but rather somewhere on the side or shoulder of the canopy. Therefore, the lower sampling density resulted in a bias towards underestimating canopy heights using both methods. Even with smaller footprint, higher sampling density LIDAR data, LIDAR-derived estimates of canopy height typically underestimate heights due to the fact that some local maximums in canopy height DTMs or individual LIDAR return height are assumed to be crown apexes when in fact they are often the sides of canopies (Nilsson 1996, Magnussen et al. 1999,

Naesset 2002, Gaveau and Hill 2003). This known bias was likely magnified by the larger footprint, lower sampling density LIDAR data analyzed in this study. Errors associated with bare earth DEMs derived from LIDAR data also can result in an underestimation of canopy height (Reutebuch et al. 2003).

A second limitation was the lack of suitable ground validation data. The limited sample size of field measured individual stem heights was not suitable for calculating an arithmetic mean stem height, or mean dominant or predominant height for each stand.

Despite these concerns, the method utilized to estimate predominant height across large geographic areas with coarse resolution LIDAR data produced useful results for assessing general canopy configuration across the region. The total size of the study area necessitated the use of large footprint, statewide-scale LIDAR data. An assessment of such a large area with small footprint, higher sampling density LIDAR data has never been accomplished because it would be too cost prohibitive in terms of data acquisition and data processing requirements. The method used in this research was more efficient because estimates could be derived directly from the all return data and did not require the development of a top of canopy DTM surface over such a large area, which greatly reduced data processing requirements. Although the method used would require some modification if it were applied in areas of significant topographic relief, it does present a feasible method that produces reasonable estimates of forest stand height from small scale LIDAR data over large geographic areas.

Although we found that LIDAR data could be used to estimate canopy heights, we conclude that this capability cannot be used to characterize habitat suitability for RCWs within the DSS, at least not for our study areas. It could of course be used to distinguish pine and hardwood habitats, but does not provide an accurate estimate of stand age. We were specifically interested in using LIDAR data to assign ages to stands because that is the critical attribute in one of the two landscape options in the DSS, the land cover option, and ages often are unavailable for stands located off base. Our inability to detect a strong relationship between stand age and stand height can likely be attributed to issues of spatial scale. Professional foresters regularly use height growth curve models to estimate age of individual trees. Within a specific soil type, even single variable (height) models of longleaf pine have explained as much as 85% of the variation in age (Boyer 1980). In this analysis, however, we had access only to stand age, not individual tree age. It is very likely that the difference in scale explains why we were unable to use LIDAR data to accurately predict stand age.

Results and Discussion, Part 1: Description of the DSS

Basic Description

The DSS runs as a tool within ArcMap. It was designed to be useful to land and resource managers tasked with managing and restoring RCW populations. Its interface guides the user through a step-by-step process using landscape and population information to simulate the response of RCW populations to management and landscape change. With this system, users are able to assess the effects of landscape fragmentation, habitat loss, habitat restoration, recruitment cluster construction and ‘no management action' on current and future RCW populations. In addition, the DSS is specifically designed to enable evaluations of the importance of individual habitat parcels to an RCW population and to track dispersal of populations between user-defined groups.

The toolbar is available only through ArcMap and is installed with a setup program. The toolbar provides access to three tools, the DSS Wizard interface, the Scenario Manager interface, and the Recruitment Clusters Interface (Figure 31).

Figure 31. RCW DSS Toolbar.

The DSS as a User-Friendly Tool

The DSS was designed to guide managers and biologists through the process of developing a management scenario that will accurately reflect the population dynamics of RCWs through time. At every step of the scenario building and results review processes, there is access to a fully developed help file that is searchable and indexed (Figure 32). The help file is accessed from any tool within the DSS. It is also included as a Word® document with the install program and is attached as Appendix A.

The DSS was created to work within ArcMap so that the user can use ancillary spatial and non-spatial data to help guide decisions throughout the entire modeling lifecycle. For example, a user can incorporate a layer depicting future development of forested areas to determine where to place recruitment clusters, even though this layer would not directly be used in the model.

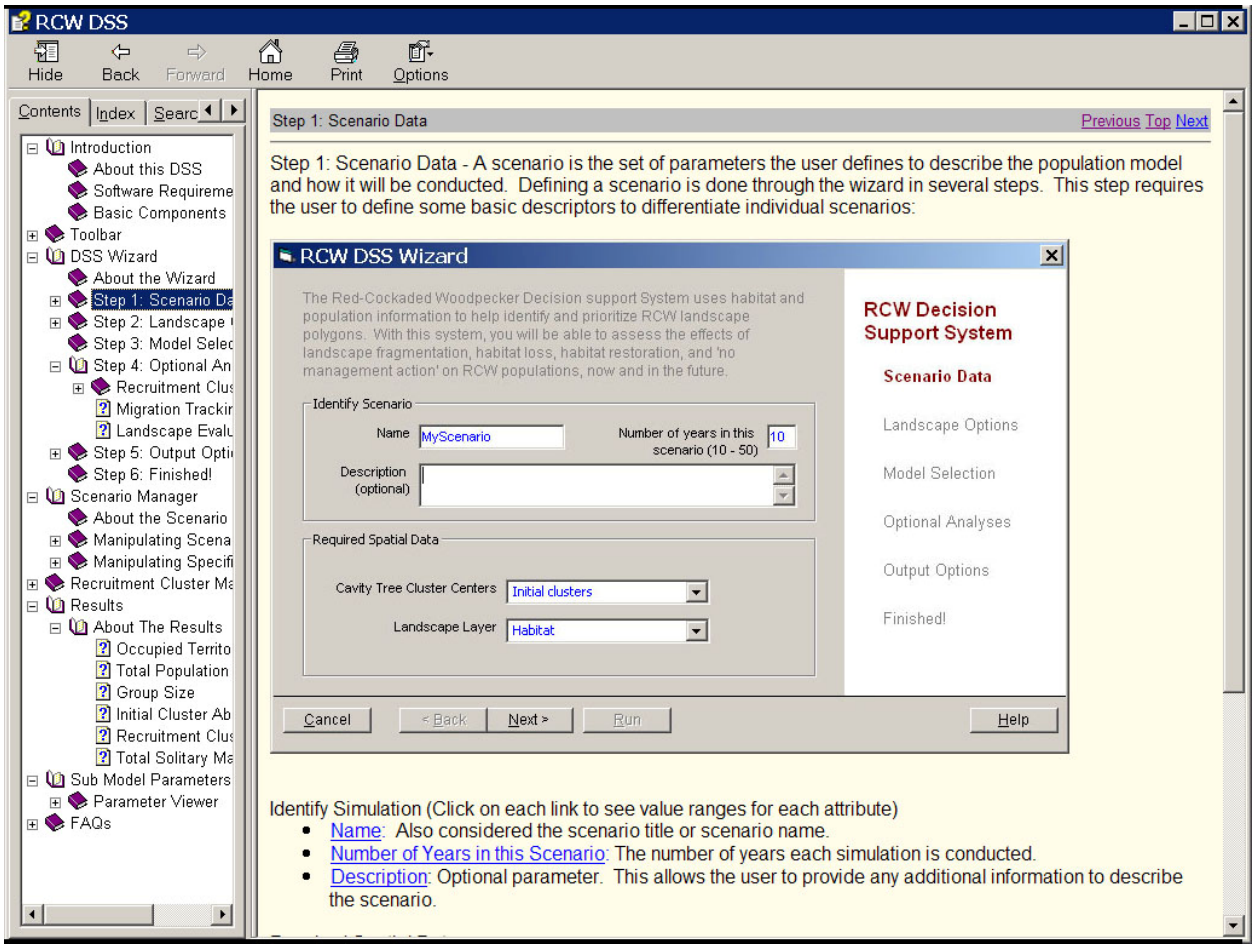


Figure 32. Help File

Wizard

The Wizard is the main entry point for the DSS and breaks down the scenario building process into six steps:

Step 1 - Define basic DSS parameters (Figure 33).

A scenario is the set of parameters the user identifies to describe the population model. This step requires the user to define some basic descriptors to differentiate individual scenarios:

- Name – a unique scenario identifier;
- Years – the number of years a simulation will run (10-50);
- Description – an optional parameter provided to the user to help the user differentiate between scenarios;
- Required Spatial Data – the name of the point Shapefile representing territory cluster centers and of the polygon Shapefile representing the landscape.

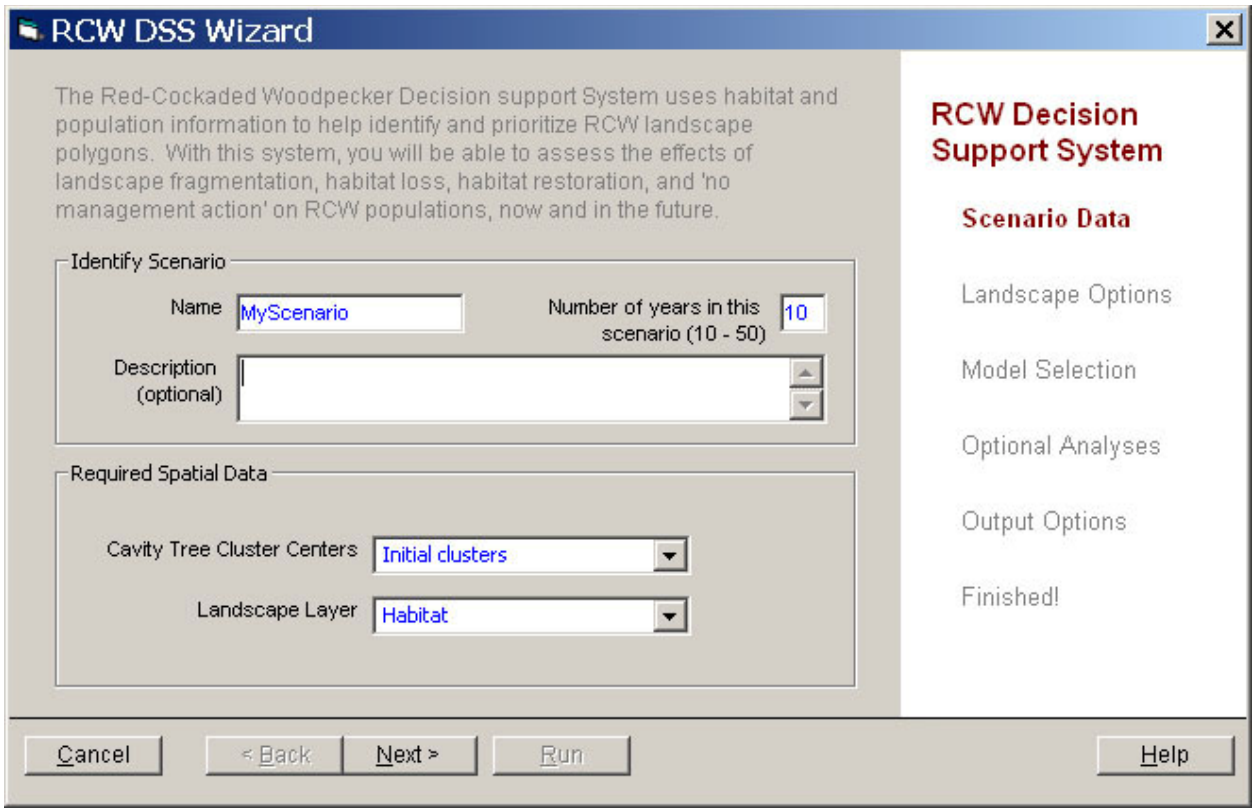


Figure 33. Step 1 in the scenario building process.

Step 2 -Define Landscape Parameters (Figure 34)

There are two landscape options.

a) Constrain by minimum stand score (optional) - Users can use the habitat quality index field to influence how the model handles habitat quality. To use this feature, each stand should be attributed with a value between 1 and 5 that represents a relative index of habitat quality. The USFWS RCW Matrix Application provides this capability if detailed stand metrics are available. The user then chooses a threshold value that represents the minimum score for which a stand is considered suitable for nesting and foraging. Stands with values less than this threshold are classified as unsuitable, regardless of age and cover type. The second landscape option, land cover, is the default option.
b) Minimum required habitat – New territories must have sufficient unallocated foraging and nesting habitat for budding to occur or recruitment clusters to be successful. This option determines the minimum value. The possible values are 120, 150, and 200 acres.

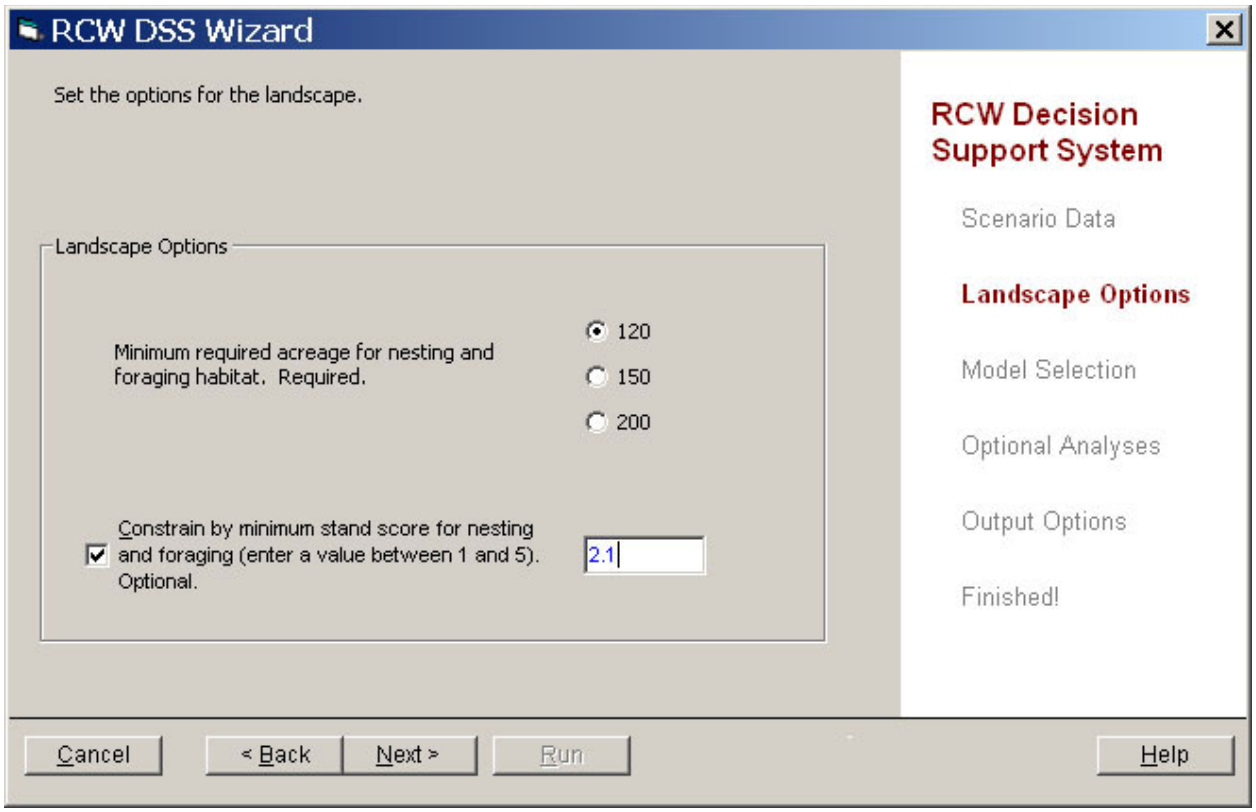


Figure 34. Step 2 in the scenario building process.

Step 3 - Choose appropriate models to define the initial population (Figure 35)

There are two demographic models used within the DSS, Sandhills and Coastal. Sandhills is based on the demography of the RCW population in the Sandhills region of south-central North Carolina and Coastal on the demography of the RCW population on Marine Corps Base Camp Lejeune in coastal North Carolina. Sandhills has higher reproductive rates and lower survival rates than Coastal. Generally, Sandhills will be the appropriate choice for modeling more northern and inland populations, and Coastal for more southern and coastal populations.

Although the user cannot change the underlying demography within the DSS, the user is able to choose the structure of the initial population. If the user wants to choose a predefined initial population, then they simply pick the population from the drop-down box by choosing a Mean Group Size value. This value determines the proportion of territories occupied by unpaired males, unassisted breeding pairs, and breeding pairs assisted by helpers. All initially occupied territories are assigned at least a male.

A custom population file can also be chosen. With this option the user specifies for every territory whether it contains a breeding female and how many helpers it contains. If the user is using a custom initial population file, they are still required to define the associated demographic model, either Sandhills or Coastal.

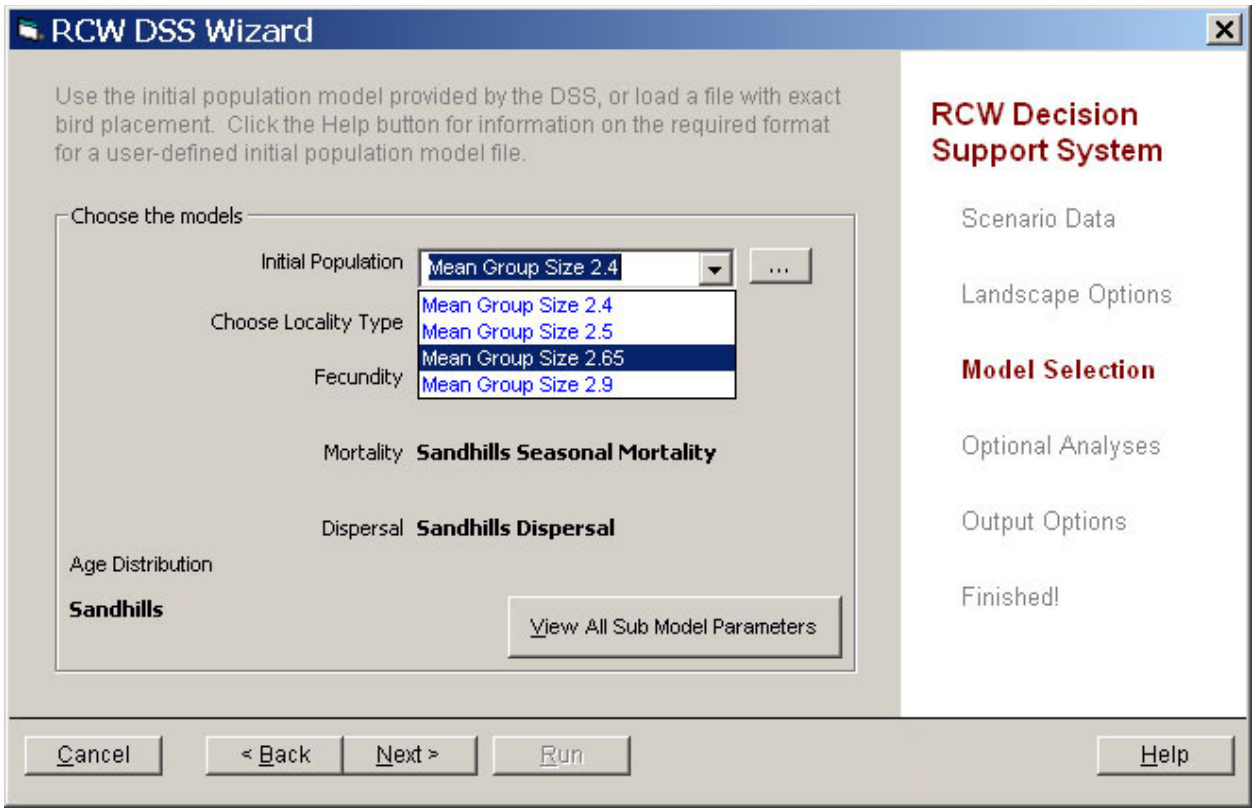


Figure 35. Step 3 in the scenario building process.

Step 4 - Conduct optional analyses (Figure 36)

Users may choose two optional assessments: the effects of adding artificial recruitment clusters and effects of removing habitat (also called Landscape Evaluation) from the landscape.

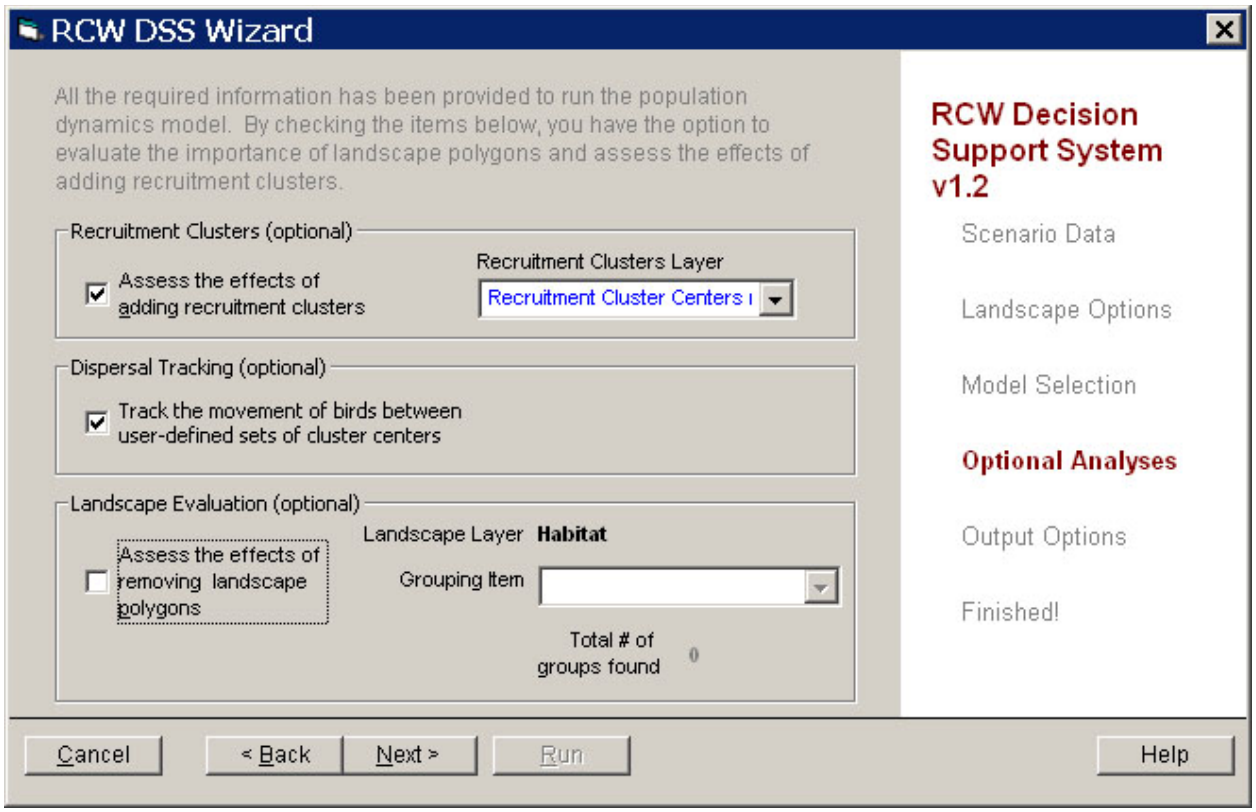


Figure 36. Step 4 in the scenario building process.

Step 5 - Set output options (Figure 37)

This step allows the user to select the location of the output folder and to indicate which data should be automatically added to the Map. Spatial data produced by the model are stored regardless of the output options to add to the Map.

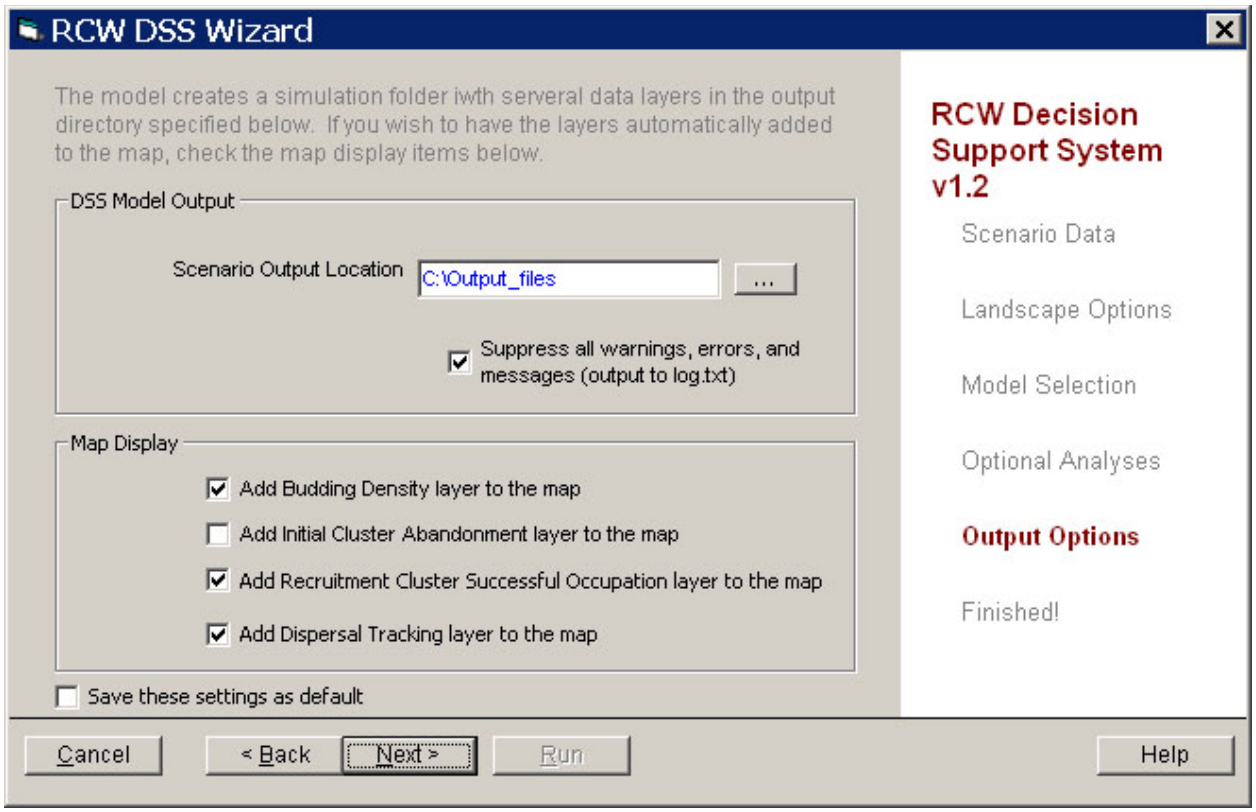


Figure 37. Step 5 in the scenario building process.

Step 6 -Compile and run (Figure 38)

This final step validates schema prior to initiation of the model run and reports identified errors to the user.

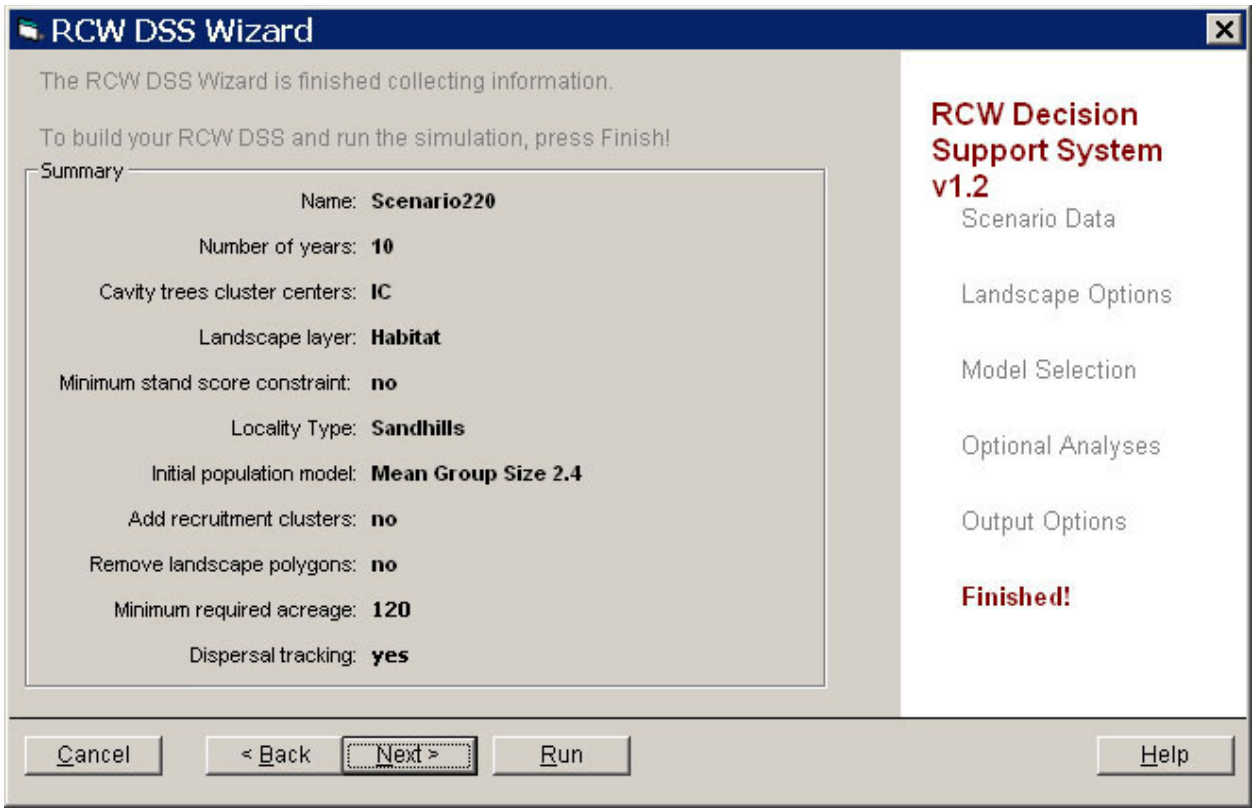


Figure 38. Final step in the scenario building process.

Scenario Manager

The Scenario Manager (Figure 7) allows the user to view, compare or delete existing scenarios, use existing scenarios as a template for new scenarios, and display the results from conducted analyses in an organized manner. When the Scenario Manager is initially loaded, it defaults to the Scenario Statistics tab unless it is loading multiple scenarios, then it defaults to the Compare Results tab. Drop-down boxes provided within the Scenario Manager allow the user to toggle between different scenarios loaded into the Scenario Manager.

Scenario properties

Scenario properties are the parameters defined by the user in the wizard during the scenario building process (Figure 39).

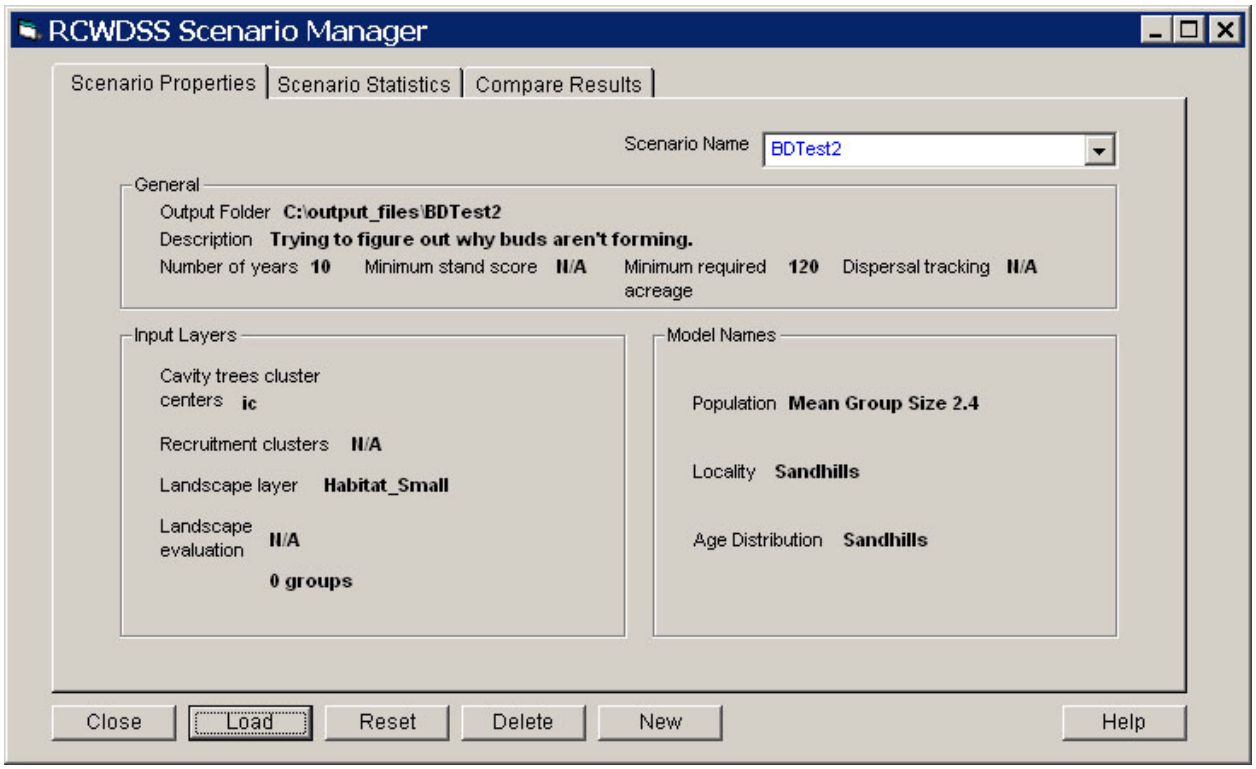


Figure 39. Scenario properties

Scenario statistics

Scenario Statistics are calculated for each scenario and are the basis for analyzing the results of the DSS (Figure 40). There are a variety of statistics calculated by the DSS. Raw data in graphical or tabular form are also available by clicking on the respective "Chart" and "Table" buttons. The raw data are stored as DBF files (or Shapefiles, if appropriate) in the specified scenario output folder. The list of statistics calculated by the DSS is provided below.

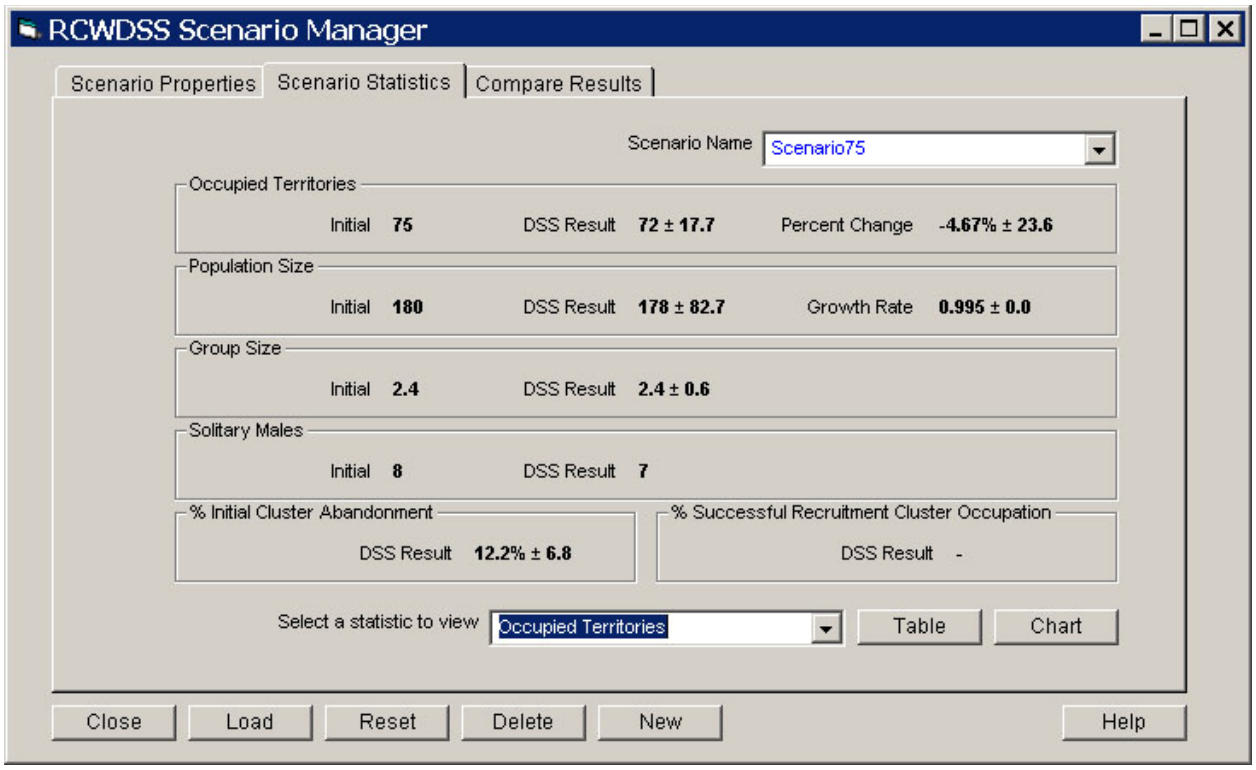


Figure 40. Scenario statistics

Occupied territories

The number of occupied territories is calculated at the end of each year.

Percent change in occupied territories

In addition to the number of occupied territories, the DSS calculates the percentage change in occupied territories relative to the initial territories. This statistic is not calculated year to year, but rather at the end of the entire simulation. The equation for this statistic is:

$$Percent\ Change = \left(\frac{remaining\ occupied - initially\ occupied}{initially\ occupied}\right) * 100$$

Total population

Total population is a count of the number of birds in the simulation in a given year. This statistic is calculated at the end of each year before the breeding season of the next year. Therefore, there are technically no fledglings in this statistic.

Population growth

Population growth is based on the Total Population statistic. It is the modeled geometric growth of the population. The equation used is:

$$Growth\ Rate = \left(\frac{total\ population}{initial\ population}\right)^{\frac{1}{years}}$$

Group size

Group size is the total number of birds in a given group, at a given time. The DSS reports group size as the average group size within the population.

$$Total\ Birds/Total\ Occupied\ Territories$$

This statistic is calculated at the end of a year, before the breeding season of the next year, and therefore includes no fledglings.

Initial cluster abandonment

Initial Cluster Abandonment is reported several ways in separate files: it is reported as a total number of clusters abandoned in a simulation per year and as the number of times a specific cluster is abandoned over the replicate runs of a scenario.

Successful recruitment cluster occupation

If recruitment clusters are created for a scenario, then occupation statistics are calculated. A recruitment cluster is considered successfully occupied if the cluster has at least one successful breeding year. The number of times a specific recruitment cluster is successful is reported in a point Shapefile. If the value in this file is -1, then the recruitment cluster was not added to the model. This occurs when there is insufficient habitat to support a group at the location, an improper location, or the Year Added attribute exceeds the length of the model run.

Total number of solitary males

This is a count of the number of solitary (unpaired) males at the end of a simulation.

Compare results

When multiple scenarios are loaded into the Scenario Manager, their results can be compared in tabular or graphical form. For each scenario the user wants to include in the comparison graph, they check the box next to its name, choose an attribute in the drop down box for the comparison, and click the Chart button (Figure 41).

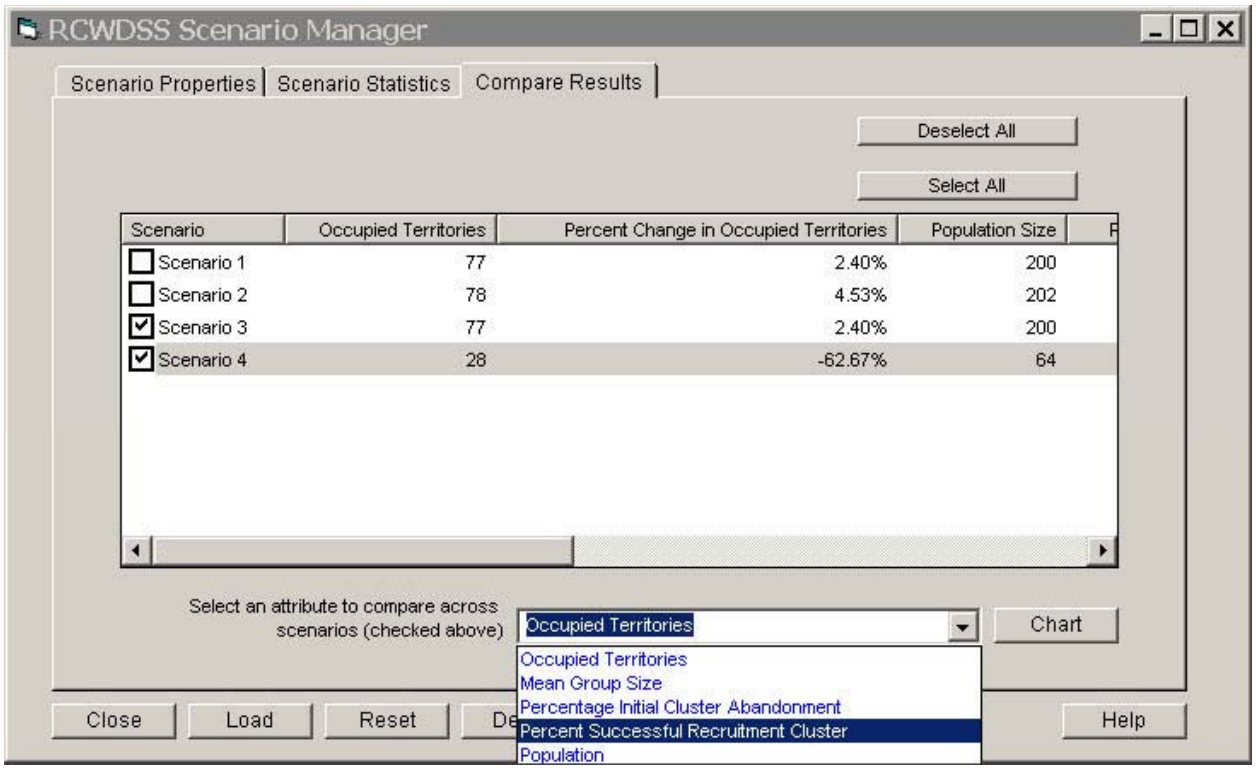


Figure 41. Scenario Manager allows for comparing recruitment cluster success between multiple scenarios.

Recruitment cluster manager

This tool allows the user to add recruitment clusters via mouse clicks within ArcMap and set the year at which they will be added to the model. They are permanently added to the selected Recruitment Cluster Shapefile. This functionality allows the user to assess the effects of recruitment clusters on population parameters.

Parameter viewer

The parameter viewer (Figure 42) allows users to view the internal model parameters. It is accessible from within the Wizard. The parameters can be differentiated into two groups, (a) parameter sets over which the user has no control, DSS Model Parameters; and (b) parameter sets which the user can control, User Model Parameters.

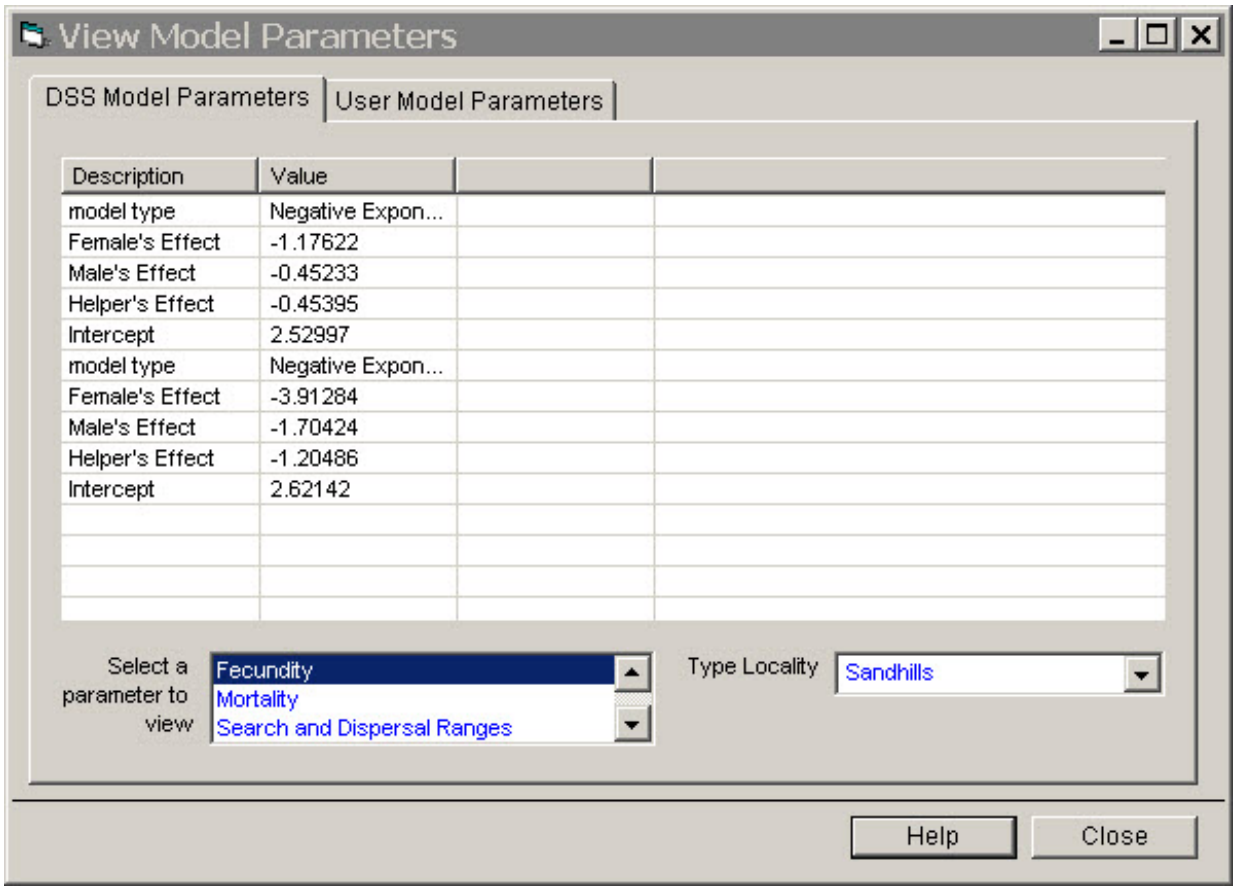


Figure 42. Parameter Viewer allows users to view model parameters.

Results and Discussion, Part 2: Applications of the DSS

Introduction

We used two study areas to test the DSS, (a) the North Carolina Sandhills, consisting of Fort Bragg and surrounding areas, and (b) the Onslow Bight, consisting of Marine Corps Base Camp Lejeune and surrounding areas. We will first describe our initial application of the DSS to these areas, including model verification and model validation exercises, and will then present and discuss results of two more complex modeling exercises we conducted with the DSS, one involving the Onslow Bight and the other Fort Benning in Georgia.

Landscape Processing

North Carolina Sandhills

We created an ESRI Shapefile that described the landscape within 5 km of known RCW groups within the Sandhills region (Figure 43). This landscape measured approximately 93 km by 59 km, and encompassed parts of 9 counties. This landscape file was used for all Sandhills modeling simulations.

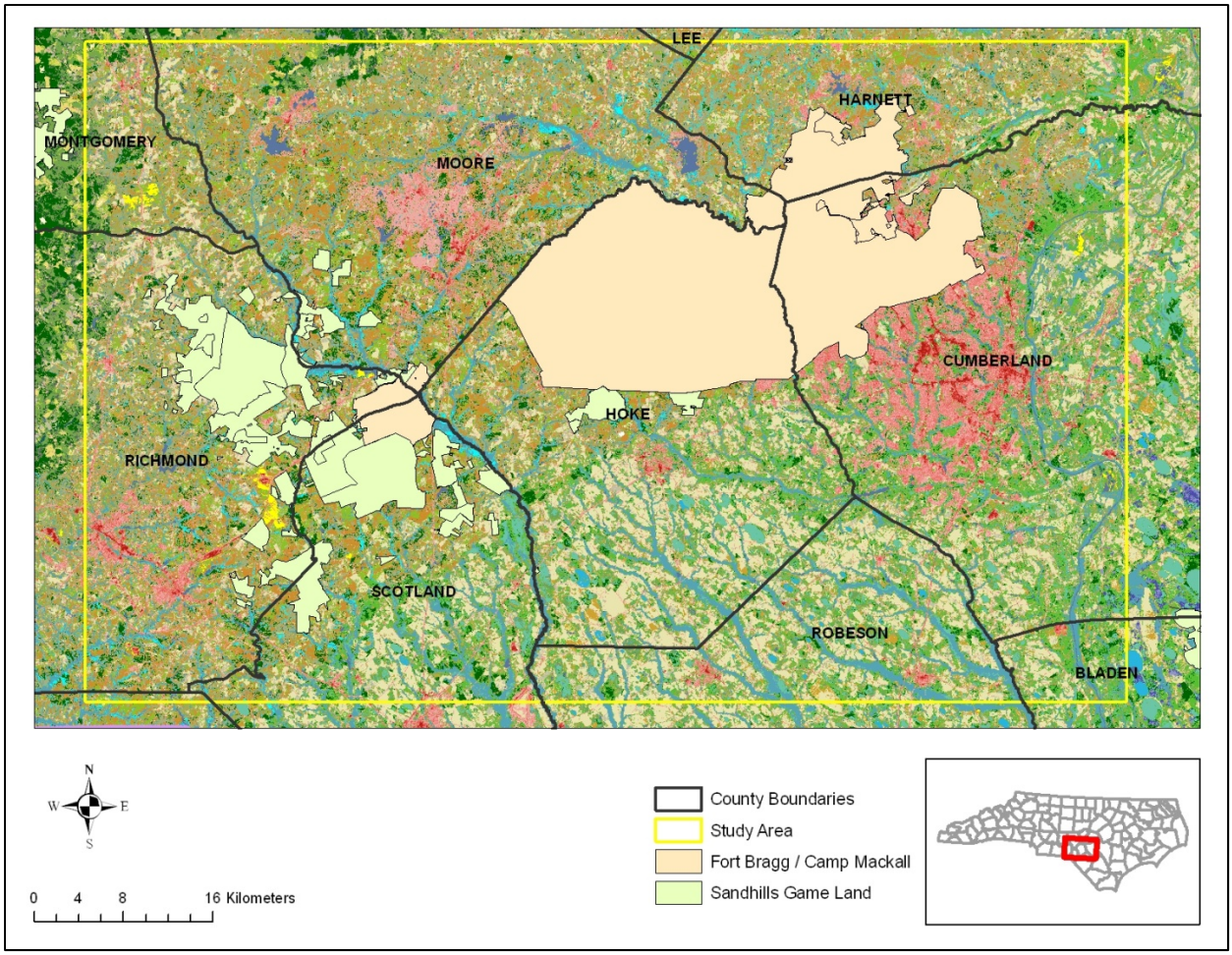


Figure 43. Sandhills region study area and sources of data used to create the land cover layer employed in modeling. Vector format forest stand data were used for Fort Bragg, Camp Mackall, and the Sandhills Game Lands; raster based southeastern GAP land cover dataset was used elsewhere.

We used three sources of data to create the landscape layer: 1) forest stand data from Fort Bragg and Camp Mackall (DOD); 2) forest stand data from the Sandhills Game Lands (North Carolina Wildlife Resources Commission); and 3) the Southeastern GAP land cover dataset (http://www.basic.ncsu.edu/segap/EcoSys.html). Data from Fort Bragg, Camp Mackall and the Sandhills Game Lands were vector based products at the forest stand scale that included attributes such as pine age, site index and cover type (pine, hardwood, water, etc). The Southeastern GAP data was a raster based product at 30 m pixel resolution that described only land cover class, using the ecological systems classification system (Comer et al. 2003).

We converted the raster based Southeastern GAP dataset to polygon format using the ESRI procedure RasterToPolygon, employing the procedures' default parameters. Before performing this operation, the GAP classifications were reclassified to one of the following land cover types: pine, hardwood, open, water, and other. Table 2 presents GAP classes and the corresponding cover type used in this project. We then combined the three vector datasets to create a complete landscape (Figure 44) using the ESRI Update command.

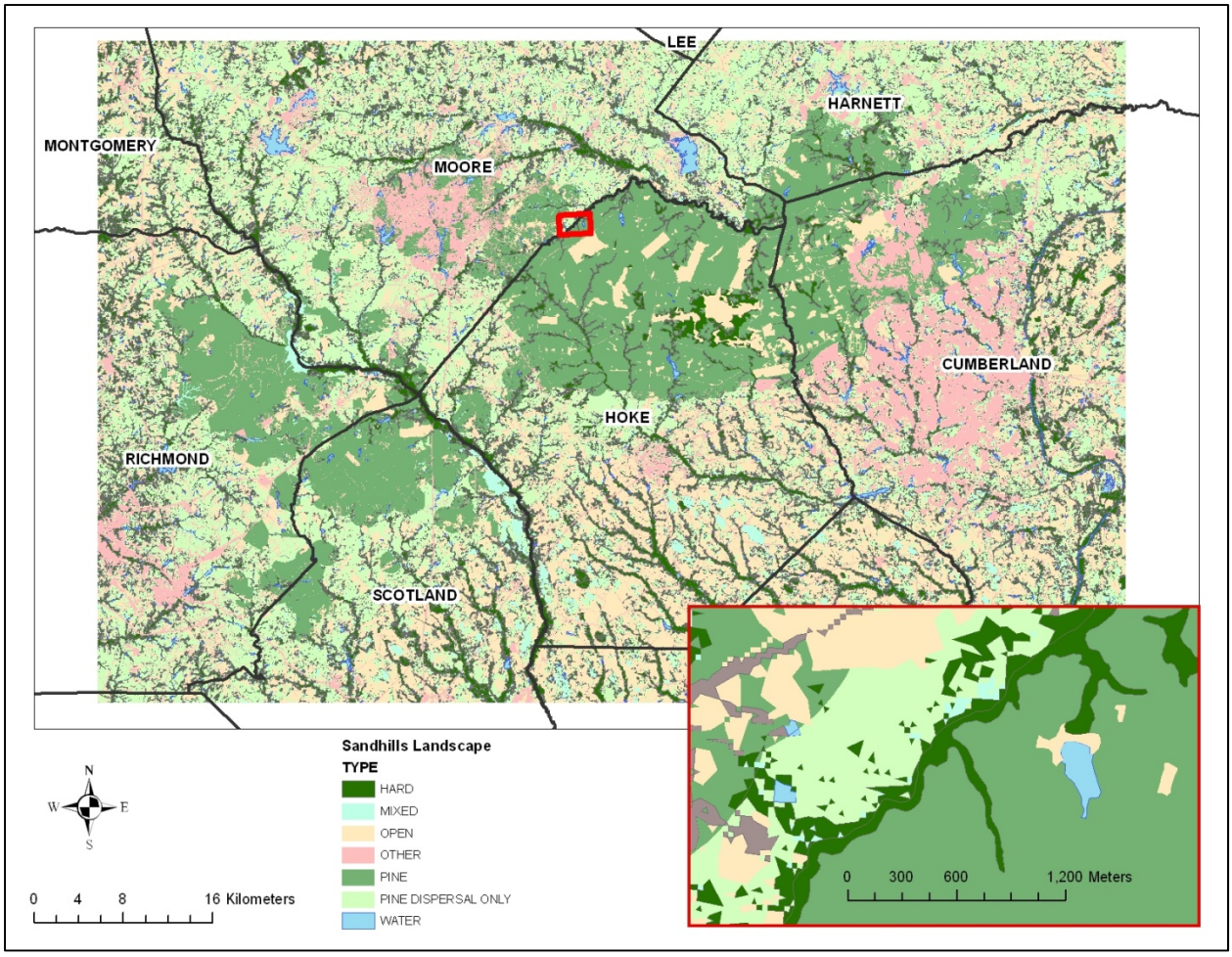


Figure 44. The final Sandhills landscape encompassed measured 93 x 53km. Inset shows landscape in detail.

Table 2. Southeastern GAP classifications and associated cover types used in this study. Class Name and Code values come from Southeastern GAP.

