FINAL PROJECT MEMORANDUM
SECASC Project 017

1. ADMINISTRATIVE

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Project Title:

An adaptive landscape planning and decision framework for gopher tortoise (*Gopherus polyphemus)* conservation

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Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. This study was performed under the auspices of the University of Georgia under Animal Use Permits A2012 09-010-Y3-A1, A2014 02-024-Y3-A1, and A2015 07-021-Y3-A0.

2. PUBLIC SUMMARY

The gopher tortoise is a familiar turtle species across the southeastern Coastal Plain, but its population has declined significantly over several decades. A principal reason is that much of its primary habitat – sparse, open stands of mature pine – has been replaced by development or agriculture, or has become degraded through the suppression of low-intensity, forage-producing ground fires. The gopher tortoise is a "keystone" species, meaning that its disappearance from the landscape would negatively impact many other species that make use of its underground burrows. Out of concern over its decline and its important role in the ecosystem, the gopher tortoise is being considered for listing under the federal Endangered Species Act across its range. However, because gopher tortoises occur on many private lands, federal listing could have widespread impacts on the economy of the region and the livelihood of its citizens. The State of Georgia is interested in conserving lands to safeguard tortoise populations within its borders and ultimately make federal listing unnecessary. We undertook research to better understand life history patterns and habitat affiliations of the tortoise and to evaluate alternative strategies for creating networks of conservation reserves. In one effort, we recaptured wild tortoises first marked in research conducted over 20 years ago, and we used these data to refine our knowledge about long-term survival and movement patterns. Conservation agencies routinely count tortoise populations under standardized surveys, and we developed models that indicate a population's capacity

for increase based on these "snapshots" of the population. From survey data collected statewide, we developed models and predictive maps of habitat suitability. Finally, we developed computing algorithms that evaluate alternative ways to assemble land parcels into connected conservation reserves, where better strategies are those that maximize amount of suitable habitat and capacity for population increase through the acquisition of least acreage. Our results will be useful to conservation agencies in interpreting the data they collect and in planning conservation strategies.

3. TECHNICAL SUMMARY

The principal goal of this work was to provide to an identified partner-client, the Georgia Department of Natural Resources (DNR), a science-based framework for conservation reserve planning for the gopher tortoise (*Gopherus polyphemus*) within the State of Georgia. The research project comprised efforts both in the field and lab. In our field component, we captured wild gopher tortoises over two field seasons at a study site where gopher tortoises had been previously marked in a study conducted 1995-2000. The data we obtained provided insight into survival rates over a span of time more commensurate with the generation time of the species and much longer than the 2 to 3-year timeframe of a typical field study. The data also revealed information on movement patterns of wild tortoises. Whereas survival and permanent emigration are confounded in many mark-recapture studies, our analysis of movement data allowed us to distinguish true survival from apparent survival and to provide information on the tortoise's needs for spatial connectivity in conservation planning. Our lab efforts were focused in three areas: (1) development of a tortoise demographic model linked to counts collected through standardized population surveys; (2) development of spatial layers and models for predicting gopher tortoise occurrence based on data obtained through DNR's statewide population surveys; and (3) development of optimization tools for the selection of land parcels into spatially connected reserves that achieve population and cost objectives.

All work described above, except for portions of the habitat modeling component, was made possible through SE CASC funding; however, description of the excepted work is included in this memorandum as the SE CASC study provided important direction and context for the work. In addition, the SE CASC-funded work provided leverage and momentum for subsequent work focusing on gopher tortoise conservation on private lands and survey design enhancements. We anticipate the publication of seven peer-reviewed manuscripts out of this work, with one already published. Our work will have impact in the region as it directly affects gopher tortoise conservation, but it will also contribute to scientific knowledge more broadly. Our publications will describe innovations in demographic modeling, mapping stand structural characteristics with satellite remote sensing, habitat modeling, and spatial optimization.

