B A N I S T E R I A

A JOURNAL DEVOTED TO THE NATURAL HISTORY OF VIRGINIA

ISSN 1066-0712

Published by the Virginia Natural History Society

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Banisteria 56: 10–17

RESEARCH ARTICLE

ASSESSING THE EFFECTS OF ELEVATION ON THE PEAKS OF OTTER SALAMANDER (*PLETHODON HUBRICHTI*) USING BODY CONDITION INDEX

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Editor: T. Fredericksen | Received 14 June 2022 | Accepted 8 July 2022 | Published 13 July 2022

https://virginianaturalhistorysociety.com/banisteria/banisteria.htm#ban56

Citation: Reichenbach, N., E. Russell, H. Suber, H. Kinsley, L. Cusack, C. Dawson, S. Dunn, O. de Arujo and T. R. Brophy. 2022. Assessing the effects of elevation on the Peaks of Otter Salamander (*Plethodon hubrichti*) using body condition index. Banisteria 56: 10–17.

ABSTRACT

The Peaks of Otter Salamander (*Plethodon hubrichti*; POS) is a montane species found at elevations above 442 m within a 117 km^2 area of the Blue Ridge Mountains in central Virginia. In allopatric areas (areas without the Eastern Red-backed Salamander, *P. cinereus*, a known competitor), POS body condition was hypothesized to decline both above and below some optimal elevation. Decreased condition at lower elevations would most likely be due to increased temperatures and lower relative humidities, which may adversely affect the ability of salamanders to forage effectively on vegetation due to desiccation risk. Decreased condition at elevations above the optimum would likely be caused by a shortened active season due to the colder temperatures at these elevations. In October 2018, POS were collected by turning over rocks and logs at eight sites ranging in elevation from 518 to 1143 m. The mass and snout-vent length (SVL) of female POS were measured at each elevation. From these SVL and mass data, residual salamander condition index values were calculated and regressed against elevation. The relationship between salamander condition and elevation was curvilinear with highest POS condition at 1025 m (0.18). Below this elevation POS condition declined linearly over approximately 375 m to a low of -0.17. Above 1025 m, POS condition declined linearly over approximately 125 m to 0.07. The residual condition index followed similar trends across elevations for density and reproductive output for this species, making it a simple and less time-consuming surrogate measure for these demographic variables. These results support the importance of conserving mature, hardwood forests, particularly at lower elevations, which represent fragile environments for POS.

Keywords: Plethodontidae, ecology, montane salamander, body condition index.

INTRODUCTION

The Peaks of Otter Salamander (*Plethodon hubrichti*; POS) has a restricted distribution of about 117 km^2 in the Blue Ridge Mountains of central Virginia. This species is found at elevations greater than 442 m in mature, hardwood forests, primarily on National Park and National Forest property (Pague & Mitchell, 1990; Petranka, 1998). Its range was shown to be limited by competition with the Eastern Red-backed Salamander (*P. cinereus*) in areas of sympatry (Brophy & Reichenbach, 2020). In addition to competition, elevation may be a major factor limiting the distribution of this and other montane species in allopatry (i.e., where congeneric competitors are absent) since their relative health tends to decline with elevation. Past studies have suggested this relationship to be due to increases in temperature and decreases in relative humidity as elevation declines (Hairston, 1951, 1981; Kozak & Wiens, 2006; Reichenbach & Brophy, 2017). At elevations below 900 m, densities, survival rates, growth rates, eggs per female, and relative reproductive output of surface-active (SA) POS decreased with elevation as environmental conditions became warmer and drier (Reichenbach & Brophy, 2017). Additionally, at elevations above 1100 m, these same demographic parameters declined due possibly to colder temperatures resulting in shorter active seasons (Reichenbach & Brophy, 2017). Therefore, high and low elevation sites represent particularly fragile environments for POS.

