SALAMANDRA **50**(1) | 40–52 | 30 April 2014 | ISSN 0036–3375

# Movement patterns of *Tomistoma schlegelii* in the Sekonyer Kanan River (Tanjung Puting National Park, Central Kalimantan, Indonesia): preliminary range size estimates

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Manuscript received: 29 October 2013
Accepted: 10 February 2014 by Jörn Köhler

**Abstract.** Studies on home ranges and movement patterns have scarcely been conducted for crocodilians so far. Herein we present observations on movement patterns as preliminary home range size estimates for the endangered *Tomistoma schlegelii* (Crocodylia). Fieldwork was conducted at the Sekonyer Kanan River (Tanjung Puting National Park, Central Kalimantan, Indonesia). Three specimens were caught using a snare-pole, fitted with VHF radio tracking transmitters, and studied for a duration of two months between 31 August 2009 and 28 October 2009. Within this period, the individuals were relocated between 23 and 42 times, respectively. We analysed movement patterns by determining the animals' linear range sizes (LR), minimum convex polygon ranges (MCP), kernel density estimators (50% and 90% KDEs), and local *a*-convex hulls (50% and 90% LoCoH). Linear range sizes (LR) were 0.104, 0.276 and 0.739 km while minimum convex polygon sizes (100% MCP) were 0.1, 0.577 and 1.758 ha. The study animals' kernel range sizes (90% KDE) were 0.094, 0.663 and 2.08 ha. Core areas (50% KDE) were 0.02, 0.211 and 0.639 ha in size. Local *a*-convex hull range sizes (90% LoCoH) were 0.025, 0.323 and 0.821 ha whereby core areas (50% LoCoH) for two study animals measured 0.103 and 0.34 ha. Although, our study was limited to a single dry season and therefore likely underestimates full range sizes for the species – our results provide important baseline data for urgently required follow-up studies on movement patterns of this endangered crocodile species.

Key words. Crocodylia, radio telemetry, minimum convex polygon, kernel density estimator, local convex hull, activity patterns.

## Introduction

The knowledge of activity ranges and movement rates, especially of top predators such as crocodilians, is essential to understand habitat use patterns and the related impacts affecting lower trophic levels (Rosenblatt et al. 2013). Although crocodilians represent important keystone species in wetland ecosystems (Mazzotti et al. 2009), radio telemetry studies have been sparse due to cryptic behaviour, wide geographic distributions, and sensitivity to human disturbance (Read et al. 2007). Radio telemetry studies were conducted on *Alligator mississippiensis, Caiman crocodilus yacare*, *Crocodylus acutus, Crocodylus porosus*, *Crocodylus intermedius, Crocodylus niloticus*, *Gavialis gangeticus, Melanosuchus niger* and *Paleosuchus trigonatus* (Rodda 1984a, b, Hutton 1989, Magnusson & Lima 1991, Hocutt et al. 1992, Martin & da Silva 1998, Muñoz & Thorbjarnarson 2000, Kay 2004, Campos et al. 2006, Strauss et al. 2008, Lang & Whitaker 2010, Rosenblatt et al. 2013). Transmitter attachment techniques applied in previous studies comprise ingestion, tethering, surgical implantation, as well as the use of collars and bone pins combined with epoxy glue (Strauss et al. 2008).

*Tomistoma schlegelii* (Müller, 1838) is a very reclusive species predominantly restricted to freshwater swamp forests (peat swamps) in Southeast Asia (Trutnau & Sommerlad 2006, Bezuijen et al. 2010, Rödder et al. 2010). Overexploitation, habitat loss and fragmentation form the key threat for the species. Recent studies suggest that the global population amounts to approximately 3,000 individuals (Rödder et al. 2010). Due to the species' preference for anthropogenically less disturbed, remote areas, which are difficult to access, knowledge on distribution and ecology in the wild remains poor (Bezuijen et al. 2010, Rödder et al. 2010). Therefore, *T. schlegelii* is one of the world's most endangered and at the same time least known crocodilian species. Although previous studies provided first ecological insights into the ecology of this species (Bezuijen et al. 1998, Ross et al. 1998, Simpson et al. 1998, Auliya 2000, Bezuijen et al. 2001, Auliya 2002a, b, Auliya 2003, Simpson 2004, Stuebing et al. 2004, Auliya et al. 2006), no long-term studies have been conducted. Except for a few unpublished internal reports hardly any literature exists (see Stuebing et al. 2006).

Herein we report on the first successful transmitter attachment and radio tracking of *T. schlegelii* and present observations on movement patterns as preliminary home range size estimates for three individuals from Tanjung Puting National Park, Central Kalimantan in Indonesia. Fieldwork and data collection were conducted in the course of the senior author's PhD thesis, which deals with the population ecology of *T. schlegelii* in the Tanjung Puting National Park.

## Materials and methods

### Study site

Tanjung Puting National Park (TPNP) (2°35'–3°35' S, 111°45'–112°45' E) is situated in Central Kalimantan Province, Indonesia, on the south coast of Borneo island and covers 3,040 km². It is the largest protected forest in the province of Central Kalimantan and one of the largest protected heath and peat swamp forests in Southeast Asia. The vegetation of the area comprises expansive dry dipterocarp and secondary forests as well as coastal forests with mangroves. The national park is characterized by daytime temperatures reaching up to 30°C while nighttime temperatures rarely decrease below 21°C. The area has an annual precipitation of 2.000–3.000 mm (Galdikas & Shapiro 1994).

A network of interconnected black-water rivers stretches throughout the national park. In the north and west, the TPNP is bordered by the Sekonyer River. Extensive mining activities in the north turn the stream into muddy, tarnished water of dark colour. Forest habitats bordering the national park have been completely destroyed. A research camp (Pondok Ambung Tropical Forest Research Station) was established by the Orangutan Foundation, UK, a sub-organization of the Orangutan Foundation International (OFI), and is situated close to the junction of the Sekonyer River and its tributary, the Sekonyer Kanan River. The Pondok Ambung Tropical Forest Research Station provided infrastructure and logistics during the study (Fig. 1).

