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Site Occupancy of Two Endemic Stream Frogs in Different Forest Types in Pakistan

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Abstract.—**We identified the habitats where Murree Hills Frog (*Nanorana vicina*) and Hazara Torrent Frog (*Allopaa hazarensis*) are most likely to occur in Pakistan, and examined how their occurrence at a particular stream or water body is influenced by site and survey covariates. Although these two frog species are listed as Least Concern in the Red List of Threatend Species by the International Union for Conservation of Nature, major conservation threats to these species in Pakistan include habitat degradation, urbanization, and climate change. We made visits to 69 sites during the 2-y study period (June 2016 to July 2018) in three forest types of Islamabad Capital Territory, District Rawalpindi (Province Punjab) and District Abbottabad, (Province Khyber Pakhtunkhwa), Pakistan. We found Murree Hills Frog at 51% of sites, and Hazara Torrent Frog at 30% of sites. Our logistic regression model explained 78.0% of the variance in Murree Hills Frog occurrence and correctly classified 87% of the cases. Increased elevation and availability of permanent water were associated with an increased likelihood of occurrence of this species. The logistic regression model explained 51.0% of the variance in Hazara Torrent Frog occurrence and correctly classified 70% of the cases. Both species were more likely to be found at sites with Sub-tropical Pine and Moist Temperate Forest compared to Sub-tropical Broad-leaved Evergreen Forest. Our results will help biologists design survey methods for future abundance estimation and population monitoring and will benefit wildlife managers in improving conservation management strategies.**

Key Words.—Chir pine; Dicroglossidae; endemism; Sub-tropical Pine Forest

Introduction

Amphibians have gained attention among scientists due to their population declines and extinction, considered a global conservation crisis, yet in many regions species status and biology remain poorly documented. To understand population structure and document habitat requirements and preferences of amphibians, occupancy models are used to produce unbiased estimates of occupancy and related parameters, (Schmidt and Pellet 2005). These models use information from repeated observations at each site to estimate detection. The detection and occupancy may vary with site characteristics (e.g., habitat variables) or survey characteristics (e.g., weather conditions; MacKenzie et al. 2002). When multiple species co-occur, these models can be useful to discern differences in habitat preference.

The 24 amphibian species known from Pakistan belong to the families Bufonidae, Megophryidae, Microhylidae, and Dicroglossidae (Khan 2014). There are 11 species of frogs in the family Dicroglossidae (Khan 2014). The Murree Hills Frog (*Nanorana vicina*; Fig. 1) was first recorded in Murree (Rawalpindi, Punjab). It is endemic to Pakistan and India. Besides reports on its discovery (Stoliczka 1872), rediscovery (Baig 2002), and description of adults and tadpoles (Rais et al. 2014; Gill et al. 2020), not much is known about the species ecology and biology beyond the knowledge that it occurs in the streams of hilly and rocky areas. The Hazara Torrent Frog (*Allopaa hazarensis*; Fig. 1) also is endemic to Pakistan. It was first reported and described by Dubois and Khan (1979) from Rush Valley, Hazara Division, Khyber Pakhtunkhwa (KP). It is associated with torrential streams and nearby pools, and also frequents quieter and clear water pools near waterfalls (Khan et al. 2008). The two species are listed as Least Concern by the Red List of Threatened Species by the International Union for Conservation of Nature with known threats that inlcude habitat degradation, urbanization, and climate change (Ohler and Dutta 2004; Khan et al. 2008).

Developing models for site occupancy and detection probability of amphibian species, particularly endemics, is important for conservation planning. Environmental covariates that have been used to model occupancy and detection probability of frog species are wide in scope (Gooch et al. 2006; Adams et al. 2011; Amburgey et al. 2014; Annich et al. 2019). The goals of this study are to identify the habitats where these species are most

Figure 1. (Left) Murree Hills Frog (*Nanorana vicina*), Village Parhana, Tehsil Murree, District Rawalpindi, Punjab, Pakistan. (Right) Hazara Torrent Frog (*Allopaa hazarensis*), Village Parhana, Tehsil Murree, District Rawalpindi, Punjab, Pakistan. (Photographed by Muhammad Saeed).

likely to occur, and to examine how the occurrence at a particular stream or water body of each species is influenced by site and survey covariates. We expect this information to help biologists design survey methods for future abundance estimation and population monitoring, and in providing data that will help inform future conservation actions. Additionally, this information will benefit wildlife managers to devise improved conservation management strategies.

