List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE
NSF 15-501

☐ Special Exception to Deadline Date Policy

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)
DBI - BIO PostDocs

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				NR	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)
Not Shown

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE
Clark Robert E

AWARDEE ORGANIZATION CODE (IF KNOWN)
P269987644

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
281 Main Street Apt. A3
Farmington, CT 06032-2954

NAME OF PRIMARY PLACE OF PERF
University of Connecticut

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
University of Connecticut
75 North Eagleville Road
Storrs ,CT ,062693043 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **NSF Postdoctoral Fellowship in Biology FY 2017**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **138,000**	**24** months	**09/01/17**	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____
PHS Animal Welfare Assurance Number _____
☒ FUNDING MECHANISM **Fellowship**

☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
☒ COLLABORATIVE STATUS
Not a collaborative proposal

PI/PD DEPARTMENT
Biology

PI/PD FAX NUMBER

PI/PD POSTAL ADDRESS
281 Main Street Apt. A3
Farmington, CT 060322954
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME **Robert E Clark**	**PhD**	**2016**	**860-518-1954**	**rclark@wesleyan.edu**
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of AAG Chapter IV.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research. The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has not been convicted of a felony criminal violation under any Federal law within the 24 months preceding the date on which the certification is signed.

Certification Dual Use Research of Concern

By electronically signing the certification pages, the Authorized Organizational Representative is certifying that the organization will be or is in compliance with all aspects of the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

Application Form

NAME

Clark	Robert	E.		
Last	First	MI	TITLE	Other Names Used

MAILING ADDRESS for correspondence. It is imperative that you keep NSF informed of a current mailing address.
281 Main Street Apt. A3

Farmington CT 06032-2954

CURRENT ADDRESS (if different from Permanent Mailing Address):

CURRENT E-MAIL ADDRESS: rclark@wesleyan.edu

TELEPHONE NUMBERS:
At Home: (860)518-1954
At your institution: (860)518-1954
FAX number:

CURRENT POSITION
Department Biology
Institution Wesleyan University
Type of Institution Liberal Arts
Title of Position PhD Candidate
Date this position started 09/01/2010
Source of support Biology Deparment Research and Teaching Fellowship

CITIZENSHIP (check one)
__ US Citizen or National __ Permanent Resident __ Foreign National(give country: United States)
If you are a Permanent Resident you must provide your Permanent Resident Registration Number:

HIGHEST DEGREE EARNED: PhD YEAR CONFERRED: 2016

DOCTORAL DEGREE
Department and Institution Biology Wesleyan University
Date awarded or anticipated date of receipt 05/28/2017

PROPOSED FELLOWSHIP INSTITUTION including department and address
University of Connecticut Ecology and Evolutionary Biology
75 N. Eagleville Road
Storrs CT 06269-3043

PROPOSED SPONSORING SCIENTIFIC ADVISOR OR MENTOR including title, e-mail address, telephone and FAX numbers:
Bagchi Robert
Assistant Professor robert.bagchi@uconn.edu
(860)486-6587
(Telephone) (FAX)

BRIEF TITLE of your proposed research or field of study:
Plant population responses to habitat fragmentation and decline of seed dispersal mutualisms

Application Form

REFERENCES(do not use your mentor).

	Name	Department	Institution	Phone
1.	Singer Michael S.	Biology	Wesleyan University	(860)685-2548
2.	King Joshua R.	Biology	UCF	(407)832-1082
3.				
4.				

EXPECTED STARTING DATE OF FELLOWSHIP: 09/2017 (Month, year) DURATION OF TENURE: 24 (# of months)

OTHER SUPPORT

Have you applied for any other fellowships or similar appointments for all or part of the tenure herein requested? NO

If so, name of agency or program _____

Have you ever received any NSF postdoctoral fellowship? NO

If yes, when and from what program? _____

Please provide the following information:

OTHER INSTITUTION AND SPONSOR if short-term international experience is proposed

_____

PROJECT SUMMARY

Overview:

Habitat fragmentation is a leading cause of global biodiversity loss, but it is unclear what factors allow some species to persist in fragmented environments while other species decline. It is predicted that the most vulnerable species require specialized interactions, such as plant populations which utilize a single animal disperser for reproduction. This project will therefore determine how forest fragmentation disrupts specialized seed dispersal services and resulting impacts on plant populations. Employing historical plant population data from the University of Connecticut herbarium, experiments will determine landscape, population, and microevolutionary changes for 40 ant-dispersed and vertebrate-dispersed plant species across a gradient of forest fragmentation regimes. To demonstrate mechanisms causing plant population changes, the PI will gain substantial training from the Sponsor in quantitative ecology, using spatial and phylogenetic analytical methods. Outreach components provide research training opportunities for undergraduate students from underrepresented groups and ecological education programs for the public.

Intellectual Merit:

The proposed project will determine plant population responses to habitat fragmentation that have not yet been addressed comprehensively, including population decline, reduced dispersal distance, and microevolutionary changes in seed traits. Results will provide a mechanistic understanding of how reduced dispersal services alter populations in environments impacted by human activity. Past research on habitat fragmentation typically examined short-term changes in plant populations for a single focal species, and the proposed work expands this framework through comparative analysis of 40 herbaceous plant species from two plant seed dispersal syndromes. Using biological collections, the PI will be able to compare the response of ant-dispersed and vertebrate-dispersed populations to forest fragmentation in shared habitats. These results will provide critical insights into the biology of specialization and environmental change, contributing to the fields outside of population ecology and dispersal biology, including conservation biology, forest management, and research on the impacts of urbanization on ecological networks.

Broader Impacts:

The broader impacts of the proposed work include scientific training for the PI and students from underrepresented groups, improved public engagement in science through education programs, and contributions to biological collections providing data that will facilitate conservation monitoring efforts. First, training will be provided to the PI in order to effectively analyze spatially and phylogenetically correlated data, and the proposed project will provide research experience to at least two students from underrepresented groups. Second, the PI will run 12 education programs for environmental organizations and K-12 schools, utilizing an established and previously successful format developed by the PI. Third, field components of the project will donate specimens to UConn?s herbaria collections from 128 locations in Connecticut and contribute to monitoring for four species of rare plants. In total, this project will facilitate the development of careers in STEM, contribute to public scientific literature through outreach, and develop data infrastructure that can be utilized beyond basic ecological research.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

	Total No. of Pages	Page No.* (Optional)*
Cover Sheet for Proposal to the National Science Foundation		
Project Summary (not to exceed 1 page)	1	
Table of Contents	1	
Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	6	
References Cited	5	
Biographical Sketches (Not to exceed 2 pages each)	1	
Budget (Plus up to 3 pages of budget justification)	0	
Current and Pending Support	1	
Facilities, Equipment and Other Resources	0	
Special Information/Supplementary Documents (Data Management Plan, Mentoring Plan and Other Supplementary Documents)	6	
Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		
Appendix Items:		

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description

Introduction

Habitat fragmentation has dramatic impacts on biodiversity (Fahrig 2003), but it is still unclear what mechanisms cause population decline in highly fragmented landscapes (Debinski and Holt 2000, Ewers and Diham 2006, Fischer and Lindenmayer 2007). Recent work has demonstrated that species involved in specialized or obligate interactions are most vulnerable to environmental change caused by habitat fragmentation (Laurance et al. 2011, Liu et al. 2016, Rocha-Santos et al. 2016). For example, seed dispersal mutualisms involve a diversity of animal taxa, but plant species that depend on a single animal dispersal agent are more sensitive to changes in dispersal services than those that rely on many dispersal agents (Henle et al. 2004, Aguilar et al. 2006). For plant populations, loss of seed dispersal services leads to decreased population size (Laurance et al. 2006), reduced dispersal distance (Harrison et al. 2013), and even microevolutionary changes in seed traits (Kiers et al. 2010). However, it is difficult to predict the effects of habitat fragmentation since it may take decades for the loss of mutualistic services to impact populations (Cordeiro and Howe 2003, Ewers and Diham 2006). Consequently, integrative studies linking the fragmentation, seed-dispersal services, and plant populations are lacking (reviewed in Fischer and Lindenmayer 2007, Miguet et al. 2016). The use of herbarium records can fill this gap by providing historical data on multiple plant populations across a landscape of fragmentation regimes, which in turn can then be compared to contemporary plant populations in the field. Moreover, collections can provide data on many plant species in shared habitats, which is necessary for making comparisons between plant populations with varying degrees of dispersal specialization.

