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Evidence for homing in *Bufo gargarizans* Cantor, 1842 from a radiotelemetry study in the Republic of Korea

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Amphibians are known to use various sensory cues to navigate and orient themselves within their environment. These cues include celestial signals, visual landmarks, chemical cues (such as pond odours), auditory signals, and geomagnetic orientation (Sinsch, 1990a, b, 2006; Phillips et al., 2010). Rather than relying on a single cue, amphibians are thought to integrate multiple sensory inputs in a complementary manner to enhance navigational accuracy (Vitt and Caldwell, 2013). For example, even non-vocal salamanders have been reported to respond to the advertisement calls of sympatric toads to locate breeding sites, suggesting an ability to utilize heterospecific auditory cues (Diego-Rasilla and Luengo, 2004). In certain species, these navigational abilities facilitate homing behaviour, in which individuals return to a previously occupied or specific habitat (Jaeger et al., 1993). Although homing behaviour has been observed in numerous amphibian species, it remains understudied, particularly in terms of quantitative field data. One of the best-documented examples is the dendrobatid genus *Allobates*, with frogs having demonstrated the capacity to return to specific sites despite anthropogenic disturbances (Pašukonis et al., 2013, 2014; Pichler et al., 2017).

In this study, we report incidental observations of homing behaviour in two individuals of the Asiatic Toad (*Bufo gargarizans*), obtained during a radiotelemetry study conducted in South Korea. While the original study was not designed to investigate homing, the observed behaviours offer valuable insights into the species' spatial orientation capabilities. Additionally, we review the existing literature on amphibian homing to identify species in which this behaviour has been documented and to explore potential ecological or behavioural patterns associated with homing tendencies.

The observations of homing behaviour in *B. gargarizans* were made near Bichon Village in Gwangyang-si, Jeollanam-do, South Korea (35.0479°N, 127.7161°E). Our radiotelemetry study was conducted in August–November 2016, and the methodology has been described elsewhere (Park et al., 2024, 2025). Individuals were tracked four times per week, and their positions were recorded using a handheld GPS unit at each relocation. Among the tracked individuals, one male and one female exhibited homing behaviour by returning to previously occupied sites.

To contextualize our findings, we conducted a literature survey to assess how frequently homing behaviour has been reported in amphibians. Using Google Scholar, we searched for peer-reviewed articles using the keywords "amphibians" and "homing." Studies were screened to confirm whether they included documented evidence of homing behaviour, species identity, and methodological details.

Homing behaviour was observed in two individuals of *B. gargarizans*, one male and one female (Fig. 1A). The male was tracked from 11 September–11 November, and evidence of homing was observed between 6 and 17 October (Fig. 1B). The male was tracked at five different locations between 6 and 16 October (Fig. 1B, Points 1–5, in numerical order), and on 17 October it returned to its initial location (Fig. 1B, Point 1, marked with a star). The total movement distance over this period was 288 m.

The female was tracked from 28 September–11 November. Evidence of homing was detected between the time of initial release (28 September) and 7 October (Fig. 1C). The female was first tracked at Point 1 on 28 September and subsequently at Point 2 on 1 October (Fig. 1D). However, Point 2 was near a residence, whose owner requested that the toad be relocated.