4. PURPOSES AND OBJECTIVES

As we described in our proposal, the State of Georgia has a broad goal of developing a "viable landscape" for the gopher tortoise and associated species, involving both public and private lands. The impetus for conservation stems from the forthcoming decision on federal listing of the species under the Endangered Species Act. In discussions with DNR that preceded our research proposal, we understood that the state had four broad mechanisms, or actions, that could be taken towards this goal: (1) direct acquisition of lands into public ownership, (2) protection of privately-held lands through easements, (3) provision of direct habitat management assistance to private landowners, and (4) provision of incentives for private landowner-conducted habitat improvement. The stated objective of our research was to formalize the selection of actions towards this goal under a dynamic decision framework that accounts for uncertainties about actions and tradeoffs among them. In subsequent discussions with Georgia DNR, including a stakeholder workshop conducted with DNR and its partners that this project funded, we learned that the agency had undertaken a formal programmatic initiative with a focus on land acquisition. Therefore, we refined our problem focus on the optimal selection of parcels to create contiguous reserves.

Because reserves are most often constructed through a series of purchase transactions carried out over time rather than all at once, we had proposed modeling land acquisition as a dynamic decision process, incorporating information feedbacks at each step to guide successive acquisitions. However, we concluded that we could not muster the computational resources required to conduct a fully spatial dynamic optimization for problems even of small size (dozens of parcels), much less problems of more relevant scale (thousands of parcels). Instead, we considered static optimization approaches to the problem, using a simplified representation of acquisition over time under a deterministic framework with time-varying land costs and total budget. This optimization model has been published (Jafari et al. 2017). Other papers to be published will cover other phases of research that provide data inputs to this optimization model.

5. ORGANIZATION AND APPROACH

The research effort was organized into a field research component and two lab-based components, with work under each component led by different project personnel. Parts of a third lab-based component, the development of habitat-relationship models for gopher tortoises in Georgia, was supported by SE CASC funding. This work was conducted by other lab personnel not supported by this grant, but the work contributed to outcomes of this project.

Field component: Alex Wright, a Warnell School of Forestry and Natural Resources masters student, conducted field work over two seasons (2014-2015) at the Jones Ecological Research Center (Newton, GA). Alex designed a sampling framework for the goal of capturing wild gopher tortoises that had been previously marked in a Jones Center study two decades prior (1995-2000). In addition to saturation sampling of core areas where tortoises had been marked before, the framework incorporated sampling at strategically chosen peripheral sites to maximize the chance of capturing surviving tortoises that had dispersed from the original capture sites. Mark-recapture data collected under this design were analyzed in a Cormack-Jolly-Seber estimation framework that incorporated a model for movement distance.

Lab component 1 – Integrated population projection modeling: Dr. Bryan Nuse (postdoc) developed a predictive model of population viability that uses as input the detections of tortoises collected under standardized population surveys carried out by Georgia DNR and its partners. Tortoise surveys are conducted under a line-transect distance sampling protocol in which observers walk straight transects through appropriate habitat, record the perpendicular distance of every detected burrow to the transect line, and assess the burrow for tortoise occupancy. By integrating a distance sampling model, a body growth model, and a stage-based population model, Dr. Nuse developed a novel technique to predict population growth and the number of 'surplus' tortoises potentially available to disperse from the population.

Lab component 2 – Modeling of habitat occurrence and suitability: Although this activity was not supported solely by SE CASC, the importance of its outcomes with respect to the SE CASC-supported work merits a description of the effort and the associated funding partners. In work supported by the National Council for Air and Stream Improvement (NCASI), we sampled vegetation across the gradient of tortoise habitat quality, and we used the data to train a predictive model of forest stand structure and composition. This model relied on time series of spectral indices produced by Landsat 8, along with climatic data. In work supported by the USGS Cooperative Research Units Program and by Georgia DNR, we modeled gopher tortoise occurrence and habitat suitability in Georgia on the basis of a suite of soil, topographic, vegetation, and physiographic region predictors. SE CASC support for the co-PI, Hepinstall-Cymerman, provided for completion and integration of these efforts into refined predictive maps for habitat suitability derived from soil and current vegetation conditions.