Many herbaceous plants and shrubs specialize in seed dispersal by ants (Rico-Gray and Oliveira 2007, Lengyel et al. 2010). In this interaction, ants rapidly disperse seeds to protected microsites, providing protection from hazards such as seed predation (Fedriani et al. 2004, Garrido et al. 2009, Gomez and Espadaler 2013). This dispersal syndrome has evolved multiple times independently (Lengyel et al. 2010), and is characterized by a suite of plant traits: seeds have nutrient-rich appendages called "elaiosomes" that are consumed by ants during seed dispersal (Clark and King 2012); ant-dispersed plants produce larger seeds as compared to closely-related vertebrate-dispersed plants (Thompson 1981, Guitian and Garrido 2006); and ant-dispersed plants produce proportionally fewer seeds per generation (Gomez and Espadaler 2013). Ant-dispersed plants also typically specialize on only few ant species that can effectively disperse seeds quickly enough to avoid seed predators (Ness and Morin 2008, Warren and Giladi 2014). These dispersal attributes greatly increase the susceptibility of ant-dispersed plant population to loss of dispersal mutualists compared to other dispersal syndromes (Ness et al. 2004, Lach et al. 2010). In shared habitats with ant-dispersed plants, vertebrate-dispersed plants can facultatively use a wider range of seed dispersers (Matlack 2005), and vertebrate-dispersed plants do not respond as negatively to disturbance as ant-dispersed plants (Ness and Morin 2008).

The proposed project will use records of plant populations in University of Connecticut herbaria to contrast the responses of ant-dispersed and vertebrate-dispersed plant populations to historical habitat fragmentation in Connecticut forests. Connecticut currently has 60 percent forest cover, but development has split these habitats into increasingly smaller fragments over the last 30 years, as reported by University of Connecticut's Center for Land Use and Education Research (CLEAR, 2012). While it is expected that habitat fragmentation will have negative impacts on plant populations overall (Cordeiro and Howe 2003, Ewers and Diham 2006), I predict three mechanisms in which ant-dispersed plants may be more susceptible compared to vertebrate-dispersed plants in particular: First, if ant mutualists are not found in fragmented habitats, ant-dispersed plant populations will experience high rates of mortality from

seed predators (Ness and Morin 2008, Kwit et al. 2012) and consequently face population declines (Boyd 2001, Ness and Morin 2008). Second, reduced seed dispersal services increases the proximity of seedlings to parent plants (Canner et al. 2012), leading to more clustered spatial distribution of plants (Wiegand et al. 2007, Harrison et al. 2013). Third, changes to ant communities will alter natural selection for certain seed traits, particularly seed size, since there is a high degree of specificity between seed mass and ant body size (Garrido et al. 2002, Bas et al. 2009).

Hypothesis and predictions

This study will compare the population and evolutionary consequences of forest fragmentation for ant-dispersed and vertebrate-dispersed plant species. My central hypothesis is that loss of highly specific interactions with ants drives population changes in fragmented habitats. Since ant-mediated seed dispersal has evolved independently multiple times (Lengyel et al. 2010), I will use vertebrate-dispersed relatives as a phylogenetic control to make this comparison. Experiments focus on three mechanistic hypotheses addressing the specific responses of ant-dispersed plant populations to habitat fragmentation:

1. ***Population persistence hypothesis (PPH)*** *Habitat fragmentation causes decline or failed persistence of plant populations due to loss of seed dispersal services, with more specialized dispersal syndromes exhibiting increased susceptibility to fragmentation.*
2. ***Spatial structure hypothesis (SSH)*** *Habitat fragmentation increases seedling proximity to parent plants due to loss of seed dispersal services, leading to more clustered spatial arrangement of individual plants which rely on specialized seed dispersing mutualists.*
3. ***Dispersal co-evolution hypothesis (DCH)*** *Habitat fragmentation causes changes in seed-disperser communities that select for smaller seeds, leading to smaller seed sizes in habitats that have been historically fragmented.*

Figure 1. Predicted hypothetical response for vertebrate and ant-dispersed plant populations

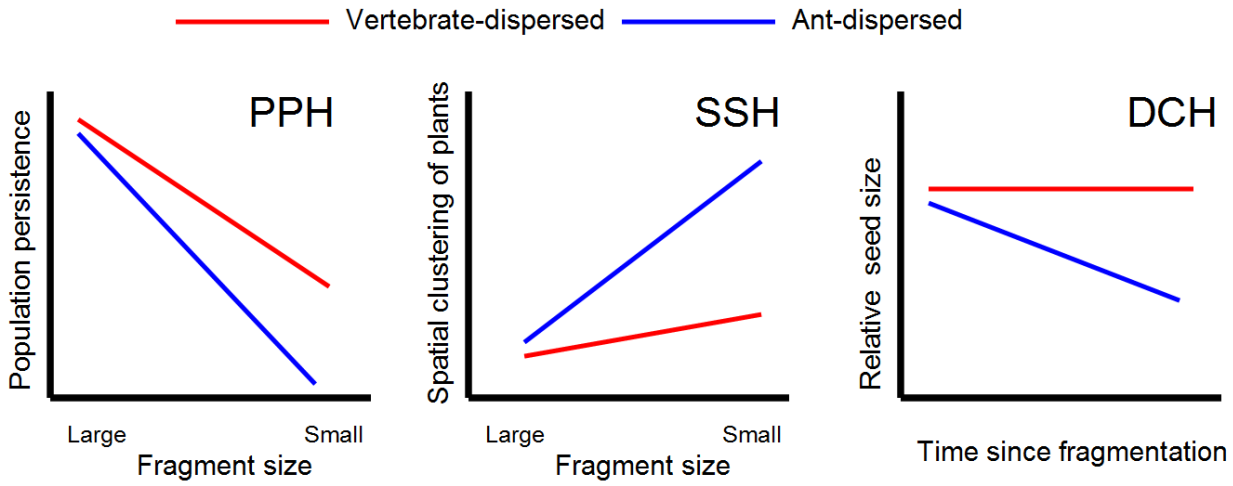

Fig. 1. Trendlines indicate idealized, predicted responses of understory forest plants to habitat fragmentation. Note that differences in the slopes indicate independent responses of ant-dispersed and vertebrate-dispersed plants in shared habitats, and actual analyses may reveal non-linear responses. In the PPH, I expect fragmentation to negatively impact both dispersal syndromes, however ant-dispersed plants will be less likely to persist in small fragments. Likewise, in the SSH, fragmentation will lead to more clustered spatial arrangement, but this effect will be magnified for ant-dispersed plants (i.e. Gomez et al. 2003). Finally, for simplicity, in the DCH prediction I show responses of plants in small fragments only, with the x-axis indicating time since fragmentation event occurred. This hypothesis predicts ant-dispersed plants that have persisted in smaller fragments are more likely to exhibit reduced seed size compared to vertebrate-dispersed plants.