Estimating the demographic parameters noted above requires a great deal of time and field work. Body condition might be a simpler measure to assess the effects of elevation on overall fitness, as has already been done for assessing the impact of land management practices on salamanders (Riedel et al., 2012; Mazerolle et al., 2021). The residual condition index is a body condition index that regresses body mass against body size and estimates body condition based on the distance of individual animals from the resulting regression line. Animals that fall above the regression line are considered in better condition compared to those below the line (Jakob et al., 1996).

Here we examine the use of the residual condition index for assessing the impact of elevation on the condition of allopatric POS populations along an elevational gradient. We hypothesize that POS body condition will decline both above and below some optimal elevation.

MATERIALS AND METHODS

On the 13th and 20th of October 2018, seven people collected POS during the cool daytime hours, several days after rain when the forest floor was still moist. Salamanders were collected by carefully turning over rocks and logs at eight of the same allopatric sites used by Reichenbach & Brophy (2017) to assess SA densities, survival rates, growth rates, eggs per female, and relative reproductive output along an elevational gradient (518, 579, 655, 762, 991, 1052, 1128, and 1143 m). The goal of the present study was to collect at least ten female POS per site. Only females were used in this study to reduce variability in the condition index values calculated that might be due to sex and because we were comparing our condition index values to POS reproductive output calculated previously by Reichenbach & Brophy (2017). Approximately one hour of collection and measurement were performed at each site, with four sites being done on 13 October 2018 and the other four sites on 20 October 2018. All POS found were temporarily placed in zip-lock bags with damp paper towels and then placed in coolers. We limited the number of salamanders placed in each bag to avoid overcrowding during field collection activities. Prior to determining sex and taking measurements, POS were separated into individual zip-lock bags. The sex of each salamander was determined by the presence/absence of testes and vas deferens, which can be seen using a non-destructive candling method with an LED light (250 lumens LED headlamp, Craftsman CMXLHB1, Craftsman Corp. Towson, Maryland) (Gillette & Peterson, 2001; Reichenbach & Brophy, 2017; Rucker et al., 2021). Females with complete tails, were measured for mass (g), using an electronic balance (± 0.01 g; Scout Pro SP202, Ohaus Corp., Pine Brook, New Jersey, USA), and snout-vent length (SVL) using the salamander-stick method with digital calipers (CD-6"CSX, Mitutoyo Corp., Aurora, Illinois, USA) (Walston & Mullin, 2005). All salamanders were returned to their capture area following processing, usually within 30 min after capture.

Residual condition index values were calculated for all female POS by regressing mass against SVL (Jakob et al., 1996). The condition index values for POS from all eight sites were then regressed against elevation. For all statistical tests $\alpha = 0.05$. Finally, graphical comparisons were made between the mean and predicted condition index values per elevation relative to predicted SA POS densities and eggs per 1000 m^2, with the latter values being obtained from prior research using regression models fit to data on POS (Reichenbach & Brophy, 2017).

Results and Discussion

Only four female salamanders were collected at the lowest elevation of 518 m due to low salamander density. Eighteen female salamanders were found at 579 and 655 m; 15 at 762, 1128, and 1153 m; 16 at 991 m; and 13 at 1052 m for a total of 114 female POS. Our sites at 1128 and 1153 m are some of the highest elevations in the range of POS where it is not sympatric with *P. cinereus* (Reichenbach & Brophy, unpublished data).

As SVL increased, mass increased linearly [mass(g) = - 2.9076 + 0.0910 (SVL (mm))] ($F=533.6$, $df=1, 112$, $P=2.07\times10^{-44}$, $r^2=0.83$; Fig. 1). The relationship between salamander condition and elevation was curvilinear with highest POS condition at 1025 m (0.18). Below this elevation POS condition declined linearly over approximately 375 m to a low of -0.17. Above 1025 m, POS condition declined linearly over approximately 125 m to 0.07 (condition = 4.539 - 0.0192 (elevation(m)) + 2.504×10^{-5} (elevation^2(m^2)) - 1.019×10^{-8} (elevation^3(m^3)) ($F=16.1$, $df=3, 110$, $P=9.83\times10^{-09}$, $r^2=0.30$; Fig. 2).