CLASS NAME	CODE	Cover Type
Open Water (Fresh)	SEGAP111	WATER
Developed Open Space	SEGAP211	OTHER
Low Intensity Developed	SEGAP220	OTHER
Medium Intensity Developed	SEGAP230	OTHER
High Intensity Developed	SEGAP240	OTHER
Bare Sand	SEGAP311	OPEN
Bare Soil	SEGAP312	OPEN
Quarry/Strip Mine/Gravel Pit	SEGAP313	OPEN
Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest	CES203.241	HARD
Atlantic Coastal Plain Mesic Hardwood and Mixed Forest	CES203.242	HARD
Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier	CES202.339	HARD
Southern Piedmont Mesic Forest	CES202.342	HARD
Evergreen Plantations or Managed Pine, can include dense successional regrowth)	SEGAP420	PINE
Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier	CES202.339b	HARD
Atlantic Coastal Plain Fall-Line Sandhills Longleaf Pine Woodland - Loblolly Modifier	CES203.254c	PINE
Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland - Open Understory Modifier	CES203.254a	PINE
Atlantic Coastal Plain Fall-line Sandhills Longleaf Pine Woodland - Scrub/Shrub Understory Modifier	CES203.254b	PINE
Atlantic Coastal Plain Longleaf Pine Woodland	CES203.281	PINE
Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier	CES202.339c	MIXED
Successional Shrub/Scrub (Clear Cut)	SEGAP511	OPEN
Successional Shrub/Scrub (Other)	SEGAP513	OPEN
Clearcut - Grassland/Herbaceous	SEGAP710	OPEN
Other - Herbaceous	SEGAP720	OPEN
Utility Swath - Herbaceous	SEGAP730	OPEN
Pasture/Hay	SEGAP810	OPEN
Row Crop	SEGAP820	OPEN
Atlantic Coastal Plain Blackwater Stream Floodplain Forest - Forest Modifier	CES203.247a	HARD
Atlantic Coastal Plain Brownwater Stream Floodplain Forest	CES203.248	HARD
Atlantic Coastal Plain Small Blackwater River Floodplain Forest	CES203.249	HARD
Atlantic Coastal Plain Small Brownwater River Floodplain Forest	CES203.250	HARD
Southern Piedmont Small Floodplain and Riparian Forest	CES202.323	HARD
Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Taxodium/Nyssa Modifier	CES203.304b	HARD
Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Oak Dominated Modifier	CES203.304a	HARD

Atlantic Coastal Plain Clay-Based Carolina Bay Forested Wetland	CES203.245a	HARD
Atlantic Coastal Plain Peatland Pocosin	CES203.267	MIXED
Atlantic Coastal Plain Streamhead Seepage Swamp, Pocosin, and Baygall	CES203.252	MIXED
Atlantic Coastal Plain Northern Wet Longleaf Pine Savanna and Flatwoods	CES203.265	PINE

Where age and site index were available (Fort Bragg, Camp McCall, and Sandhills Game Lands data sets) we incorporated this information into our final landscape. For areas outside of these properties where this information was lacking, we used the Southeastern GAP land cover dataset to determine cover type and we made some assumptions about age. Pine areas were assumed to be 60 years of age if they were within 1 km of active or recently active (5 years) RCW cluster centers. This determination was made based on our observations of the forest age structure in those areas. Pine areas beyond 1 km from the selected cluster centers were designated as Pine Dispersal Only. As described elsewhere, the DSS treats the Pine Dispersal Only cover type as pine suitable for dispersal, but not nesting or foraging.

Onslow Bight

The Onslow Bight landscape file, which included all known RCW groups from Croatan National Forest on the east to and including Holly Shelter Game Lands on the west, was prepared in collaboration with Geo-Marine Incorporated, using techniques similar to those described above, with some minor modifications. As for the Sandhills, forest stand and Southeastern GAP data were the primary data sources used to create the landscape file. However, for six properties of special interest, Geo-Marine used a combination of aerial photography, wetlands data, soils data, and on-the-ground knowledge to create and classify polygons by age and cover type. These properties of special consideration were:

- Holly Shelter Game Lands – 22,638 ac
- Bear Garden – 9,969 ac
- Shaken Creek – 4,688 ac
- Stones Creek Game Lands – 2,386 ac
- Hoffman Forest Block 10 – 6,709 ac
- Everett Creek – Allen Property – 148 ac

The final land cover product (Figure 45) was analogous to the Sandhills land cover dataset: a polygon file describing cover type, age, and site index (where known). This file was used in all DSS model runs for the Onslow Bight.

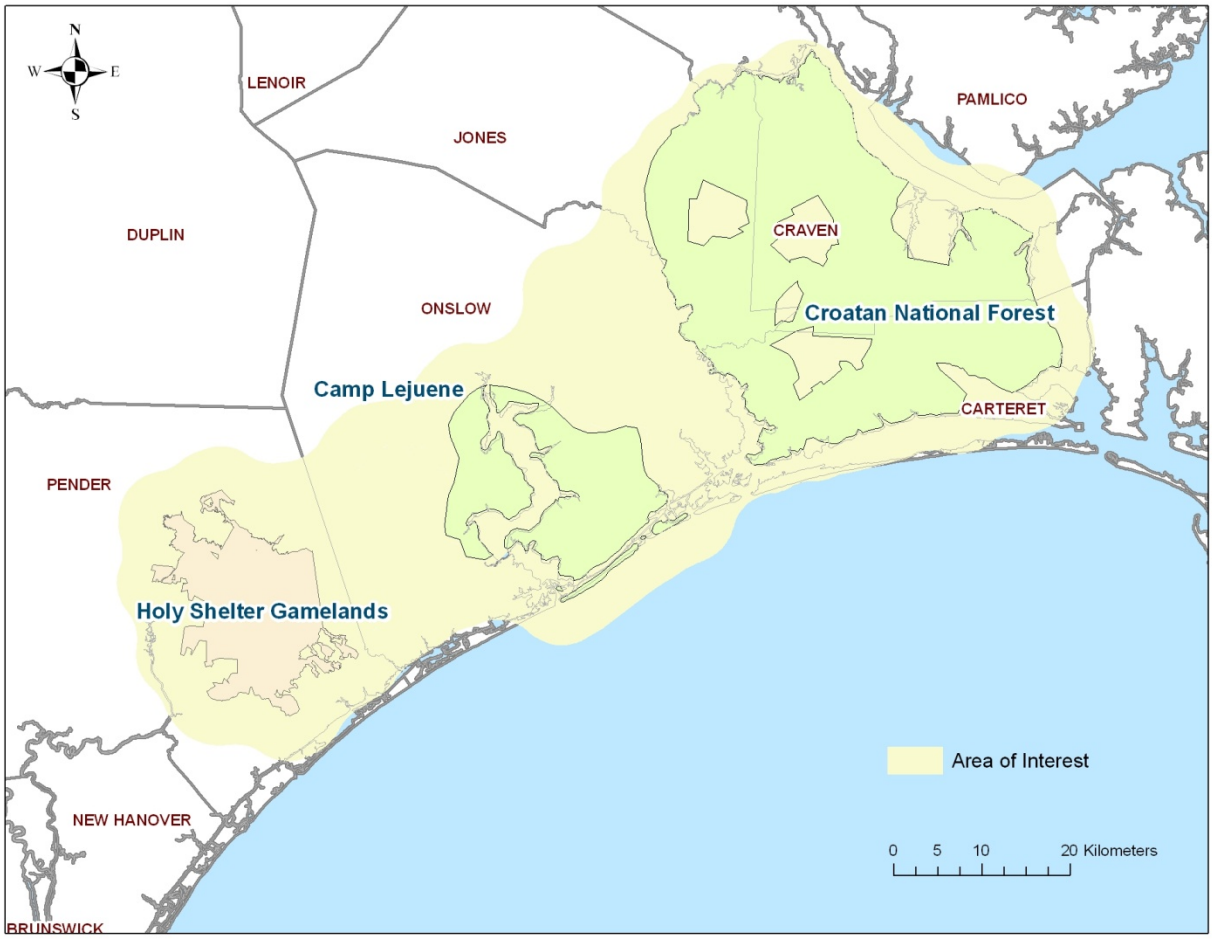


Figure 45. Shaded area indicates the Onslow Bight study area, which encompasses three areas with RCW populations, Croatan National Forest, the Mainside portion of Marine Corps Base Camp Lejeune and the Holly Shelter Gamelands.

Model Testing

Our testing of the DSS included both model validation (comparing model predictions to empirical data) and model verification (testing whether the model has been successfully transformed from one form into another). This project involves transformation of a previous model of RCW population dynamics into a different form, specifically a more user-friendly form. It also involves changing the model, by altering movement rules and adding interaction with the landscape a population occupies. We verified the model before incorporating the new dispersal rules and interaction with the landscape, by comparing simulation results of the old and new versions of the model run on the same baseline population. After incorporating the new dispersal rules and interaction with the landscape we validated the final DSS by comparing its simulation of the study populations to real data from these populations.

Model verification

The purpose of the model verification exercise was to verify that the RCW population model that served as the foundation of the DSS was successfully transformed from its original form into the user-friendly form used in the DSS. To verify the model we compared simulations of the 2007 MCBCL RCW population conducted with the two forms of the model. The RCW data necessary to conduct the simulations (i.e., locations of all active RCW territories, appropriate initial group size) were available from long-term studies of this population by the PI. Note that these simulations do not involve the entire Onslow Bight area, but only the Mainside portion of MCBCL where all RCWs currently found on the base reside.

We simulated 12 different scenarios, all of 20 years duration. In the base scenario (scenario 1-1) the 75 RCW territories containing potential breeding groups and solitary males were treated as occupied and the nine captured clusters and 10 unoccupied recruitment clusters were treated as open territories that could be occupied by dispersing birds. A captured cluster is one used for roosting by birds whose primary residence is another cluster and its associated territory (and thus it is not occupied by an independent group). We ran additional scenarios to help base biologists evaluate management options they were considering. First we ran three scenarios involving construction projects that would result in the loss of RCW territories, including a best case scenario (1-2) in which three territories were lost to construction, an intermediate scenario (1-3) in which five territories were lost to construction, and a worst case scenario (1-4) in which seven territories were lost to construction. We then ran scenarios in which three recruitment clusters were placed on the landscape as open territories each year in years 2-18 of the simulation, again including a 2007 base population scenario (2-1), a best case construction scenario (2-2), an intermediate case construction scenario (2-3) and a worst case construction scenario (2-4). Then we ran some future population scenarios, in which all 198 potential woodpecker territories identified by base biologists (this total includes the currently active ones and all potential recruitment clusters) were treated as occupied, including a base population scenario (3-1) with all 198 territories, a best case construction scenario (3-2), an intermediate case construction scenario (3-3) and a worst case construction scenario (3-4). We ran 100 replicates of each scenario. Note that all 198 of these future territories are located on the Mainside portion of the base, and none are on the Greater Sandy Run portion to the west.

In each model run the same initial conditions were applied randomly to each territory. Each territory had a 90% chance of beginning with a breeding pair, and territories without a breeding pair contained a solitary male. One helper was placed on each territory, and a second helper was placed on 10% of the territories at random. This procedure resulted in the average group sizes that characterize the real population. The ages of the birds were assigned randomly from a distribution designed to reproduce the age distribution of birds observed in the Sandhills population in 1991, a typical year.

To verify the model we compared the following primary model predictions between the new and old versions of the model: population growth rate (measured in terms of number of occupied territories), number of territories gained and lost, and social structure (numbers in each status class). We also compared results for two secondary predictions, age distribution of male and female breeders at the end of the simulation period and annual probability of transition from helper to breeding status. The two versions of the model produced essentially identical results

(Figure 46 and Figure 47) and thus the DSS was successfully verified. Completely identical results were not expected because of the stochastic elements within the model, which cause even two runs of the same scenario to differ slightly.

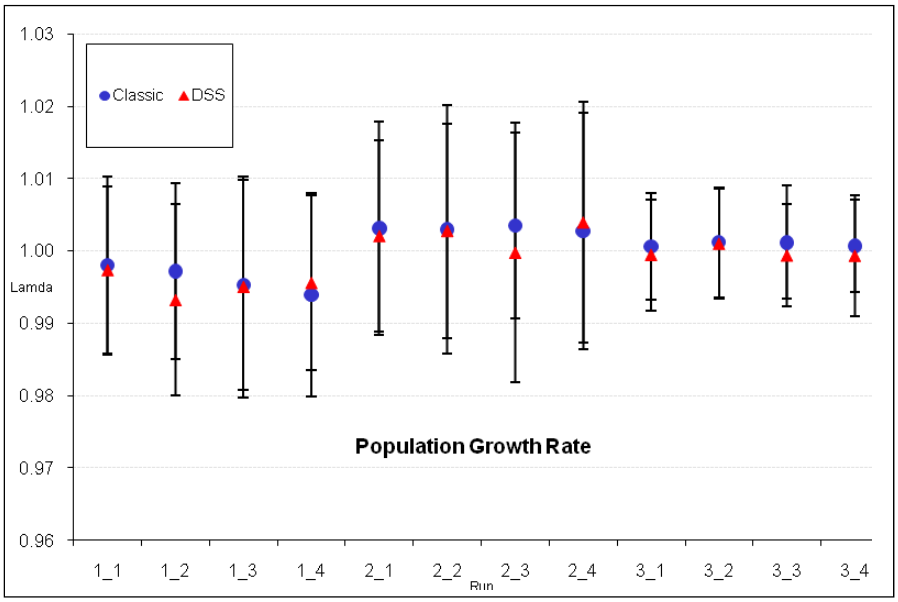


Figure 46. Population growth rates for the original (classic) and new (DSS) versions of the RCW population model for simulations of the 12 Marine Corps Base Camp Lejeune scenarios.

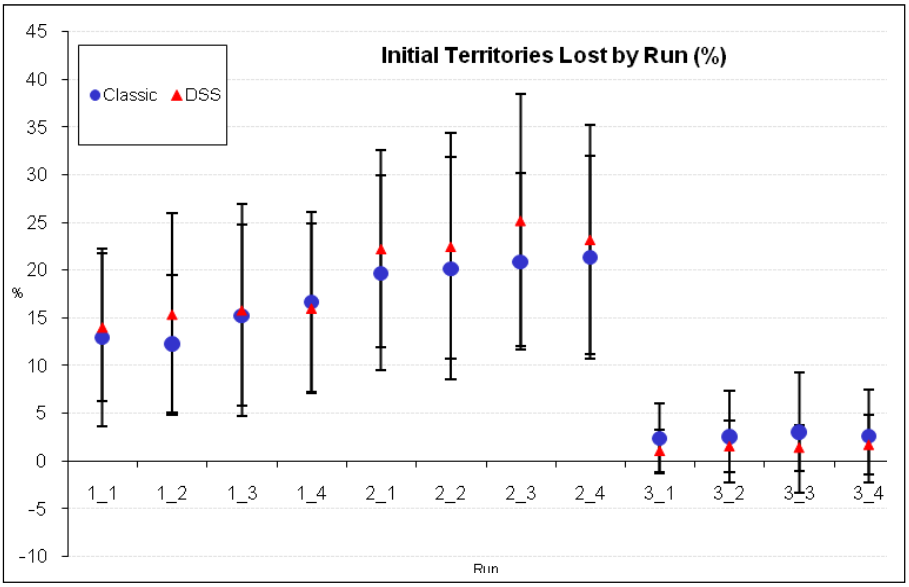


Figure 47. The proportion of initially occupied territories that were abandoned in simulations of the 12 Marine Corps Base Camp Lejeune scenarios run using the original (classic) and new (DSS) versions of the RCW population model.

Model validation

Introduction

The original RCW population dynamics model (Letcher et al. 1998) has already been validated (Schiegg et al. 2005). However, several important changes to the model were made in order to create the DSS, so it was important to re-validate the DSS to demonstrate that the model remained robust and suitably predictive.

The model creates primary predictions (such as change in population size over time) which are the outputs of most value to managers and also demonstrate the predictive ability of the model when applied to real life situations. In addition the model creates secondary predictions (such as population structure, dispersal and breeding parameters) which can demonstrate that the underlying structure of the model is valid even if these outputs are not of direct value to managers. It is these secondary predictions that reflect the structure of the model and validity of the model may fail when these predictions are not accurate, even if the primary predictions appear reasonable. This may be caused by other compensatory factors in the model resulting in an accurate prediction at the population level even when the model is not accurately predicting other important parameters.

To validate the DSS we used data from the same study site (Sandhills) that was used to parameterize the original model. However, in doing so we used a different time period for the comparison, that is, we compared simulated and actual population behavior during a time period after the period in which the data used to parameterize the model were collected. Also, we repeated the validation procedure using data from MCBCL. This second validation exercise was essential because the DSS now includes a "coastal" model based on vital rates determined with data from MCBCL, and the coastal model had not been validated previously. Again, the data used to validate and parameterize the model came from different time periods.

Methods

Input clusters – initial clusters

RCW data were available for both study areas from long-term population studies by the PI (Brust et al. 2004, Walters 2004). The locations of the initial occupied territories/clusters used in each simulation were based upon the geometric mean of the locations of the active cavity trees for each group. Thus the location used by the simulation is not a real location on-the-ground and so may not necessarily appear in the GIS layer within a suitable habitat type. However, the model assesses the suitability of the habitat for each cluster location based not on the location of the individual point but on the area of suitable habitat (pine aged 60 years old or more) within an 800 m radius from that point. While habitat is assessed at an 800 m range, it should be noted that territory centers can be as close as (but not closer than) 400 m. The initial territories included in the simulations were all those that contained a real breeding pair (with or without helpers) in 1997 (year 0 for the simulation). In the Sandhills there were also some captured clusters in 1997. These were treated as unoccupied recruitment clusters, available in year 0. The initial territories and recruitment clusters for the Sandhills are shown in Figure 48, and those for MCBCL in Figure 49.

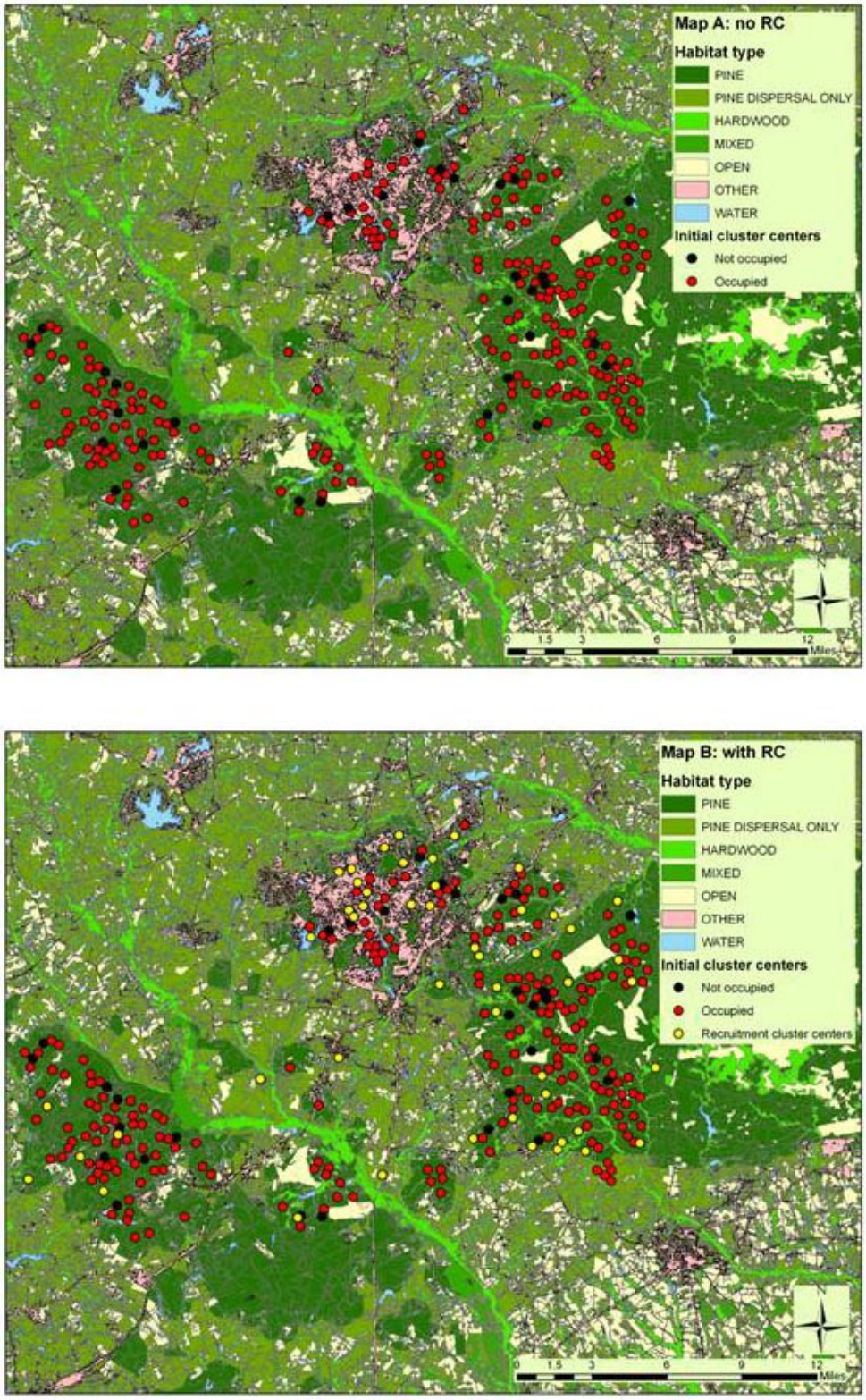


Figure 48. Map of the Sandhills study area showing the locations of occupied (red circles ●) and unoccupied (black circles ●) initial territories (Map A). Map B shows the locations of recruitment clusters added during some simulations (yellow circles ●).

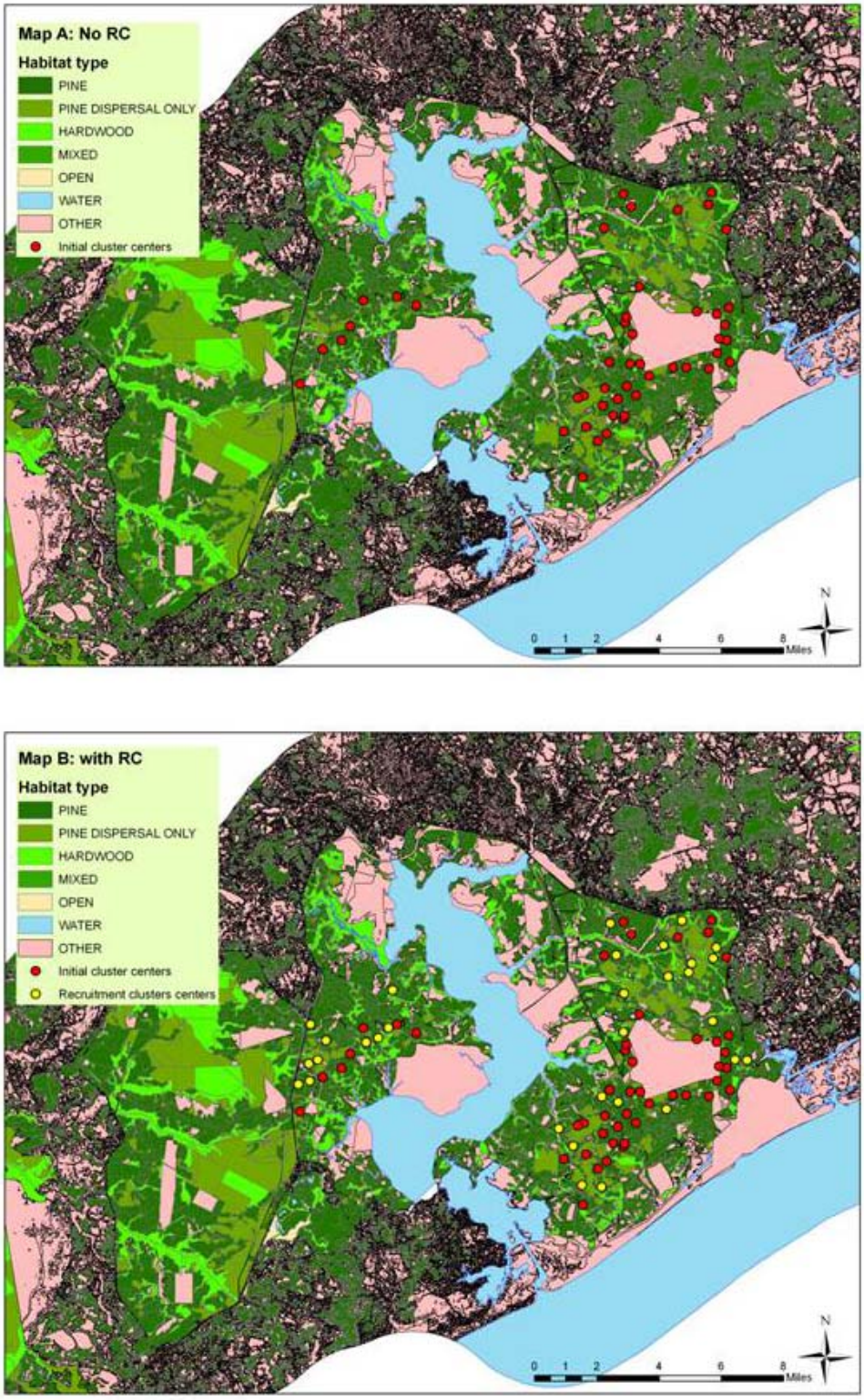


Figure 49. Map of the Marine Corps Base Camp Lejeune study area showing the locations of initial territories (red circles ●) (Map A). Map B shows the locations of recruitment clusters added during some simulations (yellow circles ●). Note that all territories are on the eastern Mainside portion of the base and none are on the western Greater Sandy Run area.

Input clusters – recruitment clusters

In both study populations current management activities include the use of recruitment clusters. For each study population we not only modeled the populations with initial clusters present in 1997 but also separately modeled the effects of adding recruitment clusters to the populations. For each study site we used the DSS to add recruitment clusters in the same year in which they were added to the real landscapes. While in real populations recruitment cluster cavities are constructed in multiple trees the DSS uses only a single location as the (prospective) territory center (the geometric mean of the individual cavity tree locations), as is the case with initial territories. In the Sandhills 50 recruitment clusters were added (Figure 48: Map B) over the 10 years of the simulation, and 31 recruitment clusters were added at MCBCL, all on the Mainside portion of the base (Figure 49: Map B).

Input values

Input values for the mean group size were needed for the DSS in order to simulate each of the two populations. In the Sandhills the actual initial mean group size in the real population was 2.4 and in the MCBCL population it was 2.6. Since 2.6 was not an available input value in the DSS the nearest value of 2.65 was used for the MCBCL simulations.

It was also necessary to select a type locality for each model run. The Sandhills model runs used the “Sandhills” type locality and the MCBCL runs used the “Coastal” type locality. These model type localities of course are based on the two study populations respectively.

Empirical data analysis

All empirical values used to compare to the DSS simulation outputs were extracted from existing databases collated during ongoing projects in the Sandhills area and at MCBCL (Brust et al. 2004, Walters 2004). All data from both localities were from the years 1997 to 2007 inclusive. Some of the empirical values from 1997 were used to initiate the DSS simulations: territory center locations, years in which recruitment clusters were added to the populations, and mean group size.

Occupied territories from the empirical datasets were included in the comparison if they were active initial territories, known buds or known successful recruitment clusters. Mean (± standard deviations) numbers of occupied territories each year were calculated to compare to simulated population growth. In order to compare real and simulated social structure of each population the proportion of each of the following categories was calculated relative to their overall total *only* for the year 2007: breeding females, breeding males, helpers, floaters, and solitary males.

Natal dispersal distances for all male and female dispersers were calculated by measuring the distance from the geometric mean territory center of a bird’s natal site to the geometric mean territory center of the bird’s breeding site. Distances between territory centers were measured using Hawth’s Analysis Tools (Beyer 2009) in ArcGIS 9.3. The median distance moved was then calculated for all males (including birds breeding on their natal site, i.e., natal dispersal distance = 0 km), dispersing males (i.e., natal breeding males were removed from the dataset before the median distance was calculated) and female dispersal distance (for all females).

The total number of birds breeding for the first time at each age was calculated, but only for birds fledged in the first six years because many helpers do not become breeders until the age of four, or even older. The number of helper males that became breeders in the *subsequent* year was calculated for each year of the study. This was expressed as a proportion of the total number of helpers in the initial year in order to calculate the probability of helper males transitioning to breeders each year.

For each year the mean (± standard deviation) group size was calculated. Also, the location of each initial territory that was abandoned (not occupied for five years or more) between 1997 and 2007 was recorded and mapped using ArcGIS 9.3. Similarly, the location of each recruitment cluster was mapped and whether it was successfully occupied during the period of the study was noted. This was also done for all known successful budding events during the study period.

Simulation data analysis

In addition to the standard outputs of the release version of the DSS (number of occupied territories per year, mean group size per year, probability of initial territory abandonment, successful occupation of recruitment clusters and budding probability and location), data were extracted from the outputs of all simulations for all the remaining parameters of interest that were calculated from the empirical data. Great care was taken to ensure that the data outputs were calculated to be comparable with the empirical data. All data analysis was performed using SPSS 12.0 (SPSS 2002).

Results of the DSS compared to empirical data

Primary prediction – population size

Over the 10 years of the model run the number of occupied territories in the Sandhills population was predicted to essentially remain stable, with only a slight mean decrease in the number of occupied territories over that period (Figure 50). The addition of recruitment clusters made little difference to the predicted change in the number of occupied territories. The predicted change across the ten years of the simulations was -2.9% (± s.d. = 11.1%) without recruitment clusters and -2.1% (± s.d. = 13.3%) with recruitment clusters. Note the large variance in these data. Despite the slightly negative prediction for the number of occupied territories, the predicted rate of annual population growth in terms of number of birds was still positive (i.e., >1, 1.002 without recruitment clusters and 1.003 with recruitment clusters), indicating an increase in group size. In contrast to the prediction of the DSS the actual number of occupied territories in the Sandhills increased slightly during the study period rather than remaining stable (Figure 50).

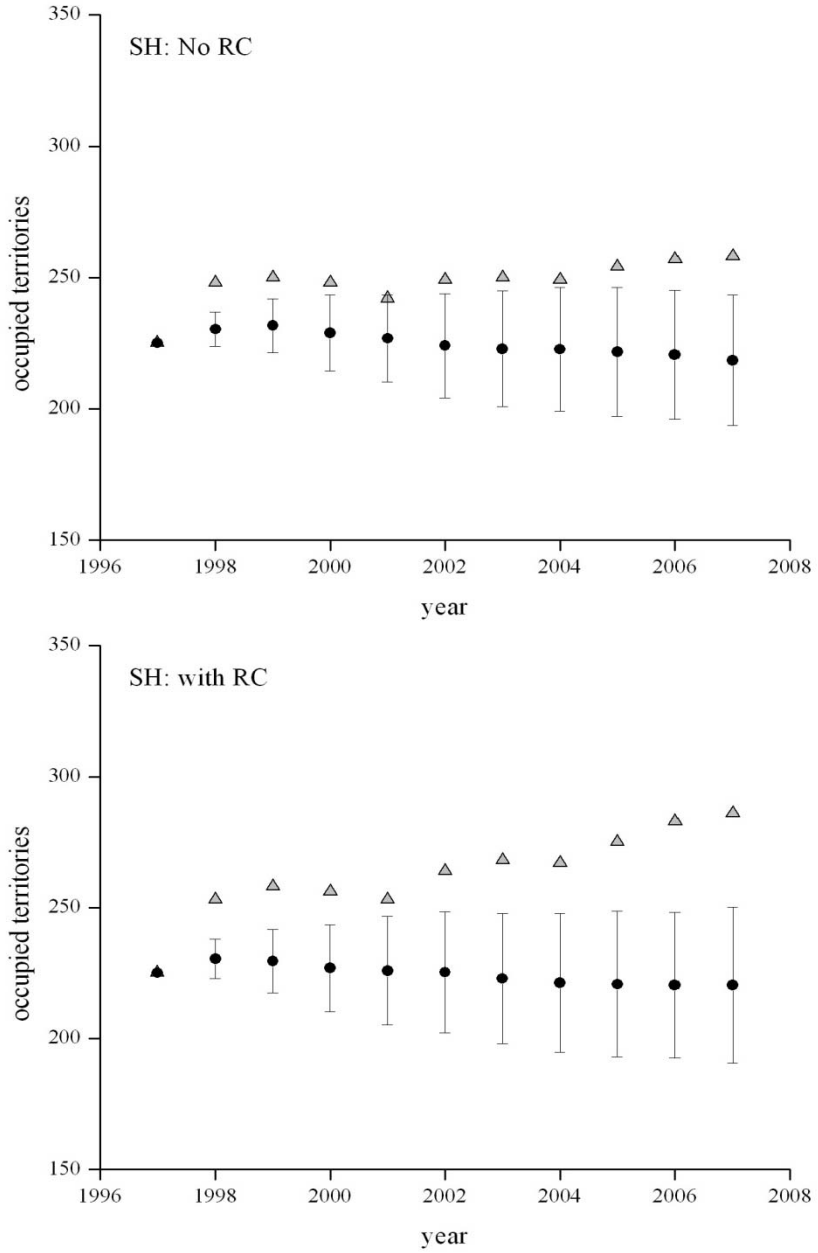


Figure 50. Number of occupied territories over time in the Sandhills (SH) RCW population. Actual population data are represented by the gray triangles. Filled circles represent the mean (± s.d.) of 70 simulation runs of the DSS. One simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (no RC).

The predicted change in occupied territories was slightly different for MCBCL. The DSS predicted a mean change in the number of occupied territories over ten years of -0.76% (± s.d. = 3.7%) without recruitment clusters, and +6.7% (± s.d. = 5.3%) with recruitment clusters (Figure 51). Note the much smaller variance in these data compared to the Sandhills data. Again in both simulations population growth rate in terms of number of birds was positive (1.019 without recruitment clusters, 1.027 with recruitment clusters). However, for both sets of simulations the prediction was conservative when compared to the empirical data. In the real data population

growth in terms of number of occupied territories was much more positive, as the MCBCL population increased substantially with and without recruitment clusters (Figure 51).

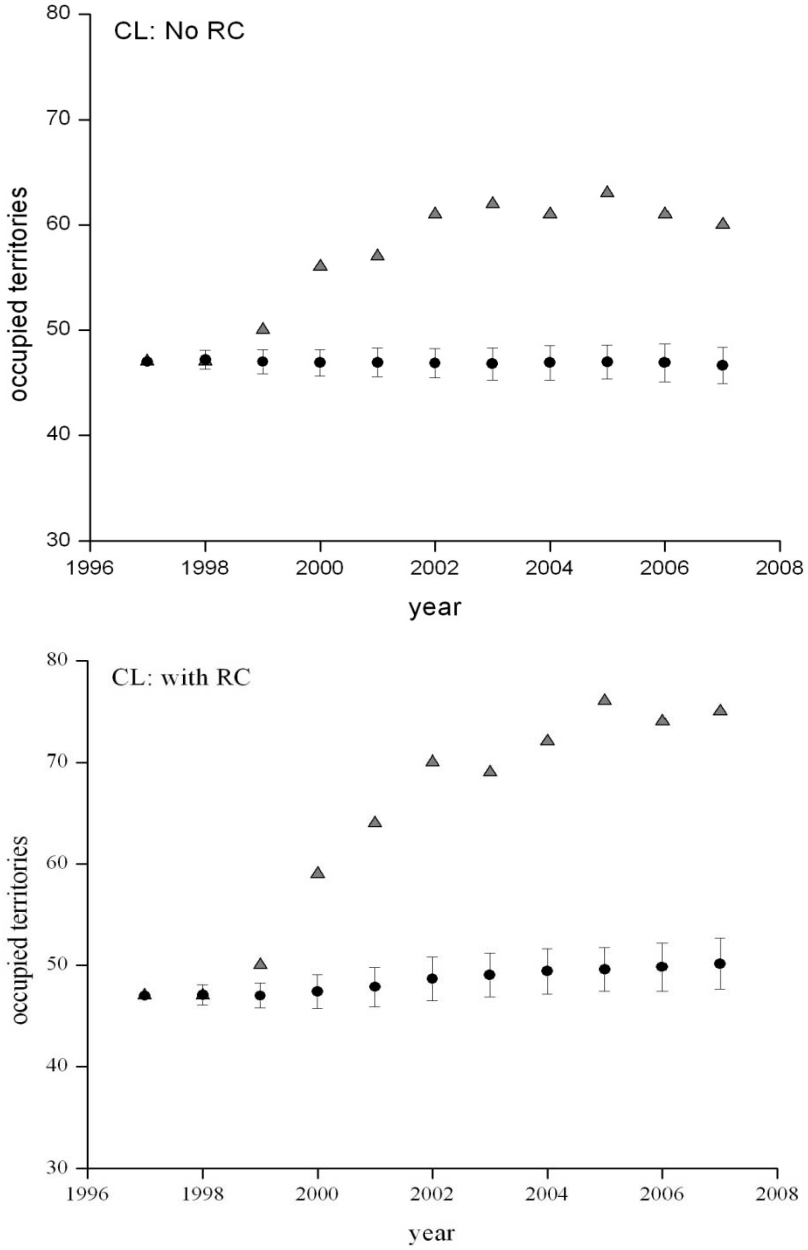


Figure 51. Number of occupied territories over time in the Marine Corps Base Camp Lejeune (CL) RCW population. Actual population data are represented by the gray triangles. Filled circles represent the mean (± s.d.) of 70 simulation runs of the DSS. One simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (no RC).

Secondary prediction – social structure

There were slight differences in social structure between the simulated and real populations, specifically in the distribution of non-breeding birds among social classes. The model

underestimated the number of floaters in all four simulations and overestimated the number of solitary males in the Sandhills (Figure 52). The number of helpers was underestimated in the Sandhills and overestimated at MCBCL. All of these differences were relatively small and generally the model predicted social structure well. The inclusion of recruitment clusters made little difference to the outcomes for this parameter in either the empirical or simulated data.

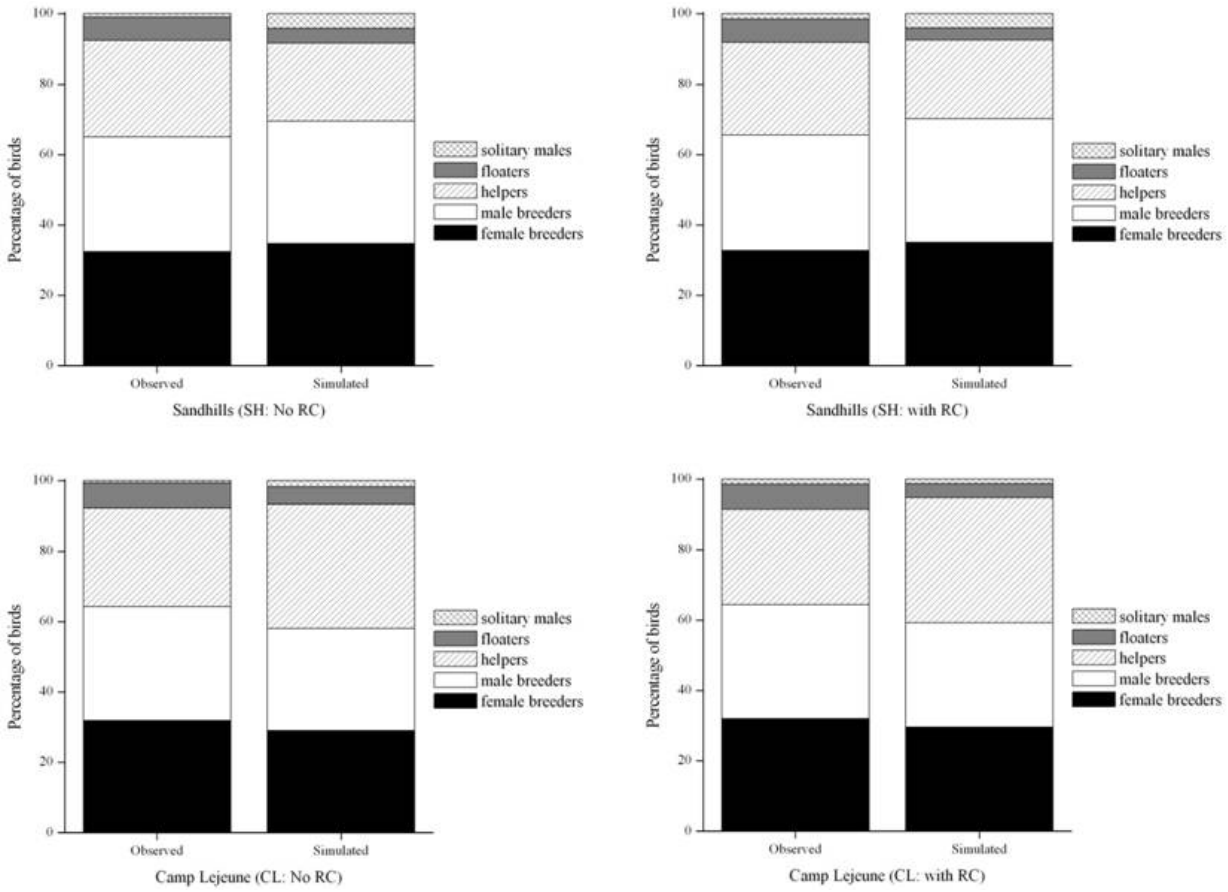


Figure 52. Social structure of the real and simulated (means over 70 simulations) RCW populations in the Sandhills (SH) and at Marine Corps Base Camp Lejeune (CL). Plots represent relative proportions of each social category in the population in 2007 for empirical data (Observed) and at the end of a ten year model run (Simulated). For each study site one simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (no RC).

Results for social structure were reflected in estimates of mean group size. In the Sandhills where the model underestimated the proportion of helpers group size was smaller in the simulated population than in the real population (Figure 53). However, this difference was exceedingly small and thus the model estimated group sizes quite well. The mean group size in the final year of the comparison, and indeed throughout the period of study, was very similar for model runs with and without recruitment clusters. At MCBCL where the model overestimated the proportion of helpers group sizes were larger in the simulated population than in the real population. The difference between real and simulated data was much larger than in the Sandhills, with divergence of values beginning in year four and increasing through to the end of the comparison

in 2007 (Figure 54). The presence of recruitment clusters made little difference to either the predicted or empirical estimates of group size for MCBCL.

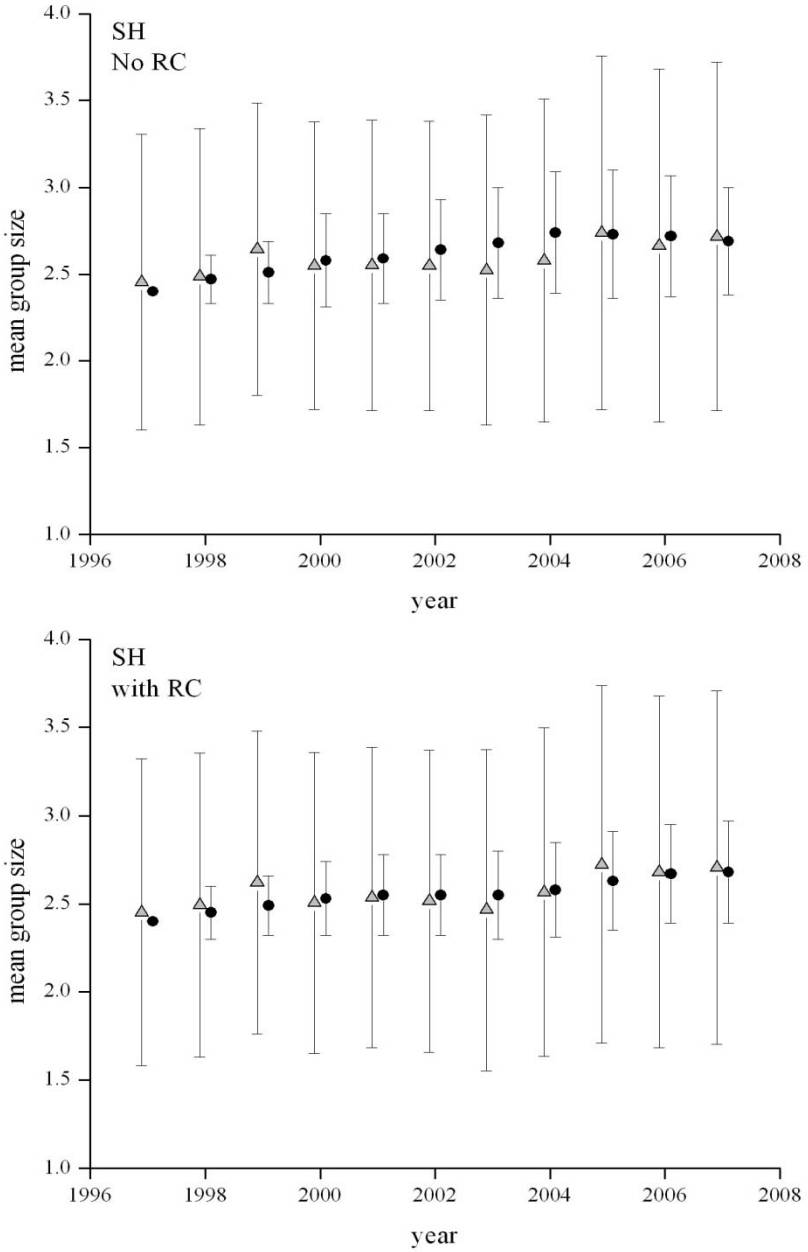


Figure 53. Mean group size over time in the Sandhills (SH) RCW population. Mean (± s.d.) empirical population data are represented by the gray triangles. Filled circles represent the mean (± s.d.) of 70 simulation runs of the DSS. One simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (no RC).

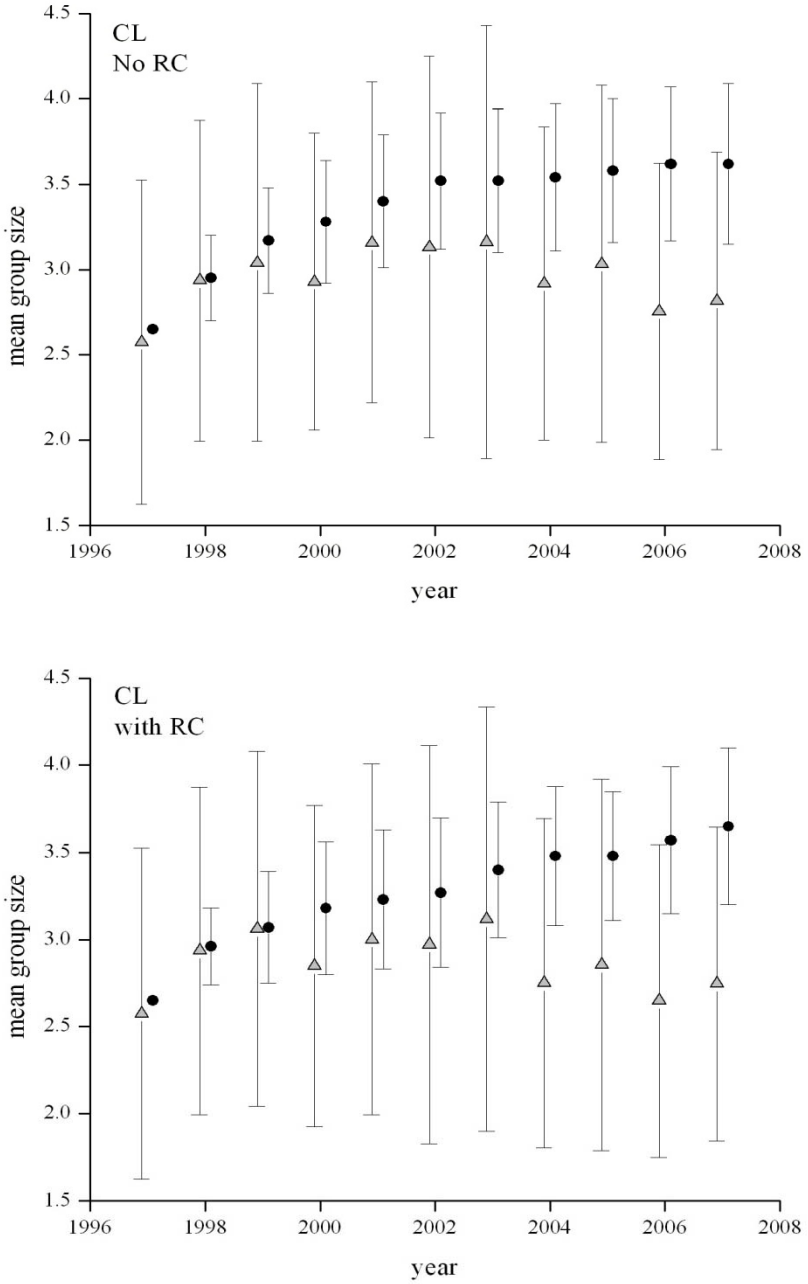


Figure 54. Mean group size over time in the Marine Corps Base Camp Lejeune (CL) RCW population. Mean (± s.d.) empirical population data are represented by the gray triangles. Filled circles represent the mean (± s.d.) of 70 simulation runs of the DSS. One simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (no RC).

Secondary predictions – dispersal distances

For all three categories examined – females, all males (including those breeding on their natal territory) and dispersing males (males that dispersed from their natal territory to breed) – the median distance travelled between the natal site and site of first breeding was larger for the empirical data than the simulated data with the exception of all males at MCBCL (Table 3). In

both Sandhills comparisons the model underestimated the farthest distances travelled for all categories, whereas in the MCBCL simulations the model overestimated the farthest distances traveled with one exception. Note that the simulated maximum natal dispersal distances for the Sandhills and MCBCL are similar, but the empirical data show much greater maximum natal dispersal distances in the Sandhills than at MCBCL.

Table 3. Natal dispersal distances (km, medians and ranges) of RCWs in the Sandhills and at Marine Corps Base Camp Lejeune from empirical (real) and model (simulated) data, for females, all males including those breeding on their natal territory (all) and males that dispersed from their natal territory to breed (disp). For each study site one simulation scenario was run with recruitment clusters added to the landscape (RC) and another without recruitment clusters (no RC). For the simulations, n = number of dispersal events across all years in all 70 runs of each scenario.

			Males (all)	Males (disp)	Females
SANDHILLS	No RC	simulated	0.74 (0 - 20.1; n = 43132)	1.5 (0.5 - 20.5; n = 27064)	2.36 (0 - 22.6; n = 48718)
		real	0.0 (0 - 31.5; n = 287)	2.7 (0.5 - 31.5; n = 136)	3.7 (0 - 35.4; n = 293)
	RC	simulated	0.78 (0 - 16.7; n = 43660)	1.25 (0.5 - 16.7; n = 27889)	2.25 (0 - 22.5; n = 48580)
		real	0.56 (0 - 29.9; n = 315)	2.73 (0.48 - 29.9; n = 137)	3.12 (0 - 35.4; n = 431)
CAMP LEJEUNE	No RC	simulated	0.0 (0 - 16.4; n = 6619)	1.25 (0.5 - 16.4; n = 2738)	2.2 (0 - 15.6; n = 8126)
		real	0.0 (0 - 11.8; n = 67)	2.2 (0.5 - 11.8; N = 29)	3.7 (0 - 13.8; n = 102)
	RC	simulated	0.0 (0 - 18.5; n = 6904)	1.25 (0.5 - 18.5; n = 3179)	2.35 (0 - 13.4; n = 8481)
		real	0.69 (0 - 16.6; n = 103)	2.4 (0.5 - 16.6; n = 56)	3.7 (0 - 20.8; n = 141)

In the Sandhills, for birds that left their natal site to breed, there was a general pattern for the model to overestimate successful dispersal close to the natal site but underestimate the furthest distances of dispersing birds (Figure 55). For males, the model also underestimated the relative number of males that obtained breeding positions on their natal territory, though the inclusion of recruitment clusters reduced this disparity. Other than this, the inclusion of recruitment clusters made little difference to the distribution of natal dispersal distances in the Sandhills. The pattern was different at MCBCL. Dispersal close to the natal site was better predicted by the model, as was the proportion of males obtaining breeding positions on their natal territory (Figure 56). For females at MCBCL dispersal within 1 km of the natal site was very well modeled with some overestimation over the next kilometer, regardless of the presence of recruitment clusters. The model overestimated the largest dispersal distances (unlike the Sandhills) but the spatial scale was smaller. The exception to this pattern was the simulation of female natal dispersal distance where recruitment clusters were included. The empirical data showed that several females made longer jumps than the model predicted.

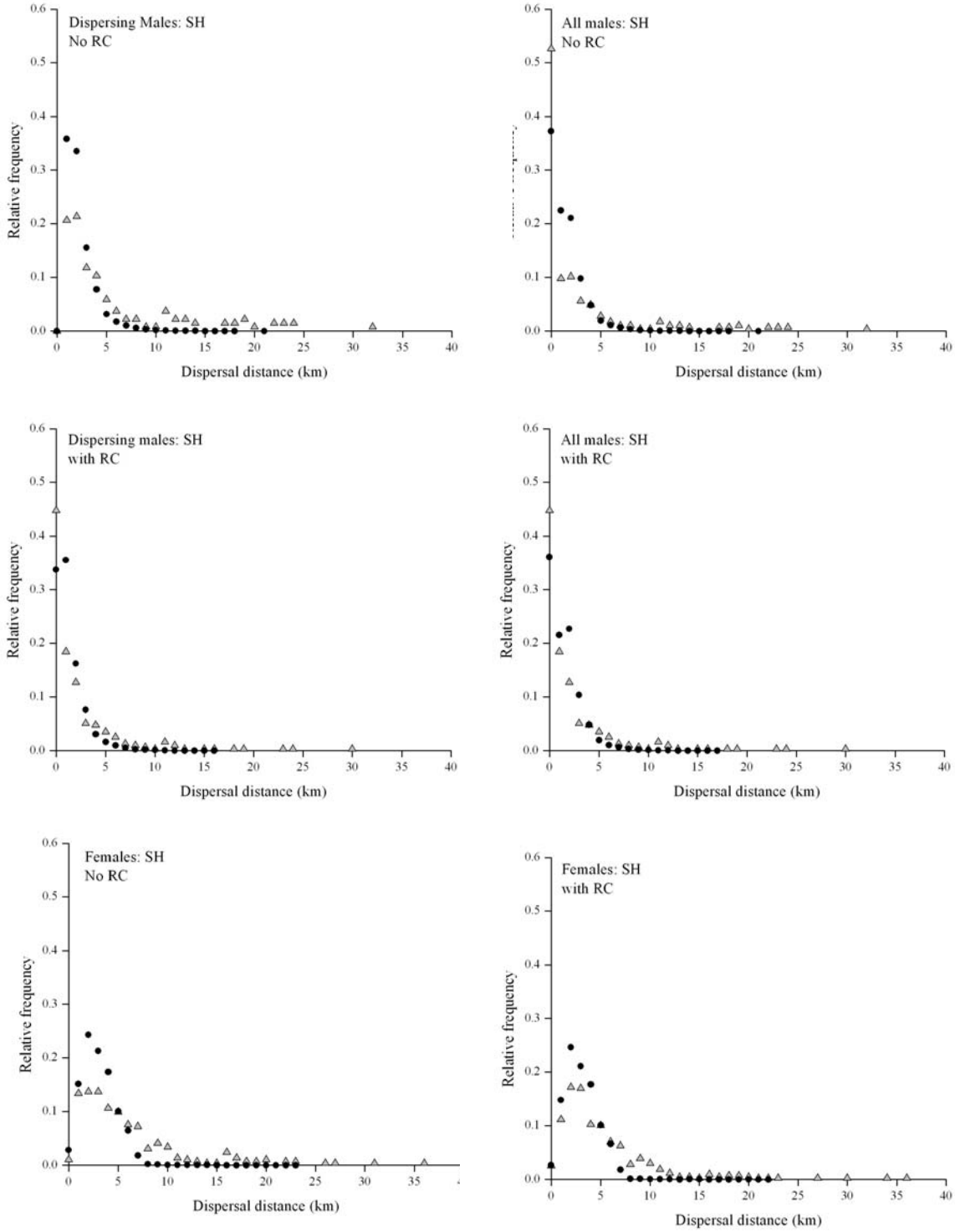


Figure 55. Distribution of natal dispersal distances of all male (including those breeding on their natal sites), dispersing male (only those dispersing from the natal territory to breed) and female RCWs in the Sandhills (SH). Triangles represent empirical data and circles the mean of the simulated data across 70 simulations. One simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (No RC).

