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Spatial problem solving in a poison frog

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Spatial information processing is an important consideration in animal behaviour. An individual may be faced with novel obstacles within a known territory during dispersal, or experience heterogeneous or even seasonal changes to habitats (e.g. flooding). Understanding how individuals deal with these novel challenges may come from behavioural experiments such as mazes (Liu et al. 2016) or, on rare occasions field observations such as we detail here. Although countless hours have been spent observing poison frogs move throughout their habitats, and a number of studies have been carried out regarding movements in response to stressors such as escaping predator pursuit (Ozel and Stynoski, 2011; Pröhl and Ostrowski, 2011; Dugas et al., 2015; Blanchette and Saporito, 2016), there is a dearth of documentation detailing how frogs mitigate other complications such as unfamiliar obstacles.

Limited evidence is available to demonstrate how poison frogs learn to navigate their local environments (Pašukonis et al., 2014). Learning in navigation suggests that memorable elements within frogs' local environments are important and permits and/or facilitates choosing routes of travel. Behavioural experiments in the poison frog species *Dendrobates auratus* (Girard 1855) demonstrated that they are capable of using visual cues to solve simple, reversible puzzles (e.g. the 'correct' choice switches between trials) and that learning improves over time (Liu et al., 2016). The ability to navigate local habitats is likely important to facilitate parental care, where adults are thought to invest significant time and effort locating suitable deposition sites (Summers, 1989; 1990). Although limited to a single observation, we feel it is important to document a problem-solving exercise witnessed in a wild *D. auratus*, which serves as additional support to experimental problem-solving and spatial reasoning observations of Liu et al. (2016, 2019).

On a clear morning at approximately 11 AM June 2, 2019 an adult male *Dendrobates auratus* was observed within 1m of a stream at Santa Lucia Falls, San Josecito, Puntarenas Providence, Costa Rica (9.2235, -83.725833). The stream was experiencing flooding due to recent rains usual at rainy season, and therefore represented a novel obstacle, inhibiting *D. auratus* movement. Streams and rivers can often comprise barriers to gene flow in terrestrial anuran species (Fouquet et al., 2015). Insights gained from watching frogs navigate such potential barriers are therefore useful in discussions related to navigation, problem-solving and even dispersal capabilities. In this case, the frog first jumped across a small stream in response to the approach of the observer, crossing into a novel region (Figure 1, point A). Next the *D. auratus* traversed the periphery of the stream in an apparent attempt to look for places to cross back. After approximately 3m of travel the frog explored the edge of rock, making two complete circles and as no exit was feasible due to the elevation of the rock and a water barrier (Figure 1, point B). This led the frog to return to the initial starting point after completing a circular movement of approximately $4m^2$. After a short pause, the frog then changed orientation and returned back down the boulder with a series of hops, followed by lengthy pauses, and orientation changes. Subsequently the frog hopped around the periphery and inspected all stream boundaries, where the majority of borders were rapidly flowing currents of >20cm depth and 2m width. Finally it reached the border of the stream again and tried a first attempt to jump (Figure 1, point C). However, in crossing at this point the frog was confronted by a stronger current at a wider region of the stream and dragged downstream a couple of meters. In line with Liu et al. (2016) *D. auratus* have demonstrated the ability to gauge an unprofitable route and reverse

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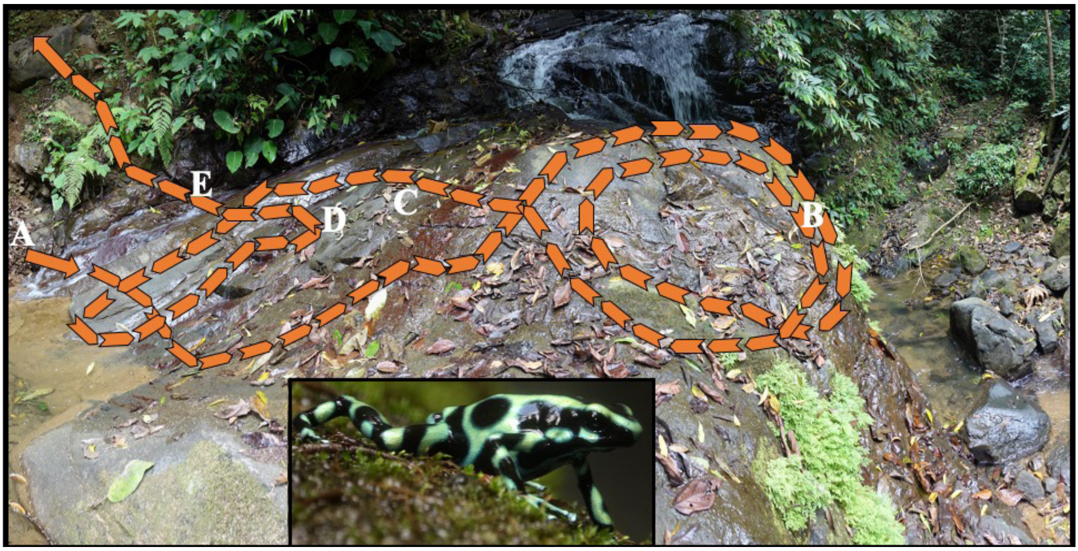

Figure 1. Route taken by *D. auratus* (insert) to navigate a stream barrier which had risen due to recent heavy rains. Letters (A-E) refer to events detailed in text. Video of the encounter is also available (https://zenodo.org/record/3708477#.Xmrbyy3MxZp).

directions, potential evidence of rule-based learning strategies. After a short recovery period (~1 minute) of no movements, the frog was still located in the midst of the bifurcated water streams. After climbing again to an intersection of the bifurcating paths of water flow, and following another lengthy pause (~25s), the frog once again jumped into the midst of the current, only to be carried several meters further downstream (Figure 1, point D). After remerging at this point the frog was capable of crossing the final region of the flowing stream (approximately 40 cm, Figure 1, point E) at which point it cleared the water obstacle. The total time spent by the frog to overcome this water barrier summed to nearly an hour (entire route detailed in Figure 1). Although the entire event was witnessed and filmed with a zoom lens (Figure 1), we feel it prudent to reassure that the frog was not chased and showed no obvious stress caused by the presence of the viewer.

Recently, researchers have highlighted the value of publishing natural history observations to serve as the foundation, and aid in the planning of future experimental research (Rojas and Pašukonis, 2019). For small terrestrial amphibians, streams can cause minor disturbances forcing frogs to alter their calls due to auditory competition (Vargas-Salinas and Amézquita, 2013), or impose significant barriers to limit or block gene flow (Fouquet et al., 2015). Inferences into whether, and how a species may overcome obstacles to dispersal provides useful points of references when interpreting data which include biogeographical contexts. We feel this observation conveys a number of interesting points. First, it highlights the ability of a species of poison frog to encounter physical obstacles and intend and revise decisions. Previous authors refer to this as 'behavioural flexibility' which we feel this observation constitutes an *in situ* demonstration of what has been experimentally shown (Liu et al., 2016). Second, we can gain some insights into how a terrestrial species can deal with habitat uncertainty such as that caused by seasonal obstacles such as flooding. Finally, we are provided with insights on how small terrestrial anuran species can mitigate barriers, therefore permitting their dispersal throughout heterogenous habitats.

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