Research Objective, Methods and Significance

Study system

The proposed project will examine understory herbaceous plant communities typical to Northeastern U.S. forests. Using preliminary data from the UConn herbaria, I identified 20 species of ant-dispersed species found in Connecticut forests, and paired these with 20 vertebrate-dispersed plants of similar phylogenetic breadth (Fig. 2). I expect habitat fragmentation to impact ant-dispersed plants in this region because extensive empirical work has established *Aphaenogaster* ants as key dispersal agents (Morales and Heithaus 1998, Ness et al. 2009, Warren et al. 2010), and these ants are less abundant in disturbed habitats or forest edges (Ellison et al. 2012). Furthermore, ant-dispersed plants are shown to be less abundant in habitats where *Aphaenogaster* are rare or absent (Ness and Morin 2008, Ness et al. 2009). The proposed research will use detailed, public records of forest coverage by CLEAR, which provides aerial photographs of Connecticut forests at yearly intervals over the last 36 years, allowing me to quantify forest fragment attributes including area and time since fragmentation occurred. The 3,580 physical specimens in UConn's George Safford Torrey Herbarium provide sufficient coverage of habitats in Connecticut to quantify the historical changes that plant populations have experienced in this timeframe.

Figure 2: Digitized records for ant-dispersed and vertebrate-dispersed plants in UConn Herbarium.

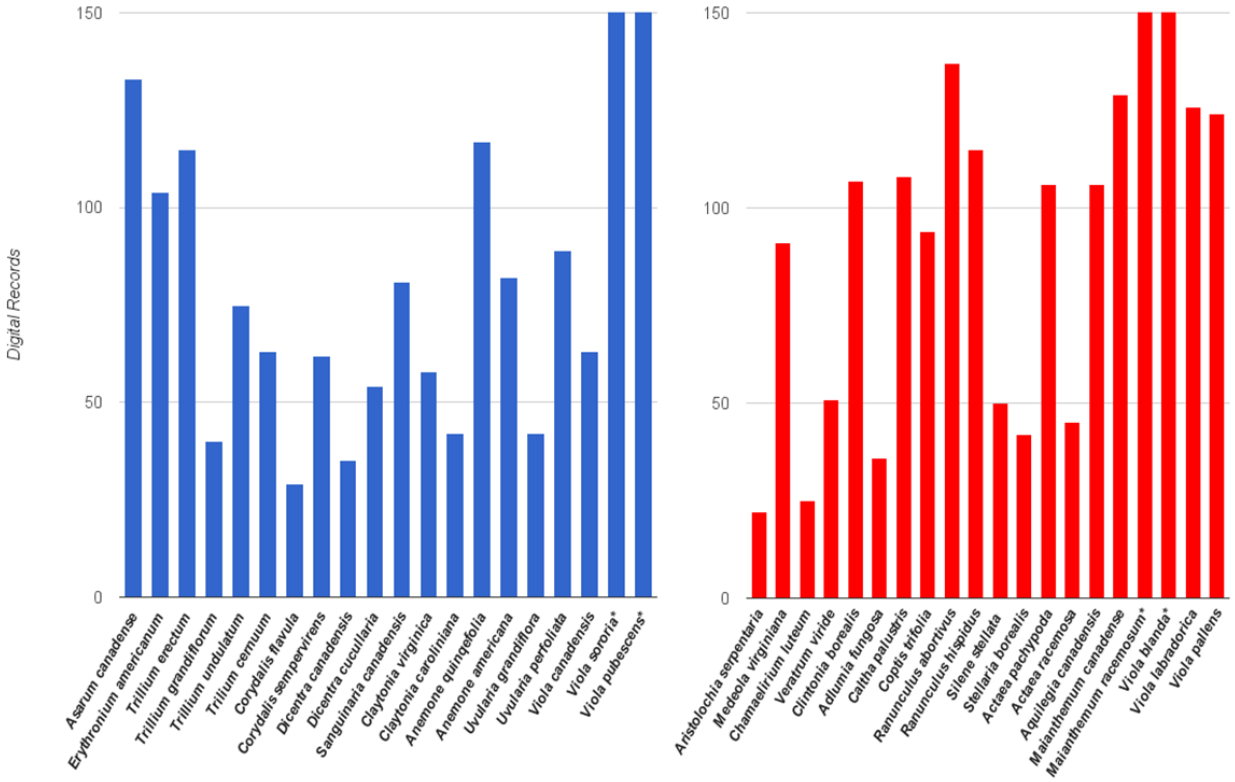

Fig. 2. Digital records for 20 species of ant-dispersed from Connecticut forests deposited in the UConn Herbarium (1729 records in blue), to be compared with 20 vertebrate-dispersed species (1861 records in red). All ant-dispersed plants are reportedly dispersed by *Aphaenogaster* ants, while vertebrate-dispersed plants in this list produce fruits that are consumed by migratory or resident birds and mammals. Each dispersal syndrome category encompasses 6 phylogenetic groups (families or suborders) determined using current the flowering plant phylogeny (Stevens, P. F. 2001, Angiosperm Phylogeny Group 2016) and preliminary data from the UConn Herbarium. All listed species have >20 records, while asterisk indicate species with >150 records.

Experimental Design

To test the **population persistence hypothesis**, herbaria records will provide data on historical plant locations to be cross-referenced with public data from CLEAR (clear.uconn.edu/projects/landscape). These data will generate a list of 200 field assessments (five sites per plant species) to verify presence or absence of plant populations across a gradient of fragment sizes (10-1000 hectares) located in Connecticut at locations and within 1.5-hour drive from UConn. Over two three-month field seasons, plant populations will be recorded in rapid $50m^2$ plot surveys with the GPS waypoint centered on the biological collection locality. Using a statistical modeling approach for phylogenetically correlated data, analyses will regress fragment area against population persistence for each seed dispersal syndrome (Fig. 1), fitting 40 plant species as random effects to account for intraspecific variation in response to habitat fragmentation (following Funk et al. 2015). The PPH would be supported if population persistence is lower for ant-dispersed plants as compared to vertebrate-dispersed plants (Fig. 1).

To test the **spatial structure hypothesis**, six species will be examined from each dispersal group (species with >100 records in Fig. 2). These represent widespread species that will be found across a range of forest fragmentation sizes (10-1000 hectares). For example, *Erythronium americanum* (ant-dispersed) and *Mianthemum canadense* (vertebrate-dispersed) are abundant species according to herbarium records (Fig. 2) and botanical maps (Gleason and Cronquist 1991). Using locality information, 72 plots ($25m^2$) will be designated where these populations are established (six plots per 12 species), and the spatial arrangement of individual plants will be recorded in two dimensions (following Bagchi et al. 2011). At these same locations, ants will be sampled with 25 pitfall traps at 5m intervals to measure ant community composition (following Ellison et al. 2007). For analysis, we will regress plant spatial structure against dispersal syndrome, fragment area, and their interaction using replicated point pattern analysis (Bagchi and Illian 2015), incorporating metrics of ant community composition as a co-variate (Schmidt et al. 2013). The SSH would be supported if ant-dispersed plants are more clustered as fragment size decreases, while fragmentation has no effect or a weaker effect on the clustering of vertebrate-dispersed plants (Fig. 1). Furthermore, ant-mediated mechanisms underlying the SSH would be supported if clustering of ant-dispersed plants occurs in locations without *Aphaenogaster* and plants are more clustered at locations where ant community composition is biased towards smaller ants.

To test the **dispersal co-evolution hypothesis**, seed size will be measured by dry seed weight from herbaria and field-collected specimens. Ant-dispersed and vertebrate-dispersed seed sizes will be compared between field-collected samples from SSH (72 plots), finding the average seed size in each plot from 25 actively fruiting plants. Analyses will use Bayesian hierarchical models to evaluate change in seed size between herbaria and field-collected specimens across fragment size and date of fragmentation provided by CLEAR, fitted for 40 species independently. The DCH will be supported if ant-dispersed plant seed sizes have become smaller compared to seeds of vertebrate-dispersed plants in the same locations. In addition to these analyses, two guided undergraduate research will use seeds collected from SSH experiments. First, seeds from varying fragment sizes will be reared in a common garden experiment in the greenhouse to assess the potential role of phenotypic plasticity for seed size (Monty and Mahy et al. 2010). Second, field experiments will present *Aphaenogaster* ants with a range of seeds from each of the six species to determine if smaller seeds are less likely to be dispersed. Evidence for seed trait evolution would be observed if common garden plants from small fragments produced equally small seeds, and evidence for natural selection by ants would be provided if *Aphaenogaster* were more likely disperse relatively smaller seeds.