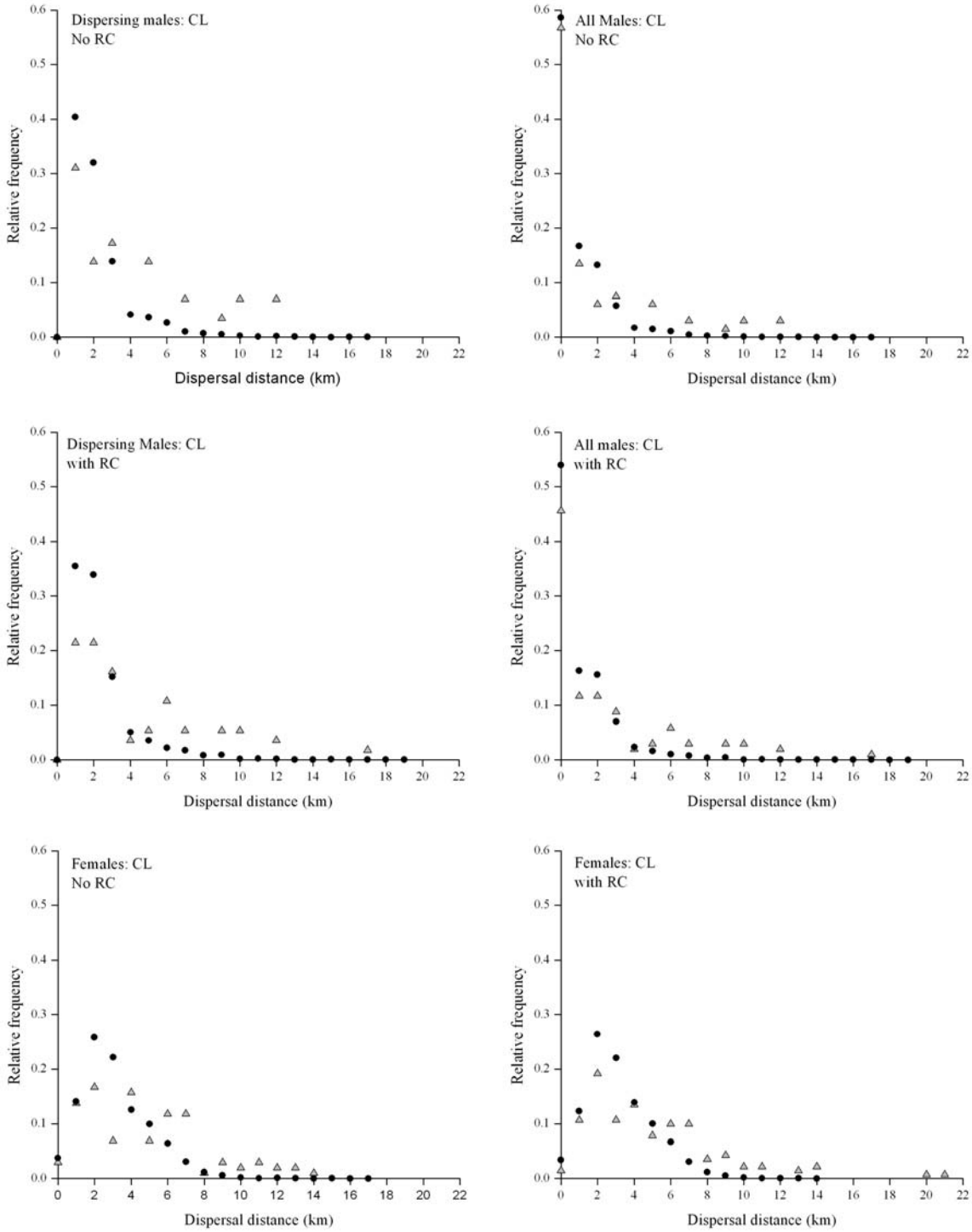


Figure 56. Distribution of natal dispersal distances of all male (including those breeding on their natal sites), dispersing male (only those dispersing from the natal territory to breed) and female RCWs at Marine Corps Base Camp Lejeune (CL). Triangles represent empirical data and circles the mean of the simulated data across 70 simulations. One simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (No RC).

Secondary predictions – age at first breeding

There were very few differences between the simulated and empirical data in the age at first breeding of both male and female birds at both study sites (Figure 57 and Figure 58). The one exception was that for females the model consistently overestimated acquisition of breeding status at age 1 and underestimated acquisition of breeding status at age 2.

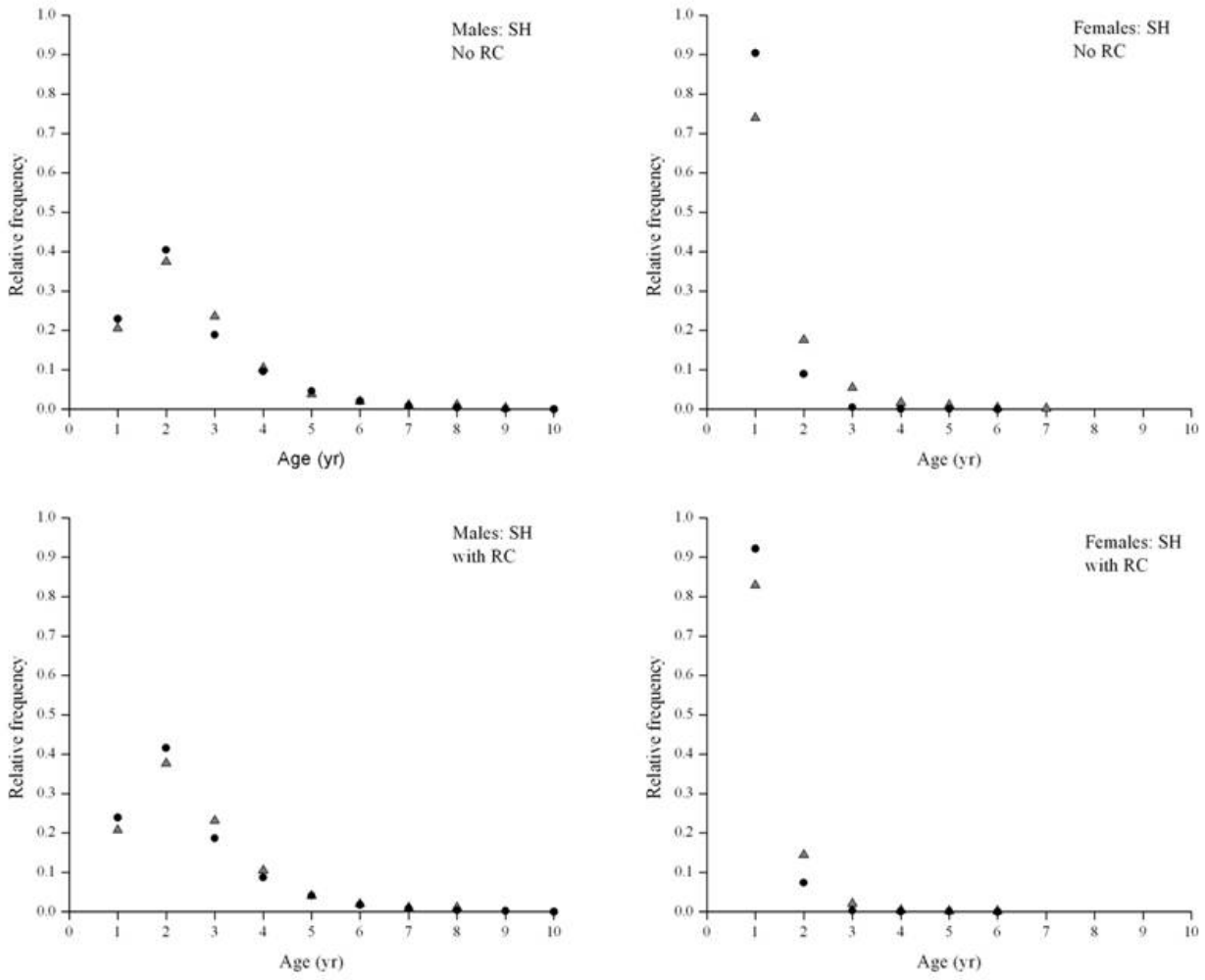


Figure 57. Age of male and female RCWs when first obtaining breeding status in the Sandhills (SH). Triangles represent empirical data and filled circles represent simulation data across 70 runs for each scenario. One simulation scenario was run with recruitment clusters added to the landscape (RC) and another without recruitment clusters (No RC).

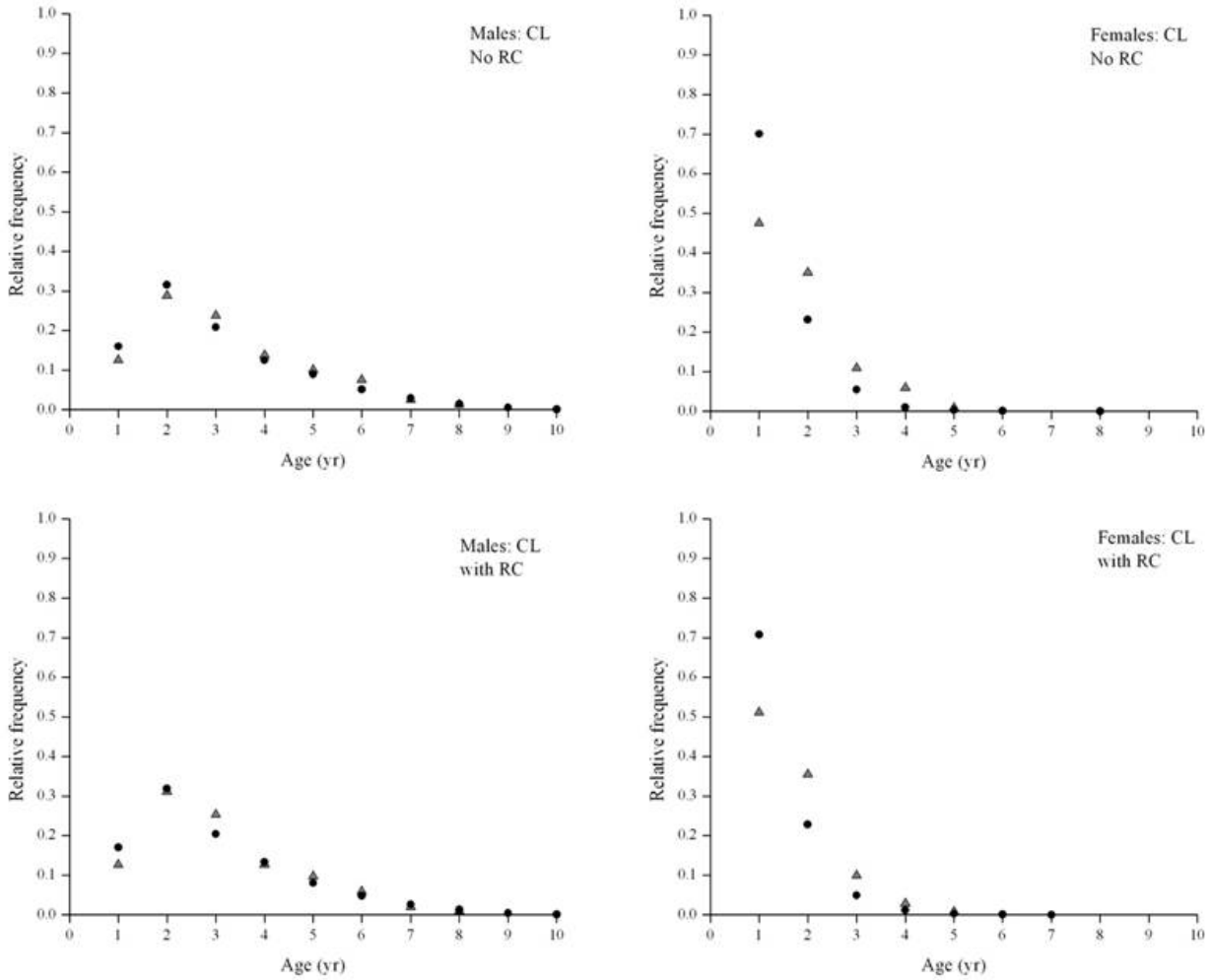


Figure 58. Age of male and female RCWs when first obtaining breeding status at Marine Corps Base Camp Lejeune (CL). Triangles represent empirical data and filled circles represent simulation data across 70 runs for each scenario. One simulation scenario was run with recruitment clusters added to the landscape (RC) and another without recruitment clusters (No RC).

Secondary predictions – age distribution of breeders

The overall pattern of the age distribution of breeding birds in the final year of the simulated and empirical data was similar in all cases (Figure 59). Generally the simulations produced smooth distributions which were shifted toward older ages at MCBCL relative to the corresponding distribution for the Sandhills, more so for males. The presence of recruitment clusters made very little difference to the predictions of the model. The patterns in the empirical data were more irregular, with particular age groups being over-represented (e.g., age 3 for Sandhills females, age 7 for Sandhills males, age 5 for MCBCL females, age 3 for MCBCL) or under-represented (e.g., age 2 for Sandhills males, age 4 for MCBCL females), especially in the smaller MCBCL population (Figure 59).

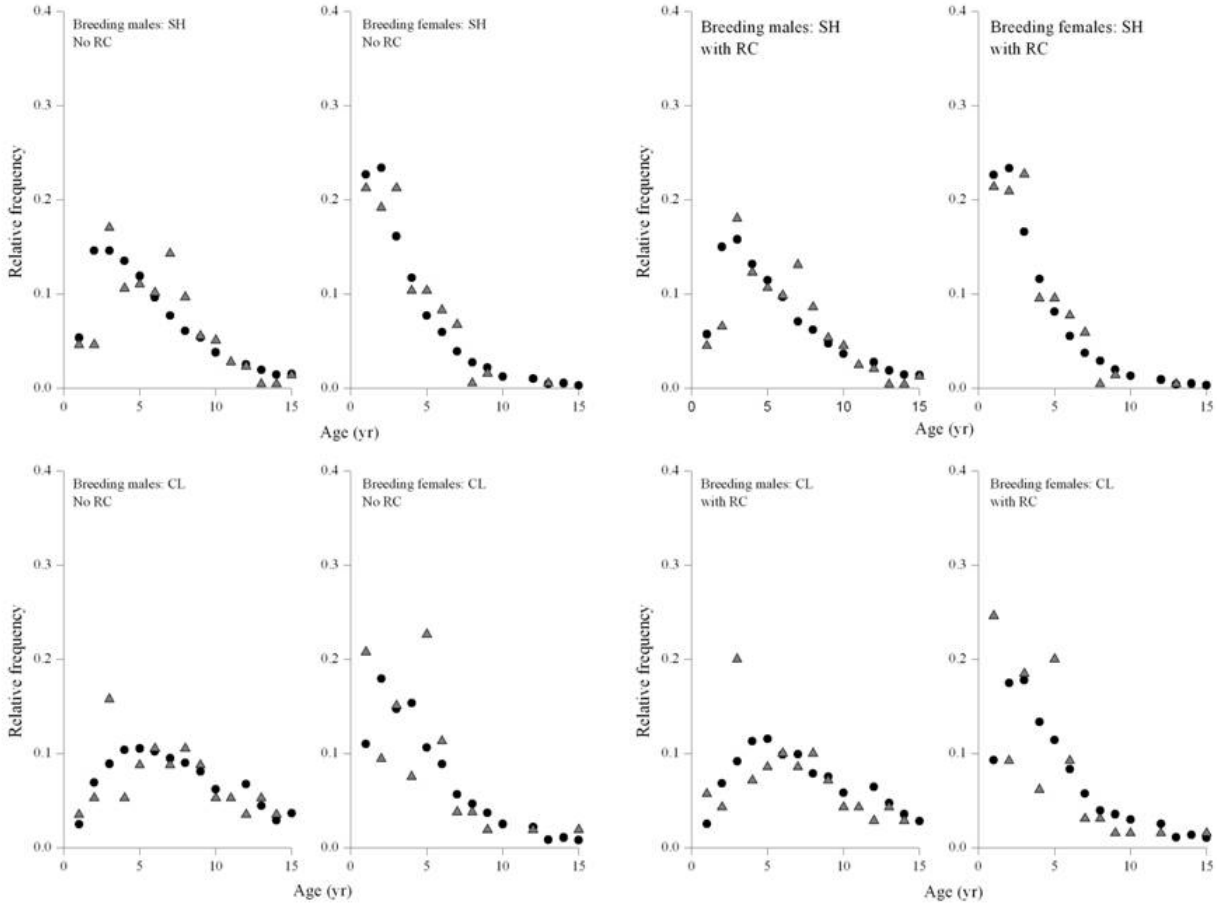


Figure 59. Age distribution of breeding male and female RCWs in 2007 (real populations, triangles) and after 10 years of simulation (simulated data, n = 70 runs, filled circles) in the Sandhills (SH) and at Marine Corps Base Camp Lejeune (CL). For each study site one simulation scenario was run with recruitment clusters added to the landscape (with RC) and another without recruitment clusters (No RC).

Spatial predictions – initial cluster abandonment

In the Sandhills most of the actual abandonment of clusters during the period of study occurred in the north of the study area around the town of Southern Pines. The simulation also predicted that abandonment of the initial clusters would be most likely in this same area in runs both with and without recruitment clusters (Figure 60). The simulation predicted relatively little initial cluster abandonment, with the majority of clusters predicted to be abandoned only once in 70 runs or not at all, and virtually none more than half the time (Figure 60). This is consistent with the very low rates of cluster abandonment observed in the real population.

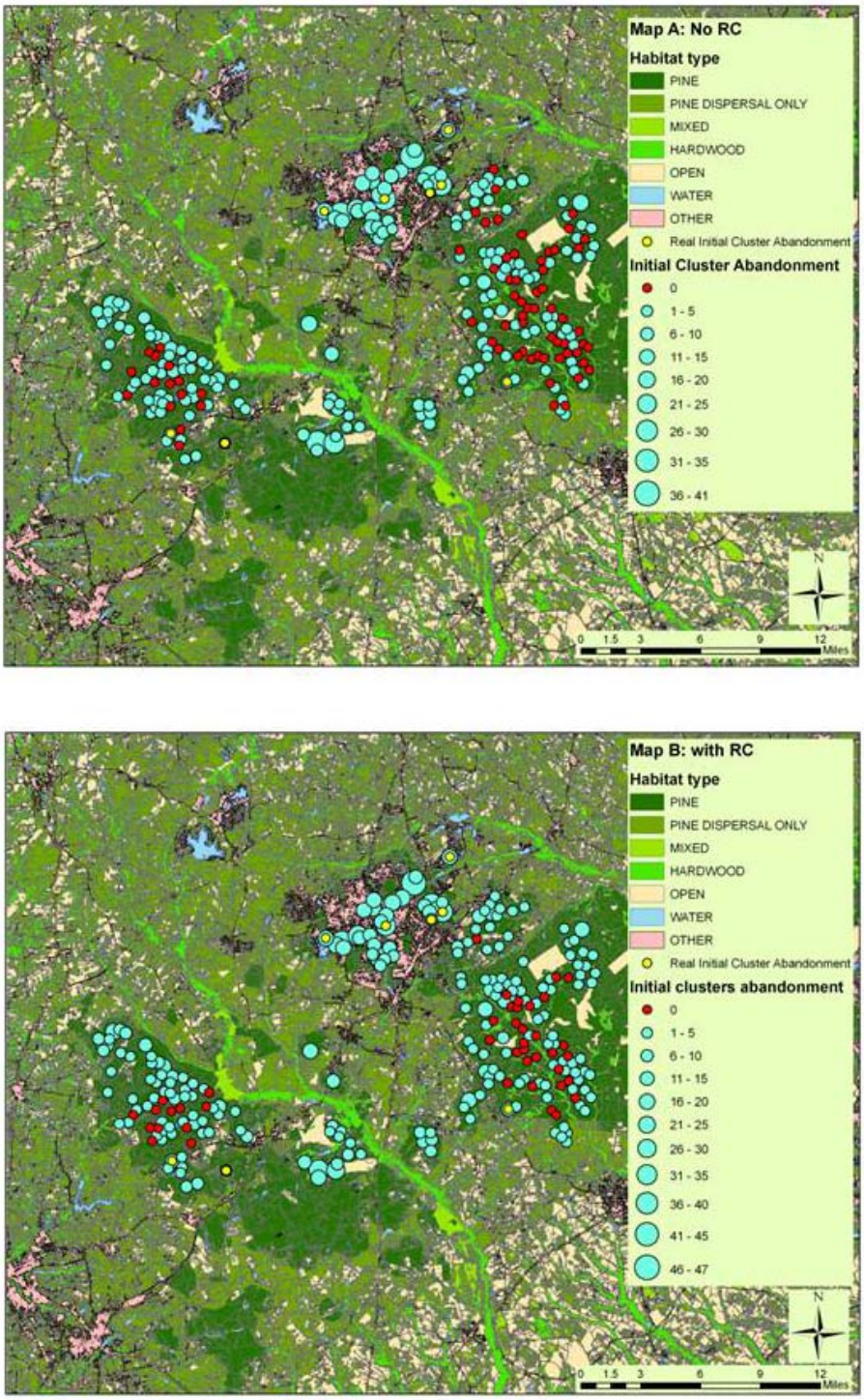
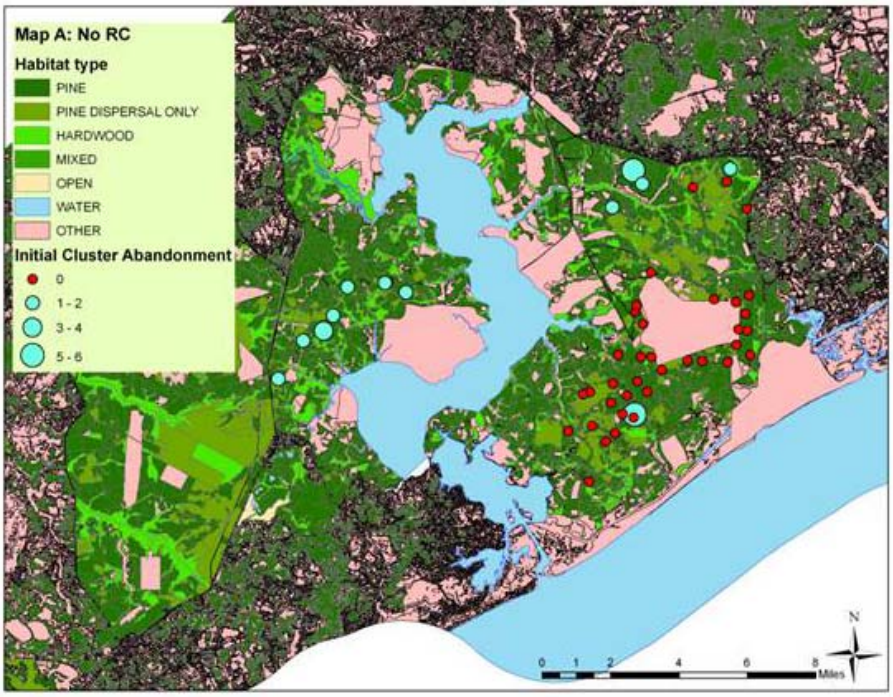


Figure 60. Map of the Sandhills study area showing initial cluster abandonment in simulations with no recruitment clusters (Map A) and with recruitment clusters included (Map B). Initial clusters that were abandoned in the real population are shown as yellow circles (●) in both Map A and Map B. Initial cluster abandonment estimated by the simulation is shown as red circles (●) where the cluster was predicted never to be abandoned and in blue (●) where the cluster was predicted to be abandoned at least once by the model. Different sizes of blue cluster represent the number of simulations of a scenario (of 70) in which the model predicted the cluster would be abandoned.

Abandonment of initial clusters was much lower at MCBCL than in the Sandhills, but this was across many fewer clusters. None of the initial clusters were abandoned during the period of study in the real population. In both the simulation with recruitment clusters and that without recruitment clusters the initial clusters in the western part of the population were predicted to be more likely to be abandoned than those in the eastern part. This is likely due to the small number of western clusters and their isolation from the remainder of the population by a large body of water, the New River (Figure 61).



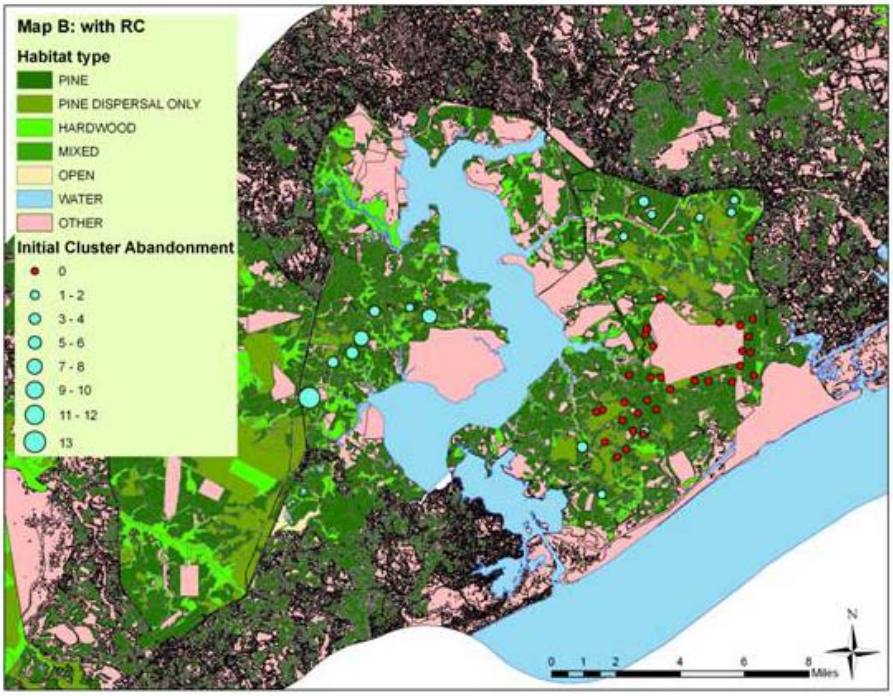


Figure 61. Map of Marine Corps Base Camp Lejeune showing initial cluster abandonment in simulations with no recruitment clusters (Map A) and with recruitment clusters included (Map B). Initial cluster abandonment estimated by the simulation is shown as red circles (●) where the cluster was predicted never to be abandoned and in blue (●) where the cluster was predicted to be abandoned at least once by the model. Different sizes of blue cluster represent the number of simulations of a scenario (of 70) in which the model predicted the cluster would be abandoned. No initial clusters were abandoned in the real population.

Spatial output – recruitment cluster success

The model predictions of the success of recruitment clusters were conservative at both study sites. Both the total number and the spatial distribution of successful recruitment clusters were different in the simulation results compared to the empirical data. In the Sandhills most of the recruitment clusters in the real population were successful, whereas in the simulations most recruitment clusters were rejected and never added to the landscape due to insufficient habitat. In the real population all of the unsuccessful recruitment clusters were in the Southern Pines area, which the model did reflect as it did not add any of those clusters to the landscape.

At MCBCL, the model again did not add most of the recruitment clusters to the landscape due to insufficient habitat. The model added 19% of the recruitment clusters to the landscape, and all of these were occupied in the real population; 47% were not added to the landscape by the model and were not occupied in the real population. The remaining 34% represent a disparity between the model and the real data as they were not added to the landscape by the model but were occupied in the real population. There was no strong spatial pattern in either the simulated recruitment clusters success or that of the real MCBCL population.

Spatial output – budding density

In the Sandhills the simulation predicted budding density to be highest around the periphery of the existing population. However, the simulation performed relatively poorly in relation to the spatial locations of real buds, many of which occurred in the midst of existing territories rather than on the periphery of the population (Figure 62). The model did not find sufficient suitable, unoccupied habitat to support a new group at the locations where many of the real buds occurred. The inclusion of recruitment clusters in the model run made very little difference to the budding density results with respect to both spatial extent and the total index value (Figure 62: Map B).

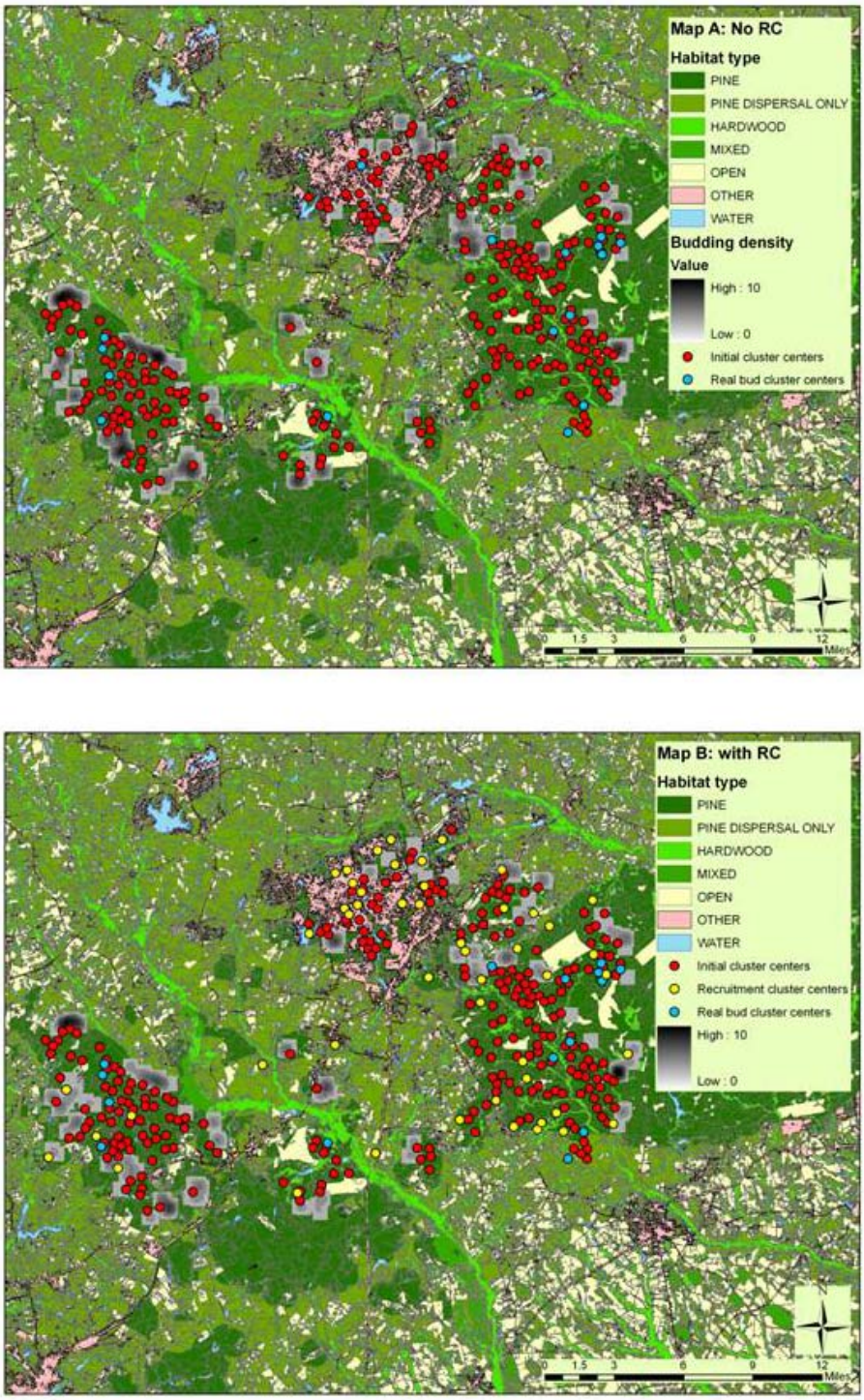


Figure 62. Map of the Sandhills study area showing real budded cluster centers (blue circles ●) and the budding density estimated by the simulation (shown in a gray scale from white = 0 to Black = 10). See text for details of budding density index. Map A shows the results of the simulation without recruitment clusters and Map B the results with recruitment clusters.

At MCBCL there was more budding in the real population than in the Sandhills. The simulation again was conservative in its prediction of the numbers and locations of potential buds (Figure 63). In the real population budding occurred throughout the spatial extent of the initial clusters whereas, again, the simulation predicted most budding to occur around the edges of the population. In the simulation without recruitment clusters budding occurred relatively evenly east and west of the New River (Figure 63: Map A) whereas in the simulation with recruitment clusters more budding occurred east of the river (Figure 63: Map B). Presumably this was because west of the river recruitment clusters were placed in several of the areas that had extensive suitable habitat.

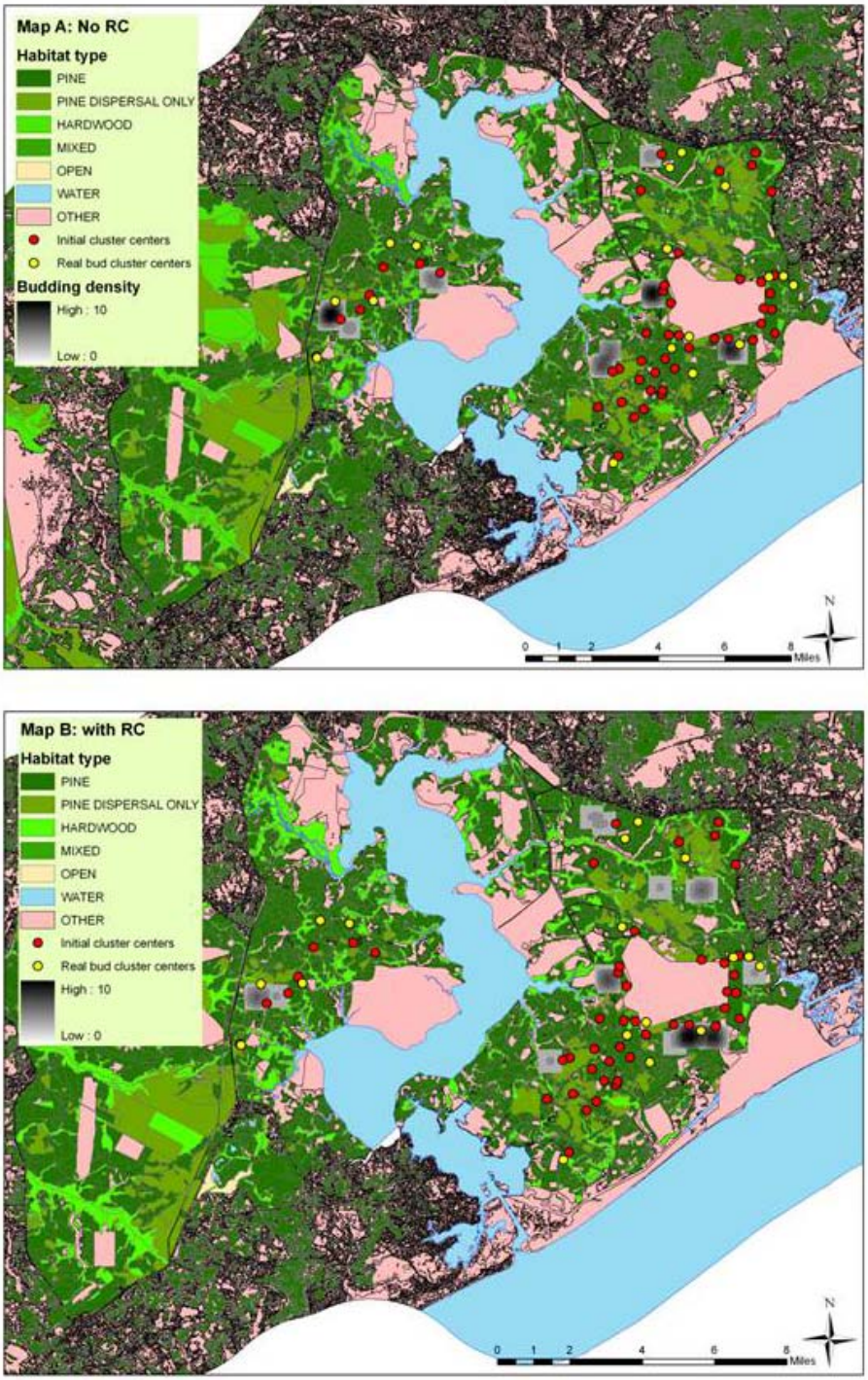


Figure 63. Map of Marine Corps Base Camp Lejeune showing real budded cluster centers (●) and the budding density estimated by the simulation (shown in a gray scale from white = 0 to Black = 10). See text for details of budding density index. Map A shows the simulation results without recruitment clusters and Map B with recruitment clusters.

Discussion

Since the DSS is based upon the 'classic' model, which has previously been well validated against the real data (Schiegg et al. 2005), it is perhaps not too surprising that the DSS performed well in this analysis. However, there have been important changes to the model in converting it from the classic version to the DSS version, particularly in dispersal behavior and interaction with the landscape. That the model performed well in simulating dispersal distance distributions suggests that these changes were effective improvements. It is also notable that the DSS was able to perform well using data from a different time period than was used in the previous validation process on the "classic" model. This provides strong evidence that the DSS is robust and reliable for the management of RCW populations.

The most notable discrepancy between the real and simulated data was in the number of occupied territories, especially at MCBCL. The DSS was unable to simulate the observed population increase at MCBCL. This was also the case in the previous validation of the classic model (Schiegg et al. 2005). The budding rate is unusually high at MCBCL, and this is the only RCW population in which pioneering occurs regularly (Walters 2004). Thus the model may underestimate the rate of new group formation for this population. The active RCW management program at MCBCL, which has been effective in improving habitat quality, may also be a factor in the unusually positive population behavior at MCBCL. However, underestimation of population increase in number of occupied territories in the Sandhills suggests a more general deficiency in the model. We suggest that requirements for suitable habitat incorporated in the model are overly conservative, that is, that RCW groups can persist on fewer acres of suitable habitat, and/or acres that do not meet the suitability criteria, required in the model. The performance of the spatial outputs of the model supports this contention. Initial cluster abandonment was well modeled, particularly at MCBCL, but initial territories are not required to meet the habitat criteria to be added to the landscape or persist. In contrast both buds and recruitment clusters must meet the habitat criteria, and the model was conservative in predicting both: budding occurred in the real populations in areas in which it did not occur in the model, and the model rejected due to insufficient habitat some recruitment clusters that were successful in the real populations. Budding was especially underestimated in areas in the midst of existing groups where the habitat criteria would be most restrictive.

That the habitat requirements in the DSS are overly restrictive is not surprising. The habitat suitability criteria described in the RCW Recovery Plan (USFWS 2003) and used in the DSS represent optimum habitat for RCWs, but the acreage criteria are based on habitat use by RCW groups existing on habitat that is less than optimum. In fact very few forest stands in current RCW populations meet the suitability criteria. We expect that RCW densities will be higher when habitat is improved to the point that the suitability criteria are met, but as yet there are no data to indicate what the appropriate acreage requirement might be. When such data are available it will be easy to add a new option that allows for higher densities. Currently we predict that the model will perform better in identifying areas with suitable habitat for new groups if the RCW matrix option rather than stand age is used, as pine age is an especially restrictive habitat suitability criterion and the matrix allows for use of less-than-optimum habitat. Given that the RCW is an endangered species, we are comfortable with a conservative model as managers invariably will want their actions to result in population behavior that is as good as or better than projected rather than risking actions that may result in worse population behavior than projected.

The DSS did not error on the side of being overly optimistic about population behavior, for example it did not predict recruitment clusters that were unsuccessful in the real populations to be successful. The DSS was instead consistently conservative with respect to landscape effects on population behavior.

Generally the model performed very well in its projections of dispersal and social dynamics and the minor discrepancies between real and simulated behavior observed all are consistent with one omission from the model, complex social behavior by dispersing birds. The model assumes that dispersing birds detect and compete for breeding vacancies. However the studies of dispersal conducted as part of SERDP project RC-1471 described above revealed that dispersing individuals often engage in prolonged interactions with groups in which no breeding vacancy currently exists and often become floaters in order to continue to do so. Currently we do not understand this complex behavior well enough to include it in the model, and its absence accounts for the model's underestimation of the number of floaters and overestimation of dispersal success near the natal site (since individuals sometimes ignore breeding vacancies close to home to interact with groups lacking a vacancy farther away). That the model underestimates the number of males breeding on their natal territory similarly can be attributed to such males rejecting some breeding vacancies in order to wait for a vacancy on the natal site. Note however that in all these respects the DSS performs better than the classic model did (see results in (Schiegg et al. 2005). It appears that the changes to movement behavior have improved the models predictive ability, particularly for females, but simulated dispersal remains simpler than real behavior. It is not clear that the minor discrepancies between simulated and real behavior merit adding more parameters to the model even were the data needed to do so available.

Those predictions that were strongly dependent on the survival and fecundity parameters of the DSS such as social structure in year 10, natal dispersal distance and age structure of the breeding population, performed particularly well. The DSS appears to be robust with strong predictive abilities when it is used within the limits of the inputs. MCBCL provides an excellent example of the ability of the DSS to provide strong secondary predictions, showing that the model structure is sound, even when the primary prediction does not perform with accuracy. Validation results suggest that the best avenues for model improvement lie with habitat requirements. Feedback from early users of the DSS suggests that the inclusion of more forest dynamics in the model would be an especially useful addition to the DSS. Currently only pine age changes over time in the DSS, whereas inclusion of temporal dynamics for other habitat elements would better allow impacts of management actions to be incorporated in simulations. This also would allow for incorporation of more flexible model requirements for quantity and quality of habitat in the DSS.

Note that the MCBCL simulations did not include the Greater Sandy Run area purchased by DOD and added to the base in 1992 (Figure 49). Much of the habitat in Greater Sandy Run is not appropriate for RCWs, and the appropriate pine stands that do exist there are much too young to support RCWs currently. Therefore it would not be appropriate to include Greater Sandy Run in simulations of the current RCW population. However, Greater Sandy Run should be included in simulations of the future populations such as simulations 3-1, 3-2, 3-3 and 3-4. We excluded it here in order to make more straightforward comparisons to the other scenarios, but we explore the potential impact of Greater Sandy Run on RCW population behavior in the additional Onslow Bight application below.

Fort Benning Application

Fort Benning in Georgia epitomizes the type of installation for which the DSS was designed. It is a key training installation, especially for mechanized units, and it is also a key installation for RCW recovery. The Fort Benning RCW population is substantial – over 300 active clusters in 2008 – and it is designated a Primary Core Population in the Recovery Plan (USFWS 2003). Furthermore, spatial requirements for training are increasing substantially due to BRAC and other programs which are bringing new units and weapon systems to the base. Conflicts between land use requirements for RCWs and military training reached a crisis point in 2008 when the Maneuver Center of Excellence (MCOE) program created a need for a substantial amount of new range area that will result in the loss of some active clusters to forest clearing and possible adverse impacts on the remaining groups. The Army sought to design range locations and configurations that would minimize impacts on the RCW population and retain potential for recovery. We worked with Fort Benning staff to design and run scenarios that simulated the future dynamics of the RCW population on landscapes altered by new range construction. This provided us an opportunity to apply the DSS in a real life situation and obtain feedback from users while providing managers at Fort Benning valuable information to include in their decision making process.

Methods

There were two assumptions of the model that are particularly important in the application of the DSS to the habitat and RCWs at Fort Benning. First, the model assumes that habitat quality does not deteriorate. Hence there was no allowance for possible reductions in foraging habitat due to the high rates of mortality of mature pines that is currently occurring at Fort Benning. To the extent that the mortality of overstory pines results in the loss of some pine stands, our results are overly optimistic.

Second, we evaluated only the direct effects of landscape change on projected RCW population dynamics. We ran two simulation scenarios, comparing the existing RCW population on the existing landscape to the population and landscape expected to result from new range construction and other development planned for Fort Benning. In the second scenario some current pine habitat was converted to cleared land, and some existing RCW groups were removed from the population. Thus comparison of the results of simulation of the two scenarios projects the impact of reduction of population size and pine habitat on the RCW population in a spatially explicit fashion. However, we assumed that there would be no indirect impacts of increased levels of military training activity on RCWs. To the extent that increased training will reduce productivity and survival of the birds our results are again optimistic. Such impacts are likely due either to disturbance of the birds themselves, or disturbance of habitat that reduces its quality for RCWs, but evaluation of these indirect effects was beyond the scope of our work.

The first scenario, termed the baseline scenario, included all of the current (i.e., breeding season 2008) active clusters on the base except for 37 clusters in the A20 Impact Area in the southwest part of the installation. These clusters were excluded because base biologists cannot access them for monitoring, and hence they are not included as part of the recovery population. The habitat in this area is counted as pine habitat, but is treated as unavailable (PINE DISPERSAL ONLY, Figure 64). Thus birds can move through it as they do other pine habitat, but new groups cannot

form by budding or in recruitment clusters within it, nor can it be used as foraging habitat by any group. Hardwood areas are treated similarly (i.e., as unsuitable habitat through which the birds can disperse) in the model, based on our observation that birds disperse through hardwood stands readily but do not inhabit them. The initial population size in the baseline scenario was 305 active clusters (Figure 64).

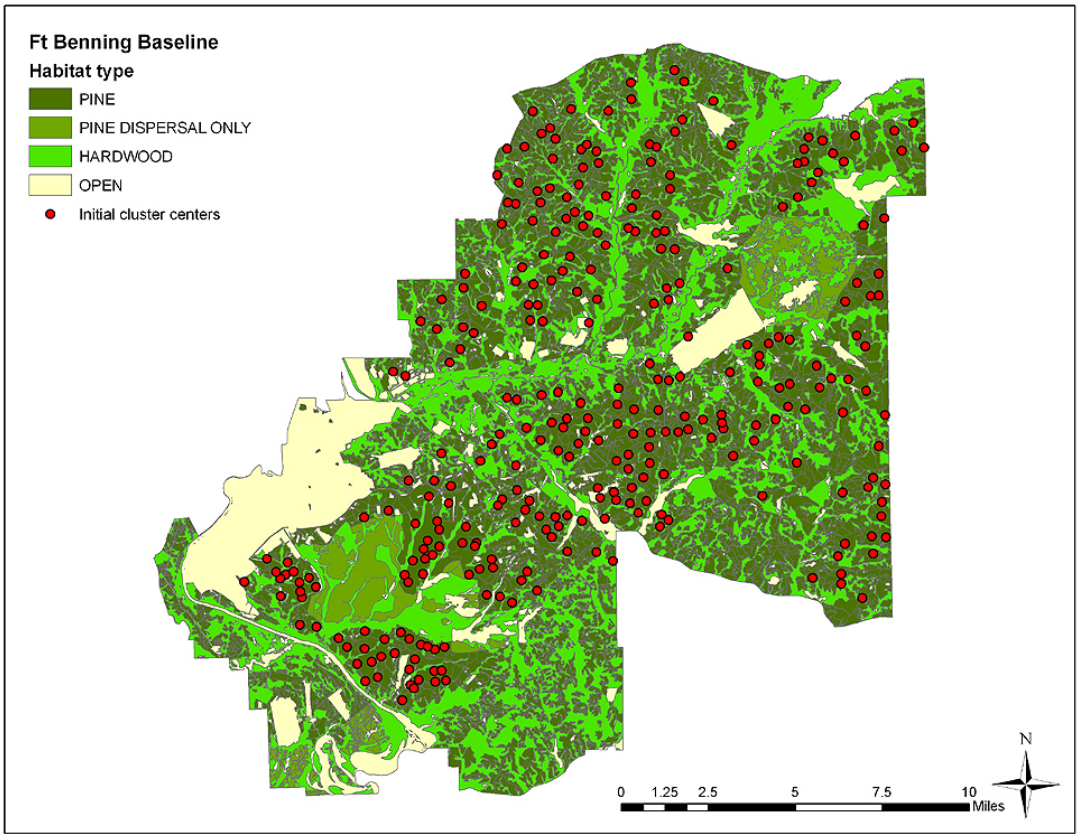


Figure 64. Baseline RCW population and habitat at Fort Benning. Note the area of Pine Dispersal Only habitat in the southwestern portion of the base, which is the A20 Impact Area.

The second scenario, termed post-MCOE, represented the projected landscape under a worst case scenario for loss of active clusters and pine habitat to new range construction and other development necessary to support the expanded military mission under the MCOE and other programs. The initial population size in this scenario was 229 active clusters (Figure 65). A dramatic increase in the amount of open land is evident in comparing the post-MCOE landscape (Figure 65) to the baseline landscape (Figure 64). The reduction in number of active clusters, though substantial, is not as dramatic as the increase in amount of open land because some of the cleared areas are in parts of the base that have few or no active RCW clusters.

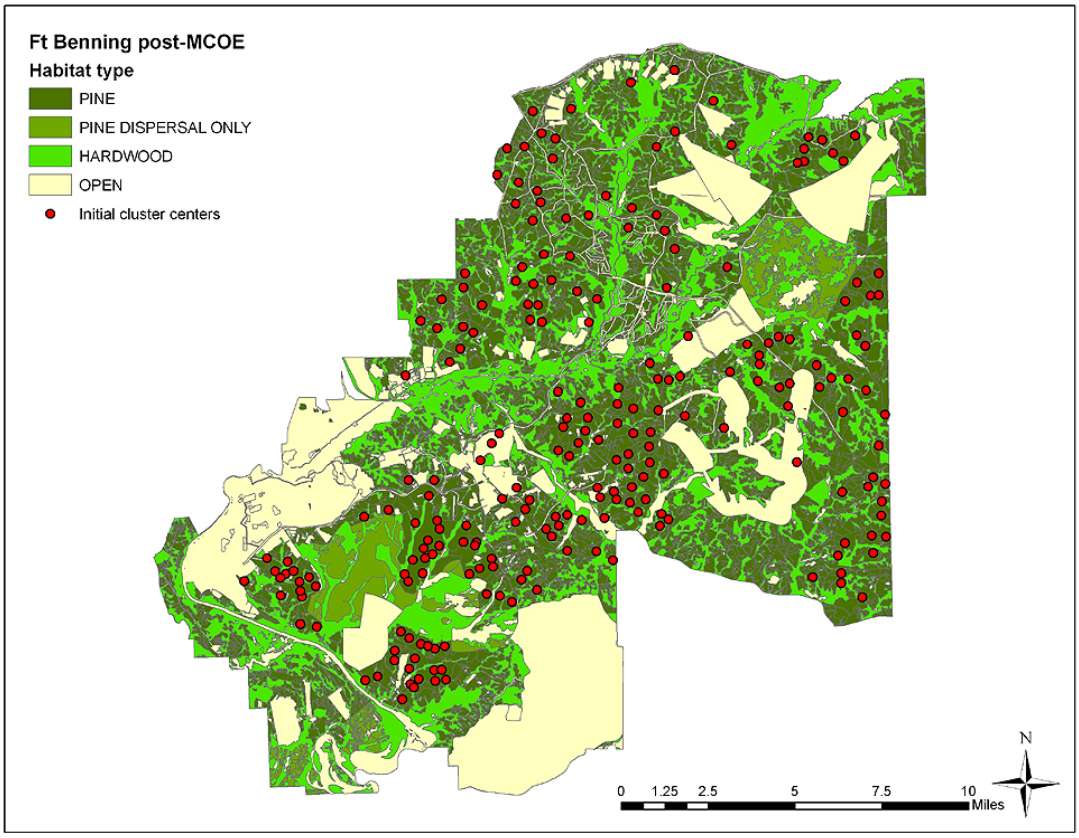


Figure 65. Post-MCOE RCW population and habitat at Fort Benning.

Both scenarios were run for first 20 years, and then 50 years. We considered the 20 year simulations the most realistic, as assumptions about habitat change become less valid with time, i.e., it is difficult to project with confidence what the landscape will look like far into the future, as additional changes in training and other factors are likely to increasingly alter land use further as time passes. The 50-year simulation of course replicates the 20-year simulation for the immediate future, but its longer term projections provide additional information about the future capacity of the landscape. As in all simulations, results should be interpreted in terms of generalities rather than details, and overall patterns rather than specific outcomes.

Results

Baseline population

The results of the 20 year baseline simulation suggest that the current population is viable, as the population grows rather than declines (Figure 66). The average annual population growth rate in number of groups was 0.87%, which is about half of the maximum possible growth rate of 2%. The realized rate of growth is expected to be less than the maximum possible growth rate because some of the 2% of territories randomly selected for budding in a particular year cannot bud due to insufficient habitat in their vicinity. In this case budding at the maximum rate would

add about three territories per year, whereas in the simulation about one territory per year was added on average. In eight of the 70 runs the population declined rather than increased. This suggests that the baseline population is somewhat vulnerable: even though within most of the range of possible environmental stochasticity the population is projected to increase, there is a part of that range within which it could decline slightly.

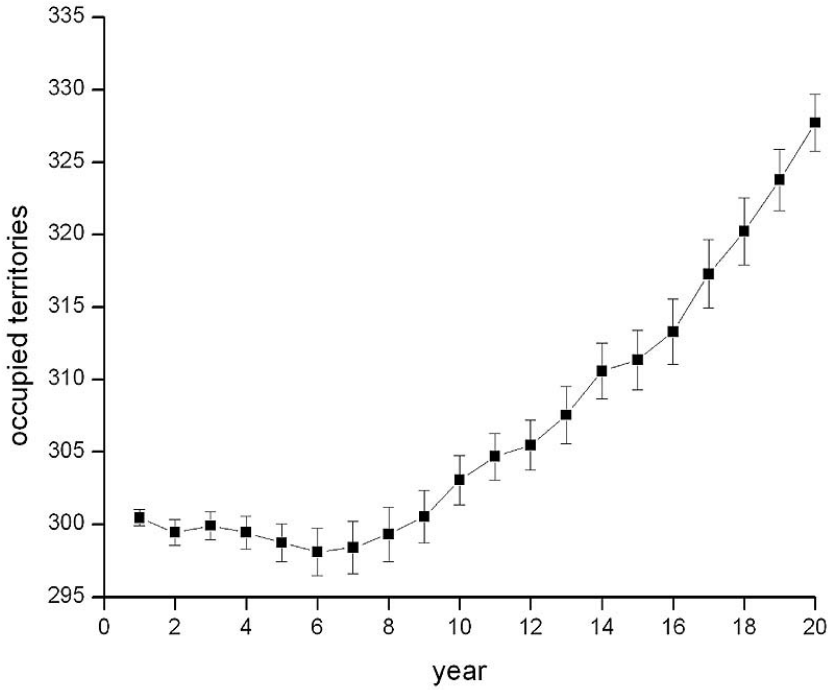


Figure 66. Projected dynamics of the existing Fort Benning RCW population over the next 20 years. Population size is measured in number of active territories. Error bars indicate variance among the 70 runs of the simulation.

Note that the increase in population size was not immediate: the average population size declined slightly for the first 6-7 years before population growth began (Figure 66). Thus, through the first half of the simulation there is roughly a balance between territories lost and territories gained, whereas beyond that time gains consistently outnumber losses. We think that this is due to two factors. First, the spatial configuration of the population improves as spatially isolated territories are lost in some areas, and the density of groups increases due to budding in other areas. Second and more importantly, group size in the initial population was fairly small (roughly 2.5) but increased to an asymptotic value of roughly 2.8 by about half way through the simulation (Figure 67). Larger group sizes translate into more birds available to fill breeding vacancies, and thus a reduced probability of territories being lost and an increased probability of new territories formed by budding remaining occupied. We believe this resulted in improved population dynamics in the latter part of the simulation, that is, that the similar timing of approaching peak group size and beginning sustained population growth is no coincidence.

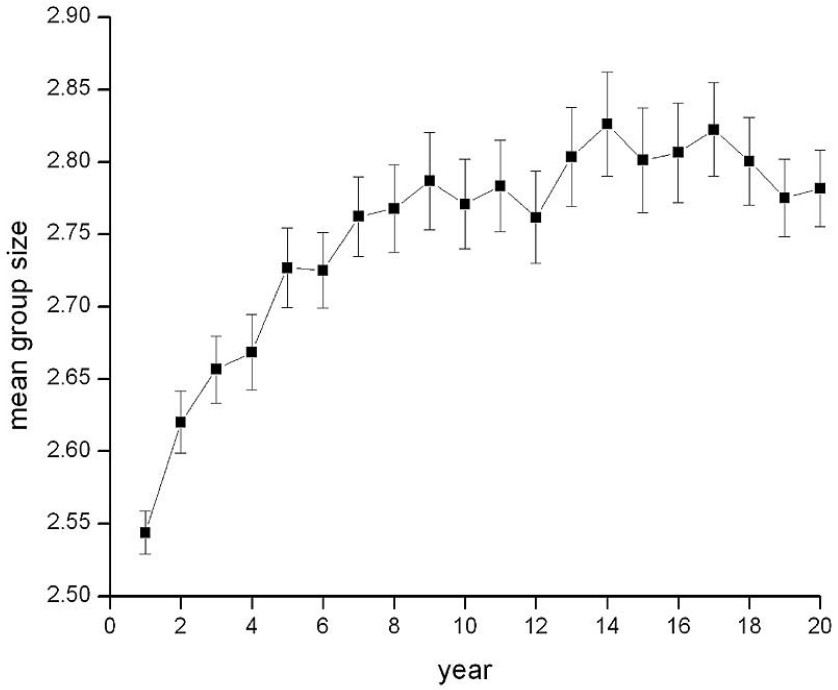


Figure 67. Mean group size as a function of time in the 20 year baseline simulation. Error bars indicate variance among the 70 replicates of the simulation.

No clear areas of population instability were evident in the 20 year simulation of the baseline population. No particular territory was abandoned in more than five of the 70 runs of the simulation, and most territories were lost at least once (Figure 68). This indicates that the current spatial configuration of territories is reasonably good. The most stable area was the cluster of territories to the northeast of the A20 Impact Area: none of these territories were lost in any model runs (Figure 68). Territories at the northeast corner of the population appeared to be the most vulnerable to loss, and generally territories at the edge of the population were lost more often than interior territories, a finding in agreement with empirical data from many populations.

