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

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Abstract

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 (< 7m/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*.

Keywords: Riparian buffer zone, Life zone, Salamandridae, Radio telemetry, Kernel density estimation

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 James, 2005; Crawford and Semlitsch, 2007; Rittenhouse and Semlitsch, 2007; Ryan and Calhoun, 2014), whereas very little information exists for stream-dwelling 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 haeptaphylla*) 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–July 2013; 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 0.01g 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 hour). Newts with surgical implants were held in captivity for 24 hours 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 $\leq 10\%$ 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, USA). Transmitter detection distances ranged from 50 to 200 m, depending on the topography of the site. We recorded geographic coordinates of located newts with a handheld GPS unit. Newts were tracked until either: 1) transmitter battery expired, 2) transmitter was regurgitated, 3) signal from transmitter was lost, or 4) newt was found dead. Transmitter were assumed to be regurgitated if we find a bare transmitter on the ground surface without any obvious sign of the animal being predated upon.

Habitat use was recorded for each unique location at macrohabitat and microhabitat scales (*sensu* Morris, 1987). Macrohabitat refers to one of the five general habitat

categories described above (e.g. forest, shrubland); microhabitat refers to particular substrate, cover or shelter objects used by the animal when it was located (e.g. leaf litter, ground surface, rocks, and coarse woody debris). Distances between unique locations used by an individual were determined using the `stlength` function in Geospatial Modelling Environment (Beyer, 2012). Home range sizes (95% minimum convex polygons; MCP) and centroid of home ranges were determined using the R package ‘adehabitat’ (Calenge, 2006).

2.3. *Core terrestrial habitat*

To determine the spatial distribution of *P. hongkongensis* during the non-breeding season, we systematically searched for newts in the terrestrial habitats surrounding breeding streams at the four sites (Table 1). Surveys were conducted during daytime in the middle of the wet season (June–August) of 2014 and 2015. Methods followed Crawford and Semlitsch (2007) with slight modifications. At each site, which was visited eight to ten times over the course of three months, we established ten 300-m long 1-m wide transects spaced approximately 10 m apart extending perpendicularly from opposite sides of the stream bank into adjacent forests (i.e. five parallel transects on each bank) using Google Earth Pro, and preloaded waypoints along each transect to a handheld GPS unit. In the field, two researchers looked for newts while walking along each transect, and conducted area-constrained searches in twenty 2 x 2 m quadrats spaced at 15-m intervals (e.g. 15, 30, 45, 60, 75...300 m) from the stream margin along each transect. In each quadrat, all aboveground vegetation, leaf litter, rocks, and other cover objects were searched for an average of 10 minutes in order to locate newts. Thus, at each site we searched a total of 800 m² of terrestrial habitat, and each transect and associated quadrats were surveyed

once. In MTL, all transects were placed on the same side of the bank because a steep hillslope and dense bamboo stands limited accessibility on the opposite side.

We measured body mass, SVL, and TL of each newt found and recorded its life stage (adult or subadult) and geographic location as described above. We measured distance (m) of newt location (hereafter, occurrence distance) from the nearest stream using ArcMAP (ESRI, Version 10.1, Redlands, CA, USA). Newts with SVL < 50 mm (smallest post-metamorphic newt found in breeding pools) were considered to be subadults.

Determination of sex of *P. hongkongensis* during the non-breeding period based on external morphology can be difficult, therefore no determination of sex was made. All newts were released at the original site of capture following data collection.

To identify individuals, we photographed the ventral pattern of each newt with a DSLR camera (Nikon D90 paired with a 60 mm macro lens) and photo identification software (WildID ver 1.0, available at <http://www.dartmouth.edu/~envs/faculty/bolger.html>; Bolger et al., 2012) was used to match abdominal markings of captured individuals with those that had been captured and photographed earlier at the same site. If an animal was captured twice during our survey, the occurrence distance of said animal was average between the initial capture and recapture.

2.4. Statistical analyses

We conducted all statistical analyses in R version 3.1.1 (R Development Core Team, 2015). Data that did not meet equal variance and normality assumptions were transformed to approximate normal distributions; when transformations were ineffective, non-parametric tests were used.

