Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.15.4.554

RESEARCH ARTICLE

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Short-term movements of the Pig-Nosed Turtle (*Carrettochelys insculpta*) in the Kao River, South Papua, Indonesia

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Article History
Received
21 November 2024
Revised
22 January 2025
Accepted
24 January 2025

Keywords
Carrettochelys insculpta, daily home range, daily movement, freshwater turtle

ABSTRACT

Understanding animal movement is essential for assessing species' ecological needs and informing effective conservation strategies. This study investigates the short-term daily movement and home range of the Endangered (EN) pig-nosed turtle (*Carettochelys insculpta*) in the Kao River, Boven Digoel District, South Papua, Indonesia. Native to Papua New Guinea, Northern Australia, and Southern Papua, this freshwater turtle faces heavy egg harvesting pressure. Using low-cost GPS tracking devices, we monitored six adult individuals (one male and five females) over a three-day period during November–December 2023. The results indicated that the daily movements of *C. insculpta* ranged from 84.95 to 648.77 m. Average home range estimates were 18.03 ha (minimum convex polygon), 7.51 ha (50% kernel density), and 12.44 ha (95% kernel density). The movement overlaps among the four turtles totaled 30.64 ha, with an average overlap of 6.12 ha. The hotspot analysis identified 76.16 ha as key movement areas, revealing that the pig-nosed turtles tend to stay near sandbanks, primary dryland forest, secondary dryland forest, and shrublands. Our study provides important baseline ecological data that can be used to inform future conservation and recovery programs. Elaboration between stakeholders and the local community can be carried out to protect the species.

Introduction

Studying animal movement is fundamental to understanding species ecology and its relationship with the environment [1]. This knowledge is critical for developing conservation strategies and managing spatial needs and habitats [2,3]. Animal movement can be classified into two temporal categories: daily movement and long-term seasonal or annual movement [4]. The range and frequency of daily movements help describe the activity of turtles, whereas long-distance and extended period movements reveal yearly patterns related to acquiring food, water, and breeding areas [5]. In turtles, movement is performed to select nesting sites, migrate, search for mates during the mating season, and find suitable habitats. A suitable habitat can provide the conditions needed by animals for long-term survival and breeding [6]. Turtle movement is affected by intrinsic factors such as sex and extrinsic factors such as season, resource availability, and environmental conditions [7–9].

Movement and home range are not well known for many freshwater turtle species. However, these data are important because many turtle species worldwide are experiencing a population decline. Of the 369 recognized extant turtle species, 187 (approximately 52%) were classified as threatened according to the criteria of the International Conservation of Nature (IUCN) and 127 (approximately 35%) were considered Endangered or Critically endangered[10–13]. These declines are a result of, but are not limited to, habitat loss and degradation, climate change, pressure from illegal, harvest, mesopredators, and overcollection for pet and meat trade. Indonesia has 25 species of freshwater turtle, of which 80% are listed as Vulnerable, Endangered, or Critically Endangered by the IUCN. The key challenges that drive freshwater turtle populations in Indonesia include habitat loss and degradation, unsustainable trade and utilization, and climate change

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[14]. Freshwater turtle populations are declining across Southeast Asia, including in Indonesia. However, our knowledge of their biology, particularly their ecology, remains limited.

The pig-nosed turtle (*Carettochelys insculpta*, Ramsay 1886) is a species that inhabits only the regions of southern Papua New Guinea and northern Australia [15]. This turtle remains in water throughout its life, except when females venture onto river sandbanks to lay eggs. It is under legal protection by the Indonesian government, recognized as Endangered (EN) on the IUCN Red List, and listed in Appendix II of CITES [15]. An examination of the literature on Indonesia's freshwater turtles highlights a significant gap in basic data, especially regarding the movement patterns and home range of the pig-nosed turtle. Information regarding pig-nosed turtles, particularly in Indonesia, predominantly focuses on harvesting for trade. Although it is one of the most traded turtle species, there are almost no data on the bioecology or behavior of pig-nosed turtles, especially in Indonesia. There is limited research on the species ecology, with most studies conducted in Australia [16,17].

Pig-nosed turtles in South Papua, particularly in the Boven Digoel District, have been reported on the Kao River [18,19]. Most of the areas mentioned previously were found to have pig-nosed turtles based on interviews with egg-harvesters and pig-nosed turtle nest surveys along the river [18]. Tracking species movement can identify essential habitat types, enabling the development of management plans for these critical areas. In the case of pig-nosed turtles, successful conservation efforts depend on identifying key aspects of their life history, such as movement patterns and home ranges. Effective habitat and species management plans must consider all critical habitats and life stages. The daily movement and home range of pig-nosed turtles in the Kao River remain unknown. Our specific objectives were to: 1) measure daily movements of pig-nosed turtles; and 2) measure a daily home range of pig-nosed turtles. Information on daily movements and home ranges can provide insights into the habitat use of pig-nosed turtles in the Kao River. Understanding the movement and home range of pig-nosed turtles is crucial for developing effective management and preservation strategies. Therefore, conservation efforts should be implemented to ensure long-term survival. Here, we discuss the implications of our findings for the conservation and management of this endangered species.