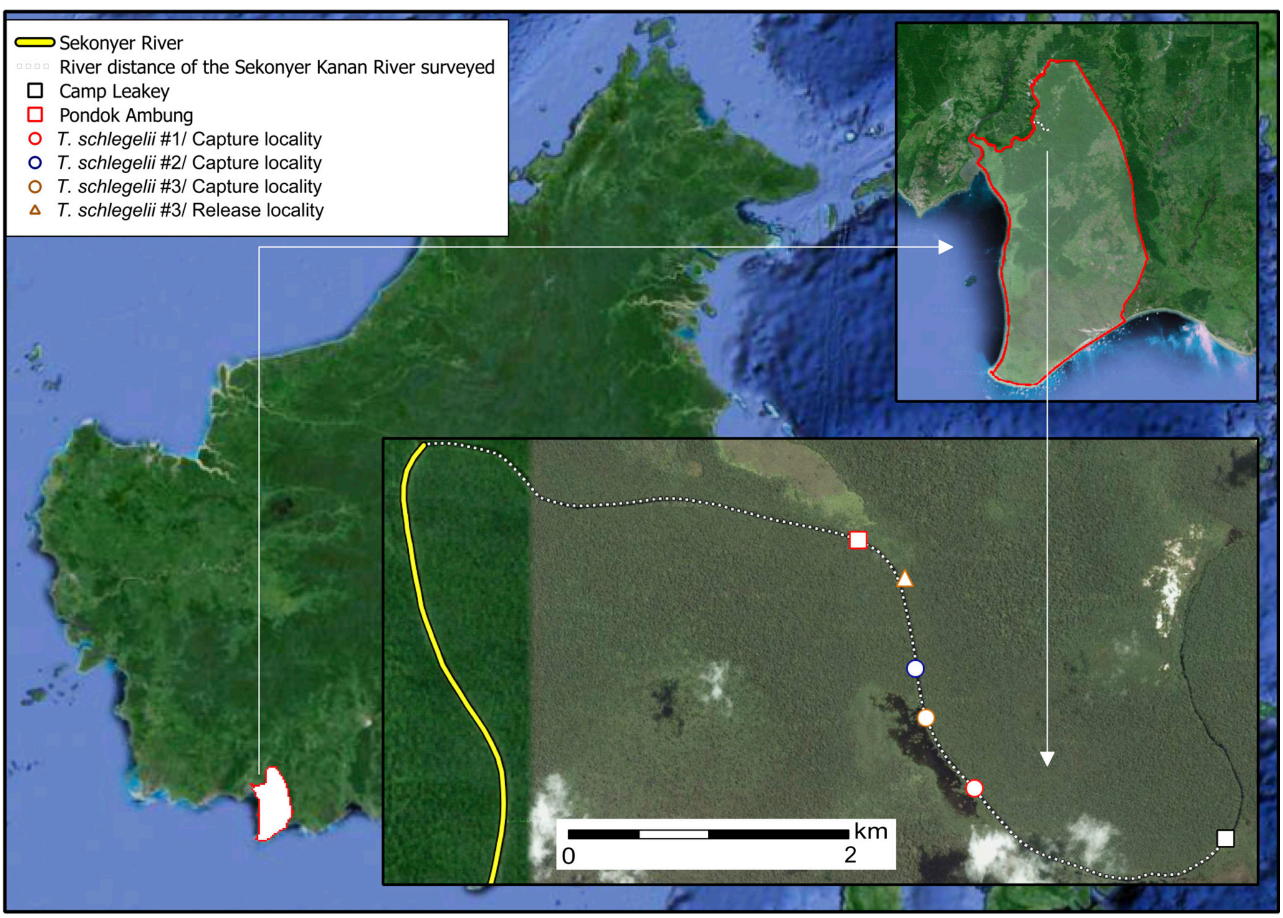



Figure 1. Details of the *T. schlegelii* study area.

### Capture and transmitter attachment

Spotlight surveys and capture trials by boat were carried out along both the Sekonyer River and the Sekonyer Kanan River. Animals of suitable size for transmitter attachment were captured solely in the Sekonyer Kanan tributary, as lower water levels allowed locating specimens even when they were submerged.

Spotlight surveys along the Sekonyer Kanan River were of 7.5 km in length with durations varying from 2:07 to 2:42 h. Detecting crocodilians based on eyeshine is a standard technique (Magnusson et al. 1982). Small-sized *T. schlegelii* (< 100 cm total length (TL)) were manually captured while larger individuals were caught using a large landing net or a self-constructed snare-pole. The snare-pole consisted of a wooden pole (length: 2 m, diameter: 50 mm) holding a wire-snare (diameter: 8 mm; min. breaking force 500 kg) at its terminal end. Capture points of all individuals were recorded using a handheld GPS (Global Positioning System) device (Magellan® Triton 500™). All specimens captured were physically restrained using draperies and duct tape and taken back to the research camp for morphometric data collection prior to their release. Although we tried to identify the sexes of captured specimens using a speculum, unambiguous identification was not possible. Three specimens of *T. schlegelii* (#1: total length: 118 cm, body mass: 3.8 kg; #2: 178 cm, 12.8 kg, #3: 134 cm, 5.4 kg) were selected for very high-frequency (VHF) radio tracking transmitter attachment.

We used ear-tag transmitters (TX-124E, 150 MHz, TELENAX, Mexico) that have originally been designed for tracking livestock, but were also successfully used to track aquatic species such as Dahl's toad-headed turtle *Mesoclemmys dahli* (Forero-Medina 2011). This transmitter was selected due to its expedient dimensions (size: 27 × 11 mm; weight: 17 g) and shape, which would not interfere with the study animals' movements. As an added advantage, these transmitters were equipped with an activity/mortality detection sensor, facilitating the assessment of movements even if our study animals were submerged. After a functional test, the tail scutes were cleaned with 70% ethanol, and a tiny hole (diameter: 6 mm) was punched out using punching pliers. Transmitters were then attached by piercing the transmitter's steel plug (diameter: 4 mm) through the hole and securing it with a counter disk (Fig. 2). While two study animals were released at their respective capture points, we translocated the third to a small secondary branch of the Sekonyer Kanan River at a distance of approximately 1 km from its capture point to analyse potential site fidelity, which has been reported from other crocodilian species (see Read et al. 2007).

### Radio telemetry and data collection

Fieldwork was carried out between 31 August and 28 October 2009. The study animals were relocated by boat during daytime. The tracking intervals were dependent on the availability of survey vessels. The crocodilians were relocated almost daily, using a hand-held receiver unit RX-TLNX (TELENAX, Mexico) and a three-element foldable Yagi antenna (TELENAX, Mexico). Locations were directly recorded as latitude / longitude (WGS 84). Due to the muddy water, exact locations could rarely be confirmed by sight.