Using location data obtained from radio telemetry, we calculated total movement (cumulative distance traveled by an individual during radio tracking), average daily movement (total movement divided by tracking duration), maximum daily movement (maximum single movement divided by days between consecutive tracking attempts), frequency of movement (percentage of movement >1 m between consecutive tracking attempts), and net movement (Euclidian distance from the nearest stream margin) using ArcMAP. As none of the data were normally distributed and transformations were ineffective, we tested for differences among sites (KP vs. PNS vs. TT) and transmitter implant methods (stomach implant vs. surgical implant) using a series of Mann-Whitney U or Kruskal-Wallis H tests, where appropriate. Post hoc pair-wise comparisons were made with Dunn's tests.

From the transect survey data, we calculated mean occurrence distances from the nearest stream margins and compared these among sites and size classes (adults vs. subadults) using a Mann-Whitney U-test or Kruskal-Wallis H test. As occurrence distances were not normally distributed, we applied a univariate kernel estimation to approximate the distribution of *P. hongkongensis* in core terrestrial habitat (Rittenhouse and Semlitsch, 2007). Radio-tracked animals, which were collected opportunistically, do not represent an unbiased sample of habitat use and hence were not used in calculations to estimate core terrestrial habitat. Our analysis is based on the assumption that most of the individuals detected migrate to and from the closest stream, although this movement was not directly observed for each individual. However, this assumption is reasonable given our telemetry data. We calculated univariate kernel density estimates based on Gaussian density using the R package 'ks' (Duong, 2007). Bandwidth was selected using the

Sheather-Jones (“SJ”) smoothing parameter (Jones et al., 1996). We used the R default settings for bandwidth multiplier (= 1) and 512 grid points when estimating the density function, and determined the 50% and 95% isopleth values of the resulting kernel using the ‘ks’ package (Vokoun, 2003; Rittenhouse and Semlitsch, 2007).

3. Results

3.1. Movements and home range

We tracked movements of 52 *P. hongkongensis* from three sites (PNS n = 14; KP n = 21; TT n = 17) for a total of 1012 days (average duration: 17 days, range: 1-76 days). Of 31 individuals that received stomach-inserted implants, only four (13%) retained the transmitter in their stomachs for duration of battery life; the remainder eventually regurgitated their transmitters. Twenty-one newts received surgical implants, but 12 (57%) died within a week after surgery. Transmitter signals were lost from five individuals (23%) with surgical implants and one individual (3%) with a stomach implant. To reduce any bias in movement by individuals that were only tracked for a short period, we report only data from 28 newts (PNS n = 8; KP n = 10; TT n = 10) that were tracked for more than 10 successive days or recorded from more than five unique locations (Table 2).

Although total movement, average daily movement, maximum daily movement, home range size, and net movement did not differ between attachment methods, newts with surgical implants were tracked for an average of 14 days longer ($W = 47.5$, $p = 0.03$) than those with stomach implants (Table 2). However, as tracking duration was not related to total movement ($R^2 = 0.077$, $p = 0.15$) or home range size ($R^2 = 0.008$, $p = 0.65$), we pooled data from newts with different implant methods and compared movement data

between sites (Table 2). Net movement and frequency of movement differed among sites. On average, newts from PNS and KP moved 37 m and 26 m farther away from the stream margin than those from TT ($H = 2.43$, $df = 2$, $p = 0.029$; KP vs. TT, $z = 1.71$, $p = 0.001$; PNS vs. TT, $z = 1.20$, $p = 0.0006$), and newts from PNS moved more frequently than those from TT (PNS vs TT, $z = 1.29$, $p = 0.003$) (Fig. 1; Table 2). Average daily movements between newts subjected to different transmitter implant methods did not differ among sites ($W = 116$, $p = 0.3007$). Average MCP home range occupied by *P. hongkongensis* was 0.0398 ha (range = 0.0002 – 0.5580 ha) and did not differ between sites ($H = 4.43$, $df = 2$, $p = 0.11$). One animal from PNS (#2889) had a home range an order of magnitude larger than the average because it undertook a series of unidirectional movements (Fig. S1).