Lab component 3 – Optimal temporal selection of parcels for reserve construction: Building on work conducted in her doctoral program, Dr. Nahid Jafari (postdoc) developed a model to perform optimal selection and sequencing of parcel acquisitions over time for the objective of building a contiguous reserve that achieves maximum specified attributes within given budgetary constraints. Her approach employs a mixed-integer programming framework used in applications that involve flow of a capital resource over a landscape, such as transportation logistics. Given a landscape of discrete parcels and projection of land costs and budget availability over a fixed time horizon, her model provides a schedule for the acquisition of specific parcels that satisfies budget constraints and that results in a connected reserve maximizing some conservation criterion, such as total suitable habitat.

The project provided graduate education and furthered the professional development of early-career researchers:

- Alex Wright, M. Sci., Warnell School of Forestry and Natural Resources (advisor: J. Hepinstall-Cymerman); conducted the field portion of the project and estimated demographic parameters
- Dr. Bryan Nuse, postdoctoral researcher, Warnell School of Forestry and Natural Resources (supervisor: C. Moore); developed models for analysis of line-transect survey data, built the demographic projection model, led the development of habitat and dispersal models
- Dr. Nahid Jafari, postdoctoral researcher, Warnell School of Forestry and Natural Resources (supervisor: C. Moore); created the algorithm to conduct optimal parcel selection for reserve design over a temporal and spatial framework

6. PROJECT RESULTS

Field component: Of nearly 600 tortoises marked and released in the 1995-2000 study, 80 were recovered. The majority (72) were recovered within the original site where marked, but 8 were recovered in a different marking site or outside any of the sites (median dispersal distance = 1105 m; range 113-2316 m). It is clear that a recapture effort conducted solely within the footprint of the original marking sites would have yielded data that confounded emigration with true mortality. Our use of habitat suitability information to assign probabilities for drawing a sample of peripheral sites helped us to efficiently probe areas beyond the original study sites in the discovery of dispersed tortoises.

Lab component 1 – Integrated population projection modeling: We created a Bayesian model that approximates posterior distributions of parameters that describe the underlying dynamics of a tortoise population and its capacity for future growth. Input to the model are data on occurrences of tortoises collected under standardized line transect surveys. The data, once adjusted for detection bias within the model, are informative about a population's current density and size structure. Other inputs to the model are prior distributions on parameters used in other model components. A size growth model component translates size distribution information from the survey data into an age class distribution. Parameters of age-specific survival and recruitment, used in a traditional Leslie matrix model component, may be informed by estimates in the literature or by expert opinion. We used a mix of published values and values derived from our field component. The model then simulates candidate population trajectories from the past, all constrained to replicate the current conditions, and carries them forward into the future.

Lab component 2 – Modeling of habitat occurrence and suitability: In our final report to NCASI (Hepinstall-Cymerman et al. 2017), we described our sampling of 188 vegetation plots in sites of known suitable habitat and presumed unsuitable habitat to characterize multi-strata and fine-scale vegetation attributes. We then used the data to classify temporal sequences of Landsat 8 satellite imagery and climatic attributes into a suite of variables describing attributes of the canopy, the midstory, the understory, and the grass-forb structure of a 30-m pixel. We found that use of these variables as predictors in modeling burrow occurrence outperformed the use of classifications provided by the National Land Cover Dataset (NLCD), classifications that have received common use in previous modeling efforts of tortoise habitat. In our final report to the USGS Cooperative Units Research Program (Nuse et al. 2017), we extended the habitat modeling effort to develop predictive models of burrow occurrence in response to soil, topographic, and vegetation attributes within each of four ecoregions of the Georgia coastal plain. We developed habitat suitability models and maps for the State of Georgia, and we delineated areas where habitat is currently suitable, where habitat is currently unsuitable but potentially restorable on the underlying appropriate soils, and where unsuitable soils are unlikely to ever sustain tortoises (Nuse et al. 2017). Products from this work will be publicly available as published reports and spatial data layers.

