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Dynamics of a Western Anatolian population of *Natrix natrix* and *Natrix tessellata* (Serpentes: Natricidae)

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Abstract: Due to their secretive nature, snakes are the most challenging animal group for monitoring. Nevertheless, population size estimates are indispensable to accurately determining conservation status and management strategies. We used passive integrated transponder (PIT) tags to track aquatic snakes *Natrix natrix* and *Natrix tessellata* in Lake Işıklı, Denizli province, Turkey. 304 *N. natrix* and 1563 *N. tessellata* specimens were captured and marked over the four-year sampling period. Of the marked individuals, 14 *N. natrix* and 97 *N. tessellata* were recaptured at least once. The three-year average population size was estimated at 1940 ± 1055 for *N. natrix*, and 10,146 ± 1679 for *N. tessellata*. The annual survival rate is 0.57 ± 0.19 (range = 0.22–0.86) and 0.37 ± 0.06 (0.27–0.50) for *N. natrix* and *N. tessellata*, respectively. In April, which is the most active month for water snakes, 60% of the snakes were captured. This study represents the first comprehensive demographic estimates of *Natrix* species in Turkey.

Key words: Population dynamics, population size, mark-recapture, water snake, *Natrix*

1. Introduction

Understanding the population dynamics of the snakes gives insight into their roles and effects on ecosystems (Lind et al., 2005). With reliable demographic research, snakes could indicate the trends in trophic dynamics and community. For example, snakes have been used in detecting declines in their amphibian prey populations (Matthews et al., 2002), or microhabitat quality (Angarita–Sierra and Lozano–Daza, 2019). Demographical data derived from nature can reveal important features of a species' ecology, provide a close look at life-history evolution, and play a critical role in determining changes in population size (Lind et al., 2005).

Among reptiles, snakes have some of the lowest detection rates (Durso et al., 2011). Occupancy and N-mixture methods are generally applied to snake populations due to their low-cost, as well as nonnecessity of detection rate and individual identification; however, they may fail to determine the fluctuations in population size (Ward et al., 2017). Even though their time-consuming and high-cost aspects, capture-mark-recapture methods are the most useful methods for gathering individual information and estimating the size of the wild populations.

There are many comprehensive studies on marking reptiles (e.g., Winne et al., 2006; Plummer and Ferner, 2012). Preferably, the tags should not affect the behavior, growth, survival, or recapture of the animal; they should be simple and practical under field conditions (Plummer and Ferner, 2012). The most promising technique in marking is the PIT (*Passive Integrated Transponder*) tags. PITs are radiofrequency equipments that transmit specific numeric and alphanumeric codes when a reader is held a few cm away (Plummer and Ferner, 2012). Even though they can vary in size, usually they are 10–14 mm long and 2 mm wide (Gibbons and Andrews, 2004). PITs enable to identify the individual without capturing or handling. Biologically reusable and glass-covered tags do not include batteries and can last about 75 years (Plummer and Ferner, 2012). PITs are implanted under the skin, in the muscle tissue or body cavity of the animal (Gibbons and Andrews, 2004). Through these special tags, long-term monitoring studies get easier, and animals can be marked individually. Generally, PIT tagging is a safe and effective method for marking vertebrates (e.g., Murray and Fuller, 2000; Taggart et al., 2021).

Grass snake, *Natrix natrix* (Linnaeus, 1758) has a wide ecological tolerance and is distributed from England to Lake Baikal, from southern Europe to the Middle East and North Africa. Dice snake, *Natrix tessellata* (Laurenti, 1768), on the other hand, is distributed from central and southern Europe, middle eastern countries, and the Nile Delta to Kazakhstan and China, excluding the Iberian Peninsula and France (Gruschwitz et al., 1999).

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A recent comparison of independent long-term snake population studies revealed that many snake populations have decreased drastically over the past decade (e.g., Reading et al., 2010; Luiselli et al., 2011; Reading and Jofré, 2020). Nevertheless, although water snakes are known as abundant species, there is no demographic data reported for Anatolian populations. The primary objective of this study is to provide first quantitative estimates of the population size of *N. tessellata* and *N. natrix* for Anatolian populations.