Training objectives

The proposed project will gather a large amount of spatially and phylogenetically correlated data on plant populations, and I will be trained by the sponsor in use of R packages for Bayesian modeling JAGS (Plummer et al. 2016) and INLA (Rue et al. 2009), and spatial statistics using replicated point pattern models. Geographic Information System (GIS) courses will be provided UConn's Center for Land Use Education and Research programs, which offers a Geospatial Training Program (GTP) in GIS and interpretation of land-use records, available to biologists working at UConn. To supplement training from the project sponsor, the proposal will provide tuition for R online workshops provided by PR statistics, which organizes training workshops for postdoctoral ecologists (PR~Stats, Ltd.). These workshops include training for the three major techniques in this proposal, including Spatial Analysis of Ecological Data in R, Applied Bayesian Modeling for Ecologists, and Introduction to Phylogenetic Data Analysis.

Career development

Training goals of this project will support my career aspirations of developing a productive academic research program at the intersection of community, population, and evolutionary ecology. These fields increasingly depend on collaborative, quantitative work with large data sets (Hampton et al. 2013), and the training provided in this project will set me apart from other job candidates. I will complete a self-assessment at the start of the project using AAAS's MyIDP career planning tool, followed by monthly meetings to evaluate long-term goals with the sponsor (Table 1). I will attend seminars co-taught by UConn Ecology and Evolutionary Biology faculty that provide guidance for postdoctoral scientists seeking careers in ecology and evolution biology. Topics include science communication, peer-review, and teaching, supporting my long-term career goals in academia. I will also participate in UConn's *Statistics in EEB* seminar, where I can gain experience teaching statistics to graduate students and collaborating on quantitative tasks with other ecologists.

This work broadens my research portfolio beyond my graduate focus on entomology and community ecology. My dissertation research examined community ecology and trophic interactions, where I examined the ecological consequences of ant predation of caterpillars. This gave me broad training in field biology and the experience working with ecological interaction networks. I currently have no experience employing phylogenetic, Bayesian, or spatial statistical models proposed in this work. My Master's thesis examined the nutritional benefit ants gain from consuming seeds produced by ant-dispersed plants, however this project included no components of plant ecology or landscape ecology. The proposed project allows me to employ my training in field biology and forest natural history, facilitating the considerable logistical requirements of this project; testing the PPH and SSH would not be feasible without knowledge of Connecticut forests and taxonomy of the study species.

Choice of sponsor and host institution

The project objectives fit the research program of sponsor Robert Bagchi, which includes examining the effect of anthropogenic environmental change on plant diversity and seed dispersal ecology. Notably, the proposed project has multiple synergies with an NSF-funded project in the Bagchi lab examining the impacts of habitat fragmentation on antagonistic interactions between birds, caterpillars, and host plants (DEB-1557086). This synergy provides permits for access to forest sites, mutual logistical support, and shared GIS data. UConn and the EEB will provide training in GIS and opportunities to present research to EEB faculty through a postdoctoral seminar series, and the proposed biological collections are located on-site. The sponsor's area of expertise in ecological modeling, plant population ecology, and landscape ecology facilitate training opportunities not available at my Ph.D. granting institution.

Broader Impacts

Biological collections are becoming increasingly relevant to evolutionary ecology since they provide historical data on species traits and populations (Leger 2013). This project will contribute to data infrastructure at UConn's Herbarium through donation of specimens and locality data. Statistical tools developed to test PPH and SSH in R will be made available through the sponsor's GitHub page (github.com/robertbagchi), and data through Dryad digital repository. I will report population declines or new population records for state-listed plants of conservation concern (ct.gov/deep), including the special concern species in this project *C. flavula*, *D. canadensis*, *E. serpentaria*, and *S. stellata* (Fig. 2).

This project includes outreach components for the public and experiments which will involve undergraduate students from underrepresented groups. In collaboration with members of the Bagchi lab, the Fragmentation in Ecological Networks Grant (NSF-DEB-1557086), and UConn EEB, this project will provide outreach programs for the public, improving participation in scientific research and promoting STEM in public schools. I will continue public "walk and talk" programs developed during my doctoral dissertation improvement grant (DEB-1404177), using land-use history in Connecticut and forest ecosystem services as program topics. Previous programs demonstrated high attendance (over 250 adults and children total). Sponsor Bagchi is a current mentor for the McNair program at UConn, providing research opportunities to students form underrepresented groups. I have designed field components in DCH where I will provide training in plant taxonomy, insect behavior, data analysis, during the summer, and students will receive course credit in the fall semester at UConn (EEB3881).

The proposed work will use collection to address habitat fragmentation, which is a key challenge in conservation biology (Wilcove et al. 2016, Wilson et al. 2016). Global estimates for ant-dispersed plant diversity are currently 11,000 species (Lengyel et al. 2010), but it is unclear how many are threatened by habitat fragmentation and loss of dispersal mutualists. Along these lines, emerging research in evolutionary ecology predicts anthropogenic environmental change may facilitate rapid evolution in response to altered species interactions (Carroll et al. 2007, Urban 2011, Urban et al. 2012), and this is explicitly tested in the DCH. If we observe support for the DCH, this would suggest that rapid adaptation to new dispersers may help mitigate some of the impacts of fragmentation. This outcome would be assessed during experiments testing the PPH since I will directly record what populations persist in highly fragmented habitats.

Table 1. Training and Research Time-Table

	2017-2018				**2018-2019**			
Task	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Training Goals								
Phylogenetic and simulation models	X							
GIS and Replicated Point Pattern Models		X						
Applied Bayesian Modeling					X			
EEB workshops and manuscript prep						X	X	X
Collections and Fieldwork Goals								
Population locality data from herbarium	X							
Cross referencing herbarium with CLEAR		X						
Population persistence and spatial structure			X	X			X	
Seed trait data from herbarium	X				X			
Outreach								
Public education programs			X				X	
Dispersal experiments w/ McNair scholars				X				X

References

Aguilar, R., L. Ashworth, L. Galetto, and M. A. Aizen. 2006. Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. Ecology Letters 9:968–980.

Angiosperm Phylogeny Group. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV Bot. J. Linn. Soc. 181: 1-20. doi: mobot.org/MOBOT/research/APweb/

Bagchi, R., P. A. Henrys, P. E. Brown, D. F. R. P. Burslem, P. J. Diggle, C. V. S. Gunatilleke, I. A. U. N. Gunatilleke, A. R. Kassim, R. Law, S. Noor, and R. L. Valencia. 2011. Spatial patterns reveal negative density dependence and habitat associations in tropical trees. Ecology 92:1723–1729.

Bagchi, R., and J. B. Illian. 2015. A method for analysing replicated point patterns in ecology. Methods in Ecology and Evolution 6:482–490.

Bas, J. M., J. Oliveras, and C. Gomez. 2009. Myrmecochory and short-term seed fate in *Rhamnus alaternus*: Ant species and seed characteristics. Acta Oecologica-International Journal of Ecology 35:380–384.

Boyd, R. S. 2001. Ecological benefits of myrmecochory for the endangered chaparral shrub *Fremontodendron decumbens* (Sterculiaceae). American Journal of Botany 88:234–241.