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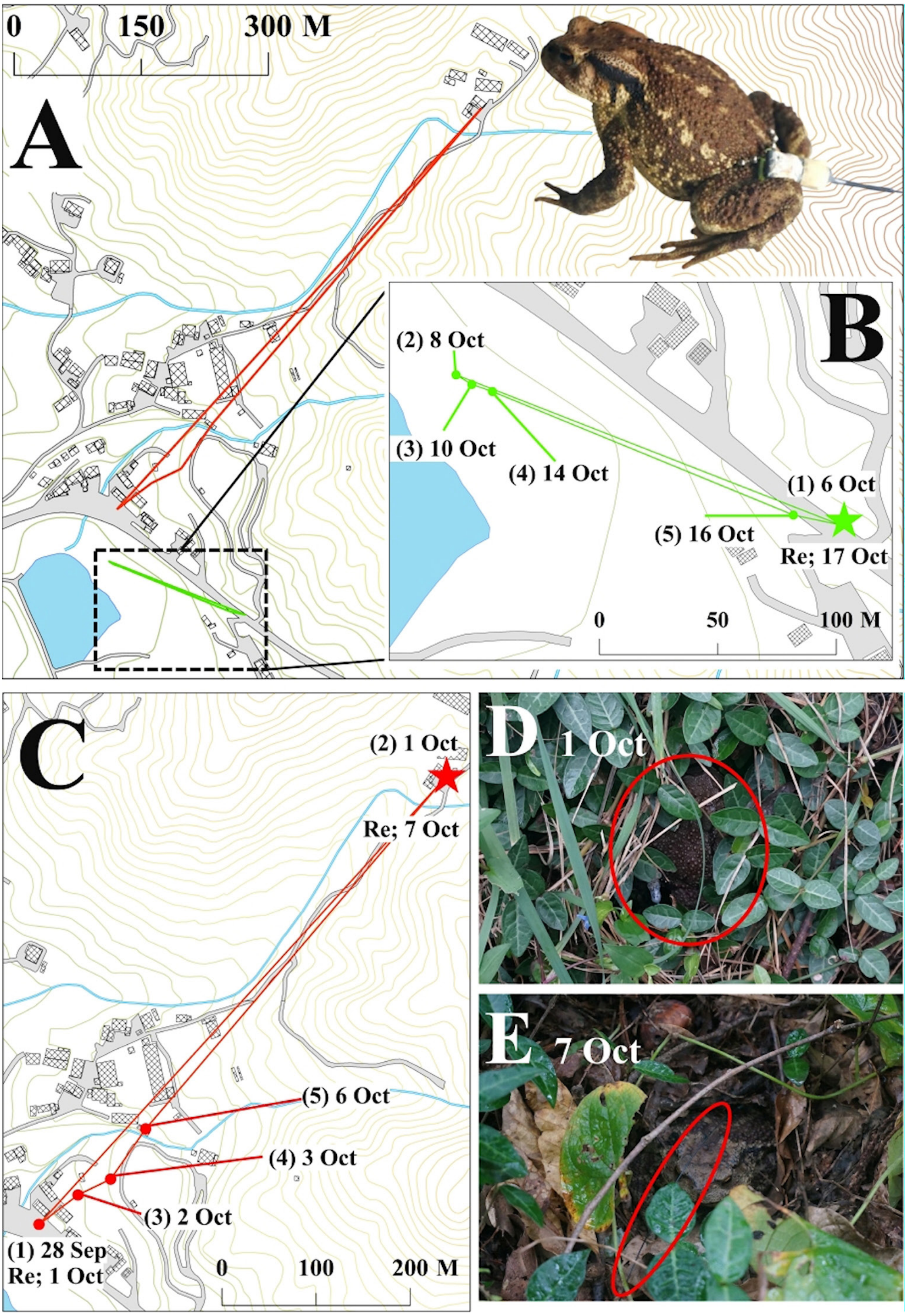

Figure 1. Homing behaviour of *Bufo gargarizans* (inset) in South Korea. (A) Overview of the study area. Blue lines indicate water networks, grey areas represent asphalt roads, hatched areas represent buildings, and the coloured lines show the movement of the toads (red: female; green: male). (B) Enlarged view of the male's movements, with the star indicating the "home" location. (C) Detailed view of the female's movements, with the star indicating the "home" location. (D) The female observed at the home location in on 1 October, where it was seen again (E) on 7 October. Maps in (A–C) generated using ArcGIS v10.7 (ESRI, USA). Photos by Hee Jin Kang.

As a result, the female was captured and re-released at Point 1, the previous location, which constituted an artificial disturbance.

Following the re-release, the female moved sequentially through Points 3–5 between 2 and 6 October. On 7 October, the toad was found again at Point 2, the site it had previously occupied on 1 October (Fig. 1E). The straight-line distance between Points 1 and 2 was approximately 536 m, with elevations ranging from 74–154 m. After the second release, the total distance travelled was approximately 538 m.

A Google Scholar search for existing research on "homing" yielded 21 studies encompassing 20 species (Table 1). Among these, *Taricha rivularis*, a member of the family Salamandridae, exhibited the longest homing distance (approximately 4000 m; Twitty et al., 1964). Species in the genus *Allobates* have been observed to exhibit homing behaviour even at the tadpole stage, with measured return distances of up to 400 m (Pašukonis et al., 2013, 2014; Pichler et al., 2017). The average homing distance among the identified research findings was approximately 200 m, with 12 of 20 species belonging to the family Bufonidae (Table 1).