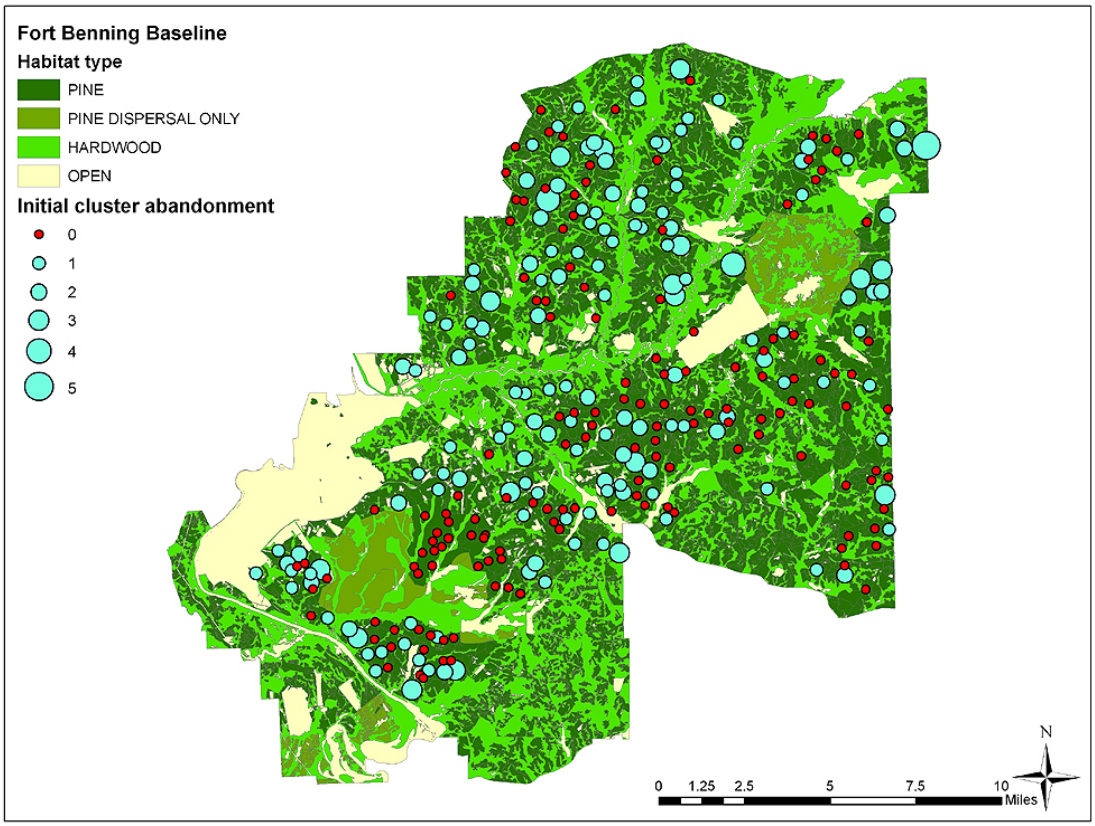


Figure 68. Number of runs (of 70) in which each individual territory was abandoned in the 20 year simulation of the baseline population.

The population increase in the 20 year simulation suggested that there was sufficient suitable habitat on Fort Benning to hold more groups than currently exist there. The results of the 50 year simulation further support this conclusion, as the population is projected to continue to increase, reaching 434 active clusters at year 50 on average (Figure 69). The average rate of population growth in the 50 year simulation was 0.97%, which is slightly higher than that in the 20 year simulation, but still about half of the maximum possible rate of growth. Over the 50 year period pine stands that are currently too young to constitute suitable habitat become available, increasing the total amount of suitable habitat beyond that which currently exists. As discussed above, we assume that no habitat is lost over the 50 year period, so amount of habitat can only increase in the simulation, which clearly is overly optimistic. If any pine stands are harvested or lost to catastrophes such as wind damage, fire damage or excessive tree mortality then habitat availability will be less than projected in the simulation. Nevertheless these results indicate that the base has the potential to house a substantially larger population than that which exists today: the average increase in the simulation represents nearly a 50% increase in population size. Projected population growth in the first 20 years of the 50 year simulation (Figure 69) is virtually identical to that in the previous, 20 year simulation (Figure 66). Results for changes in group size are virtually identical as well (Figure 70 versus Figure 67). Note that the asymptotic group size persisted over the longer duration of the second simulation (Figure 70).

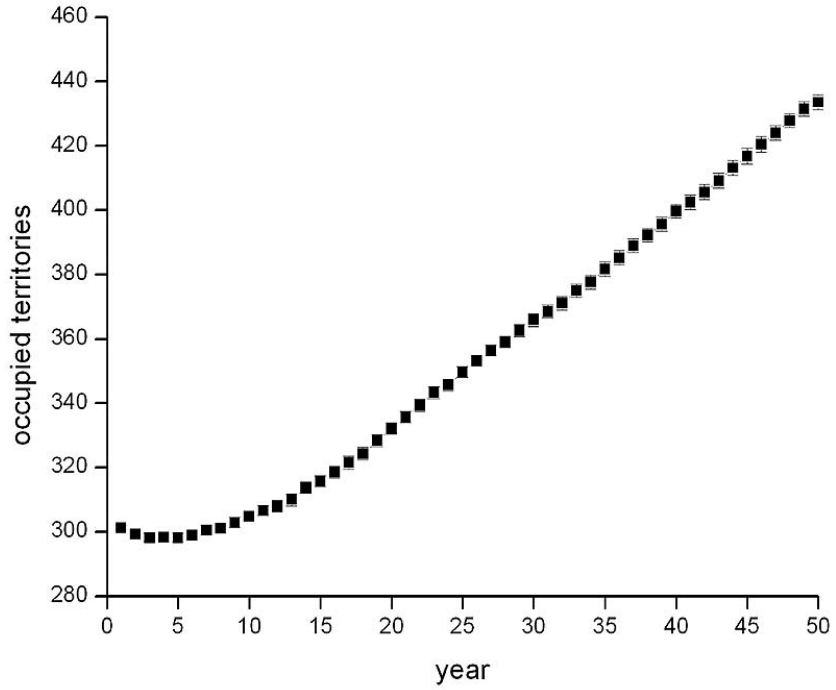


Figure 69. Projected dynamics of the existing Fort Benning RCW population over the next 50 years. Population size is measured in number of active territories. Error bars indicate variance among the 70 replicates of the simulation.

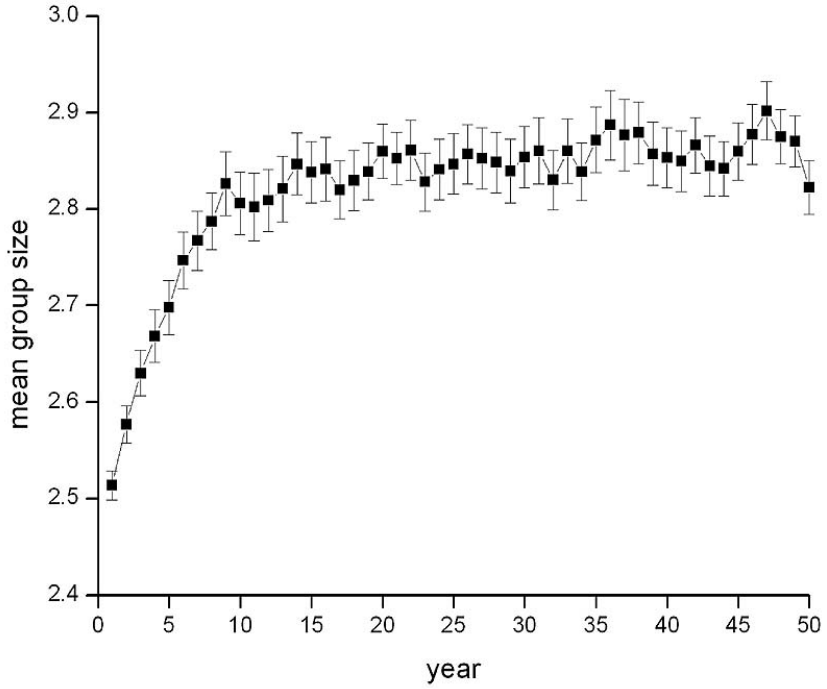


Figure 70. Mean group size as a function of time in the 50 year baseline simulation. Error bars indicate variance among the 70 replicates of the simulation.

The relative vulnerability of territories to abandonment was more clearly revealed by the longer simulation. The most vulnerable territories were located at the southwest and especially northeast edge of the population (Figure 71). There were clusters of territories in both of these locations that were lost in 10-20% of the runs. What generally occurred is that in some runs, but not others, some of these territories in these areas were lost due to stochastic events. This reduced the density of territories in the area, making those that remained more vulnerable to abandonment, and thus additional territories were lost. Our interpretation of this result is that the spatial configuration of the population in these areas, due to the relatively small number of territories and their spatial isolation from the rest of the population, potentially is unstable within a small portion of the range of environmental stochasticity observed in RCWs.

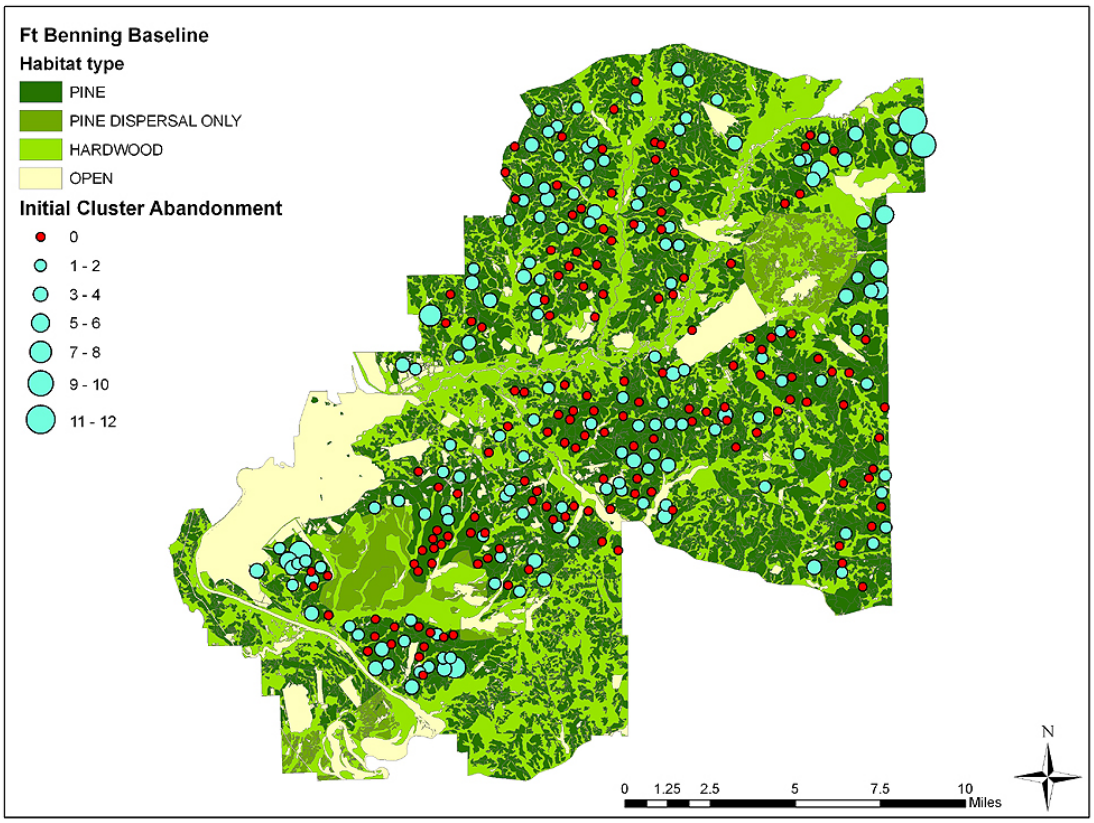


Figure 71. Number of runs (of 70) in which each individual territory was abandoned in the 50 year simulation of the baseline population.

It is in the areas in which territories were seldom abandoned that population growth was sustained in the simulation. It is difficult to portray average population growth spatially since each run of the simulation has unique results, that is, the set of occupied territories at the end of the simulation is different in every run. To portray an “average” final population, we took the average number of active territories at the end of the simulation, found the single run with the final population size closest to that average, and produced a map of the active territories at the end of that run (Figure 72). In this “average” run for the 50-year baseline simulation, population size changed very little in the areas in which territories were abandoned most frequently. In these

areas at the northeast and southwest edges of the base, a few territories were lost (initial cluster center with no associated polygon in Figure 72), and a few new territories formed (polygon with no associated initial cluster center in Figure 72). In contrast there were many new territories in three areas, (1) northeast of the A20 Impact Area, (2) immediately northeast of the first area in the center of the base and (3) in the north-central part of the base. This output suggests that the potential instability of the northeast and southwest edges of the base may be due not only to the isolation of these areas, but also lack of habitat for additional growth. It also suggests that potential habitat exists to support a large, stable core population in the center of the base, running from northeast of the A20 Impact Area to the north-central boundary of the base (Figure 72).

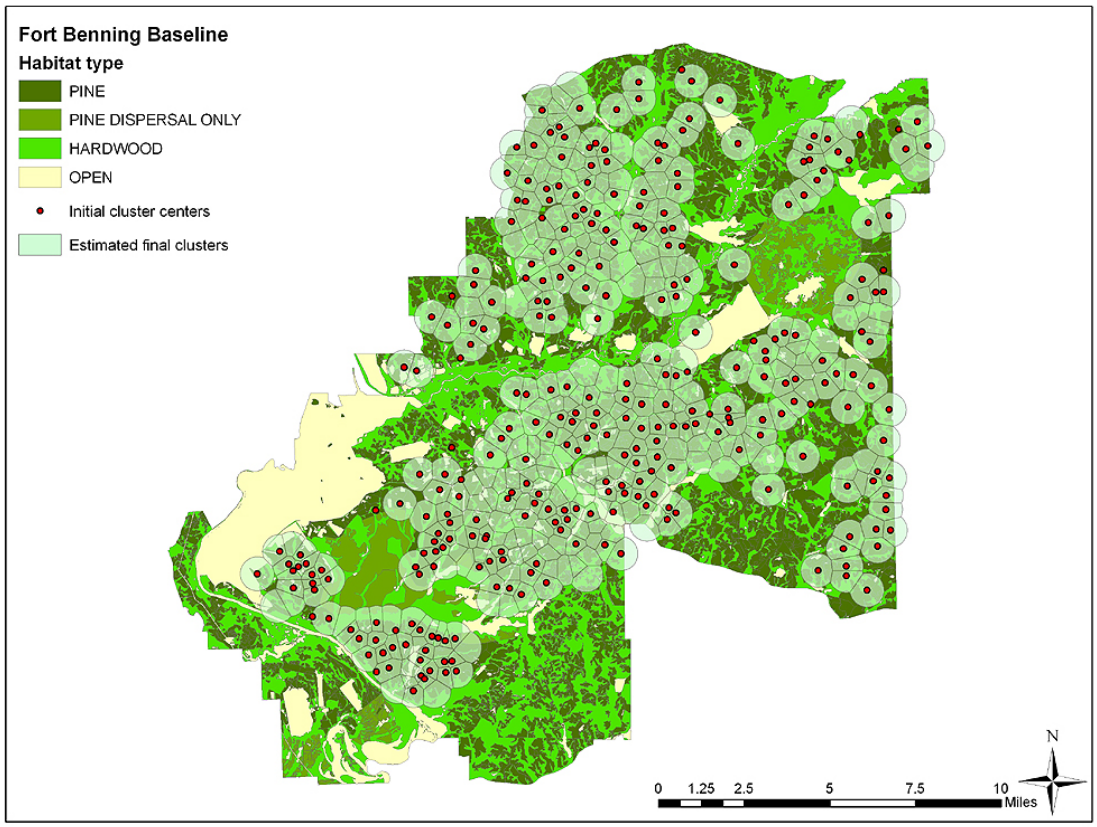


Figure 72. Active territories at the end of the simulation in the run (of 70) with the number of final active territories closest to the simulation average, for the 50-year baseline simulation. Polygons depict the habitat assigned to each territory.

Our overall general conclusion for the baseline scenario is that the model results indicate the current size and spatial configuration of the population is such that the population is projected to be viable provided that existing habitat is retained and is managed so that it qualifies as good quality foraging and nesting habitat. The model projects that the existing population could be recovered on the current landscape.

Post-MCOE population

The post-MCOE population was smaller (by 76 active territories) than the baseline population, and was more fragmented by additional habitat gaps (Figure 65). Despite these changes, the population was still projected to increase, again following an initial lag over the first six years (Figure 73). The mean annual population growth rate was 0.74%, which is about 15% lower than the mean annual growth rate of the baseline population. The population declined in 10 of the 70 runs, compared to 8 of 70 for the baseline population. Our interpretation of these results is that the loss of habitat and active territories to construction represented by the difference between the baseline and post-MCOE populations increases the chances that the Fort Benning population will decline slightly, but the most likely outcome still is that the remaining population will be stable or increasing. These results are not surprising. Previous work with the model indicated that populations above 250 groups were always stable and populations below 100 groups were generally unstable, whereas between 100 and 250 groups stability depends on both population size and spatial configuration (Walters et al. 2002a). At 229 groups the post-MCOE population was still large enough to be near the upper end of the range where poor spatial structure can induce instability, and the spatial structure was good enough to avoid instability. In particular the spatial structure of the post-MCOE population had one very positive element: it retained the large central core running from northeast of the A20 Impact Area to the north-central portion of the base (Figure 65), the same area that supported most of the population growth in the baseline scenario (Figure 72). We think this is the key to the positive behavior of the post-MCOE population.

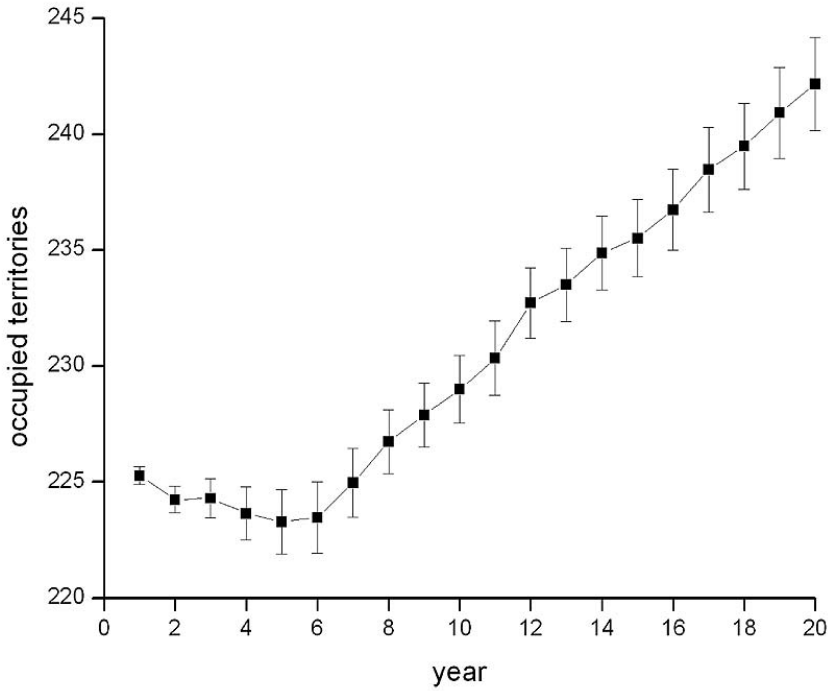


Figure 73. Projected dynamics of the post-MCOE Fort Benning RCW population over the next 20 years. Population size was measured in number of active territories. Error bars indicate variance among the 70 replicates of the simulation.

The initial lag in the growth of the post-MCOE population can be explained in the same way as the identical lag observed in the growth of the baseline population: improving spatial structure and increasing group size (Figure 74) resulted in more favorable population dynamics after the first few years. Group size increased more slowly in the post-MCOE simulation (Figure 74) than in the baseline simulation (Figure 67) and fluctuated more around its asymptotic value. This again indicates more stochasticity, and thus somewhat greater vulnerability to poor population behavior, in the post-MCOE population compared to the baseline population.

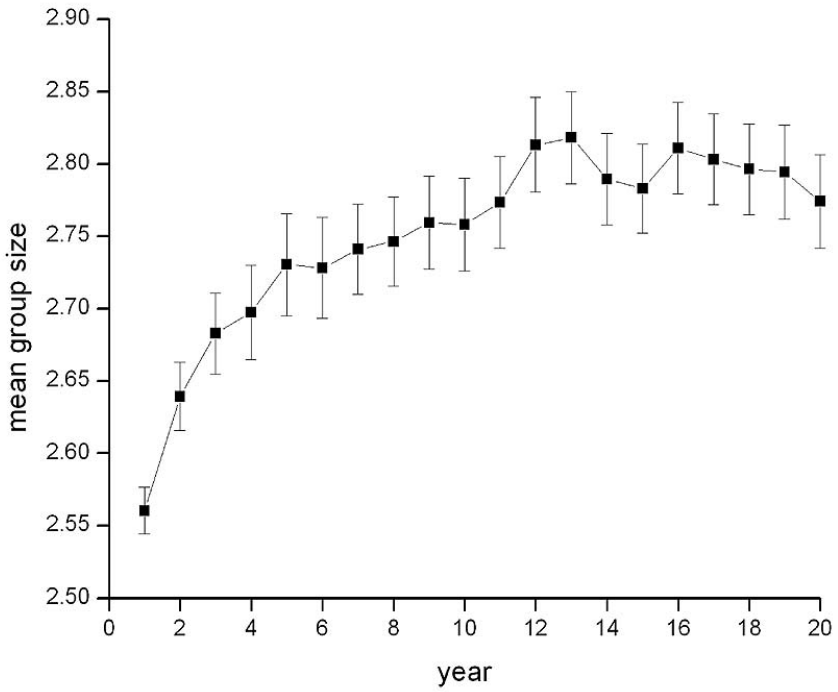


Figure 74. Mean group size as a function of time in the 20 year post-MCOE simulation. Error bars indicate variance among the 70 replicates of the simulation.

An examination of the individual territories lost suggests much the same thing. The number of runs in which a particular individual territory was lost is larger in the post-MCOE simulation (Figure 75) than in the baseline simulation (Figure 68). Several territories were lost in 10 or more runs of the post-MCOE simulation, whereas no territory was lost in more than five runs of the baseline simulation. There was also some shifting in the degree to which different areas were vulnerable to territory loss. In the post-MCOE simulation edge territories were more vulnerable to loss than central ones as before, but there was a marked increase in the vulnerability of the territories at the northeastern edge of the base (Figure 75) compared to the baseline simulation. The subpopulation in this area was highly vulnerable to loss on the post-MCOE landscape. This was likely due to the increased spatial isolation of this subpopulation resulting from the creation of several new, large habitat gaps in this area. The adjacent edge territories to the north and west were also more vulnerable to loss in the post-MCOE scenario than they were in the baseline scenario (Figure 75). Thus it appears that the largest impact of the projected MCOE and related construction over the short term would be to put the subpopulation located in the northeastern corner of the base at risk.

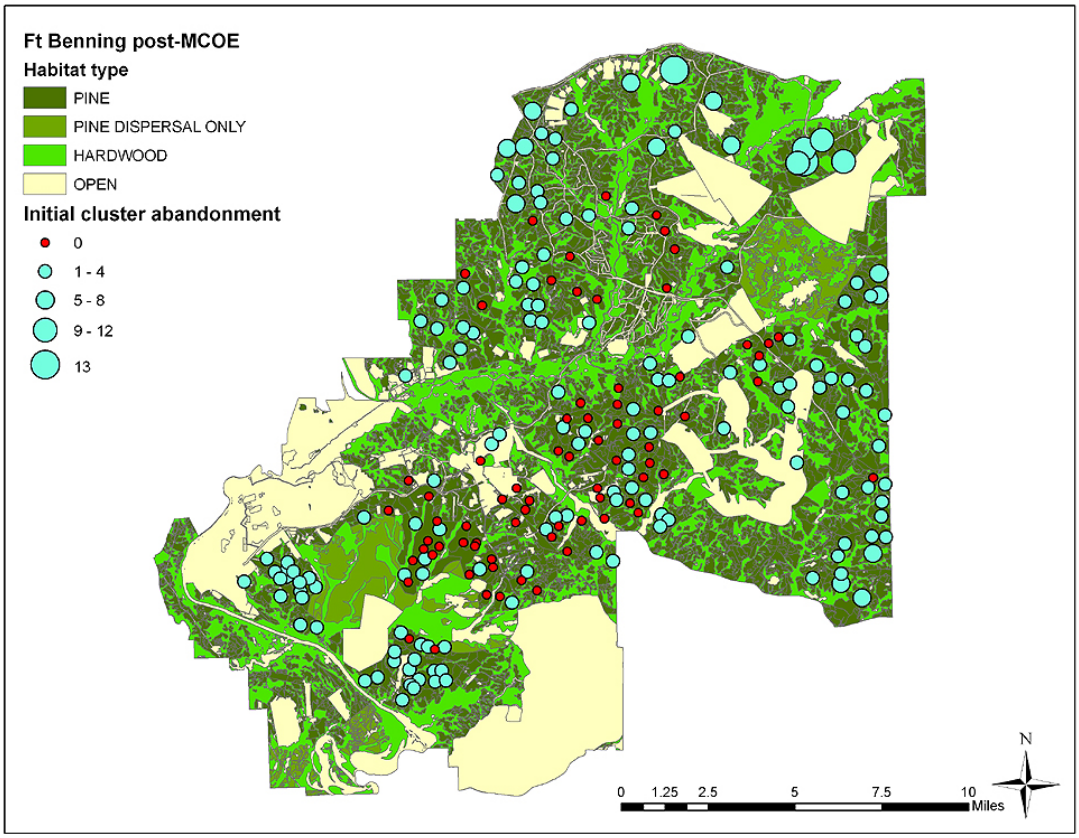


Figure 75. Number of runs (of 70) in which each individual territory was abandoned in the 20 year simulation of the post-MCOE population.

The 50-year simulation of the post-MCOE population confirmed the vulnerability of the northeastern subpopulation over the long term. The group of territories in the northeast corner of the base was lost in nearly half the runs (Figure 76), and territories to the west along the northern edge of the base were lost frequently as well. The longer-term simulation revealed an additional area of vulnerability along the eastern edge of the base, and especially in the southeastern corner (Figure 76). In contrast, territories in the southwestern part of the base were seldom lost, despite some degree of apparent isolation from the core of the population to the northeast. Presumably this was because the new construction in the southwestern part of the base is outside the edges of this subpopulation rather than between it and the population core. The southwestern subpopulation is separated from the core by distance, but is still connected to the core because birds can disperse through the intervening A20 Impact Area and hardwood stands. In contrast, the vulnerable subpopulations in the northeast and southeast are separated from the core population not only by distance, but also by new habitat gaps that impede dispersal.

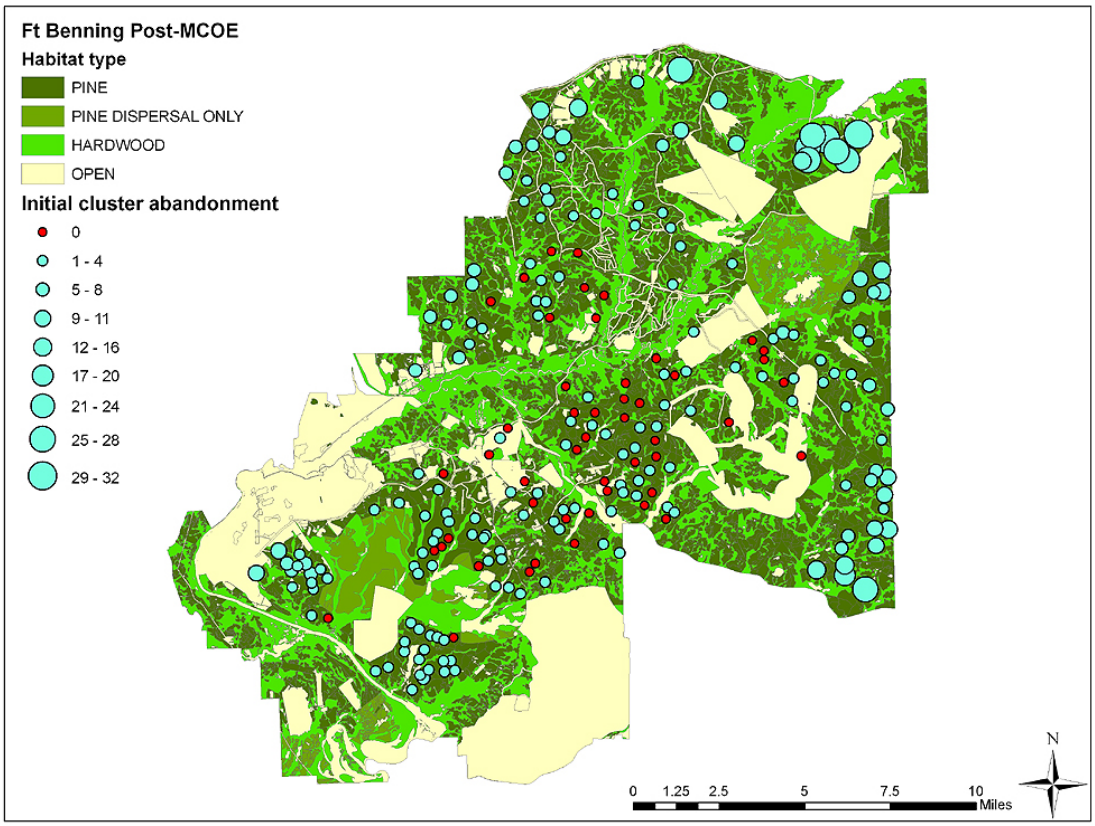


Figure 76. Number of runs (of 70) in which each individual territory was abandoned in the 50 year simulation of the post-MCOE population.

The "average" simulation run of the post-MCOE population exemplified these patterns. In this run the northeastern subpopulation was nearly extirpated, with only two active territories remaining (Figure 77). Two of the three closest territories to the west were also abandoned. In this run, unlike some of the others, the southeastern subpopulation increased. This illustrates the stochasticity associated with the fate of this subpopulation in the post-MCOE landscape. It may start on a path of decline or a path of increase depending on chance events such as births, deaths and movement directions of particular individual birds, and thereby move above or fall below a 'critical mass' necessary for long term stability. The odds of climbing above this 'critical mass' were better than even for this subpopulation, whereas they were very slim for the northeastern subpopulation. The consistent growth areas over the long term were the southwestern subpopulation and the central core running from northeast of the A20 Impact Area to the northeast and then to the north (Figure 77). Our results suggest that in the post-MCOE landscape there will be sufficient habitat in these portions of the base to support population growth over the long term, assuming no additional habitat is lost.

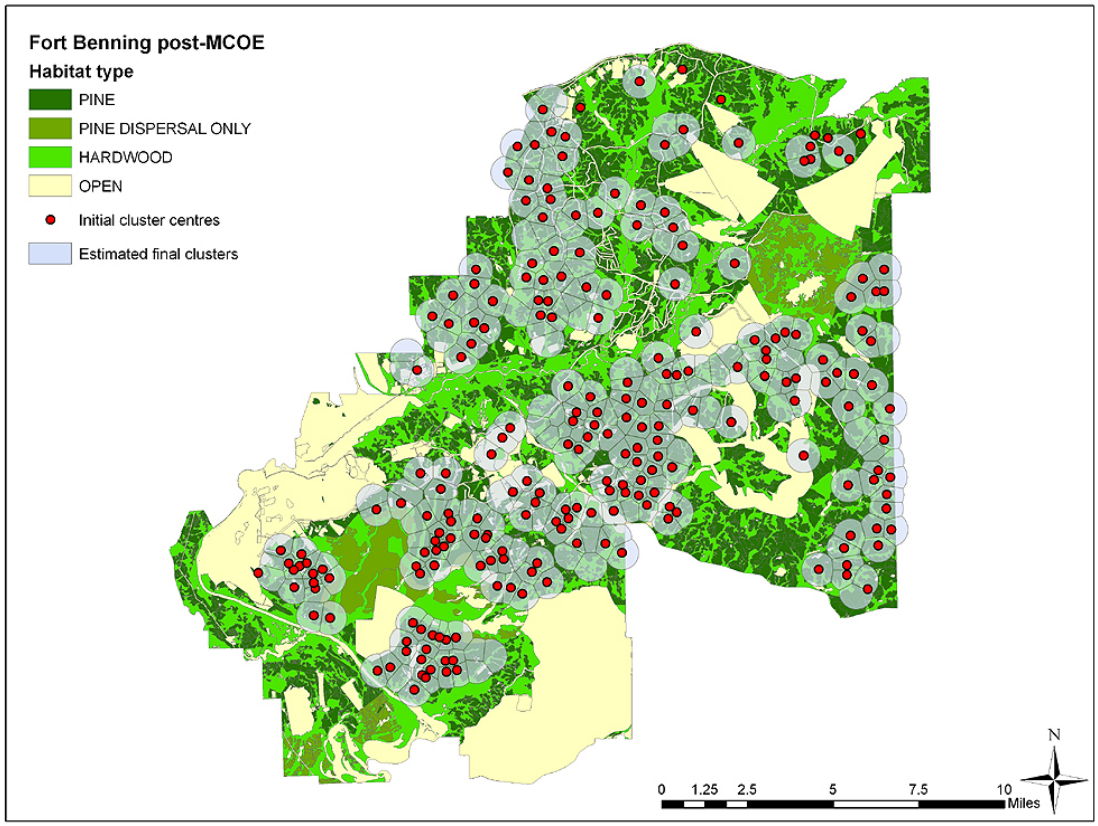


Figure 77. Active territories at the end of the simulation in the run (of 70) with the number of final active territories closest to the simulation average, for the 50-year post-MCOE simulation. Polygons depict the habitat assigned to each territory.

The post-MCOE population was projected to grow over the long term, with an average annual growth rate over 50 years of 0.77%, slightly higher than in the 20 year simulation. One of the most interesting results of these simulations was that the projected final size of the post-MCOE population after 50 years is virtually identical to the initial population size in the baseline simulation (Figure 78). Thus our results indicate that it is unlikely that the MCOE and related construction will trigger a decline of the RCW population on Fort Benning, but it is very likely to set the population back 50 years on its course toward recovery, and increase the degree to which it is concentrated in its central core. In the 50 year simulation of the post-MCOE population, group size reached a clear asymptote at about 2.8 birds per group (Figure 79), the same asymptotic value observed in the baseline simulation (Figure 70), but it did not reach that value until roughly year 15. This reinforces the lack of a clear asymptote in the 20 year simulation of the post-MCOE population (Figure 74), and represents yet another sign of the more stochastic behavior of the post-MCOE population compared to the baseline population.

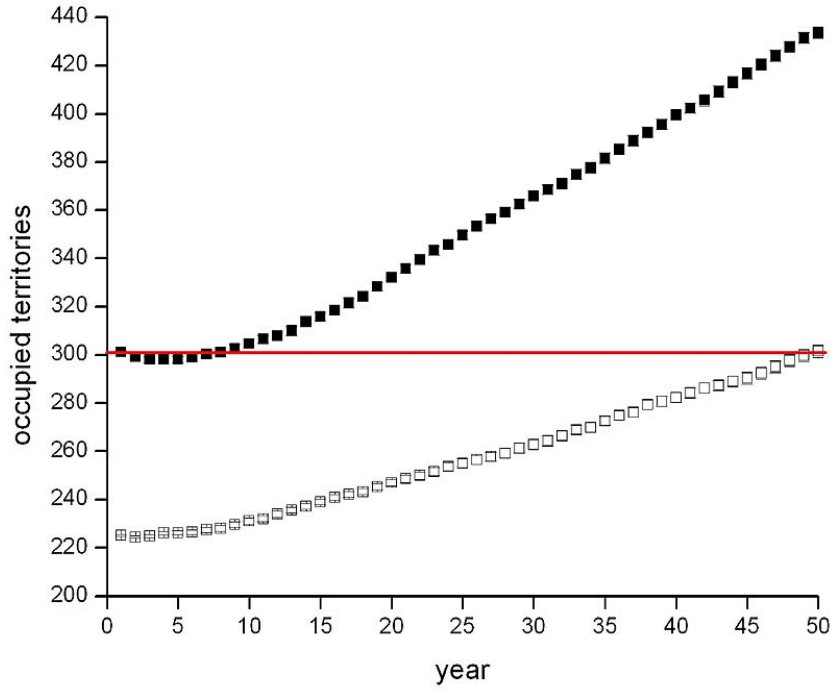


Figure 78. Projected dynamics of the existing Fort Benning RCW population (solid squares ■) and the post-MCOE population (open squares □) over the next 50 years. Population size is measured in number of active territories. Error bars indicate variance among the 70 replicates of each simulation. The red line depicts the initial size of the baseline population.

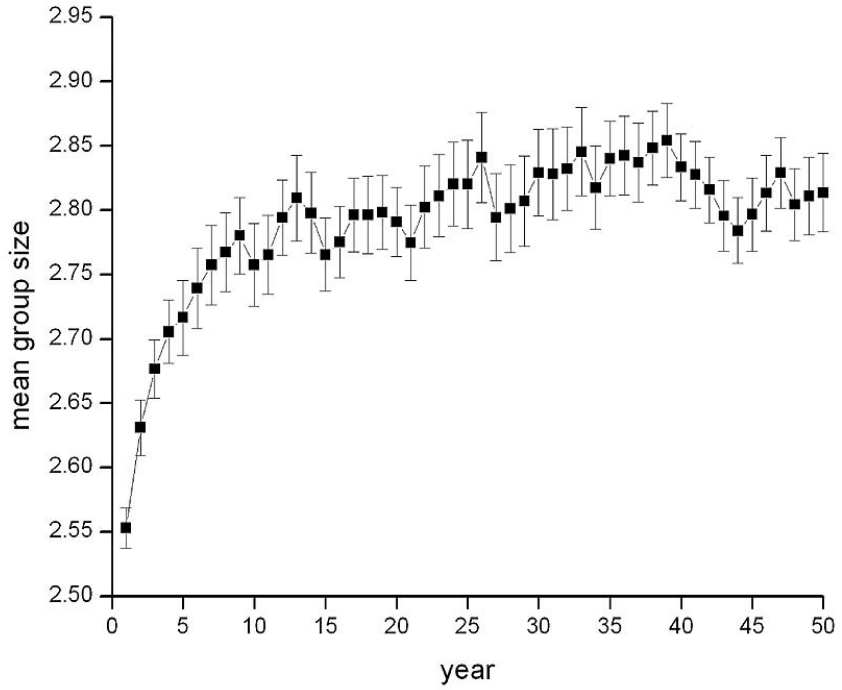


Figure 79. Mean group size as a function of time in the 50 year post-MCOE simulation. Error bars indicate variance among the 70 replicates of the simulation.

Potential impact of recruitment clusters

In the above simulations population growth occurred only through budding, limiting the maximum possible annual growth rate to 2%, with realized annual growth of less than half that in all scenarios. In real populations annual growth by natural processes (i.e., budding and pioneering) typically is 1-2%, and to our knowledge growth rates by these processes above 4% have never been observed. In contrast managers routinely stimulate population growth rates of 10%, and sometimes even higher rates, by placing recruitment clusters at strategic locations on the landscape (Walters 2004). The DSS has the capability to simulate the effect of this management technique, by placing recruitment clusters on the landscape as open territories in a predesignated year. To assess the potential capacity of recruitment clusters to stimulate higher rates of population growth and stabilize areas in which territories are vulnerable to loss, we repeated the post-MCOE simulations, adding recruitment clusters in strategic locations and at appropriate times (i.e., when sufficient habitat at a location was likely to be available) identified by Fort Benning staff. A total of 144 recruitment clusters were added, the first ones in year 3 of the simulations and the last ones in year 50. Recruitment clusters were distributed throughout the base, but were more concentrated in some areas than others (Figure 80). Notable features of their distribution include the following: (1) they were more concentrated toward the edges of the base than in the center, including extending beyond the existing population to the southwest; (2) a large number were located in the southeastern part of the base, augmenting the eastern edge subpopulation and better connecting it to the central core population; and (3) a large number were located in the north-central part of the base, augmenting the population there (Figure 80).

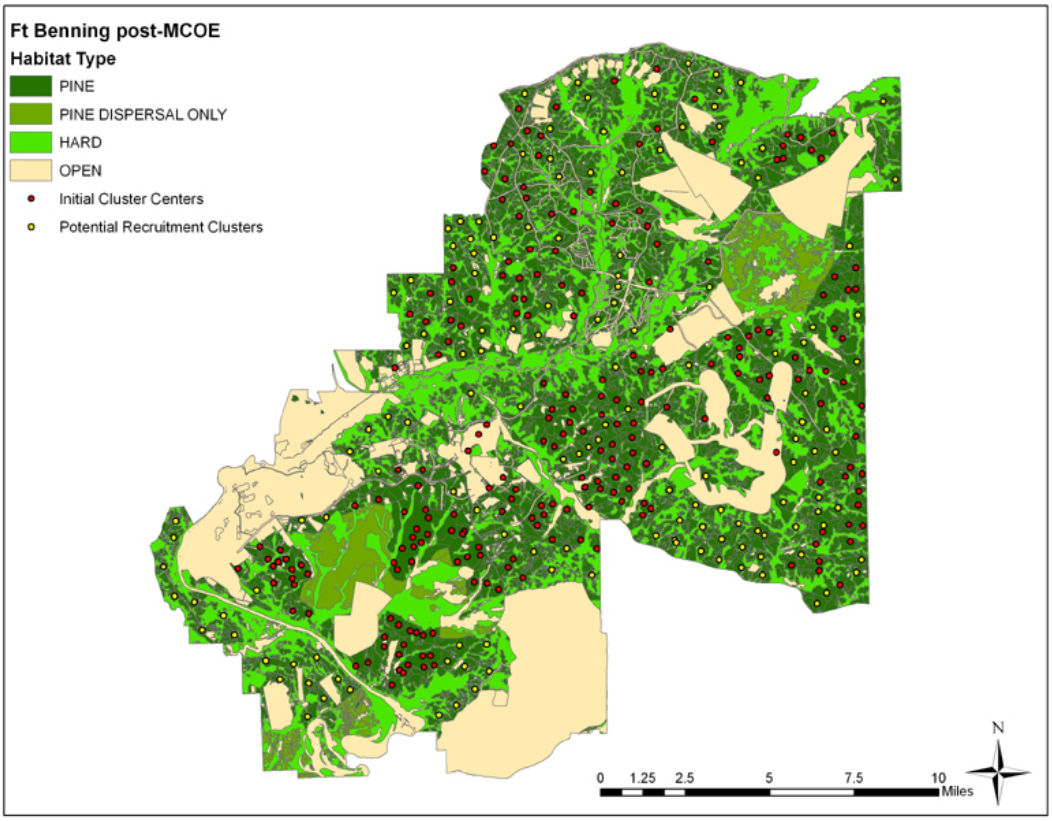


Figure 80. Post-MCOE RCW population and habitat, with recruitment clusters added.

The recruitment clusters had a large impact on the projected dynamics of the post-MCOE population. On average the addition of recruitment clusters resulted in significant growth of the post-MCOE population over 20 years, whereas without recruitment clusters growth is projected to be modest (Figure 81). Still, the population declined in 11 of the 70 runs of the post-MCOE population with recruitment clusters, nearly twice as often as in the runs of the baseline population. This indicates that there is still more stochasticity and thus uncertainty in the behavior of the post-MCOE population, even with the addition of recruitment clusters. This is not surprising, as whether or not a particular recruitment cluster becomes occupied is an additional source of stochasticity and uncertainty in the dynamics of the population. Group sizes were somewhat lower in runs with recruitment clusters than in runs without them. This is expected, as recruitment clusters provide new breeding opportunities and hence attract young birds that might otherwise remain with their natal group as helpers.

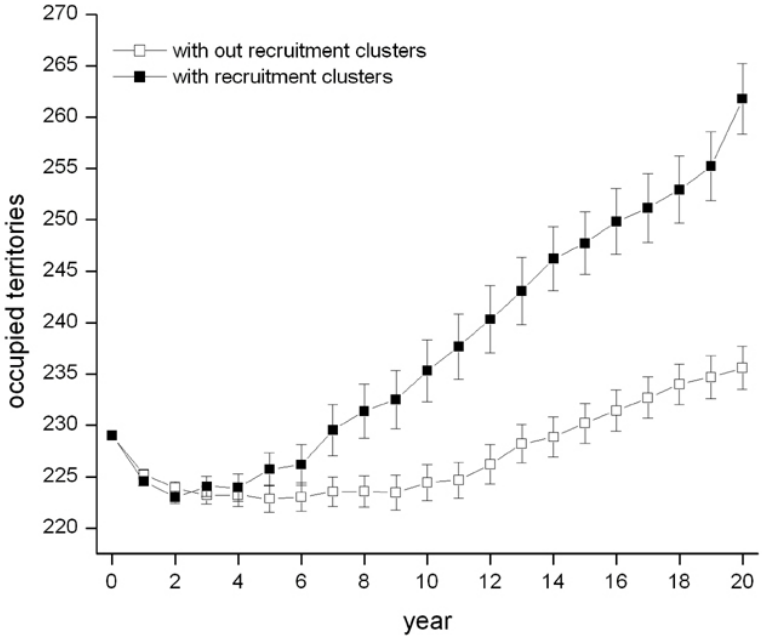


Figure 81. Projected dynamics of the post-MCOE Fort Benning RCW population over the next 20 years, with and without the addition of recruitment clusters. Population size is measured in mean number of active territories across the 70 simulations. Error bars indicate variance among the 70 replicates of the simulation.

With the addition of recruitment clusters the post-MCOE population is projected to recover to beyond baseline levels in 50 years (Figure 82). However, over the long term the post-MCOE population, even with the addition of recruitment clusters, is not projected to grow as much as the baseline population (Figure 69).

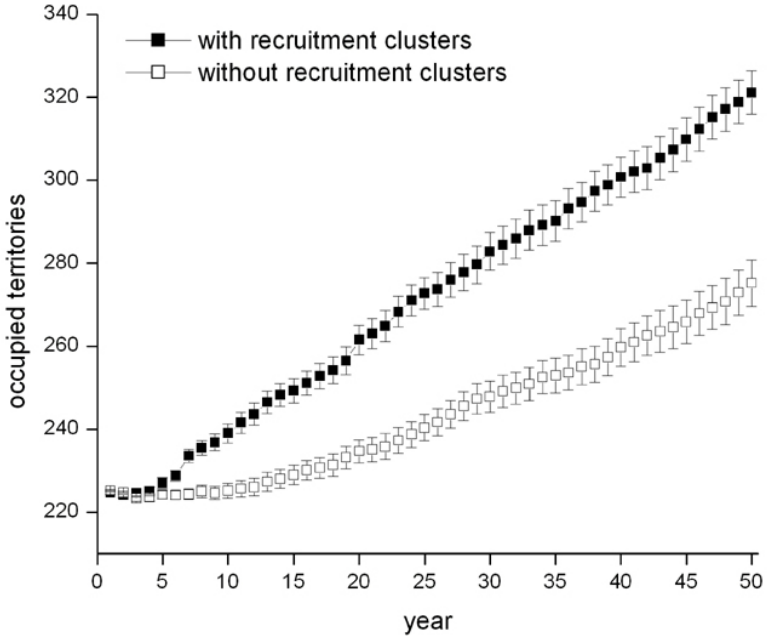


Figure 82. Projected dynamics of the post-MCOE Fort Benning RCW population over the next 50 years, with and without the addition of recruitment clusters. Population size is measured in mean number of active territories across the 70 simulations. Error bars indicate variance among the 70 replicates of the simulation.

In the 50-year, post-MCOE scenario with recruitment clusters population growth slowed over time. This was because of a decline in the rate of addition of new groups in recruitment clusters with time. Most of the successful recruitment clusters, i.e., recruitment clusters that resulted in addition of groups to the population, were added in the first 25 years of the simulation (Figure 83). Recruitment clusters contributed relatively little to population growth beyond 25 years. There were two reasons for this. First, addition of recruitment clusters was not distributed evenly over time: nearly 60% of them were added in the first 20 years. Second, the DSS rejected some of the proposed recruitment clusters due to lack of sufficient suitable habitat available in their vicinity, and the probability that this would occur increased with time as the population grew and new groups formed by budding claimed some of the habitat originally designated for recruitment clusters.

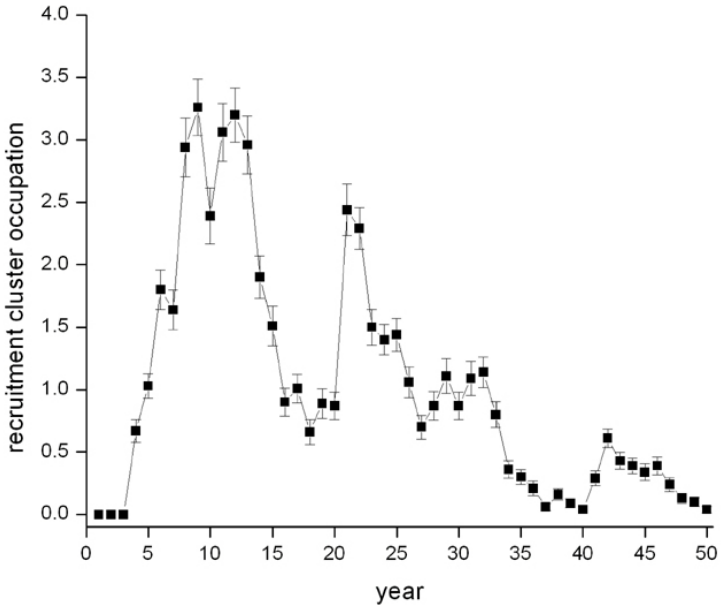


Figure 83. Projected number of recruitment clusters occupied each year over the next 50 years for the post-MCOE population. Values are means across the 70 simulations. Error bars indicate variance among the 70 replicates of the simulation.

Interestingly, the addition of recruitment clusters did not change the relative vulnerability of existing territories to loss significantly: the northeastern and eastern edge territories that were vulnerable to loss without recruitment clusters (Figure 76) remained equally vulnerable to loss when recruitment clusters were added (Figure 84). For the northeastern subpopulation this is not surprising, as relatively few recruitment clusters were added in this area (Figure 80). However, recruitment cluster locations appear well designed to reduce the vulnerability of the eastern edge subpopulation (Figure 80), but they did not have this effect. This likely is due to the increased complexity of population dynamics that results from addition of recruitment clusters. The same classes of individuals that replace breeders on existing territories (i.e., helpers and juveniles) also occupy recruitment clusters. Recruitment clusters sometimes attract birds that otherwise would have replaced a deceased breeder on an existing territory and thereby prevented it from being abandoned. Thus recruitment clusters can increase or decrease the vulnerability of a particular territory to loss, depending on when and where breeding openings appear, and when and where there are nonbreeders available to fill breeding vacancies and occupy recruitment clusters. We suggest that because of such chance events in some runs the addition of recruitment clusters is successful in stabilizing and even building the eastern edge subpopulation, and in some runs adding recruitment clusters results in increased vulnerability of this subpopulation to loss. In contrast, in areas of high density addition of recruitment clusters can only augment the existing population because there are always plenty of nonbreeders available to both fill breeding vacancies and occupy recruitment clusters. This is clearly true in this case: with the addition of recruitment clusters there were almost no territory losses in the core population running from

northeast of the A20 Impact Area to the center of the base (Figure 84), despite the fact that relatively few recruitment clusters were added in this area (Figure 80).

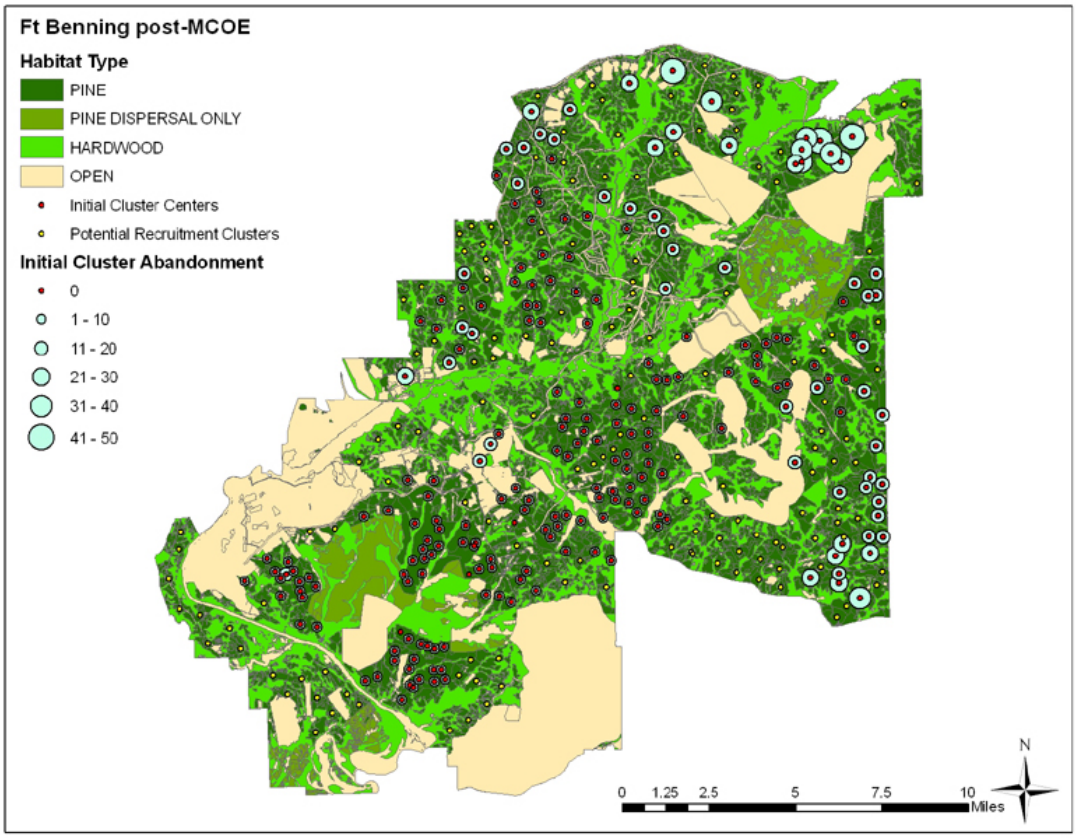


Figure 84. Number of runs (of 70) in which each individual territory was abandoned in the 50 year simulation of the post-MCOE population with recruitment clusters.

Although the recruitment cluster locations were selected specifically for the post-MCOE population, we also ran the baseline population with the recruitment clusters as a means to assess the potential to stimulate growth of the baseline population through management. Growth of the baseline population was substantially greater with recruitment clusters: population size reached 376 occupied territories on average over 20 years, and 503 occupied territories over 50 years (Figure 85), compared to 328 and 434 respectively without recruitment clusters. These results suggest the existing population has considerable capacity for expansion, certainly sufficient to achieve recovery (350 groups, USFWS 2003).

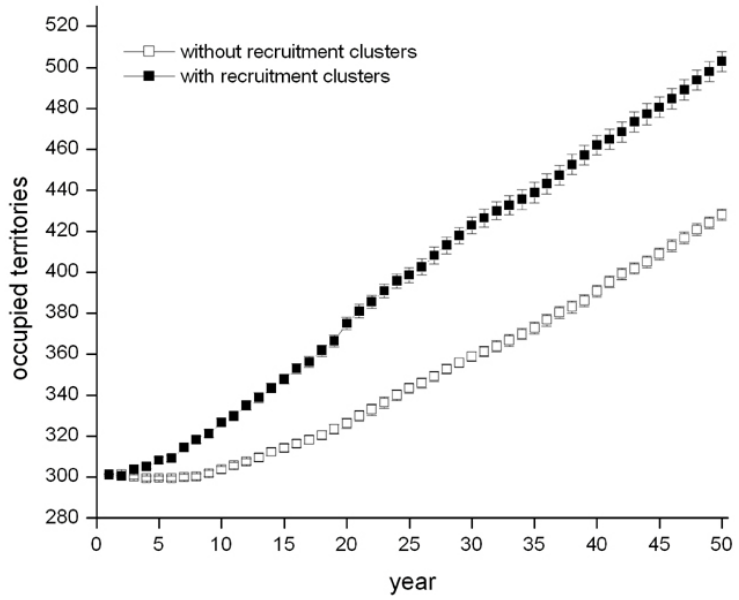


Figure 85. Projected dynamics of the baseline population over the next 50 years, with and without the addition of recruitment clusters. Population size is measured in mean number of active territories across the 70 simulations. Error bars indicate variance among the 70 replicates of the simulation.

Discussion

The MCOE and related construction can be viewed as a disturbance that introduces some stochastic instability into the behavior of the RCW population. The immediate impact of the disturbance of course is the initial reduction in population size from 305 to 229 active territories, an impact that our simulations indicate will require a recovery time of 50 years. A likely, additional outcome of this disturbance is the loss of the subpopulation of eight groups at the northeastern edge of the base, and perhaps an additional 3-4 somewhat isolated groups to the west, due to fragmentation of habitat created by the disturbance. An outcome with a probability of about 15% is that the population will decline, most likely due to losses of groups in the southeastern part of the base. However the more likely outcome is that the population will increase toward its pre-disturbance size.

