MAPPING HABITAT CONNECTIVITY FOR MULTIPLE RARE, THREATENED, AND ENDANGERED SPECIES ON AND AROUND MILITARY INSTALLATIONS.

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ABSTRACT

Background: One of the most commonly implemented conservation tools available to offset habitat fragmentation is the protection or creation of connections among existing populations and habitats. Protecting lands that connect habitat patches particularly benefits rare, threatened and endangered species, which are often confined to relatively small areas of habitat isolated within a matrix of non-habitat. Many military bases serve as 'islands' that harbor endangered species, and the DoD and conservation organizations are investing heavily in purchasing lands, including areas that connect to nearby reserves, to increase the viability of rare populations. However, conservation purchases often are made to protect a single species such as the endangered red-cockaded woodpecker. Ideally, conservation purchases would promote connectivity for suites of species as well, including those with divergent life histories and habitat affinities.

Objective: The goal of this project is to develop methods for identifying lands on and around military bases that provide high connective value for suites of species of management concern. Using a set of rare, threatened, and endangered species with divergent life histories (red-cockaded woodpeckers, St. Francis' satyr butterflies, Carolina gopher frogs, and tiger salamanders), we will develop a system for multiple-criteria optimization of habitat connectivity management. We will accomplish this by integrating field observations of animal movement, movement models, and habitat and landscape models, in a spatially explicit analysis framework. The widely varying life histories of the species we propose to study are reflective of the actual conservation challenges faced on and around many DoD installations.

A key outcome of the proposed research is a spatially explicit decision support system for managing habitat connectivity for multiple taxa within the context of land-use, land-management, and land procurement objectives, constraints, and opportunities on and around DoD installations. This framework will be developed at Ft. Bragg, NC, and tested at Camp Lejeune, NC.

Summary of Process/Technology: Using easy-to-measure animal movement behaviors on all of our focal rare taxa, we will use simulation, analytical, and spatial modeling to predict optimal habitat areas that simultaneously provide the greatest level of connectivity to all of our species. Simulation and analytical models will be run within our support system that uses remotely sensed data and GIS technologies to provide a detailed map of suitable breeding and dispersal habitat. Using these technologies, we will evaluate the impacts of connectivity for animals in the context of monetary and other costs imposed by networks of conservation actions.

Benefit: This research will result in novel approaches for understanding and managing habitat connectivity for multiple taxa in the context of fragmented, multiple-use landscapes on and around DoD installations. These approaches will be applicable to DoD management of habitat connectivity because they are based on flexible, adaptive management that incorporates constraints placed by military land-uses as well as constraints and procurement opportunities on lands surrounding DoD installations. This research will also directly aid in the recovery and conservation of our focal taxa at Ft. Bragg and other southeastern installations.

Transition Plan: Because we have chosen to study rare, threatened, and endangered animals with divergent life histories that mimic complexes of rare species on or around other installations, the system we propose will be extensible to other bases and their surrounding regions. Most immediately, continued development and implementation of our management approach would be carried forward by the Endangered Species Branch at Ft. Bragg. In addition, we will be able to transition our analyses to at least one other base that harbors similar species as we are studying at Ft. Bragg. Red-cockaded woodpeckers are important flagship species in the southeastern US that occur on a number of military bases. In years 4 and 5 of our project, we would transition our approach to Camp LeJeune, North Carolina. Our approach will apply to many military bases where there are multiple rare species of management concern.

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A Proposal in Response to: BAA, SERDP-SON; November 10, 2004; CSSON-06-01.

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SERDP RELEVANCE

Recent U.S. Department of Defense (DoD) purchases of lands surrounding Ft. Bragg and Camp LeJeune, North Carolina, connect endangered red-cockaded woodpecker (RCW) populations on these bases to those on nearby reserves (Herring 2004). These land acquisitions reflect the importance placed on habitat connectivity for managing rare, threatened and endangered species on military bases. Yet, the conservation value of acquired lands depends on how well target species disperse through them, and the degree to which these lands protect habitat or promote habitat connectivity for other rare species of management concern. In the absence of information on the ability of species to disperse through different habitats, it is unclear whether lands that are protected based solely on their availability, or on their potential value to a single species, will provide dispersal opportunities for target species, or for other rare, threatened and endangered species. For the proposed work, we have chosen a set of species with widely varying habitat requirements, life-histories, and dispersal modes, thus reflecting the varied conservation needs of rare, threatened and endangered species found on many military installations.

A key outcome of the proposed work is a spatially-explicit decision-support system for quantifying and managing habitat connectivity for multiple rare taxa within the context of the DoD objectives, constraints, and opportunities for land use, land management, and land procurement. This framework will be developed at Ft. Bragg, North Carolina, and tested at Camp Lejeune, North Carolina.

Our approach seeks to maximize the conservation effectiveness of DoD land use, procurement, and management activities by explicitly incorporating knowledge of animal movement behavior, and the landscape resistance to dispersal for multiple rare taxa. Our framework will allow DoD to evaluate the overall conservation impact of multiple land-management scenarios, and to determine optimal strategies for managing connectivity for suites of rare species present on and around installations. The explicitly spatial and biological approaches integrated in this work are of critical and increasing importance as lands surrounding military installations are undergoing rapid fragmentation and permanent conversion to non-habitat.

TECHNICAL OBJECTIVE UNDER CSSON-06-01

***Background*:** A difficult challenge faced by the military is the protection of multiple rare, threatened and endangered species, while minimizing impact on military training efforts. In many, if not most cases, the major threats to rare species on and around military lands, and in general, are habitat loss and fragmentation (Wilcove, et al. 1998). A valuable conservation tool for offsetting habitat fragmentation is the strategic preservation of connections among existing populations and protected habitats (Beier & Noss 1998, Tewksbury et al. 2002). In this vein, the military has accelerated land acquisition around major bases with the goal of enhancing connectivity among existing habitats for rare species (Herring 2004). Identifying the appropriate lands to preserve for this purpose is challenging, however, because species vary in their abilities to disperse through different habitats and landscape features (Ricketts 2001).

***The goal of this project is to develop methods to identify lands on and around DoD installations that provide high connective value for suites of rare, threatened and endangered species*.**

Protecting lands that connect habitat patches benefits rare, threatened and endangered species by increasing available habitat, increasing the viability of small populations, and promoting metapopulation dynamics. In cases where connecting lands are similar to breeding or foraging habitat, they can benefit populations of rare species by increasing habitat area and resource availability. Lands that connect habitat patches further enhance populations of rare species by promoting migration among existing populations. Such migration increases the viability of small fragmented populations (the so-called rescue effect; Brown & Kodric-Brown 1977) by reducing the effects of random demographic and genetic changes, and by sustaining sink populations in marginal habitats connected to highly productive source populations (e.g. Wooten & Bell 1992; Stacey et al. 1997). Finally, connecting quality habitats enhances populations of rare species by facilitating colonization of habitats that lack extant populations (e.g. following restoration), and by promoting within-population dispersal for species that operate at large spatial scales, such as red-cockaded woodpeckers.

While dispersal is the primary force that generates animal distributions, dispersal data are often difficult to collect, and reflect patterns at a scale generally much larger than the processes determining them (Lima & Zollner 1996). Because of this difficulty, recent attempts to identify lands with high connective value for multiple species of concern have relied on expert opinion weighed against overall management objectives (Beier et al. 2005). The methods developed by Beier et al. (2005) do provide a mechanism for weighting multiple management goals, and examining the relative costs and benefits of different management options. However, the reliance on expert opinion to identify lands with high connective value means that the conservation value of different habitats is based on subjective, if informed, decisions.

In comparison to dispersal data, movement data are generally much easier to collect, and occur at the same spatial scales as environmental factors determining individual movement. Thus, an alternative approach to quantifying habitat connectivity is to model dispersal on the basis of more easily obtained data on local movement behavior (Turchin 1988; Morris 1993). Using this approach, movement behaviors provide a quantitative and objective basis for predicting which land has highest connective value for conservation. For example, Levey et al. (2005) showed that movement behaviors at the edge of habitat patches guided birds to disperse seeds along habitat corridors, demonstrating how local animal movement behaviors can scale up to determine connectivity for plant populations. Schultz (1998) used similar approaches to show the importance of alternate landscape configurations in conservation. She demonstrated that differences in movement behaviors in suitable habitat vs. surrounding, poor-quality matrix habitat would preclude corridors from connecting subpopulations of the Fender's blue butterfly, however stepping stone patches of quality habitat would promote connectivity. Likewise, Revilla et al. (2004) showed that differences in movement behaviors through different matrix habitats significantly affected Iberian lynx dispersal among subpopulations. Similarly, differences between declining and stable populations of Australian brown treecreepers, a species with a complex social system like that of the RCW, are attributable to large effects of matrix habitats on dispersal efficiency (Cooper & Walters 2002a; 2002b; Cooper et al. 2002). In sum, these results show how movement behaviors can be used to predict landscape connectivity for animal dispersal. Two key features of these studies, and specific foci of this proposal, are the importance of habitat boundaries and habitat matrix in determining landscape connectivity.

We propose to use habitat-specific movement behaviors to quantify and map the connective value of landscapes for four rare, threatened, and endangered species found on Ft. Bragg, NC: the red-cockaded woodpecker, St. Francis' satyr (butterfly), the Carolina gopher frog, and the eastern tiger salamander. By integrating observed and modeled animal movement data with dispersal models and spatially distributed landscape attributes, we will develop spatially-explicit models of both habitat and landscape connective value for each species.

One of the unique aspects of this proposal is our attempt to evaluate the connective value of land areas for multiple species with very different life histories and dispersal capabilities (Table 1). The red-cockaded woodpecker (RCW) depends on old-growth longleaf pine forests and is a strong flier, potentially capable of dispersing relatively large distances across many habitats. In contrast, St. Francis' satyr depends on early-successional wetland habitat, is a weak flier, and disperses primarily along stream corridors. Both the Carolina gopher frog and eastern tiger salamander use two habitats, ephemeral pools and upland longleaf pine forests. These species disperse by walking, and are therefore subject to dispersal barriers easily overcome by the RCW and St. Francis' satyr. The differences in life history and dispersal capabilities among these species mean that they will likely benefit from different types of connective habitats promoting dispersal. For example, the butterfly may benefit from habitat corridors and potentially from small habitat patches between populations (stepping stones). The gopher frog may benefit from stepping stone breeding pools separated by low-risk habitats, while the RCW may benefit only from low-risk habitats.

Our work will result in approaches for assessing and managing habitat connectivity for multiple species with different life-histories and dispersal habitats. This approach will benefit management of rare species not only at Ft. Bragg, but also on and around other DoD installations harboring suites of species with similar characteristics to those considered in this study (Table 1).

Table 1. Examples of military bases with federally listed threatened or endangered species suites similar to those included in the proposed study.

	Life History or Taxonomic Attribute			
Military Installation	**old growth forest bird**	**wetland invertebrate**	**butterfly**	**semi-terrestrial amphibian**
Ft. Bragg, NC	RCW	St. Francis' satyr	St. Francis' satyr	Carolina gopher frog[1] eastern tiger salamander[2]
Camp LeJeune, NC	RCW			Carolina gopher frog[1]
Ft. Stewart, GA	RCW			flatwoods salamander
Ft. Huachuca, AZ	Spotted owl	Huachuca spring snail		Sonoran tiger salamander Chiricahua leopard frog
Ft. Ord, CA	Spotted owl			California tiger salamander
Presidio Monterey (and Annex), CA			Smith's blue	California tiger salamander California red-legged frog
Ft. Lewis, WA	Spotted owl		Taylor's checkerspot[1] Mardon skipper[1]	

1 Candidate for listing.

2 Listed at state level only.

The techniques proposed here also provide methods for determining how well management schemes directed toward one species cover other rare, threatened and endangered species. In many cases, conservation efforts are directed toward one charismatic or "flagship" species. In the southeastern US, where we propose to work, that species is the RCW. Habitat conservation measures in the southeastern U.S., including at a number of military bases and their surroundings (i.e., Table 1), are directed primarily at acquiring or restoring high quality habitat for these birds. There is strong rationale for such an approach to conservation: RCWs are rare and highly restricted to longleaf pine woodland habitats that have been reduced to a fraction of their former extent. The woodpeckers have specialized habitat requirements (old pine trees; open, fire-maintained woodlands), which also fill requirements of other rare species in these landscapes. Furthermore, because of the large area needed to sustain viable populations, RCWs could serve as "umbrella" species, drawing in other species with smaller range requirements. Although habitat requirements for RCWs drive conservation and restoration on and in the vicinity of military bases in the US southeast, little research assesses the consequences of such strategies for other rare species.

We propose to study how to optimize habitat conservation for species like the red-cockaded woodpeckers in a way that also enhances the population viability of other rare species in the landscape.