Lab component 3 – Optimal temporal selection of parcels for reserve construction: The multi-period reserve design model was demonstrated in a case study application for one focal region in Georgia (Jafari et al. 2017). For the case study, from a candidate set of 841 qualifying parcels, we sought to build a single contiguous reserve that maximized a criterion of amount of potentially suitable habitat. We explored alternative scenarios of budgets available and land costs, both fixed and varying over a 5-year time horizon. Parcels selected for acquisition and the order they were selected over the timeframe were both sensitive to the budgetary and cost constraints.

7. ANALYSIS AND FINDINGS

Initial findings from our field study (Wright 2016) suggest that tortoises at sites positioned within a more fragmented landscape exhibit fewer long-range movements than those at sites where habitat is more contiguous. This has implications in conservation reserve design as it suggests that successful expansion and colonization into newly established reserve lands is dependent on contiguity of habitat being added. In a forthcoming manuscript, we will present an analysis of the data in a multi-state modeling framework that will enable us to distinguish permanent emigration from mortality by age and sex class and to better quantify long-term tortoise movements.

Our integrated population projection model is an innovative analysis that makes use of data collected at a single point in time (i.e., a population "snapshot") and some assumptions about the structure and parameterization of population dynamics. Ideally, a time series of survey data would be available to make projections less dependent on such assumptions, but surveys are expensive to conduct, and conservation organizations prioritize their limited resources to surveying at more sites rather than repeating surveys on fewer sites. The model is an example of how available scientific knowledge (e.g., estimates of vital rates) can be integrated with contemporary population assessments to project population growth and guide conservation decision making. Carrying the innovation further, we joined the model to a mapped landscape of habitat suitability to produce heat maps of potential tortoise dispersal volume from any given population center. Assuming that a current population serves as the nucleus of a candidate reserve, then mapping potential dispersal volume around the center provides decision guidance about the utility of any connecting parcel considered for acquisition. Forthcoming manuscripts will describe the population projection model and its application in the mapping of demographic connectivity.

The work of Jafari et al. (2017) extended previous work on optimal reserve design by considering how acquisitions may occur over a timeframe in which budgets and land costs are expected to vary. In a forthcoming publication, we will use mixed-integer programming to design reserves that maximize a joint utility measure of suitable habitat and demographic connectivity.

8. CONCLUSIONS AND RECOMMENDATIONS

We generated new knowledge about life history patterns of the gopher tortoise, and we developed new analytical and computational tools that will have direct application for the conservation of many terrestrial species. Long-term studies of this long-lived species are exceedingly rare, and through this project we have refined our understanding about survival and movements that will help inform conservation decisions. We developed a means to use population survey data and other available information to project populations forward in time and to make inferences about a population's capacity to export surplus individuals into the surrounding landscape. From population data collected systematically across the state by Georgia DNR and its partners, we conducted synergistic work to develop predictive habitat models for the gopher tortoise in Georgia. We also developed new algorithms to guide the optimal selection of parcels across space and time for the creation of contiguous reserves. Finally, by combining the demographic model with habitat information, we created a tortoise "viability landscape" on which the parcel selection algorithm was employed for conservation reserve design in the State of Georgia.

Despite these significant achievements, our project fell short of our original vision in two important ways. We had desired to develop a dynamic and fully adaptive decision support framework for guiding conservation actions on the landscape for the objective of securing the statewide population of the gopher tortoise. As we stated earlier, achieving this goal was simply limited by computational resources that we did not have. We believe that we could have focused our energies on the development of heuristic techniques that could provide approximate (i.e., not globally optimal) but satisfactory solutions, but this likely would have come at the expense of other products we developed – products that inform the objective function of any decision guidance algorithm. By relaxing the need for a dynamic solution, we ultimately developed an algorithm that provides exact solutions for the selection and sequence of parcels to acquire over time that results in a contiguous reserve that maximizes a criterion (population or habitat-based) within a specified budget constraint.