Our simulations indicate that the current (i.e., baseline) population is very likely to increase to recovery levels in a fairly short time frame, especially if recruitment clusters are employed to stimulate population growth. The MCOE and related construction is projected to push the possibility of recovery back into the distant future. Our simulations indicate that the base currently contains sufficient habitat to support recovery, whereas they do not indicate whether the post-MCOE landscape will contain sufficient habitat to achieve recovery, only that it will contain sufficient habitat to support a future population equal in size to the current population.

Our simulations projected a larger impact of the proposed MCOE and related construction on the RCW population than desired. As a result, Fort Benning staff redesigned the ranges to reduce

this impact, specifically by reconfiguring the ranges in a manner that reduced the projected spatial isolation and thus vulnerability of the southeastern subpopulation. We worked with Fort Benning staff to design and run a series of additional scenarios using the DSS to determine a design for range location and configuration that resulted in better connectivity between RCW subpopulations on the post-MCOE landscape. This improved design was submitted to USFWS, along with the results of our simulations, as part of the consultation process for the proposed MCOE and related construction. Thus our Fort Benning experience proved to illustrate the utility of the DSS as a planning tool for military installations with RCW populations.

In recognition of the important role these simulations with the DSS played in the assessment of the impact of proposed MCOE and related construction on the RCW population conducted by Fort Benning, one of us (RM) received a Cross Functional Team of Excellence Award from the Commanding General at Fort Benning on April 24, 2009.

Onslow Bight Application

One of the primary intended uses of the DSS is to evaluate the value of individual habitat parcels or properties to RCWs in terms of their potential impact on population dynamics. An exercise undertaken by managers at Marine Corps Base Camp Lejeune provided us with an opportunity to test this function of the DSS. The RCWs on MCBCL are considered part of the Onslow Bight Primary Core Population (USFWS 2003), along with the subpopulations on Croatan National Forest and the state-owned Holly Shelter Game Lands. Managers at MCBCL were interested in the potential for additional private and state-owned lands in the Onslow Bight area to contribute to RCW recovery and thereby reduce recovery responsibilities on lands heavily used for training. If properties with high potential for contributing to RCW recovery could be identified DOD would consider purchasing them and establishing some of the new groups needed to reach the recovery goal on these properties rather than on the base. The DSS provided a means to project the potential of different properties to support RCWs, how those RCWs would interact with the existing subpopulations, and how those RCWs would affect the overall dynamics of the Onslow Bight RCW population. We worked with managers at MCBCL and contractors from GeoMarine Inc. to conduct these assessments.

Methods

Five properties were evaluated, Stones Creek Game Lands, Shaken Creek Natural Area, the Allen property, Bear Garden Game Lands and Hoffman Forest (Figure 86). Note that outside of these five properties and the properties containing existing RCW populations most of the non-forested habitat was classified as “other” land cover (Figures 86-96). Most of this “other” land cover is comprised of open habitat types, chiefly agricultural fields, old fields and developed areas. The evaluations of the five properties were made based on future potential rather than current conditions. GeoMarine conducted a habitat assessment of the properties and designated habitat partitions on each. A habitat partition is an area with sufficient suitable habitat to support an RCW group. In most cases all the habitat within a partition was not suitable currently, but when mature could be if managed properly. MCBCL had already conducted such an analysis and identified 173 habitat partitions on the base, which represents the installation’s population goal. There were active RCW clusters in 89 of these partitions in 2008, and unoccupied recruitment

clusters in an additional nine partitions. Partitions had also been previously identified on Croatan National Forest and Holly Shelter Game Lands. In a model run each partition was used as an initial active cluster (Figure 86).

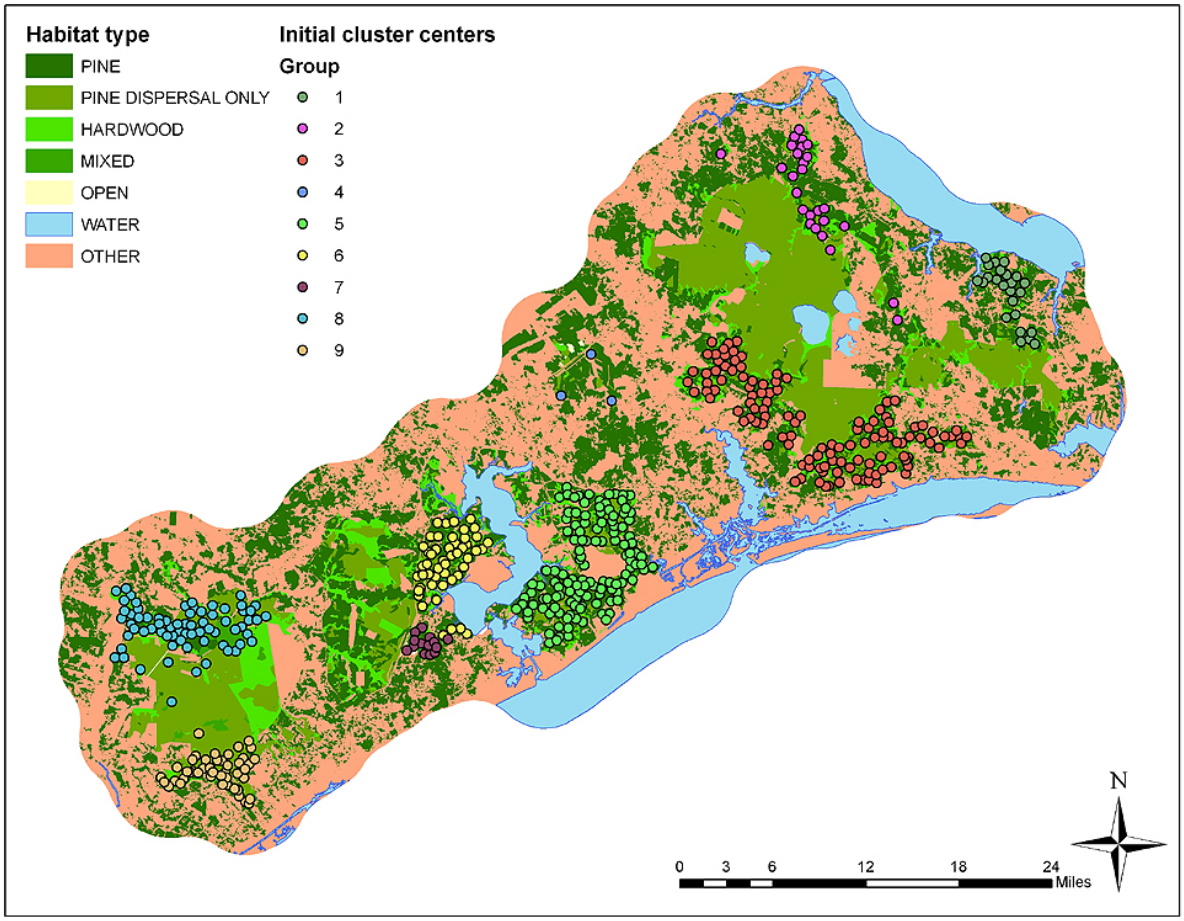


Figure 86. Map of the Onslow Bight region showing the spatial arrangement of the initial clusters used for the simulations in each of the subpopulations (Group). From east to west, 1-3 = Croatan National Forest, 4 = Hoffman Forest, 5-6 = Marine Corps Base Camp Lejeune, 7 = Allen property and Stones Creek Game Lands, 8 = Bear Garden Game Lands and Shaken Creek Natural Area, 9 = Holly Shelter Game Lands.

The properties were grouped into nine subpopulations according to their spatial relationships to one another (Figure 86). Ten combinations of subpopulations were simulated, including some individual subpopulations alone. This enabled us to evaluate interdependence among subpopulations, and by comparing runs with and without particular subpopulations, assess the contribution of those subpopulations to the dynamics of the overall Onslow Bight population. We augmented these assessments by simulating the entire population and comparing the output of that run to those from the ten subpopulation combinations.

For each simulation the starting population had a mean group size of 2.4 and the type locality chosen was the “coastal” model, which is based upon empirical data collected at MCBCL. All simulations were run for 50 years.

Among the various types of output produced by the DSS, of particular importance in this case is the number of movements between designated groups. We designated each subpopulation as a group and hence were able to track movement between subpopulations as a metric of their interdependency. The DSS provides these data as the total number of successful movements between each group across all 70 replicates of each simulation and across all years (in this case 50). These data were transformed into the mean number of successful movements per annum by dividing the output values by 70 to calculate the number of movements by simulation, and again by 50 to calculate the number of movements per annum. Note that successful movements represent *only* natal dispersal, that is, successful movements from the natal territory to the site of first breeding.

Results

The ten scenarios simulated are shown in Table 4. The MCBCL population was projected to increase in the absence of the other subpopulations (simulation 2). Surprisingly the small subpopulations (Holly Shelter, Bear Garden + Shaken Creek, Stones Creek + Allen, simulations 3, 4 and 9 respectively) were projected to be stable in the absence of interactions with other subpopulations except for Hoffman Forest, which was predicted to go extinct (simulation 7). These results suggest that the properties evaluated, with the exception of Hoffman Forest, have potential to house persistent RCW populations that can contribute to recovery of the overall Onslow Bight population.

Table 4. Results of 10 simulations of different combinations of RCW subpopulations in the Onslow Bight region. Group refers to the subpopulations (see Figure 86). Initial territories is the mean number of occupied territories at the beginning of the 50 year simulation. % change in OT is the percentage change in the number of occupied territories between the initial and final years of the simulation. Number of buds is the average number of territories added by budding during the simulation. %ICA is the percentage of initial clusters that were abandoned across all 50 years of the simulation.

Site name	Simulation	Group	Initial Territories	% change in OT	Number Of Buds	% ICA
Lejeune + Holly Shelter	1	5, 6, 9	211	-0.68%	0.17	0.5
Lejeune	2	5, 6	173	0.98%	2.11	0.1
Holly Shelter	3	9	38	-3.12%	0.00	2.4
Bear Gardens + Shaken Creek	4	8	60	-0.38%	0.01	0.1
Bear Gardens + Shaken Creek + Lejeune + Holly Shelter	5	5, 6, 8, 9	271	-0.03%	0.71	0.1
Bear Gardens + Shaken Creek + Holly Shelter	6	8, 9	115	-0.15%	0.00	0
Hoffman	7	4	3	-100%	0.00	100
Hoffman + Croatan + Lejeune	8	1, 2, 3, 4, 5, 6	345	-1.52%	1.54	1.6
Stones Creek + Allen	9	7	14	-3.57%	0.01	2.6
Stones Creek + Allen + Lejeune + Holly Shelter	10	5, 6, 7, 9	225	0.30%	0.14	0.3

Interaction among subpopulations is evident in spatial patterns in abandonment of initial clusters. Generally stability of subpopulations did not depend on interaction with other subpopulations, but there were some instances where particular clusters were vulnerable to abandonment, and in some of these cases interaction with other subpopulations eliminated this vulnerability. The MCBCL subpopulation increased in isolation, but the clusters in the extreme southwestern edge of the population were frequently abandoned (simulation 2, Figure 87). This vulnerability remained despite the addition of the Holly Shelter subpopulation (simulation 1, Figure 88), which is the closest existing subpopulation currently, but it was eliminated by the addition of the Stones Creek – Allen subpopulation (simulation 10, Figure 89). Similarly, initial cluster

abandonment was relatively common in the Stones Creek – Allen subpopulation in isolation (simulation 9, Figure 90), but was essentially nil when the MCBCL subpopulation was added (simulation 10, Figure 89). These findings suggest that if RCWs could be established on the Stones Creek and Allen properties they would become part of the MCBCL subpopulation, thus increasing its size and its stability.

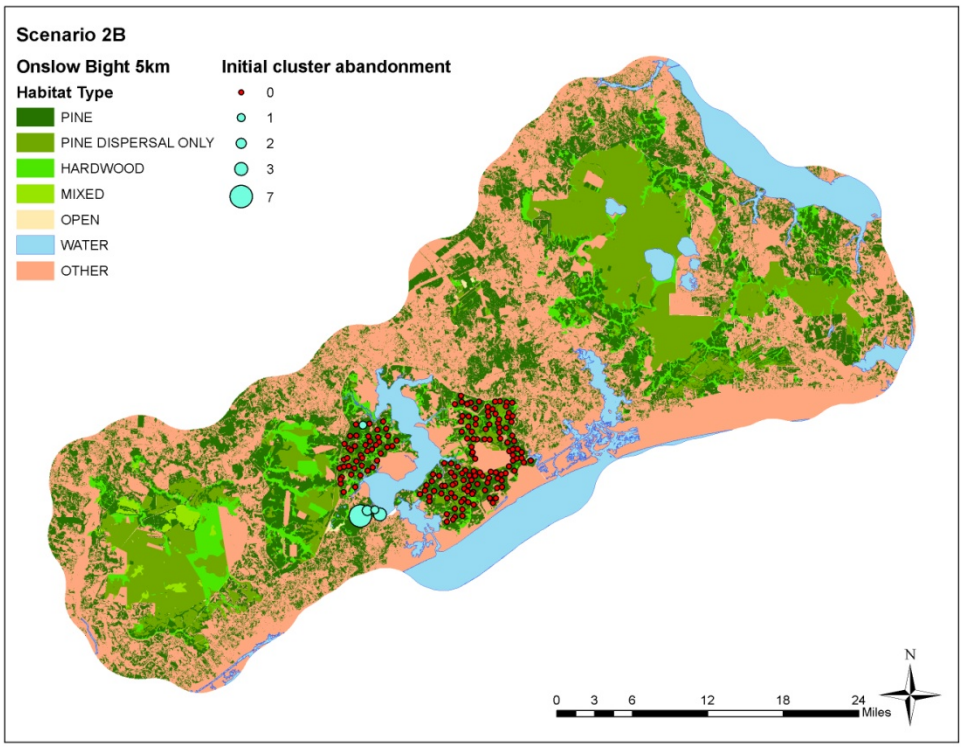


Figure 87. Map of predicted initial cluster abandonment (ICA) in simulation 2 (Marine Corps Base Camp Lejeune). See Table 4 for descriptions of simulations.

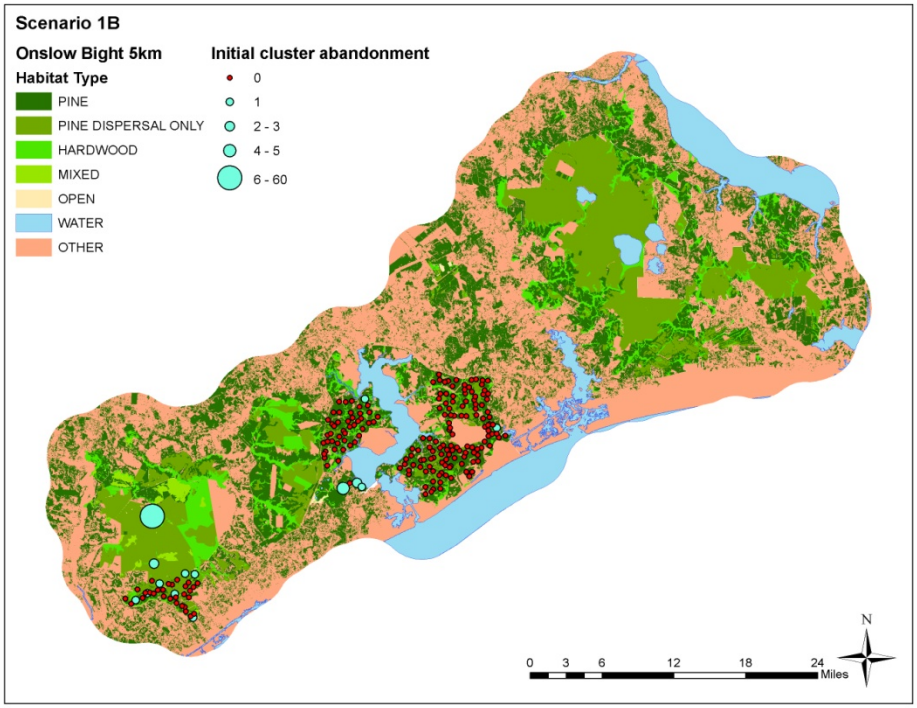


Figure 88. Map of predicted initial cluster abandonment (ICA) in simulation 1 (Marine Corps Base Camp Lejeune + Holly Shelter). See Table 4 for descriptions of simulations.

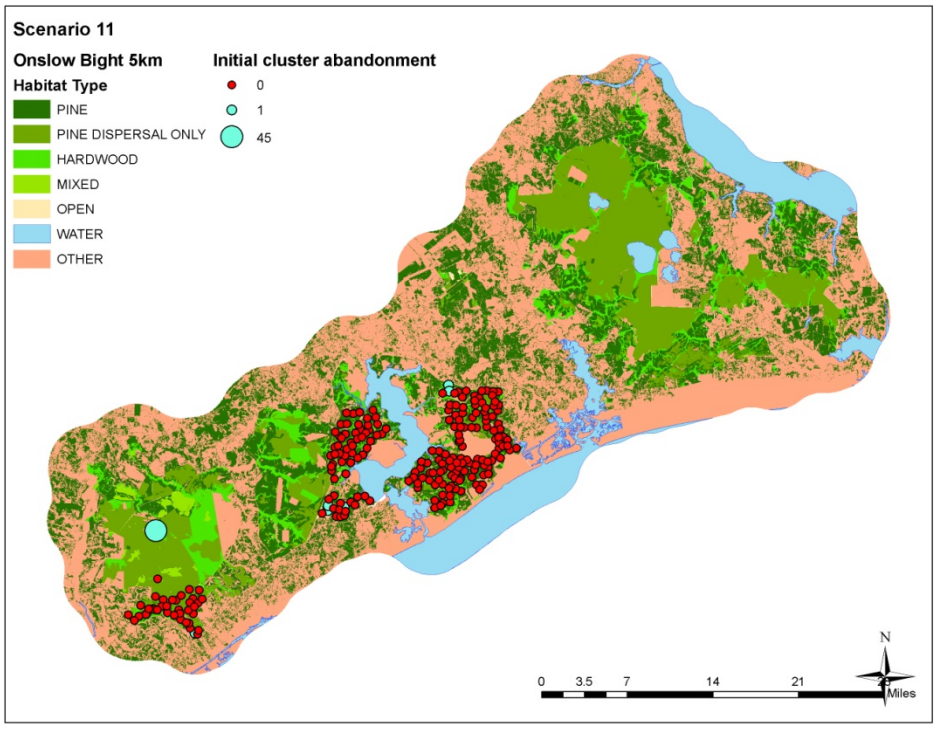


Figure 89. Map of predicted initial cluster abandonment (ICA) in simulation 10 (Stones Creek + Allen + Marine Corps Base Camp Lejeune + Holly Shelter). See Table 4 for descriptions of simulations.

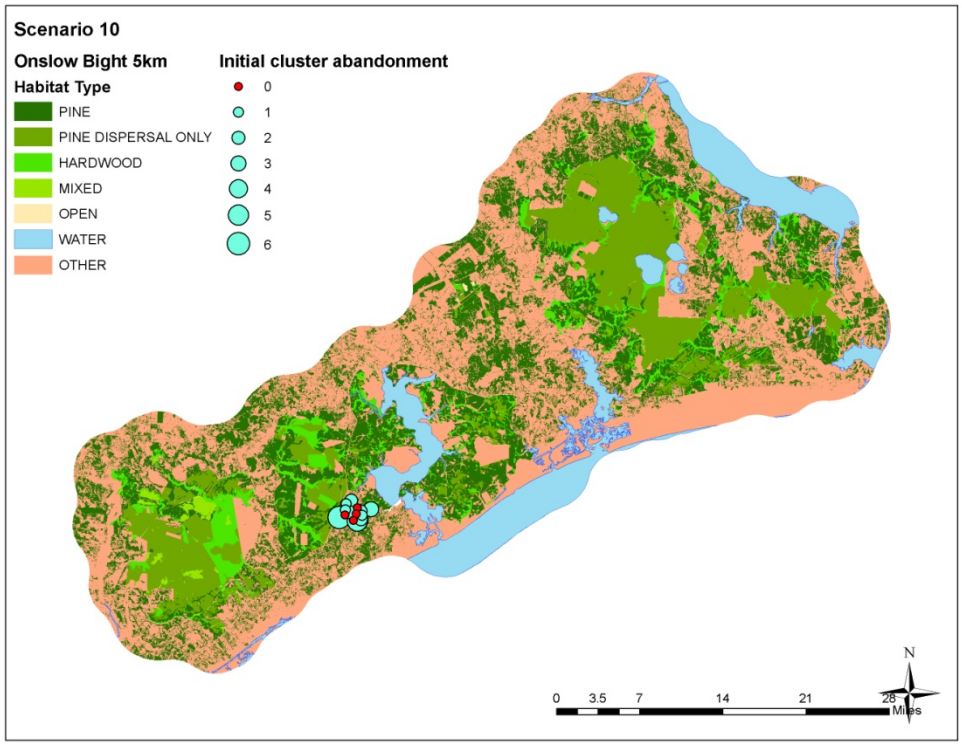


Figure 90. Map of predicted initial cluster abandonment (ICA) in simulation 9 (Stones Creek + Allen). See Table 4 for descriptions of simulations.

The Holly Shelter subpopulation was stable in isolation, but a single isolated cluster north of the rest of the subpopulation was highly vulnerable to abandonment (simulation 3, Figure 91). This cluster remained vulnerable despite the addition of the MCBCL subpopulation (simulation 1, Figure 88), but it was no longer vulnerable once the Bear Garden – Shaken Creek subpopulation was added (simulations 5 and 6, Figure 92 and Figure 93). The Bear Garden – Shaken Creek subpopulation had no areas of vulnerability even in isolation (simulation 4, Figure 94). These results suggest that if RCWs could be established on the Bear Garden and Shaken Creek properties they would constitute a new, stable subpopulation that would also include the single isolated northern cluster that currently exists on Holly Shelter. These two western subpopulations would not interact much with each other, or with the MCBCL subpopulation.

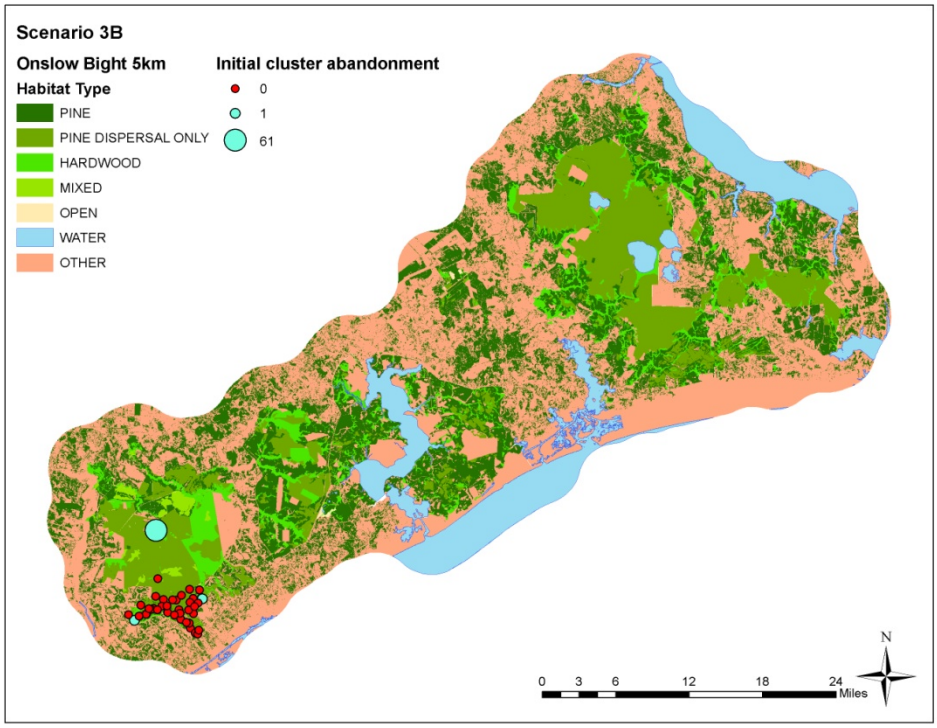


Figure 91. Map of predicted initial cluster abandonment (ICA) in simulation 3 (Holly Shelter). See Table 4 for descriptions of simulations.

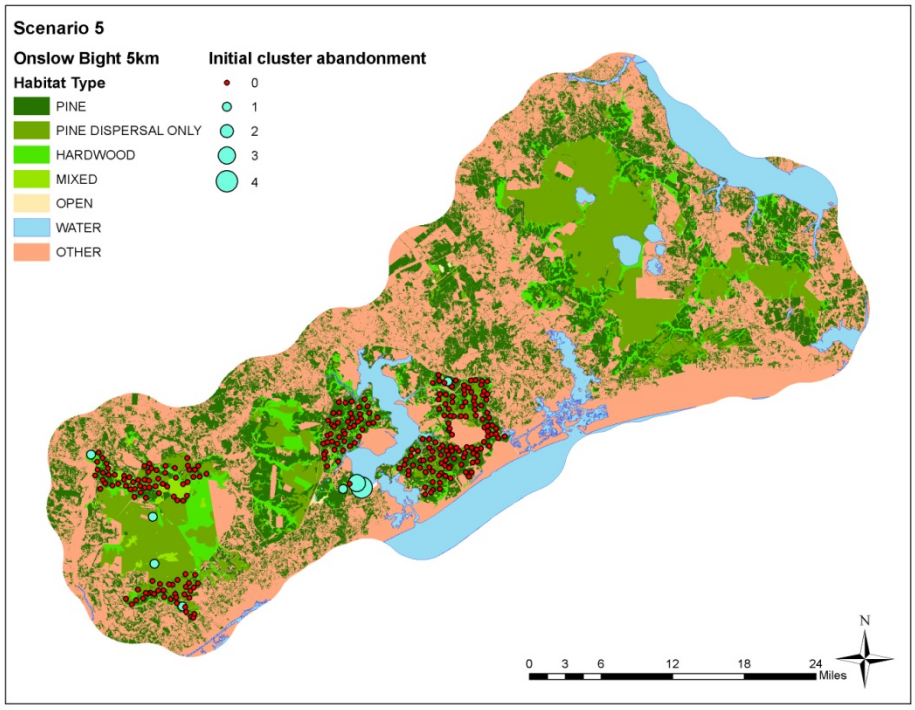


Figure 92. Map of predicted initial cluster abandonment (ICA) in simulation 5 (Bear Gardens + Shaken Creek + Marine Corps Base Camp Lejeune + Holly Shelter). See Table 4 for descriptions of simulations.

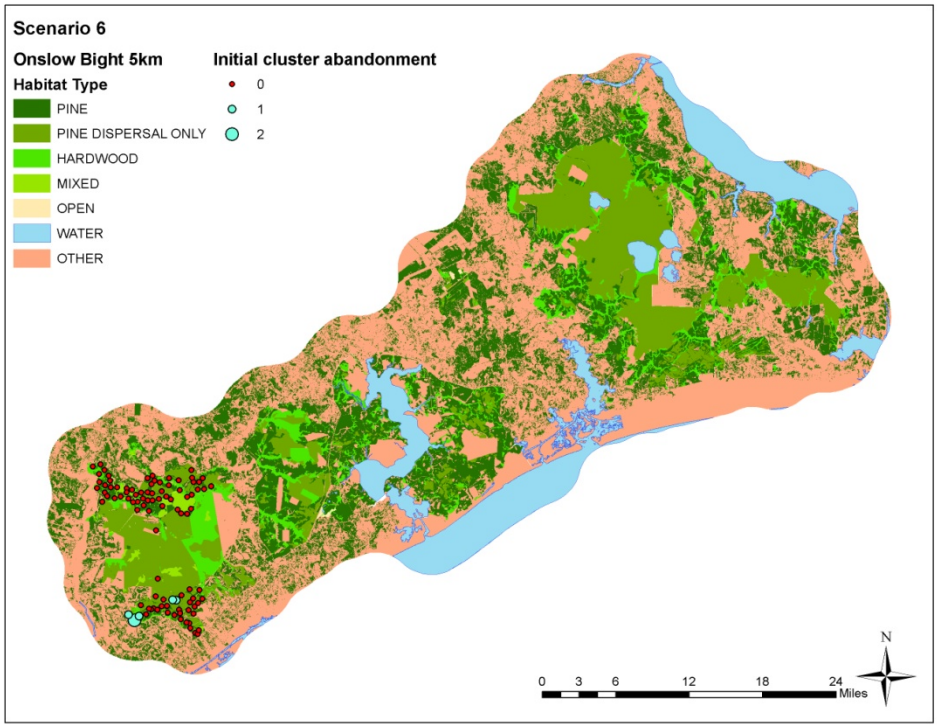


Figure 93. Map of predicted initial cluster abandonment (ICA) in simulation 6 (Bear Gardens + Shaken Creek + Holly Shelter). See Table 4 for descriptions of simulations.

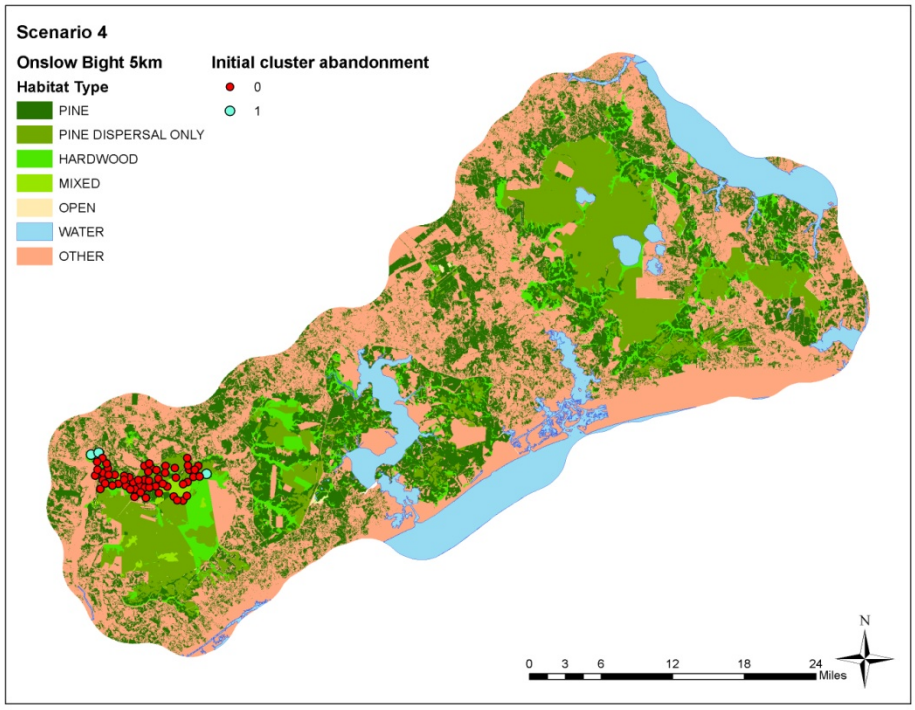


Figure 94. Map of predicted initial cluster abandonment (ICA) in simulation 4 (Bear Gardens + Shaken Creek). See Table 4 for descriptions of simulations.

The tiny Hoffman subpopulation is projected to go quickly extinct both in isolation (simulation 7, Figure 95) and with the addition of the closest other subpopulations on Croatan National Forest and MCBCL (simulation 8, Figure 96). This property has no potential to contribute to recovery of RCWs in the Onslow Bight.

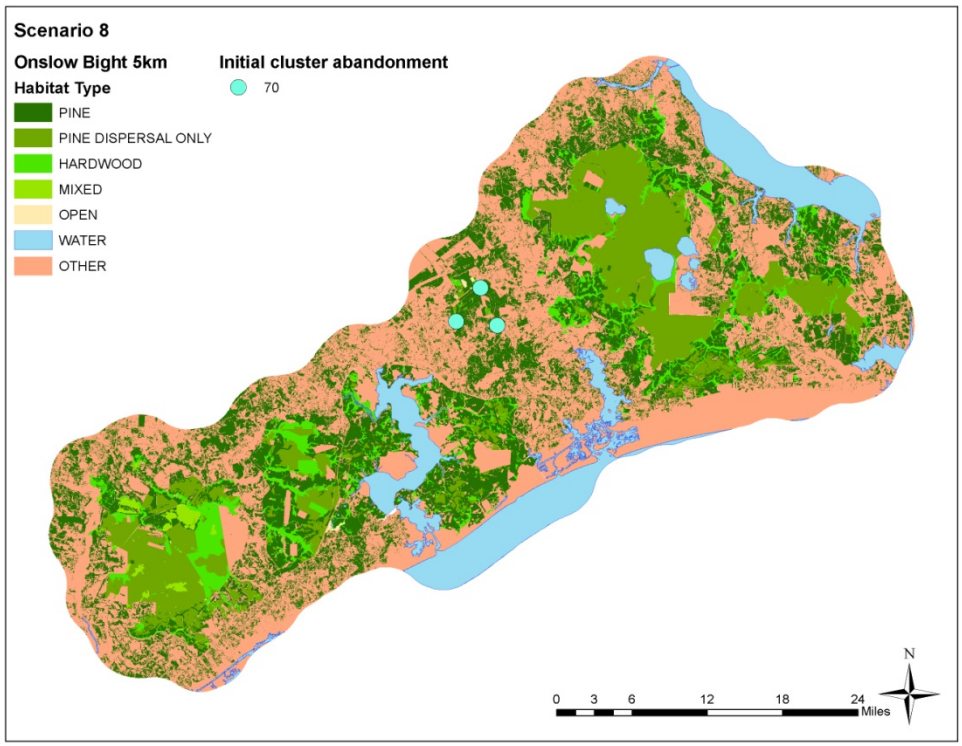


Figure 95. Map of predicted initial cluster abandonment (ICA) in simulation 7 (Hoffman). See Table 4 for descriptions of simulations.

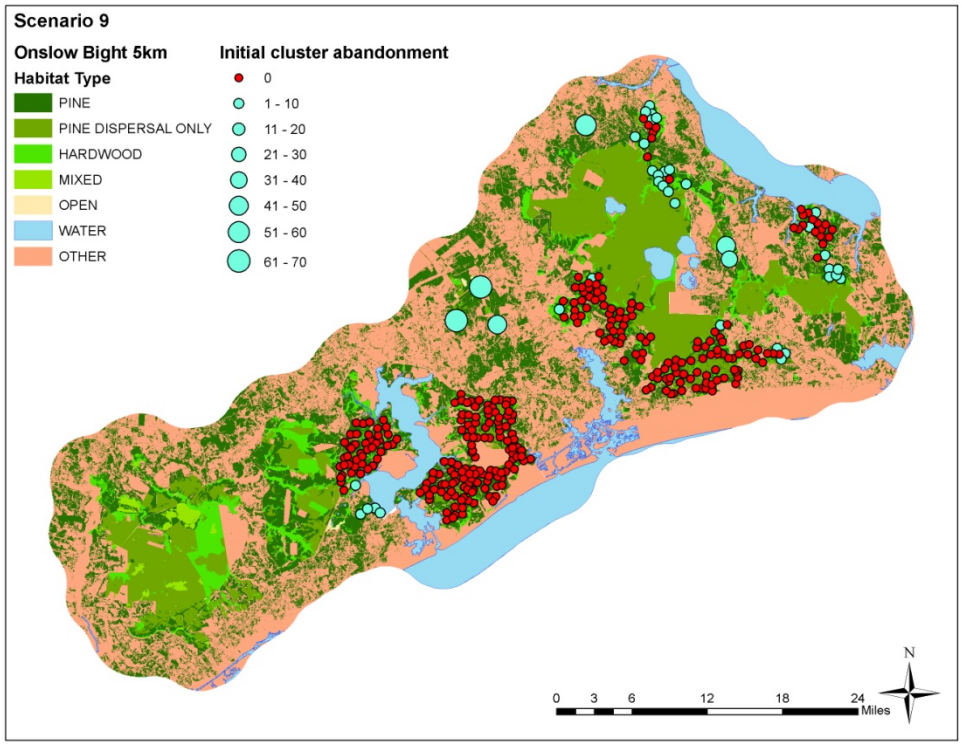


Figure 96. Map of predicted initial cluster abandonment (ICA) in simulation 8 (Hoffman + Croatan + Marine Corps Base Camp Lejeune). See Table 4 for descriptions of simulations.

Croatan National Forest appears to contain not a single subpopulation but three, located in the north, east and southwest. Our simulations suggest that only the large southwestern one is stable, as territory abandonment is frequent in the northern and eastern subpopulations (simulation 8, Figure 96). The Croatan subpopulations do not affect the MCBCL subpopulation or the other subpopulations west of MCBCL.

Overall our results suggest the properties evaluated have the potential to support four distinct subpopulations that will be stable but have little impact on one another: a Croatan subpopulation (or set of subpopulations); a MCBCL – Stones Creek – Allen subpopulation; a Holly Shelter subpopulation; and a Shaken Creek – Bear Garden subpopulation. When this entire potential Onslow Bight population was simulated it was predicted to remain stable with on average a decrease of only a couple of occupied territories over 50 years (Figure 97). Losses of territories on Hoffman and northern and eastern Croatan (Figure 98) were balanced by gains elsewhere.

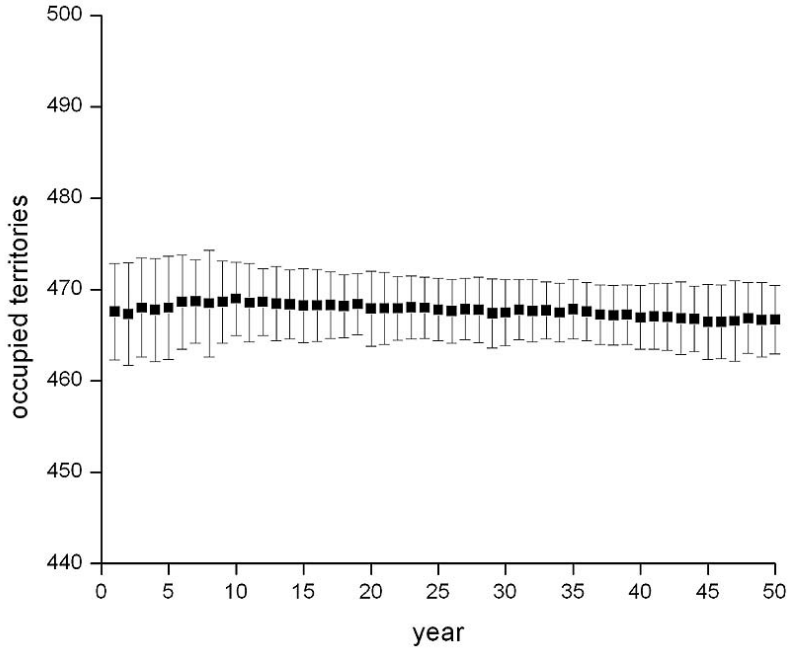


Figure 97. Plot of change in the number of occupied territories over time for the simulation of the entire Onslow Bight population.

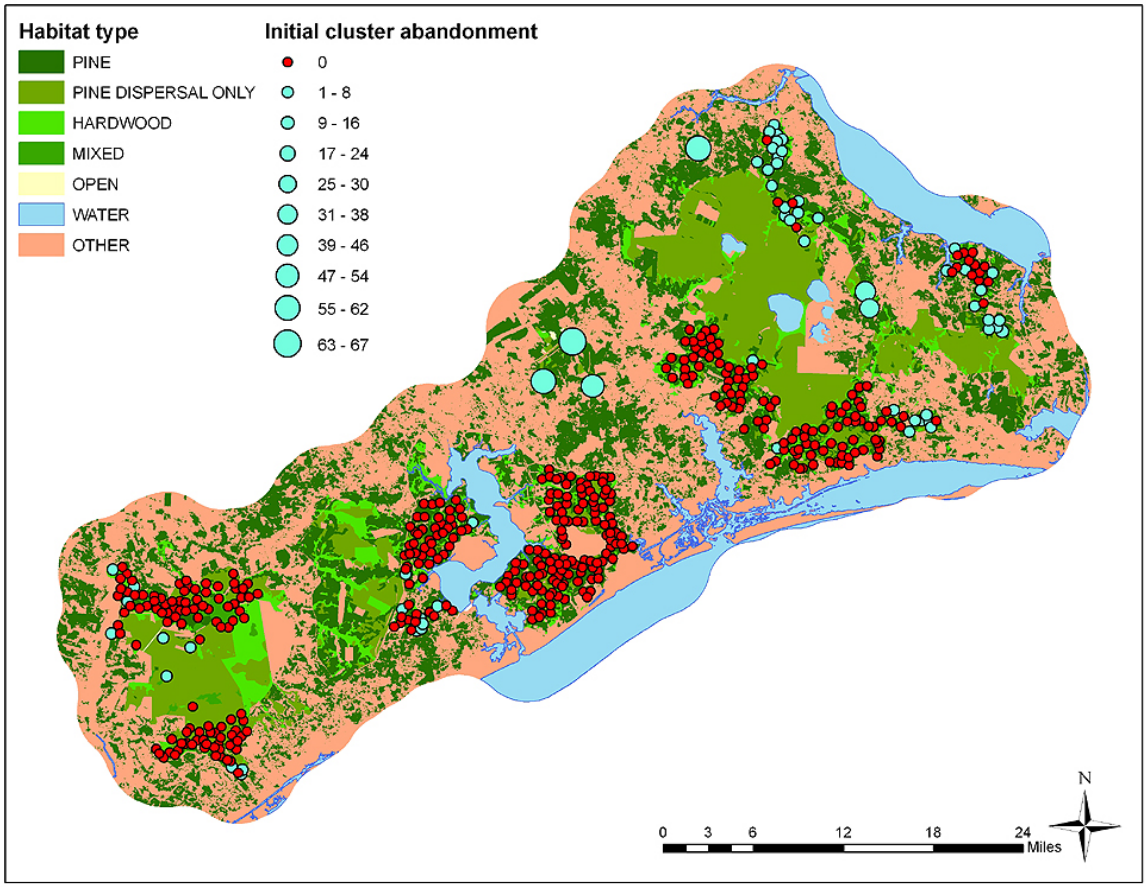


Figure 98. Predicted initial cluster abandonment (ICA) from the simulation of the entire Onslow Bight population.

Patterns in movements between subpopulations support the conclusions drawn from patterns in initial cluster abandonment. The predicted movement between subpopulations generally was very infrequent (Table 5) with an overall mean (± s.d.) number of movements of 0.14 (± 0.26) per annum (i.e., one movement every seven years) for females and 0.03 (± 0.05) (i.e., one movement every 33 years) for males. This supports the conclusion that the subpopulations generally are independent of one another demographically.

Table 5. Predicted mean number of movement per annum between subpopulations for female and male RCW's. See Figure 86 for identities of subpopulations.

FEMALES	FROM								
TO	1	2	3	4	5	6	7	8	9
1		0.008	0.056						
2	0.024		0.269						
3	0.048	0.107		0.001	0.011				
4			0.013		0.055				
5			0.005	0.011		0.025	0.006		
6					0.057		0.781	0.028	0.005
7					0.028	0.950		0.008	0.007
8						0.051	0.012		0.689
9						0.010	0.008	0.538	

MALES	FROM								
TO	1	2	3	4	5	6	7	8	9
1		0.024	0.012						
2	0.007		0.005	0.001					
3	0.025	0.066		0.034	0.016	0.001			
4			0.001		0.001				
5			0.024	0.057		0.129	0.020		
6			0.001	0.005	0.074		0.158	0.002	
7				0.000	0.012	0.156		0.002	0.003
8						0.003	0.003		0.049
9						0.001	0.002	0.074	

The highest rates of predicted movement for both females (Figure 99) and males (Figure 100) were between western MCBCL (subpopulation 6, Table 5) and Stones Creek – Allen (subpopulation 7, Table 5). The rates are high enough (more than one bird per year in each direction) to indicate that these two areas function as a single subpopulation. Projected rates of movement between the eastern and western portions of MCBCL (subpopulations 5 and 6, Table 5) across the New River (see Figure 49) are considerably lower (about one bird every seven years), suggesting considerable isolation between the two portions of the MCBCL population. Males were projected to move between eastern and western MCBCL more often than females, reflecting the sex-specific aversion to openings such as the New River incorporated in the DSS. There was also significant movement by females (Figure 99), but not males, between Holly Shelter (subpopulation 9, Table 5) and Shaken Creek – Bear Gardens (subpopulation 8, Table 5). This was largely due to movement into and out of the isolated northern cluster that in name was part of the Holly Shelter subpopulation, but in function was part of the Shaken Creek – Bear Garden subpopulation. There was some movement of females between the northern and eastern portions of Croatan (subpopulations 2 and 3, Table 5), but otherwise little movement between the different areas of Croatan (subpopulations 1-3, Table 5). This supports the conclusion that the three concentrations of RCWs on Croatan function as relatively independent subpopulations.

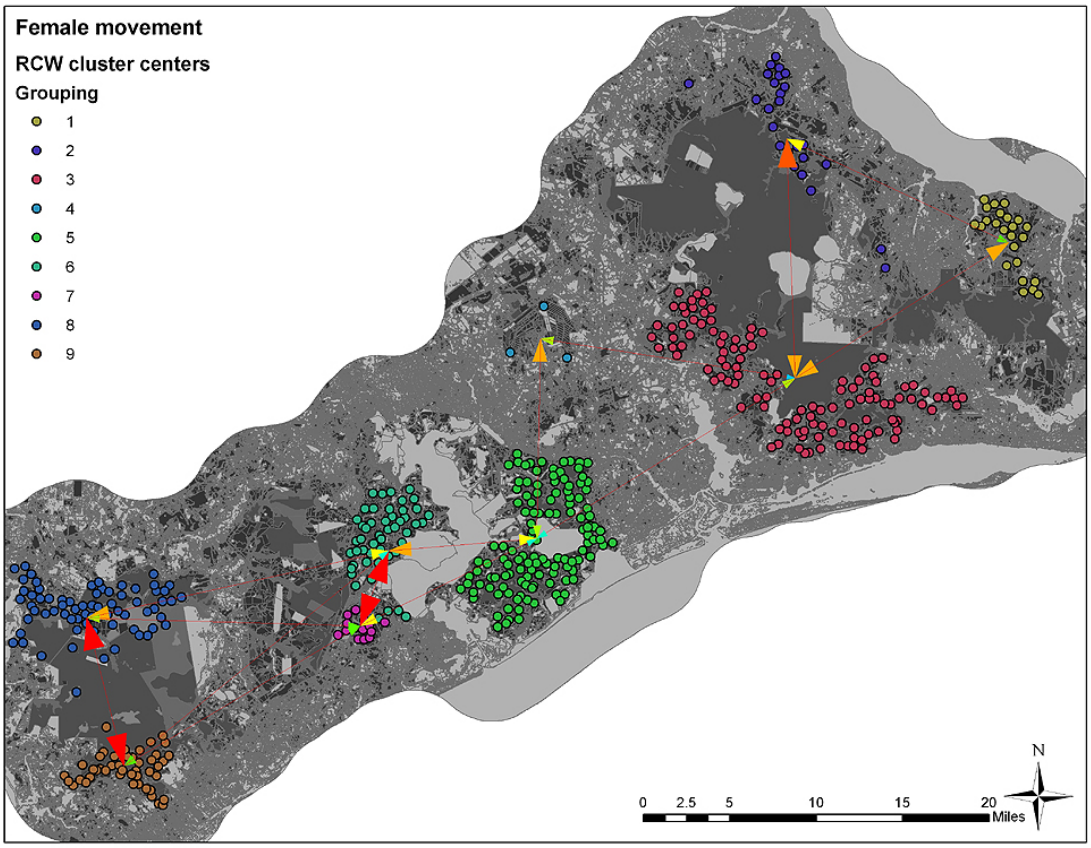


Figure 99. Predicted movement of females between subpopulations. Relative number of successful movements is indicated by the size and color of the arrowheads between groups. Larger and redder arrowheads indicate more movements than smaller and yellower arrowheads. Arrows indicate the direction of movement between the geometric mean of the territories from which birds originated. See Figure 86 for identities of subpopulations.

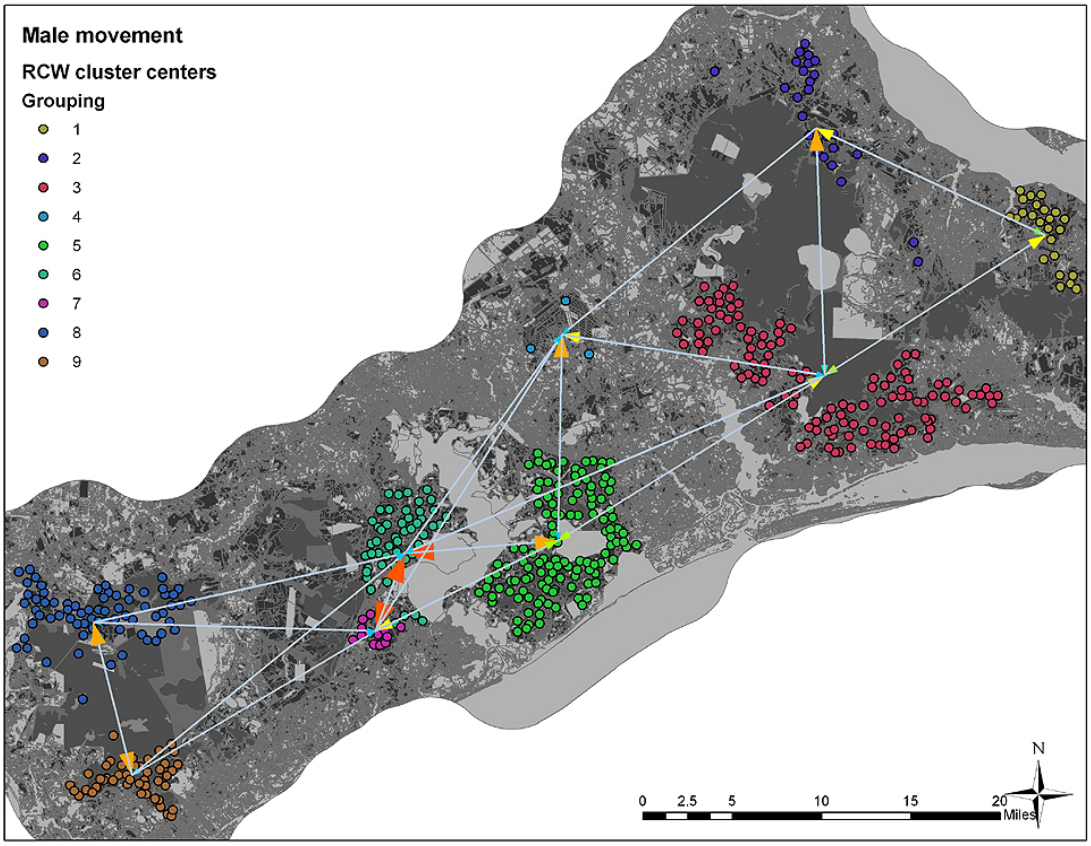


Figure 100. Predicted movement of males between subpopulations. Relative number of successful movements is indicated by the size and color of the arrowheads between groups. Larger and redder arrowheads indicate more movements than smaller and yellower arrowheads. Arrows indicate the direction of movement between the geometric mean of the territories from which birds originated. See Figure 86 for identities of subpopulations.

Discussion

Our application of the DSS to Onslow Bight was highly successful in demonstrating the utility of the tool in performing one of its primary functions, determining the relative value of habitat parcels for RCW conservation. The exercise revealed that the Allen and Stones Creek properties along the southwestern border of the base have high potential to augment the size and stability of the Marine Corps Base Camp Lejeune RCW population, and as a result base managers have made these properties their highest priority for conservation action. In addition they are further pursuing linking the base subpopulation to the Holly Shelter subpopulation to the west by examining additional properties between the two, specifically the Greater Sandy Run area previously purchased by DOD and the private Oak Island property, and are employing the DSS to do so. In contrast, because of the lack of potential for linkage to Croatan National Forest and Hoffman Forest revealed by the simulations, they are no longer pursuing increasing connectivity to these areas to the east. Thus base managers used the DSS to set priorities, and they used the data generated from the simulations as their primary data in negotiations with USFWS over their recovery responsibilities with respect to RCWs. In this case the DSS is being used to make decisions about land purchases and conservation priorities, and is stimulating engagement among

the various agencies involved in RCW conservation. For example renewed discussions of cooperative conservation efforts between MCBCL and the state of North Carolina are a direct result of the finding that many of the properties with the highest potential for interaction with the base RCW subpopulation are owned and managed by the state. These interactions are likely to lead to a new, comprehensive regional plan for recovery of the Onslow Bight Primary Core Population, and this new plan is likely to result in reduced pressure to provide conservation benefits on lands heavily used for training, and thus more flexibility in training.

An additional benefit of the exercise, like that at Fort Benning, is that it provided an opportunity to receive feedback from users that helped us improve the DSS. In this case there was a further benefit not available at Benning: because we had empirical data on movement between subpopulations to compare to model output, we were able to validate the model's ability to project long-distance movements on complex landscapes. The DSS underestimates the frequency of these rare events. The DSS projects dispersal from eastern to western MCBCL roughly once every seven years (subpopulation 5 to 6 in Table 5), whereas the actual movement rate over the past 20 years has been about twice that, roughly two birds in seven years. This is a trivial difference demographically, but does suggest that the frequency of "jumping" by females in the model (i.e., 10% probability of jumping a gap) is too low. This is a fairly clear test of the validity of the jumping parameter, as there is only one significant gap, the New River and adjacent openings, between eastern and western MCBCL (Figure 49). The discrepancy was much larger over the much longer distance between MCBCL and Croatan. The model estimated almost no movement across the highly fragmented landscape between these two subpopulations (Figure 86), only one movement roughly every 30-35 years (subpopulations 1-3 to 5-6 in Table 5), whereas the observed rate of movement is nearly an order of magnitude greater, roughly one movement every four years. Again the difference is trivial demographically, but it is significant with respect to degree of genetic connectivity. One possible explanation is that the model evaluates jumping for every gap encountered, making movement over long distances across fragmented landscapes in which a series of gaps are encountered highly unlikely (e.g., only 1% chance for females to cross two gaps in succession). This presumably is why the frequency of movement from Croatan to MCBCL is five times higher for males, for which only distance matters, than for females, for which landscape openings also matter (Table 5). It appears that the DSS does a somewhat poor job of estimating rare long-distance movements between populations and subpopulations. This does not affect its performance in simulating population dynamics however, since these are trivial events with respect to population performance. Further study of long-distance dispersers would be necessary to better parameterize the behavior of jumpers.

Finally, the DSS greatly underestimated frequency of movement between the northern and southwestern Croatan subpopulations. It projected low rates of movement between these subpopulations, whereas high rates of movement have been documented through monitoring of marked birds (Walters, unpublished data). It appears that the habitat type between these subpopulations, pocosin, promotes dispersal. We treated it as pine dispersal only habitat rather than incorporating a positive effect on movement. Study of movement through this habitat type would be necessary to incorporate this effect into the DSS. This will be relevant only where this habitat type occurs, and thus for only a small number of RCW populations. However, it is highly relevant in the Onslow Bight region, and could be a significant factor in conservation of the MCBCL RCW population. There are extensive areas of pocosin in the Greater Sandy Run area

and the lands to the west of Greater Sandy Run. Thus, although Greater Sandy Run may have little potential to house RCW groups currently, it might function as an effective corridor linking the existing RCW population on MCBCL to the properties to the west examined in this exercise. Hence the potential conservation value of these properties may be even greater than our simulations indicate. It would be interesting and informative to incorporate the positive effect of pocosin on dispersal into the DSS and reexamine connectivity between MCBCL and properties to the west through Greater Sandy Run.

Transition

The Fort Benning and Onslow Bight exercises provided us with opportunities to introduce the DSS to potential users within DOD at two installations. In both cases we provided sufficient training that managers at these installations were able to run the DSS on their own by the time the exercise was completed. At MCBCL managers have used the DSS frequently subsequently, whereas at Fort Benning they have not. This difference appears to be more a matter of need than interest.

In order to facilitate more widespread adoption of the DSS as a tool for the management of RCW populations in and around DOD installations we conducted two workshops for potential users. A workshop was held at Eglin Air Force Base, Florida, on 24 September 2009 and another at the Sandhills Ecological Institute, Southern Pines, North Carolina on 30 September 2009. Potential future users of the DSS were contacted and invited to attend either workshop. Each workshop began with a presentation of the background of the DSS project and the development of the model. Attendees were then shown how to set up and successfully run the DSS on an example landscape on a live version of the DSS. The model output was discussed in detail and attendees were shown how to extract, display and interpret these data. Finally, we presented examples of the use of the DSS.

