Northeast Climate Adaptation Science Center Final report

ADMINISTRATIVE INFORMATION:

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Project title Characterizing local and rangewide variation in demography and adaptive capacity of a forest indicator species

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Actual total cost of the project: $149,758

PUBLIC SUMMARY:

The red-backed salamander (*Plethodon cinereus*) is considered an indicator of forest health. The range of the species covers much of the eastern and central US, and is often locally abundant where it occurs, primarily in deciduous forest. While there are expectations that changes in climate will result in changes in forest ecosystems, the ability of a forest indicator such as the red-backed salamander to adapt to those changes, has not been assessed. We found that the red-backed salamander may have little adaptive capacity, but that changes in climate conditions may be buffered by salamander behavior, including its typical response to retreat underground during times of high temperature or during short-term drought. Effective conservation measures will likely need to increase the range of within-population climate tolerance in order for populations to persist locally.

PROJECT SUMMARY:

Climate change will have sweeping impacts across the northeast, yet there are key gaps in our understanding about whether species will be able to adapt to this changing environment. Results from this project will illuminate local and region-wide changes in forest ecosystems by better understanding the behavioral and physiologic response of the red-backed salamander, a species that is a strong indicator of forest conditions. We studied multiple populations across the range of the species, which primarily occurs in mature deciduous forests across the northeastern half of North America. We describe the potential adaptive capacity of the salamander using multiple lines of evidence, including field observations of free-ranging populations, behavioral observations in laboratory mesocosms, and measurements of metabolism under different climate conditions. We have found evidence that salamanders will be negatively impacted by warmer temperatures and drier conditions, both in terms of how well they might survive but also in their ability to move around on the forest floor. With reductions in surface activity, there are fewer opportunities to forage or find mates.

Purpose and Objectives:

Methods used to predict species responses to climate change, such as static species distribution or habitat capacity modeling, have limited capacity to account for adaptive potential in forecasts of range shifts and population extinction risk (Charmantier et al., 2008; Urban et al., 2014). Species responses will be affected by 1) the ability of animals to adapt behaviorally, 2) genetic and phenotypic variation within populations, and 3) the degree to which populations are locally adapted to climate differences within their range. Our research focused on the red-backed salamander (*Plethodon cinereus*), an important indicator species of forest health and environmental conditions (Gibbs and Karraker, 2006; Jordan et al., 2008; Welsh and Droege, 2001), as a model species. Hardwood-dominated forests comprise nearly 80% of the northeastern landscape (Thompson et al., 2013) and are a dominant habitat type throughout the Northeast Climate Adaptation Science Center (NE CASC) region. Therefore, understanding the adaptive capacity of red-backed salamanders to environmental changes will improve the development, application, and monitoring of forest management plans.

The range of the red-backed salamander includes forests across the entire NE CASC region, and the species is representative of a large family of terrestrial salamanders (genus Plethodon) with narrow physiological tolerances. This includes 5 species of co-occurring Plethodon salamander which may be at acute extinction risk from landscape change (Brand et al., 2014), but for whom ecological knowledge is more limited. Because range-restricted Plethodon salamanders are often habitat specialists and poor dispersers (Dirnböck et al., 2011), understanding the potential for local adaptation in Plethodonids will improve predictions of population decline or extinction risk for this taxa. The red-backed salamander is the sister species to *P. shenandoah*, and is closely related to other range-restricted species (Pyron and Wiens, 2011), often occurring sympatrically and subject to the same environmental conditions. Though the red-backed salamander has a larger range than *P. shenandoah* and other range-restricted Plethodn (which is hypothesized to be a result of greater adaptive capacity at the species level), there is evidence that populations are locally divergent in key traits which may underlie diversification in this genus (Maerz et al., 2006). This suggests that understanding adaptive capacity in this species has implications for other rare or range-restricted Plethodon in particular, and forest resource condition and response to environmental change in general.

Organization and Approach:

The funding received supported a graduate student and a part-time postdoctoral scientist, which contributed to building capacity among beginning researchers. As such, work on the project goals is being finalized into a dissertation and associated publications. Using both observational and experimental methods, we set out to address three overarching questions in climate change adaptation:

Question 1 –What is the potential for behavioral plasticity to mitigate climate impacts within populations?

Using spatial capture-recapture analyses, we planned to test 3 population-level predictions:

1) that the timing of surface use in the spring and fall varies along a latitudinal climate gradient;

2) that the realized surface conditions when salamanders are on the surface are similar across the latitudinal climate gradient (i.e, salamanders in the north and south behaviorally select for similar temperatures when on the surface);

3) that salamanders shift the timing of surface use based on annual variability in temperatures.