### Data analysis

Movement area sizes were determined as linear range sizes (LR), minimum convex polygons (100% MCP), kernel density estimators (50% and 90% KDE) and local *a*-convex hulls (50% and 90% LoCoH). We used Quantum GIS 1.8.0 (Quantum GIS Development Team 2012) to quantify linear range sizes (LR) as the direct distance between the most distant locations of each *T. schlegelii* (Sexton 1959, Pluto & Bellis 1988, Lue & Chen 1999). MCPs, KDEs and LoCoHs were quantified using the *adehabitatHR* package (Calenge 2006) for Cran R 2.15.2 (R Core Team 2012).


Figure 2. *Tomistoma schlegelii*, animal #1 (TL 118 cm) with ID tag and radio-tracking transmitter attached to its tail scutes.

Maps displaying the study area and spatial range analyses of *T. schlegelii* were created using the Georeferencer plugin and Google Satellite OpenLayers plugin of Quantum GIS 1.8.0 (Quantum GIS Development Team 2012).

Although MCPs revealed to be highly affected by the number of fixes, they are one of the most frequently used approaches to analyse animal movement in general and hence, were used to facilitate comparisons with previous studies (Jennrich & Turner 1969, Harris et al. 1990, White & Garrott 1990, Powell 2000, Nilsen et al. 2008).

By computing a probability range for each location through assigning more frequently used areas with a higher value, KDEs provide quantitative information on the intensity of habitat use and selection (Row & Blouin-Demers 2006). As numerous studies found least square cross validation (LSCV) to yield most accurate results and besides perform best for distributions composed of tight clusters of locations, we identified individual bandwidths, *h*, through LSCV (Worton 1989, Seaman & Powell 1996, Seaman et al. 1998, 1999, Gitzen et al. 2006, Row & Blouin-Demers 2006, Calenge 2006) using the *adehabitatHR* package for Cran R (Fig. 3).

LoCoHs facilitate the identification of distinct boundaries such as river banks in our particular case (Getz & Wilmers 2004, Getz et al. 2007). In LoCoH algorithms, a utilization distribution (UD) is obtained by creating convex polygons (i.e., convex hulls) around each sample point with its *n* nearest neighbours (Getz & Wilmers 2004, Getz et al. 2007). Currently, three methods for selecting the nearest points for each convex hull exist: *k*-LoCoH, *r*-LoCoH and *a*-LoCoH (Getz et al. 2007). Herein, we applied the recently developed alpha-convex hull (*a*-LoCoH), which represents a modification of the more basic *k*-LoCoH. The *a*-LoCoH approach was selected as it has been found to generally perform better than *k*- and *r*-LoCoHs and be less affected by highly variable sample sizes (Getz et al. 2007). As in KDEs, LoCoHs are based on a user-selected parameter. We followed Ryan et al. (2006) in performing a parameter optimisation in which *a*-values are plotted against range size. Therefore, parameter optimisation steps of 10 m (#1, #3) and 30 m (#2) were selected. Asymptotes suggest range estimates to be stable (Fig. 4). If more than one plateau was observed, we followed Korte (2008) in selecting *a*-values that eliminated areas not utilized within ranges, because the physical borders of the study area were known (Fig. 5). This procedure followed the “minimum spurious hole-covering” (MSHC) rule proposed by Getz & Wilmers (2004). Individuals’ bandwidth, *h*, and selected *a*-LoCoH values, as well as selected MCP, KDE and LoCoH range sizes are summarized in Table 1. For both KDE and LoCoH, we used the 90% isopleth to estimate the total range sizes while the 50% isopleth was used to estimate core areas.

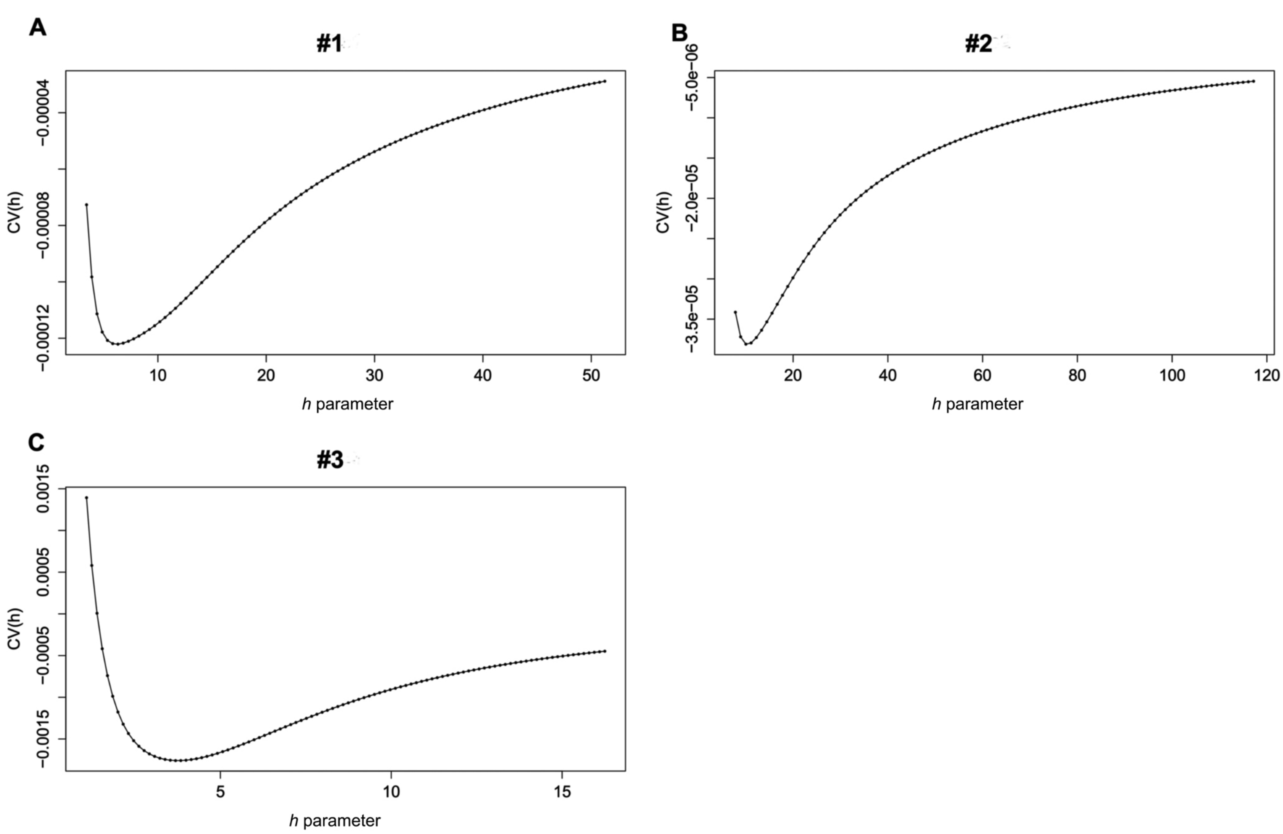



Figure 3. LSCV-identified bandwidth for the three study animals.