Workshop Contents

First, we explained the development of the DSS in the context of the original Statement of Need, "Examination of Endangered and Threatened Species Habitat Fragmentation on and in the Vicinity of Department of Defense Installations". We then explained the development of the DSS from the original spatially explicit individual-based model into a user friendly format within the ArcGIS environment. Finally, we presented attendees with examples of the potential uses of the DSS in assessing RCW populations, including evaluating effects of base expansion and other habitat acquisition, evaluating placement of recruitment clusters and their impacts on the RCW population, and determining placement of new ranges.

The major differences between male and female birds in how demography and movement is modeled in the DSS were explained, though the fine detail of the population dynamics model was not discussed. Users were shown a flow diagram of the model structure for both sexes (Figure 1) and the basis for the model structure was explained.

We described the assumptions made by the model and the potential limitations these may impose on the use and interpretation of the output from the DSS. The habitat constraints were described, in particular the important role of age within the PINE habitat classification in the model. We informed users that PINE habitat was not suitable as nesting and foraging habitat for RCWs until it was 60 years or older. We carefully explained that this rule may not necessarily apply well to every stand in a landscape so results must be interpreted with this caveat in mind. We also discussed the limitation caused by the DSS only allowing an increase in occupied territories by

budding (or recruitment clusters if used) and not including pioneering. We also discussed the impact of excluding female helpers from the model. Dispersal rules were carefully explained including movement across gaps, dispersal range of males and females and competition rules. We mentioned the model default rules for populating initial clusters, a topic we discussed in greater detail when reviewing the type locality and custom population file.

We displayed the address of the project website as the location to obtain a copy of the software, or to download updates to the software. In addition we made a copy of the DSS on compact disc (CD) available to all participants. The CD included detailed installation instructions, a copy of the document "How the DSS works" and a copy of the workshop presentation.

We discussed setting up the input habitat and cluster layers (both initial clusters and recruitment clusters) and their requirements in great detail, showing all of the required attribute table fields, relating the need to create very high quality habitat layers and explaining the use of the "Add recruitment clusters" tool.

We explained the use of the "DSS Wizard" (Figure 6) to set up and run the model using a live example dataset. We walked the attendees through all of the various requirements and options of setting up the DSS and started a simulation. As most simulations take at least several hours to complete, once all of the aspects of running the model (such as computer requirements) were described we aborted the run and showed live examples of output from the model from previous simulations in ArcGIS 9.3.

We described both numeric (e.g., occupied territories, population size etc.) and spatial (e.g., initial cluster abandonment, budding density, etc.) outputs in great detail. We explained the use of the DSS "Scenario manager" (Figure 7) live using previously run example simulations. We showed all of the output summary data available through the Scenario Manager as well as how to access the raw output files created by the DSS, should users wish to perform further analysis or create their own plots. We described all four types of spatial output in detail including how to re-display the outputs when they were loaded fresh from the output file (these are displayed by the DSS at the end of a model simulation, but not if the data have to be re-loaded). The four types of spatial output described were: Initial Cluster Abandonment (Figure 10), Recruitment Cluster Successful Occupation (Figure 11), Budding density (Figure 12) and Movement (Figure 99). The spatial output of the movement option was not shown live as displaying this output can be complicated and slow, so we showed an example using PowerPoint.

We described the error reporting system of the DSS including: the ability to suppress errors to the log file (log.txt); the type of information that may be logged in this file; the presence of known errors in the FAQ section of the help file; and the need to report new errors (preferably to the listserv) in order to assist any future development of the DSS.

We briefly showed the help file (Figure 32) and described it as a standard windows help file with contents, index and search functions. Users were urged to read the help file carefully and consult it before reporting any errors.

We considered it very important to underline the care needed in using and interpreting the output from the DSS. We emphasized that the DSS is most useful when making comparisons between scenarios rather than producing a single result (i.e., the “magic box” syndrome). Users were encouraged to test the sensitivity of their populations to potential changes and to take care in examining all of the output from their simulations. We underscored the fact that the DSS is intended to provide a “big picture” view of RCW populations and that users should not be overly concerned with small details in the output. Finally, we pointed out that the DSS is a model and the value of the output is very dependent on the quality of the input.

We explained the potential for customizing the DSS (within limits), using our addition of the movement output in response to feedback from users at Fort Benning as an example of possible customization of the DSS.

When using a model as complicated as the DSS problems can occur for new users. We discussed potential problems that users may encounter in setting up, running and interpreting output from the DSS. Users were encouraged to think very carefully about running scenarios to ensure the simulations will answer the questions they may be posing. We mentioned the simple mechanical problems that can occur (e.g., computer crashes) as well as the more complicated problems that may arise (e.g., problems with polygon overlap and slivers in habitat layers). Users were encouraged to provide us with feedback about any persistent problems they may encounter and to establish self support user groups. We pointed to the RCW_DSS listserv as a useful mean to achieve this (see below).

We showed users how we had employed the DSS to answer real life questions about management of RCW populations. We presented a brief outline of the work carried out at Fort Benning, and showed the results obtained and our interpretation of them. We also demonstrated the implementation of the optional movement parameter using our Onslow Bight application. We discussed the ability of the output of the DSS to generate further questions and thus further testing in light of these examples.

We announced the creation of an email discussion listserv and strongly encouraged users to join. The listserv has the potential to act as a self-help community of users which should facilitate the use of the DSS. The listserv could also act as a useful archive of errors and problems that users may encounter that could be used in any potential future updates or upgrades to the DSS.

Attendees

The workshop at Eglin Air Force base was attended by approximately 15 people from the following organizations: US Air Force; Florida Fish and Wildlife Conservation Commission; USDA Forest Service; and Virginia Tech. The Sandhills workshop was attended by 12 people from the following organizations: Fort Bragg Endangered Species Branch; U.S. Fish and Wildlife Service; North Carolina Wildlife Resources Commission; Dr. J. H. Carter and Associates, Inc.; and the Sandhills Ecological Institute.

The majority of the feedback from attendees at both workshops was extremely positive. The few concerns were largely based upon the limitations of the habitat dynamics used by the current

model. Most attendees that expressed an opinion were concerned that the model only allowed the forest to age and not to decline. There was also some concern with the assumption that all management is assumed to be equal and constant over the time span of the model run. We explained that these problems can be addressed somewhat by conducting multiple simulations that provide some bounds within which the real population is likely to occur, e.g., running worst case and best case scenarios. Completely addressing these concerns will require adding an underlying forest dynamics model to the DSS, an addition we plan to make as part of a subsequent SERDP project (RC-1696, "Developing dynamic reference models and a decision support framework for southeastern ecosystems: an integrated approach").

Attendees provided several additional suggestions for potential changes or additions to future iterations of the DSS including: being able to remove selected habitat polygons at specific years in the simulation (similar to adding recruitment clusters in specific years); and a feature similar to the "Add Recruitment Clusters" wizard but for selecting habitat polygons for removal.

Conclusions

Both workshops were well attended by a useful cross section of potential users. All attendees expressed the value of the workshop in demonstrating the use and utility of the DSS and all attendees received a copy of the DSS on CD. Useful discussions were initiated and continued after the completion of both workshops. The attendees at the Sandhills workshop agreed to form a "users group" in order to maximize the benefit of the DSS to those involved in the management of RCW populations in and around Fort Bragg.

Conclusions and Implications for Future Research/Implementation

The primary objective of the project, to develop a user-friendly GIS-based spatially-explicit decision support system that will help DOD personnel identify and prioritize habitat parcels on and in the vicinity of DOD installations according to their value for RCW conservation, was achieved. Validation exercises indicate that the DSS performs well, and user feedback and results from applications to current RCW conservation issues on two bases demonstrated that the DSS can accomplish what it was designed to do, is easy to use and is attractive to potential users. The DSS is applicable to problems involving land use change, habitat fragmentation, habitat restoration, evaluation of management options, range design and land acquisition. As such, on installations harboring RCWs it can be applied to help resolve the issue identified in the Statement of Need toward which this research was directed, namely the impact of habitat fragmentation on and in the vicinity of DOD installations on endangered and threatened species. Generally what the DSS does is allow users to project the impact of any change in land use or management within their existing land base, or additions to or subtractions from that land base, on their RCW population. Specifically users will be able to assess the effects of landscape fragmentation, habitat loss, habitat restoration, recruitment cluster construction and ‘no management action' on current and future RCW populations. In addition, the DSS is specifically designed to enable evaluations of the importance of individual habitat parcels to an RCW population and to track dispersal of birds between user-defined groups of territories. The DSS requires only three user inputs, initial RCW territory centers, habitat, and optional recruitment cluster centers, and any manager working with RCWs likely will have this information readily available. We are confident that the DSS will allow managers to make more accurate projections about the dynamics of their RCW populations and of their management actions on those populations.

The DSS represents an increase in complexity and specificity relative to our previous RCW population model. As such it is less general and therefore less applicable to other species. It could be adapted to other cooperatively breeding species, especially those that respond to landscape features similarly to RCWs. The one such species that occurs in the region is the Florida Scrub Jay (*Aphelocoma coerulescens*) and indeed researchers working with this species have used a model very similar to the DSS to capture its population dynamics (Stith et al.1996). The DSS could be modified to fit other species through removal of some of its features, notably all the elements related to the presence of a helper class, and might have some value for species that share other features with RCWs such as use of dispersal forays and sensitivity to habitat gaps. The unique general feature of the DSS is its detailed depiction of dispersal behavior. Where dispersal is of particular interest, whether to explore its possible impact on population behavior or assess impacts of landscape change, modifying the DSS to fit other species may have some appeal. But such modifications would require the existence of considerable data in order to parameterize the model, and for most species sufficient data would not exist. Such modifications would also require extensive programming. Where dispersal behavior is not of particular interest, the more prudent choice will be to use one of the several other existing, more general, simpler population dynamics software packages rather than attempt to adapt the DSS.

The DSS provides a capability to examine interaction of the RCW population with the landscape, a capability that did not exist previously. Also, it incorporates new data on RCW movement to provide a more realistic portrayal of dispersal behavior and thus interaction of movement with the landscape than existed previously. Although these two advances represent significant improvements in capability to accurately model RCW population dynamics, the two questions involved still represent the two areas where further research is most needed. First, the landscape with which the RCW population interacts in the DSS is static except for aging of the pine canopy and addition of recruitment clusters. The value of the DSS would be greatly improved if this mostly static landscape could be replaced by a forest dynamics model. We hope that a new SERDP project (RC-1696) will provide this capability. Such a capability would enable managers to evaluate how their management of their forest, including forestry operations and fire management, would impact their RCW population. It would also enable managers to project the impact of land use changes at various points in the future instead of being restricted to examining impacts of proposed changes on the current RCW population. Finally, it would enable managers to better evaluate the impact of improvements or reductions in habitat quality, whereas the current DSS is mostly restricted to evaluating changes in the quantity of habitat available.

Second, the model validation exercises and applications carried out as part of this project indicate that although the DSS represents improved modeling of RCW movement, some deficiencies in modeling movement remain, specifically ability to predict rare, long distance movements. We added capacity for such movements to the model by incorporating a parameter that reflects recently discovered “jumping” behavior, but it is clear that the model underestimates the frequency of jumping. Further behavioral research on RCW dispersal is required to generate the data necessary to better parameterize jumping behavior. Such data will be extremely difficult to acquire, and probably can only be obtained through radio-telemetry studies. In particular we need data on how jumping birds react to successive habitat gaps.

The social behavior of dispersing birds clearly is more complex than depicted in the model. The DSS models dispersal in terms of detection of breeding vacancies, whereas behavioral studies, including RC-1471 (see also Walters et al. 1988, Walters 1990), have shown that dispersing birds interact regularly with existing, intact groups in complex ways rather than focusing their attention on breeding vacancies. Minor discrepancies between real and simulated dispersal and social dynamics can be traced to omission of complex social behavior by dispersing birds from the model Examples include underestimation of the number of floaters and overestimation of the number of helpers in the populations, and overestimation of the number of females breeding at age one. Still, the DSS depicts social structure quite well and these minor discrepancies have little or no effect on the most critical projections of the model such as population size and territory occupancy. Thus we do not view this as an important deficiency, and would argue that our somewhat simplified model is preferable over the possibly overly parameterized model that would result from attempting to add more complex details of social behavior.

Of more concern is the fact that the DSS is overly conservative in its depiction of the habitat requirements of RCWs. Actual population growth in terms of number of occupied territories was greater in the real data than in the simulations for both the Sandhills and MCBCL populations, and the model was overly conservative in estimating the success of recruitment clusters. Many recruitment clusters that were occupied in the real populations were rejected by the model due to

insufficient habitat. The model was overly conservative in predicting budding for similar reasons, especially in areas between existing groups. We conclude that RCW groups can persist on fewer acres of suitable habitat, and/or acres that do not meet the suitability criteria, required in the model. This suggests that the USFWS foraging habitat requirements for the species on which our suitability criteria are based are overly conservative. Given the great concern over extirpation of RCW populations due to its endangered status, it is better to be overly conservative in projecting its population behavior than overly optimistic, but still incorporating more accurate habitat requirements is one avenue by which the DSS could be significantly improved.

An important issue affecting the use of the DSS is availability of habitat data required as input. Generally the data required for one of the input options, land cover type and stand age, will be available for federal lands such as military installations and national forests. However, such data will be lacking for private lands and often even state lands in the vicinity of federal lands in most cases. Cover type can often be determined from widely available maps and remote sensing data of various sorts, but determining stand age is problematic. We explored the possibility of using LIDAR technology to estimate stand age but determined that this technology is not capable of estimating this variable accurately. Hence availability of habitat data for key properties off base remains a problem. Until this problem is solved installations will need to collect the required data on stand age or be satisfied with crude, often inaccurate, estimates. In working with several military installations over the course of the project we discovered that the more detailed habitat data required for the second habitat input option, habitat quality index, is unavailable for even most (and perhaps all) federal properties. Although use of the habitat quality index data will result in more accurate projections of RCW population dynamics than the overly conservative land cover type option due to its more accurate and flexible portrayal of habitat suitability, it appears that this is not a viable input option currently. This is surprising, given that the USFWS requires managers to use these data to evaluate RCW habitat availability on public lands (USFWS 2003). Generally managers have data for most of the required variables but lack data for others, most commonly ground cover.

Despite these issues and shortcomings, the potential for direct implementation of the DSS by DOD personnel is high. It is already being routinely used on one installation (Marine Corps Base Camp Lejeune), personnel on a second installation (Fort Benning) have the capacity to use it, and it has been provided to personnel on three additional installations (Eglin Air Force Base, Fort Bragg, Camp Mackall). It is freely available for downloading to the remaining ten installations with RCW populations. The biggest issue affecting whether this potential will be realized, that is, whether the DSS will come to be routinely used on all 15 installations with RCW populations, is lack of availability of technical support. New users no doubt will encounter problems with installing and running the software, and if there is no one to whom they can turn for help, they may give up on mastering the tool. Also, users may identify previously unknown bugs or have needs for outputs not currently available, problems which would require programming “fixes”. The DSS is designed as a user-friendly, point-and-click tool, and as such the underlying programming is not available to the user. Hence such “fixes” currently are not possible. The solution to all these problems is to acquire a modest amount of funding for the next 1-3 years to support the programmer who built the DSS (Paige Baldassaro) part-time so that she will be available to provide technical support and make modifications to the DSS. We anticipate that

after this 1-3 year period of transition, all the potential users of the DSS should be running the model on their own and no additional technical support and model changes would be required.

Potential for use by managers of other federal properties and state properties is also high. Many national forests house RCW populations, as do some USFWS wildlife refuges and several state properties. There is certainly not only need for the DSS on such properties but also interest in it, as evidenced by attendance by personnel from national forests, USFWS and state agencies at our workshops. The largest obstacle to use of the DSS by managers of these properties, as on military installations, is having staff with sufficient time and GIS expertise to set up and run simulations. It may be easier for multiple partners concerned with a regional RCW population to pool resources in order to support the modeling required by all than for a single agency to dedicate the required resources to this task. More often than not, such regional partnerships already exist (e.g., the North Carolina Sandhills Conservation Partnership at Fort Bragg, the Onslow Bight Partnership at MCBCL and the Gulf Coast Plain Ecosystem Partnership at Eglin Air Force Base). Adoption of the DSS by such partnerships would enable more proactive modeling such as is being done in the Onslow Bight region. Elsewhere use of the DSS has been more reactive, that is, the DSS is employed only when the USFWS requires such population modeling during consultation over a proposed activity on an installation. Such reactive modeling is likely to continue, as the USFWS coordinator for RCWs, Will McDearman, has communicated to us his intent to require use of the DSS in such circumstances.

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Appendix A: DSS Help File

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Introduction

About This DSS

This decision support system (DSS) uses landscape and population information to simulate the response of Red-cockaded Woodpecker (RCW) populations to management and landscape change. With this system, users are able to assess the effects of landscape fragmentation, habitat loss, habitat restoration, recruitment cluster construction, and 'no management action' on current and future RCW populations. In addition, the DSS is specifically designed to enable evaluations of the importance of individual habitat parcels to an RCW population.

The RCW model was originally created with colleagues at North Carolina State University. This DSS was created by personnel from the Conservation Management Institute and Department of Biological Sciences at Virginia Tech, and the Duke University Marine Laboratory in North Carolina.

This DSS is provided AS-IS with no warranty, expressed or implied.

Software Requirements

The DSS (version 1.2.1) has only been tested on Windows XP ArcMap 9.3, SP3. It will not work on versions of ArcMap older than 9.3, and is currently not Windows Vista compatible. It requires at least 1 gigabyte of RAM.

Basic Components

The DSS has 4 basic components: Toolbar, Wizard, Scenario Manager, and Recruitment Cluster Manager. Each of the components is discussed in detail throughout this help file. The user is required to have a basic working knowledge of ArcMap in order to use this DSS. This includes, but is not limited to, creating a map document, creating data layers, adding data to maps, adding attributes, and simple editing.

Toolbar

About The Toolbar

The toolbar is available only through ArcMap and is loaded when you install RCWDSS.DLL through the setup program provided (installation instructions). The toolbar provides access to 3 tools, the DSS Wizard interface ("DSS Wizard"), the Scenario Manager interface ("DSS Scenario Manager"), and the Recruitment Clusters Interface ("Add Recruitment Clusters").

Install

WARNINGWill only install on Windows XP with ESRI AcrMap version 9.3 or higher.

1. Make sure all ESRI programs are shut down. The software may not install/uninstall correctly if ESRI programs are running.
2. Double-click on Setup_v1.2.1.exe.
3. Follow the instructions on the screen.
4. Open ArcMap**.**
5. Click on Tools → Customize → Add From File.
6. Browse to the folder where you installed the DLL (default folder is C:\Program Files\RCWDSS).
7. Click on RCWDSS.dll.
8. Click ok.
9. Check the box next to the entry RCW DSS.
10. Click Close.

Uninstall

1. Make sure any ESRI programs are shut down. The software may not install/uninstall correctly if ESRI programs are running.
2. Go to Start → Programs → RCWDSS v1.2.1 → Uninstall
3. Follow the instructions on the screen.

DSS Wizard

About the Wizard

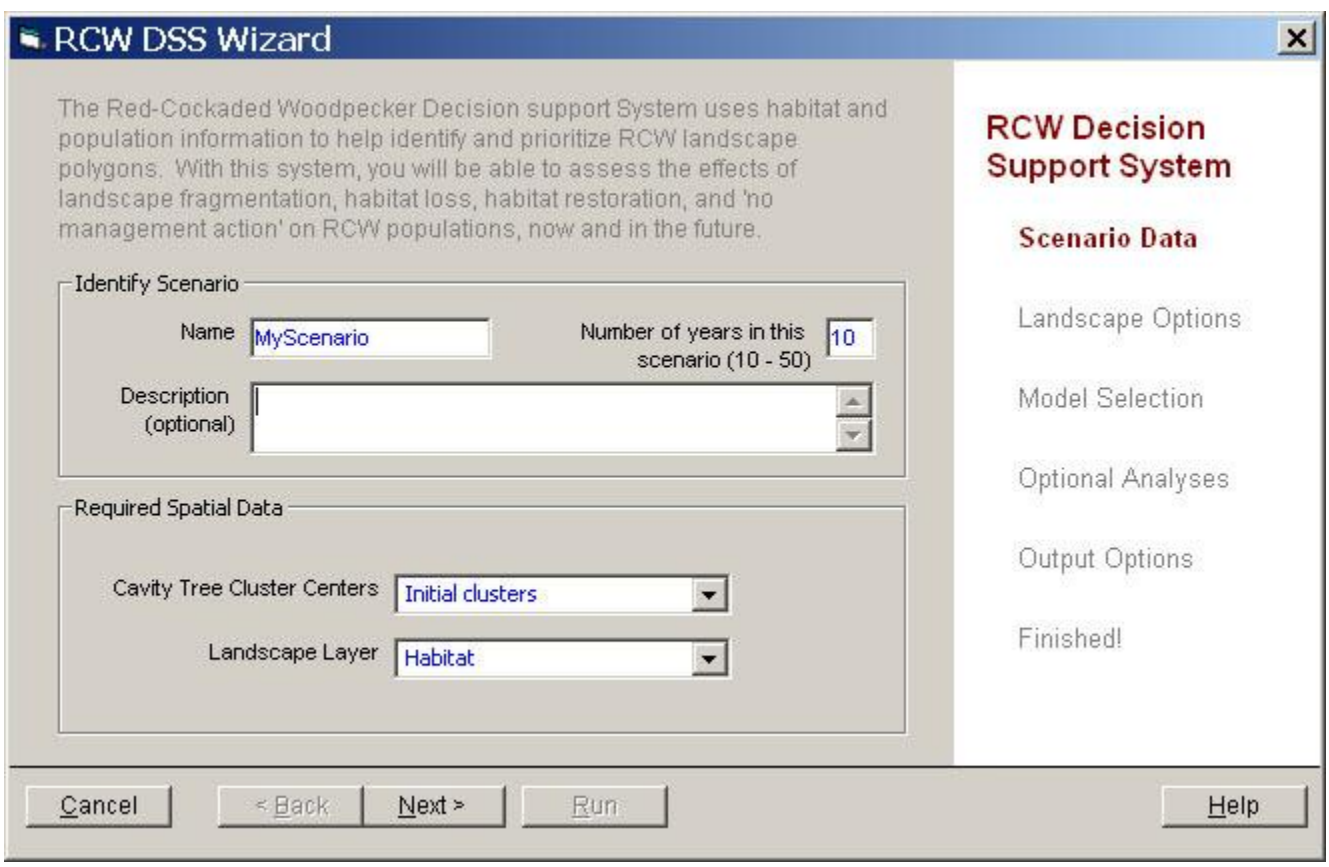
The Wizard is the main entry point for the DSS. It has 5 steps:

1. Define basic DSS parameters (Scenario Data)
2. Define landscape parameters (Landscape Options)
3. Choose appropriate models to define the initial population (Model Selection)
4. Conduct any optional analyses (Optional Analyses)
5. Set output options (Output Options)
6. Finished! (Finished!)

Each step is detailed in its own specific section in the help file.

Step 1: Scenario Data

A scenario is the set of parameters the user defines to describe the population model and how it will be conducted. Defining a scenario is done through the wizard in several steps. This step requires the user to define some basic descriptors to differentiate individual scenarios:



Identify Scenario (Click on each link to see value ranges for each attribute)

- Name: Also considered the scenario title or scenario name.
- Number of Years in this Scenario: The number of years each simulation is conducted.
- Description: Optional parameter. This allows the user to provide any additional information to describe the scenario.

Required Spatial Data

- Cavity Tree Cluster Centers: a projected point Shapefile representing RCW cavity tree clusters or territory centers within the landscape of interest.
- Landscape Layer: A projected polygon Shapefile representing landscape polygons within the landscape of interest.

All layers to be used in the DSS are required to be loaded in the ArcMap document before you start the Wizard and ***must*** have the same spatial reference.
Layers used by the DSS ***must*** all be projected into the UTM coordinate system.
If the above criteria are not met, the DSS will not run.

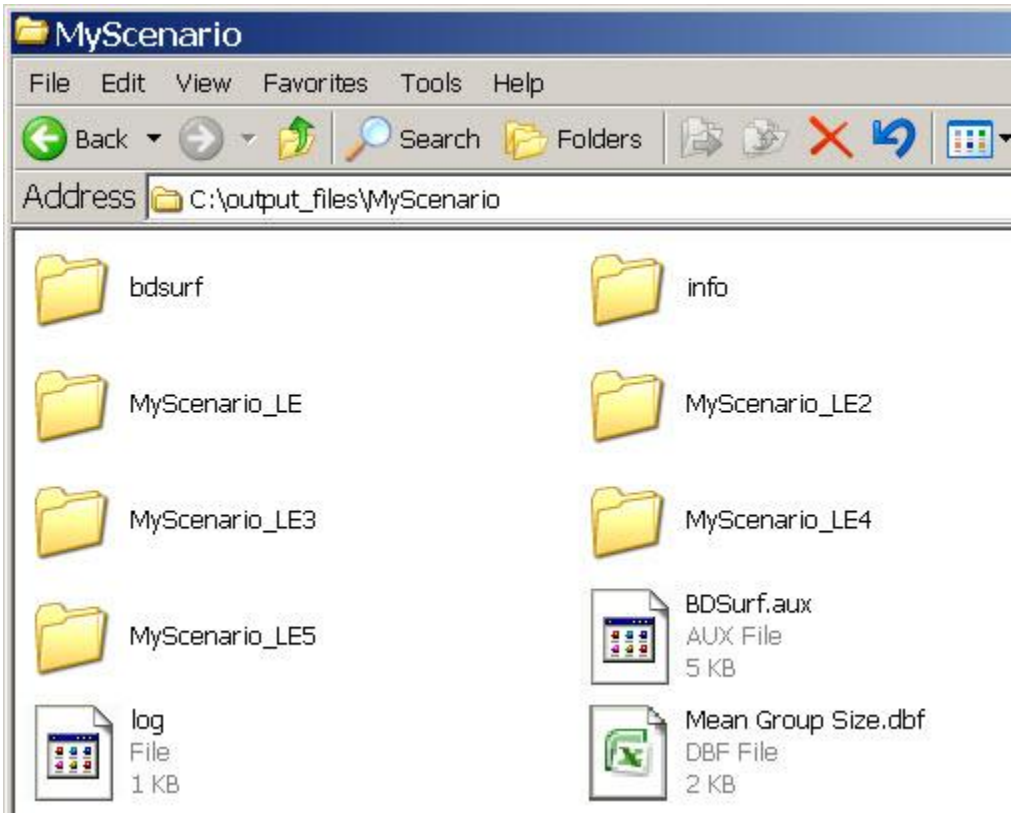
Scenario Name

The Scenario Name is provided by the user and is a unique code used to distinguish individual DSS scenarios. Each scenario has its own folder, whose name corresponds to the Scenario Name. If you use the name of a folder that already exists, the DSS will prompt you to choose another one. Long scenario names are strongly discouraged. Use the description field to provide any extraneous information.
Scenario Names have the following limitations

- Only letters, numbers, spaces, and underscores are allowed.
- First character must be a letter.

Each DSS scenario is stored in its own folder in the output location provided by the user. It is considered the primary DSS Scenario. Landscape evaluation scenarios are scenarios conducted immediately after the primary scenario, using the same parameters. These secondary scenarios are stored in their own folder within the root folder of the primary DSS Scenario. The attribute value specified by the user is appended to the primary DSS Scenario name to get the name of a specific secondary scenario.

For example, your primary scenario name is MyScenario. In this scenario, you are conducting 5 landscape evaluations, each time removing a different set of polygons. Each set of polygons is identified by the value of the 'Group' attribute in the landscape attribute table: LE, LE2, LE3, LE4, and LE5. Therefore, each landscape evaluation will be in its own folder within MyScenario and listed as MyScenario_LE, MyScenario_LE2, MyScenario_LE3, MyScenario_LE4, and MyScenario_LE5.



Number of Years in this Scenario

This parameter is required by the DSS, and represents the length of the model run, in years. By default, the model conducts 70 simulations for each scenario. Each simulation is run over the number of years specified by the user. The acceptable range of values for this parameter is between 10 and 50 inclusive.

Description

This is a textual description of the model. It provides the user with a method to store user defined information about the scenario for later use and differentiation. It is an optional parameter.

Landscape Layer

The DSS requires a polygon Shapefile containing landscape/stand information that has the following characteristics:

- It has a spatial reference defined *and* it matches the spatial reference of the cavity cluster center layer and the recruitment cluster layer (if provided).
- The spatial reference must be in UTM.
- The layer should contain the following attributes (names and types must be exact). The types (Text, Long Integer) are ESRI attribute types defined when you add a field to the

shapefile attribute table. See ESRI documentation about how to add attributes to shapefiles. Click on each link to see acceptable values for each attribute.

1. STAND_ID: Text
2. TYPE: Text
3. PINE_AGE: Double
4. Stand_Scor: Double, optional parameter
5. Landscape Evaluation Attribute: Text, optional parameter

Stand_ID

Stand_ID is a unique text identifier for each landscape polygon. This value cannot be empty.

Type

Type is *case sensitive* (all upper case) and can only come from the following list of values:

- Nesting and foraging habitat
  - PINE – polygon delineating pines stands
- Gap, unsuitable for nesting, foraging, and movement by females
  - OPEN – polygon delineating open area
  - WATER – polygon delineating a body of water
  - OTHER – polygon with no clear designation such as a building or road.
- Non gap (suitable for movement), non-nesting and non-foraging habitat
  - HARD – polygon delineating hardwood stands
  - PINE DISPERSAL ONLY – polygon delineating pine stands that are unsuitable for nesting and foraging
  - MIXED – polygon delineating mixed pine-hardwood stands

Pine_Age

Pine_Age is an integer value that represents the age of the polygon. It cannot be negative.

Stand_Scor

This parameter provides a way to define stand suitability and influence how the model deals with habitat quality. To use this feature, each stand should be attributed (using the STAND_SCOR field in the Landscape Layer) with a value between 1 and 5 (inclusive). The user then chooses a minimum stand score that represents the minimum value for a stand to be considered suitable for nesting and foraging. Stands with values less than this threshold are not counted with respect to the minimum number of acres required for budding or recruitment clusters.

Landscape Evaluation Attribute

If you wish to group polygons for removal from a scenario as a way to test the contribution of those polygons to RCW population dynamics, assign those polygons a unique value within the layer under a specific attribute. You can do this for multiple values and they will be removed

independently. Polygons that should never be removed will not have a value in the attribute field.

The name of this attribute is user-defined. The user will choose which attribute designates landscape evaluation in the wizard. More information about Landscape Evaluation can be found in Optional Analyses: Landscape Evaluation

Cavity Tree Cluster Centers Layer

The DSS requires a point Shapefile containing RCW cavity tree cluster or territory centers and has the following characteristics:

- It has a spatial reference *and* it matches the spatial reference of the landscape layer and the recruitment cluster layer (if supplied)
- The spatial reference must be in UTM
- The layer should contain the following attributes (names and types must be exact). The types (Text, Long Integer) are ESRI attribute types defined when you add a field to the shapefile attribute table. Please review ESRI documentation on how to add attributes to a shapefile. If the model cannot find the attribute, Occupied, it will be added to the layer with a default value of 1 (occupied). Click on each link to see acceptable values for each parameter.
    1. ID: Text
    2. Occupied: Long Integer
    3. DispGroup: Text, optional parameter

ID

Unique identifier for a territory cluster. Valid characters are letters, numbers, underscores, and dashes. Value cannot be empty.

Occupied

Valid values for this attribute are 1 or 0. If the attribute does not exist, it is created and set to 1. This field indicates whether the RCW territory starts off as occupied (1) or vacant (0).

DispGroup

If you wish to track dispersal between groups, then all features in the Cluster Center Layer must have this attribute and an associated value. This attribute must start with a letter and all features must contain a value and establishes to which group the cluster belongs. If you track dispersal for Cavity Tree Cluster Centers, then you also must track dispersal for Recruitment Clusters.

Step 2: Landscape Options

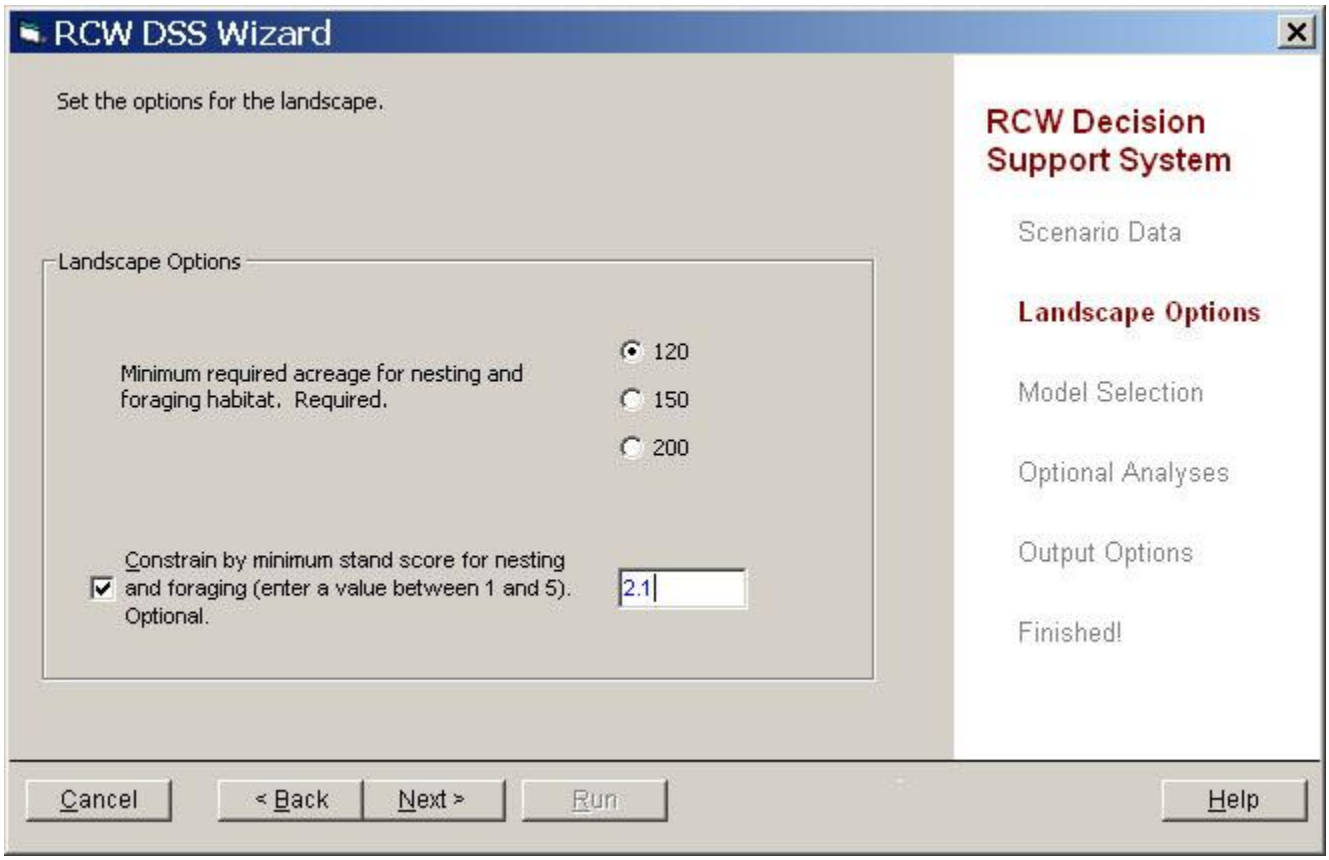
There are 2 options the user can set for manipulating the landscape.

Constrain by Minimum Stand Score for Nesting and Foraging

The Minimum Stand Score is a score that indicates the quality of the habitat. This parameter is optional. If used, it indicates the minimum quality acceptable for a polygon to be considered viable nesting and foraging habitat. The valid values are between 1.0 (poor) and 5.0 (good) inclusive. If you wish to activate this feature, you are required to have an attribute in the landscape layer called Stand_Scor. In the Wizard, check the box, "Constrain by minimum stand score" and then enter your minimum value in the text box.

Minimum Required Acreage for Nesting and Foraging Habitat

One of the limitations to both recruitment clusters and buds being added to the model is acreage. A new territory must have sufficient acres of foraging habitat, not already assigned to existing groups, to support a new group. Thus both recruitment clusters and budded territories must be located in a spot that provides a minimum acreage for nesting and foraging habitat. This option determines what that minimum value is. The possible values are 120, 150, and 200 acres.



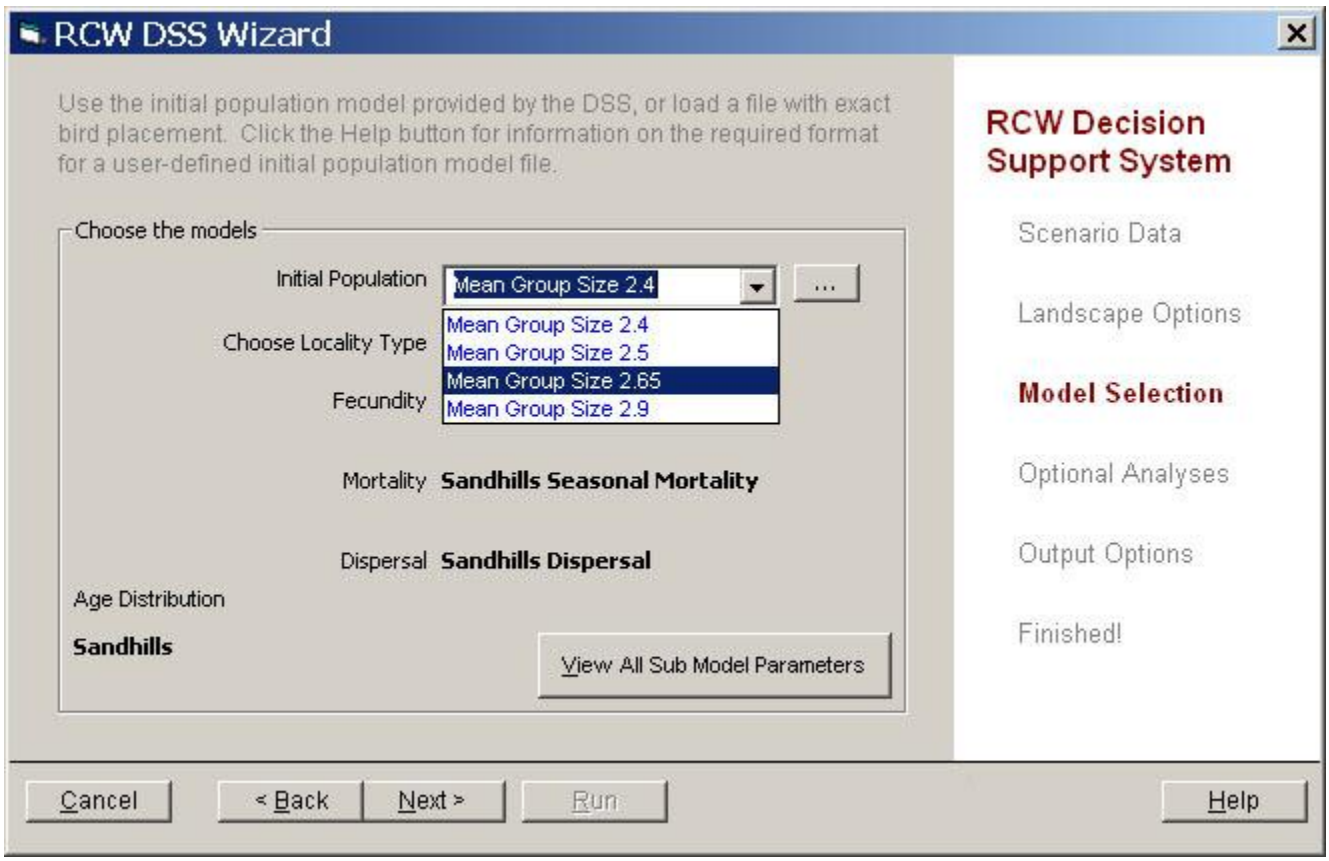
Note: All initial territories are given a radius of 500 meters. They are then processed against each other to produce a Thiessen polygon layer, which is then converted to a grid to be used in the model. It is possible that the resulting initial territories would not meet the minimum required acreage set in the model. Initial territories are not required to meet this minimum

acreage. Nor is any other spatial verification performed on the placement of initial territories since they are presumed to be preexisting and therefore valid.

Step 3: Model Selection

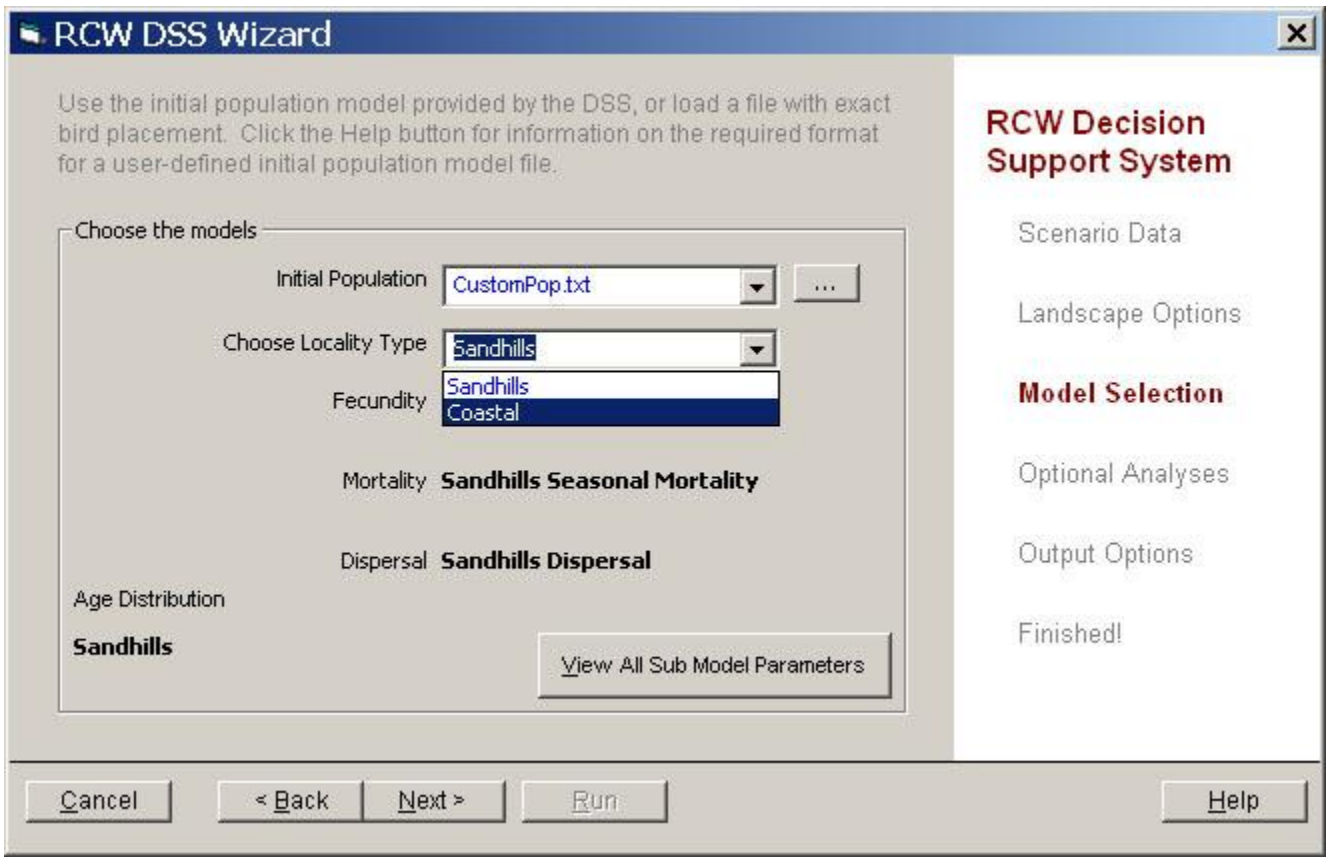
There are two demographic models used within the DSS to describe the red-cockaded woodpecker, Sandhills and Coastal. Sandhills is based on the demography of the RCW population in the Sandhills region of south-central North Carolina and Coastal on the demography of the RCW population on Marine Corps Base Camp Lejeune in coastal North Carolina. Sandhills has higher reproductive rates and lower survival rates than Coastal. Generally Sandhills will be the appropriate choice for modeling more northern and inland populations, and Coastal for more southern and coastal populations.

Although the user cannot change the underlying demography within the DSS, the user is able to choose the structure of the initial population, thus it is called a User Model Parameter. If the user wants to choose a predefined initial population, then they simply pick the population from the drop-down box by choosing a Mean Group Size value. This value determines the proportion of territories occupied by unpaired males, unassisted breeding pairs, and breeding pairs assisted by helpers. All initially occupied territories are assigned at least a male.



A custom population file can also be loaded by pressing the Browse button on the right, and navigating to its location. With this option the user specifies for every territory whether it contains a breeding female and how many helpers it contains.

As mentioned previously, each population is associated with a demographic model. This demographic model is then used to define the remaining sub models. If the user is using a custom initial population structure file, they are still required to define the associated demographic model, either Sandhills or Coastal.

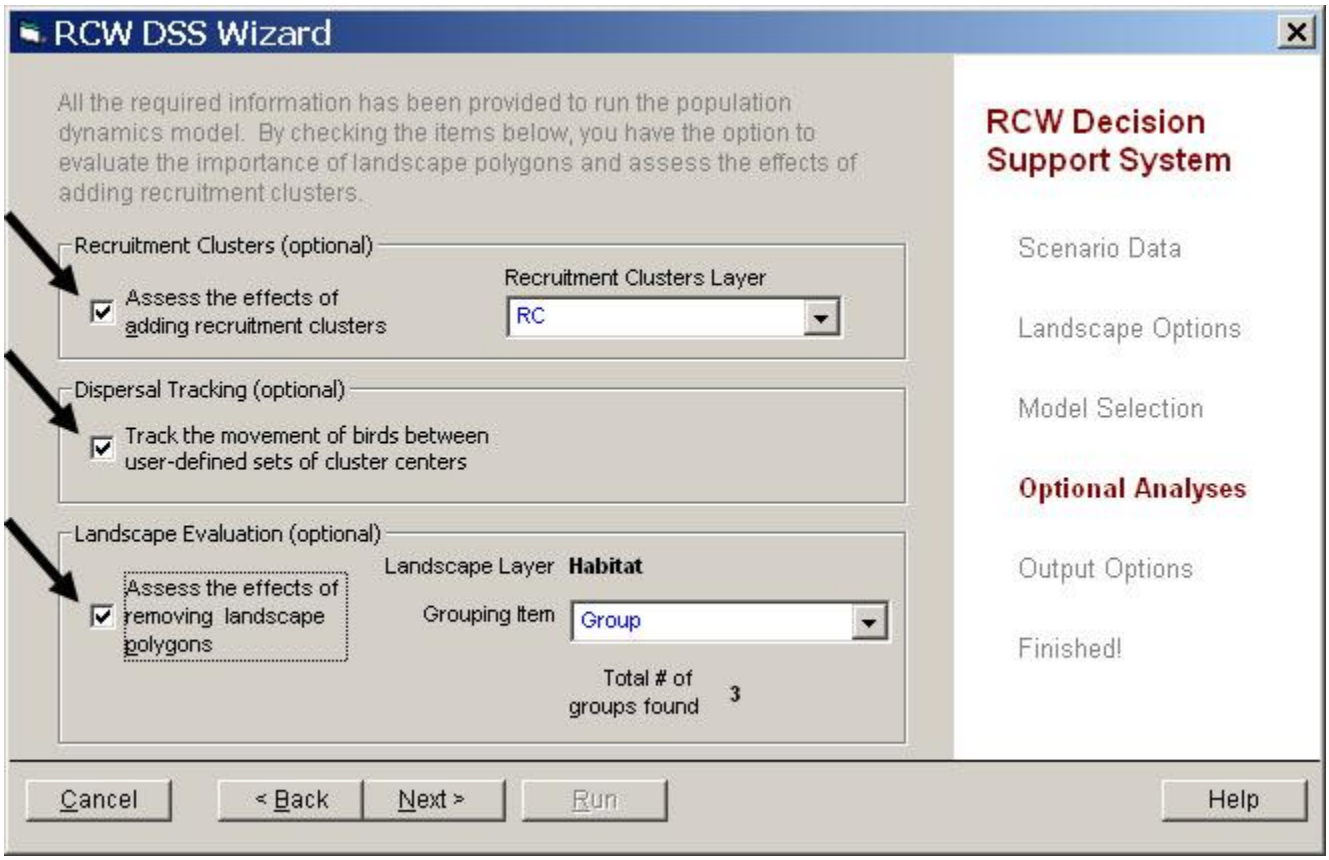


The values used within these models and others in the DSS can be examined by clicking the 'View All Sub Model Parameters' button. For more information about these parameters, go to Sub Model Parameters.

Step 4: Optional Analyses

At this stage, the user is able to choose any of 3 optional assessments they wish to have conducted. The first assessment is the effect of artificial recruitment clusters, the second assessment is to track dispersal between cluster groups, and the third is the effect of removing habitat stands (also called Landscape Evaluation) from the model. In order to activate either of

these assessments, the user must check the appropriate checkbox and set any necessary options.



Recruitment Cluster Layer

If the user wishes to designate a recruitment cluster evaluation, they can do so by supplying a recruitment cluster layer name and activating the assessment by checking the appropriate checkbox. This layer is a point Shapefile containing recruitment cluster centers and has the following characteristics:

- It has a spatial reference *and* it matches the spatial reference of the cluster center layer and landscape layer.
- The layer must be in UTM
- The layer should contain the following attributes (names and types must be exact). Click on each attribute to examine the valid value ranges for that attribute.
    1. ID: Text
    2. YearAdded: Long Integer
    3. DispGroup: Text, optional parameter

ID

Unique text defining the ID of the recruitment cluster. Valid characters are letters, numbers, underscores, and dashes. Value cannot be empty.

YearAdded

Attribute designating what year the recruitment cluster is to be added to the model. It is model year, not calendar year. If a value for this attribute exceeds Number of Years in this Scenario, the recruitment cluster in question will not be included in the model. A message will be printed to the log file indicating this. The valid values are 1 to 50.

DispGroup

This is an optional parameter. If you wish to track dispersal between groups, then all features in the Recruitment Cluster Layer must have this attribute and an associated value. This attribute must start with a letter and all features must contain a value and establishes to which group the cluster belongs. If you track dispersal for Recruitment Clusters Centers, then you also must track dispersal for Initial Cluster Centers.

Dispersal Tracking

If you establish groups using the attribute, Group, for cluster centers and recruitment clusters, then you can track the dispersal between these groups. Dispersal is tracked for both direction (A to B and B to A) and Gender (Female A to B and Male A to B). This effectively yields 4 potential tracks between any two groups (Female A to B, Male A to B, Female B to A, and Male B to A). Each feature must have a group assigned to it, and if you are doing the recruitment cluster optional analysis in addition to dispersal tracking, then that layer must also have groups assigned to its features.

Landscape Evaluation

The DSS can assess the importance of a particular landscape polygon or group of polygons to the RCW population. The DSS enables the user to evaluate the contribution of polygons to a scenario. This evaluation is done by first running a scenario with all polygons included, then running similar scenarios with selected polygons removed from the landscape. The concept of being “removed” means being rendered unsuitable nesting and foraging habitat or dispersal habitat. In other words, the polygon is considered a gap.

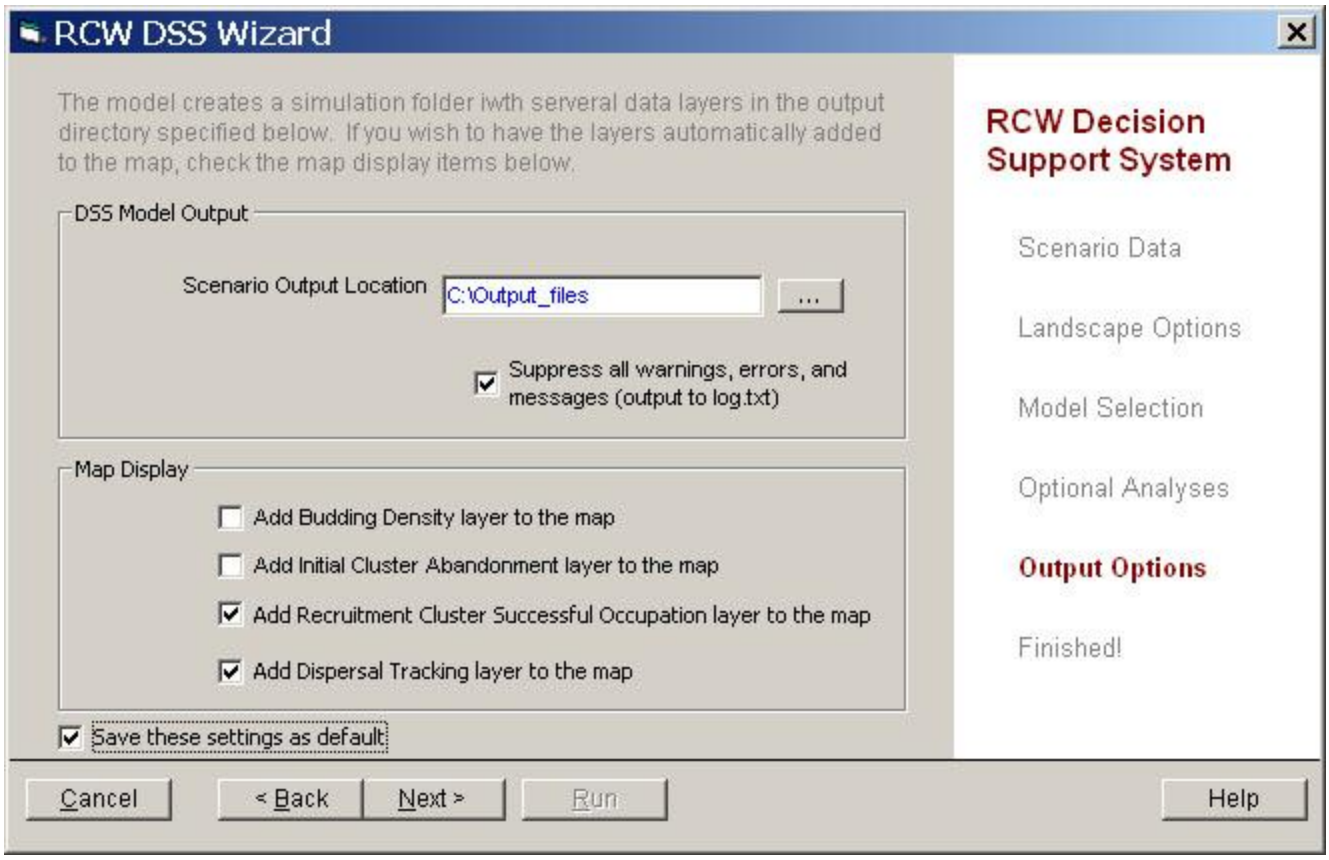
In order to use this feature, the user must check the box and then select the attribute from the landscape layer which will contain the grouping information.

At this point, the DSS retrieves the selected polygons. It is possible that some polygons selected will never be viable for nesting and foraging habitat because the habitat is the wrong type (i.e. not pine), the (pine) habitat will never reach an appropriate age for RCWs, or the available stand score does not meet the minimum (if one has been set). These polygons are listed in the log file or displayed to the user depending on the choice the user made in the Wizard to suppress output. The user is given the option to be warned when a polygon is not available for nesting and foraging habitat (and therefore will never have an impact on the model) or to allow the DSS to output such warnings/errors/information to a log file.

Once this initialization process is finished, the scenario is rerun using the same parameters for each unique value found in the attribute table. The only difference between these scenarios and the initial baseline run is that the selected polygons are now considered gaps.

Step 5: Output Options

There are several options that the user can select, or produce by allowing the defaults. Each option is described below.



Scenario Output Location - default location for all output files. This box cannot be left empty.

Suppress all warnings, errors, and messages - designate that any model information be sent to a log file instead of displayed on the screen. This is not the output or results of the model, but information, warnings, and errors that might be produced during the course of the model. They will require user interaction (pressing OK on the message box), so it is helpful to choose this option for unattended runs or runs with recruitment clusters. The name of the log file is Log.txt. It can be found in the location defined in Output Directory. Messages are appended to the log file for each run unless the user deletes or renames the log file. Therefore, this file should periodically be deleted as it can get quite large and slow down the simulations.

Add Budding Density layer to the map - layer showing the budding density for all scenarios. The budding density is the proportion of the 70 runs of a scenario in which budding occurred in a particular location. If this box is unchecked, the layer is still created, just not automatically displayed in the map after a scenario is conducted.

Add Initial Cluster Abandonment layer to the map - layer showing the number of times (in the 70 runs) specific initial clusters are abandoned. If this box is unchecked, the layer is still created, just not automatically displayed in the map after a scenario is conducted.