Materials and Methods

Study Area

This study was conducted in the Kao River area, located within the administrative boundaries of the Boven Digoel District, South Papua (4°98'–7°10' S and 139° 90'–141° E) in Indonesia (Figure 1). This region is part of the Digoel drainage system, with the Kao River stretching 200 km in length, ranging from 20 to 360 m in width, and has a current speed of 3 to 5 km/hour [20]. The river is vital in supporting local transportation, livelihoods, and ecological functions within the surrounding lowland rainforest ecosystem.

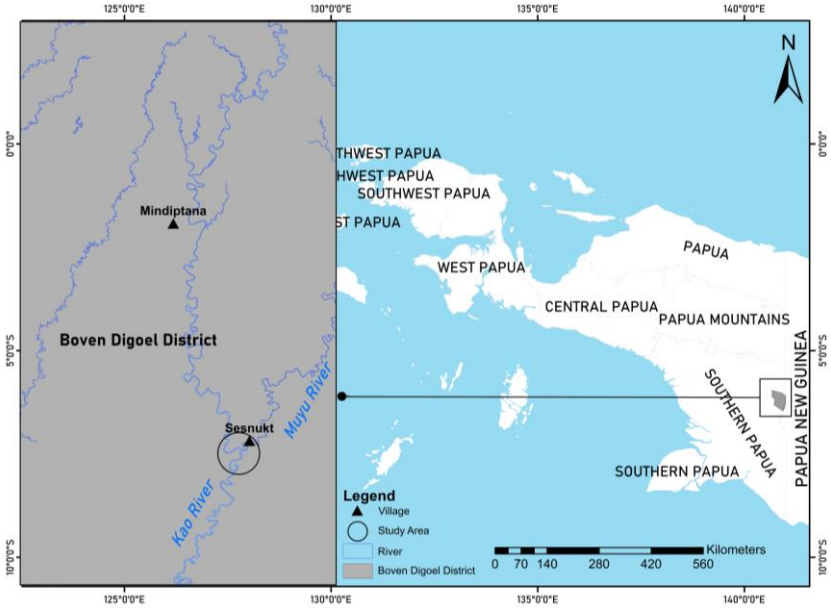

Figure 1. Research location map of the Kao River in Boven Digoel, South Papua, Indonesia.

Turtles Tracking

This research was conducted from November 7 to December 3, 2023, during the nesting season (October-November) [18]. Six pig-nosed turtles were captured by fishing (using a hook and line). These turtles were found at different locations within the same river. We weighed, measured, and individually marked each turtle with an ear tag at the left rear of the carapace [21]; their sex was determined by inspecting the tail length. The turtles used in this study were adults, with a straight carapace length (SCL) ranging between 30 and 47 cm and weight ranging between 3 and 12 kg. Pig-nosed turtles are categorized as juveniles with SCL of < 20 cm [22] (Table 1). Each turtle was equipped with a LoRA GPS module transmitter that was less than 5% of its total body weight and weighed 300 g per unit [23] . The LoRA GPS module transmitter is fixed to the right side of the rear carapace. The transmitter was secured to the pig-nosed turtles by creating three openings in the rear section of the carapace with a sterilized awl and then fastening it with cable ties measuring 2.54 mm in width (Figure 2). First, we used three zip ties in a cross configuration to secure the transmitters. This method proved to be more effective in maintaining transmitters in place. Positioning the transmitter at a specific spot on the carapace minimized the risk of becoming entangled in vegetation and debris and prevented any potential interference with mating. Turtles were then released at the capture points.