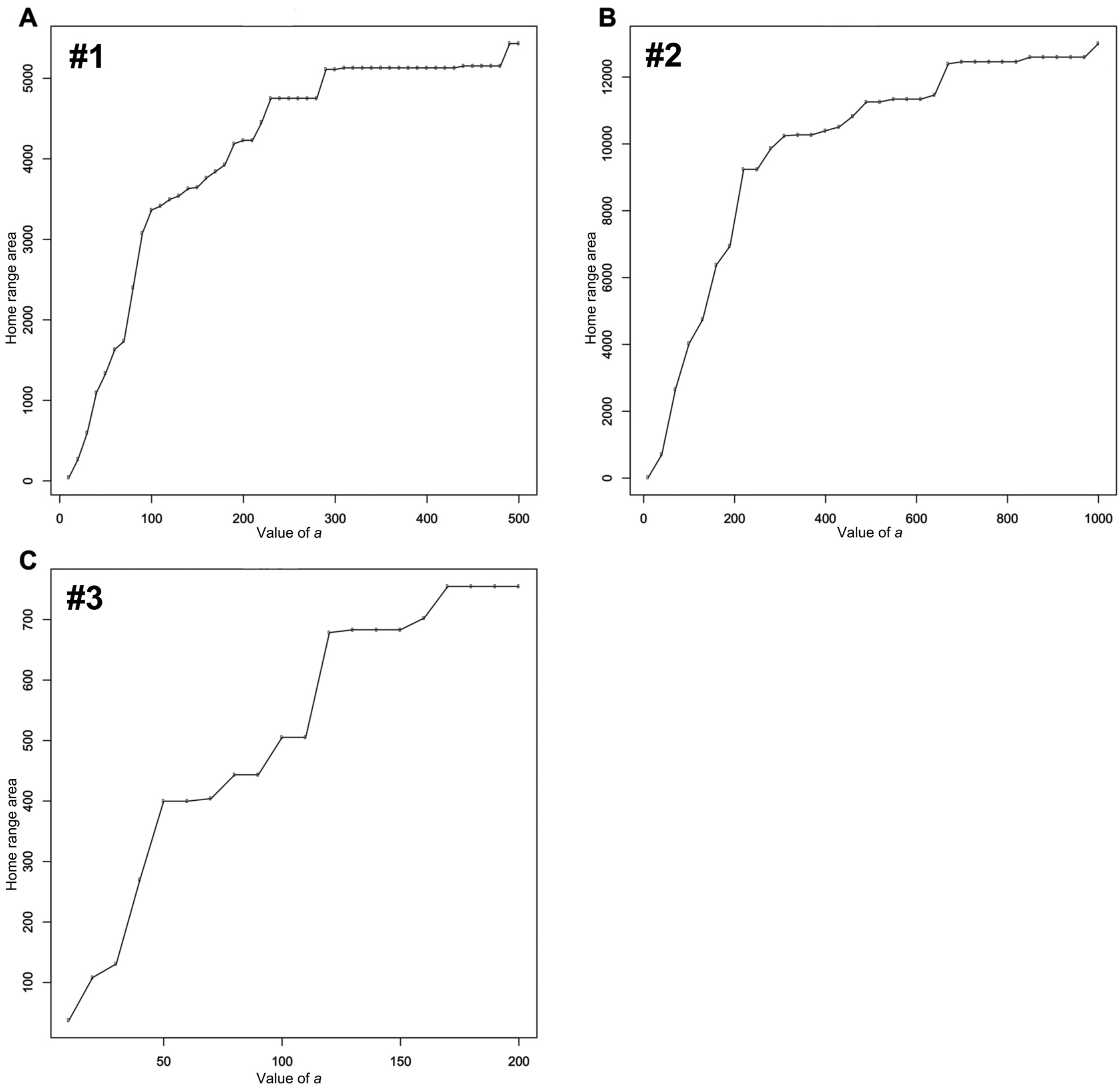



Figure 4. Parameter optimisation plots for the *a*–LoCoH values of the three study animals.

## Results and discussion

Between 31 August and 28 October 2009, a total number of 110 fixes were collected ranging between 29 and 42 fixes per specimen. A total of 104 fixes were used to perform range size estimates. Capture and release dates, capture locations, and body mass (BM) of study animals are compiled in Table 2. The translocated individual (#3) returned to its original capture site after 17 days. For range size analyses, we only used fixes obtained after the study animal had successfully returned to the initial capture locality.

### Comparisons of methods

Transmitter performance was generally high without technical failures. Dense vegetation and water reduced signal strength to approximately 350 m. Activity detection sensors performed well, providing information on movement and status of the study animals. Although previous studies mentioned constrains when attaching transmitters to tail scutes in *C. niloticus* this transmitter attachment technique has proven highly suitable in our study (Strauss et al. 2008). While in *C. niloticus*, transmitters were placed

Table 1. Bandwidth *h*, *a*–LoCoH values, MCP, KDE and LoCoH range sizes calculated for *T. schlegelii*.

| Animal | *h* | *a* | MCP 100% [ha] | KDE 90% [ha] | KDE 50% [ha] | *a*-LoCoH 90% [ha] | *a*-LoCoH 50% [ha] |
|---|---|---|---|---|---|---|---|
| #1 | 6.315 | 310 | 0.577 | 0.663 | 0.211 | 0.323 | 0.103 |
| #2 | 10.023 | 720 | 1.758 | 2.080 | 0.639 | 0.821 | 0.340 |
| #3 | 3.687 | 100 | 0.100 | 0.094 | 0.020 | 0.025 | NA |

Table 2. Table summarizing capture and release dates and sites as well as body proportions of *T. schlegelii* equipped with VHF transmitters. * total number of VHF fixes collected / **VHF fixes used to perform range size estimates.