Canner, J. E., R. R. Dunn, I. Giladi, and K. Gross. 2012. Redispersal of seeds by a keystone ant augments the spread of common wildflowers. Acta Oecologica 40:31–39.

Carroll, S. P., A. P. Hendry, D. N. Reznick, and C. W. Fox. 2007. Evolution on ecological time-scales. Functional Ecology 21:387–393.

Center for Land use Education And Research (2012) 2010 Land Cover Data. Center for Land use Education and Research (CLEAR), Connecticut, USA. doi: http://clear.uconn.edu/projects/landscapelis/pdfs/LandCover2010_v2-03_metadata.pdf

Clark, R. E., and J. R. King. 2012. The ant, *Aphaenogaster picea*, benefits from plant elaiosomes when insect prey is scarce. Environmental Entomology 41:1405–1408.

Cordeiro, N. J., and H. F. Howe. 2003. Forest fragmentation severs mutualism between seed dispersers and an endemic African tree. Proceedings of the National Academy of Sciences of the United States of America 100:14052–14056.

Debinski, D. M., and R. D. Holt. 2000. A survey and overview of habitat fragmentation experiments. Conservation Biology 14:342–355.

Ellison, A. M., S. Record, A. Arguello, and N. J. Gotelli. 2007. Rapid Inventory of the Ant Assemblage in a Temperate Hardwood Forest: Species Composition and Assessment of Sampling Methods. Environmental Entomology 36:766–775.

Ellison, Aaron M., N. J. Gotelli, E. J. Farnsworth, and G. D. Alpert. 2012. A Field Guide to the Ants of New England. Yale University Press. New Haven, CT. USA.

Ewers, R. M., and R. K. Didham. 2006. Confounding factors in the detection of species responses to habitat fragmentation. Biological Reviews 81:117–142.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology Evolution and Systematics 34:487–515.

Fedriani, J. M., P. J. Rey, J. L. Garrido, J. Guitián, C. M. Herrera, M. Medrano, A. M. Sánchez-Lafuente, and X. Cerdá. 2004. Geographical variation in the potential of mice to constrain an ant-seed dispersal mutualism. Oikos 105:181–191.

Fischer, J., and D. B. Lindenmayer. 2007. Landscape modification and habitat fragmentation: a synthesis. Global Ecology and Biogeography 16:265–280.

Funk, J. L., C. S. Rakovski, and J. M. Macpherson. 2015. On the analysis of phylogenetically paired designs. Ecology and Evolution 5:940–947.

Garrido, J. L., P. J. Rey, X. Cerdá, and C. M. Herrera. 2002. Geographical Variation in Diaspore Traits of an Ant-Dispersed Plant (Helleborus foetidus): Are Ant Community Composition and Diaspore Traits Correlated? Journal of Ecology 90:446–455.

Garrido, J. L., P. J. Rey, and C. M. Herrera. 2009. Influence of elaiosome on postdispersal dynamics of an ant-dispersed plant. Acta Oecologica 35:393–399.

Gleason, H. A., and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. 2nd edition. New York Botanical Garden Pr Dept, Bronx, N.Y., USA.

Gomez, C., P. Pons, and J. M. Bas. 2003. Effects of the Argentine ant Linepithema humile on seed dispersal and seedling emergence of Rhamnus alaternus. Ecography 26:532–538.

Gómez, C., and X. Espadaler. 2013. An update of the world survey of myrmecochorous dispersal distances. Ecography 36:1193–1201.

Guitián, J., and J. L. Garrido. 2006. Is early flowering in myrmecochorous plants an adaptation for ant dispersal? Plant Species Biology 21:165–171.

Hampton, S. E., C. A. Strasser, J. J. Tewksbury, W. K. Gram, A. E. Budden, A. L. Batcheller, C. S. Duke, and J. H. Porter. 2013. Big data and the future of ecology. Frontiers in Ecology and the Environment 11:156–162.

Harrison, R. D., S. Tan, J. B. Plotkin, F. Slik, M. Detto, T. Brenes, A. Itoh, and S. J. Davies. 2013. Consequences of defaunation for a tropical tree community. Ecology Letters 16:687–694.

Kiers, E. T., T. M. Palmer, A. R. Ives, J. F. Bruno, and J. L. Bronstein. 2010. Mutualisms in a changing world: an evolutionary perspective. Ecology Letters 13:1459–1474.
Kwit, C., G. J. Marcello, J. L. Gonzalez, A. C. Shapiro, and R. D. Bracken. 2012. Advantages of Seed Dispersal for a Myrmecochorous Temperate Forest Herb. American Midland Naturalist 168:9–17.

Lach, L., C. L. Parr, and K. L. Abbott. 2010. Ant ecology. Oxford University Press, Oxford.

Laurance, W. F., H. E. M. Nascimento, S. G. Laurance, A. Andrade, J. E. L. S. Ribeiro, J. P. Giraldo, T. E. Lovejoy, R. Condit, J. Chave, K. E. Harms, and S. D'Angelo. 2006. Rapid decay of tree-community composition in Amazonian forest fragments. Proceedings of the National Academy of Sciences of the United States of America 103:19010–19014.

Leger, E. A. 2013. Annual plants change in size over a century of observations. Global Change Biology 19:2229–2239.

Lengyel, S., A. D. Gove, A. M. Latimer, J. D. Majer, and R. R. Dunn. 2010. Convergent evolution of seed dispersal by ants, and phylogeny and biogeography in flowering plants: A global survey. Perspectives in Plant Ecology, Evolution and Systematics 12:43–55.

Matlack, G. R. 2005. Slow plants in a fast forest: local dispersal as a predictor of species frequencies in a dynamic landscape. Journal of Ecology 93:50–59.

Miguet, P., H. B. Jackson, N. D. Jackson, A. E. Martin, and L. Fahrig. 2016. What determines the spatial extent of landscape effects on species? Landscape Ecology 31:1177–1194.

Morales, M. A., and E. R. Heithaus. 1998. Food from Seed-Dispersal Mutualism Shifts Sex Ratios in Colonies of the Ant Aphaenogaster rudis. Ecology 79:734–739.

Monty, A., and G. Mahy. 2010. Evolution of dispersal traits along an invasion route in the wind-dispersed *Senecio inaequidens* (Asteraceae). Oikos 119:1563–1570.

Ness, J. H., J. L. Bronstein, A. N. Andersen, and J. N. Holland. 2004. Ant Body Size Predicts Dispersal Distance of Ant-Adapted Seeds: Implications of Small-Ant Invasions. Ecology 85:1244–1250.

Ness, J. H., and D. F. Morin. 2008. Forest edges and landscape history shape interactions between plants, seed-dispersing ants and seed predators. Biological Conservation 141:838–847.

Ness, J. H., D. F. Morin, and I. Giladi. 2009. Uncommon specialization in a mutualism between a temperate herbaceous plant guild and an ant: are Aphaenogaster ants keystone mutualists? Oikos 118:1793–1804.

Plummer, M., A. Stukalov, and M. Denwood. 2016. rjags: Bayesian Graphical Models using MCMC.

Rico-Gray, V., and P. S. Oliveira. 2007. The ecology and evolution of ant-plant interactions. University of Chicago Press, Chicago.

Rocha-Santos, L., M. S. Pessoa, C. R. Cassano, D. C. Talora, R. L. L. Orihuela, E. Mariano-Neto, J. C. Morante-Filho, D. Faria, and E. Cazetta. 2016. The shrinkage of a forest: Landscape-scale deforestation leading to overall changes in local forest structure. Biological Conservation 196:1–9.

Rue H., S. Martino, and N. Chopin. 2009. Approximate Bayesian inference for latent Gaussian models using integrated nested Laplace approximations (with discussion). Journal of the Royal Statistical Society 71(2):319-392.