We had also envisioned that our decision support product would be largely automated, free of the need of proprietary software, and operated with little technical training by the end user (Georgia DNR). Most of the technical products we developed are accessible to the end user. Our Bayesian models for analyzing line-transect distance data offer advantages over the traditional maximum likelihood-based approaches, and these models are implemented in R. The demographic projection model is also implemented in R. Our habitat models exist as linear equations from which predictions can be projected onto a map with access to the required input layers. The viability landscape, which integrates the demographic projection model and the habitat model, can also be mapped in widely available GIS software. However, the parcel selection algorithm was developed in a proprietary software environment (IBM CPLEX Optimization Studio) that Georgia DNR or any conservation agency is not likely to own or successfully access. After the departure of Dr. Jafari, we searched for suitable non-proprietary or open source alternatives, but we lacked Dr. Jafari's expertise in evaluating the options. We believe that continuing this search would be a fruitful area of work. Even if not, our viability landscape product, in conjunction with a spatial layer of landscape parcels, could be provided as input to a freely-available heuristic algorithm such as Marxan to generate candidate reserves.

9. MANAGEMENT APPLICATIONS AND PRODUCTS

We expect that our product will be used by Georgia DNR to inform their monitoring effort and their land acquisition initiative. The agency has had access to our habitat prediction maps for several months and are using them to inform additional survey locations. Our understanding is that parcel acquisition under the land acquisition initiative is conducted semi-formally, where parcels are prioritized for acquisition based on their known population and habitat conditions, size, and proximity to other protected properties. Desired parcels are then acquired as transaction opportunities arise. We do not know whether our product will supplant their current approach, will be used as a 'first-cut' to identify a broad set of acquisition candidates, or used as a secondary confirmation of targets already chosen. Quoting Mr. Matt Elliott, Assistant Chief of the Wildlife Conservation Section of the Georgia DNR Wildlife Resources Division, "We have found the results of the habitat prediction maps from this project to be very useful, and we expect them to inform both future field surveys and land acquisition and protection efforts. In addition, the data improvements and clean-ups they provided us as corollaries to creating the prediction maps have proven extremely helpful."

Our other products will inform efforts within and beyond Georgia relating to the upcoming Species Status Assessment for the gopher tortoise. At the heart of the SSA is a quantitative assessment of population viability. Our demographic projection model has for the first time made direct use of tortoise population assessments being conducted across a state's portion of the range. Vital rates estimated from the field portion of our project will inform that model, and others. The habitat associations we derived for Georgia can be tested in other states in the range, and we have provided a blueprint for developing such models from population data collected in other parts of the range.

We received much assistance from Mr. Elliott, who provided information about DNR's objectives and needs, data and other information resources, and feedback on our ideas. We met less frequently with other agency personnel to discuss agency perspectives of tortoise conservation within Georgia, including Mr. Steve Friedman of Georgia DNR and Dr. Don Imm of the U.S. Fish and Wildlife Service. Dr. Lora Smith of the Jones Ecological Research Center helped design the field component of our project and gave critical guidance to our master's student in those aspects of the study.

10. OUTREACH

Our outreach consisted of a combination of one workshop at the start of the project, hosted at the Jones Ecological Research Center, multiple additional stakeholder workshops and information meetings, consultations and service on advisory and expert panels, public lectures, scientific conference presentations, one M. Sci. Thesis, reports, and refereed journal publications. A complete list is provided below, including synergist publications.

Peer-reviewed articles

Jafari, N., B. L. Nuse, C. T. Moore, B. Dilkina, and J. Hepinstall-Cymerman. 2017. Achieving full connectivity of sites in the Multiperiod Reserve Network Design Problem. Computers and Operations Research 81:119-127. http://dx.doi.org/10.1016/j.cor.2016.12.017

Theses

Wright, A. D. 2016. Long-term population ecology and movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwest Georgia. M. Sci. Thesis, University of Georgia, Athens.

Reports in preparation

Wright, A. D. et al. Survival and movement patterns of gopher tortoises (*Gopherus polyphemus*) based on long-term mark-recapture. Manuscript in preparation for Journal of Wildlife Management.