| Animal | Capture date | Capture location | Release date | Release point | TL [cm] | BM [kg] | No. of fixes |
|---|---|---|---|---|---|---|---|
| #1 | 31.08.2009 | S 2°45'25.5" E 111°55'35.8" | 01.09.2009 | Identical to capture point | 118 | 3.799 | 42 |
| #2 | 03.09.2009 | S 2°44'58.3" E 111°55'22.4" | 05.09.2009 | Identical to capture point | 178 | 12.792 | 39 |
| #3 | 16.09.2009 | S 2°45'09.6" E 111°55'24.8" | 17.09.2009 | S 2°44'37.6" E 111°55'20.0" | 134 | 5.389 | 29*(23)** |

into PVC tubes and subsequently attached to the tail scutes with cable ties, which are likely prone to disintegration from UV radiation (Strauss et al. 2008), ear tag transmitters could be attached directly to the tail scutes without using additional attachment material. The simplified attachment in combination with the small housing dimensions minimized the risk of the transmitter breaking off in the dense riparian vegetation. Besides, intraspecific aggressive behaviour was considered the prime cause of transmitter loss in *C. niloticus* (Strauss et al. 2008), but was not observed during this study.

## Animal movement analyses

The linear range sizes (LR) of #1, #2 and #3 were 0.276, 0.739 and 0.104 km, respectively. KDEs produced the largest range size estimates, followed by MCPs and LoCoHs. One exception of these findings was observed in #3 in which MCP and KDE were of similar sizes. LoCoHs yielded core area estimates (50% LoCoH) of approximately half the size of the corresponding KDE core area (50% KDE). Due to the limited number of fixes, no LoCoH core area estimate could be performed for #3. Range overlap was only observed between #2 and #3 at 90% KDE (1.89%). MCP, KDE and LoCoH range sizes are compiled in Table 1. Contours of MCPs (100% isopleth), KDE, LoCoH range areas (90% isopleth), and KDE, LoCoH core areas (50% isopleth) are illustrated in Figure 6.

Numerous methods for animal movement pattern analyses exist with the minimum convex polygon (MCP) and the kernel density estimator (KDE) being the most widely applied approaches (Worton 1987, Laver et al. 2008). MCPs connect the outermost locations, and therefore provide a maximum size estimate without information on intensity of use (Hayne 1949, Kenward 2001, Row & Blouin-Demers 2006, Ryan et al. 2006). Therefore, MCPs tend to overestimate ranges by including habitats that are not utilized (Kenward 2001, Ryan et al. 2006). Besides, MCPs have been suggested to be subject to unpredictable bias (Börger et al. 2006). Nilson et al. (2008) questions the value of MCPs for ecological applications. Despite these shortcomings, MCPs are still widely used for animals' range size estimations and consequently had to be used to facilitate comparisons with previous studies. In concordance with Kenward (2001) and Ryan et al. (2006), MCPs were found to slightly overestimate range sizes for *T. schlegelii* by including unused terrestrial habitat and hence, are considered a maximum range size estimate.

Due to its accuracy and consistency, the KDE is currently the most widely used approach to estimate animals' range sizes and intensity of use (Worton 1995, Seaman & Powell 1996, Seaman et al. 1999). However, Row & Blouin-Demers (2006) argue that KDEs might not accurately perform for herpetofauna due to the multiple use of locations, which may lead to spatial autocorrelation. However, as the studied *T. schlegelii* always had sufficient time between subsequent fixes, the influence of spatial autocorrelation was considered negligible. Besides, correction techniques to remove spatial autocorrelation were found to reduce the biological relevance of range size estimates, while constant tracking intervals reduced the impact of such spatial autocorrelation without compromising the validity of range size estimates (De Solla et al. 1999). Furthermore, KDEs have been demonstrated to perform poorly in creating distributions in landscapes with distinctive boundaries (Getz & Wilmers 2004, Huck et al. 2008), which also was the case in our study. Despite the 95%-density isopleth being widely used to identify the boundaries of animals' range sizes (Getz et al. 2007), we rather followed Börger et al.

(2006) and used the 90%-KDE, which had been identified to reduce biases in area calculations especially when sample sizes are limited.

LoCoHs have recently been applied for a range of aquatic, semiaquatic and terrestrial animals (Elwen et al. 2006, Ryan et al. 2006, Wittemyer et al. 2007, Huck et al. 2008, Korte 2008, Winnie et al. 2008, Loveridge et al. 2009, Morse et al. 2009, Castellanos 2011, Peters & Nibbelink 2011, van Beest et al. 2011, Sawyer 2012, Scull et al. 2012, Leuchtenberger et al. 2013). As an advantage, LoKoHs capture distinct boundaries such as river banks (Getz & Wilmers 2004, Getz et al. 2007). While KDEs were found to include a terrestrial portion, which is uninhabitable for the highly aquatic *T. schlegelii*, LoCoHs in contrast performed well and therefore are considered superior in our particular case. The LoCoH parameter optimisation performed well, with values coinciding with the "rule of thumb" method suggested by Getz et al. (2007)