Species with large area requirements, such as the RCW, may serve as umbrella species in two key ways. First, conservation of habitat for such species may automatically conserve habitat that is important to other species. Eastern tiger salamanders, for example, spend much of the year in upland terrestrial forest used by red-cockaded woodpeckers for nesting. An important point for our study is that, while suitable breeding habitat for RCWs may may not serve as breeding habitat for other species, it may provide important dispersal habitat (e.g., for tiger salamanders). Second, species requiring large land areas for their conservation, are likely to encompass the habitat requirements of other rare species. For example, eastern tiger salamanders and Carolina gopher frogs live in ephemeral ponds that may be nested within longleaf pine forest. Likewise, St. Francis satyr lives in wetlands along streams that could be encompassed within larger conservation purchases for red-cockaded woodpeckers. If RCWs and other flagship species do serve as general umbrellas for rare species with diverse life histories, conservation efforts could be substantially simplified and the efficacy improved. This project will test how widely the umbrella concept can be applied to the conservation of landscape connectivity for rare species in general.

The results of our work will have a direct impact on habitat conservation at our focal site, Ft. Bragg, and at Camp LeJeune, where we will concentrate efforts to transition our work beyond the focal site. At Ft. Bragg and surroundings, the project will support the North Carolina Sandhills Conservation Partnership (NCSCP), a well organized coalition of state and federal agencies and private organizations whose mission is to conserve, protect and enhance the unique ecosystems encompassing Ft. Bragg. The Partnership is implementing a land acquisition strategy that is based on population modeling for the RCW, and expert opinion with respect to other species of concern. Currently, the Partnership is attempting to assess the connective value of private lands separating two portions of the RCW population in northeastern Fort Bragg. The woodpecker model currently employed assumes that there are no effects of habitat on dispersal behavior, and thus provides little basis for determining the relative value of different parcels of potential conservation land. Our project will provide the tools needed to make such evaluations. Our project will also benefit the Carolina Onslow Bight Conservation Forum, a partnership in the southeastern Coastal Plain of North Carolina (including Camp LeJeune), whose conservation strategy is closely modeled on the NCSCP.

TECHNICAL APPROACH

Study System

Our focal study site encompasses Ft. Bragg in North Carolina and private land along its boundaries (Fig. 1). Ft. Bragg is approximately 65,000 ha, comprised mainly of longleaf pine woodland and riparian habitat. Longleaf pine woodland on base is subject to controlled burning on a 3-yr rotation. Fire planning is designed to complement management for military training.

***Habitats of primary interest*:** Suitable breeding and foraging habitats differ among the four species we are considering. Red-cockaded woodpeckers nest and forage in high quality longleaf pine woodlands with an open understory. St. Francis' satyr and related butterflies live and reproduce in wetland meadows that occur intermittently along streams. Both the eastern tiger salamander and the Carolina gopher frog breed in ephemeral ponds that are isolated from streams, and, in the non-breeding season, they migrate to upland longleaf-pine and other forest where they live in holes or under coarse woody debris.

This project focuses largely on identifying "dispersal habitats." Dispersal habitats can include both high quality areas that might also serve as "breeding habitats" (especially for the RCW), as well as poorer quality "matrix habitats" that animals must traverse in colonizing suitable breeding and foraging sites. For all of our study species, and especially for the butterflies and amphibians that live in discrete, isolated wetlands, dispersal through less suitable matrix habitat is the only way for individuals to move between patches of quality habitat. We will study four dominant suitable and matrix habitats, including 1) high-quality longleaf pine woodland, 2) low-quality pine forest, 3) hardwood (including riparian) forest, 4) open habitats, including drop zones on military installations and agricultural areas off installations, and 5) developed areas. In addition to our interest in dispersal through each habitat type, we are also interested in the influence of boundaries on dispersal between habitats patches. Boundaries can affect connectivity, either by creating barriers to dispersal, or by directing dispersers through the landscape (Levey, et al. 2005). Thus, we will also study and incorporate these boundary effects into the proposed work.

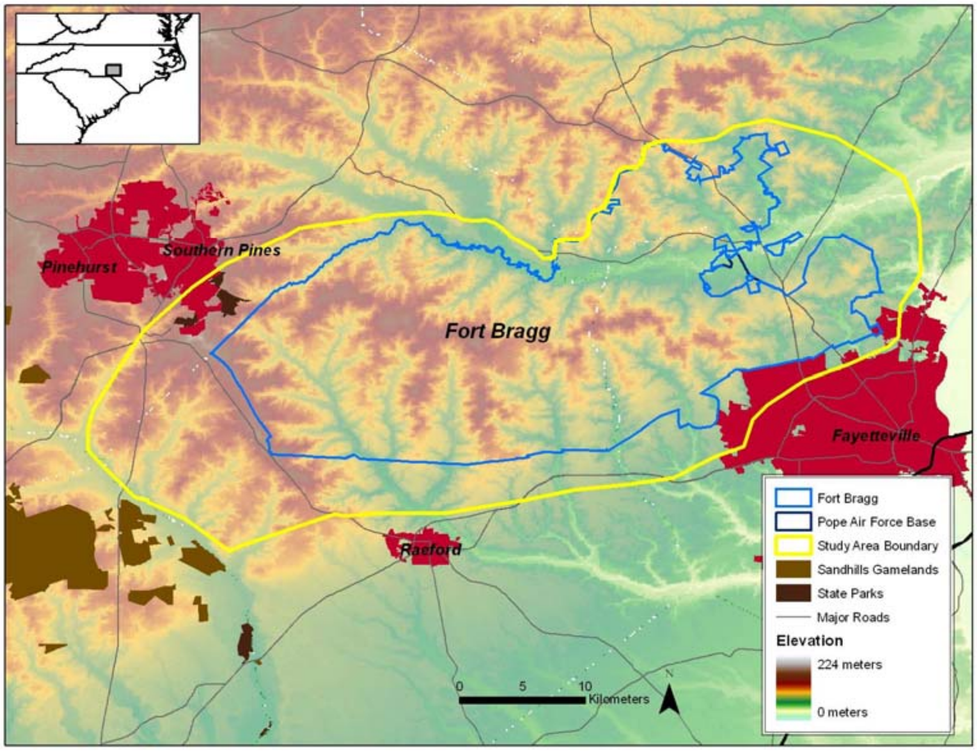

Figure 1. Proposed study area on and around Ft. Bragg, NC.

Species Descriptions and Justification

***Red-cockaded woodpecker*:** The red-cockaded woodpecker (RCW; *Picoides borealis*) is a federally endangered species endemic to the southeastern U.S. It is found on 15 military installations, and has significant populations on the most active bases in the region, including Fort Bragg, Camp Lejeune, Eglin Air Force Base, Fort Stewart, Fort Benning and Fort Polk. J. Walters has studied marked populations of RCWs in the Sandhills, including western Fort Bragg, since 1981, and also directs a study of the RCW population on Camp Lejeune, ongoing since 1986. He has also developed (with L. Crowder and others at Duke University) a spatially-explicit, individual-based model of red-cockaded woodpecker population dynamics. Conservation of RCW dominates conservation management on military bases and other public lands throughout the southeast, and the military has been the leader in making progress toward recovery (Walters 2004). The biology of the species is well known, allowing for the development of a management strategy (Walters 1991) that has been highly effective (Walters 2004; Rudolph et al. 2004) and is codified in a new recovery plan for the species (USFWS 2003). This management strategy depends heavily on constructing artificial cavities to create new territories called recruitment clusters as the primary means to increase populations. This strategy is most cost-effective if recruitment clusters can be occupied through natural dispersal processes. Although much is known about the complex dispersal strategies the birds employ (Walters 1990; Pasinelli & Walters 2002; Pasinelli et al. 2004) and costs of dispersal (Daniels & Walters 2000), information about how habitat affects movement during the dispersal process is nonexistent. This is arguably the most important knowledge gap for the species currently. We propose to address this gap by 1) analyzing nearly 2000 dispersal events we have recorded for this species in the North Carolina Sandhills over the past 25 years to determine the effect of intervening habitat on the frequency of movement between woodpecker territories; and 2) using radio-telemetry to examine the response of birds to different habitat types during the process of dispersal.

***St. Francis' satyr*:** St. Francis' satyr (SFS; *Neonympha mitchellii francisci*) is a federally endangered species that occurs only at Ft. Bragg and that lives in wetland meadows that occur along small streams. These openings are created by pond inundation and abandonment by beavers. Beavers were once abundant on the landscape, but were eliminated from North Carolina by 1897, which probably explains the loss of habitat that has restricted the butterfly's distribution. Initially, the flooding caused by beaver dams has a negative impact on butterfly subpopulations, as caterpillars cannot withstand submergence. Following beaver lodge abandonment and flood recession, however, the plant communities progress through a natural process of succession from wetland meadow, which provides SFS habitat, to woody and shrubby vegetation that excludes the butterfly's food plants. Thus, because available habitat is constantly shifting, the butterfly needs to disperse to new habitat in order to persist in the landscape. Dispersal for SFS could occur along riparian corridors, or possibly through upland habitat. Because beavers have been restored to the landscape, there may be suitable habitat on or off Ft. Bragg that has yet to be colonized. One goal of this study is to identify ways to increase connectivity and restore SFS on and off base.

For the past 3 years, N. Haddad's group has studied the population sizes and trends of SFS. In total, SFS adult population sizes outside artillery impact areas number around 1000 individuals, spread primarily among four wetland populations. Because of the small size and range of SFS populations, it would be detrimental to conduct experimental movement studies, as are required for this project, that entail releasing butterflies into matrix habitat. It is also unlikely that we would observe a sufficient number of natural dispersal events over the course of this study. Thus, we propose to supplement observational studies of SFS within known habitats with observational and experimental studies of two other species, Georgia satyr (*Neonympha areolata)* and Appalachian brown *(Satyrodes appalachia)*, that are in the same sub-family as SFS, live in the same or similar wetlands as SFS, are extremely habitat restricted, and are rare (but not of federal concern) (Kuefler 2005). The Georgia satyr is nearly identical morphologically to SFS and can be reared to adulthood on the same larval food plants (Hall & Haddad 2005). The Appalachian brown consumes the same host plant on Ft. Bragg as that consumed by the other endangered subspecies of *Neonympha mitchellii* in the Great Lakes region. Because these species are less restricted than SFS, we can conduct experimental release studies with them.

***Amphibians*:** Eastern tiger salamanders (*Ambystoma tigrinum tigrinum*) and Carolina gopher frogs *(Rana capito capito*) are both NC-state listed as threatened species. The Carolina gopher frog is also considered a federal species of concern. These amphibians breed in late fall (*A. tigrinum*) and winter (*A. tigrinum* and *R. capito*) in temporary pools within upland sandhills habitats (Petranka 1998; Palis 1997; A. Braswell personal communication). Little is known about where adults spend the summer (non-breeding) months, but it is believed that they inhabit upland longleaf pine woodlands, spending most of their time in holes created by rotted or burned out roots (A. Braswell, E. Hoffman, R. Sutherland personal communication). N. Haddad (with B. Hudgens) is currently conducting mark-recapture and radio-telemetry studies on these species to determine their breeding and non-breeding habitat requirements. Both species are particularly well-suited for developing methods for understanding connectivity since they must migrate between breeding and non-breeding habitats as well as among spatially isolated breeding pools. Consequently, methods developed including these species will have greater applicability, especially for other bases with rare, threatened or endangered amphibians (see Table 1) than if we considered only species restricted to one habitat type.

As part of ongoing work, we have established marked populations of *A. tigrinum* at all accessible breeding pools on Ft. Bragg. Adult salamanders and gopher frogs visiting breeding pools are photographed; they can be distinguished individually be unique marking patterns. We encountered more than 50 adult salamanders and one adult gopher frog in 2004-5. In addition, we have developed methods for radio-tracking adult salamanders and gopher frogs observed leaving breeding pools throughout this summer to identify non-breeding habitat. This proposal builds on ongoing work by utilizing the methods developed for marking and radio-tracking these species, and our increasing understanding of habitat requirements. The information on habitat requirements for tiger salamanders and gopher frogs will also be used to restore breeding pools on base, which we will use to test our movement models (see below). We will conduct studies on natural behaviors of both species, but will restrict our experimental release studies to tiger salamanders, which are more common on and off base.

Collection of Movement Data

One of the most useful frameworks for characterizing movement behaviors is in terms of a correlated random walk (Kareiva & Shigesada 1983; Turchin 1998). In this framework, movement paths are broken down into a series of steps, with each step characterized by five parameters: step length, step direction, velocity, correlation between sequential steps, and directional bias. These parameters can all be estimated from movement paths collected by following individual organisms (e.g. Schultz 1998; Schultz and Crone 2001; Levey, et al. 2005) or from radio-telemetry data sampled at frequent intervals (e.g. Revilla et al. 2004). In this study, we will follow individual movements of two butterfly analogues to SFS, and take frequent radio telemetry data on two species of amphibians and one bird species to characterize their movement behaviors, in terms of a correlated random walk, through various matrix habitats within the study area.