The rising trend for POS condition from low to optimal elevation is likely related to foraging efficiency. After a rainfall event, the forest is damp and humidity levels are high enough to permit POS to climb vegetation at night without risking desiccation (Jaeger, 1978; Kramer et al., 1993). Salamanders foraging on damp vegetation do so with greater efficiency relative to those foraging on the forest floor (Jaeger, 1978) and also avoid ground-dwelling predators (Roberts & Liebgold, 2008; McEntire, 2016). Humidity tends to increase with elevation, likely allowing salamanders at higher elevations to forage more frequently on vegetation with less risk of desiccation (Reichenbach & Brophy, 2017). Thus, these salamanders tend to develop into healthier animals overall. In contrast, POS found at the lower elevation sites were noticeably thinner than those found at elevations above 900 m (see Fig. 2). Salamander condition probably declines in these areas due to relatively warmer and drier environments (Reichenbach & Brophy, 2017) that reduce the number of days salamanders can forage on vegetation without risk of desiccation. Similar declines in condition observed at the highest elevations, although to a lesser degree, might be due to colder temperatures (Reichenbach & Brophy, 2017). This could result in a shorter active season for POS where salamanders stay underground for longer periods of time during which little feeding occurs (Heatwole, 1962; Fraser, 1976; Feder, 1983).

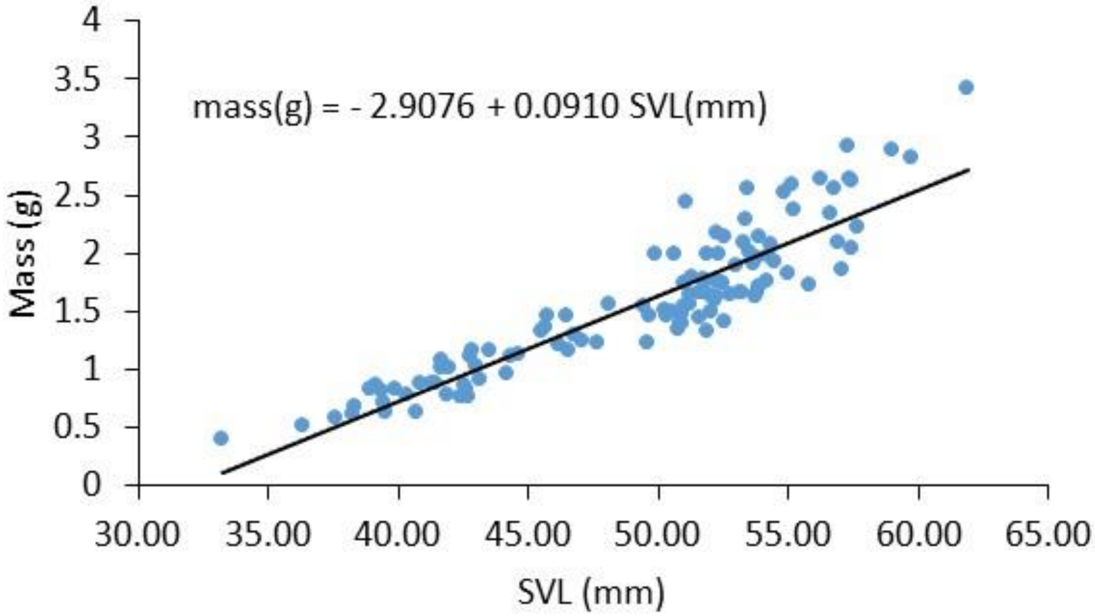

Figure 1. Relationship between mass and snout-vent length (SVL) for Peaks of Otter Salamanders, *Plethodon hubrichti*, collected from elevations ranging from 518 to 1143 m.