Method 2 – PIT tag study

We had planned to use a laboratory mesocosms study to assess in-situ behavioral changes to environmental conditions (temperature and soil moisture, induced by changing snowpack and precipitation; Hayhoe et al., 2008). We could not address these planned objectives, because the novel application of our PIT-antenna design required more development before implementation in an experimental context. However, we have now conducted this necessary work – (1) confirmed that *P. cinereus* can be tagged with PIT tags, and that this method does not alter survival, growth, or behavior under EMF exposure, and (2) confirmed that sub-surface movements can be detected using PIT tags and a novel antenna configuration in the lab.

Question 2 – Does within-population variation in climate tolerances provides a genetic pool that may facilitate adaptation?

Multiple pathways exist for species to respond to changing climates; however, dispersal-limited species must rely solely on within-population pathways as large-scale movements from degrading habitats are unlikely. We tested predictions using a single population in the center of the salamander's range for which we could find a time series of sufficient length to capture multiple seasons and years of data.

Question 3 – Is there evidence of local adaptation to environmental conditions across the species' range?

While phenotypic plasticity may allow a population to respond to changing environmental conditions, local adaptation may impose limits on the ability of populations to respond to climate change. Thus, understanding among- and within-population variation in potential response is important (Charmantier et al., 2008). If local populations are highly adapted to their current climate, this would suggest that adaptive potential may be limited and that range-wide niche models (e.g., Milanovich et al. 2010) may overestimate the ability of species to cope with change (Urban et al., 2014). We conducted a common garden experiment to measure the degree to which local populations differ in their environmental tolerances. Our goal was to test whether physiological tolerances differ among study areas throughout the range.

Project Results, Analysis and Findings:

This project contributed to graduate student education and professional training, and produced products (with several more in the final draft stages). Here, we provide a brief summary related to the project's proposed steps; more specific details are available in the project's published and forthcoming products.

Question 1 –What is the potential for behavioral plasticity to mitigate climate impacts within populations?

We found that the timing of surface activity differs among populations, while correlations to temperature and recent rainfall are highly conserved among populations. Across populations, timing of surface activity appears similarly to be tied to temperature and recent rainfall, leading to different seasonal activity patterns among populations driven by differing temperature and precipitation regimes. In addition, salamanders in study areas in the south are more active on the surface in the spring compared to the fall. With additional data collection funded by outside collaborators, we have extended the temporal period, and spatial extent of the network over which data were collected, and find similar qualitative patterns (Miller, Grant et al. *in prep*).

Question 2 – Does within-population variation in climate tolerances provides a genetic pool that may facilitate adaptation?

Here, we focused on existing data for a population in the south-central part of range. In Muñoz et al. (2016) we assess adaptive capacity in *P. cinereus*, a dispersal-limited woodland salamander. We used comprehensive mark-recapture data from October 2009 through April 2013 to evaluate its behavioral plasticity and fitness in regards climate variation. Additionally, several lines of previous evidence posit that a common color polymorphism may be a visual indicator for differences in heat and moisture tolerance, so we generated eight predictions based on supposed differences to assess whether the color morph is a legitimate indicator of within-population variation in climate tolerance. We found no support for use of the color polymorphism; however, we did find strong evidence that temperature and rainfall influence *P. cinereus* surface activity, indicating future climate change may restrict suitable conditions for foraging. We also found that warmer temperatures can negatively impact fitness by reducing growth rates. Future reduced growth rates may delay reproductive maturity, further stressing population dynamics.

We found that there were no differences in phenology of surface activity either in the spring or the fall between color morphs. In response to surface activity in relation to climate variables, we see that surface activity decreases at higher temperatures and decreases slightly at lower levels of rainfall. With climate models predicting higher temperatures and higher periods of drought, surface activity may be restricted and fitness may be reduced (foraging and courtship occur on surface). In regards to survival, we also see no differences between morph, but over-summer survival is much lower than winter, suggesting that higher temperatures and stronger desiccation risk play an important role in regulating populations. From this study, we get a clear picture that climate change will impact salamander populations, but it also reveals that the color polymorphism is not sufficient for characterizing within-population genetic variability as has been predicted by the literature.

Question 3 – Is there evidence of local adaptation to environmental conditions across the species' range?