***Red-cockaded woodpecker*:** While some juvenile females disperse soon after fledging, many remain with their natal group through the winter, and then disperse just prior to the next breeding season in March and early April. Thus, there exists a class of individuals whose propensity for dispersal can be reliably predicted. We will take advantage of the ongoing population study of RCWs on western Fort Bragg, which provides a large pool (about 170/yr) of color-marked juveniles, to identify juvenile females that remain with their natal group in February. We will similarly identify additional juvenile females in groups monitored by Fort Bragg Endangered Species Branch in other key areas, such as northeastern Fort Bragg. J. Walters currently possesses the only permit that has been issued by the U.S. Fish and Wildlife Service for for the use of radio telemetry on RCW. Of the juvenile females that remained with their natal group, we will attach tail-mounted radio transmitters to a sample of 35 individuals, selected for their location relative to habitats and landscape features of interest, and monitor their movements during March and April. Locations of birds bearing radio-transmitters will be identified daily for the entire sample, and continuously for those birds found to be traveling outside their natal territories. For the latter, locations will be recorded every hour each day until that individual settles in a new location with a new group. All movement data will be georeferenced and incorporated with the project's spatial database described in the Spatial Modeling section below.

To further assess the effect of matrix habitat on movement, we will incorporate nearly 2000 dispersal events already known from the study population, and quantify the frequency of dispersal between territories as a function of distance and intervening habitat. To do this, we will employ an existing GIS data layer containing the location of all woodpecker territories in the study area, and an existing program that plots dispersal paths as the shortest distance between territory centers. These will be integrated with the spatial database for this project to characterize intervening habitat. Where significant changes to habitat have occurred, we will limit our analysis to dispersal events that occurred after the habitat was converted to its current condition.

***Butterfly movement paths*:** We will characterize butterfly movement by following the flight paths of marked individuals through breeding and matrix habitats (see Study System, above). To accomplish this, we will record movement behaviors in 60 x 60 m grids of 6 x 6 m cells. Corners of grid cells will be marked by 10 ft. tall PVC poles that are easily visible above emergent vegetation from a distance. We have used this technique in previous studies (Haddad 1999; Kuefler 2005), including for Satyrine butterflies (Kuefler 2005). We will establish three different grids in each of the five habitat types, as well as at boundaries between each pair of habitats (both breeding and matrix). Thus, there will be 15 grid types with 3 replicates of each type. We will locate grids as close as possible to existing populations of surrogate species, on or off base. Within grids, individual butterflies will be followed for up to 30 min or until they leave the grid. For each flight path, we will record each grid cell that a butterfly passes through, and the duration of activity within each grid cell. At each grid cell, we will record the percent cover of total vegetation and graminoid vegetation (the butterflies all have graminoid hosts and do not consume nectar at flowers as adults). These variables have proven sufficient for predicting movement characteristics of Satyrine butterflies at Ft. Bragg (Kuefler 2005).

In breeding habitats (wetland meadows), we will mark and follow movements of naturally occurring individuals of SFS, Georgia satyr, and Appalachian brown and quantify their behaviors when they encounter matrix habitats. This will allow us to test landscape effects on movement rates and biases for the three species, and provide data for calibrating movement behavior of SFS to the two surrogate species that will be used for experimental release studies.

The release studies will be conducted in matrix habitats using captured individuals from existing populations of the Georgia satyr and the Appalachian brown butterflies. Captured butterflies will be placed into individual containers, cooled for up to one hour, and transported to release sites. Release containers will be covered with mesh that can be removed from a distance by use of a string and pulley. Animals will be allowed to acclimate to containers at the release point before being released. Using this approach, observers will not influence butterfly dispersal behavior (Kuefler 2005). Over two years (years 1 and 2), we will collect data from at least 4 independent movement paths from each species for each grid (=180 movement paths per species). Based on previous efforts (Kuefler 2005), we estimate that two field workers will be able to capture and release 16 individual butterflies per day. Marked animals from known populations or release sites observed at known recipient populations will be recorded as dispersal events and used as one source of validation for dispersal models (see below).

***Amphibian movement paths*:** We will characterize amphibian movement paths using radio telemetry. The location of radio-fitted animals will be recorded every hour during periods of movement for 1-3 consecutive nights. Locations will be determined from triangulation based on 3 readings for each location. Readings will be taken from 5-50 meters to avoid interfering with animal movement.

As with butterflies, we will record movement paths through breeding and matrix habitats (identified above). For both species, individuals will be captured at breeding pools, fitted with transmitters, and followed to non-breeding habitats. For tiger salamanders, we will tag a minimum of10 individuals per pool in six pools, located both on and off base. For gopher frogs, we will tag all individuals that we capture.

In addition to observations of individuals in breeding pools, we will conduct release experiments with tiger salamanders to characterize behaviors in all matrix habitats and at boundaries between habitats. As with butterflies, we will identify three replicates each of 15 types (5 habitats plus 10 types of boundaries). Release sites will be located nearby breeding ponds on or off base. Animals leaving leaving breeding pools will be fitted with a radio transmitter, placed in individual containers, kept at ambient temperature for up to two hours, and transported to release sites. Released animals will be followed for 1-3 consecutive nights. During the first two years of the project we will collect data on at least two movement paths at each release location (=90 movement paths). At each release point the distance and direction to the nearest breeding pool, suitable non-breeding habitat, and change in habitat type will be recorded.

Modeling Movement and Dispersal

***Analysis of movement data*:** The movement data described above will serve two purposes. First, they will allow us to test directly how specific movement behaviors are influenced by different habitat types and boundaries. Second, these data will be used to estimate movement parameters that are required to run quantitative models of dispersal. Dispersal models will allow us to link local scale movement observations to the larger landscape context relevant for dispersal processes and for conservation management. In addition, the effect of land-use changes can be determined by simulating movement among populations connected by affected pathways.

For each species, we will use the locations of individual moving organisms, recorded over fixed time intervals, to estimate 3 variables (move lengths, turning angles, and directional bias) that summarize movement within habitat types, as well as the response to habitat boundaries. Habitat and landscape effects on the mean move length will be analyzed using standard statistics (e.g., t-tests and linear regressions). Turning angles and directional bias will be analyzed using circular statistics (Batschelet 1981). We will also use circular statistics to analyze whether moves at differing distances from a habitat boundary are significantly clustered in the direction toward or away from the boundary, which would indicate that dispersers are attracted to or repelled by the boundary, respectively.

***Modeling dispersal*:** Models parameterized with data on movements of individual animals will allow us to explore how particular configurations of habitat types on the landscape will influence the amount of dispersal between Ft. Bragg and nearby conservation areas. We will evaluate both computer simulation models

(Letcher et al. 1998, Walters et al. 2002, Revilla et al. 2004) and analytical dispersal models. These two approaches are complimentary. Simulation models incorporate a wealth of biological detail but their predictions may be highly specific to particular landscapes. On the other hand, analytical models parameterized directly from movement data provide general indices of habitat conductivity. By using both approaches, we aim to find the most accurate and efficient predictor of successful dispersal.

***Computer simulation modeling*:** For each of our study species, we will simulate individual dispersers moving on a grid with the habitat type and landscape features at each grid point imported from the GIS database. Simulated individuals will move according to the variables estimated from the movement data, and will die at a rate which may vary by habitat type. Thousands of individuals, originating at the sites of known populations, will be simulated moving across the study area. Grid points visited frequently by individuals (of 1 or more species) that disperse successfully between suitable breeding habitats will be identified. These points map out parcels of land through which organisms successfully disperse, and can be quantified or ranked in terms of their value as dispersal habitat depending on the number of individuals of each species that disperse through them. We will run simulations under different habitat configurations (e.g. by converting present-day forest to housing developments) to see which parcels are critical to maintaining a minimum amount of dispersal within, and into and out of, Ft. Bragg. Although we will initially use the simulation model to assist conservation decision-making at Ft. Bragg, the model will be made "portable" to other bases by importing landscape and movement features.

***Individual-based Modeling for RCWs*:** Modeling for RCW is analogous to the methods we will use for all species, but builds on previous modeling work for RCW. We will extend the spatially-explicit, individual-based simulation model developed by Walters and colleagues (Letcher et al. 1998; Walters et al. 2002). This model simulates population dynamics, including dispersal of birds between territories within the landscape. The movement data we collect will be used to modify the model, which currently assumes that dispersal is unaffected by habitat type, to include the observed effects of habitat on dispersal direction, dispersal speed and mortality during dispersal. The model will provide an additional means to evaluate the connectivity value of land parcels for RCWs, by simulating population dynamics with a given parcel as protected habitat versus dynamics assuming the parcel is converted to other land uses. This will be particularly useful in assessing the value of parcels proposed for protection, for example private lands between subpopulations in northeastern Fort Bragg. The model can be validated by comparing simulated dispersal patterns to observed dispersal patterns in the study area. Collection of movement data for RCWs will be completed early in year 2, and hence modifications of the model based on the movement data can be completed in year 3. We will run simulations using the model in years 4 and 5, including applications to Camp Lejeune in year 5.

***Analytical Models*:** In addition to providing the basis for simulation models, movement variables (move lengths, turn angles, etc.) can be used to estimate parameters for analytical dispersal models, such as diffusion models (Okubo 1980, Turchin 1998, Morris 1993) and correlated random walk models (Kareiva & Shigesada 1983). Parameters such as diffusion coefficients may serve as useful indices of the "conductivity" of habitat types or land parcels for dispersing individuals. For example, if dispersers are equally likely to turn to the left or the right, then a correlated random walk model (Kareiva & Shigesada 1983) predicts that the average distance of dispersers away from their starting point will increase with each successive move by a factor:

$$Var(L) + \overline{L}^2\left(1 + 2C/(1 - C)\right), \tag{1}$$

where $\overline{L}$ and $Var(L)$ are the mean and variance of the move lengths and C is the average cosine of the turning angle (which will be largest when turning angles are clustered near zero, reflecting a tendency of individuals to move in straight lines). All of these variables can easily be estimated from the movement data. We will compute parameters from analytical dispersal models for each habitat type and point on the landscape. We will then test whether any of these easily-computed conductivity metrics, in combination with proximity to habitat boundaries and mortality rate, are highly correlated with the value of landscape points as determined by the more detailed computer simulation models.

***Testing movement models*:** We will test the ability of the movement models to accurately depict dispersal through a landscape by comparing patterns of dispersal predicted by model simulations to patterns observed in the studies described above. In each case we will simulate thousands of movement paths in the landscapes where dispersal is to be observed, and use these simulations to predict the relative dispersal rates among multiple source (where dispersers originate from) and destination pairs. We will compare model predictions to observations of 1) daily and weekly displacement distances of radio-tracked RCWs and amphibians and 2) dispersal of marked butterflies released within 100-200 meters of known populations to those populations. For RCWs we will also use over 2000 recorded dispersal events between known territories. For amphibians we will use observed colonization events of breeding pools to be restored by Ft. Bragg in conjunction with ongoing research on these species. For butterflies we will compare model predictions to observed dispersal of marked individuals from known populations or release sites to known recipient populations. Mortality risks in matrix habitat are important determinants of landscape connectivity (Hudgens and Haddad 2003), and we will generate one estimate of habitat-specific mortality from the difference between observed dispersal and predicted dispersal based on movement models.

Spatial Modeling

The movement models described above are organism-centered approaches for quantifying habitat connectivity, requiring species-specific information on movement behaviors in different habitats. We will combine this approach with a landscape-centered approach, whereby the landscape is partitioned into habitat classes based on environmental characteristics, each conferring a degree of resistance to the movement of any given species of organism. This approach requires detailed environmental information, but can be applied systematically over large areas and, because it is inherently geographic, is conducive to the purposes of land management and procurement. A landscape-centered approach will be used to provide the environmental template upon which the movement studies, described above, will be implemented. In addition, it will provide the basis for extending our study from the scales and localities of collected field data up to the entire study area. The landscape approach will also be used to develop models for quantifying and mapping connectivity across the landscape. These models will be compared with field observations and dispersal model results to test the potential to map connective value across the landscape using readily obtainable environmental data and general life-history information on species of concern.

The spatial modeling component of the project includes four main activities: 1) *Spatial Database Development*, 2) *Habitat Modeling*, 3) *Modeling Movement Resistance Surfaces*, and 4) *Habitat Connectivity Analysis*. Activities 2, 3, and 4 will be conducted using spatially distributed data on hydroperiod regime, land cover/land use/land management classes (hereafter referred to as "land use" classes), and canopy structure, all of which will be produced as described in the *Spatial Database Development* section below. These elements of the database will be used to map the distribution of habitat types in and around Ft. Bragg. The suitability of these habitat types as breeding, foraging or dispersal habitat will be determined for each species from the field studies and movement models described above. Finally, the dispersal patterns determined from the field-studies and movement models will be combined with habitat distribution data to develop landscape-based models of habitat connectivity, and to support multi-criteria analysis for managing habitat connectivity.