Nuse et al. Inferring vital rates from population surveys when physical attributes are linked to age. Manuscript in preparation for submission to Methods in Ecology and Evolution

Nuse et al. Accommodating movement in metapopulation models with resistant kernels. Manuscript in preparation for submission to Landscape Ecology.

Nuse et al. Optimal parcel selection for gopher tortoise conservation. Manuscript in preparation for submission to Ecological Applications.

Publications sponsored under other synergistic activities

Hepinstall-Cymerman, J., R. L. Bormann, T. J. Prebyl, and B. L. Nuse. 2017. NCASI Final Report: Validating gopher tortoise habitat and population predictions for Georgia. Final Report submitted to National Council for Air and Stream Improvement, 49 pp.

Nuse, B. L., R. L. Bormann, J. Hepinstall-Cymerman, and C. T. Moore. 2017. Habitat models and predictions for gopher tortoises in Georgia. Final Report submitted to USGS Cooperative Research Units Program, 87 pp.

Prebyl, T., and J. Hepinstall-Cymerman. Sensing the southeastern savanna: mapping vegetative structure of upland habitats in the southeastern coastal plain. Manuscript in preparation for Forest Ecology and Management.

Nuse et al. Habitat models for gopher tortoises in Georgia, derived from soil maps and forest structure. Manuscript in preparation for submission to Chelonian Biology and Conservation.

Stakeholder workshops and informational meetings

Stakeholder decision-structuring workshop: "Adaptive landscape planning and decision framework for gopher tortoise conservation", 7-8 May 2014, J. W. Jones Ecological Research Center, Newton, GA.

Project presentation to Steering Committee of the Southeast Regional Partnership for Planning and Sustainability, 4 March 2015, Atlanta, GA.

Project presentation to U.S. Fish and Wildlife Service, Southeast Climate and Adaptation Science Center, and Georgia DNR, 12 February 2016, Athens, GA.

Participation in Southeast Climate Science Center Stakeholder Advisory Meeting: presentation and discussion of funded work, 3 May 2017, web conference.

Consultation and service on advisory and expert panels

Definition of population benchmarks for gopher tortoise conservation and recovery efforts (Workshop 1). Gopher Tortoise Council, 13-14 March 2013, Mansfield, GA.

Definition of population benchmarks for gopher tortoise conservation and recovery efforts (Workshop 2). Gopher Tortoise Council, 4-5 March 2014, Andalusia, AL.

Gopher tortoise soils classification meeting. USDA Natural Resources Conservation Service, 7-8 April 2015, Andalusia, AL.

Consultation to GA DNR (Matt Elliott) and US Fish and Wildlife Service (Mike Harris): Estimation of gopher tortoise densities in Georgia, over soils of differing suitability ratings, October 2015.

Designing gopher tortoise conservation planning units in Georgia. Consultation with Georgia DNR and U.S. Fish and Wildlife Service, 20 March 2017, Athens, GA.

Considerations for assessing Alabama Statewide gopher tortoise population status. Consultation with Alabama DCNR, 11 October 2017, Box Springs, GA.

Definition of range-wide conservation targets for gopher tortoise (Workshop 3). Gopher Tortoise Council, 14-16 November 2017, Newton, GA.

Public lectures

Nuse, B. L., N. Jafari, R. L. Bormann, A. D. Wright, C. T. Moore, J. Hepinstall-Cymerman, and M. Elliott. 2016. Accommodating space and demographic uncertainty, in pursuit of gopher tortoise conservation in Georgia. Invited seminar. Warnell School of Forestry and Natural Resources, University of Georgia. 27 October 2016. https://www.warnell.uga.edu/research/news/seminar-accommodating-space-and-demographic-uncertainty-pursuit-gopher-tortoise

Conference presentations and posters
(Oral presentation, unless marked '[Poster]'; † denotes sponsorship under synergistic activity)

Moore, C., and J. Hepinstall-Cymerman. 2013. [Poster] A landscape planning and decision framework for gopher tortoise conservation in Georgia. 35th Annual Gopher Tortoise Council Meeting, 11-13 October 2013, Ponte Vedra Beach, FL.