2. Material and methods

2.1. Study site

Lake Işıklı is located in the Çivril Plain, on the headwaters of the Great Menderes River within the borders of Denizli province (38° 13' N, 29° 54' E; 820 m a.s.l.). The lake is about 7 m deep, and its surface is 9749 hectares. Lake Işıklı has been used as a reservoir to store water for large-scale irrigation in the surrounding plains for 40 years. With the completion of the flood protection works initiated by DSI (General Directorate of State Hydraulic Works under the Ministry of Agriculture and Forestry) in 1968, the western, southern, and eastern shores of the lake were surrounded by embankments. According to the International Criteria, Lake Işıklı is classified as "Class A" wetland. Bulrush (*Schoenoplectus lacustris*), common reed (*Phragmites australis*), European white waterlily (*Nymphaea alba*) and yellow waterlily (*Nuphar lutea*) are the most common plant species in Lake Işıklı. Reeds are found in dense groups; they even form islets in some parts of the lake.

The monthly average temperature (MAT) in Denizli province varies between 6 and 28 °C (General Directorate of Meteorology, 1957-2018, Figure 1). MAT reaches the maximum in July while it is the minimum in January. Monthly average precipitation (MAP) reaches the maximum in January with 91.1 mm while it is the minimum with 8.4 mm in August (see Figure 1). As of June, the water of the lake ebbed by 150–200 m due to agricultural irrigation and evaporation.

2.2. Sampling protocol

The field surveys were conducted for 4 years between 2016–2019. Surveys in 2016 were mostly preliminary and carried out to determine the macro-habitats around the lake and to select opportune stations for sampling. Field surveys were conducted between March and October. Each sampling was carried out with three researchers and covered the time between 07:00–19:00. To increase the number of marked individuals, the number of samplings was increased between April and May when many individuals were active, and calculations were made by adjusting the time intervals between samplings correspondingly. Snakes were captured at the shoreline by hand, hand net, or tunnel net.

Biomark HPT12 type PITs and Biomark 601 PIT readers were used for marking individuals. Before the marking, the body part where the tag implemented was locally anesthetized with Chloroethyl cooling spray in order to prevent the animals from feeling pain, antibacterial, and dexpanthenol-based pomades were applied after the application to reduce contamination risk. After the individuals were marked and the body measurements were taken, they were released back to the area where they were caught. The study was conducted in the context of

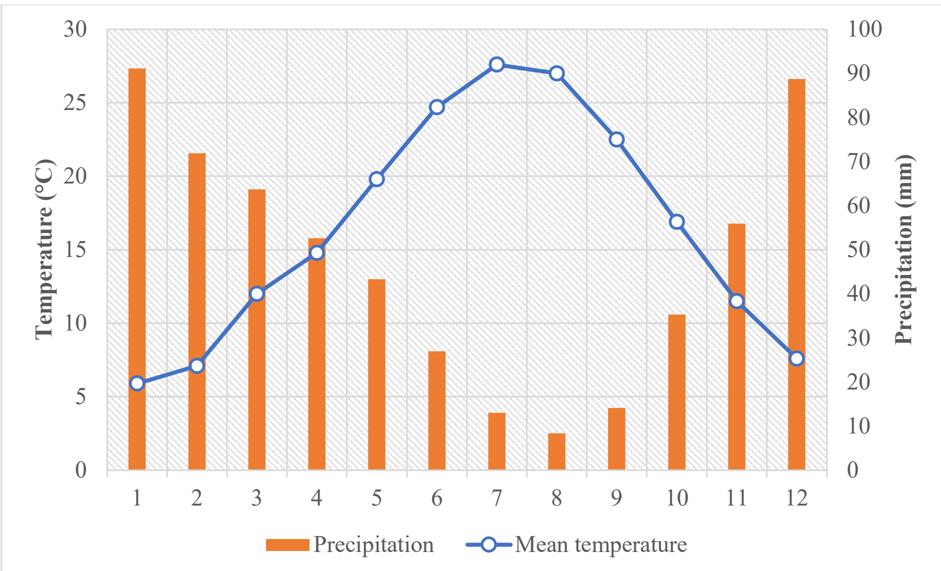

Figure 1. Mean temperature and monthly average precipitation of Denizli according to the data of the General Directorate of Meteorology (1957–2018).

the project that was confirmed by the Animal Experiments Ethics Committee of Ege University (approval number: 2016–018).