***Spatial Database Development*:** The database development activity consists of three overlapping phases. The *first phase* includes acquiring, preprocessing, and spatially integrating the basic geographic data elements into a project database. Preprocessing involves atmospheric correction (for satellite data), georeferencing of all environmental and movement data, and establishment of data organization and metadata protocols. This basic database will include the data fields identified in Table 2.

The primary task of the *second phase* will be the derivation of secondary information fields from the primary data elements identified in Table 2. This will include classification of remotely sensed data into land-use categories; mapping vegetation structural classes using 1st pulse LiDAR data; and modeling spatio-temporal variability of hydroperiod using a combination of field measurements, *in situ* hydrologic data, and the high resolution bare-earth digital elevation model (DEM) derived from LiDAR. These secondary environmental data will, in turn, be used to accomplish the *third phase* of spatial database development, which is the production of habitat-suitability maps and movement resistance surfaces. The processing steps included in the second and third phases of spatial database development are described sequentially below.

Table 2. Primary spatial data elements for Ft. Bragg and their roles in the spatial analysis component of this study. These data will be georeferenced to NAD83, along with the spatial products derived from them.

Data Type	Purpose	Notes
LiDAR	To model canopy structure and hydroperiod	1 foot spot height spacing: 95% @18.5 cm; 30 cm contours.
ASTER	For land-use classification and hydroperiod modeling	Visible and NIR at 15m resolution (0.52-0.60μ; 0.63-0.69μ; 0.76-0.86μ); TIR at 90m resolution.(Four TIR bands 8.125- 11.65μ)
DOQQ	For land-use classification	B/W & CIR at ~0.3-1.0 m resolution.
Field Data on hydroperiod, land use, and canopy structure	For modeling of land use, hydroperiod, canopy structure	Crest Gauge Monitoring; Field surveys of land-use and canopy structure
Stream Gauge Data (USGS)	Hydroperiod	4 known active gauges
Ground Water Data (USGS)	Hydroperiod	3 known active sites
Railroads, Buildings, Roads Easments, Zoning, Population	Land use	From NCDOT, Census Bureau, Cty and State Offices, Planning Agencies, Ft. Bragg.
Known populations for study organisms.	Habitat Modeling	Currently held by project personnel or Ft. Bragg endangered species branch.
Movement and dispersal data	To model movement resistance	Will be produced as part of this project and will also include historical RCW dispersals.

Land-Use Classification & Canopy Structure**:** We will use visible, near-infrared, and thermal data from ASTER to map land-use classes over the study area. Classification of ASTER data will be based on supervised algorithms that will be trained and independently validated using field survey data Field-mapped land-use polygons will be nested within digital orthophoto quarter quadrangles (DOQQs) which will be visually interpreted to extend the utility of the field data, and to facilitate scaling up to the study area using ASTER. We will use an adaptive classification algorithm that screens and automatically applies the best model for classifying each pixel. Model options will include Bayesian maximum likelihood, artificial neural networks, and decision trees. A. Moody has extensive experience in land-cover classification through integration of such data and methods (Moody et al. 1996; Frizzelle & Moody 2001; Moody & Johnson 2001; Xiao & Moody, in press). Other ancillary data sources, including canopy structure data from LiDAR , and data on human infrastructure, land management, and population, will be used to further refine the classification of land use. Multi-date ASTER data will support differentiation of evergreen and deciduous canopies by providing imagery during both leaf-on and leaf-off periods. The land-use classification (Table 3) is will discriminate land units that are relevant to the habitat potential, management status, and movement resistance of the landscape. These land-use classes can be readily and inexpensively mapped with high accuracy rates at the typical scale of DoD installations and surrounds. In the transition phases, land-status classes will be similarly defined according to the ecosystem, communities, species, and human-development scenarios of relevance.

Due to its importance for habitat production and quality, we will also characterize canopy structure to help differentiate habitat types. Canopy height and density will be determined from the 1st pulse LiDAR data (Harding et al. 2001; Hudak et al. 2002; Hurtt et al. 2004), allowing us to separate longleaf pine woodland (4.f. in Table 3) from other undeveloped landscapes (4.a-e.); to distinguish understory properties in longleaf pine (4.f.i. and 4.f.ii.); and to distinguish the form of wetland vegetation (4.g.i., 4.g.ii., and 4.g.iii.).

Table 3. This set of land-use classes is sufficient to resolve the suitable and matrix habitats for our study species. These will be further collapsed as appropriate. Note that classes e, f, and g will be further separated according to the vegetation type, land use, land ownership, and land management themes identified at *.

- **1**. Submerged – Non-vegetated
- **2**. Dense Development
- **3**. Moderate Development
  - **a**. Impervious
  - **b**. Semi-impervious
- **4**. Undeveloped/Sparse Development
  - **a**. Impervious
  - **b**. Pasture
  - **c**. Row Crop: Agriculture
  - **d**. Forest Plantation: Agriculture
  - **e**. Upland Forest (not longleaf pine):
  - **f**. Longleaf Pine Woodland:
    - **i**. LLP with Herbaceous Understory
    - **ii**. LLP with Woody Understory
  - **g**. Naturally Vegetated Wetlands:
    - **i**. Wetland Sedge-Meadow
    - **ii**. Woody/Short-Stature Wetland
    - **iii**. Forested Wetland

(e–g) ***Differentiate Gameland; Hardwood/Softwood; Private land; Parkland; Base uses; Fire/Nofire; Cut/No cut where appropriate.

***Terrain and Hydroperiod*:** Due to the geomorphic and hydrologic properties of the study area, small variations in terrain can produce large changes in site characteristics, particularly in the dynamics of inundation, and accompanying changes in the form and structure of plant and animal communities. For some of the taxa we are considering, these properties are known to be important habitat determinants, and thus must be accurately and precisely resolved in order to predict the spatial distribution and suitability of habitat. To our knowledge, no currently available DEM is of sufficient spatial detail and accuracy to support the current research. The LiDAR data currently held by the GIS group at Ft. Bragg has measurement-spacing and spot-height accuracies that are too coarse to resolve topographic variation critical to the production of habitat for amphibian species considered here. In addition to the 2nd pulse data used to produce the bare earth DEM, we also require 1st pulse data for characterizing vegetation canopy structure, an important habitat-quality parameter for SFS and RCW. We will acquire LiDAR data from Airborne 1 over the study area. These data are produced using the Airborne Laser Swath Mapping (ALSM) instrument. Flown at 3,000 ft., the ALSM produces data with an average spot spacing of 1.0m, with 95% of spot heights within 18.5cm of true heights, sufficient to produce 30 cm contours. The bare-earth DEM, derived from the 2nd pulse LiDAR returns, will be used in combination with field measurements of saturation heights, stream gauge and water table data, and ASTER data, to model and map the frequency and duration of inundation across the study area.

Field monitoring of saturation heights and inundation levels will be conducted in known amphibian breeding habitats and nearby potential habitats both on and off base. For twenty of these sites, we will install crest gauges, made from clear PVC pipe and other simple materials. Crest gauges are a simple and effective means to monitor saturation heights at regular time intervals, and at numerous locations. They will be used in our analysis to the height and duration of inundation in known and potential breeding pools.

The data collected from crest gauges will be combined with the bare-earth DEM and data from nearby stream gauges, ground-water monitoring wells, and soil data to produce simple models that will be used to predict inundation frequency (mean seasonal frequency and standard deviation of inundation events) and duration (mean seasonal duration and standard deviation of inundation lengths). It will initially be assumed that any location in the landscape that is below the level of the stream height will be inundated. This relationship between stream height and ponding in depressions will be improved through calibration with field data, which will also be used to calibrate for the decay time of depression dry down (i. e. the lag between changes in stream height and depression inundation level). We will also model the occurrence and duration of surface-water connections among depressions, and to the main drainage networks, as these connections are also important habitat determinants for amphibians. This will be done using a simple flow model, where flow is initiated when surface water height exceeds the height of the tip point for a depression. ASTER near-infrared (NIR) reflectance and surface temperature (Ts), acquired during time periods that coincide with high and low inundation levels and with field-data collection, will allow us to extend validation of modeled inundation patterns. NIR reflectance and thermal emissivity are strongly responsive to the presence of standing water. Using historical streamflow records, we will use our calibrated models to characterize the hydroperiod regime of all areas that are intermittently inundated.

Based on land use, vegetation structure, and inundation properties that are important for the production of suitable habitat and matrix habitat, the study area will be partitioned into landscape spatial units that define the environmental characteristics of the landscape that are relevant for movement simulation modeling (described previously) and for the development of movement resistance surfaces (described below).

***Modeling Potential Habitat*:** The combination of enviromental parameters that produce suitable habitat and matrix habitat will be determined for each species by integrating on the locations of known animal populations, movement data, and the results from movement experiments with the spatial database described above. The result of this integration will be a database containing detailed data on animal behavior and dispersal, georeferenced to spatial distributions of critical environmental properties, i. e. land use, inundation regime, and vegetation structure. Correlative models between environmental properties and animal behavior will be developed and used to model and map suitable and matrix habitats for each species over the study area. For the purposes of this work, it will be assumed that the optimal conditions for each species are those prevailing at the sites where they are found and through which they are moving.

Suitable and matrix habitat will be modeled as ranked ordinal variables using generalized linear models (GLM) and/or decision tree models. The response of organisms to environmental conditions can be highly nonlinear, and subject to critical thresholds of response. Thus GLM is an appropriate and commonly used tool for habitat modeling (Franklin 1995). However, multiple factors often interact to influence habitat suitability. Thus, modeling approaches that also incorporate hierarchical relationships and interactions among environmental variables, such as decision trees (Breiman et al. 1984; De'Ath 2002), or structural equation modeling (Bollen 1989; Weiher 2003), may be more suitable (Meentemeyer et al. 2001).

Habitat models developed using the above methods will be validated by checking the properties of predicted suitable and matrix habitats in the field; and through cross-validation, whereby habitat models developed for Ft. Bragg will be tested for their accuracy in mapping the locations of known populations at camp LeJeune. Once habitat models have been developed, they will be used to map potential habitat over the study area.

***Modeling Movement Resistance Surfaces and Landscape Connectivity*:** One of the unique elements of the work we propose is that the animal movement data will provide information on actual landscape connectivity based on observed movement events through the landscape matrix (e.g., Chardon, et al. 2003; Calabrese & Fagan 2004). For a given species, any location within matrix habitat will impose some level of resistance to the movement of individuals. Likewise, the size and arrangement of units in the landscape will shape the least-cost pathways connecting habitat patches. Our first approximation of the connectivity of the landscape will be based on distances between patches of suitable habitat; the resistance of the landscape units situated between habitat patches; and the density of landscape-unit boundaries between habitat patches. Thus, each spatial unit in the landscape can be given a connectivity value that is a combined index of its ability to transmit organisms (a function of its size, structure, and other properties), its value for maintaining connectivity among habitat patches (a function of its proximity to at least two habitat patches), the size and quality of the habitat patches that it helps connect, and the other land-use and boundary types along pathways connecting habitat patches through a given spatial unit. Using this general approach, the pathways that most effectively maintain connectivity between habitat patches can be identified and mapped.

The resistance value for any given location will be determined in two ways: 1) resistance values will be assigned as a function of distance from suitable habitat and geographic constraints caused by impassable boundaries; and 2) using the movement observations and dispersal modeling results. The first approach approximates connectivity on the basis of readily obtained biological information, and is thus more generally operational and extendable. In the latter case, observed and modeled animal movement patterns will reveal the propensity of different landscapes to direct movement among suitable habitat patches, and their impact on disperser survival and fecundity. This information will be used to guide the assignment of resistance values based on environmental properties. Conceptually, landscapes through which a species moves quickly (high velocity) toward a habitat patch (biased towards the nearest habitat patch) will have low resistance, and vice versa. The precise resistance value for any location throughout the landscape will be determined from simulations of individuals dispersing between two populations separated by a fixed distance of a given landscape-unit type. The two approaches described above will be developed and compared for all four study organisms at Ft. Bragg, and for RCW they will be tested at Camp LeJeune.

The above approaches can be used to map habitat connectivity for multiple species. However, each landscape unit also has some costs and benefits associated with either maintaining or changing its state. For example, a unit of privately owned woodland may have high connective value, but would incur some costs for purchase and proper management as habitat. These values can be incorporated and used to determine least cost solutions for maintaining a given level of connectivity in the habitat network, and, conversely, to maximize connectivity subject to budgetary and geographic constraints.