Add Recruitment Cluster Successful Occupation Layer to the map – layer showing the number of times (in the 70 runs) each specific recruitment cluster successfully produced at least one fledgling. This box is enabled only if the option to evaluate recruitment clusters was selected on the Optional Analyses page. If this box is unchecked, the layer is still created, just not automatically added after a scenario is conducted.

Add Dispersal Tracking layer to the map – layer showing number of birds dispersing from one group to another. Dispersal tracking tracks both gender and direction. Therefore, any 2 groups can have the following entries in the table: A to B Female, A to B Male, B to A Female, and B to A Male. The dispersal tracks are represented as straight lines between the calculated centroids of the groups. The line width is proportional to the number of migratory birds, the wider the width, the greater the number of dispersals. Lines fall on top of each other, so it is possible that a wide-width line will obscure other dispersal tracks between the groups. This box is enabled only if the option to track dispersal was selected on the Optional Analyses page. If this box is unchecked, the layer is still created, just not automatically displayed in the map after a scenario is conducted.

Save these settings as default - If you wish to preserve these settings for other scenarios then check this box.

Output Directory

The output directory will store any permanent file outputs. If no folder exists, the user will be prompted to create one. This box cannot be left empty.

Output Suppression

The DSS supplies messages to the user in a variety of ways.
DSS status (year and simulation number) is displayed to the user through a message box dialog. Various status messages are also displayed here about Bud placement and Recruitment Cluster placement.
Messages that might need to be considered separately are messages that might affect the initial data layers. These messages include:

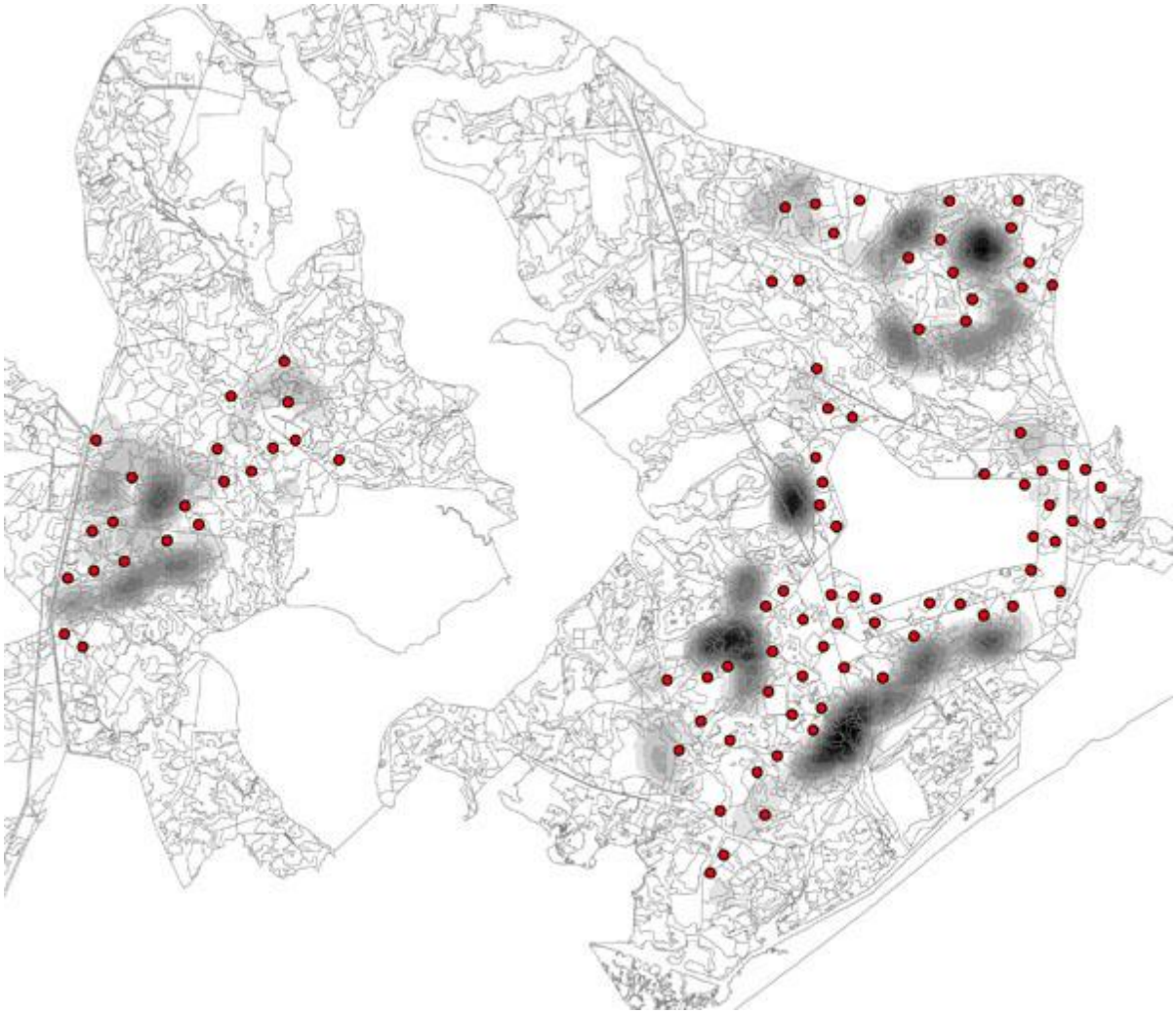
- Recruitment clusters that are added beyond the years of the simulation.

- Recruitment clusters that cannot be added because they are located in invalid locations.
- Landscape evaluation polygons that would never be considered valid polygons are excluded from the model.
- Errors.

These messages can be displayed to the user each time or output to a log file (recommended). Suppressing messages eliminates the need for user input and allows the model to be run overnight.
Also, eliminates the need for input about creating directories, auto-creates some attributes or directories.
The DSS Wizard is set to default to not suppress message and require user input.
If the user is conducting a landscape evaluation, they are asked if they wish to see all output to screen or log it to a log file. If they choose to log, this box becomes checked. The user is capable of toggling this value again in the Wizard. The log file is appended each time a new scenario is conducted. Therefore, periodic deletion of the log file is necessary so that it does not become too big.

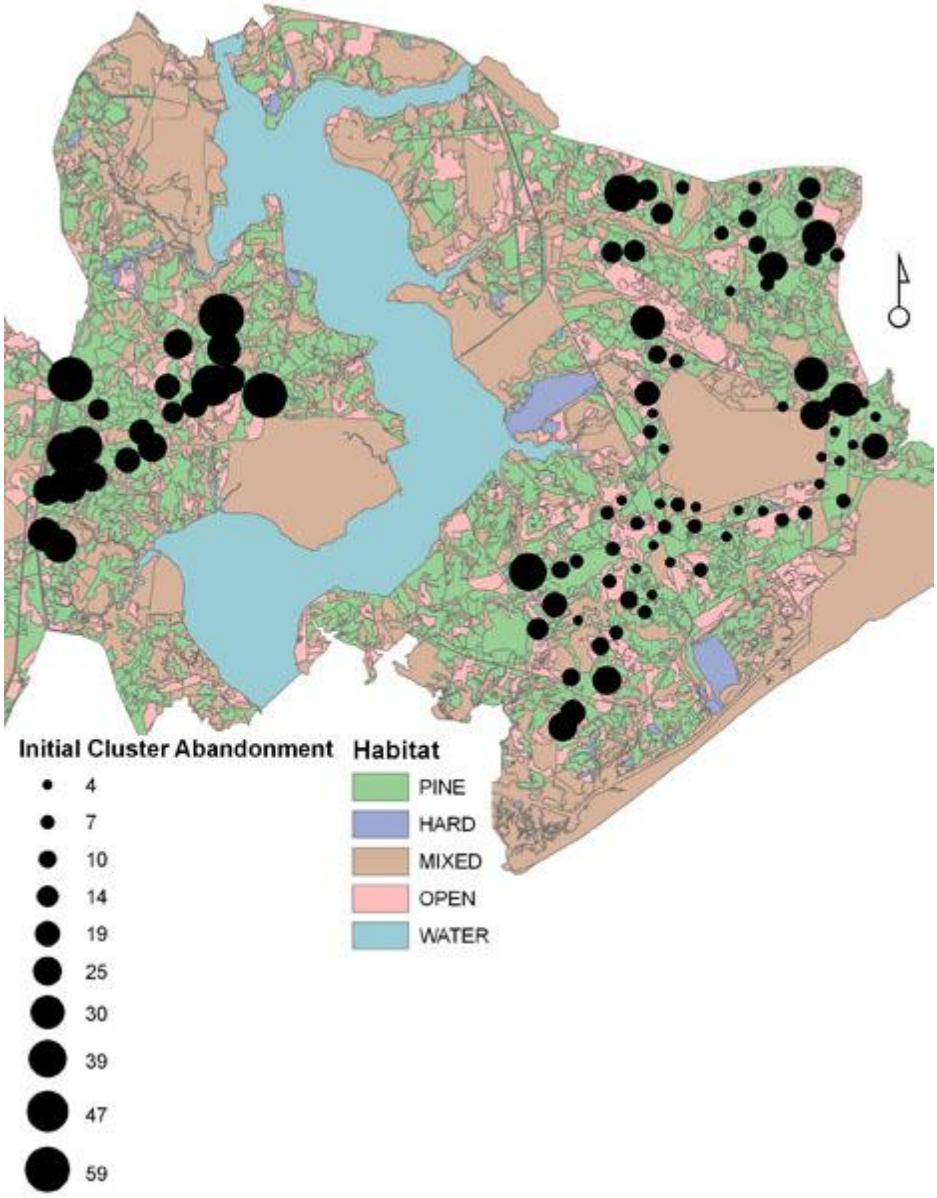
Budding Density Layer

This layer illustrates where budding occurred in the scenario. The budding density layer displays categorical values from low to high indicating the budding density across all 70 simulations of the scenario. The closer a cell is to a budding site center, the higher its value. Each cell accumulates a value for each budding site. The DSS considers a 750 m radius when calculating the cell values and does so using a 10 cell by 10 cell window moving across the landscape. The equation to calculate the cell value is 1 - (distance from cell to budding site center / 750). A value of 1 indicates the budding site is located in the center of the cell. The name of the file is ‘bsurf’.



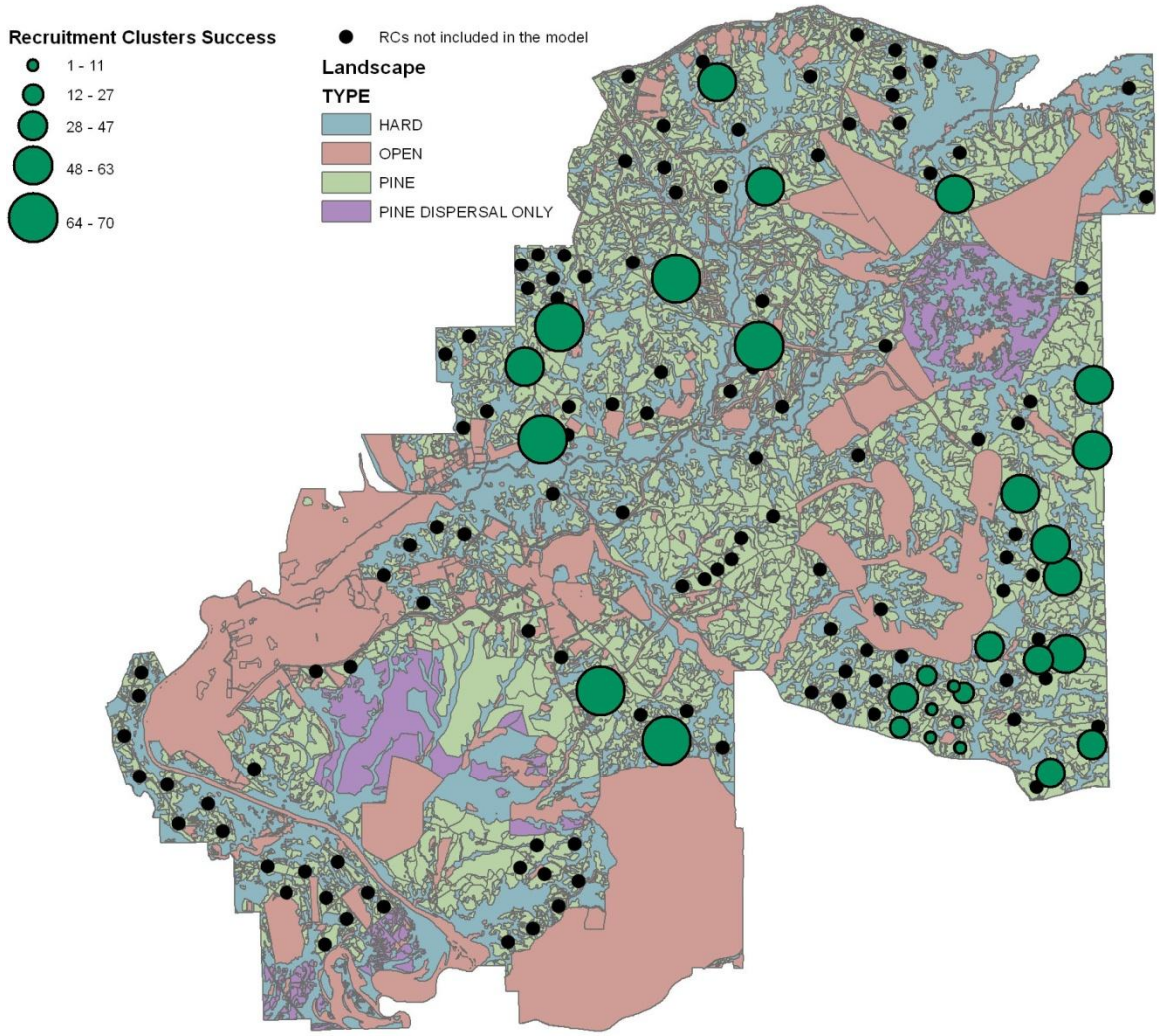
Initial Cluster Abandonment Layer

The Initial Cluster Abandonment layer shows the propensity of a specific initial territory to be abandoned within the scenario. It is the total number of times that a territory has been permanently abandoned out of 70 simulations of a scenario. The name of the file is <MyScenario>_ICA.shp.



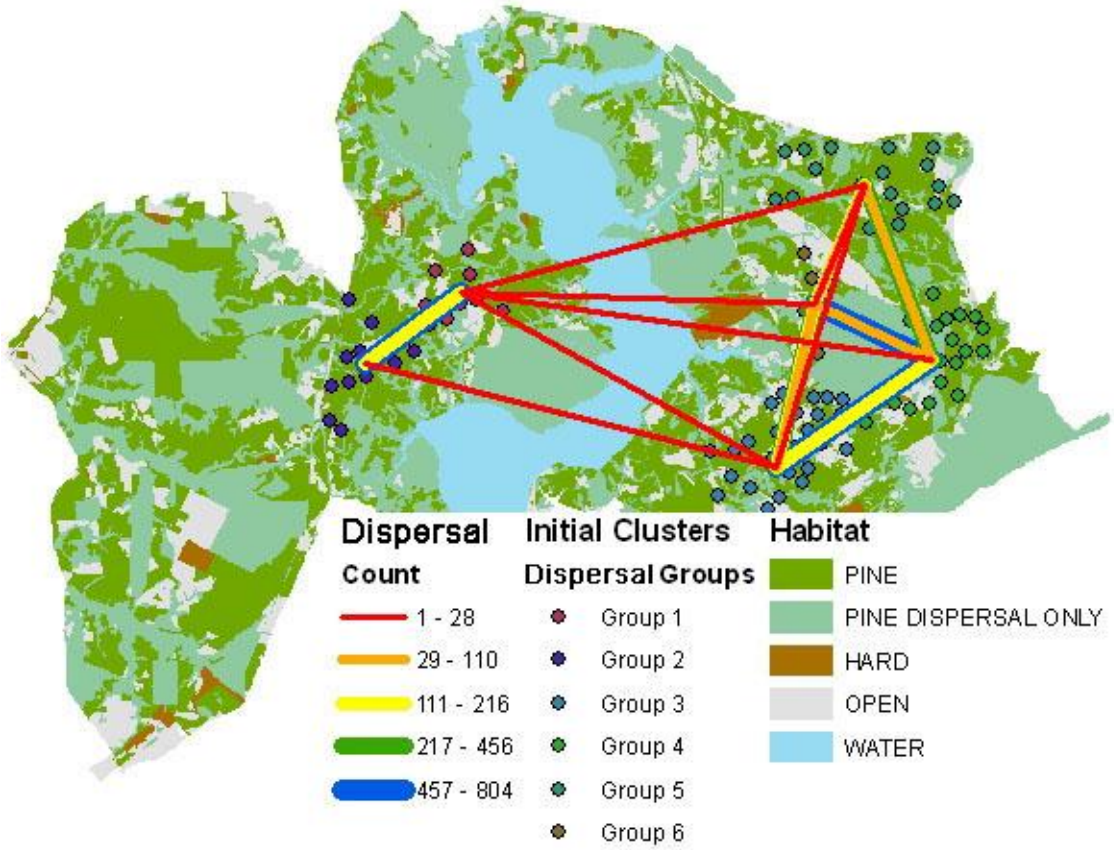
Recruitment Cluster Success Layer

The Recruitment Cluster Success layer shows the propensity of a specific recruitment cluster to produce at least one fledgling during the scenario. The values in the attribute table indicate the total number of times (out of 70) that each recruitment cluster has produced at least one fledgling. If the Add Recruitment Cluster Success Layer to Map box is unchecked, the layer is still created, just not automatically added to the map after a scenario is conducted. The name of the file is <MyScenario>_RCSO.shp.



Dispersal Tracking Layer

This layer tracks dispersal from one group to another. The groups are established using a 'DispGroup' attribute in both the Clusters Center layer and the Recruitment Center layer (if used). Dispersal tracking tracks both gender and direction. Therefore, any 2 groups can have the following entries in the table: A to B Female, A to B Male, B to A Female, and B to A Male. The dispersal tracks are represented as straight lines between the calculated centroids of the groups. The line width is proportional to the number of migratory birds, the wider the width, the greater the number of dispersals. Lines fall on top of each other, so it is possible that a wide-width line will obscure other dispersal tracks between the groups. The name of the file is <MyScenario>_Dispersal.shp.

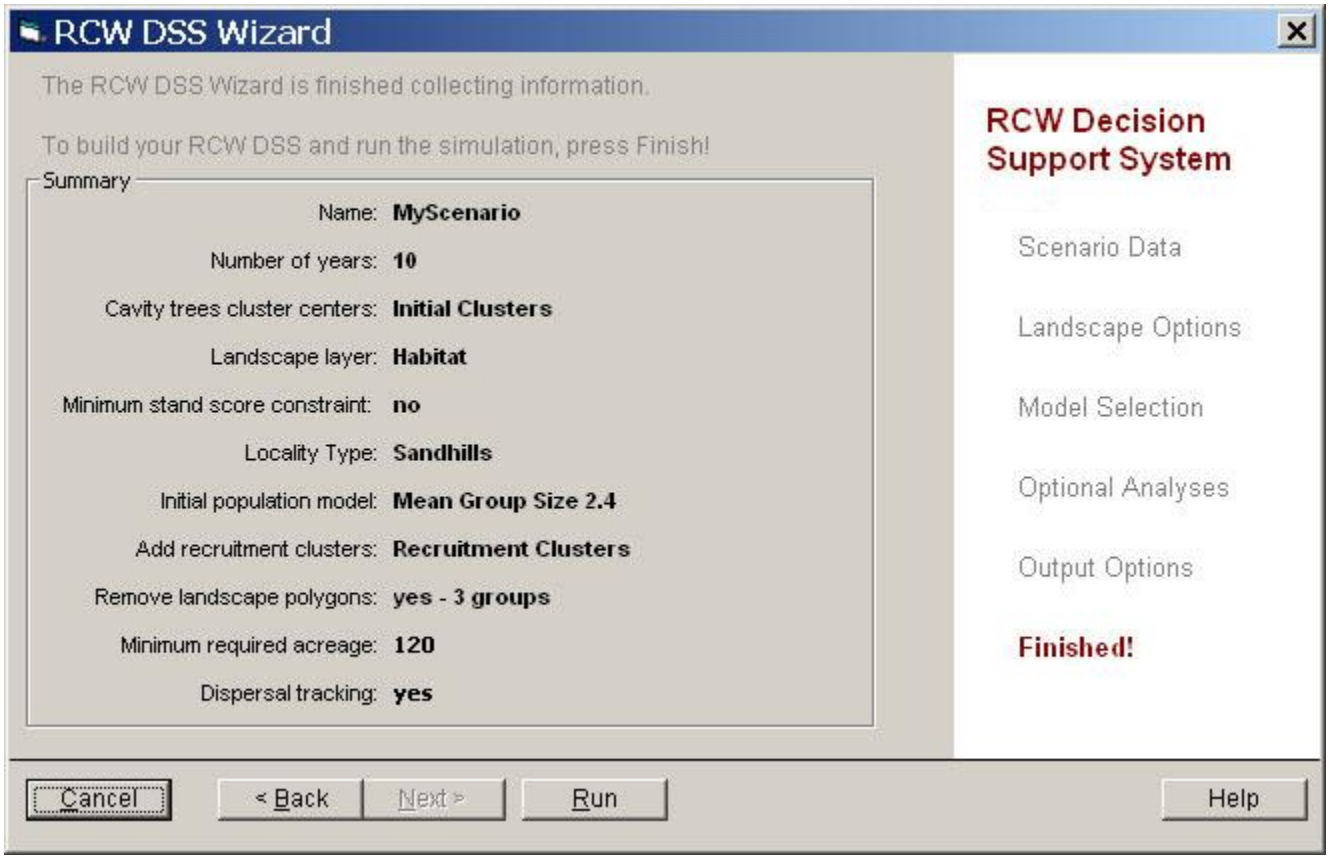


Save these settings as default

If this box is checked, the settings are written to the registry. If you uninstall the software, you will lose the settings.

Step 6: Finished!

This step displays a summary of the options chosen. When the user presses Run, it compiles the input parameters and prepares them for the DSS. All input parameters are saved automatically in a text file with the extension "*.rcw". The DSS automatically runs once the input parameters have been compiled.



If there is an error with the input data, the DSS will not run. This error is reported directly to the user or a log file, depending on the option selected in Suppressing output to log file.

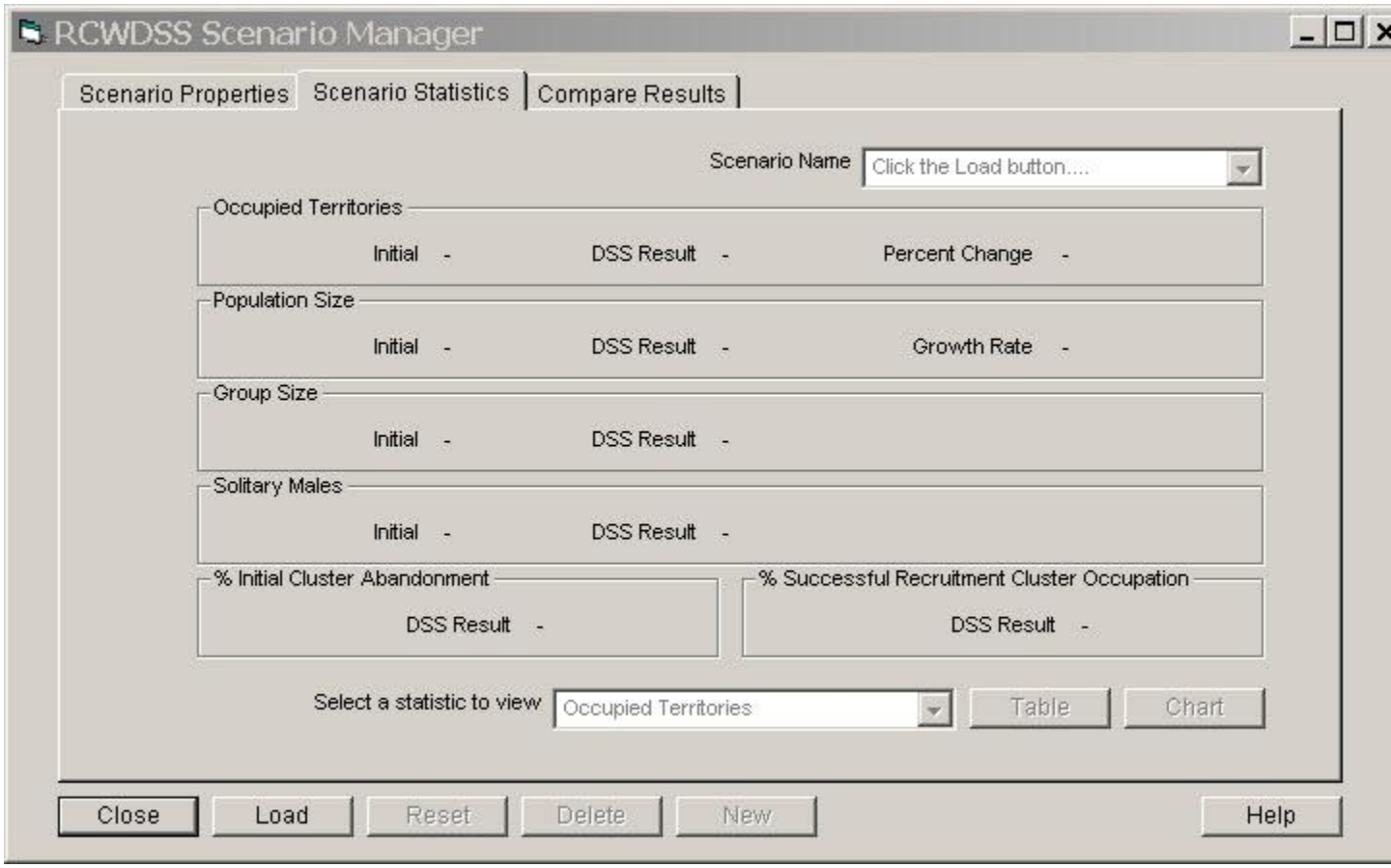
DSS Scenario Manager

About the Scenario Manager

The Scenario Manager allows the user to view, compare, or delete existing scenarios, use existing scenarios as a template for new scenarios, and display the results from conducted analyses. When the Scenario Manager is initially loaded, it defaults to the Scenario Statistics tab unless it is loading multiple scenarios, then it defaults to the Compare Results tab.

It has 3 tabs across the top: Scenario Properties, Scenario Statistics, and Compare Results to display and manage the results.

It has buttons along the bottom to work with the scenarios: Close, Load, Reset, Delete, New, and Help (this help document).



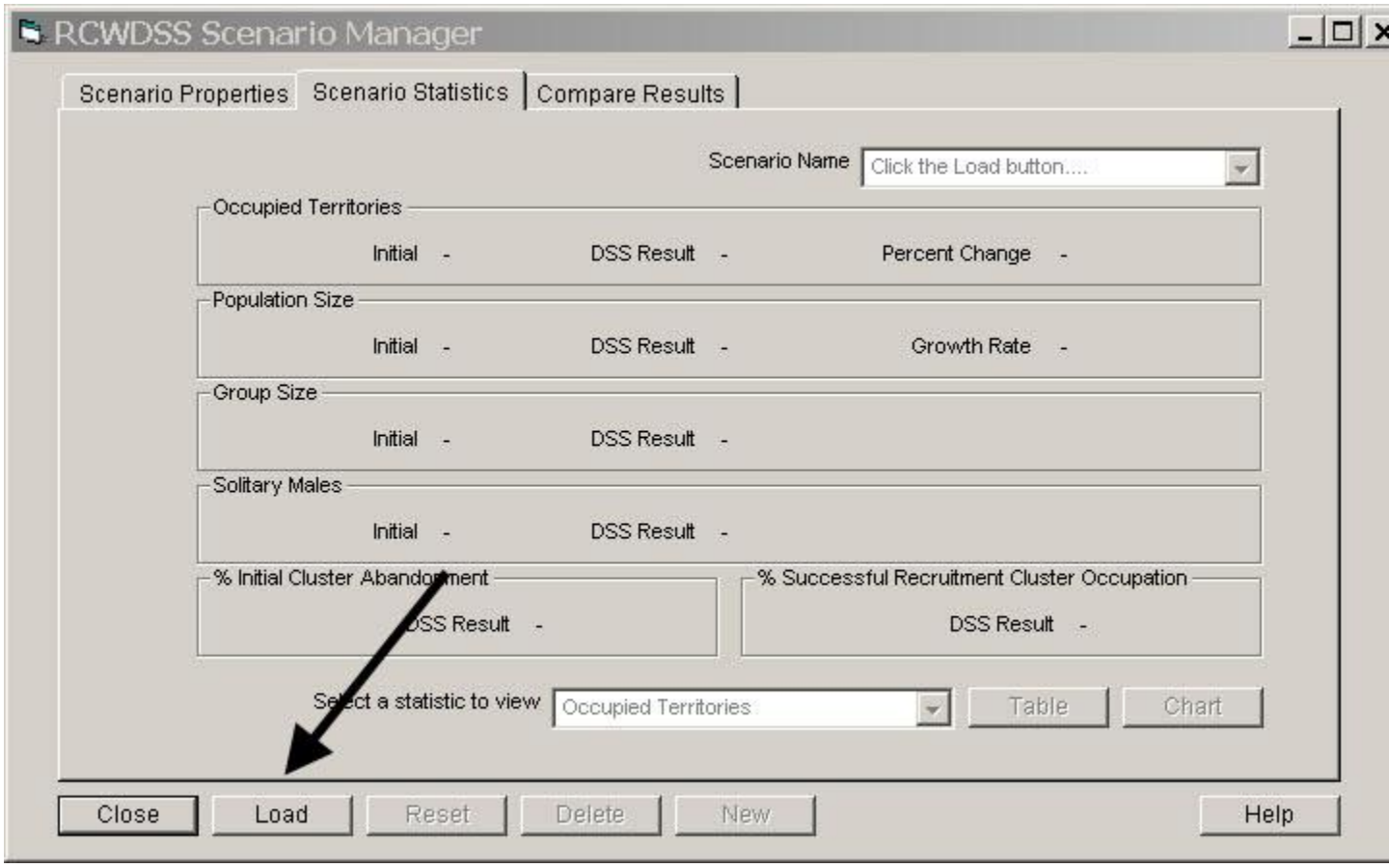
Manipulating Entire Scenarios

The series of buttons at the bottom of the Scenario Manager allows the user to manipulate entire scenarios.

- Load (Existing Scenario)
- Delete (Existing Scenario)
- New (Use Existing Scenario as Template)
- Reset (Scenario Manager)
- Close (Scenario Manager)

Load (Existing Scenario)

The user can view previously generated scenarios by pressing the Load button in the Scenario Manager, navigating to the output folder of the previously generated scenario, looking for the corresponding *.rcw properties file, and pressing 'OK'. The properties and result of the scenario will be displayed in a series of tabs.



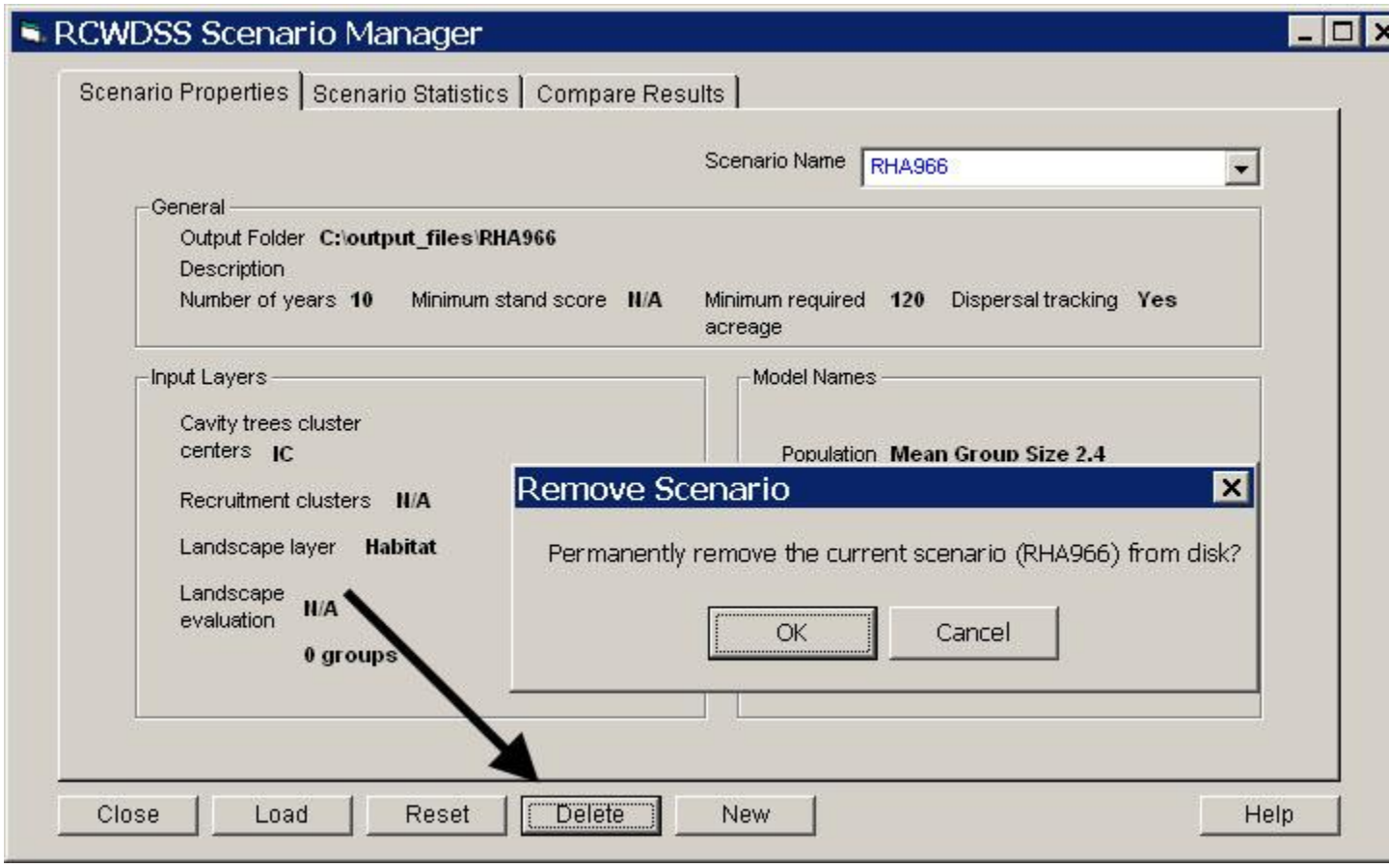
The user can view multiple scenarios by following the procedure to load a single scenario for each scenario of interest. The active scenario is the last scenario loaded. You can activate any loaded scenario by choosing it from the Scenario Name drop down box.

Delete (Existing Scenario)

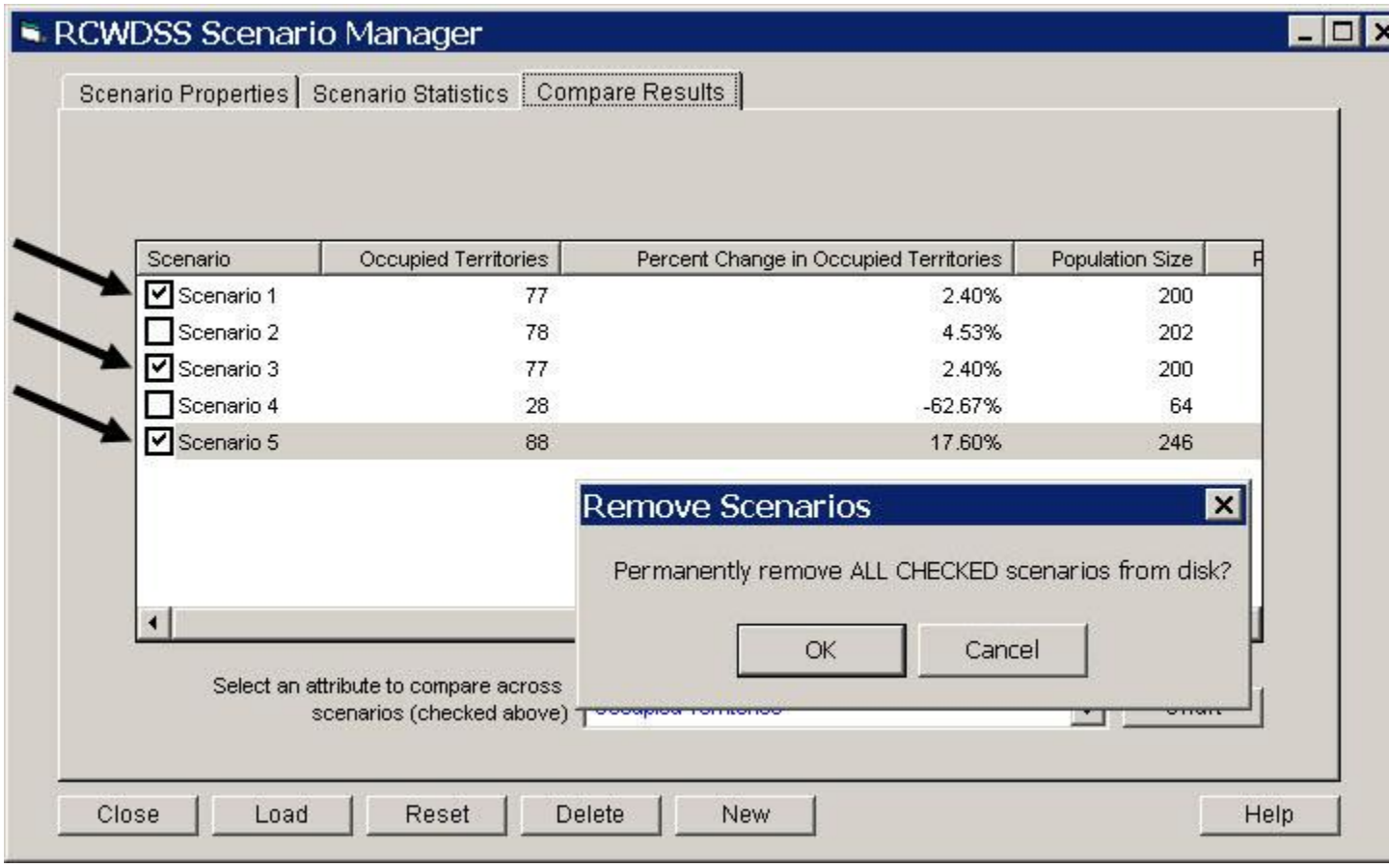
WARNING Using this option completely deletes the scenario files from your computer. You will be unable to recover them.

Part of the functionality of the Scenario Manager is to allow the user to delete a scenario that is no longer relevant. You are unable to restore scenarios once they have been deleted. If the user wishes to send the deleted scenario to the Recycle Bin for possible recovery later, then they should manually delete the folder through Windows.

In order to delete a scenario, the user has to first load the scenario into the Scenario Manager through the Load button. Then, once loaded, the user can delete the scenario by pressing the Delete button and then confirming OK.



If you wish to delete multiple scenarios, then load all the scenarios you want deleted, go to the Compare Results tab, select all scenarios you want deleted by marking the appropriate checkbox, then click on Delete. Confirm by pressing 'OK'.

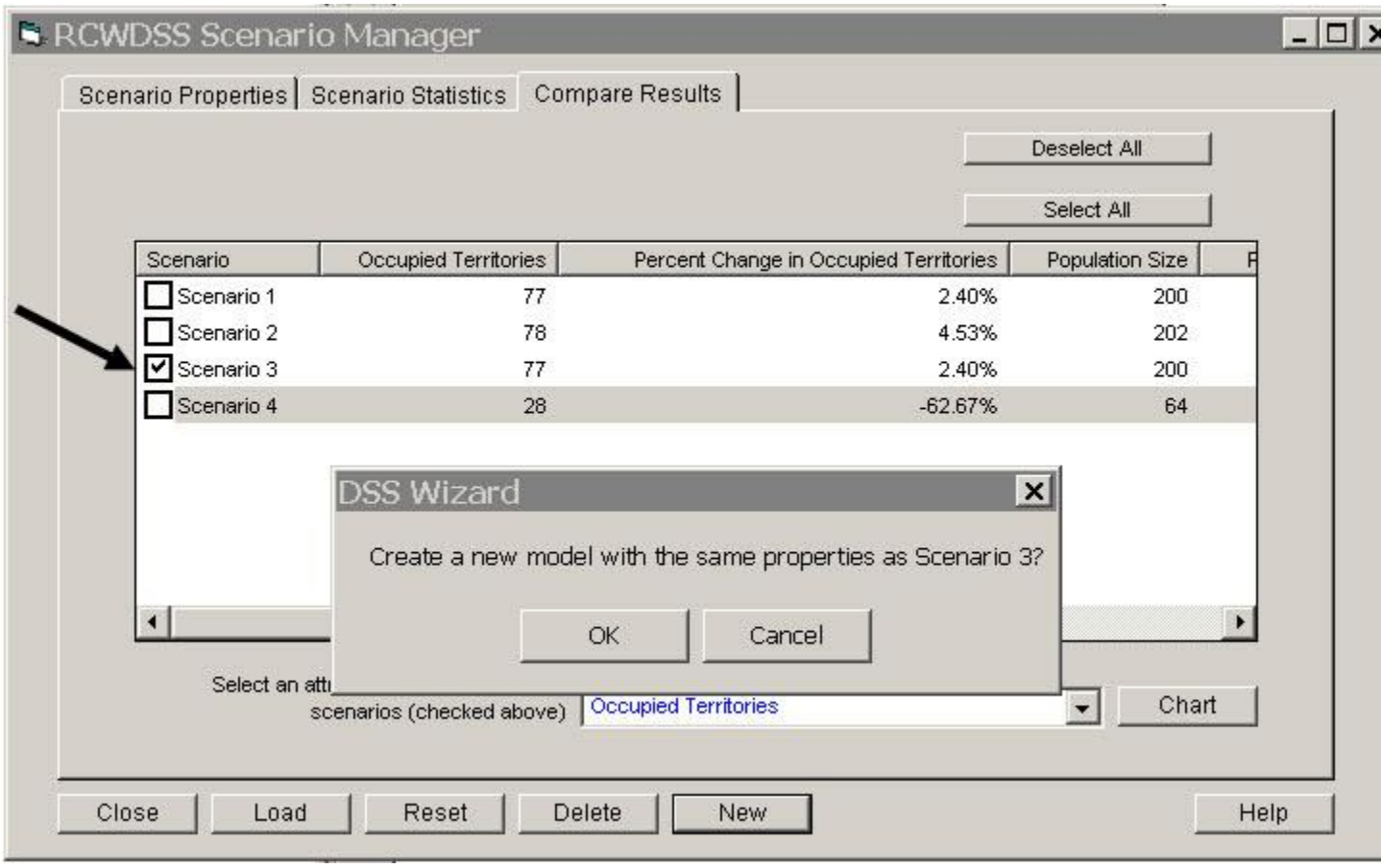


New (Use Existing Scenario as Template)

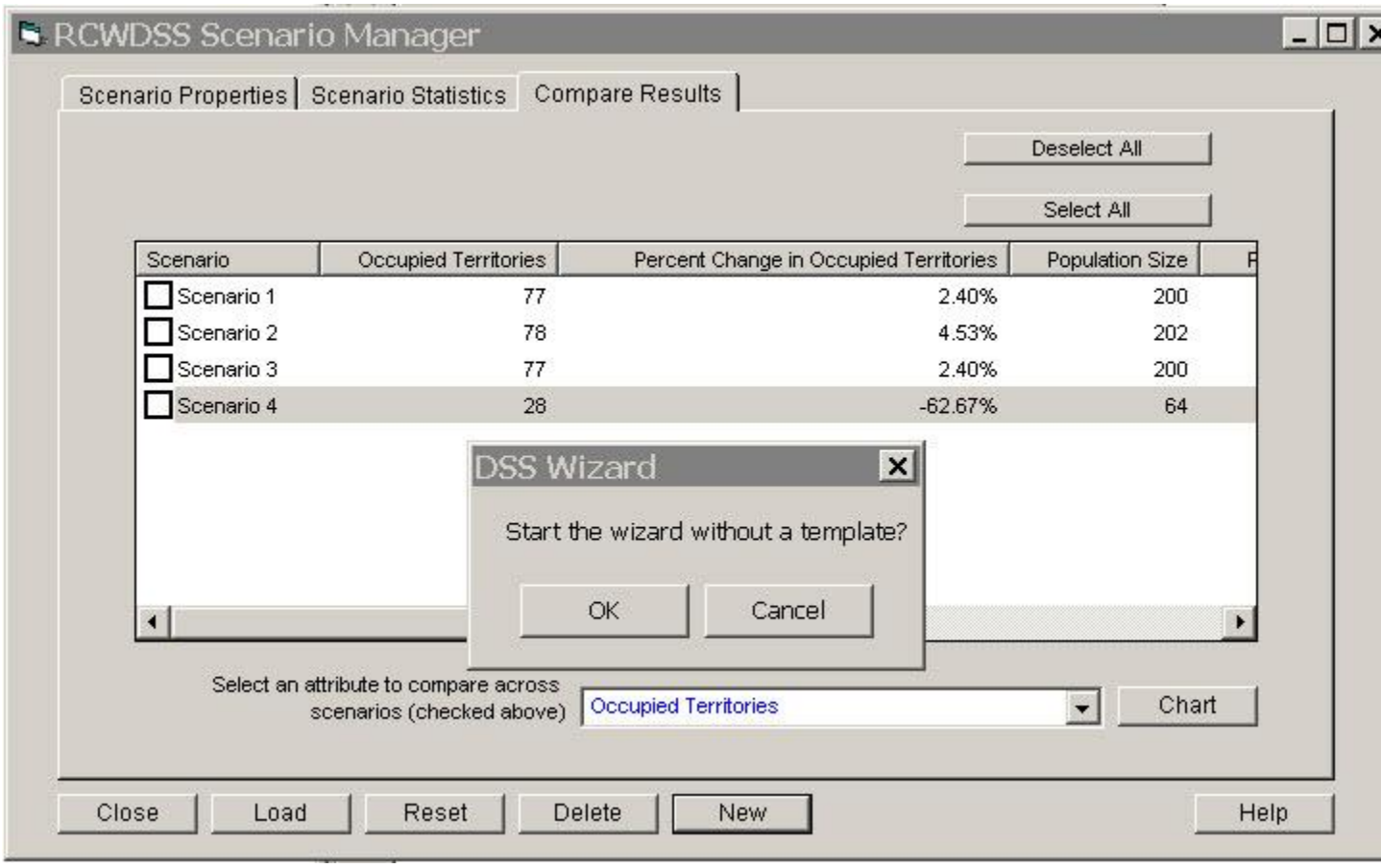
The user can create new empty scenarios, or scenarios that are based on an existing scenario loaded in the Scenario Manager.

If the user chooses to create a new scenario based on an existing scenario, the existing one must be loaded into the Scenario Manager and selected on the Compare Results tab. Once the existing scenario is selected, press the New button. The Wizard activates with the appropriate fields populated with the information from the *.rcw file of the existing scenario. The user will be required to provide a unique Scenario Name, and then can modify any information contained within the Wizard, and rerun the new scenario given the new information. The template scenario is neither modified nor deleted.

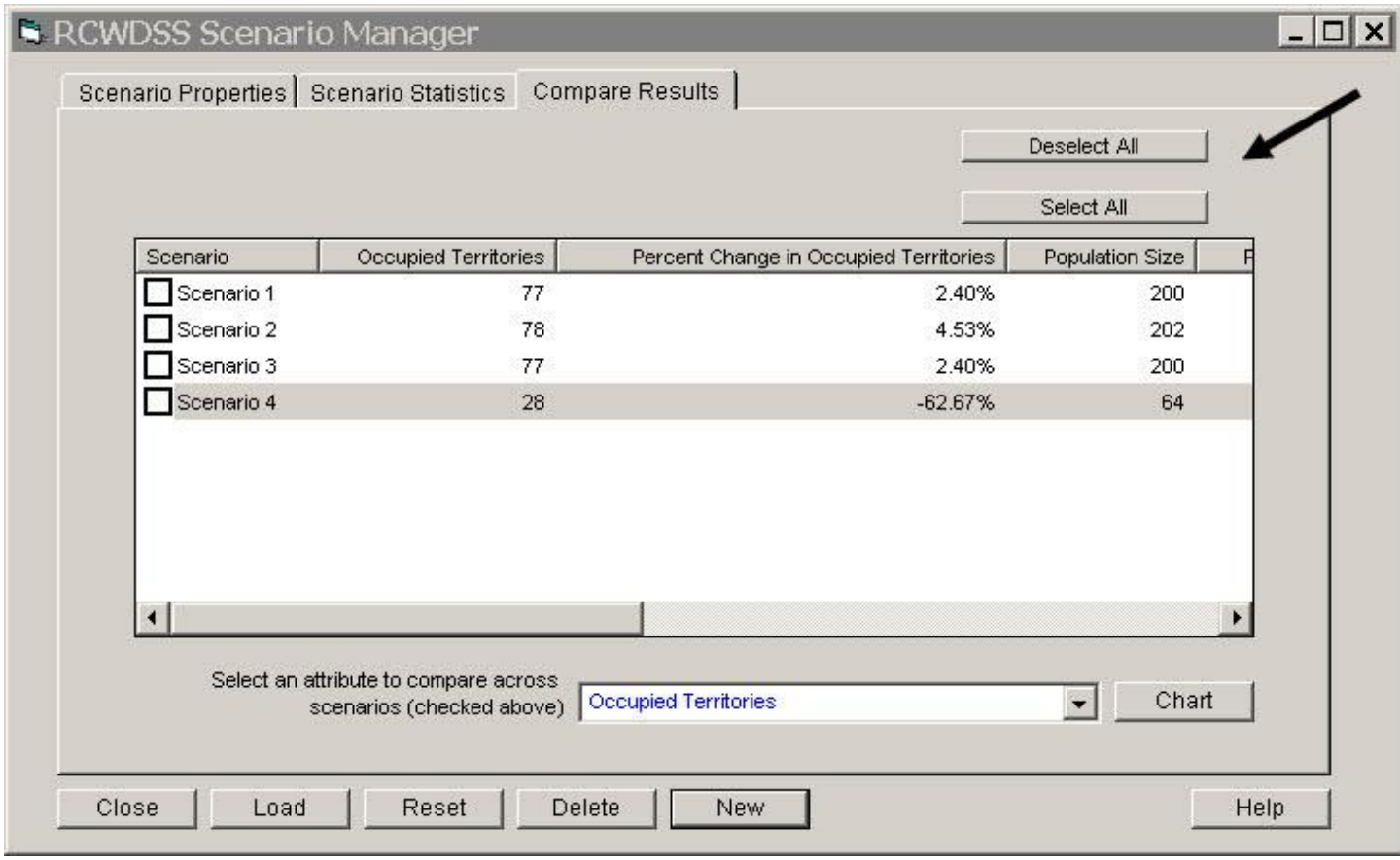
If the active tab is the Compare Results tab, then the scenario that is checked in the table will be the template used to populate the Wizard.



If the user wishes to start the Wizard with empty fields, then unselect all scenarios in the Compare Results tab and click the New button.



The Select All and Deselect All buttons merely check the appropriate check boxes next to each scenario.



Reset (Scenario Manger)

Pressing the Reset button in the Scenario Manager will clear out all fields in the dialog box, but will not affect the underlying data on the hard drive.

Close (Scenario Manager)

Press Close to close the Scenario Manager and clear out any fields.

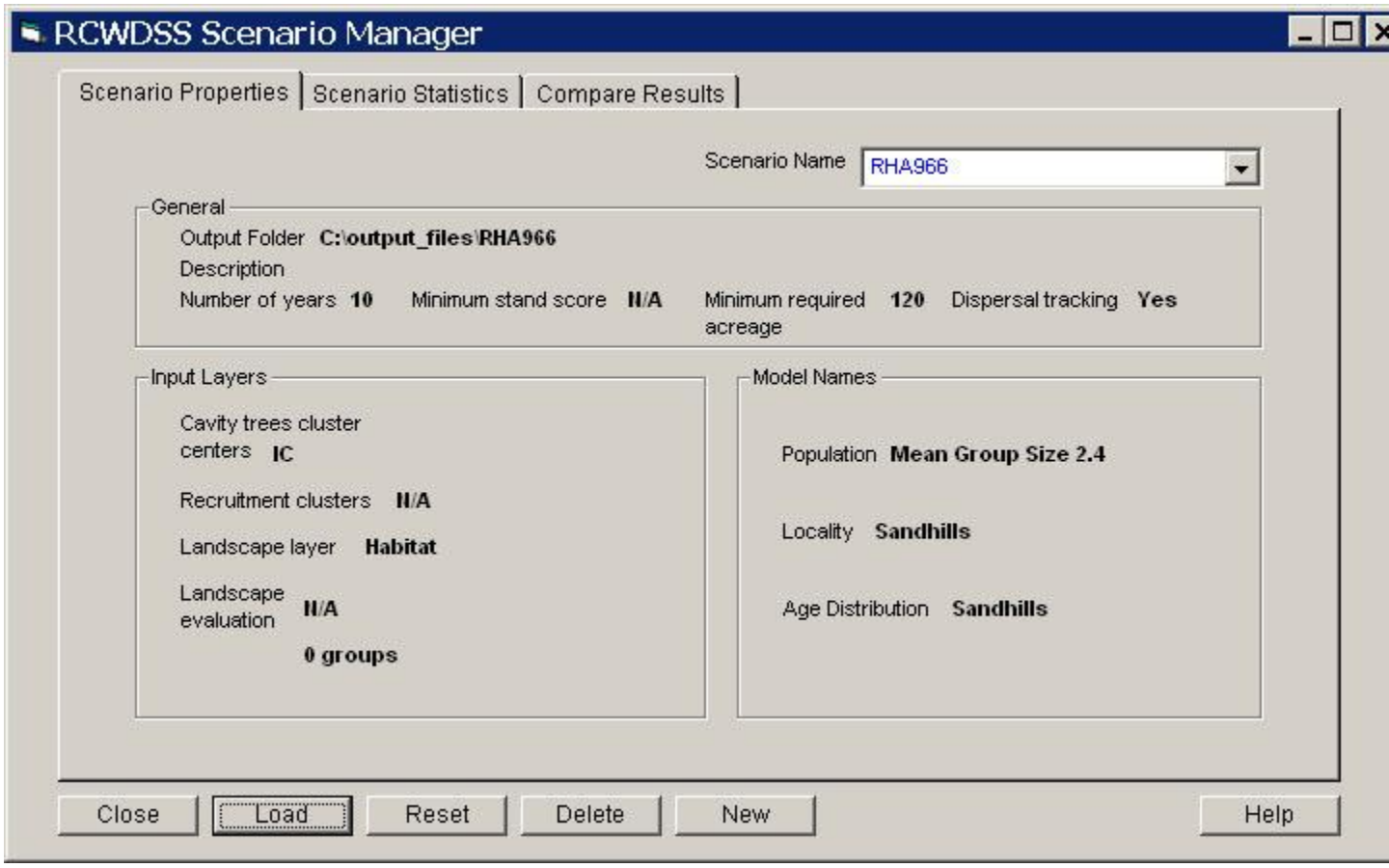
Manipulating Specific Scenarios

With the tabs along the top of the dialog box, you can look at specific

- Scenario Properties
- Scenario Statistics
- Compare Results (across multiple scenarios)

Scenario Properties

The properties of a scenario are defined through the DSS Wizard. They are saved in the *.rcw file located in the specified output folder. This file is read to populate the fields of the Scenario Properties tab of the Scenario Manager. Any loaded scenario can be accessed using the Scenario Name drop down menu.



General

- Output Folder: This is the original location of the file. If the folder and/or its contents have been moved, this will not be correct.
- Description: This is the optional description provided by the user in the DSS Wizard.
- Number of years: The number of years over which each simulation was conducted.
- Minimum stand score: If applicable, the minimum stand score a habitat polygon must have to be counted as suitable nesting and foraging habitat.
- Minimum required acreage: Minimum required acreage of nesting and foraging habitat to support new budded clusters and recruitment clusters.
- Dispersal tracking: indicates if dispersal tracking option was enabled for the scenario.

Input Layers

- Cavity Trees Cluster Centers: The name of the layer containing information about cluster or territory centers.
- Recruitment Clusters: Name of the optional recruitment cluster layer.
- Landscape layer: The name of the landscape layer.
- The Landscape evaluation section is not a separate layer, but describes the name of the

attribute used and number of unique values found for that attribute within the table, if the user is performing the optional Landscape Evaluation assessment.