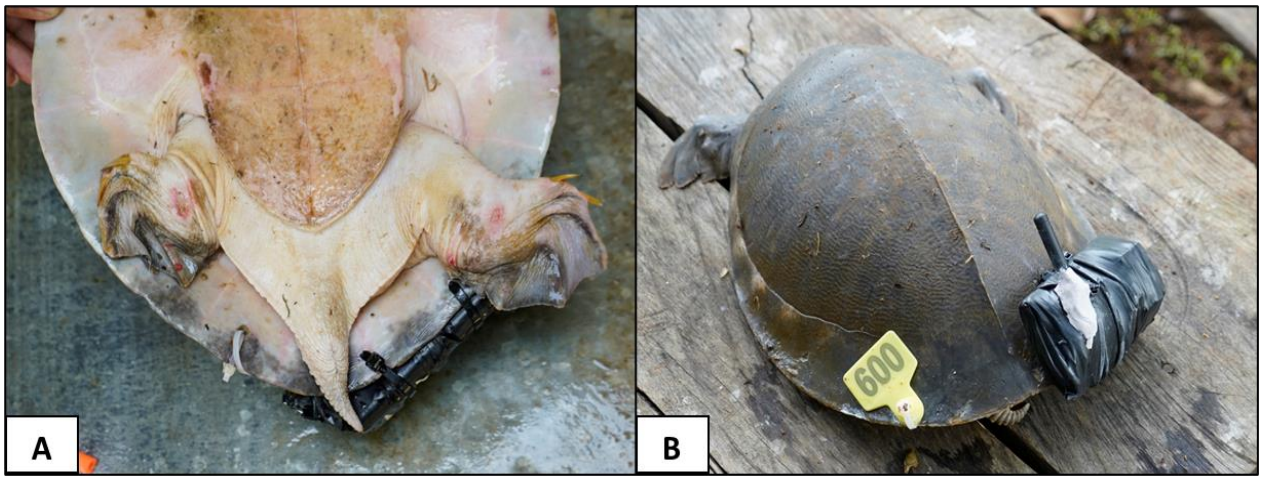

Figure 2. LoRA GPS module attachment for *C. insculpta* (a) Ventral view and (b) Dorsal view.

Table 1. Tagging code of pig-nosed turtle, sex, straight carapace length (SCL), curved carapace length (CCL), mass, and date of capture.

No code	Sex	SCL (cm)	CCL (cm)	Mass (kg)	Date of captured	No fixes points
003	Female	37	38	5.5	09/11/2023	17
004	Female	43	45	9.8	18/11/2023	23
005	Male	43	44	8.2	19/11/2023	32
006	Female	41	42	7.2	17/11/2023	24
007	Female	47	48	12	16/11/2023	21
008	Female	30	31	3	20/11/2023	20

We tracked each turtle within 24 h of being released at the point of capture using a boat. The observations were conducted three days per week between November 14 and December 3, 2023, each for three days. Observations were made twice during the day; the first observation started in the morning at 8:00 and was made by following the river upstream for 3 km; if no data were found, then the observation was carried out by following the river downstream for 3 km from the turtle release point. The observation would stop if the receiver received the data sent by the turtle transmitter. The second observation started at 15:00 and stopped when the receiver received the data. If the receiver does not receive data, observations are conducted by extending the observation time by 40 mins. However, if the receiver still does not receive data after 40 min, the observation is stopped to conserve the boat's fuel. The distance between the release points was small, making concurrent tracking feasible. We tracked the first turtle at the first site for three consecutive days. Observations were conducted for three consecutive days within three weeks for the second to sixth turtles at each site.

Data Analysis

The pig-nosed turtle is highly aquatic and uses only land for nesting; thus, the movement study was restricted to the river channel. We used ArcMap 10.8 ESRY (Environmental System Research Institute, Inc.) software to analyze the short movements and home ranges of pig-nosed turtles. Location data obtained via the LoRA unit GPS data logger were used to determine space use with the arc toolbox. We calculated daily movement (m/day) by individuals using the COGO tools in ArcMap 10.8, which calculated the distance from release points and consecutive points along the river until the last points were located. We calculated the daily movement by taking the distance covered between each consecutive location and dividing it by the number of days involved. The daily home range of individuals was calculated using the minimum convex polygon (MCP) method. The overlapping area was calculated using ArcGIS 10.8. We also calculated the areas of an individual's daily home range at 50% and 95% using the kernel density estimator (KDE); the 50% KDE represented the core area, whereas 95% KDE indicated the overall size of the daily home range. The polygons resulting from the MCP and KDE analyses were then cropped to fit the Kao River polygon.

The analysis of pig-nosed turtles' hotspot movement was conducted using the Getis-Ord-Gi* statistic, a spatial analysis tool in ArcMap 10.8. The input data, consisting of point features (hotspot data), allowed the tool to cluster these points based on their frequency within each grid (fishnet) that was automatically generated during the process. This analysis identified statistically significant spatial clusters of high values (hot spots), low values (cold spots), and areas without significant values. The hot- and cold-spot areas were further classified into 90%, 95%, and 99% probability occurrences, respectively. After obtaining the hot-spot results, they were overlaid with land cover buffered 150 m from the river's edge. The overlay results were then used to identify the land cover types that served as hotspots for pig-nosed turtle movement in the Kao River.