We will use a graph-theoretic framework to quantify overall connectivity within all or portions of the habitat network. This framework considers the landscape as a network of occupied and unoccupied habitat patches and pathways between them, within a matrix that is spatially varying in its tendency to promote movement of individuals (Bunn et al. 2000; Urban & Keitt 2001). Within this framework, we will assess the impact of changes in landscape properties on overall connectivity among a set of habitat patches embedded in matrix habitat. In addition, the effect of prioritizing habitat connectivity for one species on overall habitat connectivity for other rare species, can readily be evaluated in this way.

Our technical plan concludes with Table 4, showing our estimated timeline for critical project milestones, and Table 5, indicating approximate costs for each project task.

Table 4: Proposed project timeline and milestones.

Activity	2006	2007	2008	2009	2010
Collection of Movement Data: RCW	x	x	x		
Collection of Movement Data: SFS	x	x	x		
Collection of Movement Data: CGF & ETS	x	x	x		
Movement Modeling: Analysis of Movement Data		x	x	x	
Movement Modeling: Computer Simulation Modeling		x	x	x	x
Movement Modeling: Individual-based modeling for RCW		x	x	x	x
Movement Modeling: Analytical Modeling		x	x	x	x
Movement Modeling: Testing Movement Models			x	x	x
Spatial Modeling: Spatial Database Development	x	x	x	x	
Spatial Modeling: Land-Use Classification & Canopy Structure	x	x	x	x	
Spatial Modeling: Terrain and Hydroperiod	x	x	x	x	
Spatial Modeling: Modeling Potential Habitat		x	x	x	x
Spatial Modeling: Movement Resistance and Landscape Connectivity			x	x	x

Table 5: Approximate Costs by Project Task:

Task	Approximate Cost
Collection of Movement Data	
Red Cockaded Woodpecker	$232,700
St. Francis' Satyr	$114,800
Amphibians	$115,300
Movement and Dispersal Modeling	
Analysis of Movement Data	$49,000
Computer Simulation Modeling	$77,000
Individual Based Modeling for RCW	$67,200
Analytical Modeling	$61,100
Testing Dispersal Models	$68,200
Spatial Modeling	
Spatial Database - Acquisition and Development	$237,200
Land-Use and Canopy Structure Classification	$161,200
Terrain and Hydroperiod modeling	$133,200
Habitat Modeling	$109,700
Movement Resistance and Landscape Connectivity	$160,000

RESEARCH TEAM

A. Moody has extensive research experience in landscape ecology, spatially-explicit habitat and ecological modeling, spatial data analysis, remote sensing of vegetation, and GIS. N. Haddad has studied the behavioral, population, and landscape ecology of butterflies for the past decade. His work includes using movement behaviors to predict butterfly use of habitat corridors and mark-recapture and behavioral studies of the St. Francis' Satyr for the past three years. He is currently working with B. Hudgens on mark-recapture and radio-telemetry studies on the eastern tiger salamander and Carolina gopher frog. W. Morris is a population ecologist with expertise in quantitative conservation biology, and in modeling animal dispersal and population spread. In his work on modeling dispersal, he has used random walk models, diffusion models, and (in recent work) integro-difference equation models. Part of this work has involved estimating model parameters from data on movement of individuals, as would be performed in the proposed work. Jeff Walters has studied RCWs and longleaf pine ecosystems extensively. He is a coauthor of the new Recovery Plan for the woodpecker (USFWS 2003), and is co-director of a study of RCW in the Sandhills, including Fort Bragg, which has been ongoing since 1980. He also directs a study of the RCW population on Camp Lejeune that has been ongoing since 1986, and has developed (with L. Crowder and others at Duke University) a spatially-explicit, individual-based model of RCW population dynamics.

COOPERATIVE DEVELOPMENT

Cooperative Development for RCW: J. Walters has existing work at both Fort Bragg and Camp Lejeune that provides the demographic data needed, as well as logistical support in the field. These studies also provide a vehicle for communicating the results of the proposed project to natural resource managers on those bases. Additional contacts within DoD natural resource management throughout the southeast will further help facilitate transition.

Cooperative Development for SFS: N. Haddad has ongoing studies monitoring population size and trends for SFS at Ft. Bragg. This work will provide baseline data on habitat requirements and dispersal. Ongoing work accomplishes one aspect of recovery, which is to ensure populations are stable or growing. The other recovery objective is to expand SFS populations off base, and this proposal will provide tools to determine which habitats to purchase or restore that will have the greatest likelihood of increasing population viability

Cooperative Development for Amphibians: N. Haddad, in collaboration with B. Hudgens, has ongoing studies monitoring population distribution, size and trends of the eastern tiger salamander and Carolina gophger frog at Ft. Bragg. This work will provide baseline data on habitat requirements and dispersal. This proposal will provide tools to determine which habitats to purchase or restore that will have the greatest likelihood of increasing population viability, and to evaluate the impacts of management decisions geared toward other rare species on amphibian conservation.

TRANSITION PLAN

Many DoD installations harbor multiple species of management concern (US Army Environmental Center, 2005). Moreover, the management of connectivity among populations of threatened species is widely regarded and implemented as a management tool for promoting recovery. It is expected that our results and approaches will improve knowledge and methods applicable to conservation management on and around numerous bases, such as those identified in Table 1. In particular, our work will apply to the evaluation and management of habitat connectivity for multiple species on and off military installations, and improve decision making for land procurement off base. These contributions will be especially transferable to other bases with RCW and/or functional analogues with SFS, CGF and ETS. In addition, we will test the effectiveness of employing the umbrella species concept for conservation management, which is similarly applicable for numerous military installations. Most directly, we will transfer all methods developed for RCW to Camp LeJeune, where they will be evaluated and compared for their relative efficacy for habitat management. The detailed information we have for both bases will provide a rigorous test of our methods, and will increase our project's effectiveness and applicability.

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COST Estimates & Justifications

UNC-Chapel Hill

Labor: A. Moody is requesting 1 month of salary/yr to fund his role as overall project coordinator. Moody will be involved in field data collection for water table modeling, spatial database development, and spatial modeling. He will lead development of reports and papers, and in transitioning the work to management at Ft. Bragg and to other installations. Moody's salary starts at $7,305/mo, and increases each year by 4%. Fringe benefits are calculated at 19% to cover retirement, health care, and other costs.

A postdoctoral researcher will be hired for the duration of the project for overall project management, coordination among the personnel involved in the work, and to coordinate transition to Ft. Bragg and other DoD installations. The postdoc will also help direct modeling of hydroperiod and canopy structure, and will help direct the graduate student in producing habitat models, movement resistance surfaces, and sensitivity analyses of habitat connectivity under a range of feasible management scenarios. The postdoc will also be involved in development of reports and papers, and production of appropriate GIS interfaces for effective transitioning . The postdoc salary starts at $35,000/yr, with 4% annual increases, and a fringe benefit rate of 7.65% plus health insurance of $2,072 in year 1, also budgeted to increase at 4% annually.

A graduate student researcher is requested for each year of the study beginning at a 12 month stipend of $18,000, and budgeted to increase by 4% annually. Graduate student compensation also includes tuition and health care, currently at $3,413/yr and $1,302/yr, respectively, and budgeted to increase by 4% annually. The graduate student will be primarily involved in generating land-use classifications (including leading field reconnaissance and visual interpretation of DOQQs), producing spatially distributed habitat models and movement resistance surfaces, and for running sensitivity analyses of habitat connectivity under the range of feasible management/procurement scenarios and priorities.

Two undergraduate assistants are requested for 3 summer months during each year of the project. Their work will include help with field data collection, database development, and data analysis. They will be paid $1,500/mo with a 4% annual increase. The fringe benefit rate for undergraduates is 7.65%.

Supplies: UNC requests funding for two PCs and one field laptop in year 1 ($2000 each), with PC upgrades in year 3. Additional money is requested for computer support, disk space rental and backup from the UNC main server facility, and contribution to software license upgrades ($1200/yr). For field data collection in support of hydroperiod modeling, we request money for PVC pipe, cork, water bottles, and field boots for 2 crews of 2 ($1200 in year 1; $600/yr in years 2 and 3) and two GPS units in year one ($1,000 each). In addition, we request money to purchase high resolution ASTER imagery ($600/scene, 2 scenes per year in years 1 and 2, four scenes per year thereafter).

LIDAR Data: We request $99,000 in year 1 to acquire LIDAR data over the Ft. Bragg study area.

Publication Costs: We request money for publication costs starting at $1,000 in years 1 and 2, and increasing to $2,000/yr in years 3-5. These funds will support the production of reports and project summaries, and defray costs of page charges and color figures in journal publications.

Travel: We request $1,700/yr to offset the costs of travel to the SERDP In-progress Review and to the Annual SERDP Symposium, where the results of our work will be shared. An additional $3,000/yr is requested to offset travel costs to professional conferences (ESA, SCB, AAG), where our work will also be presented in posters and presentations. Finally $2000/yr is included to cover travel to the field and to project meetings.

Indirect Costs: The standard UNC overhead rate of 46% is charged to all UNC budget items, and to the first $25,000 of each of the three sub-contracts included in the budget. Overhead is not included for graduate student tuition.

NC-State University

Labor: We request summer salary for a graduate student to help oversee data analyses and provide technical assistance to technician, as well as to conduct their independent research. The student will be paid for 3 months each summer at the rate of $1,500 per month in year 1, and increasing by 5% each year. We request funding for a technician to oversee collection of field data on movement and dispersal in the first 2.5 years of the project. The technician will start at a salary of $25,000 in the first year, increasing by 5% each year. We request funding for undergraduate field technicians for 9 months in years 1-3 to assist in collecting field data on movement and dispersal, paid at the rate of $1,500 per month. Fringe benefits for graduate students are 13%, and for other employees are 8.55%.

Supplies: For amphibian studies, we request funding to purchase a radio receiver in 2006 ($900) and 20 transmitters (10 ea for salamanders and frogs, $150/transmitter) in 2006 and 2007. We also request additional support for supplies used maintain sampling transects, as well as for nets and waders, lights, batteries, waterproof paper and pens, and other items needed to collect amphibian data. For butterflies, we funding for supplies to establish sampling grids, butterfly nets, and containers used in butterfly movement study.

Publication Costs: We request $1500 in year 4 and 5 of the study to defray costs of publications.

Travel: We request $6,000 to fund rental of a 4WD vehicle year around for field work at Ft. Bragg in the first two years of the project. We also request $3,000 in years 1-5 to fund travel to annual meetings, including meetings at SERDP.

Indirect Costs: The field component of this proposal will take place at Ft. Bragg, and so the project will be charged at the off-campus rate of 27.3%.

Cooperative Funding: Habitat restoration efforts for SFS and Carolina eastern tiger salamanders and gopher frogs will be funded through the Ft. Bragg Endangered Species Branch as part of ongoing population studies. These studies will also contribute to the cost of technicians associated with conducting mark-release-recapture data on SFS and eastern tiger salamanders and Carolina gopher frogs and part of the telemetry work on eastern tiger salamanders and Carolina gopher frogs. The budget here reflects costs beyond those covered by existing funding.

Virginia Tech

Labor: Funds are requested in years 1 and 2 for 18 months of support for a postdoctoral associate, through June 2007. The postdoc will conduct the radio telemetry field work on RCWs, and prepare the resulting data for use in subsequent analyses. The postdoctoral salary is based on a current salary of $35,000, with 6.5% increases effective on December 1 each year. Summer salary is requested for the PI for years 1-3, but not for years 4-5 when the work conducted at Virginia Tech will be a smaller part of the project. PI summer salary is based on a current 9-month salary of $111,000, and a 6.5% increase on December 1 each year. Funds are requested for one year of graduate student support, including tuition, beginning in August 2007 (years 2 and 3), to enable analysis of effects of habitat features on frequency of dispersal between territories, using the GIS data layer to be developed in years 1 and 2 and dispersal records from Walters' long-term study of the Sandhills population (including data collected by SEI). In years 4 and 5 funds are requested to support a graduate student for the spring semester and summer (7.5 mo) to assist in integrating woodpecker data into connectivity analyses and individual-based modeling. Tuition is based on the current rate of $3231 for S05, with a 9% increase effective on 8/16 each year.

Travel: Travel costs include funds for all project personnel to travel to Washington, DC to fulfill SERDP reporting requirements, funds to support travel to the field site for the PI in years 1 and 2, funds to support travel by the graduate student to work with other project PIs at other institutions in years 3-5, funds to support travel by the PI to work with other project PIs at other institutions in all years, and funds for the postdoc (years 1-2), graduate students (years 3-5) and PI (all years) to travel to scientific meetings to disseminate research results. Funds are also requested for contract labor and vehicle rental in order to make use of the resources of the Sandhills Ecological Institute, a non-profit organization located at the field site that specializes in ecological research. SEI will supply trained personnel and a vehicle to support the radio telemetry study conducted by the postdoc in years 1 and 2.