2.3. Population size analysis
The methods developed by Pollock et al. (1990), Lebreton et al. (1992) were used to calculate population size, demographic parameters, and modelling. In order to calculate the population parameters, a matrix showing whether individuals were captured (1) or not (0) was created. Year-based matrices were created in the data set for population size calculations. While creating the annual matrices, the marked individuals captured from previous years were evaluated as a new capture. To calculate the survival and capture rates, a matrix was created from all the field surveys made between 2016 and 2019. Due to the unequal time intervals between samplings, we specified intervals in program MARK[1] (White and Burnham, 1999).

While evaluating the annual data of the stations, the populations were assumed as "open" [individuals may join (birth and immigration) or leave (death and emigration)] due to the large sample size and long sampling periods. For open population calculations, Jolly-Seber (*JS*, Jolly, 1965; Seber, 1965, Pollock et al., 1990; Schwarz and Arnason, 1996) and Cormack-Jolly-Seber (*CJS*, Cormack, 1964; Jolly, 1965; Seber, 1965) formulations were used. CJS formula calculates the survival rate, capture rate, and standard error of the marked individuals.

Since there are different modifications of the JS formula, the statistically robust model POPAN (Schwarz and Arnason, 1996) was applied. This model calculates the population size, survival rate (phi), recapture probability (p), recruitment (pent), and confidence intervals. Models were applied with the program MARK and its POPAN implementation. The smallest sample Akaike Information Criteria (AICc) used to select suitable models were allowed to vary among samplings (*t*) or to remain constant (.). *Goodness of Fit* (GOF) tests were applied to the matrices with the RELEASE program to confirm that the model adequately fits the data.

The population density was estimated along the 1 km line transect at station 3, where the snakes were most abundant. Calculations were made according to the closed population model [an approach used in short-term sampling, which assumes that there are no individuals that enter the population (birth and immigration) or leave (death and emigration)] with CAPTURE implementation of program MARK.

3. Results
As a result of the field studies, 304 *Natrix natrix* and 1563 *N. tessellata* were captured and marked. Of the marked individuals, 14 *N. natrix* were recaptured 16 times and 97 *N. tessellata* were recaptured 103 times in total (Table 1).

The number of snakes captured decreases dramatically, especially in the postbreeding season. As of March, individuals who just emerged from hibernation were encountered and the majority of the snakes were captured (about 60% of all snakes captured) in the following month April. Considering the meteorological data given in Figure 1, temperature around 15 °C and precipitation around 50 mm are the optimum environmental parameters for the activity of water snakes in Lake Işıklı. Through the summer months, the number of captured individuals decreases dramatically.

According to the results of the GOF tests, Test 2 + Test 3 is statistically insignificant in the models created for both *N. natrix* ($X^2 = 1.88$, $df = 8$, $P = 0.984$) and *N. tessellata* ($X^2 = 14.89$, $df = 22$, $P = 0.866$). That is, a fully time-dependent model [phi(*t*) p(*t*)] allowed to be used. According to AICc, a model in which the survival and the capture rates were constant [phi(.)p(.)] was suggested for *N. natrix*. For *N. tessellata*, a model in which the survival rate was constant, but the capture rate varied over time [phi(.)p(*t*)] was suggested.

