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ASSESSING THE ABUNDANCE OF CAUCASIAN SALAMANDER, *MERTENSIELLA CAUCASICA* (CAUDATA, SALAMANDRIDAE), WITH N-MIXTURE MODEL IN NORTHEASTERN ANATOLIA

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Assessing the Abundance of Caucasian Salamander, *Mertensiella caucasica* (Caudata, Salamandridae), with N-mixture Model in Northeastern Anatolia. Yakın, B. Y., Arslan, D., Çiçek, K., Tok, C. V. — The endangered Caucasian salamander, *Mertensiella caucasica* (Waga, 1876), is endemic to the western Lesser Caucasus. Here, we used N-mixed models to analyse repeated count data of Caucasian salamanders from the eastern Black Sea region of Turkey. We estimated a mean detection probability of 0.29, a population size of 21 individuals, and a range of 9 to 36 individuals per 20 × 10 m plot. Our results provide preliminary data on the population status of the Caucasian salamander in northeastern Anatolia. These results would contribute to the effective management and conservation of the species.
Key words: abundance estimation, Caucasian salamander, *Mertensiella caucasica*, Turkey.

Introduction

The Caucasus Ecoregion covers more than 500,000 km^2, containing Azerbaijan, Georgia, and Armenia, the North Caucasian part of the Russian Federation, northwestern Iran, and northeastern Turkey (Zazanashvili et al., 2020). With its distinctive biodiversity and high endemism, the Caucasian area is one of the 36 designated biodiversity regions in the world (WWF, 2018). The region is home to fourteen amphibian species, four of which are endemic (Tuniyev et al., 2020). The Caucasian Salamander, *Mertensiella caucasica* (Waga, 1876), is one of the endemic and endangered amphibians of the region, distributed in the western part of the Trialeti mountain range, in the Meskhetian and Lazistan regions of Georgia (Kaya et al., 2009), and in the north-eastern part of Anatolia, Turkey (Ardahan, Artvin, Bayburt, Giresun, Gümüşhane, Ordu, Rize Trabzon) (Başoğlu et al., 1994; Sparreboom, 2014, Çiçek et al., 2018 a; Yaşar et al., 2021). Due to its area of occupancy being less than 2000 km^2 and its severely fragmented distribution, *M. caucasica* is listed as a Vulnerable category in the IUCN Red List (Kaya et al., 2009). The species inhabit relatively narrow streams up to about 2800 m a. s. l. (Franzen, 1999), which are typically no wider than 1–1.5 m and only 20–30 centimeters deep in the spring (Tarkhnishvili & Gokhelashvili, 1999; AmphibiaWeb, 2023). The Caucasian salamander is found along the banks of mountain creeks and small rivers, mainly in the subalpine belt, in the beech, mixed forests, coniferous, and in alpine meadows (Tarkhnishvili & Gokhelashvili, 1999; Tarkhnishvili & Kaya, 2009; Kaya et al., 2009, Sparreboom, 2014).

Counting species and estimating population size is essential for monitoring and understanding the status of a species over time (Ficetola et al., 2018). This information can help identify trends and patterns and can inform conservation efforts to protect endangered or threatened species. Unfortunately, this could be a challenging mission for rare species due to many factors, such as their cryptic habits, elusive behavior, or the surveyors' limited ability (Mazerolle et al., 2007). For this reason, several estimation methods have been developed to detect the exact number of individuals (Ficetola et al., 2018). Capture-mark-recapture (CMR) methods are widely used and considered to be one of the most appropriate techniques for estimating population parameters, such as abundance, occupancy, and species richness, as well as vital rates such as survival probabilities and extinction probabilities (Williams et al., 2002; Mazerolle et al., 2007). However, these approaches require capturing and identification of individuals, which is mostly labor-intensive to determine reliable population estimates (Ficetola et al., 2018). Recently, N-mixture modeling framework has been proposed to estimate animal abundance from repeated counts at stable sites based on counts of unmarked individuals (Royle & Nichols, 2003; Royle, 2004 a, b; Ficetola et al., 2018), and can be considered as a hierarchical variant of a CMR model (Kéry, 2018). N-mixture models (Royle, 2004 a) are frequently used in recent studies to estimate the abundance of amphibians and reptiles (Mazerolle et al., 2007; Kéry et al., 2009; Romano et al., 2017) due to its limited sampling effort, not need to manipulate individuals, and cost-effectiveness (Ficetola et al., 2018; Costa et al., 2020).