Duke University - Subcontract

Labor: Funds are requested to support one graduate student researcher for the summer semester of each year of the funding period, beginning in 2006. Cost includes a $6830 stipend plus $2030 in student fees in Year 1, with 8% annual increases. The graduate student will assist Dr. Morris in processing animal movement data to estimate parameters describing dispersal, and in constructing computer simulation models to predict animal dispersal across GIS-based representations of the landscape at Ft. Bragg and the other DoD installations described in the proposal.

Funds are also requested for 20% of a programmer's salary for 6 months in year 3, 12 months in year 4, and 6 months in year 5, with associated fringe benefits calculated at 21%. Travel funds are requested for one trip/year to Washington, DC to report results to SERDP, and for 2 trips/year for project meetings. Funds in the amount of $1,500 are requested in year 1 for the purchase of specialized software to accomplish the project and $300 is requested in years 2 and 3 for back-up media and printing. An additional $200 is requested each year for long distance service to communicate project collaborators. Indirect costs are computed at 54% of direct costs.

OVERLAPPING SUPPORT:

Walters: Jeff Walters has three funded projects relevant to the proposed research. All involve research on the biology and conservation of RCWs. The relevant studies are (1) "Evaluation of effects of training activities on red-cockaded woodpeckers on Camp LeJeune Marine Base" ($589,386 for 4 years, 5/01 - 9/05), funded by the Department of Defense, Camp LeJeune (contact: John Townson, Director, Fish and Wildlife Division, Environmental Management Department, Building 58, Camp Lejeune, NC 28542-5001, 910-451-2195, TownsonJR@lejeune.usmc.mil); (2) "Endangered species management and monitoring on Eglin Air Force Base, Florida" ($950,598 for 3 years, 2/05-1/08, with C. A. Haas), funded by the Department of Defense, Eglin Air Force Base (contact: Bruce Hagedorn, Eglin Natural Resources Branch, AAC/EMSN, 501 DeLeon Street, Suite 101, Eglin Air Force Base, FL 32542-5133, 850-882-4164, x325, bruce.hagedorn@eglin.mil); (3) "An experimental study of the impact of location on the effectiveness of recruitment clusters for red-cockaded woodpeckers at the Savannah River site" ($261,875 for 5 years, 9/00-9/05), funded by the USDA Forest Service, Savannah River Research Park (contact: John Blake: USDA Forest Service, Savannah River, PO Box 700, New Ellenton, SC 29809, 803-725-8721, jblake@fs.fed.us). In addition he serves as President of the Sandhills Ecological Institute, which is contracted to monitor RCWs in the North Carolina Sandhills, including the western portion of Fort Bragg. The latter effort provides demographic data that can be used to analyze dispersal patterns in relation to habitat features, and through SEI also provides a source of field support for the proposed radio telemetry research. All of the studies provide information about the biology of the RCW that will inform the proposed analyses, including modifications of the simulation model to be used to evaluate connectivity.

Haddad: Haddad has three ongoing projects that are relevant to this proposal. All three are conducted at Ft. Bragg, and are funded through the Endangered Species Branch, Natural Resources Division there. The three studies are: (1) "Developing techniques and protocols for monitoring St. Francis' satyr" ($45,000/yr 2002-5), which is focused specifically on estimating population sizes and trends of SFS in known habitat locations on Ft. Bragg; (2) "Examining effects of beaver activity on St. Francis' satyr distributions" ($40,000/yr 2004-5), which is focused specifically on determining how beavers influence habitat quality for the butterfly; and (3) "Status and ecology of reptiles and amphibians on Ft. Bragg: ($110,000 for 2004-6), which is focused on estimating population size and habitat use at known breeding locations on Ft. Bragg. (contact: Erich Hoffman, Endangered Species Branch, Ft. Bragg, 910-396-2867, erich.hoffman@us.army.mil). These projects supplement, but do not replicate any of the work proposed here.

UNC BUDGET (08-15-05) - CSSON-06-01 - Proposal Number: 06 CS01-008

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Personnel						
PI-Moody ~ 1 mo	$7,305	$7,597	$7,901	$8,217	$8,546	$39,566
Post-Doc ~ 12 mo	$35,000	$36,400	$37,856	$39,370	$40,945	$189,571
Graduate Researcher ~ 12 mo	$18,000	$18,720	$19,469	$20,248	$21,057	$97,494
Undergrad Assistant ~ 6 mo	$9,000	$9,360	$9,734	$10,124	$10,529	$48,747
TOTALS	$69,305	$72,077	$74,960	$77,959	$81,077	$375,378
Benefits						
PI-Moody	$1,388	$1,443	$1,501	$1,561	$1,624	$7,518
Post-Doc	$2,678	$2,785	$2,896	$3,012	$3,132	$14,502
Post-Doc ~ Health Insurance	$2,072	$2,155	$2,241	$2,331	$2,424	$11,223
Graduate Researcher Tuition	$3,413	$3,550	$3,692	$3,839	$3,993	$18,486
Graduate Researcher Health	$1,302	$1,354	$1,408	$1,465	$1,523	$7,052
Undergraduate Fringe	$689	$717	$745	$775	$806	$3,732
TOTALS	$11,541	$12,003	$12,483	$12,983	$13,502	$62,512
Travel						
Field/Conferences/Meetings	$7,000	$7,000	$7,000	$7,000	$7,000	$35,000
Materials and Supplies						
Field/Computing	$11,600	$3,000	$8,200	$3,600	$3,600	$30,000
Publication Costs	$1,000	$1,000	$2,000	$2,000	$2,000	$8,000
Other Expenses						
Data (LiDAR)	$99,000	$0	$0	$0	$0	$99,000
Subcontracts						
NC-State University	$83,368	$83,739	$52,462	$14,495	$13,597	$247,661
Duke University	$13,644	$14,736	$31,654	$42,538	$33,111	$135,683
Virginia Tech	$108,680	$83,232	$44,428	$24,051	$24,951	$285,342
Totals	$405,138	$276,787	$233,187	$184,625	$178,838	$1,278,576
Indirect Costs	$119,452	$47,328	$46,438	$45,863	$47,466	$562,632
TOTAL	**$524,590**	**$324,115**	**$279,625**	**$230,488**	**$226,303**	**$1,585,122**

VIRGINIA TECH SUBCONTRACT BUDGET (08-15-05) - CSSON-06-01 - Proposal Number: 06 CS01-008

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Personnel						
Co-I - Walters ~ 1 mo	$13,135	$13,989	$14,898	$0	$0	$42,022
Post-Doc	$37,477	$19,957	$0	$0	$0	$57,434
Graduate Researcher	$0	$7,027	$11,711	$12,063	$12,425	$43,226
TOTALS	$50,612	$40,972	$26,609	$12,063	$12,425	$142,681
Benefits						
Co-I - Walters	$1,265	$1,364	$1,453	$0	$0	$4,082
Post-Doc	$12,977	$6,947	$0	$0	$0	$19,924
Graduate Researcher	$0	$527	$878	$905	$932	$3,242
Graduate Tuition	$0	$3,839	$4,184	$4,561	$4,971	$17,555
TOTALS	$14,242	$12,677	$6,515	$5,466	$5,903	$44,803
Travel						
Field/Conferences/Meetings	$3,000	$3,000	$2,000	$2,000	$2,000	$12,000
Field Vehicle Rental	$6,000	$3,000	$0	$0	$0	$9,000
Materials and Supplies						
Field/Computing	$2,000	$2,000	$1,000	$500	$500	$6,000
Contract Labor	$10,400	$5,200	$0	$0	$0	$15,600
Totals	$86,254	$66,849	$36,124	$20,029	$20,828	$230,084
Indirect Costs	$22,426	$16,383	$8,304	$4,022	$4,123	$55,258
TOTAL	**$108,680**	**$83,232**	**$44,428**	**$24,051**	**$24,951**	**$285,342**

NC-STATE SUBCONTRACT BUDGET (08-15-05) - CSSON-06-01 - Proposal Number: 06 CS01-008

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Personnel						
Graduate Researcher	$4,500	$4,725	$4,961	$5,209	$5,470	$24,865
Technician	$25,000	$26,250	$13,781	$0	$0	$65,031
Undergrad Assistants ~ 6 mo	$13,500	$13,500	$13,500	$0	$0	$40,500
TOTALS	$43,000	$44,475	$32,243	$5,209	$5,470	$130,397
Benefits						
Graduate Researcher	$585	$614	$645	$677	$711	$3,232
Technician	$5,750	$6,038	$3,170	$0	$0	$14,957
Undergraduate Assistants	$1,154	$1,154	$1,154	$0	$0	$3,463
TOTALS	$7,489	$7,806	$4,969	$677	$711	$21,652
Travel						
Field/Conferences/Meetings	$3,000	$3,000	$3,000	$3,000	$3,000	$15,000
Field Vehicle Rental	$6,000	$6,000	$0	$0	$0	$12,000
TOTALS	$9,000	$9,000	$3,000	$3,000	$3,000	$27,000
Materials and Supplies						
Butterflies	$1,000	$1,000	$500	$500	$0	$3,000
Amphibians	$5,000	$3,500	$500	$500	$0	$9,500
Publication Costs	$0	$0	$0	$1,500	$1,500	$3,000
TOTALS	$6,000	$4,500	$1,000	$2,500	$1,500	$15,500
Totals	$65,489	$65,781	$41,211	$11,387	$10,681	$194,549
Indirect Costs	$17,879	$17,958	$11,251	$3,109	$2,916	$53,112
TOTAL	**$83,368**	**$83,739**	**$52,462**	**$14,495**	**$13,597**	**$247,661**

DUKE - SUBCONTRACT BUDGET (08-15-05) - CSSON-06-01 - Proposal Number: 06 CS01-008

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Personnel						
Graduate Researcher	$6,830	$7,376	$7,967	$8,604	$9,292	$40,069
Staff Programmer	$0	$0	$5,811	$11,971	$6,165	$23,947
TOTALS	$6,830	$7,376	$13,778	$20,575	$15,457	$64,016
Benefits						
Graduate Researcher	$2,030	$2,192	$2,368	$2,557	$2,762	$11,909
Staff Programmer	$0	$0	$1,209	$2,490	$1,282	$4,981
TOTALS	$2,030	$2,192	$3,577	$5,047	$4,044	$16,890
Travel						
Field/Conferences/Meetings	$0	$0	$1,500	$1,500	$1,500	$4,500
TOTALS	$0	$0	$1,500	$1,500	$1,500	$4,500
Materials and Supplies						
Software and Supplies	$0	$0	$1,500	$300	$300	$2,100
Communications	$0	$0	$200	$200	$200	$600
TOTALS	$0	$0	$1,700	$500	$500	$2,700
Totals	$8,860	$9,569	$20,554	$27,622	$21,501	$88,106
Indirect Costs	$4,784	$5,167	$11,099	$14,916	$11,611	$47,577
TOTAL	**$13,644**	**$14,736**	**$31,654**	**$42,538**	**$33,111**	**$135,683**

Overall Itemized Project Budget

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Personnel						
PIs	$20,440	$21,586	$22,799	$8,217	$8,546	$81,588
Post-Docs	$72,477	$56,357	$37,856	$39,370	$40,945	$247,005
Graduate Researchers	$29,330	$37,848	$44,108	$46,124	$48,244	$205,654
Undergrad Assistants	$22,500	$22,860	$23,234	$10,124	$10,529	$89,247
Technicians	$25,000	$26,250	$19,592	$11,971	$6,165	$88,978
TOTALS	**$169,747**	**$164,901**	**$147,589**	**$115,806**	**$114,429**	**$712,472**
Benefits						
PIs	$2,653	$2,807	$2,954	$1,561	$1,624	$11,599
Post-Docs	$17,727	$11,887	$5,137	$5,243	$5,556	$45,550
Graduate Researchers	$7,330	$11,549	$12,297	$13,099	$13,960	$58,235
Undergraduate Assistants	$1,843	$1,871	$1,899	$775	$806	$7,194
Technicians	$5,750	$6,038	$4,379	$2,490	$1,282	$19,939
TOTALS	**$35,303**	**$34,152**	**$26,666**	**$23,168**	**$23,228**	**$142,517**
Travel						
Field/Conferences/Meetings	$13,000	$13,000	$13,500	$13,500	$13,500	$66,500
Field Vehicle Rental	$12,000	$9,000	$0	$0	$0	$21,000
TOTALS	**$25,000**	**$22,000**	**$13,500**	**$13,500**	**$13,500**	**$87,500**
Materials and Supplies						
Field/Computing/Communications	$19,600	$9,500	$11,900	$5,600	$4,600	$51,200
Contract Labor	$10,400	$5,200	$0	$0	$0	$15,600
Publication Costs	$1,000	$1,000	$2,000	$3,500	$3,500	$11,000
Other Expenses						
Data (LiDAR)	$99,000	$0	$0	$0	$0	$99,000
Totals	**$360,050**	**$236,753**	**$201,655**	**$161,574**	**$159,257**	**$1,122,629**
Indirect Costs	**$164,541**	**$86,836**	**$77,092**	**$67,910**	**$66,116**	**$462,495**
TOTAL	**$524,590**	**$324,115**	**$279,625**	**$230,488**	**$226,303**	**$1,585,121**

AARON MOODY - CURRICULUM VITAE

Office Address:
Department of Geography, University of North Carolina at Chapel Hill, 205 Saunders Hall, Chapel Hill, NC 27599-3220

Telecommunications:
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Education:
1995 Boston University: Ph.D. (Geography)
1991 UC Santa Barbara: M.A. (Geography)
1988 UC Santa Barbara: B.A. (Geography, Highest Honors)

Relevant Employment:
2002-present Associate Professor, Geography, UNC-Chapel Hill.
1995-2001 Assistant Professor, Geography, UNC-Chapel Hill.
1991-1994 Research Assistant, Geography, Boston University.
1989-1990 Research Assistant, Geography, UC Santa Barbara.