In the year 2017, population size was estimated at 2208 ± standard error: 944 (min –max: 989–4931) individuals for *N. natrix*, 9989 ± 1163 (7957–12541) individuals for *N. tessellata*. In 2018, the population size was estimated at 1837 ± 1008 (672–5022) individuals for *N. natrix*, 11484 ± 2472 (7567–17428) individuals for *N. tessellata*. In 2019, the population size was estimated at 1777 ± 1215 (528–5985) individuals for *N. natrix*, 8966 ± 1402 (6611–12159) individuals for *N. tessellata*. Population sizes for years are shown as a bar chart in Figure 2. Considering the average of three years, the population size of Lake Işıklı was estimated at 1940 individuals for *N. natrix* and 10,146 individuals for *N. tessellata*.

The population density was calculated as 45 ± 7 (35–62) individuals/km for *N. natrix* and 485 ± 28 (434–545) individuals/km for *N. tessellata*.

The annual survival rate for *N. natrix* is 0.57 ± 0.19 (0.22–0.86) and the capture rate is 0.011 ± 0.004 (0.006–0.022), while the annual survival rate for *N. tessellata* is 0.37 ± 0.06 (0.27–0.50) and the average capture rate is 0.015 ± 0.006 (0.008–0.037).

4. Discussion
In general, snakes have life-history characteristics such as long lifespan, late sexual maturity, low reproductive frequency, site fidelity, and high mortality in juveniles that make them vulnerable to population declines (Scott and Seigel, 1992; Shetty and Shine, 2002; Beaupre and Douglas,

[1] Cooch E, White GC (2019). Program MARK, A Gentle introduction. 19th ed. (online). Website http://www.phidot.org/software/mark/docs/book/pdf/mark_book.zip [accessed 09.02.2022].

Table 1. Number of the captured individuals in each sampling [i: sampling, n(i): total number of individuals captured in sampling i (u(i)+m(i)), u(i): number of new captured (unmarked) individuals, m(i): number of recaptured individuals (marked)].

N. natrix									***N. tessellata***									
2017									**2017**									
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Total**
n(i)	5	21	52	9	4	2	2	95	97	209	96	8	40	2	12	8		472
u(i)	5	21	51	8	3	2	2	92	97	203	93	8	36	2	12	8		459
m(i)			1	1	1			3		6	3		4					13
2018									**2018**									
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Total**
n(i)	19	25	36	10	7	14	8	119	45	165	167	85	58	54	23	21	7	625
u(i)	19	24	35	10	6	13	7	114	45	161	161	84	55	53	20	21	7	607
m(i)		1	1		1	1	1	5		4	6	1	3	1	3			18
2019									**2019**									
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Total**
n(i)	6	5	36	24	12	9	6	98	26	74	27	137	86	74	37	38	18	517
u(i)	6	5	36	24	12	9	6	98	26	72	25	130	80	72	37	37	18	497
m(i)								0		2	2	7	6	2		1		20