Jafari, N. 2014. An innovative exact formulation for the Reserve Network Design Problem. Meeting to consider research needs in dynamic reserve design, 24 April 2014, Gainesville, FL.

Moore, C. 2014. An adaptive landscape planning and decision framework for gopher tortoise conservation: Overview, progress, and reserve design needs. Meeting to consider research needs in dynamic reserve design, 24 April 2014, Gainesville, FL.

Moore, C. 2014. Adaptive landscape planning and decision framework for gopher tortoise conservation. Gopher Tortoise Candidate Conservation Agreement meeting, 9 July 2014, Savannah, Georgia.

† Bormann, R., J. Hepinstall-Cymerman, L. German, J. Rice, C. Moore, and M. Elliott. 2014. [Poster] Modeling gopher tortoise habitat and habitat connectivity in Georgia, and analyzing the role of private landowners in their conservation. 36th Annual Gopher Tortoise Council Meeting, 17-19 October 2014, Albany, GA.

Nuse, B. L., and C. T. Moore. 2014. [Poster] A Bayesian population model to inform gopher tortoise conservation planning in Georgia. 36th Annual Gopher Tortoise Council Meeting, 17-19 October 2014, Albany, GA.

Wright, A. D., J. Hepinstall-Cymerman, L. L. Smith, and C. T. Moore. 2014. [Poster] Long-term population ecology and large-scale movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwest Georgia. 36th Annual Gopher Tortoise Council Meeting, 17-19 October 2014, Albany, GA.

Jafari, N., and C. T. Moore. 2014. Designing a dynamic reserve problem under stochastic uncertainties. INFORMS Annual Meeting, 9-12 November 2014, San Francisco, CA.

Moore, C. T. 2015. ‘Sustainability’ in the eyes of a decision analyst: three case studies in conservation. 2015 Sustainability Science Symposium at UGA, 23 January 2015, Athens, GA.

Jafari, N., C. T. Moore, and J. Hepinstall-Cymerman. 2015. Solution alternatives to achieve parcel connectivity in the dynamic reserve design problem. Twenty-Ninth Conference of the Association for the Advancement of Artificial Intelligence (AAAI-15), Workshop on Computational Sustainability, 25 January 2015, Austin TX.

Moore, C. 2015. Adaptive landscape planning and decision framework for gopher tortoise conservation: Project update. Meeting of the Gopher Tortoise Candidate Conservation Agreement Team, 10 June 2015, Spanish Fort, AL.

Nuse, B. L., J. Hepinstall-Cymerman, C. T. Moore, and M. Elliott. 2015. Assessing functional connectivity in the face of uncertainty about population processes: a Bayesian modeling approach applied to conservation of the gopher tortoise in Georgia, USA. International Association of Landscape Ecology World Congress, 5-10 July 2015, Portland, OR.

Wright, A. D., C. T. Moore, J. Hepinstall-Cymerman, and L. Smith. 2015. [Poster] Estimating dispersal rates and landscape resistance to understand functional connectivity for a long-lived endangered species. International Association of Landscape Ecology World Congress, 5-10 July 2015, Portland, OR.

Jafari, N., and C. T. Moore. 2015. Achieving the spatial connectivity of parcels in the dynamic reserve network design problem. International Symposium on Mathematical Programming, 12-17 July 2015, Pittsburgh, PA.

Nuse, B. L., C. T. Moore, J. Hepinstall-Cymerman, and M. Elliott. 2015. [Poster] Comparing hypotheses about missed burrows in gopher tortoise line transect surveys: Bayesian distance analysis with data augmentation. 2015 Ecological Society of America Annual Meeting, 9-14 August 2015, Baltimore, MD.

Wright, A.D., J. Hepinstall-Cymerman, L. Smith, and C.T. Moore. 2015. [Poster] Data are scarce but action is necessary: Using agent-based models for conservation. Annual Student Conference on Conservation Science, 7-9 October 2015, New York, NY.