Materials And Methods

Study system.—We conducted the study in 69 randomly selected sites (Fig. 2) of the District Rawalpindi (Province Punjab), Islamabad Capital Territory (ICT) and District Abbottabad, (Province Khyber Pakhtunkhwa), Pakistan. The district Rawalpindi is divided into seven administrative units known as tehsils: Rawalpindi, Gujar Khan, Murree, Kahuta, Taxila, Kotli Sattian, and Kallar Syedan. The district Rawalpindi spreads over an area of 5,286 km^2 and features a humid sub-tropical climate with hot summer (May-June), a monsoon (July-April), and mild wet winters. The area is rocky and has mostly scrub vegetation. The wetlands of the area include the rivers Korang and Sowan, with slow flowing water and a water storage reservoir (Rawal Dam, Simly Dam, and other several small dams associated with marshes; Chaudhry and Rasul 2004). The average temperature ranges from 2º C in January to 38.6º C in the June. The administrative unit Murree (elevation = 804–2,291 m, total area = 697.5 km^2) has a mean annual precipitation of 1,789 mm. The area features mainly sub-tropical Chir Pine (*Pinus roxburghii*) Forest (900–1,700 m elevation; Fig. 3) and Himalayan Moist Temperate Forest (Fig. 3). Other units such as Gujar Khan, Taxila, Rawalpindi, Kotli Sattian, and Kallar Syedan of District Rawalpindi have predominantly Sub-tropical Broad-leaved Evergreen Forest or Scrub Forest (< 900 m elevation; Sheikh and Hafez 2001; Fig.3). The District Abbottabad (Khyber Pakhtunkhwa, 2,500–2,700 m elevation, total area = 967 km^2) has a mean annual precipitation of 1,366 mm. The district is drained by perennial and intermittent streams.

Survey methods.—We visited each site on three occasions from June 2016 to July 2018 to: (1) gather presence only data on each frog species; (2) measure the site covariates of elevation, forest type, wetland type, hydroperiod, land use; and (3) document the survey covariates of air and water temperature. We carried out surveys at each site during Spring (February-March), Summer (May-June), and monsoon seasons (July-August). We used standard time-constrained (20–30 min per stream) visual encounter surveys (Heyer et al. 1994) conducted by a team of observers consisting of the first author (familiar with the identification of the species) and a group of students, who actively searched streams moving in an upstream direction. We also searched the small water storage tanks and ponds associated with the streams.

Statistical analysis.—We used binomial logistic regression to determine if likelihood of each frog species occurrence (response variable, 0 = absent, 1 = present) was influenced by the site covariates of elevation (m), forest type (1 = Subtropical Pine and Moist Temperate Forest, 2 = Scrub Forest and mixed forest with dominant scrub vegetation), wetland type (1 = stream, 2 = pond including small water storage tanks), hydroperiod