Using *P. cinereus* salamanders collected from 4 populations, we investigated whether the species is able to 1) modify metabolic rates based on thermal cues, 2) adjust rates to future climate conditions, and 3) show consistent responses across populations. This work will be included as a chapter in the dissertation by Munoz (in prep), and subsequently submitted for publication.

We found plasticity in VA and PA populations between spring and summer temperatures. Both populations reduced the magnitude of their maintenance costs after acclimating to summer temperatures. This reduced maintenance costs by 48% for the Virginia population and 27% for the Pennsylvania population. New York and Massachusetts populations showed no plasticity between spring and summer temperatures. No populations showed differences between summer and +4C warming regimes. When acclimated at the same temperature, there were no differences in magnitude or sensitivity among the four populations. Our findings indicate some populations may be locally adapted to warm conditions via plasticity in metabolic rate. Either the southern populations have maintained an ancestral thermal plasticity in metabolic rate, or they have adapted over the past 10000 years to warmer conditions at the southern edge of the species' range. The two northern populations exhibited no plasticity across the three regimes, and the two southern populations showed no differences between summer and climate warming regimes. This indicates these four populations are likely at the limit of their thermal plasticity and will not likely be able to avoid higher maintenance costs in the future. Future increases in maintenance energy costs will likely threaten population persistence across the species' range.

Conclusions and Recommendations:

Regarding the adaptive capacity of red-backed salamanders across their range, the research supported by the NE CASC provides some insight. First, surface activity of salamanders across populations appears to respond similarly to temperature and rainfall, suggesting that there is not local adaptation to foraging on the forest floor. Individual growth rates suffer, as expected, as metabolic costs under warmer temperatures increase, and though prior work suggests that the two color morphs have differential susceptibility to increased temperatures, our work in a range-center population fails to find support for this difference. This is despite evidence that populations from warmer climates have greater metabolic plasticity. However, these populations may be at the edge of their thermal tolerance, meaning that they lack adaptive capacity to exposure to increased temperatures. While these observations suggest a limit to the physiologic adaptive capacity, populations may still retain behavioral adaptive capacity in the timing of surface activity. Our current research is following up on this hypothesis to test the subsurface activity and physiologic responses to edaphic climate conditions.

Challenges encountered in achieving the research objectives included:

1) Technological advances in subsurface detection are needed before PIT methods are implemented in the field. We applied, and were recommended, for additional USGS funding to support development of the technology, but funding was not awarded in that particular fiscal year. Nonetheless, we have demonstrated that the technology may be adapted to describe the subsurface behavior of terrestrial salamanders, and are currently conducting research using this technology.
2) Timescale to fully achieve the project objectives was ambitious, when relying on natural variation in climate conditions to relate to population demographic rates. While we were not able to estimate the effects of winter severity on salamander survival across the range, the NE CASC funding was critical in establishing the network necessary to address this question. With additional years of data, we will be able to fully address this question.

Nevertheless, our results have relevance to forest management across the northeastern US. As resource managers are unable to simultaneously manage habitat for every species, USFWS has chosen a set of surrogate species for development and application of predictive models, choosing among management options, and monitoring changes in resource condition and response to management treatments. Terrestrial, forest-dependent amphibians are not among the list of candidate species, though red-backed salamanders and other species of Plethodon are considered indicators of forest condition (Welsh and Droege, 2001).

Outreach and Products:

Articles in preparation, under review, accepted, or published in peer reviewed journals and other non-peer reviewed journals:

Muñoz D., Miller DAW, Schilder R, Grant EHC. In prep. Intraspecific variability in metabolic plasticity to warmer temperatures in the red-backed salamander, Plethodon cinereus. PNAS

Muñoz D., Miller D.A.W., Sutherland C., Grant E.H.C. 2016.Using spatial capture-recapture to elucidate population processes and space-use in herpetological studies. Journal of Herpetology(50):570-581

Muñoz D., Miller Hesed K., Grant E.H.C., Miller D.A.W. 2016. Evaluating within-population variability in behavior and fitness for the adaptive potential of a dispersal-limited species to climate change. Ecology and Evolution(6):8740-8755

Sutherland, C., Munioz, D., Miller, D., Campbell Grant, E. 2016. Spatial Capture-Recapture: a Promising Method for Analyzing Data Collected Using Artificial Cover Objects. Herpetologia 72:6-12.

Sterrett, S.C., A.B. Brand, W.R. Fields, R.A. Katz and E.H.C. Grant. 2014. Plethodon cinereus (Eastern Red-backed Salamander). Movement. Herpetological Review. 46(1):71.