The term "homing" has already been used in early amphibian studies (Bogert, 1947; Jameson, 1957; Twitty, 1959). Later, Jaeger et al. (1993) provided a conceptual framework for "homing behaviour" by distinguishing two forms: (1) return to specific habitats (referred to as permanent residences in other studies) for hibernation and breeding, and (2) return to specific locations.

Table 1. List of amphibians in which homing behaviour has been observed, as confirmed by literature review.

Taxon	Distance (m)	Reference
SALAMANDERS		
Salamandridae		
Taricha rivularis (Twitty, 1935)	2400–4000	Twitty et al., 1964
Plethodon cinereus (Green, 1818)	30–90	Kleeberger and Werner, 1982
FROGS		
Aromobatidae		
Allobates talamancae (Cope, 1875)	0–200	Pichler et al., 2017
Allobates femoralis (Boulenger, 1884)	200–400	Pašukonis et al., 2013
Allobates femoralis	35–70	Pašukonis et al., 2014
Bufonidae		
Anaxyrus americanus (Holbrook, 1836)	up to 235	Dole, 1972 (as *Bufo americanus*)
Anaxyrus hemiophrys (Cope, 1886)	*	Kelleher and Tester, 1969 (as *Bufo hemiophrys*)
Anaxyrus boreas (Baird & Girard, 1852)	About 200	Tracy and Dole, 1969 (as *Bufo boreas*)
Anaxyrus fowleri (Hinckley, 1882)	*	Landreth and Ferguson, 1966 (as *Bufo fowleri*)
Anaxyrus terrestris (Bonnaterre, 1789)	50–400	Bogert, 1947 (as *Bufo terrestris*)
Atelopus varius (Liechtenstein & von Martens, 1856)	1–10	Crump, 1986
Bufo bufo (Linnaeus, 1758)	90–3000	Sinsch, 1990b
Bufo japonicus Temminck & Schlegel, 1838	*	Ishii et al., 1995; Okamiya and Kusano, 2018
Epidalea calamita (Laurenti, 1768)	90–200	Sinsch, 1990b (as *Bufo calamita*)
Rhinella spinulosa (Wiegmann, 1834)	90–200	Sinsch, 1990b (as *Bufo spinulosus*)
Rhinella marina (Linnaeus, 1758)	up to 1000	Brattstrom, 1962 (as *Bufo marinus*)
Rhinella marina	up to 1000	Shaykevich et al., 2022
Incilius valliceps (Wiegmann, 1833)	up to 237	Grubb, 1970 (as *Bufo valliceps*)
Dendrobatidae		
Andinobates bombetes (Myers & Daly, 1980)	5–90	Arcila-Pérez et al., 2020
Eleutherodactylidae		
Eleutherodactylus coqui Thomas, 1966	20–100	Gonser and Woolbright, 1995
Hylidae		
Pseudacris regilla (Baird & Girard, 1852)	274–914	Jameson, 1957 (as *Hyla regilla*)
Ranidae		
Lithobates pipiens (Schreber, 1782)	1000–3000	Dole, 1968 (as *Rana pipiens*)

Our observations align with the second definition. Previous research has documented that *B. gargarizans* migrate from hibernation sites to breeding areas and subsequently return to their original habitats (Sung et al., 2007), which aligns with the first definition of Jaeger et al. (1993). It is notable that most reported homing behaviour has come from members of the Bufonidae (Table 1). This family comprises primarily terrestrial amphibians, and *B. gargarizans* have a primary activity area in grasslands (Park et al., 2024, 2025). Therefore, these species are close to terrestrial areas with good access for researchers, which may explain the frequency of reports in this group.

Our observations appear to indicate that *B. gargarizans* can indeed remember and return to specific locations, even in the presence of artificial interference. Studies on orientation and movement in amphibians have been conducted since the early 20th century (Cummings, 1912; Boulenger, 1912), and amphibians are known to utilise a variety of orientation cues (Sinsch, 1990a; Mazerolle and Vos, 2006). These cues are thought to function in combination rather than independently (Oldham, 1966; Vitt and Caldwell, 2013). Although it was not possible to determine which directional signals were used for navigation in our experiments, it is likely that chemical cues and specific landscape features were involved. This study presents the first field-based evidence of homing ability in *B. gargarizans*, highlighting their capacity to return to specific locations over considerable distances. Further research is necessary to identify the sensory mechanisms involved and to determine whether this ability is prevalent across different populations or influenced by individual traits, environmental conditions, or life-history stages.

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