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Delineation of core terrestrial habitat for conservation of a tropical salamander: The Hong Kong newt (*Paramesotriton hongkongensis*)

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A B S T R A C T

Core terrestrial habitat, sometimes called fixed-width riparian buffer or life zone, is defined as the spatial delineation of 95% of an amphibian population that encompasses all breeding, overwintering, and terrestrial foraging habitats. It has been proposed as a measure of the extent of terrestrial habitat use by amphibians, from which species-specific guidelines on buffer zone width can be derived. The Hong Kong newt (*Paramesotriton hongkongensis*), one of few tropical salamandrids, is endemic to southern China and categorized by the IUCN as Near Threatened. Populations of *P. hongkongensis* have declined due to habitat degradation and overexploitation for the pet trade. Previous studies of aquatic habitat use by *P. hongkongensis* revealed distinctive patterns, with juveniles using terrestrial habitats exclusively and most adults remaining on land for about 10 months each year. However, other information on the terrestrial stage is incomplete. We combined radio telemetry and terrestrial transect surveys to study habitat use and quantify movement and distribution patterns of *P. hongkongensis* during its terrestrial stage with the goal of delineating core terrestrial habitat for the species. Fifty-two *P. hongkongensis* radio-tracked during the wet season primarily used forest, maintained small home ranges (mean = 0.04 ha), and made frequent short distance movements (<7 m/day) between cover objects. From transect surveys that detected 117 *P. hongkongensis*, we estimated that the core terrestrial habitat extends 113 m from the nearest stream margin. Currently, there are no guidelines in place for establishment of fixed-width buffer zones to protect semi-aquatic animals in Hong Kong. We recommend that buffer zones of at least 113 m be designed to protect the terrestrial stages of *P. hongkongensis*.

1. Introduction

Over a third of the world's amphibian species are threatened with extinction (Stuart et al., 2004; Chanson et al., 2008; IUCN, 2016), and habitat loss and degradation is regarded as one of the main factors linked to declines of amphibian populations (Beebee and Griffiths, 2005; Chanson et al., 2008; Ficetola, 2015). Many amphibians are semi-aquatic and rely on terrestrial habitats surrounding wetlands for foraging, overwintering and dispersal (Semlitsch, 1998), thus protection of these habitats is an essential component of amphibian conservation and management (Semlitsch, 2000; Semlitsch and Jensen, 2001; Semlitsch and Bodie, 2003). An understanding of the spatial extent and temporal use of these habitats is needed to guide land managers and conservation practitioners to identify areas that offer protection during the terrestrial stage of amphibian life cycles (Cushman, 2006; Schmidt, 2008).

Core terrestrial habitat refers to the extent of terrestrial habitats surrounding wetlands used by 95% of a given amphibian population, and it is typically derived from natural-history studies of post-breeding movements and habitat use by amphibians (Semlitsch and Bodie, 2003; Crawford and Semlitsch, 2007; Rittenhouse and Semlitsch, 2007). Estimates of core terrestrial habitats for 19 frog and 13 salamander species yielded dispersal and migration distances ranging from a mean minimum of 159 m to a mean maximum of 290 m from wetland margins (Semlitsch and Bodie, 2003). However, even this basic knowledge is lacking for many species, especially those in the tropics, partly because many amphibians have cryptic coloration, live underground, or are seen infrequently outside their breeding seasons (Mazerolle et al., 2007). To date, most work on terrestrial habitat use by urodeles has been undertaken on temperate ambystomatids or plethodontids (Semlitsch and Bodie, 2003; Petranka and Smith, 2005; Crawford and Semlitsch, 2007; Rittenhouse and Semlitsch, 2007; Ryan and Calhoun, 2014), whereas very little information exists for stream-dwelling

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salamandrids in the Paleotropics (Blaustein et al., 1994; Young et al., 2001).

Core terrestrial habitat estimated using 95% isopleths of kernel-density functions yielded considerably larger estimates for six salamander (245 m) and six frog species (703 m: Rittenhouse and Semlitsch, 2007). The kernel-density function method is preferred over alternative approaches used to quantify the extent of terrestrial habitat use because it allows for interpolation at distances where fewer individuals were observed and does not assume an unrealistic distribution pattern (Semlitsch, 1998; Crawford and Semlitsch, 2007; Rittenhouse and Semlitsch, 2007). As Rittenhouse and Semlitsch (2007) demonstrated, distribution patterns of amphibians tend to be skewed toward their wetland breeding sites, meaning that assumptions about habitat occupancy based on a normal distribution will be unrealistic and misleading.

The evidence currently available suggests that paleotropical salamandrids may differ substantially from their temperate equivalents in terms of duration of activity periods and length of breeding seasons, and in their thermal ecology (Feder and Lynch, 1982; Morrison and Hero, 2003). In addition, the recently discovered salamander chytrid fungus has been confirmed to originate from paleotropical salamandrid genera (*Cynops* and *Paramesotriton*) (Martel et al., 2014), which triggered an importation ban of these animals to the United States (USFWS, 2016) and sparked interest in this threatened yet understudied group (Stuart et al., 2014; Ficetola, 2015; Rowley et al., 2016).

The Hong Kong newt, *Paramesotriton hongkongensis* (Salamandridae), is a tropical stream-breeding salamander endemic to southern China (Fei et al., 2006) and threatened by habitat degradation and overexploitation for the pet trade (Lau and Chan, 2004; Kolby et al., 2014). The species is classified as Near Threatened by the IUCN (IUCN, 2016), protected under the Wild Animals Protection Ordinance (Cap. 170) in Hong Kong (Hong Kong SAR Government, 1997), included in "Lists of Terrestrial Wildlife under State Protection, Which are Beneficial or of Important Economic or Scientific Value" in mainland China (State Forestry Administrative Order No. 7), and will be listed in Appendix II of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, pending).