Schmidt, F. A., C. R. Ribas, and J. H. Schoereder. 2013. How predictable is the response of ant assemblages to natural forest recovery? Implications for their use as bioindicators. Ecological Indicators 24:158–166.

Stevens, P.F. 2001. Angiosperm Phylogeny Website. Version 12, July 2012 http://www.mobot.org/MOBOT/research/APweb/

Thompson, J. N. 1981. Elaiosomes and Fleshy Fruits: Phenology and Selection Pressures for Ant-Dispersed Seeds. The American Naturalist 117:104–108.

Urban, M. C. 2011. The evolution of species interactions across natural landscapes. Ecology Letters 14:723–732.

Urban, M. C., L. De Meester, M. Vellend, R. Stoks, and J. Vanoverbeke. 2012. A crucial step toward realism: responses to climate change from an evolving metacommunity perspective. Evolutionary Applications 5:154–167.

Warren, R. J., and I. Giladi. 2014. Ant-mediated seed dispersal: A few ant species (Hymenoptera: Formicidae) benefit many plants. Myrmecological News 20:129–140.

Warren, R. J., I. Giladi, and M. A. Bradford. 2010. Ant-mediated seed dispersal does not facilitate niche expansion. Journal of Ecology 98:1178–1185.

Wiegand, T., S. Gunatilleke, N. Gunatilleke, and T. Okuda. 2007. Analyzing the spatial structure of a Sri Lankan tree species with multiple scales of clustering. Ecology 88:3088–3102.

Wilson, M. C., X.-Y. Chen, R. T. Corlett, R. K. Didham, P. Ding, R. D. Holt, M. Holyoak, G. Hu, A. C. Hughes, L. Jiang, W. F. Laurance, J. Liu, S. L. Pimm, S. K. Robinson, S. E. Russo, X. Si, D. S. Wilcove, J. Wu, and M. Yu. 2016. Habitat fragmentation and biodiversity conservation: key findings and future challenges. Landscape Ecology 31:219–227.

Robert Clark
Biology Department
Wesleyan University, Middletown, CT 06459-0180

a. Professional Preparation

Institution	Location	Area	Degree	Year
Central Connecticut State University	CT	Ecology	B.S.	2008
Central Connecticut State University	CT	Biology	M.A.	2010
Wesleyan University	CT	Biology	Ph.D.	*in progress*

b. Appointments
N/A

c. Products
(i) Most closely related to the proposed project
1. *Clark, R.E.* and J.R. King. 2012. The ant, *Aphaenogaster picea,* benefits from plant elaiosomes when insect prey is scarce. **Environmental Entomology** (41)6:1405-1408
2. *Clark, R.E.,* Farkas T.E., Lichter-Marck, I., Johson E.R., and M.S. Singer. 2016. Multiple interaction types determine the impact of ant predation of caterpillars in a forest community. **Ecology** *doi:* 10.1002/ecy.1571
3. *Clark, R.E.* and M.S. Singer. *In review*. Cascading effects of mutualism are determined by changes in ant body size distribution. **Functional Ecology**

d. Synergistic activities
1. *Ad hoc* reviewer (since 2012): Environmental Entomology (2 manuscripts)
2. Research mentor: Advised 9 undergraduate students in Dr. Michael Singer's lab, providing training in entomology, plant taxonomy, applied data analysis, and preparation of work for student presentations.
3. Session organizer: Northeastern Natural History Society Meeting, Springfield MA. 2016.
4. Outreach service (since 2013): Educational programs provided for Connecticut Forest and Park Association (14), Connecticut Department of Energy and Environmental Protection (2), and New Hartford Land Trust (2). Participated as insect taxonomic expert for Bioblitz events (3).
5. Invited Seminar: Erpf Sanford Visiting Professors Program. SUNY Delhi. Delhi, NY. 2014.

e. Collaborators and Other Affiliations
Collaborators and Co-editors (last 48 months):
Dr. Timothy Farkas (University of Connecticut)
Isaac Lichter-Marck (Wesleyan University)
Emily Johnson (Wesleyan University)

Graduate advisors
Dr. Joshua King, University of Central Florida, M.A. advisor
Dr. Michael S. Singer, Wesleyan University, Ph.D. advisor

None submitted.

Plant population responses to habitat fragmentation and decline of seed dispersal mutualisms

Data Collected, Formats and Standards

We will collect data on plant populations at 128 sites across the state of Connecticut. Available data bases at UConn (e.g. CLEAR) allow this population data to be put in the context of forest fragments in the region. Data will be used to evaluate the proposed hypotheses of the PRFB, and organization will be implemented in the R.

Each fragment and sampling location within fragments will be given a unique code and spatially referenced. Data from each group will be provided in a separate comma separated file, which will include time of collection, taxonomic identity and number of individuals of each species we encounter. Meta-data will be included in an accompanying text file, briefly describing sampling protocols, processing and quality assurance protocols.

Data Storage and Preservation

Data will be stored and maintained on hard drives and servers at UConn. Towards the end of the project, quality checked community data produced will be deposited in the University of Connecticut Libraries Data Archive, a digital repository service that features publicly accessible long term data storage and redundancy to comply with national and international standards for digital preservation. Other features include contingencies for disaster recovery, permanent and citable URIs, recurring appraisal cycles, and provisions for authentication, search, discovery, and access in perpetuity. Plant and insect specimen vouchers will be deposited in the biological collections facilities at the University of Connecticut.

Dissemination Methods

Data from the project will be made publically available within 1 year of the completion of the project in DRYAD. All code used in statistical analyses will be made available via supplementary information to the relevant journal articles or via GitHub for larger projects.

Policies for Data Sharing and Public Access

No permission restrictions need to be placed on these data as they will not contain any ethically sensitive or private information. These data will be made publically accessible after a 1-year embargo to enable us to publish key results in peer-reviewed scientific journals.

Roles and Responsibilities

Clark will have oversight of the data sharing process and preparing and archiving of plant population data. Funds for data archiving will be obtained from within the PRFB.

UCONN
UNIVERSITY OF CONNECTICUT

27 October 2016

National Science Foundation
Division of Environmental Biology

Dear NSF-PRFB panel

Subject: Sponsoring scientist statement for PRFB application of Robert E. Clark.

I am delighted to provide my support for Robert Clark's application for an NSF-PRFB based in my group at UConn. I believe that Rob will contribute much to the ongoing research in my group on the effects of forest fragmentation in Connecticut on species interactions while broadening his own research horizon and gaining skills in experimental design and statistical analysis that will advance his career. The research that Rob proposes will establish how modification of disperser communities in forest fragments in Connecticut will disrupt seed dispersal and consequently affect plant population structure and persistence and lead to microevolutionary change. Rob's research will make extensive use of the biological collections available in the UConn herbarium that provide data on plant locality information and physical specimens. These historical records are critical to understanding the long-term impacts of habitat fragmentation on plant populations.

The key features of Rob's proposal that enthuse me are 1) the integrative nature of the work, examining the consequences of altered species interactions on population persistence, structure and microevolution; 2) the parallel examination of temporal variation by examining biological collections data and spatial variation using multiple contemporary forest fragments; 3) the likelihood that his work will open up a new angle to ongoing research in my lab on ecological networks in fragmented landscapes. Additionally, I believe that Rob's intimate knowledge of the natural history of New England's forests, a system I'm relatively new to, will complement my own expertise in quantitative ecology very well.