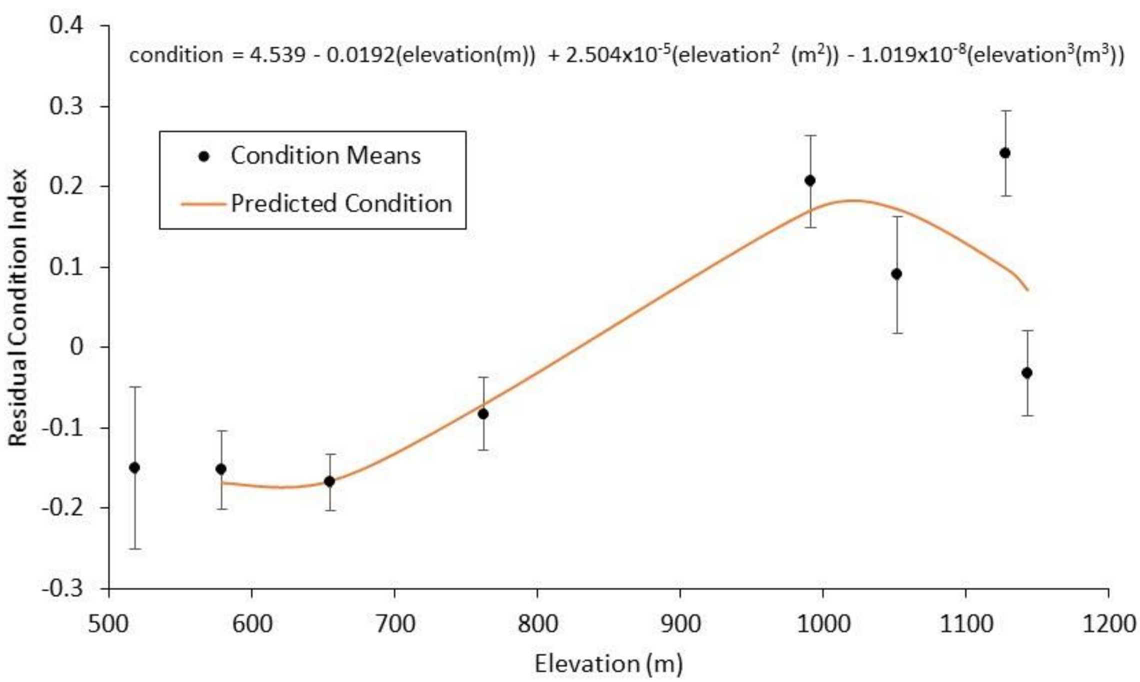

Figure 2. Relationship between residual condition index values (mean ± 1 SE) and elevation for Peaks of Otter Salamanders, *Plethodon hubrichti*, collected from elevations ranging from 518 to 1143 m.

The condition index values calculated across elevations followed a trend similar to predicted SA POS densities (salamanders per m^2) and number of POS eggs per 1000 m^2 (Reichenbach & Brophy, 2017). These two demographic measures increased with elevation to maxima between 900 and 950 m (Figs. 3 & 4). Predicted optimal elevations between our condition index values (1025 m) and these other two measures (900-950 m) might not be exactly the same because POS were collected during different years (2018 for condition indices and 2007-2008 for the other measures).