Adult *P. hongkongensis* congregate to breed in forest stream pools during the dry season, where they may occur for up to 4 months of the year, and most individuals spend 10 months in terrestrial habitats surrounding these breeding sites (Fu et al., 2013). There is thus a need to better understand the spatial extent and temporal use of core terrestrial habitat of *P. hongkongensis* in order to establish guidelines for land management that will protect this species and other paleotropical amphibians that

Our objectives were to determine the spatial extent, further quantify temporal use, and document habitats used by *P. hongkongensis* during its terrestrial stage to contribute to conservation efforts for this species. Using a combination of radio telemetry and transect surveys, we quantified movement and distribution patterns of *P. hongkongensis* during its terrestrial stage and documented macro- and microhabitat use. We investigated whether *P. hongkongensis* from four populations and subjected to two implant methods exhibited different movement patterns. To our knowledge, this study is the first to document movements and delineate the core terrestrial habitat of any tropical salamandrid.

2. Materials and methods

2.1. Study sites

We studied *P. hongkongensis* at four sites in Hong Kong Special Administrative Region, China (22.3964° N, 114.1095° E), where populations of *P. hongkongensis* have recently been studied (Fu et al., 2013). Three sites, Kowloon Peak (KP), Mui Tsz Lam (MTL) and Tai Tam (TT), are located within protected areas with minimal human disturbance and, Pak Ngau Shek (PNS), occurs in a low-altitude river valley where human disturbance is high and a large portion of the river has been channelized.

Study sites ranged from 79 (PNS) to 426 m (KP) in altitudes and terrestrial habitats are composed mainly of secondary forest (72–83%), shrubland (9–25%), abandoned agricultural land, plantation, and bamboo stands (classification adapted from Hau, 2003; Table 1). All primary forest in Hong Kong was cleared centuries ago, and following four decades of afforestation efforts by the early colonial government starting in the 1900s, the territory was deforested again during the Japanese occupation in 1941–1945 (Dudgeon and Corlett, 2011). However, post-occupation protection of the countryside has led to the establishment of extensive secondary forests in Hong Kong. They are characterized by a mixture of native and non-native trees (e.g. *Lophostemon confertus*, *Machilus* spp., *Schefflera heptaphylla*) and represent a successional stage from shrubland dominated by a few species of non-canopy forming shrubs and ferns (e.g. *Melastoma sanguineum, Rhodomyrtus tomentosa, Dicranopteris pedata*). Plantations and bamboo stands in secondary forest at KP and TT are dominated by planted and exotic Brisbane box (*L. confertus*) and native bamboo (*Arundinaria* spp.), while abandoned agriculture lands in PNS are covered in taro (*Colocasia esculenta*) and non-native para grass (*Brachiaria mutica*).

The tropical climate of Hong Kong is monsoonal, alternating between a hot and humid wet season (May–September, when monthly mean temperatures range from 26 °C to 29 °C), and a cool dry season (November–March; 16 °C to 22 °C). Annual rainfall averages 1389 mm, with 80% of it falling during the wet season (Dudgeon and Corlett, 2011).

2.2. Terrestrial movement and habitat use

We tagged 52 newts with radio transmitters at three sites (PNS in April–July2013; KP and TT in May–July 2014; Table 1). Newts were captured opportunistically while on land during the onset of wet season (April–June) within 40 m of breeding streams; the geographic location of each was recorded using a handheld GPS device (Garmin GPSMAP 62s; 3 m accuracy). We assumed these newts had recently emigrated from the nearby stream as most breeding pools are devoid of newts by mid-March (Fu et al., 2013). In the field, we also measured body mass with a portable electronic balance to the nearest 0.01 g and snout-vent length (SVL) and total length (TL) with a plastic ruler to the nearest mm of each newt. We implanted radio transmitters within the stomachs of 31 newts following procedures described in Schabetsberger et al. (2004). That entailed gently inserting a transmitter through the mouth and esophagus of an anaesthetized newt and positioning it in the stomach by applying gentle pressure from outside. In 2014, we also surgically implanted transmitters in the lower abdominal cavities of 21 newts following surgical procedures described in Jehle and Arntzen (2000). Surgical procedures were conducted by a veterinarian (PM) experienced in implantation of radio transmitters in small vertebrates in a surgical facility under sterile condition at Hong Kong Ocean Park. We anaesthetized 52 newts with tricaine mesylate (MS-222) following concentration suggested by Lowe (2004). Newts with stomach-inserted transmitters were released back at site of capture following recovery from anesthesia (indicated by the recovery of self-righting reflex, typically within 1 h). Newts with surgical implants were held in captivity for 24 h and then released at the site of capture.

We used two types of transmitters (BD-2H or BD-2NH, Holohil System Ltd., Carp, Canada; 151–152 MHz), both with internal helix antenna configuration. Transmitter weight was either 0.7 g (BD-2NH) or 1.1 g (BD-2H), depending on the size of the newt, and in each case constituted ≤10% of the body mass of an implanted newt. Thus, only newts ≥7 g in body mass were implanted with transmitters. Transmitters had a battery life of 30 (BD-2NH) or 60 days (BD-2H). Radio tracking was conducted every other day during daylight hours (0800–1800) with a 3-element YAGI antenna (Wildlife Materials, Murphysboro, IL, USA) paired with a receiver (R1000, Communications Specialists, Inc., CA,