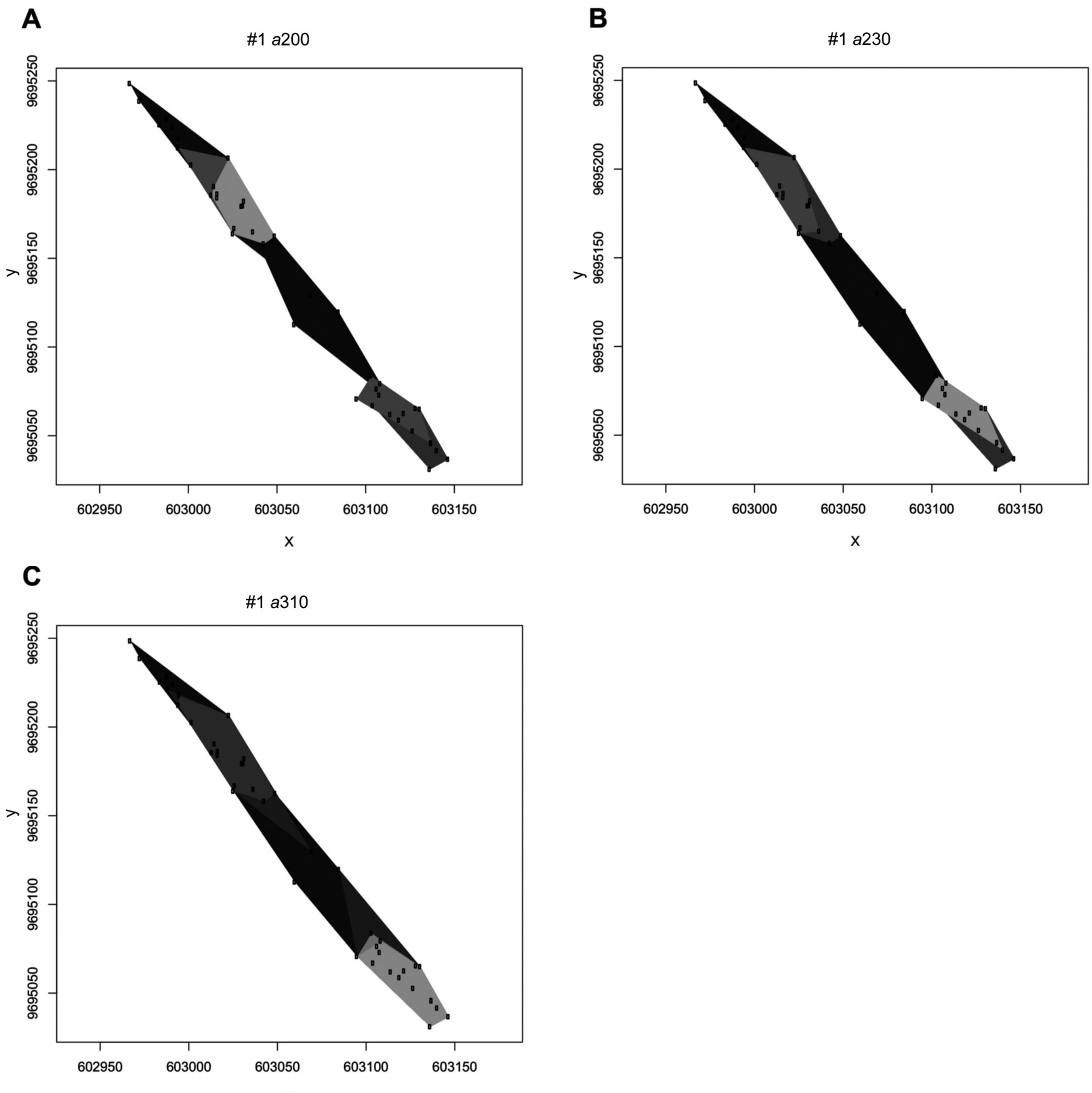



Figure 5. (A–C) Comparison of *a*–LoCoH values yielding range areas for *T. schlegelii* specimens #1, #2 (D–F) and #3 (G–J) following the MSHC rule (Getz & Wilmers 2004).

in which $a$ represents the maximum distance between any two points of the dataset.

MCPs, KDEs and $a$-LoCoHs produced very different range size estimates. Both MCP and KDE led to overestimations mainly because they incorporate unused terrestrial habitat. Hence, the $a$-LoCoH was found to yield the most realistic range size estimates for *T. schlegelii* due to its ability to capture sharp boundaries and create utilization distributions (UD).

### Constraints on spatial habitat use

Due to the restricted study period of two months, data acquisition was limited and thus, movement patterns can only provide preliminary range size estimates. Furthermore, fieldwork was restricted to the dry season, so that no data could be obtained regarding the extent of suitable habitat during the wet season when up to 50% of the TPNP is temporarily inundated (Auliya 2006). As the area occupied by