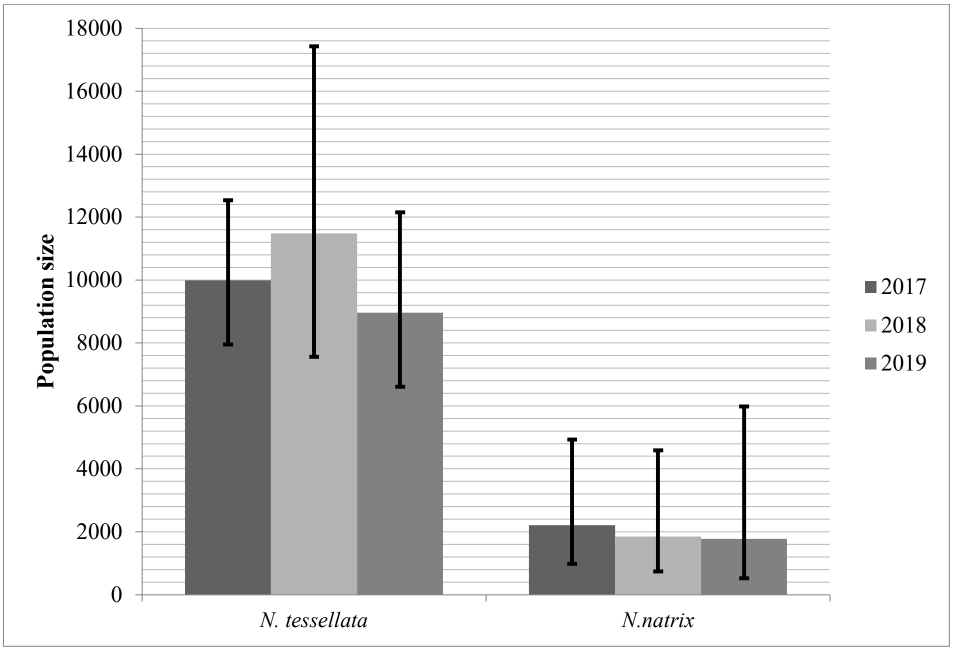

Figure 2. Estimated population sizes for 2017, 2018, and 2019. (Bars represent the minimum and maximum values).

2009). The objectives of the most monitoring studies include population-level studies such as demography, habitat use, population size and density, survival rates, and underlying causes of population fluctuations.

Estimation of the population parameters requires a great deal of time and resources. Furthermore, researchers working with snake populations must contend with the low stability of the calculated parameters due to low recapture rates and large variations in the number of captured individuals caused by the environmental conditions (Dorcas and Willson, 2009). Visual encounters of water snakes can be affected by the time of day/year, air/water temperatures, and other environmental factors (Robertson and Weatherhead, 1992; Mills et al., 1995; Burger et al., 2004, Leuenberger et al., 2019). The cryptic life of snakes, combined with their low population density, results in very low recapture numbers in mark-recapture studies (Parker and Plummer, 1987). This has made many researchers question whether snakes are suitable for mark-recapture studies (Turner, 1977; Plummer, 1985, Stanford and King, 2004).

Natrix tessellata can reach large population sizes that no other Eurasian snake can (Bendel, 1997; Gruschwitz et al., 1999; Carlsson et al., 2011). A wetland where the conditions are suitable and food is abundant, can be home to several thousand to ten thousand individuals (e.g., Luiselli et al., 2007). Population sizes and densities reported for *N. natrix* are smaller than *N. tessellata* (Table 2). Considering the average of three years, the population size was calculated as 10,146 individuals for *N. tessellata* and 1944 individuals for *N. natrix* in Lake Işıklı.

Sufficient recaptures or detections for most population estimation methods on snakes can be difficult to obtain because of low detection rates (Attum et al., 2009; Sewell et al., 2012; Ward et al., 2017, Leuenberger et al., 2019). Large standard errors are to be expected when the number of recaptured individuals and samples is small. When calculating the population size, using more than one method, and averaging between the following years gives more stable results (King et al., 2006). According to the simulation results reported by Krebs (1999), the small sample size and the low number of recaptures cause overestimated results. While the number of recaptured individuals is low (about 6% of marked individuals) in the present study, the sample size is quite large. The standard error range is between 11%–22% in *N. tessellata*, where the number of recaptured individuals is relatively high, while it is around 42%–68% in *N. natrix*, which has a lower number of recaptured individuals.

The annual survival rates of *N. natrix* (0.57 ± 0.19) and *N. tessellata* (0.37 ± 0.06) were calculated lower than the others reported, especially for *N. tessellata* (see Table 2). Predation and human impact on the population may have been effective in this low survival rate. Besides, because the CJS formula calculates the survival rate of marked individuals, it cannot distinguish emigrated individuals from those who died. This may cause the survival rates to be lower than the actual values, especially in studies where the number of recaptured individuals is low (Pradel et al., 1997).

Survival rate can be affected by predators, local hunters and human impact (Bonnet et al., 1999). Water snakes, like many other terrestrial snakes, are not at the top of the food chain in many ecosystems. We observed that Lake

Table 2. Demographic parameters reported for *Natrix* species and other Natricine snakes.