Capture-mark-recapture methods determine the population status of very few amphibians in Turkey, but this number is hardly any for caudatans (e. g., Mermer et al., 2008; Başkale & Kaya, 2009; Dereağzı, 2016; Çiçek & Cumhuriyet 2017; Arslan et al., 2020). The Caucasian salamander, *Mertensiella caucasica* (Waga, 1876), is a medium-sized stream-dwelling salamander, endemic to the southwestern Caucasus in Georgia and Turkey (Tarkhnishvili & Gokhelashvili, 1999; Tarkhnishvili & Kaya, 2009; Sparreboom, 2014; Yaşar et al., 2021). The distribution of the Caucasian salamander consists of two evolutionary lineages that have been fully separated since the Pliocene: Black Sea Basin and Borjomi Gorge in Central Georgia (Tarkhnishvili et al., 2000). Unfortunately, there are limited studies on its population status in Turkey (e. g., Tarkhnishvili & Kaya, 2009; Çiçek et al., 2018 b), which accounts for more than half of its distribution. The knowledge of ecology and population status of the species is mostly based on studies in Georgia, summarized by Tarkhnishvili & Gokhelashvili (1999). Nevertheless, knowledge about the population status of Caucasian salamanders is still insufficient and consists of descriptive information, including threats and conservation (e. g., Tarkhnishvili & Kaya 2009; Çiçek et al., 2018 b). The lack of knowledge of the species' population in northeastern Anatolia leaves us unable to conduct efficient and accurate conservation and management studies. In this study, we attempted to estimate the abundance of Caucasian salamander from Northeastern Anatolia, Turkey, with the N-mixture modeling approach.

Material and Methods

The survey was conducted in the Turkish districts Giresun, Trabzon, Gümüşhane, Rize, and Artvin, which are in the species distribution range in northeastern Anatolia (fig. 1). The study sites are covered with broad-leaved forests growing in a humid, temperate climate along the Black Sea coast and coniferous forests growing in a humid, cold climate in mountainous highlands (a humid subtropical climate Köppen: Cfa, Beck et al., 2018).

As part of the project conservation plan for the Caucasian salamander, 30 days of intensive fieldwork were carried out between June–July 2017 with a 2–3 people team by using visual encounter survey methodology (Guyer & Donnelly, 2012). We selected 5 sampling plots with 20*10 m size per sampling province, a total of

Fig. 1. General view of study area.

25 plots sampled representing suitable habitats of the species. We spent 10–15 min per plot counting the salamanders. Plot boundaries were marked with wooden sticks and GPS coordinates were recorded (table 1). At each plot, 5 replicate surveys are conducted within 3 weeks with almost constant meteorological conditions (9–11 °C temperature; no rain) during the peak of activity season. All surveys were performed after dusking due to salamander activity is often higher in this period of the day (Tarkhnishvili & Gokhelashvili, 1999). The overall study area was surveyed in three periods, depending on the transportation distance between localities. We divided the study location into three parts (1. Ordu — Giresun — 2. Trabzon — Gümüşhane, 3. Rize — Artvin) and sampled in one-week intervals.