Publications:

McDonald, R., McKnight, M., Weiss, D., Selig, E., O'Conner, M., Violin, C., & Moody, A. 200-. Species compositional similiarity in ecoregions: Do ecoregion boundaries represent zones of high species turnover? *Biological Conservation*, In Press.

Xiao, J. & Moody, A. 200-. A comparison of methods for estimating fractional vegetation cover across a large region of central New Mexico, USA. *Remote Sensing of Environment*. In Press.

Xiao, J. & Moody, A. 2005. Geographic distribution of global greening trends and their climatic correlates: 1982 to 1998. *International Journal of Remote Sensing*. **26**(11): 2371-2390.

Xiao, J. & Moody, A. 2004. Trends in vegetation activity and their climatic correlates: China 1982 to 1998. *International Journal of Remote Sensing*. **25**(24): 5669-5689.

Moody, A. & Katz, D. B. 2004. Artificial intelligence in the study of mountain landscapes. In: M. P. Bishop & J. F. Shroder, Jr. (Eds.) *Geographic Information Science (GIScience) and Mountain Geomorphology*. Springer Verlag-Praxis Scientific Publishing Ltd. pp 219-251.

Xiao, J. & Moody, A. 2004. Photosynthetic activity of U.S. biomes: Responses to the spatial variability and seasonality of temperature and precipitation. *Global Change Biology* **10**(4): 437-451.

Xiao, J., Li, J., & Moody, A. 2003. A detail-preserving and flexible adaptive filter for speckle suppression in SAR imagery. *International Journal of Remote Sensing* **24**: 2451-2465.

Meentemeyer, R. K. & Moody, A. 2002. Distribution of plant life-history types in California chaparral: The role of topographically determined drought severity. *Journal of Vegetation Science* **13**: 67-78.

Meentemeyer, R. K., Moody, A., & Franklin, J. 2001. Landscape-scale patterns of shrub species abundance in California chaparral: The role of topographically mediated resource gradients. *Plant Ecology* **156**(1): 19-41.

Frizzelle, B. G. & Moody, A. 2001. Mapping continuous distributions of land cover: A comparison of maximum likelihood estimation and artificial neural networks. *Photogrammetric Engineering and Remote Sensing* **67**(6): 693-705.

Moody, A. & Johnson, D. M. 2001. Land-surface phenologies using the discrete Fourier transform. *Remote Sensing of Environment* **75**(3): 305-323.

Moody, A. & Meentemeyer, R. K. 2001. Environmental factors influencing spatial patterns of woody plant diversity in chaparral, Santa Ynez Mountains, California. *Journal of Vegetation Science* **12**(1): 41-52.

Meentemeyer, R. K. & Moody, A. 2000. Rapid sampling of plant species composition for assessing vegetation patterns in rugged terrain. *Landscape Ecology* **15**(8): 697-711.

Meentemeyer, R. K. & Moody, A. 2000. Automated mapping of alignment between topography and geologic bedding planes. *Computers & Geosciences* **26**(7): 815-829.

Moody, A. 2000. Analysis of plant species diversity in response to island characteristics on the Channel Islands, California. *Journal of Biogeography* **27**(3): 711-724.

Moody, A. & Jones, J. A. 2000. Soil response to canopy position and feral pig disturbance beneath *Quercus agrifolia* on Santa Cruz Island, California. *Applied Soil Ecology* **14**(3): 269-281.

Katz, D. B., Simon, S. A., Moody, A., & Nicolelis, M. A. L. 1999. Simultaneous reorganization in thalamocortical ensembles evolves over several hours following perioral capsaicin injections. *Journal of Neurophysiology* **82**: 963-977.

Moody, A. 1998. Using landscape spatial relationships to improve estimates of land-cover area from coarse resolution remote sensing. *Remote Sensing of Environment* **64**: 202-220.

Moody, A., Gopal, S., & Strahler, A. H. 1996. Artificial neural network response to mixed pixels in coarse-resolution satellite data. *Remote Sensing of Environment* **58**: 329-343.

Moody, A. & Woodcock, C. E. 1996. Calibration-based models for correction of area estimates derived from coarse-resolution land-cover data. *Remote Sensing of Environment* **58**: 225-241.

Moody, A. & Woodcock, C. E. 1995. The influence of scale and the spatial characteristics of landscapes on land-cover mapping using remote sensing. *Landscape Ecology* **10**(6): 363-379.

Moody, A. & Strahler, A. H. 1994. Characteristics of composited AVHRR data and problems in their classification. *International Journal of Remote Sensing* **15**(17): 3473-3491.

Moody, A. & Woodcock, C. E. 1994. Scale-dependent errors in the estimation of land-cover proportions: Implications for global land-cover datasets. *Photogrammetric Engineering and Remote Sensing* **60**(5): 585-594.

Grants:
"Impacts of Land Cover/Land Use and Climate Change on Hydrology-Driven Ecosystem Services in the Mid-Atlantic Region," National Aeronautics and Space Administration. A. Moody (PI), L. E. Band, & G. Characklis (Co-I's), Pending.

“Impacts of Land-Cover/Land-Use Change on Forest Ecosystem Functions in Northeastern China,” National Aeronautics and Space Administration. C. Song (PI), A. Moody (Co-I), Pending.

“Tracking drought impact on managed and unmanaged ecosystems of North Carolina,” Water Resources Research Institute of North Carolina. A. Moody & L. E. Band (Co-PI's). $40,000, 6/1/01 to 5/31/02.

“Agricultural colonization in the Ecuadorian Amazon: Population, biophysical, and geographical factors affecting land use/land cover change and landscape structure,” National Aeronautics and Space Administration. R. Billsborrow and S. Walsh (Co-PI's), L. E. Band, A. Moody, L. Murphy, & L. Suarez (Co-I's). $706,000, 1/1/98 to 12/31/00.

“Population-environment interactions: An integrated program of research, instruction and training through sensing applications,” National Aeronautics and Space Administration. S. Walsh (PI), L. E. Band, R. Bilsborrow, B. Entwistle, A. Moody, & R. Rindfuss (Co-I's). $415,745, 1/1/98 to 12/31/98.

“Improved area estimates for land cover and land-cover change from low spatial resolution remote sensing,” National Aeronautics and Space Administration. A. Moody (PI). $308,294, 10/1/96 to 9/30/99.

“Impacts of Land Cover/Land Use and Climate Change on Hydrology-Driven Ecosystem Services in the Mid-Atlantic Region,” National Aeronautics and Space Administration. A. Moody (PI), L. E. Band, & G. Characklis (Co-I’s). $565,887, Pending.

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Education
Ph.D., Ecology, University of Georgia, 1997
B.S., Biology with honors, Stanford University, 1991

Employment History
2005- Associate Professor, Department of Zoology, North Carolina State University
1999-2005 Assistant Professor, Department of Zoology, North Carolina State University

Awards
2004 Outstanding Teacher Award, NC State University
2004 Outstanding Adviser Award, Agriculture and Life Sciences, NCSU
2003 Outstanding paper award in Landscape Ecology (Tewksbury, et al. 2002)
2001 Conference of Southern Graduate Schools Achievement Award for New Scholars
1993-6 National Science Foundation Predoctoral Fellowship

Publications
Levey, D.J., B.M. Bolker, J.J. Tewksbury, S. Sargent, and N.M. Haddad. 2005. Effects of landscape corridors on seed dispersal by birds. *Science* 309:146-148.

Haddad, N.M. and J.J. Tewksbury. In press. Impacts of corridors on populations and communities. In K. Crooks and M. Sanjayan, Eds, *Connectivity Conservation*, Cambridge University Press, Cambridge, England.

Brinkerhoff, R.J., N.M. Haddad, and J.L. Orrock. In press. Corridors and olfactory predator cues affect small mammal behavior. *Journal of Mammalogy*.

Weldon, A.J. and N.M. Haddad. 2005. The effects of patch shape on Indigo Buntings: evidence for an ecological trap. *Ecology* 86:1422-1431.

Haddad, N.M. and J.J. Tewksbury. 2005. Low quality habitat corridors as movement conduits for two butterfly species. *Ecological Applications* 15:250-257.

Haddad, N.M., D.R. Bowne, A. Cunningham, B. Danielson, D. Levey, S. Sargent, and T. Spira. 2003. Corridor use by diverse taxa. *Ecology* 84:609-615.

Bradley, K.L., E.I. Damschen, L.M. Young, D. Kuefler, S. Went, G. Wray, N.M. Haddad, J.M.H. Knops, and S.M. Louda. 2003. Spatial heterogeneity, not visitation bias, dominates variation in herbivory. *Ecology* 84:2214-2221.

Hudgens, B.R. and N.M. Haddad. 2003. Predicting which species will benefit from corridors in fragmented landscapes from population growth models. *The American Naturalist* 161:808-820.

Tewksbury, J.J., D.J. Levey, N.M. Haddad, S. Sargent, J.L. Orrock, A. Weldon, B.J. Danielson, J. Brinkerhoff, E.I. Damschen, and P. Townsend. 2002. Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences* 99:12923-12926.

Sisk, T.D., and N.M. Haddad. 2002. Incorporating the effects of habitat edges into landscape models: Effective area models for management. Pp. 208-240 in J. Liu and W.W. Taylor, *Integrating landscape ecology into natural resource management*, Cambridge University Press, Cambridge, UK.

Haddad, N.M., D. Tilman, and J.M.H. Knops. 2002. Long-term oscillations in grassland productivity induced by drought. *Ecology Letters* 5:110-120.

Haddad, N.M., D. Tilman, J. Haarstad, M. Ritchie, and J. Knops. 2001. Contrasting effects of plant richness and composition on insect communities: a field experiment. *The American Naturalist* 158:17-35.

Haddad, N.M., D.K. Rosenberg, and B.R. Noon. 2000. On experimentation and the study of corridors. *Conservation Biology* 14:1543-1545.

Haddad, N.M., J. Haarstad, and D. Tilman. 2000. The effects of long-term nutrient loading on grassland insect communities. *Oecologia* 124:73-84.

Haddad, N.M. 2000. Corridor length and patch colonization by a butterfly, Junonia coenia. *Conservation Biology* 14:738-745.

Haddad, N.M. and W.M. Hicks. 2000. Host pubescence and the behavior and performance of a butterfly, Papilio troilus (Lepidoptera). *Environmental Entomology* 29:299-303.

Haddad, N.M. 1999. Corridor use predicted from behaviors at habitat boundaries. *The American Naturalist* 153:215-227.

Haddad, N.M. 1999. Corridor and distance effects on interpatch movements: a landscape experiment with butterflies. *Ecological Applications* 9:612-622.

Haddad, N.M. and K. Baum. 1999. An experimental test of corridor effects on butterfly densities. *Ecological Applications* 9:623-633.

Knops, J.M.H., D. Tilman, N.M. Haddad, S. Naeem, C.E. Mitchell, J. Haarstad, M.E. Ritchie, K.M. Howe, P.B. Reich, E. Siemann, and J. Groth. 1999. Cascading effects of plant diversity on invasions, diseases, and insects. *Ecology Letters* 2:286-293.

Sisk, T.D., N.M. Haddad, and P.R. Ehrlich. 1997. Bird assemblages in patchy woodlands: modeling the effects of edge and matrix habitats. *Ecological Applications* 7:1170-1180.