3.2. Macro- and microhabitat use

Radio-tracked *P. hongkongensis* from all three sites used mainly secondary forest (KP: 98.6%; PNS: 62.7%; TT: 97.4%), but some individuals from PNS also used an abandoned agricultural land and roadway matrix located between the breeding stream and the forest (Fig. S1). In terms of microhabitat, most individuals were located on the surface (37.4%), followed by under leaf litter (28.9%) or coarse woody debris (22.7%) and rocks (10.9%) (Fig. S2).

3.3. Terrestrial distribution

We record a total of 117 *P. hongkonensis* observations, 75% of which were of adults, in searches of 3400-m² (absolute density = 3.65 newts/100 m²) of terrestrial habitat around each breeding stream (Table 1). Most individuals (90%) were encountered during area-

constrained searches in quadrats, whereas only 12 were found along the transect lines. We did not capture any individual more than once.

Mean ($\pm$ SE) occurrence distance of *P. hongkongensis* from the nearest stream margin was 43 ± 3 m ($n = 117$, range = 1 to 185 m, Table 1) and 95% of newts were located within 105 m of the nearest stream. Occurrence distances were not normally distributed ($W = 0.8393$, $p < 0.001$), and did not differ between adults and subadults ($W = 1259.5$, $p = 0.9194$) or among sites ($H = 0.5225$, $df = 3$, $p = 0.914$) (Table 1).

As we had approximately equal amounts of data from each site (Table 1), we pooled occurrence distance data from all sites and calculated a univariate kernel estimate that would be generalizable to other streams (Fig. 2). We found that 50% of newts used habitat within 31 m of the stream and 95% occupied areas within 113 m of the stream (i.e. dashed lines in Fig. 2). This estimate describes the extent of land used by the population as indicated by the 95% isopleth value.

4. Discussion

4.1. Core terrestrial habitat

We conclude that protection of forest extending 113 m from stream margins is needed to include 95% of adult and subadult *P. hongkongensis* during their terrestrial stage (Fig. 2). Our spatially-replicated distribution surveys and radio telemetry in combination provide a comprehensive quantitative and qualitative terrestrial habitat requirements of this threatened salamander. We estimated core terrestrial habitat in a new way that does not require telemetry data, which can be cost-prohibitive to acquire in less-developed

countries in Southeast Asia, where many threatened amphibians are found (Rowley et al., 2016).

Notably, our core terrestrial habitat estimate of *P. hongkongensis* is remarkably similar to those reported for two species of European salamandrids (Rittenhouse and Semlitsch, 2007), which is surprising as these temperate newts typically use terrestrial habitat for overwintering (Jehle and Arntzen, 2000; Schabetsberger et al., 2004), whereas *P. hongkongensis* is on land throughout the warmer and wetter months in Hong Kong. Its distribution pattern in relation to the stream margin is skewed towards the stream, suggesting that most animals stay relatively close to the stream margin during their non-breeding period, perhaps to take advantage of moist microhabitat and abundant prey in the riparian zone (e.g. Chan et al., 2008; Yuen and Dudgeon, 2015a). Given the monsoonal tropical climate of Hong Kong, *P. hongkongensis* has no need to aestivate or hibernate, and could potentially remain active throughout the non-breeding period, but they may be limited by rainfall and availability of invertebrate prey, which are both strongly seasonal (Dudgeon and Corlett, 2011; Yuen and Dudgeon, 2015b), or availability of cover objects (Schwarzkopf and Alford, 1997), at distances further inland.

4.2. Post-breeding movement and habitat use

Occurrence distances of *P. hongkongensis* located during terrestrial transect surveys were similar among sites and between adults and subadults, despite the difference in macrohabitat heterogeneity among these sites (Table 1). Unlike some temperate newts which seldom move during the non-breeding period after they reach underground hibernacula (Jehle and Arntzen, 2000; Schabetsberger et al. 2004), most of the *P. hongkongensis* we tracked made frequent, short distance movements of <7m within their

home ranges, which were located 20–60 m from the stream margin, presumably for foraging. These movement patterns were consistent with the “home range” and “foraging” phase defined by Pittman et al. (2014).

Terrestrial shelters occupied by salamandrids typically include leaf litter, coarse woody debris, rocks, and small-mammal burrows (Schabetsberger et al. 2004; Roe and Grayson, 2008; Phimmachak et al., 2015). When not active on the ground surface, *P.*

hongkongensis primarily used leaf litter, coarse woody debris and rocks as shelters, which is similar to what has been reported for *Tylototriton podichthys* (Phimmachak et al., 2015).