Model Names

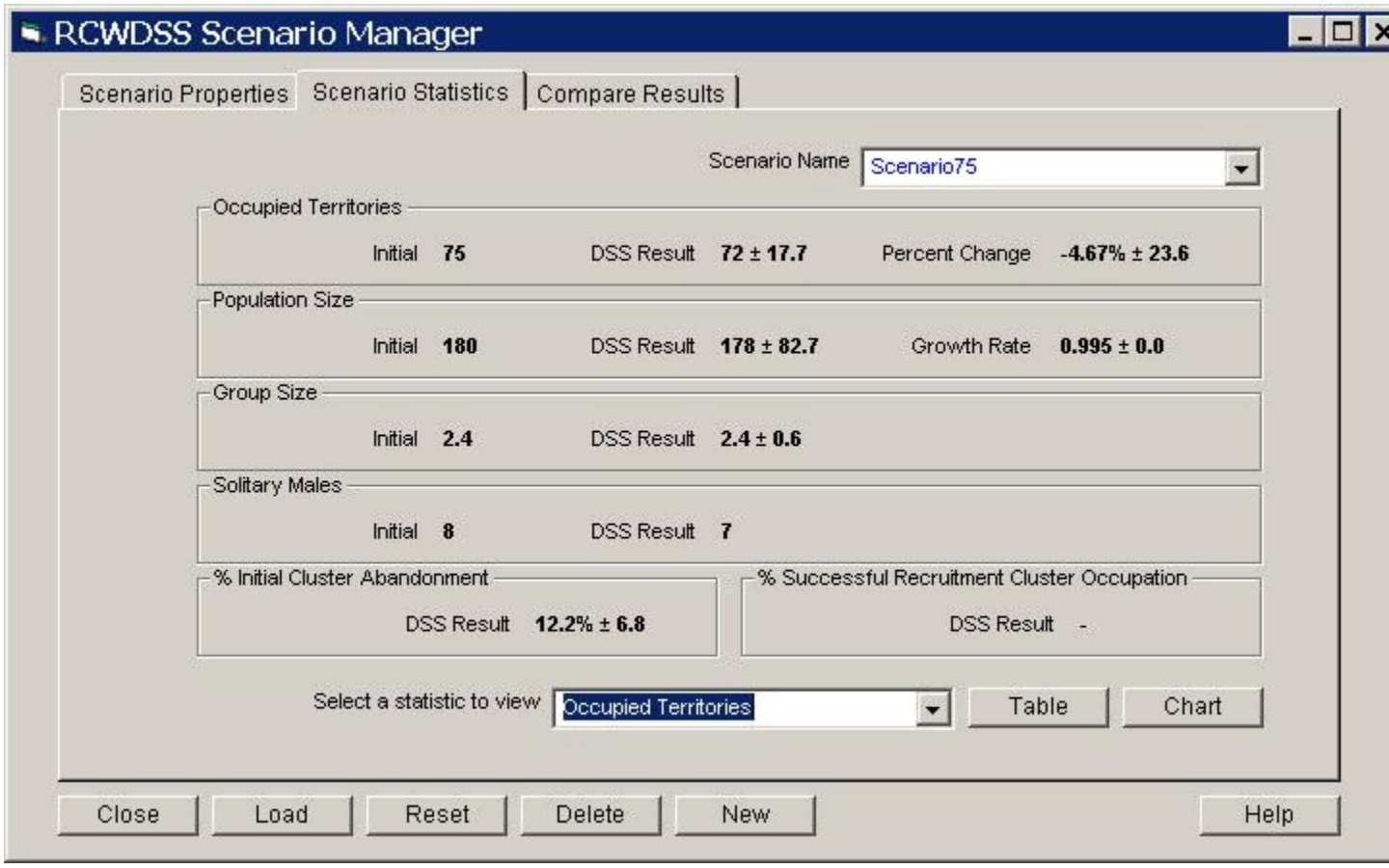
These are the different data models used within the DSS. The models are location specific, so once a demographic model is chosen; the other models were auto-filled as a result.

- Population: this is either a default population model, or one provided by the user.
- Locality: the demographic model on which the other models are based.
- Age Distribution: Age matrix used for establishing the population

Note: Multiple scenarios can be loaded into the Scenario Manager, but only one can be viewed at a time on this tab. The Scenario Name drop-down box lets you toggle between loaded scenarios.

Scenario Statistics

The purpose of this tab is to view the results relative to the initial state for each scenario conducted. This is the list of all the results that are provided to the user at the end of a scenario run or loaded from preexisting scenarios.



Occupied Territories

- Initial: Initial number of Occupied Territories established using the "Occupied" attribute in the cavity cluster center layer.
- DSS Result: The number of occupied territories at the end of each simulation averaged over 70 simulations with standard deviation.
- Percent Change: Change in the number of occupied territories from the start to the end of a simulation averaged over 70 simulations expressed as a percentage with standard deviation.

Population Size

- Initial: Total number of birds at the start of each simulation
- DSS Result: Total number of birds at the end of a simulation averaged over 70 simulations with standard deviation.
- Growth Rate: Growth of population averaged over 70 simulations with standard deviation. Growth of population is calculated using the equation.

$$Growth\ Rate = \left(\frac{Final\ Population}{Initial\ Population}\right)^{\frac{1}{Years}}$$

Group Size

- Initial: Average number of birds per territory at the start of a scenario simulation averaged over 70 simulations.
- DSS Result: Average number of birds per territory at the end of a simulation averaged over 70 simulations with standard deviation.

Solitary Males

- Number of male breeders without a female breeder at the end of each simulation averaged over 70 simulations.

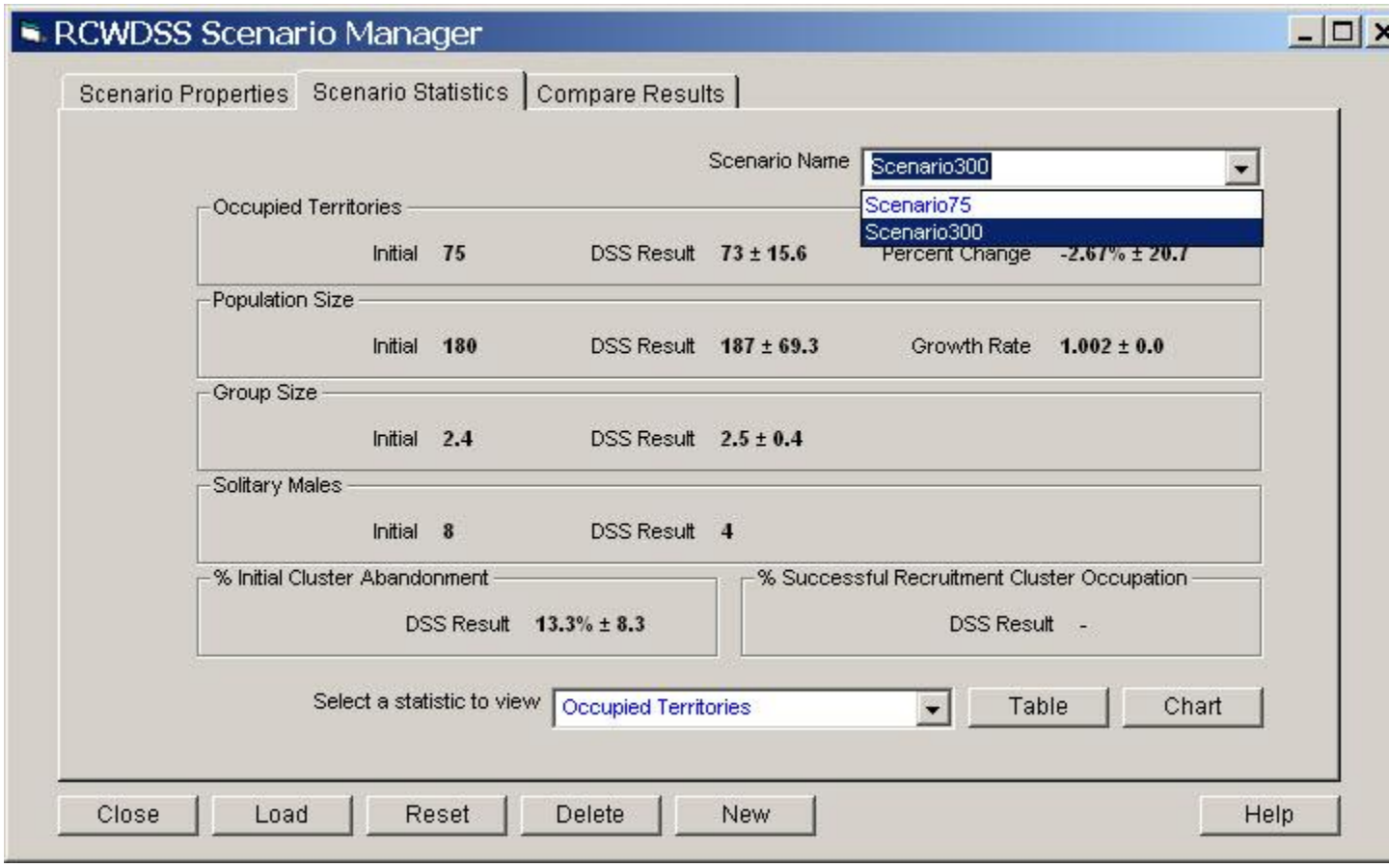
Percentage Initial Cluster Abandonment

- Percentage of initial clusters (not recruitment clusters) that become abandoned during the course of the model with standard deviation. In a model run clusters that are not occupied for more than 5 consecutive years are classified as abandoned and cannot be reoccupied thereafter. This statistic refers to the number of initial clusters that achieve that status.

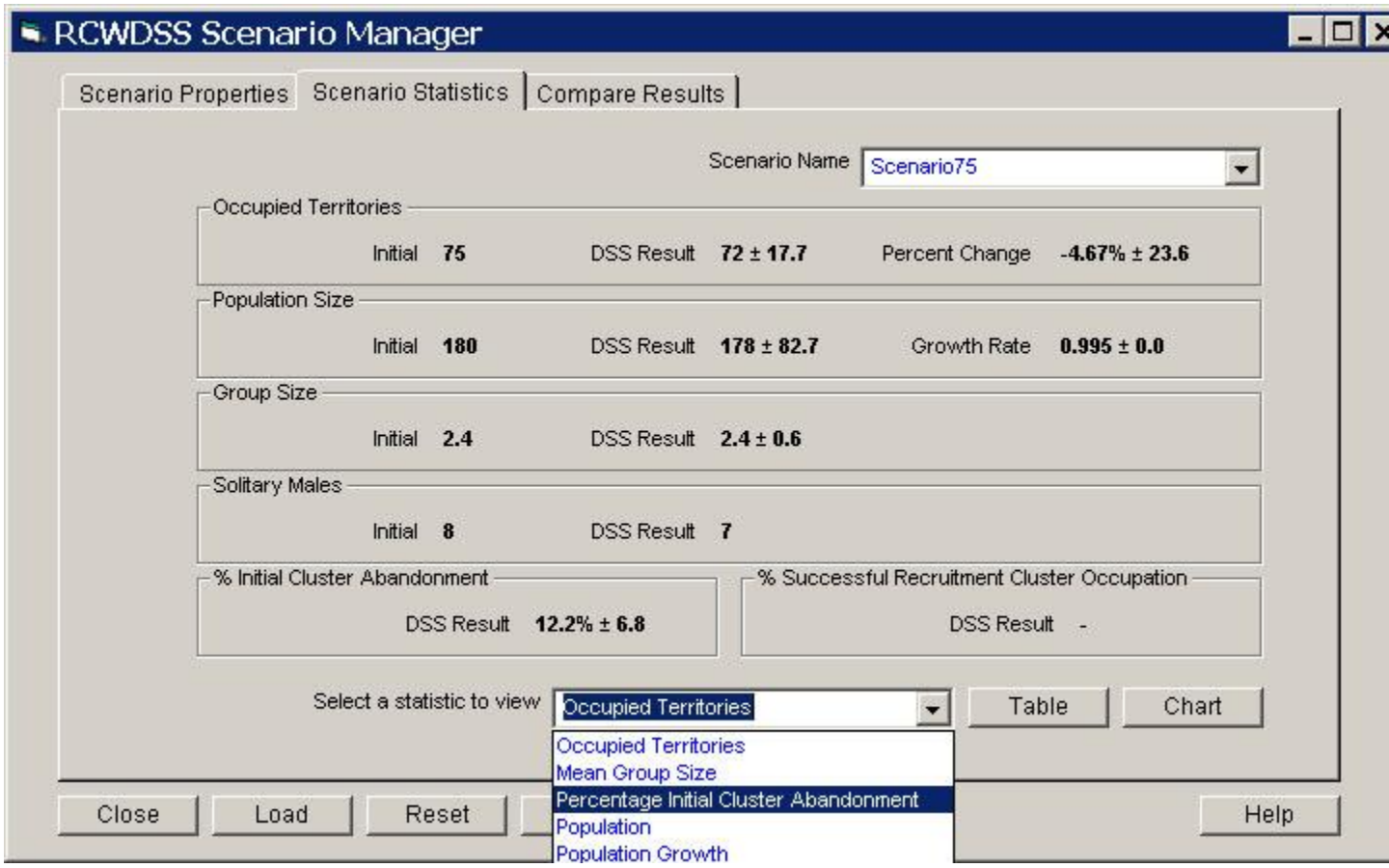
Recruitment Cluster Occupation (if applicable)

- Number of recruitment clusters to produce at least one fledgling averaged over 70 simulations.

The user can load multiple scenarios, but can only view one at a time on the Scenario Statistics tab. The Scenario Name drop-down box lets you choose which scenario to activate.

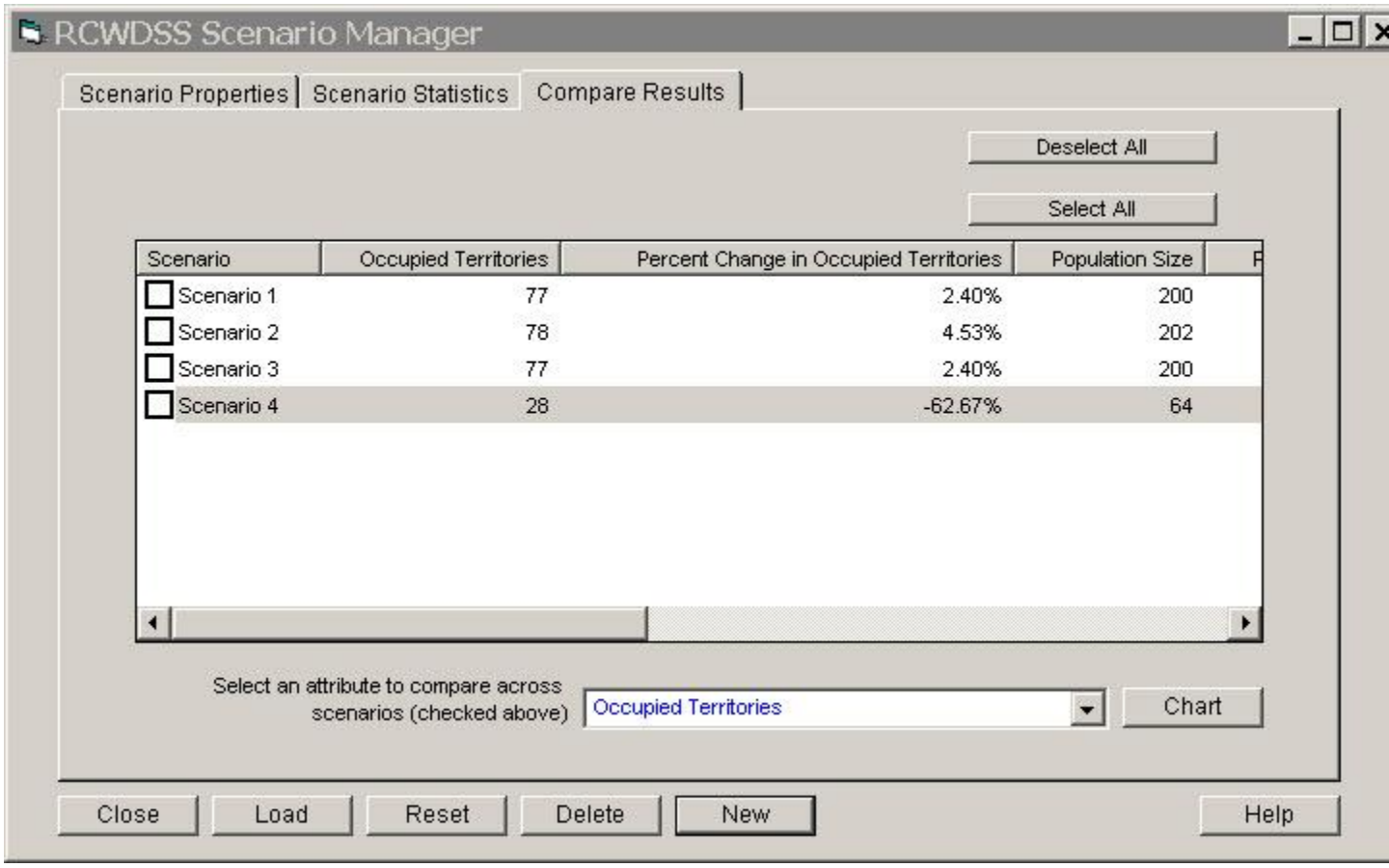


You can also view the raw data in either table or chart form by selecting the specific statistic in the corresponding drop-down box and choosing Table or Chart



Compare Results

This tab lists all the scenarios that have been loaded into the Scenario Manager and their corresponding results.



This is the list of all the results that are provided to the user at the end of a scenario run or loaded from preexisting scenarios.

Occupied Territories

- DSS Result: The number of occupied territories at the end of each simulation averaged over 70 simulations.
- Percent Change: Change in the number of occupied territories from the start to the end of a simulation averaged over 70 simulations expressed as a percentage.

Population Size

- DSS Result: Total population at the end of a simulation averaged over 70 simulations.
- Growth Rate: Growth of population averaged over 70 simulations. Growth of population is calculated using the equation.
    2. Population Growth = (Total Population / Initial Population) ^ (1 / Years In Simulation)

Group Size

- DSS Result: Average number of birds in each territory at the end of a simulation averaged over 70 simulations.

Solitary Males

- Number of male breeders without a female breeder at the end of each simulation averaged over 70 simulations.

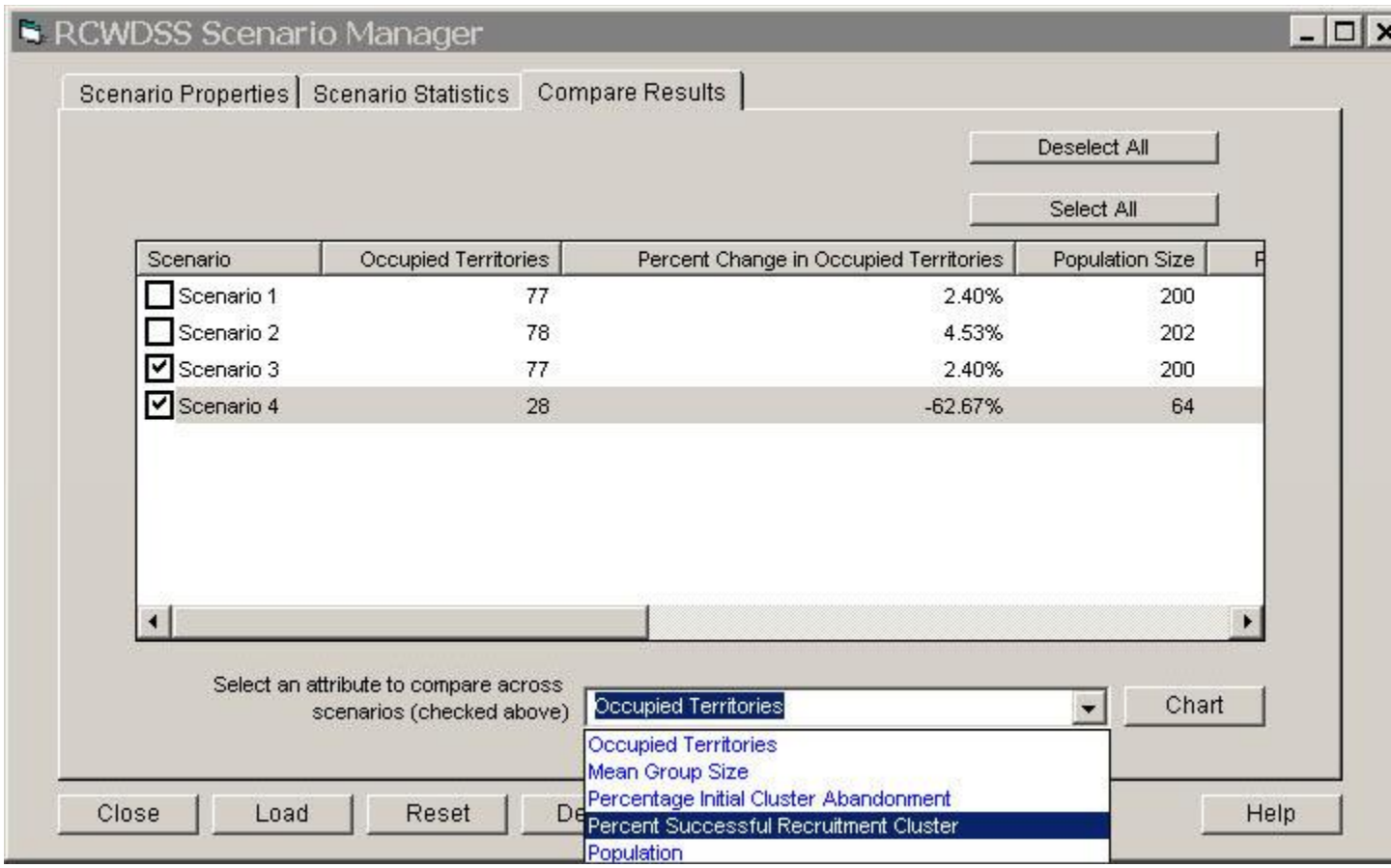
Percentage Initial Cluster Abandonment

- Percentage of initial clusters (not recruitment clusters) that become abandoned during the course of the model. In a model run clusters that are not occupied for more than 5 consecutive years are classified as abandoned and cannot be reoccupied thereafter. This statistic refers to the number of initial clusters that achieve that status.

Recruitment Cluster Occupation (if applicable)

- Number of recruitment clusters to produce at least one fledgling averaged over 70 simulations.

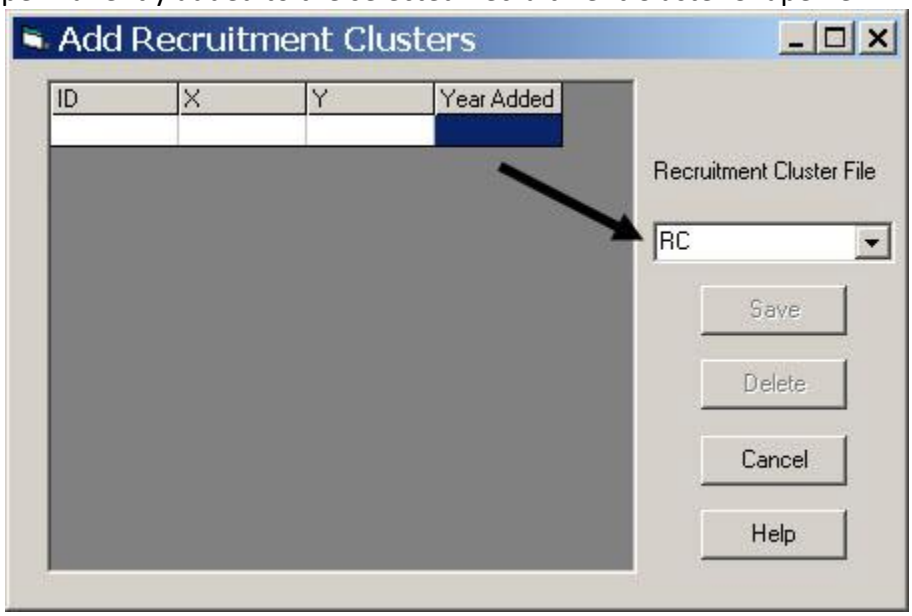
The point of this tab is to allow the user to compare results across different scenarios. For each scenario the user wants to include in the comparison, check the box next to its name, choose an attribute in the drop down box for the comparison, and click the Chart button.



Recruitment Cluster Manager

About Adding Recruitment Clusters

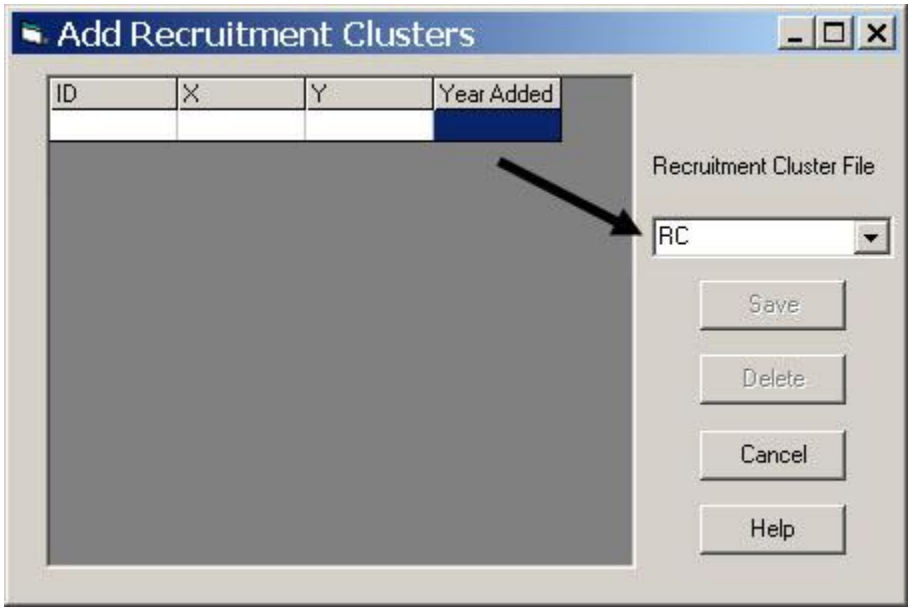
This tool allows you to add recruitment clusters via mouse clicks within ArcMap. They are permanently added to the selected Recruitment Cluster Shapefile.



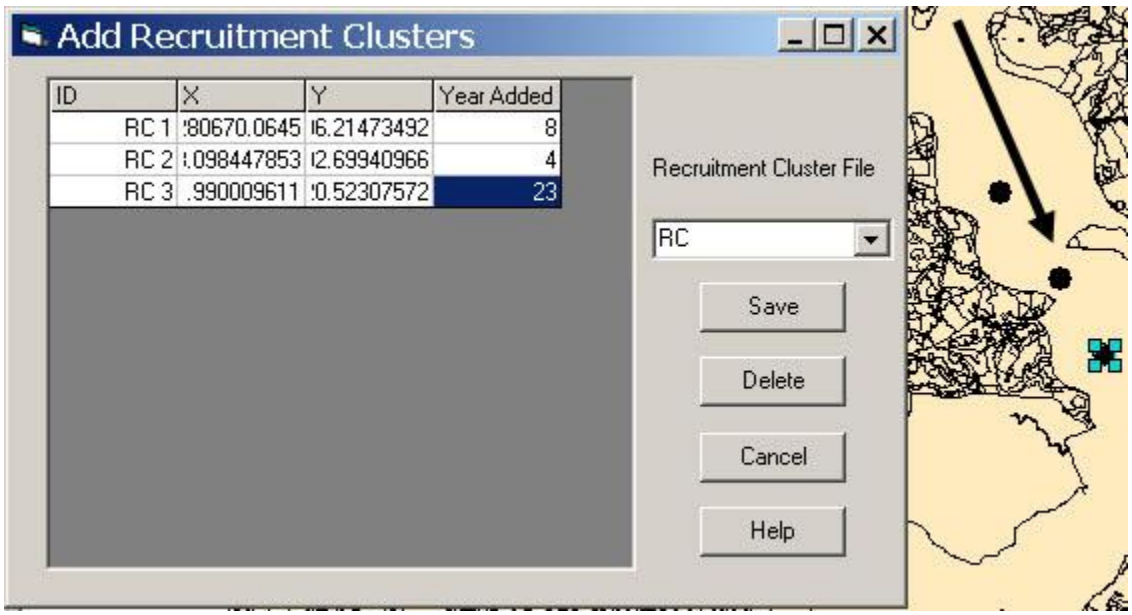
Adding Recruitment Cluster Process

If you wish, you can add recruitment clusters to an existing point Shapefile. The Shapefile must be loaded into ArcMap before starting the tool. Click on the Add Recruitment Clusters tool in the DSS toolbar.

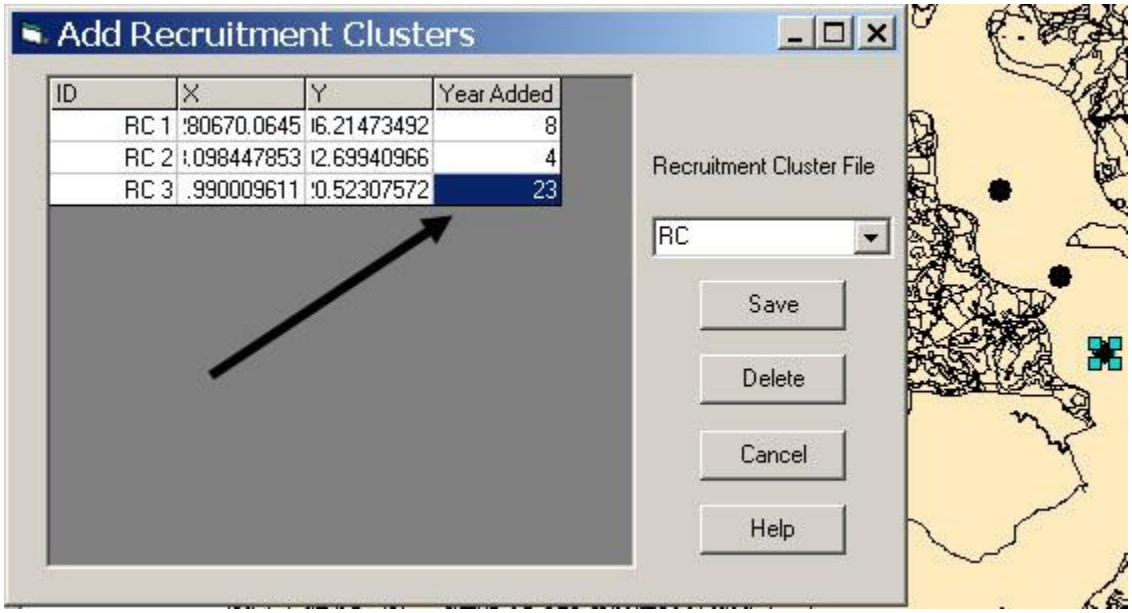
Select the layer to which you want to add the recruitment clusters in the Recruitment Cluster File drop down box. Remember, the layer must already be included in the map and must follow the rules for the Recruitment Cluster Layer.



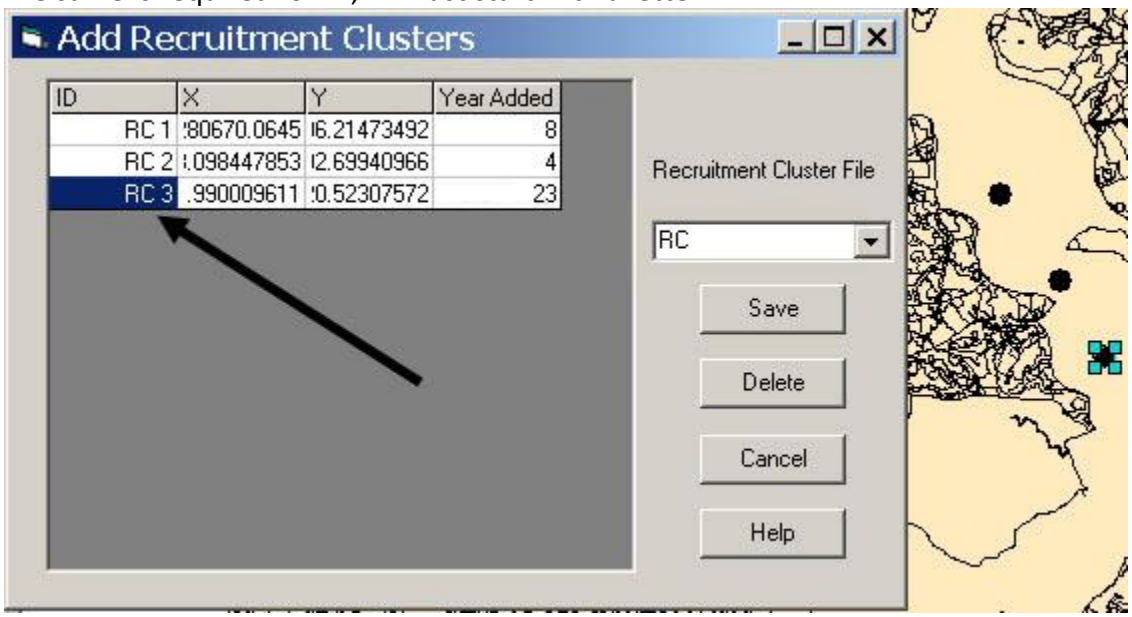
Click on the screen to add as many recruitment clusters as you wish. New clusters centers are initially added as graphic points.



You then need to select each Year Added cell and provide a year added. This defines the year at which the recruitment cluster will be introduced.



The same is required for ID, ID must start with a letter.



You can delete the point after it has been added (but before it has been saved). Select the point to delete by selecting its row in the table and then clicking the Delete button.
Press Cancel to delete all the points you have added to the map display before you save them.
When you are done, click Save. The new points are now added to the existing Shapefile.
Note: if you click save without a year added value, you will get an error.

Results

About The Results

Statistics are calculated for each scenario and are the basis for analyzing the results of the DSS. The results are displayed in a grid on the main results page. There are a variety of statistics calculated by the DSS. The list of statistics calculated by the DSS is provided below:

- Occupied territories
  - % change in occupied territories
- Total population
  - Population growth
- Group size
- Initial cluster abandonment
- Successful recruitment cluster occupation
- Total number of solitary males

In addition to the actual statistic, you can view the raw data in graphical form or table form by clicking on the respective "Graph" and "Table" button. The raw data are stored as DBF files (or Shapefiles, if appropriate) in the specified scenario output folder.

Occupied Territories

The occupied territories are calculated at the end of a specific year. Therefore, year 1 occupied territories may not equal initial territories. When calculated, this statistic does not include territories that are empty during that year but still available for occupation in subsequent years (that is, not yet classified as abandoned). The results are stored in a file called, "Occupied Territories.dbf".

In addition to the raw number of occupied territories, the DSS calculates the percentage change in occupied territories relative to the initial territories and saves them in a separate file, "Percent Change in Occupied Territories.dbf". This statistic is not calculated year to year, but rather at the end of the entire simulation. The equation for this statistic is:

Percent Change = ((remaining occupied - initially occupied) / initially occupied) * 100

Total Population

Total population is a straight count of the number of birds in the simulation at a given year. This statistic is calculated at the end of each year before the breeding season of the next year. Therefore, there are technically no fledglings in this statistic.

The raw data are stored in Population.dbf.

Population growth is based on this statistic. It is the modeled geometric growth of the population. The equation used is:

$$Growth\ Rate = \left(\frac{Final\ Population}{Initial\ Population}\right)^{\frac{1}{Years}}$$

Group Size

Group size is the total number of birds in a given group, at a given time.
Specifically, it is the average group size per occupied territory (Total Birds / Total Occupied Territories). This statistic is calculated at the end of a year, before the breeding season of the next year, and therefore includes no fledglings.

Initial Cluster Abandonment

Initial Cluster Abandonment is reported several ways in two separate files: it is reported as a total abandonment in a simulation per year (File 1, Total Initial Cluster Abandonment.dbf), as an individual cluster abandonment per scenario (File 2, Individual Initial Cluster Abandonment.dbf), and as a number of times specific clusters are abandoned (File 3, <MyScenario>_ICA.shp).
For the individual cluster statistics, the percentage of the runs in which each specific cluster is abandoned for the scenario is also reported (File 2).

Recruitment Cluster Occupation

If recruitment clusters are created for a scenario, then statistics on their successful occupation are calculated. A recruitment cluster is considered successfully occupied if the cluster has at least one successful breeding year. The number of times a specific recruitment cluster is successful is also reported in a point layer file, <MyScenario>_RCSO.shp. If the value in this file is -1, then the recruitment cluster was not added to the model. This occurs when there is unsuitable nesting and foraging habitat, improper location, or the YearAdded attribute exceeds the length of the model. If output has been suppressed, check to log file for specifics as to why the recruitment cluster was not added to the model. If output has not been suppressed, then a message box appeared during the course of the model run to indicate the issue.

Total Solitary Males

This is the total number of solitary males at the end of a simulation.

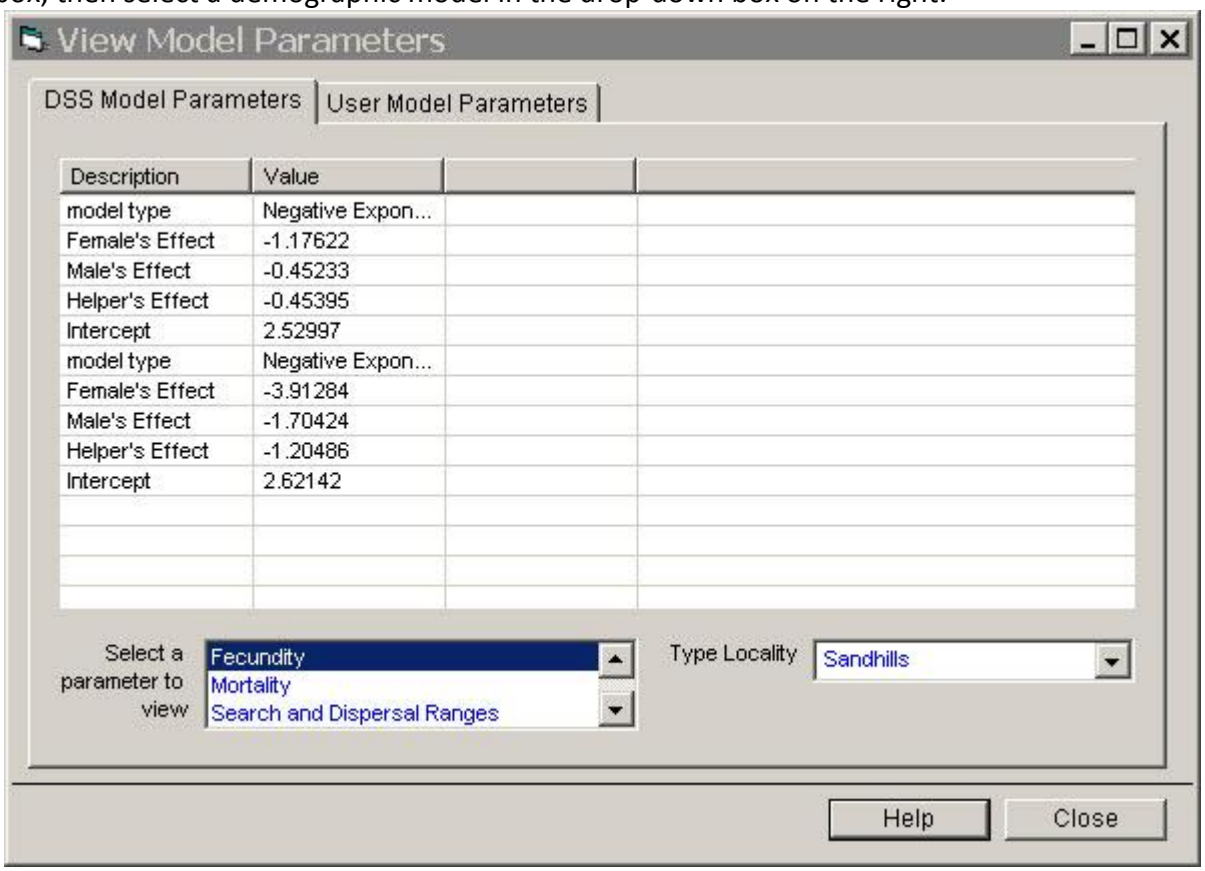
Sub Model Parameters

About The Parameter Viewer

The parameter viewer allows the user to view the internal parameters that the underlying models use in the DSS. You are not able to edit or export these parameters; they are only for information purposes.

The parameters can be differentiated into two groups, parameter sets which the user has no control over, DSS Model Parameters, and parameter sets which the user can control, User Model Parameters. To choose a specific group, click on the tab across the top of the viewer.

To choose a specific parameter group, click on its name in the Select a parameter to view list box, then select a demographic model in the drop-down box on the right.



DSS Model Parameters

DSS Model Parameters are parameters that are strictly defined by the demographic model associated with the initial population. DSS Model Parameters include: Search Range and Dispersal Distance, Age Distribution, Fecundity, and Mortality.

Search Range and Dispersal Distance

Red-cockaded woodpeckers search adjacent territories to look for available territories to inhabit and when successful in competition for a detected available territory, disperse to that territory. These parameters control the distance of the specific bird's range for searching and dispersal. They also include a percentage indicating the probability that a male fledgling that survives the first year will attempt to disperse, versus remaining on the natal territory as a helper. Each year of the model is broken down into 4 stages or "seasons". Season 1 is the breeding season, Season 2 is when Recruitment clusters are introduced, nothing specific occurs in Season 3, and Season 4 is when fledglings leave their natal territory.

- Chance of Male Fledgling Dispersal: Chance that a newborn male fledgling will leave the natal territory and attempt to disperse rather than remain as a helper.
- Male Fledgling Disperser Speed: For male fledglings that disperse, this is their dispersal speed, the distance moved in a season if they do not find an available territory and continue moving.
- Male Disperser Speed: If an adult male is not associated with a territory, and is instead dispersing (such males arise from dispersing fledglings that fail to obtain a breeding position by age one), this is its dispersal speed (distance moved per year if it does not find a territory and continues moving).
- Female Fledgling Disperser Speed: All female fledglings disperse within their first year. This is their dispersal speed (distance moved per season if they do not find an available territory and keep moving).
- Female Disperser Speed: If a female is not associated with a territory, and is dispersing through the environment (such females arise from dispersing fledglings that fail to obtain a breeding position and former breeding females whose son inherits the male breeding position on their territory), this is its dispersal speed (distance moved per year if it does not find a breeding position and keeps moving).
- Male Dispersing Seasonal Search Range: As a male disperses, it searches its environment for available territories in the vicinity of its current location. This is its search range.
- Male Replace Breeder Seasonal Search Range: When a male breeding vacancy occurs, in addition to dispersing males in the vicinity, helper males on other territories in the area compete for the breeding vacancy. This is the search range for such helper males. If helpers are present on the territory where the vacancy occurs, the oldest helper automatically becomes the new breeder.
- Female Fledgling Dispersal Range: Prior to departing the natal territory, female fledglings search for available breeding positions in the neighborhood of their natal territory. This is the distance within which they search.
- Female Dispersing Search Range: As a female disperses, it searches its environment for available territories in the vicinity of its current location. This is its search range.

Fecundity

The fecundity is based on field data and is therefore only valid for its defined demographic model. Which of the two possible fecundity models is employed is automatically determined by choice of the Sandhills versus Coastal model (Step 3 Model Selection).
Probability of nest failure and number of fledglings produced are negative exponential functions of the breeders' ages and the number of helpers.
Fecundity is determined by two stages, the probability of any fledglings at all, and the number if there are fledglings.
A detailed description of the contents of these fecundity files is beyond the scope of this document, but more information is available in Letcher, B.H., Priddy, J. A., Walters, J.R., Crowder, L.B. (1998), An individual-based, spatially explicit simulation model of the population dynamics of the endangered red-cockaded woodpecker, *Picoides borealis* Biological Conservation 86: 1-14 **.**

Age Distribution Model

The age distribution is based on field data for the age distributions of individuals in the different Status Classes and is applied to the initial population in a model scenario. Currently the model only supports an age distribution from the Sandhills.

Mortality

The mortality rates are based on field data and are therefore valid only for their defined demographic model. They describe the annual probability of death for the various Status Classes. Which of the two possible sets of mortality rates is employed is automatically determined by choice of the Sandhills versus Coastal model.

- Male Fledgling Annual Mortality: Probability of death for a newborn male in its first year.
- Male Floater Annual Mortality: Probability of death if an adult male is not associated with a territory.
- Male Helper Annual Mortality: Probability of death for helpers.
- Male Solitary Annual Mortality: Probability of death for unpaired male breeders.
- Male Breeder Annual Mortality: Probability of death for a male breeder with a mate.
- Female Fledgling Disperser Mortality: Probability of death for a newborn female in its first year.
- Female Floater Annual Mortality: Probability of death for an adult female not associated with a territory.
- Female Breeder Annual Mortality: Probability of death for a female breeder.

User Model Parameters

User Model Parameters define parameters over which the user has some control. In setting up a scenario, the user can choose an initial population structure for their territories. If the user has loaded custom initial populations, then they will be listed here for review. Normally, the user can not control the Age Distribution, but if they use a custom initial population structure,

then they will have control over the year that the age distribution will use, but not the actual age distribution model (which is controlled by the demographic model chosen, Sandhills of Coastal). Custom population structures also allow the user to control the Mean Group Size of the model.

Population Model

Population structure models based on mean group size are provided to the user as default options. Users can also provide their own initial population structure file (as a text file) as long as it follows the format below. If the user provides a custom population structure file, then it must also define the associated demographic model (Coastal or Sandhills). Currently supported status classes for custom population files are: "male", "fema", "help", and "fldg".
Any population assignment consists of two lines. The first line tells the model what to do, and the second line provides the details on how to do it. This format allows you to assign population groups and/or individual birds. Once all population lines are complete, the word 'end' must be the next line in the file. Optional user comments are allowed in the file, but only before the first 'assign' statement or after the 'end'.

For example:
User defined comments such as this must not start with the word 'assign'.
assign all males
5 91 0 1 -5 -6 0 0 0 0
End

User defined comments such as this must not start with the word 'assign'.
This section breaks each word and number down from the example above
Line 1: “assign all males”
assign <amount> <type>

- <amount> consists of a percentage (50%, 33%, 23%, etc. - no decimals please) or the keywords 'one' or 'all'.
- <type> can be 'male', 'fema', 'help', or 'fldg'

Line 2: “5 91 0 1 -5 -6 0 0 0 0”
<status> <age code> <gender> <territory> <mom ID> <dad ID> <x> <y> <direction> <distance>

- <status> is the current status of the bird: Fledgling = 1, Fledge Disperser = 2, Floater = 3, Helper = 4, Solitary = 5, and Breeder = 6.
- <age code> is the 2-digit code used for the age distribution. Its value can only be 91 if using group distributions. If setting specific birds, then this value must be the age of the bird in question.
- <gender> a binary code. male = 0 and female = 1
- <territory> The territory to which a specific bird is to be assigned. Default value for group assignments is 1.
- <mom ID> The ID of the female parent of the bird. If this value is unknown or a group

assignment, then simply use a unique negative number.

- <dad ID> The ID of the male parent of the bird. If this value is unknown or a group assignment, then simply use a unique negative number.
- <x> The X location of the bird. Use 0 for group assignments or the territory center if unknown. If you specify and exact X location, it must exactly match the X location of an initial territory in the cavity tree cluster center layer.
- <y> The Y location of the bird. Use 0 for group assignments or the territory center if unknown. If you specify and exact Y location, it must exactly match the Y location of an initial territory in the cavity tree cluster center layer
- <direction> This is the initial direction the bird will travel when searching. Defaults always to 0.
- <distance> This is the initial distance the bird will travel when searching. Defaults always to 0.
-

Examples:
assign all males
5 91 0 1 -5 -6 0 0 0 0
assign 50% females
6 91 1 1 -3 -4 0 0 0 0
assign 25% helpers
4 91 0 1 -1 -2 0 0 0 0
End

assign one male
5 10 0 23 432 211 238711 3879433 0 0
end

Status Classes

These are the status classes used in the DSS.

Fledgling: Bird born to a breeding pair
Fledge Disperser: Bird born to a breeding pair that has left the territory
Floater: Bird that is not associated with a territory
Helper: Male bird that remains in its natal territory to help with rearing young
Solitary: Male breeder with no female
Breeder: paired bird (male or female) in a territory

FAQs

Tables and Shapefiles

What is the valid schema for the shapefiles?

Landscape Layer

1. STAND_ID: Text, unique, nonempty
2. TYPE: Text, PINE, OPEN, WATER, OTHER, HARD, PINE DISPERSAL ONLY, and MIXED
3. PINE_AGE: Double, nonnegative
4. SITE_INDEX: Double, nonnegative
5. Stand_Scor: Double, optional parameter, 1.0-5.0 inclusive
6. Landscap Evaluation Parameter: String, optional parameter

Cavity Tree Cluster Center Layer

1. ID: Text, unique, nonempty, alphanumeric, underscores, and spaces
2. Occupied: Long Integer, 1 or 0
3. DispGroup: Text, optional parameter, starts with a letter, nonempty

Recruitment Cluster Layer

1. ID: String, unique, nonempty, alphanumeric, underscores, and spaces
2. YearAdded: Long Integer, nonzero and nonnegative
3. DispGroup: Text, optional parameter, starts with a letter, nonempty

Forest Dynamics

What forest dynamics are included in the model?

The only dynamic parameter for the landscape is age. The model ages the landscape during its run.

Can the landscape type be changed during the scenario?

No, the only dynamic landscape parameter is age, and the model controls this except for initial age provided by the user.

What is the minimum age for a stand to be considered a gap?

PINE stands age 15 or less are considered gaps.

Recruitment Clusters

Is there any "down side" to having too many recruitment clusters available at once?

This *might* stimulate so much dispersal that the birds become too thinly distributed on the landscape, which can have a negative impact on population dynamics.

*Note recruitment clusters are subject to the 5 year abandonment rule like initial clusters.

Budding

What are the criteria exactly for budding?

Appropriate number of acres (120, 150, or 200) of PINE aged 60 and above.

Miscellaneous

The code runs very slowly

- Reduce the size of your habitat layer. 10 KM beyond the furthest cluster center (initial or recruitment) should be more than enough.
- Delete the log.txt file. If it gets too large, it could affect performance.
- Get a faster machine.
- Do not have a lot of extra programs open while running a scenario.
- Just let it run and be patient. It is a very complex process, after all.

Error Descriptions

Error: At the conclusion of a successful run, a message box reports "Error detected, please examine log file."

Meaning:

- An error happened at the end of the run, making it seem like the run was successful.
- An error happened in a previous run, and the log file needs to be deleted.

Fix:

The log file is not ever deleted or cleared by the DSS. Therefore, check the log file, log.txt, for any errors and then delete the log file. The log file should be periodically deleted or else it will get quite large and affect performance.

Error: Error in frmWizard.cmdNav_Click

Non-modal forms cannot be displayed in this host application from and ActiveX DLL, ActiveX Control, or Property Page.
Error Number: 406
Line: 30

Meaning:

- VBA was incorrectly installed.
- VBA is not loaded into ArcMap startup.

Fix:

- Make sure VBA is correctly installed on your machine. See article, http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=17844
- Force VBA to load on startup. See article, http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=26333

Error: Error in RCW.SearchFemale

Subscript out of range
Error Number 9

Meaning:

This was a bug in version 1.0 that occurred with very small initial populations that died out during the course of a run. It is fixed in version 1.1.

Fix:

Get the latest version of the DLL.

Error: Error in clsRasterManip.Get2By2

Out of Memory
Error Number: 7

Followed by the following errors:

Error in clsHabitat.ExtractRasterGapData and Error in clsInitialize.InitVariablesDSS

Meaning:

You don't have enough memory to conduct the analysis.

Fix:

- Close all non-essential programs, and shut down ArcMap and try again.
- Decrease the size of your landscape.
- Get more memory.
- Try a different computer with more memory.

Status 5: For Female Bird…

Meaning:

Memory did not get cleared out properly from the previous run.

Fix:

Shut down ArcMap and try again.

Error on Install: Error Opening File For Writing

Meaning:

Computer user needs administrator rights to install the DSS

Fix:

- Use an account with administrator privileges
- Change to a computer on which you have administrator privileges

Toolbar disappears when loading mxd

Meaning:

Occurs in version 9.3.1

Fix:

- Goto View→ Toolbars→RCWDSS and load the toolbar

Version Changes

1.1

Bug Fixes

- Fixed a bug that occurred with very small initial populations that died out during the course of a run.
- Fixed a bug where the normal distribution for mortality was skewed.
- Fixed bug where selecting an option for recruitment clusters or dispersal tracking did not automatically select the option to add the layer to the map.

New Features

- Added feature to track dispersal between designated territory groups.
- Limited Age Distribution to a single year from the field data.
- Changed Recruitment cluster successful occupation attribute name and added new attribute to track habitat acreage.

1.1.1

Bug Fixes

- Browse For Folder button for selecting an output location folder now functions.
- Schema validation now reports errors timely.

1.1.3

Bug Fixes

- Dispersal Sets can now have a membership of one cluster.

1.1.4

Bug Fixes

- Dispersal Sets no long require groups to have identical names in both layers.
- Improved error capturing when verifying nesting and foraging habitat.

1.1.5

Bug Fixes

- Dispersal layer will not be created if only one dispersal group was tracked.
- Checks to make sure at least 2 dispersal groups are found if using this feature.
- Fixed interface bug where a Recruitment Cluster Success layer was set to be added to the map even when recruitment clusters were not a part of the model.
- Included the option to add dispersal tracking layer to the properties file and the registry (if applicable).

1.2

Bug Fixes

- Completed the conversion from “Migration” Tracking to “Dispersal” Tracking on the Wizard and Scenario Manager

New Features

- Added the budding density surface layer as a point shapefile to accommodate the failure that sometimes happens when creating the BDSurf Layer.
- Changed attribute name from “Group” to “DispGroup” to more clearly define what it represents for Dispersal Tracking.

1.2.1

Bug Fixes

- When clicking on the Reset button of the Scenario Manager, the Dispersal Tracking label disappears.
- If Landscape Evaluation option is not selected, no ‘number of groups’ information will be displayed in the Scenario Manager.
- Changed indication for not selecting dispersal tracking from “N/A” to “No”

Known Issues

- ArcMap 9.3.1: When a map document is loaded, toolbar disappears.

Appendix B: DSS CD and Download

A CD containing a working copy of the DSS is submitted along with this report.

The DSS is available for downloading, from of charge, at:

http://www.cmiweb.org/projectpage.aspx?projectid=36

Scroll down to the bottom, and click on the Related Documents and Links tab.

Appendix C: Scientific and Technical Publications

Peer-Reviewed Articles

D. C. Kesler, J. R. Walters, and J. J. Kappes, Jr. 2010. Social influences on dispersal and the fat-tailed dispersal distribution in red-cockaded woodpeckers. Behavioral Ecology 21:1337-1343.

Technical Reports

J. R. Walters, K. M. Convery, P. M. Baldassaro, R. McGregor and J. Priddy. 2009. Evaluation of the projected impact of planned landscape changes on the Fort Benning Red-cockaded Woodpecker population: baseline and post-MCOE simulations. Submitted to Fort Benning, Columbus, GA.

Conference and Symposium Abstracts

J. R. Walters, P. Baldassaro, K. Convery, L. B. Crowder and J. A. Priddy. A decision support system for identifying and ranking critical habitat parcels on and in the vicinity of Department of Defense installations. SERDP and ESTCP Partners in Environmental Technology Technical Symposium & Workshop, Washington, DC, November 28-30, 2006.

K. M. Convery, J. R. Walters, P. M. Baldassaro, L. B. Crowder and J. Priddy. Evaluating habitat value for red-cockaded woodpeckers using individual-based modeling. Spatial Tools in Conservation Planning symposium, The Wildlife Society's 14th Annual Conference, Tucson, Arizona, September 22-26, 2007.

J. R. Walters, P. Baldassaro, K. Convery, L. B. Crowder and J. A. Priddy. A decision support system for identifying and ranking critical habitat parcels on and in the vicinity of Department of Defense installations. SERDP and ESTCP Partners in Environmental Technology Technical Symposium & Workshop, Washington, DC, December 4-6, 2007.

J. R. Walters, P. Baldassaro, K. Convery. A decision support system for identifying and ranking critical habitat parcels on and in the vicinity of Department of Defense installations. SERDP and ESTCP Partners in Environmental Technology Technical Symposium & Workshop, Washington, DC, December 2-4, 2008.

J. R. Walters, P. Baldassaro, K. Convery, and R. McGregor. A decision support system for identifying and ranking critical habitat parcels for red-cockaded woodpeckers on and around Department of Defense installations. SERDP and ESTCP Partners in Environmental Technology Technical Symposium & Workshop, Washington, DC, December 1-3, 2009.

Awards

Cross Functional Team of Excellence Award, Fort Benning, presented by the Commanding General, Fort Benning, to Ross McGregor, April 24, 2009.