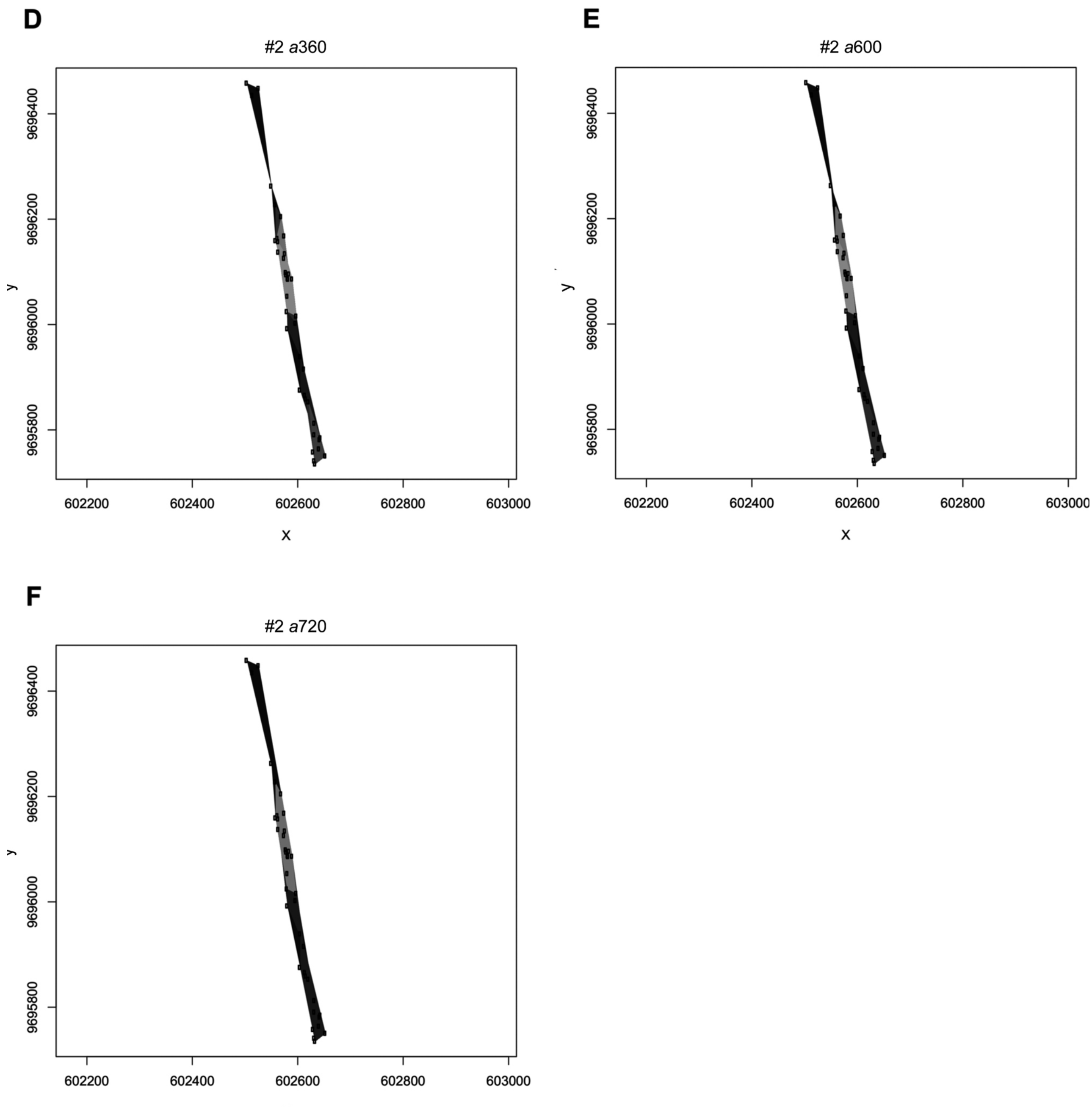
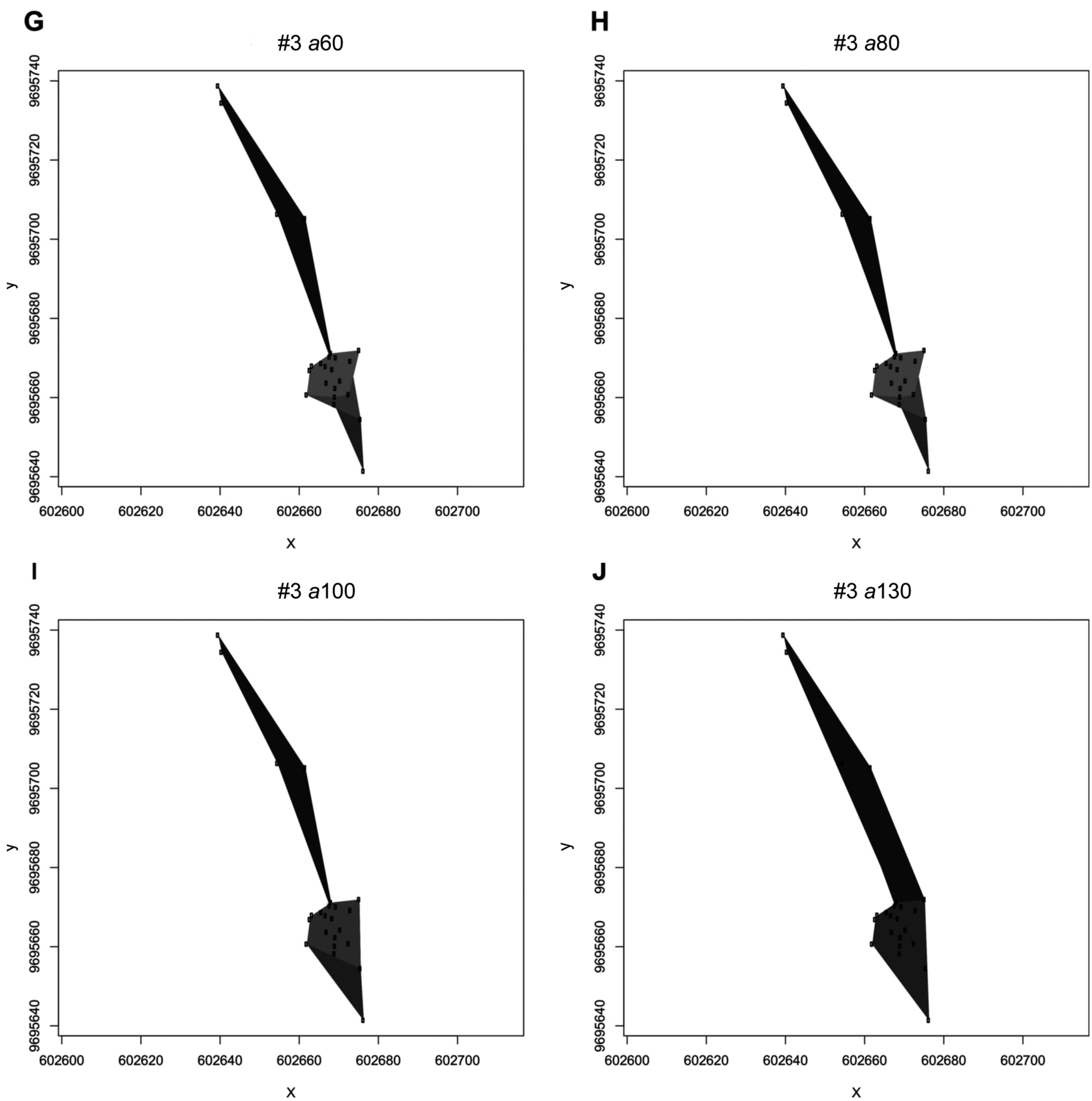



Figure 5. continued.

*T. schlegelii* is likely to expand during the wet season, our seasonal range size estimates are valid only for the dry season and likely underestimate the species full home range.

While the largest range size was obtained for the largest specimen (#2), body proportions (TL/BM) of the remaining two individuals are not in concordance with this pattern. Therefore, no correlation between body size of *T. schlegelii* and its range size could be demonstrated. *Tomistoma schlegelii* reaches sexual maturity at approximately twenty years and body sizes of 3 m in females and 4 m in males (Trutnau & Sommerlad 2006). Our study animals were considerably smaller. Hence, a sex dependent difference in range sizes appears to be unlikely.