Our spatial replications in radio telemetry allows us to compare terrestrial movement patterns of *P. hongkongensis* between two protected natural site and an unprotected suburban site. The difference in movement frequency exhibited by newts from PNS is probably caused by the presence of unsuitable transitional habitats that included a road, residential development, and abandoned agricultural fields between the stream and the forest (Fig. S1). Unsuitable habitat such as roads and abandoned fields (as seen in PNS) can act as dispersal barriers to amphibians (deMaynadier and Hunter, 1999; Rittenhouse and Semlitsch, 2006) and may limit exchange and enhance fragmentation of amphibian populations (Ficetola and De Bernardi, 2004; Cushman 2006; Becker et al., 2007; Willson and Hopkins, 2013). This is of particular concern as at least 40 *P. hongkongensis*, including one we radio-tracked, were killed on a road at PNS during the wet season of 2013 (Lau, unpublished data), thereby emphasizing the need for protected landscape buffers around newt breeding sites.

Our study provides some of the first and currently the most comprehensive research on the use of terrestrial habitats by stream-breeding salamanders in tropical Asia. However, one of the main caveats is the high percentage of newts which died following the surgical implantation procedures due to unexpected surgical complications. As all five newts we implanted and held in captivity in a pilot study survived without complications for >180 days, and earlier studies employing similar implantation methods reported low mortality (Madison 1997; Jehle and Arntzen, 2000; Faccio 2003; Ryan and Calhoun, 2014), it is unclear why *P. hongkongensis* became vulnerable to the surgical procedure after release. While all protocols were sound, approved, and executed by experts, such a high mortality needs to be considered when interpreting the findings of our study, both from an ethical perspective as well as from the scientific side. To avoid unnecessary fatality, future studies on *P. hongkongensis* movement should avoid surgical implants and opt for less invasive techniques such as harmonic direction finding (Rowley and Alford, 2007).

4.3. Conservation implications

To protect 95% of a *P. hongkongensis* population from habitat degradation caused by deforestation and development, we recommend maintaining a fixed-width buffer zone of 113 m away from the stream margin in areas where *P. hongkongensis* occur but are not protected within the existing country park system. Our research extends the previous, rather limited work on terrestrial habitat use of *P. hongkongensis* by Fu et al. (2013), and quantified core terrestrial habitat that encompasses 95% of the terrestrial habitat used by *P. hongkongensis*. Our data provided a robust estimate of the terrestrial distribution of the Hong Kong newt, based on several populations, which can be used to inform management of this species.

Although edge effects are known to penetrate significant distances into forest interior (Murcia, 1995), at this stage, we do not recommend including an additional buffer to compensate for edge effect (so called ‘buffer the buffer,’ see Crawford and Semlitsch, 2007) until further evidence that suggests *P. hongkongensis* are vulnerable to edge effects arises. We found multiple newts in quadrats adjacent to road during our transect surveys and we saw some of our radio-tracked newts from PNS settling at the forest edge abutting roads or urban development (Fig. S1). This suggests that the ecotone between these habitats is used by *P. hongkongensis* and they may be more tolerant to edge effects and fragmentation than other forest-dependent salamanders such as plethodontids (Marsh and Beckman, 2004).

There are no guidelines in place for establishment of fixed-width buffer zones to protect semi-aquatic species in Hong Kong (Kan, 2011), and the only local instance where a buffer zone has been established is at Sha Lo Tung, a site designated as a Site of Special Scientific Interest (SSSI). There, a 30-m riparian buffer has been established to “protect the habitat of rare dragonflies and butterflies” and to ensure that “...development in this area is controlled” (Kan, 2011). Our results clearly demonstrate that a 30-m buffer zone would be insufficient for the protection of *P. hongkongensis* populations, which also breed in Sha Lo Tung SSSI. We recommend that agencies responsible for the conservation of *P. hongkongensis*, a species protected in both Hong Kong and mainland China, incorporate our results into conservation action plans for the species and make these results part of site-specific conservation efforts.