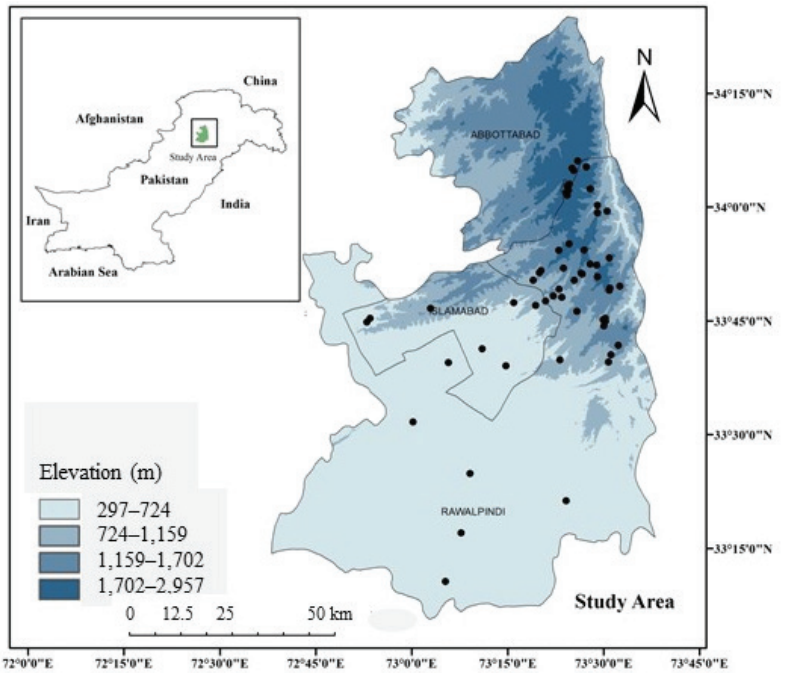

Figure 2. Locations of the sampling sites in Rawalpindi District (Punjab Province), Abbottabad District (Khyber Pakhtunkhwa Province), and Islamabad Capital Territory, Pakistan.

(1 = permanent, 2 = temporary), and land use (1 = urban, 2 = natural). For survey covariates (air and water temperature in °C), we used standard regression analysis. We used the significance values (P) of omnibus tests of model coefficients to test individual hypotheses and values of Nagelkerke R^2 to examine fit of the model (Field 2009). We performed all the analyses in SPSS 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0.; Armonk, New York, USA) and accepted significance at $P \leq 0.05$.

Results

Across all the sites visited, the naive occupancy of Murree Hills Frog (*Nanorana vicina*) was 51% and Hazara Torrent Frog (*Allopaa hazarensis*) was 30%. In all cases, detection of adults or tadpoles of the target species, where positive, was during the first few minutes of survey, indicating a high probability that our data reflected true occupancy. We observed no effects of air or water temperature on detection (Table 1). We recorded the species in freshwater streams and springs with permanent water and associated pools or storage tanks in Chir Pine Forest or other forest types in the northern part of the study area, in montane habitats. The Murree Hills Frog and Hazara Torrent Frog were absent from sites of Sub-tropical Broad-leaved Evergreen Forest (or Scrub Forest) and other low-lying areas surveyed (Table 1). For the Murree Hills Frog, the logistic regression was significant ($\chi^2 = 60.86$, df = 8, $P < 0.001$) and the model explained 78.0% (Nagelkerke R^2) of the variance

Figure 3. Major vegetation types of the study sites: (Top) Sub-tropical Scrub dominated by Hopbush, *Dodonea viscosa*; (Middle) Sub-tropical Chir Pine dominated by Longleaf Indian Pine, *Pinus roxburghii*; and (Bottom) Himalayan Moist Temperate Forest dominated by Blue Pine, *Pinus wallichiana*. (Photographed by Waseem Ahmed).

Table 1. Summary of binomial logistic regression analysis for environmental factors influencing the occurrence of Murree Hills Frog (*Nanorana vicina*) and Hazara Torrent Frog (*Allopaa hazarensis*) in Pakistan. Abbreviations are B = coefficient, SE = standard error, Wald = Chi-square test statistic, Exp (B) = exponentiation of coefficient, an odds ratio, and CI = confidence interval (upper and lower limits).