Relationship of proposal to ongoing research

The research Rob proposes will benefit from synergies with our NSF-funded project (NSF-DEB 1557086, start date December 2016) on how forest fragmentation disrupts food webs involving herbivorous Lepidoptera, their host-plants and avian predators (Fragmented Ecological Networks, FEN). The FEN project will collect detailed data on the effects of fragmentation on antagonistic interaction networks, and Rob's work on beneficial interaction networks will be an excellent complement to that system. In addition, Rob's research will benefit from the infrastructure that we are building for the FEN project, including GIS databases on forest fragments in Connecticut with information on accessibility and historical and current use, permits, trained undergraduate research teams, transport and outreach activities. The complementary nature of the two projects will provide excellent opportunities for collaboration and peer-support between Rob and the postdoc employed on the FEN project. Every summer, I expect to involve 4-5 undergraduate interns in my research in Connecticut, including one McNair's scholar (I am a

Department of Ecology and Evolutionary Biology
75 NORTH EAGLEVILLE ROAD, UNIT 3043
STORRS, CT 06269-3043
PHONE 860.486.6587
FAX 860.486.63641
EMAIL: robert.bagchi@uconn.edu
WEB: http://bagchi.eeb.uconn.edu/

mentor on UConn's McNair program), and Rob will mentor at least one of these students every year. Rob has experience providing outreach programs to education, environmental and professional organizations in Connecticut, that will allow him to effectively take part in the outreach components of the FEN project that facilitate the outreach goals of the PRFB. These activities include talks at local schools and natural history societies, a biodiversity camp for grade 5-9 students in Hartford and insect zoos for parents and children, with programs specific to the topics of the proposal (i.e. biology of ants and forest wildflowers).

Additional projects in my group have developed tools for modeling spatial structures of plant populations as functions of covariates (Replicated Point Pattern Models, RPPMs, Bagchi & Illian, 2015) and we are currently using RPPMs to contrast the effects of hunting on the spatial structures of Amazonian trees with different dispersal syndromes (Bagchi *et al*., in prep). I am keen on applying these methods to new systems to test their usefulness in a variety of contexts to highlight avenues for further code development (R package available at https://github.com/robertbagchi/ReplicatedPointPatterns). I expect Rob will use and contribute to the development of RPPMs as he addresses his second hypothesis that ant-dispersed plants will become more spatially aggregated in small forest fragments.

Current and pending research support

I am currently supported as the lead PI on NSF-DEB-1557086 (*Effects of forest fragmentation on Lepidopteran herbivores of contrasting diet breadth*, 2016-19, $610,420). I am also the lead PI on a Swiss-funded project (ETH Research Grant ETH-42 13-1, *The influence of forest fragmentation on biotic interactions involved in tree establishment and recruitment: the consequences for tree species diversity in tropical forests*, 2013-2016, CHF 196,800). I have a proposal pending as an external collaborator (ETH Research Grant, *FORESTeR: Functioning and Resilience of Ecosystem Services in Tropical* Rainforests, CHF 249,300). As outlined above, there are substantial opportunities for synergies between Rob's research and NSF-DEB 1557086, but little redundancy because Rob proposes to work on dispersal mutualisms, not antagonistic interactions. There is no funding for an additional post-doc on any current or pending projects (we have already hired a postdoc for NSF-DEB-1557086).

Identifying and meeting mentoring needs

Rob will complete a self-assessment (AAAS's MyIDP career planning tool) on arriving at UConn to outline a mentoring plan for the project and beyond. At the start of his position, we will meet to discuss the following topics: (i) independence required of a post-doc, (ii) research accountability, replicability and transparency, (iii) safety requirements, (iv) productivity and importance of scientific publications and (v) work-life balance. He will be encouraged to participate in seminars in the department on career development in EEB, grant proposal preparation and in the departmental internal peer-review panel for NSF applications (preliminary and full proposals). The Graduate School at UConn arranges regular events for postdocs including workshops on preparing job and grant applications (e.g. by Grant Writer's Seminars and Workshops), career development and a university-wide postdoc seminar series. Rob and I will identify conferences for him to attend to present results of his research and expand his research network at the start of his position, with an aim to develop both his local and international profile. Progression towards his career goals, as outlined in his mentoring plan, will be evaluated in 6-monthly meetings with me.

Department of Ecology and Evolutionary Biology
75 NORTH EAGLEVILLE ROAD, UNIT 3043
STORRS, CT 06269-3043
PHONE 860.486.6587
FAX 860.486.6364
EMAIL: robert.bagchi@uconn.edu
WEB: http://bagchi.eeb.uconn.edu/

Sponsor's role in research and training and additional resources

Rob will meet with me nearly daily on an *ad hoc* basis and in scheduled biweekly meetings. He will also participate in biweekly lab meetings. One reason that Rob is particularly keen on joining my group is to learn about experimental design and statistics and I will train him to use R effectively, including mixed-effects models, Bayesian methods (using JAGS and INLA), spatial statistics and simulation-based approaches. I will encourage Rob to simulate the expected responses in each of his experiments and surveys under multiple scenarios prior to collecting data and to optimize protocols and statistical analyses in the light of these simulations. Rob will help me organize the weekly *Statistics in EEB* seminar, in which participants (graduate students, post-docs and faculty) present their statistical analysis and elicit feedback from their colleagues. This will broaden his statistical toolbox and also give him experience in teaching quantitative techniques to graduate students. I will guide him through the process of writing and submitting manuscripts and, eventually, making job applications.

Rob is enthusiastic about joining a dedicated EEB department at a large R1 institution and the opportunities for collaboration and interaction it provides. The contrast between UConn and the liberal arts environments that Rob has become familiar with to date will broaden his experience of university cultures. The UConn herbarium, which houses the biological collections that will be used in this project, lies within the department and the curator, Dr. Robert Capers, is excited by this proposal. In addition to interacting with me and the PIs, PDRA and collaborators on the FEN project, Rob will interact with the diverse faculty in the EEB department. In particular, Rob will use species distribution models in his research and will benefit from interacting with Prof. Tingley who is an expert on Bayesian species distribution models, including presence-only models that incorporate biological collections data. Rob will also interact with Prof. Urban's group: Prof. Urban is a leading expert on the consequences of environmental change for microevolution. Both Prof. Tingley and Prof. Urban are aware of Rob's application are looking forward to collaborating with him.

Limitations regarding the research following fellowship conclusion

None.

In summary, I am looking forward to collaborating with Rob on this very exciting project. I believe that the hypotheses and approaches that Rob has developed will help us better understand how environmental change modifies species interactions and what the consequences of altered interactions will be for population and evolutionary dynamics. I hope that you agree with me.

Yours sincerely

Dr. Robert Bagchi
(Assistant Professor)

Department of Ecology and Evolutionary Biology
75 NORTH EAGLEVILLE ROAD, UNIT 3043
STORRS, CT 06269-3043
PHONE 860.486.6587
FAX 860.486.6364
EMAIL: robert.bagchi@uconn.edu
WEB: http://bagchi.eeb.uconn.edu/

Robert Bagchi
Department of Ecology & Evolutionary Biology
University of Connecticut, Storrs, CT 0629-3043

a. Professional Preparation

Institution	Location	Major	Degree	Year
University of York	UK	Ecology	B.Sc(Hons)	2002
University of Sheffield	UK	Ecology	Ph. D	2007

b. Appointments

2015-Present	Assistant Professor, Ecology and Evolutionary Biology, University of Connecticut, CT, USA
2012-2015	Senior Scientist, Department of Environmental Systems Science, ETH Zurich, Zurich, Switzerland
2010-2012	Post-doctoral Research Associate, Department of Biological and Biomedical Sciences, Durham University, UK.
2007-2010	Post-doctoral Research Associate, Department of Zoology, University of Oxford, UK.
2007-2007	Post-doctoral Research Associate, Institute for Environmental Science, University of Zurich, Switzerland.