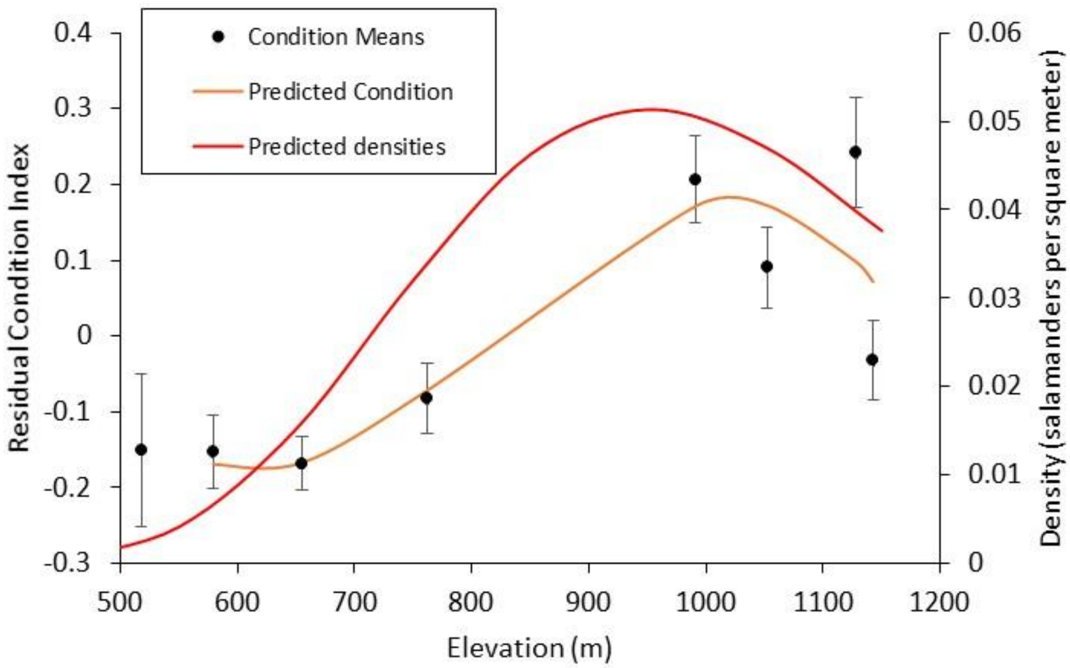

Figure 3. Relationship between residual condition index values, predicted surface-active salamander densities and elevation for Peaks of Otter Salamanders, *Plethodon hubrichti*, collected from elevations ranging from 518 to 1143 m. Densities from Reichenbach & Brophy (2017).

Our results showed the residual condition index to be a simple method for assessing the effects of elevation on POS and suggest that it might be used as a surrogate measure for other demographic characteristics. Residual condition indices can be obtained at a considerable time savings when compared to other demographic parameters like SA densities and reproductive output. We estimated the total person hours for assessing the demographic parameters in Reichenbach & Brophy (2017) to be 1920 h, compared to only 112 h for the body condition index work in the present study. Thus, body condition is a relatively simple measure that can be used to quickly assess the effects of environmental parameters, like elevation, on POS and possibly other salamander species.

This information could be used in the conservation of POS, as well as other montane species such as the federally threatened Cheat Mountain Salamander (*P. nettingi*; Pauley, 2022), to identify particularly fragile environments at elevations above and below the optimum. At low elevations, POS would be particularly susceptible to certain types of environmental changes and land management practices that cause increases in temperature and/or declines in relative humidity. For example, timbering conducted at low elevation sites would open the forest canopy and cause increases in temperature and decreases in relative humidity on the forest floor (Homyack et al., 2011; Reichenbach & Brophy, 2017). This in turn might reduce the number of days POS