† Bormann, R., J. Hepinstall-Cymerman, B. Nuse, C. Moore, and M. Elliott. 2015. [Poster] Modeling gopher tortoise (*Gopherus polyphemus*) distribution in Georgia. 37th Annual Gopher Tortoise Council Meeting, 16-18 October 2015, Covington, LA.

Wright, A. D., J. Hepinstall-Cymerman, L. L. Smith, and C. T. Moore. 2015. Long-term population ecology and large-scale movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwestern Georgia. 37th Annual Gopher Tortoise Council Meeting, 16-18 October 2015, Covington, LA.

Jafari, N., and C. Moore. 2015. Land development uncertainties in the dynamic reserve network design problem. INFORMS Annual Meeting, 1-4 Nov 2015, Philadelphia, PA.

Nuse, B. L., J. Hepinstall-Cymerman, C. T. Moore, and M. Elliott. 2015. Linking gopher tortoise processes and landscape resistance to assess functional connectivity of gopher tortoise populations in Georgia. Annual Meeting of the Southeastern Association of Fish and Wildlife Agencies, 1-4 Nov 2015, Asheville, NC.

Wright, A. D., J. Hepinstall-Cymerman, L. L. Smith, and C. T. Moore. 2015. Long-term population ecology and large-scale movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwestern Georgia. Annual Meeting of the Southeastern Association of Fish and Wildlife Agencies, 1-4 Nov 2015, Asheville, NC.

Wright, A.D., J. Hepinstall-Cymerman, L. Smith, and C.T. Moore. 2016. Long-term population ecology and large-scale movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwestern Georgia. Warnell Graduate Student Symposium, 20-22 January 2016, Athens, GA.

Wright, A. D., J. Hepinstall-Cymerman, L. L. Smith, and C. T. Moore. 2016. [Poster] Long-term population ecology and large-scale movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwestern Georgia. Annual Scientific Advisory Committee Meeting of the Joseph W. Jones Ecological Research Center, 4 February 2016, Newton, GA.

Nuse, B. L. 2016. Demography and spatial structure in Georgia's gopher tortoise populations. Gopher Tortoise project update meeting to FWS, SECSC, and partners. Warnell School of Forestry and Natural Resources, University of Georgia, 12 February 2016, Athens, GA.

Wright, A.D., J. Hepinstall-Cymerman, L. Smith, and C.T. Moore. 2016. Long-term population ecology and large-scale movement patterns of gopher tortoises (Gopherus polyphemus) in southwestern Georgia. Gopher Tortoise project update meeting to FWS, SECSC, and partners. Warnell School of Forestry and Natural Resources, University of Georgia, 12 February 2016, Athens, GA.

Nuse, B. L., C. T. Moore, and J. Hepinstall-Cymerman. 2016. Predicting spatial structure in gopher tortoise (*Gopherus polyphemus*) populations in Georgia, USA. US-IALE 2016 Annual Meeting, 3-7 April 2016, Asheville, NC.

Wright, A. D., J. Hepinstall-Cymerman, L. L. Smith, and C. T. Moore. 2016. Long-term population ecology and large-scale movement patterns of gopher tortoises (*Gopherus polyphemus*) in southwestern Georgia. US-IALE 2016 Annual Meeting, 3-7 April 2016, Asheville, NC.

† Hepinstall-Cymerman, J., R. Bormann, B. Nuse, C. Moore, and M. Elliott. 2016. Mapping gopher tortoise habitat in Georgia using multi-season Landsat imagery and multiple statistical modeling techniques. The Wildlife Society 23rd Annual Conference, 15-19 October 2016, Raleigh, NC.

Nuse, B. L., C. T. Moore, N. Jafari, J. Hepinstall-Cymerman, and M. Elliott. 2016. Informing reserve design with demography for gopher tortoise conservation planning in Georgia, USA. The Wildlife Society 23rd Annual Conference, 15-19 October 2016, Raleigh, NC.

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