c. Products

PRODUCTS MOST CLOSELY RELATED

1. **Bagchi, R.** & Illian, J.B. (2015) A method for analysing replicated point patterns in ecology. *Methods in Ecology and Evolution***, 6,** 482-490.
2. **Bagchi, R.**, Philipson, C.D., Slade, E.M., Hector, A., Phillips, S., Villanueva, J.F., Lewis, O.T., Lyal, C.H.C., Nilus, R., Madran, A., Scholes, J.D. & Press, M.C. (2011) Impacts of logging on density-dependent predation of dipterocarp seeds in a southeast Asian rainforest. *Philosophical Transactions of the Royal Society of London B Biological Sciences,* **366,** 3246-3255.
3. **Bagchi, R.**, Gallery, R.E., Gripenberg, S., Gurr, S.J., Narayan, L., Addis, C.E., Freckleton, R. P. & Lewis, O.T. (2014) Pathogens and insect herbivores drive rainforest plant diversity and composition. *Nature,* **506,** 85-88.
4. **Bagchi, R.**, Press, M.C. & Scholes, J.D. (2010) Evolutionary history and distance dependence control survival of dipterocarp seedlings. *Ecology Letters,* **13,** 51-59.
5. **Bagchi, R.**, Henrys, P.A., Brown, P.E., Burslem, D.F.R.P., Diggle, P.J., Gunatilleke, C.V.S., Gunatilleke, I.A.U.N., Kassim, A.R., Law, R., Noor, S. & Valencia, R.L. (2011) Spatial patterns reveal negative density dependence and habitat associations in tropical trees. *Ecology,* **92,** 1723-1729.

OTHER SIGNIFICANT PRODUCTS

1. Hector, A. & **Bagchi, R.** (2007) Biodiversity and ecosystem multifunctionality. *Nature,* **448,** 188-190.
2. **Bagchi, R.**, Swinfield, T., Gallery, R.E., Lewis, O.T., Gripenberg, S., Narayan, L. & Freckleton, R.P. (2010) Testing the Janzen-Connell mechanism: pathogens cause overcompensating density dependence in a tropical tree. *Ecology Letters,* **13,** 1262-1269.
3. Gamfeldt, L., Snall, T., **Bagchi, R.**, Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M.C., Froberg, M., Stendahl, J., Philipson, C.D., Mikusinski, G., Andersson, E., Westerlund, B., Andren, H., Moberg, F., Moen, J. & Bengtsson, J. (2013) Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications,* **4,** 1340.
4. **Bagchi, R.**, Crosby, M., Huntley, B., Hole, D.G., Butchart, S.H.M., Collingham, Y.C., Kalra, M., Rajkumar, J., Rahmani, A., Pandey, M., Gurung, H., Trai, L.T., Quang, N.V. & Willis, S.G. (2013) Evaluating the effectiveness of conservation site networks under climate change: accounting for uncertainty. *Global Change Biology,* **19,** 1236-1248.
5. Hector, A. Hautier, Y., Saner, P., Wacker, L., **Bagchi, R.,** Joshi, J., Scherer-Lorenzen, M., Spehn, E.M., Bazeley-White, E., Weilenmann, M., Caldeira, M.C., Dimitrakopoulos, P.G., Finn, J.A., Huss-Danell, K., Jumpponen, A., Mulder, C.P.H., Palmborg, C., Pereira, J.S., Siamantziouras, A.S.D., Terry, A.C., Troumbis, A.Y., Schmid, B. & Loreau, M. (2010) General stabilizing effects of plant diversity on grassland productivity through population asynchrony and overyielding. *Ecology,* **91,** 2213-2220.

d. Synergistic activities

1. 2010 – present, Subject Editor for *Biotropica*
2. *Ad Hoc* reviewer since 2007 for NSF (3 proposals) Norwegian Research Council (1 proposal), German Research Foundation (2 proposals), UK NERC (1 proposal) and 25 scientific journals (61 manuscripts).
3. Founding member of the Training and Education Committee of the Association for Tropical Biology and Conservation, which has particular emphasis on capacity building in early-career scientists from tropical countries. I have also taught three, week-long intensive advanced statistics courses under the aegis of this organization.
4. Lead organizer, British Ecological Society Tropical Ecology Group Annual Meeting, Oxford, 2008.
5. Public outreach talks for members of the public (2) high school students (2) field-course groups (4).

PRFB Dissertation Abstract

Ant-sap-feeder mutualists have been described as a "keystone interaction" due to their disproportionate impacts on arthropod food webs. This widespread interaction facilitates increased top-down control of herbivores by ants, potentially driving trophic cascades through reduced herbivory on a sap-feeder's host plants. Despite the ecological importance of this mutualism, the behavioral and community-level mechanisms underlying stronger ant effects in the presence of sap-feeders are poorly understood in natural communities.

To address this question, my dissertation research proposed a series of experiments to examine ant-sap-feeder mutualisms in Northeastern U.S. forests. I first examined ecological variation in ant predation on caterpillar communities and the consequences for forest trees at the community level. This system utilized a diverse assemblage of ants, caterpillars, and sap-feeding Hemiptera (treehoppers) on the tree species *Acer rubrum, Betula lenta, Carya* spp., *Fagus grandifolia, Hamamelis virginiana, Prunus serotina, Quercus alba, Quercus rubra*. Early research determined that ant predation of caterpillars was strongest on host plants with treehoppers, but sap-feeder herbivory attenuated ant indirect effects by altering host plant responses to caterpillars (Clark et al. 2016). Following this early work in 2014, I was awarded an NSF Doctoral Dissertation Improvement grant (DEB-1404177), titled "A mechanistic test of the keystone mutualism hypothesis." I had observed preliminary evidence that ant-sap-feeder mutualisms change ant behavior, ant abundance and ant community structure on forest trees, specifically *Carya* (hickories).

In the first experiments in this project, I developed a technique to manipulate ant community composition on trees, selectively excluding large-bodied ants while allowing small-bodied ants to forage on host plants. Through a factorial manipulation of both ants and sap-feeders, I found that sap-feeders drive recruitment of *Camponotus* ants to host trees, shifting the ant community composition to one biased towards relatively larger ants. I also recorded the impacts of this manipulation on caterpillars and herbivory, observing that strengthened top-down effects of ants occurred on host plans with sap-feeders due to recruitment of *Camponotus* ants (Clark and Singer *in review*). These strengthened ant effects led to measurable trophic cascades in the form of reduced caterpillar herbivory over the course of a single growing season. In addition to community ecology experiments, I examined behavioral ecology of ants engaged in food-for-protection mutualisms, with particular focus on ant aggression towards intraspecific competitors, sap-feeder predators (ladybird beetles), and caterpillars. Experiments examined two dominant ant species *Camponotus chromaoides* (which is behaviorally dominant) and *Formica neogagates* (which is numerically dominant) found in Northeastern U.S. forests. Contrary to predictions, I observed no evidence that sap-feeders altered worker behavior, but instead found that the constitutive behavioral traits of *Camponotus chromaoides* facilitated increased aggression towards competing ants, ladybird beetles, and caterpillars (Clark and Singer *in prep*).

In summary, my dissertation work examined behavioral and community level mechanisms driving the ecological impacts of ant feeding interactions in forest food webs. My training focused on designing experiments to determine the strength of ant predation on caterpillars and record changes to plant herbivory.

University of Connecticut

Department of Ecology and Evolutionary Biology
College of Liberal Arts and Sciences

25 October 2016

Dear Robert,

I am writing to extend an invitation for you to use the collection of the G.S. Torrey Herbarium at the University of Connecticut for your research on the effects of forest fragmentation on understory plant communities. Our specimens go back about 200 years so there should be material here that would be of use.

During your visit, we will make our facilities available for your use and do what we can to ensure that your time is well-spent and productive.

If you have any questions, please don't hesitate to contact me.

Sincerely,

Robert S. Capers, plant collections manager
George Stafford Torrey Herbarium (CONN)

75 North Eagleville Road Unit 3043A
Storrs, Connecticut 06269-3043 USA
Web: bgbaseserver.eeb.uconn.edu
Telephone: (860) 486-1889
Email: robert.capers@uconn.edu