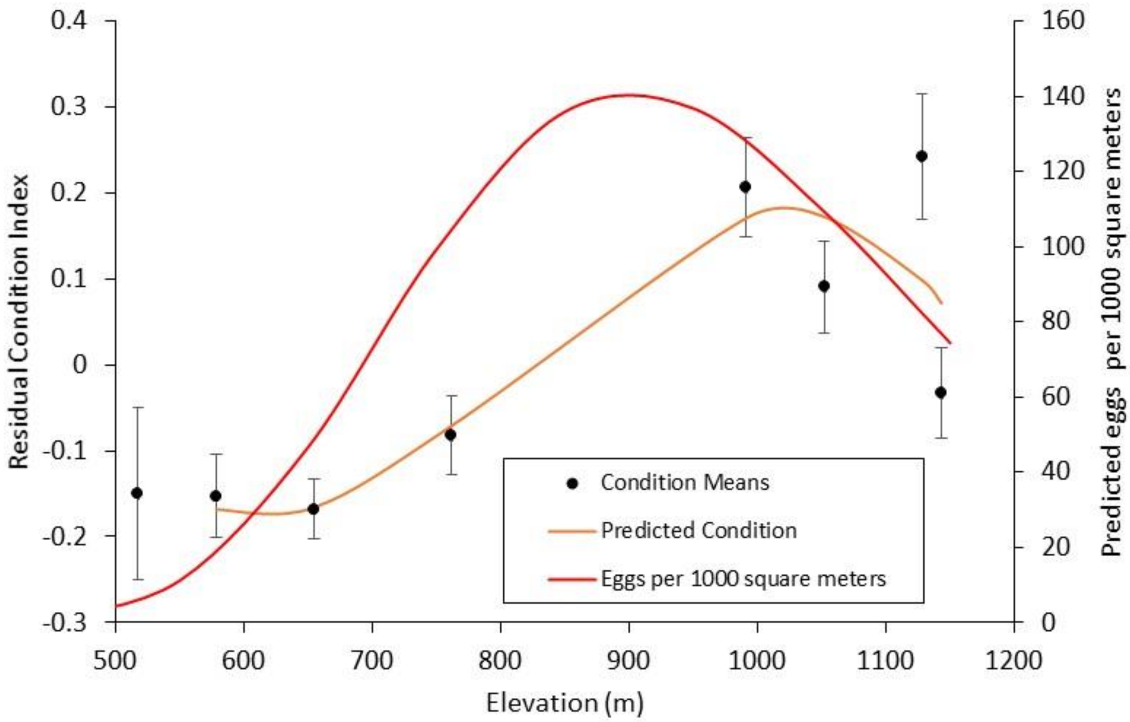

Figure 4. Relationship between residual condition index values, predicted eggs per 1000 m^2 and elevation for Peaks of Otter Salamanders, *Plethodon hubrichti*, collected from elevations ranging from 518 to 1143 m. Predicted eggs per 1000 m^2 from Reichenbach & Brophy (2017).

could effectively forage on vegetation and, therefore, we predict that body condition would decline beyond that seen in this study from the effects of elevation alone. Moreover, if such timbering practices were conducted in low elevation areas where POS is sympatric with the Eastern Red-backed Salamander, we predict that the altered conditions would impact POS to a greater degree than *P. cinereus* since POS has higher dehydration rates and lower critical thermal maxima (Reichenbach & Brophy, 2017). This might, in turn, promote encroachment by *P. cinereus* on the already limited distribution of POS. A comparable scenario is described by Pauley (2005) in the competitive interaction between *P. cinereus* and the montane species, *P. nettingi*. He found that *P. nettingi* lost body moisture faster than *P. cinereus* and that clearcutting disturbances were consequently more stressful to *P. nettingi* than *P. cinereus*. He further noted that *P. cinereus* and another salamander competitor restricted the distribution of *P. nettingi,* and that restoring *P. nettingi* to their historical distribution would require both habitat restoration and elimination of the two salamander competitors with the latter being a virtually impossible task.

Acknowledgements

Permits for this study were obtained from the Virginia Department of Wildlife Resources, National Park Service (National Park Scientific Research and Collecting Permit BLRI-2018-SCI-0006), and National Forest Service. This study complies with ethical guidelines, regarding the use of live amphibians in field research, as described by the Herpetological Animal Care and Use Committee of the American Society of Ichthyologists and Herpetologists (2004). Kirk Ricketts helped collect salamanders in 2018 and Jesse Hughes, Josh Twiddy, Cass Rupert, and Paul Sattler helped with preliminary fieldwork on the condition index in 2017. We also thank two anonymous reviewers for their helpful comments.

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