Grants

2004 Optimizing long-term monitoring plans for the St. Francis Satyr. Department of Defense, $40,000

2004 Examining effects of beaver activity on St. Francis Satyr distributions. Department of Defense, $35,000

2004-6 Status and ecology of reptile and amphibian species of concern. Department of Defense, $110,000

2004 Monitoring, development, and demography of savannah plants for restoration. U.S. Forest Service $16,000
2003 Developing techniques and protocols for monitoring St. Francis Satyr. Department of Defense, $40,000
2002 Evaluating population viability, and potential restoration of the St. Francis Satyr butterfly. Department of Defense, $35,000
99-03 Patches, corridors, and the dispersal of insects and plants: scaling up from local experiments to large complex landscapes. National Science Foundation, $350,000

Professional Activities
Contributed Papers: Ecological Society of America (1997, 1998, 2000, 2001, 2002, 2004); International Association for Landscape Ecology (1997, 1998); Society for Conservation Biology (2001); Southern Forest Insect Work Conference (1995).

Reviewer for: American Naturalist, Conservation Biology, Conservation Ecology, Ecography, Ecological Applications Ecological Entomology, Ecology, Ecology Letters, Journal of Applied Ecology, Landscape Ecology, NSF, Oecologia, Proceedings of the Royal Society, and others.

NSF Panel: LTER Cross-site awards (2000).

Teaching
ZO 260, Evolution, Behavior, & Ecology, North Carolina State University
ZO 592, Conservation Ecology, North Carolina State University
ZO 824, Classics in Ecology, North Carolina State University
ZO 824, Professional Development and Ethics, North Carolina State University
ZO 824, Population Viability Analysis

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Education
B.S., Cornell University: Biology, with Distinction, 1983.
Ph.D., University of Washington, Seattle: Zoology, 1990.

Employment History
1992-present Assistant/Associate Professor, Department of Biology, Duke University
Associate Editor, The American Naturalist, 2000-2003. 2004-present.
Post Doc, 1990-1992, Center for Population Biology, UC Davis.

Most Relevant Publications
Dwyer, G., and W.F. Morris. In Review. Resource-dependent movement and the speed of biological invasions. Submitted to *The American Naturalist*.

Doak, D.F., K. Gross, and W.F. Morris. Accepted. Understanding and predicting the effects of sparse data on demographic analyses*, Ecology* (2005).

W.F. Morris and D.F. Doak. Accepted. How general are the determinants of the stochastic population growth rate across nearby sites? *Ecological Monographs* (2005).

W.F. Morris and D.F. Doak. 2004. Buffering of life histories against environmental stochasticity: accounting for a spurious correlation between the variabilities of vital rates and their contributions to fitness*, American Naturalist* 163: 579-590.

W.G. Wilson, W.F. Morris, and J.L. Bronstein. 2003. Coexistence of mutualists and exploiters on spatial landscapes*, Ecological Monographs* 73: 397-413 .

W.F. Morris and D.F. Doak. 2002. *Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis*, Sinauer Associates, Sunderland, MA.

Morris, W.F., P.L. Bloch, B.R. Hudgens, L.C. Moyle, and J.R. Stinchcombe. 2002. Population viability analysis in endangered species recovery planning: Past use and recommendations for future improvement*, Ecological Applications* 12: 708-712.

W.F. Morris, M. Groom, D. Doak, P. Kareiva, J. Fieberg, L. Gerber, P. Murphy, and D. Thomson. 1999. *A Practical Handbook for Population Viability Analysis*, The Nature Conservancy, Washington, DC.

Gross, K.G., J.R. Lockwood, C. Frost and W.F. Morris. 1998. Modeling controlled burning and trampling reduction for conservation of *Hudsonia Montana*. *Conservation Biology* 12: 1291-1301.

Morris, W.F., and G. Dwyer. 1997. Population consequences of constitutive and inducible plant resistance: herbivore spatial spread. *The American Naturalist* 149: 1071-1090.

Morris, W.F. 1993. Predicting consequences of plant spacing and biased movement for pollen dispersal by honey bees. *Ecology* 74: 493-500.

Morris, W.F. and P. Kareiva. 1991. How herbivores find suitable host plants: The interplay between random and non-random movement, in E.A. Bernays, ed., *Insect-Plant Interactions, Volume III*, C.R.C. Press, Boca Raton, FL. USA.

Most Relevant Grants

National Center for Ecological Analysis and Synthesis (Santa Barbara, CA) Working Group: "Stochastic Demography for an Increasingly Variable World," 2004-2006, Organizers: W. F. Morris, C. Pfister (University of Chicago), S. Tuljapurkar (Stanford University).

NSF Grant DEB-0087096 (Collaborative Research with D.F. Doak, UC Santa Cruz), 2001-2006, "LTER Cross-site Research: Assessing the geographic and temporal consistency of life-history and demographic patterns: A long-term, multi-site comparison."

NSF Grant BSR-9396119, 1991-1994, "Using mathematical models of pollinator movement and pollen deposition to predict gene flow in plants."

USDA Competitive Grant 94-37302-0463, 1994-1997, "Does damage-dependent movement affect the population growth and spread of insect pests?"

CURRICULUM VITAE

JEFFREY R. WALTERS
Bailey Professor of Biology
Virginia Polytechnic Institute and State University

Communication Numbers:

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	540-953-1157 (h)
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Higher Education:

B. A.	West Virginia University	1974
Ph.D.	University of Chicago	1980

Professional Experience:

1980-81	University of California, Berkeley	NSF Postdoctoral Fellow
1980-87	NC State University Department of Zoology	Assistant Professor
1987-92	NC State University Department of Zoology	Associate Professor
1992-94	NC State University Department of Zoology	Professor
1994-	Virginia Tech Department of Biology	Bailey Professor of Biology

Service:

NC Wildlife Resources Commission Non-game Advisory Committee (3 years)
National Audubon Society Committee on Red-cockaded Woodpeckers
Associate Editor, Wilson Bulletin 1985-1992
American Ornithologists' Union Committee on Red-cockaded Woodpeckers (member 1989-1994; chair 1994-)
American Ornithologists' Union Conservation Committee (member, 1994-1999; chair, 1999-)
US Fish and Wildlife Service Red-cockaded Woodpecker Recovery Team (1996-2003)
American Ornithologists' Union, Elective Councilor (1996-1999)
Chair, American Ornithologists' Union Scientific Peer Review Panel for the Cape Sable Seaside Sparrow in south Florida (1998-1999)
Associate Editor, The Auk (1998-2000)
Board Member, Sandhills Ecological Institute (1998-)
President, Sandhills Ecological Institute (2003-)
Wilson Ornithological Society, Elective Councilor (1999-2002)
Editorial Board, Ecology (2000-2005)
North Carolina Sandhills Conservation Partnership, Red-cockaded Woodpecker Recovery Working Group (2000-)
North Carolina Sandhills Conservation Partnership, Steering Committee (2003-)

National Research Council Committee on Restoration of the Greater Everglades Ecosystem (2001-2004)
National Research Council Committee on Independent Scientific Review of Everglades Restoration Progress (2004-)
Guam Micronesian Kingfisher Recovery Committee (2001-)
Editorial Advisory Board, Ornithological Science (the journal of the Ornithological Society of Japan) (2002-2005)
Chair, American Ornithologists' Union Scientific Peer Review Panel for the USDA Forest Service report on a meta-analysis of the demography of the California Spotted Owl (2002-)
Co-chair, Sustainable Ecosystems Institute Scientific Panel on multi-species management of avian species in the South Florida ecosystem restoration (2003)
Member, Bird Conservation Alliance (representing AOU) (2003-)
North American Bird Conservation Initiative Research Working Group Member (2003-)

Honors:
Sigma Xi, NC State University, Outstanding Young Scientist Research Award, 1988
Outstanding Journal Article 1992, Southeastern Section of The Wildlife Society (with C. Copeyon and J. Carter)
Elected Fellow, American Ornithologists' Union, 1998
Elliott Coues Award, American Ornithologists' Union, 2002

Conservation Award, U. S. Fish and Wildlife Service, Red-cockaded Woodpecker Program, 2003

Selected Publications:
Walters, J. R., P. D. Doerr and J. H. Carter, III. 1988. The cooperative breeding system of the red-cockaded woodpecker. *Ethology* 78:275-305.
Reed, J. M., P. D. Doerr and J. R. Walters. 1988. Minimum viable population size of the red-cockaded woodpecker. *J. Wildl. Manage.* 52:385-391.
Walters, J. R. 1990. Red-cockaded woodpeckers: a 'primitive' cooperative breeder. Pp. 67-102 In: Cooperative Breeding in Birds: Long-term Studies of Ecology and Behavior, P. B. Stacey and W. D. Koenig, eds. Cambridge: Cambridge University Press.
Copeyon, C. K., J. R. Walters and J. H. Carter, III. 1991. Induction of red-cockaded woodpecker group formation by artificial cavity construction. *J. Wildl. Manage.* 55:549-556.
Walters, J. R. 1991. Application of ecological principles to the management of endangered species: the case of the red-cockaded woodpecker. *Annu. Rev. Ecol. Syst.* 22:505-523.
Walters, J. R., P. D. Doerr and J. H. Carter, III. 1992. Delayed dispersal and reproduction as a life history tactic in cooperative breeders: fitness calculations from red-cockaded woodpeckers. *Am. Nat.* 139:623-643.
Walters, J. R., C. K. Copeyon and J. H. Carter, III. 1992. Test of the ecological basis of cooperative breeding in red-cockaded woodpeckers. *Auk* 109:90-97.
Haig, S. M., J. R. Walters and J. H. Plissner. 1994. Genetic evidence for monogamy in the cooperatively breeding red-cockaded woodpecker. *Behav. Ecol. Sociobiol.* 34:295-303.
Letcher, B. H., J. A. Priddy, J. R. Walters and L. B. Crowder. 1998. An individual-based, spatially-explicit simulation model of the population dynamics of the endangered red-cockaded woodpecker, *Picoides borealis*. *Biol. Conserv.* 86:1-14.
Zwicker, S. M. and J. R. Walters. 1999. Selection of pines for foraging by red-cockaded woodpeckers. *J. Wildl. Manage.* 63:843-852.

Daniels, S. J. and J. R. Walters. 2000. Inbreeding depression and its effects on natal dispersal in red-cockaded woodpeckers. *Condor* 102:482-491.

Daniels, S. J. and J. R. Walters. 2000. Between-year breeding dispersal in red-cockaded woodpeckers: multiple causes and estimated cost. *Ecology* 81:2473-2484.

Davenport, D. E., R. A. Lancia, J. R. Walters and P. D. Doerr. 2000. Red-cockaded woodpeckers: a relationship between reproductive fitness and habitat in the North Carolina Sandhills. *Wildl. Soc. Bull.*28:426-434.

Khan, M. Z. and J. R. Walters. 2000. An analysis of reciprocal exchange of helping behavior in the red-cockaded woodpecker. *Behav. Ecol. Sociobiol.* 47:376-381.

Conner, R. N., D. C. Rudolph and J. R. Walters. 2001. The red-cockaded woodpecker, Surviving in a fire-maintained ecosystem. Austin, TX: University of Texas Press.

Khan, M. Z., F. M. A. McNabb, J. R. Walters and P. J. Sharp. 2001. Patterns of testosterone and prolactin concentrations and reproductive behavior of helpers and breeders in the cooperatively breeding red-cockaded woodpecker (*Picoides borealis*). *Hormones and Behavior* 40:1-13.

Walters, J. R., L. B. Crowder and J. A. Priddy. 2002. Population viability analysis for red-cockaded woodpeckers using an individual-based model. *Ecol. Appl.* 12:249-260.

Khan, M. Z. and J. R. Walters. 2002. Effects of helpers on breeder survival in the red-cockaded woodpecker (*Picoides borealis*). *Behav. Ecol. Sociobiol.* 51:336-344.

Schiegg, K., G. Pasinelli, J. R. Walters and S. J. Daniels. 2002. Inbreeding and experience affect response to climate change by endangered woodpeckers. *Proc. Royal Soc. London (B)* 269:1153-1159.

Schiegg, K., J. R. Walters and J. A. Priddy. 2002. The consequences of disrupted dispersal in fragmented red-cockaded woodpecker (*Picoides borealis*) populations. *J. Anim. Ecol.* 71:710-721.

Pasinelli, G. and J. R. Walters. 2002. Social and environmental factors affect natal dispersal and philopatry of male red-cockaded woodpeckers. *Ecology* 83:2229-2239.

Walters, J. R., S. J. Daniels, J. H Carter, III and P. D. Doerr. 2002. Defining quality of red-cockaded woodpecker foraging habitat based on habitat use and fitness. *J. Wildl. Manage.* 66:1064-1082.

Harding, S. R. and J. R. Walters. 2002. Processes regulating the population dynamics of red-cockaded woodpeckers cavities. *J. Wildl. Manage.* 66:1083-1095.

Pasinelli, G., K. Schiegg and J. R. Walters. 2004. Genetic and environmental influences on natal dispersal distance in a resident bird species. *Am. Nat.* 164:660-669.

Schiegg, K., J. R. Walters and J. A. Priddy. Testing a spatially explicit, individual-based model of the population dynamics of red-cockaded woodpeckers. *Ecol. Appl. In press.*