We used the N-mixture modeling approach based on repeated counts to estimate population size (Royle, 2004 a) with a simple Poisson model and without any covariates. We built our models based on the closed population approach in N-mixture, which assumes immigration and emigration do not occur (Royle, 2004 a, b). This approach gives reliable results as mark-recapture in estimating population sizes of small vertebrate species such as salamanders (Ficetola et al., 2018). We used Akaike's Information Criterion (AIC) (Burnham & Anderson, 2002) to select the most appropriate error distribution (Poisson or zero-inflated Poisson); we excluded negative binomial errors because they can result in indefinite abundance estimates, especially when detection probability is low (Ficetola et al., 2018). Since the overall study area could not be sampled all at once thus, we considered the week of the survey as a covariate potentially affecting the detection probability of the salamanders. The empirical Bayesian method was used to estimate the posterior distribution (mean and 95 % CI) of salamander abundances. We used the "unmarked package" (Fiske & Chandler, 2011) to build N-mixture models in R v.4.0.1 environment.

Results and Discussion

During the fieldwork, we observed 363 salamanders (range: 0–20 individuals per plot in each survey) during 5 repeated surveys (fig. 1). In N-mixture models, the Poisson model (model without covariates: AIC: 720.5) is used due to lower AIC values than the zero-inflated Poisson model (AIC: 722.5), indicating a better fit of the model to the data. An average detection probability of 0.29 (0.21–0.38) was estimated. The average population size was 21 individuals (SE = 3.157, CI = 15.64–28.20) and ranged between 9 and 36 individuals per plot (fig. 2, table 1).

The Caucasian salamander is a rare species with a patchy spatial distribution, and outnumbered individuals could be observed in suitable habitats (Tarkhnishvili & Gokhelashvili, 1999; Tarkhnishvili & Kaya, 2009; AmphibiaWeb, 2023). Its population may vary between 100 and 300 individuals in southwestern Georgia (Tarkhnishvili & Gokhelashvili, 1999). A long-term CMR study at one locality estimated the local population size about 1,000 adults and recorded average 10 individuals per 10 m along the stream bank in Borjomi Canyon, central Georgia (Tarkhnishvili & Serbinova, 1993). Similarity, based on a CMR study in the closest relative salamander *Chioglossa lusitanica,* the population size was estimated at 1300 individuals with four to five specimens estimated per meter of brook habitat, and 2 and 38 individuals were observed per 100 m in the surroundings of Porto (Portugal) (Arntzen, 1981). Ficetola et al. (2018) estimated the number of Lanza's Alpine salamander ranged between 0.4 and 14.7 individuals per plot (20 × 10 m) and an average detection probability of 0.14. The

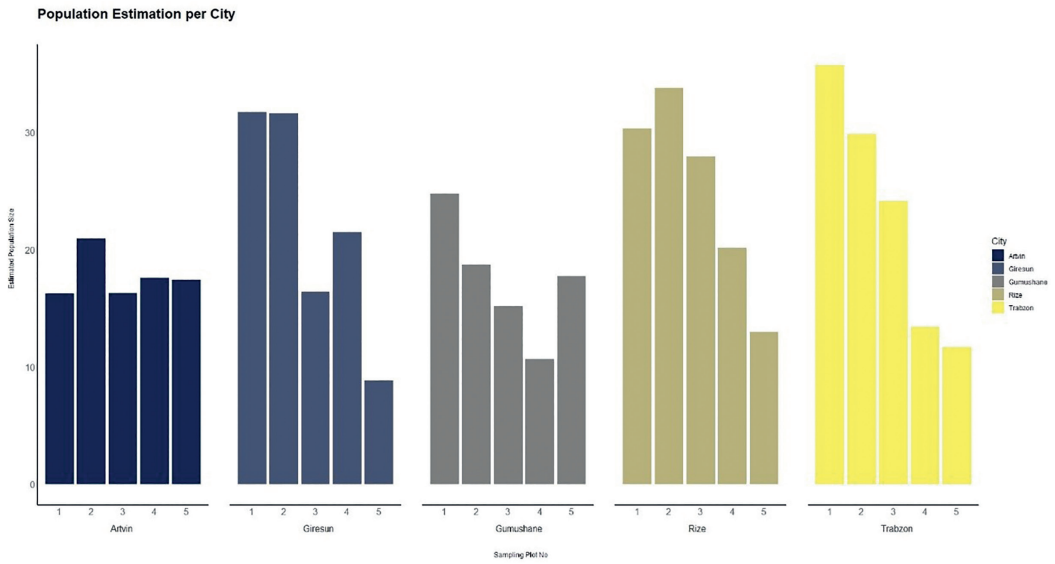

Fig. 2. The average abundance of Caucasian salamanders from the East Black Sea Region, Turkey. X-axis shows the sampling plots number in each city; Y-axis shows the estimated population size.