Family	Species	Population size	Density	Survival rate	Reference
Natricidae	*Natrix natrix*	299	3.6 ind/ha		Mertens (1995)
Natricidae	*Natrix natrix*	63–576	4.8–52.4 ind/ha	0.66	Sewell et al., (2015)
Natricidae	*Natrix natrix*			0.52	Madsen, 1987
Natricidae	*Natrix tessellata*	11,000–17,000			Carlsson et al., (2011)
Natricidae	*Natrix tessellata*	373–1301			Velenský et al., (2011)
Natricidae	*Natrix tessellata*		82.9 ind/km		Šukalo et al., (2019)
Natricidae	*Natrix tessellata*		43 ind/km	0.73	Luiselli et al., (2011)
Natricidae	*Natrix helvetica*	509–1053	0.32 ind/ha		Storniolo et al., 2019
Natricidae	*Nerodia erythrogaster*		2–5.43 ind/km		Lacki et al., (2005)
Natricidae	*Nerodia erythrogaster*			0.67	Roe et al., (2013)
Natricidae	*Nerodia sipedon*	39–1036	18–11,107 ind/km		King et al. (2006)
Natricidae	*Nerodia sipenodon*			0.63	Roe et al., (2013)
Natricidae	*Nerodia sipenodon*			0.53–0.58	Stanford and King, (2004)
Natricidae	*Nerodia harteri*			0.23–0.34	Whiting et al., (2008)
Natricidae	*Thamnophis gigas*			0.61	Halstead et al., (2012)
Natricidae	*Thamnophis elegans*			0.34–0.86	Bronikowski and Arnold, (1999)
Natricidae	*Thamnophis radix*			0.35–0.45	Stanford and King, (2004)
Viperidae	*Vipera aspis*			0.75	Flatt et al., (1997)

Işıklı has a rich ornitofauna which has aquatic raptors and herons that would prey on water snakes. Some of these birds that prey on *N. natrix* and *N. tessellata* are as follows: Short-toed snake-eagle (*Circaetus gallicus*), grey heron (*Ardea cinerea*), purple heron (*Ardea purpurea*), white stork (*Ciconia ciconia*), Eurasian buzzard (*Buteo buteo*), long-legged buzzard (*Buteo rufinus*) and western marsh-harrier (*Circus aeruginosus*). In addition, summer heron species such as Squacco heron (*Ardeola ralloides*) and Black-crowned night heron (*Nycticorax nycticorax*) can also hunt snakes. Especially western marsh-harrier, Eurasian buzzard, and white stork are among the birds that are frequently seen in the lake. We anticipate that this intense predator pressure is one of the most important factors affecting the survival rate of the *Natrix* populations in Lake Işıklı.

Like many other predator species, the theories on the snakes' biology were also affected by the prey abundance. Low prey availability may lead to low reproductive output, decline in growth rate, and, thus, low population density (Fitzgerald et al., 2004). In the contrary case, as in our study, snake populations can reach very large sizes (Madsen and Osterkamp, 1982; Bonnet et al., 2002; Madsen et al., 2006, Carlsson et al., 2011).

The capture rate (p) defines the probability of catching an individual of the species in question with a given unit effort. It is independent of population density and is simply a value that indicates how easily each individual can be captured. Generally, analysis with marking studies gives less stable results when the capture rate is low (Dorcas and Willson, 2009). Large differences between population estimates and the number of specimens captured in the field reflect "low detectability" which is common in snakes (Steen, 2010). Snakes are easier to find in the spring when it is relatively cool and has less vegetation, and, afterwards, their detection rate is greatly reduced by high temperatures and overgrowth of the habitat (Sewell et al., 2015). The capture rate for *N. natrix* in Lake Işıklı was calculated as 0.011, and similarly 0.015 for *N. tessellata*. Because snakes lead a cryptic life, their capture rate remains lower than other vertebrates. Similar results have been reported for another water snake, *Nerodia harteri paucimaculata* (0.07–0.15; Whiting et al., 2008).

This study presents the first detailed estimates of demographic characteristics in *N. natrix* and *N. tessellata* from Turkey. Four-year monitoring of water snakes revealed that, with hosting over 12,000 individuals, Lake Işıklı consists of one of the largest snake populations in Anatolia. Population size fluctuations are not significant and are evaluated as "stable".

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