Species / Factor	B	SE	Wald	df	*P*	Exp (B)	95% CI
Nanorana vicina							
Elevation	0.01	0.00	10.71	1	**0.001**	1.01	1.00, 1.01
Forest			1.45	2	0.484		
Pine Forest	2.43	2.01	1.45	1	0.232	11.33	0.22, 587.2
Scrub Forest	-20.15	14,203	0.00	1	0.999	0.00	0.00, 2.45
Pond	-0.90	0.92	0.96	1	0.326	0.41	0.07
Water Permanence	2.93	1.20	5.95	1	**0.015**	18.81	1.78, 198.7
Urbanization	1.96	1.18	2.76	1	0.096	7.08	0.70, 71.2
Water Temperature	0.04	0.13	0.11	1	0.746	1.04	0.81, 1.35
Air Temperature	0.00	0.15	0.00	1	0.975	1.00	0.74, 1.34
Constant	-12.05	4.05	8.84	1	0.000	0.00	
Allopaa hazarensis							
Elevation	0.00	0.00	0.89	1	0.344	1.00	1.00, 1.00
Forest			0.00	2	1.000		
Pine Forest	-21.90	15,252	0.00	1	0.999	0.00	0.00
Scrub Forest	-21.23	9,606	0.00	1	0.998	0.00	0.00
Pond	-0.14	0.68	0.04	1	0.838	0.87	0.23, 3.27
Water Permanence	2.38	0.81	8.71	1	**0.003**	10.83	2.23, 52.7
Urbanization	-0.21	0.79	0.07	1	0.787	0.81	0.17, 3.81
Water Temperature	0.10	0.11	0.88	1	0.349	1.11	0.89, 1.37
Air Temperature	-0.04	0.13	0.09	1	0.760	0.96	0.74, 1.24
Constant	-3.78	2.22	2.90	1	0.089	0.02	

in species occurrence and correctly classified 87% of the cases. Higher elevation and availability of permanent water were associated with an increased likelihood of occurrence of Murree Hills Frog (Table 1). These sites were 11.3 times more likely to have the Murree Hills Frogs. For Hazara Torrent Frog, the model was also significant (χ^2 = 30.86, df = 8, P < 0.001), and explained 51.0% of the variance in species occurrence and correctly classified 70% of the cases. Sites with permanent water were 10.8 times more likely to have Hazara Torrent Frogs present (Table 1).

Discussion

Our study demonstrated for the first time that the occurrence of the Hazara Torrent Frog and Murree Hills Frog is influenced by elevation and permanence of waterbody. The Murree Hills Frog and Hazara Torrent Frog were absent from sites of Sub-tropical Broad-leaved Evergreen Forest (or Scrub Forest) and other low-lying areas surveyed (< 900 m). Until now the Murree Hills Frog was known to occur between 2,000 and 3,000 m (Ohler and Dutta 2004) while the Hazara Torrent Frog was reported from 1,200 to 1,500 m elevation (Khan et al. 2008). We, however, recorded these species below these previously reported elevation ranges: the Murree Hills Frog found as low as 1,768 m and the Hazara Torrent Frog from 1,196 m. We found the two frog species in sites featuring forested wetlands such as permanent freshwater streams and springs, as well as associated pools and ponds in situated at higher elevations (> 1,000 m). Although we did not find significant results for the effect of forest type, pine trees, Long Leaf Indian Pine (*Pinus roxburghii*) and Blue Pine (*Pinus wallichiana*) dominate at higher elevations (Khan 2006), and we did observe a significant effect of elevation on the likelihood of occurrence of the studied frog species.

The higher likelihood of occurrence of the focal species in forested wetlands in northern mountain areas of Pakistan and information on the other factors influencing occurrence, namely elevation and water permanence, can be used to design survey methods for abundance estimation and monitoring of their

populations in the future. This method can be applied also to other species to help clarify site characteristics necessary for occupancy. Because the local human population relies heavily on water from streams, conservation planning related to the impact of altered water quality and diminished quantity could be focused on the habitats, with a higher likelihood of occurrence of the two species. The habitat requirements we have identified should be integrated in the ongoing and proposed developmental projects where these species occur. For instance, we believe that incorporation of different management practices such as habitat connectivity, construction of artificial wetlands, and maintenance of wetland hydroperiod (Hamer and Parris 2011; Scroggie et al. 2019; Swartz and Miller 2019) should be considered.

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