authors have also compared the results with the plots nearby the CMR study area (Andreone et al., 1999); the average density of salamanders via the N-mixture model was higher and closer to the estimates obtained using CMR. We found a high density of Caucasian salamanders near logs and wooden blocks mixed with small mountain streams flowing unevenly, consistent with Tarkhnishvili & Gokhelashvili (1999), which suggests that these types of habitats are important for the species.

Table 1. Abundance estimates of Caucasian salamanders from the East Black Sea Region, Turkey

Sampling City	Latitude	Longitude	Elevation, m	Plot ID	Mean	Mode	2.50 % CI	97.5 % CI
Trabzon	40.662380°	39.669350°	1610	*P1*	36	35	30	42
Trabzon	40.618130°	40.313180°	1385	*P2*	30	30	25	36
Trabzon	40.694340°	40.086570°	1949	*P3*	24	24	19	30
Trabzon	40.906930°	39.194570°	612	*P4*	13	13	9	18
Trabzon	40.850950°	39.184550°	1256	*P5*	12	11	8	16
Rize	40.987760°	40.967810°	823	*P1*	30	30	25	36
Rize	40.905730°	41.139520°	2023	*P2*	34	33	28	40
Rize	40.727980°	40.841860°	2460	*P3*	28	28	23	34
Rize	40.877990°	40.732820°	1351	*P4*	20	20	15	25
Rize	40.707922°	40.644930°	1430	*P5*	13	13	9	18
Giresun	40.566092°	38.471918°	1953	*P1*	32	31	26	38
Giresun	40.553338°	38.490550°	1886	*P2*	32	31	26	38
Giresun	40.694990°	38.878440°	1355	*P3*	16	16	12	22
Giresun	40.709980°	38.319720°	1266	*P4*	21	21	17	27
Giresun	40.465390°	38.398910°	2142	*P5*	9	8	5	13
Gümüşhane	40.323750°	39.164710°	2018	*P1*	25	24	20	30
Gümüşhane	40.703619°	39.079478°	562	*P2*	19	18	14	24
Gümüşhane	40.573286°	39.243284°	1500	*P3*	15	15	11	20
Gümüşhane	40.610198°	39.413036°	2031	*P4*	11	10	7	15
Gümüşhane	40.560617°	40.062329°	1846	*P5*	18	17	13	23
Artvin	41.256400°	41.359850°	490	*P1*	16	16	12	21
Artvin	41.366280°	41.473340°	416	*P2*	21	21	16	26
Artvin	41.382230°	41.549830°	512	*P3*	16	16	12	21
Artvin	40.917333°	41.871060°	1890	*P4*	18	17	13	23
Artvin	41.314610°	42.229740°	773	*P5*	17	17	13	22

The Caucasian salamander is mainly threatened by human-induced habitat alteration and loss in Turkey (Tarkhnishvili & Kaya, 2009; Çiçek et al., 2018 b). Forestry activities such as logging activities, using brooks inhabited by the salamander to transport the cut trees, and habitat destructions caused by cattle farming activities are the best-known population decline reasons (Tarkhnishvili & Kaya, 2009; Çiçek et al., 2018 b, AmphibiaWeb, 2023). Unfortunately, there is limited data on the ecology, phenology, and population status of Caucasian salamanders in northeastern Anatolia. Understanding the factors influencing its distribution, habitat quality, and abundance can help conservation efforts and management strategies to protect the species. There is an urgent need for detailed monitoring to be carried out in the long term to determine the factors that reduce its population (Çiçek et al., 2018 a, b).

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