The translocation of specimen #3 may have affected its subsequent movement pattern and consequently its range size estimate. Thus, the observed range overlap between specimen #3 and specimen #2 should be interpreted with caution. Due to the limited number of study animals, no further studies on site fidelity could be carried out, but our observations suggest the species to possess a homing ability

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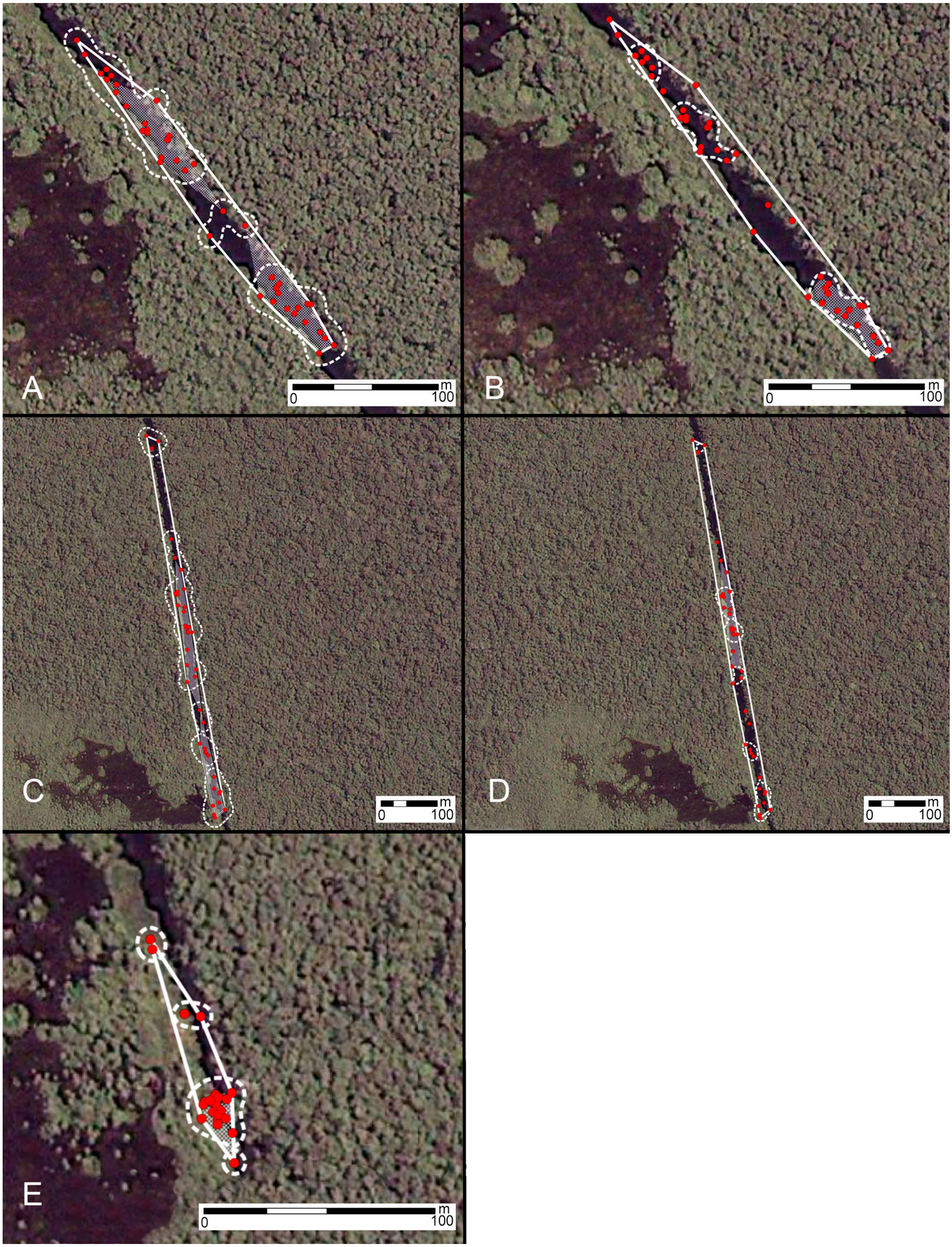


Figure 6. Spatial range analyses for *T. schlegelii*. MCP, KDE and *a*–LoCoH range size estimates for study animals #1 (A,B), #2 (C,D), and #3 (E). MCP 100% – solid line; KDE – dashed line (90%: A, C, E; 50%: B, D).

as has already been observed in other crocodilians (Gorzula 1978, Rodda 1984a, Rodda 1985, Read et al. 2007).

Through decades of tremendous conservation efforts the Orangutan Foundation (UK) has majorly contributed to the establishment of this comparatively secure population. As a result the Tanjung Puting population presently possesses the highest population density documented for the species (Auliya et al. 2006, Bezuijen et al. 2010). It therefore remains questionable if results of our study are directly assignable to other study sites where resident *T. schlegelii* populations are less protected and heavily exposed to anthropogenic hazards.

## Conclusions

Reliable conclusions on animal movements and home range sizes require large sample sizes, collected across size and age classes, as well as a broad temporal coverage (White & Garrot 1990, Garton et al. 2001, Kernohan et al. 2001, Kay 2004). Due to multiple limitations, our results can only provide preliminary data regarding homing, movement and range sizes of *T. schlegelii*. Additional extensive fieldwork is urgently required to provide deeper insights into the ecology and in particular the home range of this species. Understanding these processes is relevant to shedding light on niche segregation, habitat preferences, and seasonal movements, especially in the context of its reproductive behaviour. All these aspects must be known for establishing future *in situ* and *ex situ* conservation measures.

### Acknowledgements

For issuing the research permit (No. 0191/FRP/SM/VIII/2009), we kindly thank RISTEK (Kementerian Negara Riset dan Teknologi, Jakarta, Indonesia), CIMTROP (Center for International Cooperation in Sustainable Management of Tropical Peatland, University of Palangka Raya, Central Kalimantan, Indonesia), PHKA (Departemen Kehutanan-Direktorat Jenderal Perlindungan Hutan dan Konservasi, Jakarta, Indonesia), and the Balai Taman Nasional Tanjung Puting, Pankalan Bun, Central Kalimantan, Indonesia. For administrative help, advice and field assistance, we are deeply indebted to The Orangutan Foundation. We feel obliged to the Alexander-Koenig-Gesellschaft (AKG) e.V., the Deutsche Gesellschaft für Herpetologie und Terrarienkunde (DGHT) e.V., the Internationaler Reptillederverband e.V. Offenbach (Germany), the Tomistoma Task Force of the IUCN/SSC Crocodile Specialist Group, and the Zoologische Gesellschaft für Arten- und Populationsschutz e.V. (ZGAP) for their generous financial support. Furthermore, we express our thanks to the B&W International GmbH (Germany) and the Lupine Lighting Systems GmbH (Germany) for providing research equipment. The corresponding author wants to express his special thanks to Mark Auliya and Ralf Sommerlad for their input and advisory help to initiate this study, to Devis Rachmawan (Camp Manager, Pondok Ambung, Orangutan Foundation UK) for logistical support, and to his field assistants Androw Mikho Sion (Taman Nasional Tanjung Puting), Lesan and Pawi (both Orangutan Foundation UK) for their untiring dedication to this project.

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