Project-related conference presentations, seminars, webinars, workshops, or other presentations to the public made by research team members:

Conference

Muñoz, D, DAW Miller, EHC Grant, C Sutherland, T Matlaga, A Brand, A Dietrich, S Sterrett. 2017. Seasonal Growth Rates and Responses to Increasing Temperature Across Five Red-Backed Salamander Populations. Wildlife Society Annual Meeting.

Muñoz, D, DAW Miller, T. Matlaga, C Sutherland, S Sterrett, EHC Grant, A Brand. 2017. Responses of Individual Growth Rates to Warm Weather Conditions in Five Populations of the Red-backed Salamander, Plethodon cinereus. Northeast Partners in Amphibian and Reptile Conservation.

Muñoz, David, Sean Sterrett, Evan Grant, Adrianne Brand, David Miller. 2017. Barriers to managing for climate change: a case study. PA Wildlife Society Meeting

Muñoz, D. Research in Progress: Population Analyses and Physiology Study. 2016. SPARCnet Annual Meeting.

Sterrett, S.C., E.H.C. Grant, A.B. Brand, A. Dietrich, D. Munoz, D.A.W. Miller. 2015. Gaining knowledge and improving societal value for terrestrial salamanders: A model for amphibian conservation. Ecological Society of America. Invited presentation: Special Session - “Frontiers in Amphibian Conservation.”

Muñoz, David, Sean Sterrett, Evan Grant, Adrianne Brand, David Miller. 2015. The Salamander Population and Adaptation Research Collaboration Network (SPARCnet): The First Two Years in Regional Population Monitoring. Paper presented at Northeast Partners in Amphibian and Reptile Conservation

Muñoz, David, K. Miller Hesed, EHC. Grant, D. Miller. (2015). Predicting climate change adaptive potential in red-backed salamanders: within-population variation in responses to climate. Paper presented at Ecological Society of America.

Brand, A.B., A. Dietrich, E.H.C. Grant, D.W. Miller, D. Munoz, and S.C. Sterrett. 2014. Response of Plethodon cinereus to variation in soil freezing: the design and first year of SPARCnet. The Wildlife Society, Pittsburgh, Pennsylvania.

Sterrett, Sean C.,Todd D. Dubreuil, Matt O'Donnell and Evan H.C. Grant. 2014. Development of a novel passive integrated transponder (PIT) vertical telemetry system for studying subterranean movements of woodland salamanders (Plethodon) Joint Meeting of Ichthyologists and Herpetologists.

Outreach:

Understanding Salamander Responses to Climate Change (And Other Discoveries Along the Way). 2018. Lancaster Herpetological Society

How many animals are out there? Raleigh Charter High School: AP Statistics. 2017

How do animals respond to climate change? Raleigh Charter High School: AP Environmental Science. 2017

How many salamanders are there? 2017. Activity station at PA 4H Wildlife and Forestry Day.

A phenological tour of woodland salamander ecology with musings on citizen science. 2017. A presentation at the Hitchcock Center for the Environment (Amherst, MA), a citizen science collaborator.

Philadelphia Zoo ZooCrew Wildlife Conservation Weekend at Penn State. 2017.

Where are all the salamanders? How scientists study this sneaky amphibian. 2015. 4-H Wildlife and Forestry Field Day Guest Speaker.

On-going collaboration with Massachusetts Elementary Schools.

Literature Cited

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Hayhoe, K., Wake, C., Anderson, B., Liang, X.-Z., Maurer, E., Zhu, J., Bradbury, J., DeGaetano, A., Stoner, A.M., Wuebbles, D., 2008. Regional climate change projections for the Northeast USA. Mitig. Adapt. Strateg. Glob. Chang. 13, 425–436. https://doi.org/10.1007/s11027-007-9133-2

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Muñoz, D.J., Miller Hesed, K., Campbell Grant, E.H., Miller, D.A.W., 2016. Evaluating within-population variability in behavior and demography for the adaptive potential of a dispersal-limited species to climate change. Ecol. Evol. 6. https://doi.org/10.1002/ece3.2573

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Thompson, J.R., Carpenter, D.N., Cogbill, C. V, Foster, D.R., 2013. Four centuries of change in northeastern United States forests. PLoS One 8, e72540. https://doi.org/10.1371/journal.pone.0072540

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Welsh, H.H.J., Droege, S., 2001. A case for using Plethodontid salamanders for monitoring biodiversity and ecosystem integrity of North American forests. Conserv. Biol. 15, 558–569.