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Fig. 1. Net movement (a) and frequency of movement (b) of radio-tracked *Paramesotriton hongkongensis* (n = 28) from three sites in Hong Kong, 2013-2014. Net movement represents Euclidean distance (in m) from the nearest stream margin. Frequency of movement represents percentage (%) of movement >1 m between consecutive tracking attempts. For site abbreviations, see Table 1.

Fig. 2. Univariate kernel density estimate calculated from occurrence distances of *Paramesotriton hongkongensis* ($n = 117$) from four sites in Hong Kong, 2013-2014. Distance is the Euclidean distance from the nearest stream margin. Dashed lines represent distances in which 50% (left, 32 m) and 95% (right, 113 m) of newts occurred.

Table 1

Occurrence distances from the nearest stream margin and primary macrohabitats of *Paramesotriton hongkongensis* (n = 117) at four sites in Hong Kong, 2013-14.

Site (Site code)	Altitude	Adults	Subadults	All	Macrohabitat
Mui Tsz Lam (MTL)					
Mean $\pm$ SD (m)	140 m	44 $\pm$ 21	24 $\pm$ 14	40 $\pm$ 21	Secondary forest (83%), shrubland (17%)
(range)		(11–71)	(8–33)	(8–71)	
n		12	3	15	
Pak Ngau Shek (PNS)					
Mean $\pm$ SD (m)	79 m	33 $\pm$ 18	58	34 $\pm$ 18	Abandoned agricultural land (8%), road (2%), secondary forest (72%), shrubland (18%)
(range)		(8–67)	nil	(8–67)	
n		29	1	30	
Kowloon Peak (KP)					
Mean $\pm$ SD (m)	426 m	48 $\pm$ 52	56 $\pm$ 43	50 $\pm$ 49	Monoculture plantation (7%), secondary forest (68%), shrubland (25%)
(range)		(8–185)	(15–150)	(8–185)	
n		25	11	36	
Tai Tam (TT)					
Mean $\pm$ SD (m)	200 m	49 $\pm$ 36	39 $\pm$ 34	45 $\pm$ 35	Bamboo (9%), secondary forest (82%), shrubland (9%)
(range)		(1–105)	(5–90)	(1–105)	
n		22	14	36	
All sites					
Mean $\pm$ SD (m)		43 $\pm$ 36	44 $\pm$ 36	43 $\pm$ 35	
(range)		(1–185)	(5–150)	(1–185)	
n		88	29	117	

Table 2

Terrestrial movements of *Paramesotriton hongkongensis* radio-tracked from three sites in Hong Kong SAR, China. Home range sizes are based on 95% minimum convex polygon calculated for each newt. Fate includes animals whose transmitter was found regurgitated (R), animals whose radio signal was lost (L), animals found alive (A), and animals found dead (D). Numbers in parentheses following sample size (n) represent additional newts with transmitters surgically implanted.

Site (Site code)	Pak Ngau Shek (PNS)	Kowloon Peak (KP)	Tai Tam (TT)
	Mean (SD) range		
Tracking duration (days)	29 (22) 10–76	28 (17) 10–57	37 (14) 15–57
No. of unique locations	10 (4) 5–16	11 (7) 4–22	11 (5) 6–21
Total distance moved (m)	147 (78) 53–299	123 (83) 33–296	130 (103) 17–315
Avg. daily movement (m/day)	7 (5) 1–16	5 (2) 2–9	4 (3) 0.4–10.9
Max. daily movement (m/day)	29 (14) 12–50	16 (10) 4–37	13 (9) 3–35
Movement frequency (%)	0.9 (0.2) 0.5–1	0.8 (0.1) 0.4–1	0.7 (0.2) 0.4–0.9
Home range size (ha)	0.101 (0.188) 0.003–0.558	0.021 (0.027) 0.0002–0.082	0.010 (0.008) 0.002–0.025
Distance to stream from home range centroid (m)	39 (30) 7–99	37 (5) 6–55	16 (5) 10–25
Net movement (m)	59 (37) 20–142	48 (8) 39–57	22 (7) 14–36
n	8 (0)	10 (5)	10 (6)
Fate	7R, 1L	5R, 1A, 2L, 2D	3R, 3A, 3L, 1D