Results and Discussion

Results

Pig-Nosed Turtle Daily Movement

We recorded 137 location points for the six turtles using a LoRA GPS module transmitter. As shown in Figure 3, pig-nosed turtles in the Kao River did not exhibit a single movement pattern: turtles 003 moved downstream, and turtles 004 moved upstream, while turtles 005 moved upstream and then moved downstream, and turtles 007 moved downstream and then moved upstream.

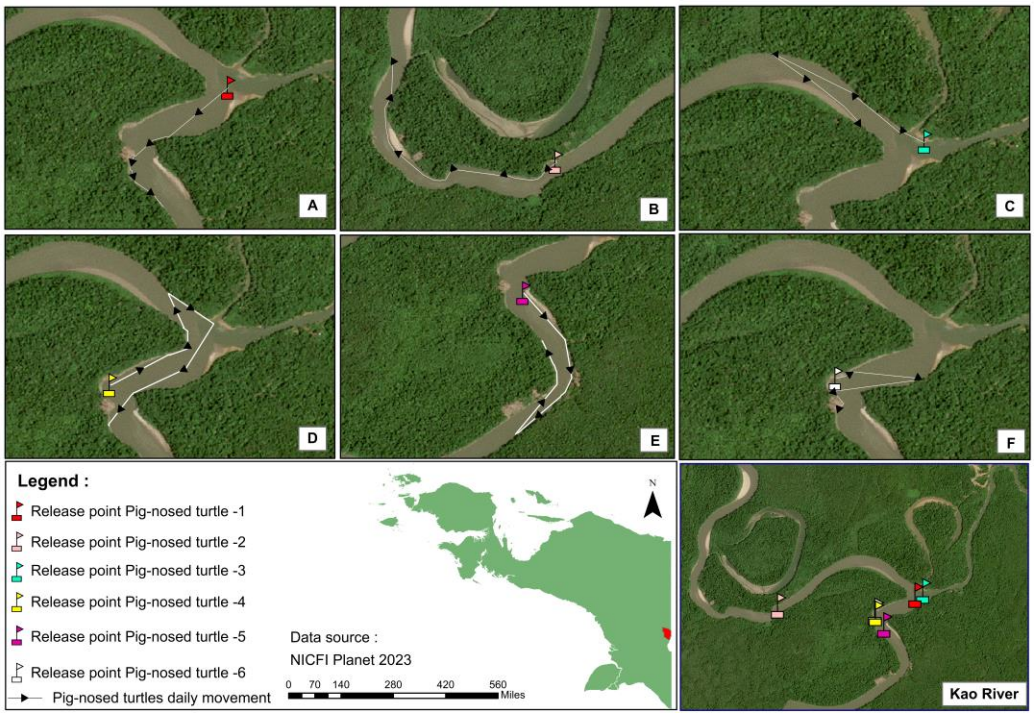

Figure 3. Daily movements of pig-nosed turtles in Kao River.

Turtles either settle at one location or move from one location to another, and pig-nosed turtles move upstream or downstream. Figure 3 shows that pig-nosed turtles in the Kao River tend to move from one location to another, indicating that they are active in their movement. Table 2 provides insights into the daily movements of pig-nosed turtles. We could not compare daily movements and daily home range sizes between sexes because there was only data for one male during the study. However, we present the results for all daily movements estimated in Table 2. The average daily movement of pig-nosed turtles in the Kao River ranged from 360.54 to 682.32 m.

Table 2. The pig-nosed turtled distance daily movement was calculated from the release point m/day.

Description	Day	003	004	005	006	007	008
Daily movement (m)/day	1	459.75	181.21	118.85	394.56	-	110.22
		225.72	365.83	347.49	247.32	440.56	-
	2	94.8	520.72	369.75	211.91	419.07	389.43
		-	-	-	311	405.29	504.99
	3	84.95	270.09	492.21	648.77	592.85	131.18
		216.4	389.72	259.66	234.29	184.44	-
Average (m)/day		360.54	575.85	529.32	682.61	680.73	378.60

Pig-Nosed Turtle's Daily Home Range

The daily home ranges of pig-nosed turtles in the Kao River are shown in Figure 4. The white polygon in Figure 4 represents the daily home range, and the gray polygon represents the space overlap of the turtles. MCP, KDE50%, and KDE95% estimate the daily home range size. The daily home range areas in our study included turtles that were captured initially. Nesting was not observed during our study; therefore, our daily home range estimates did not include nesting grounds. Table 3 provides insights into the movement of pig-nosed turtles in the Kao River.

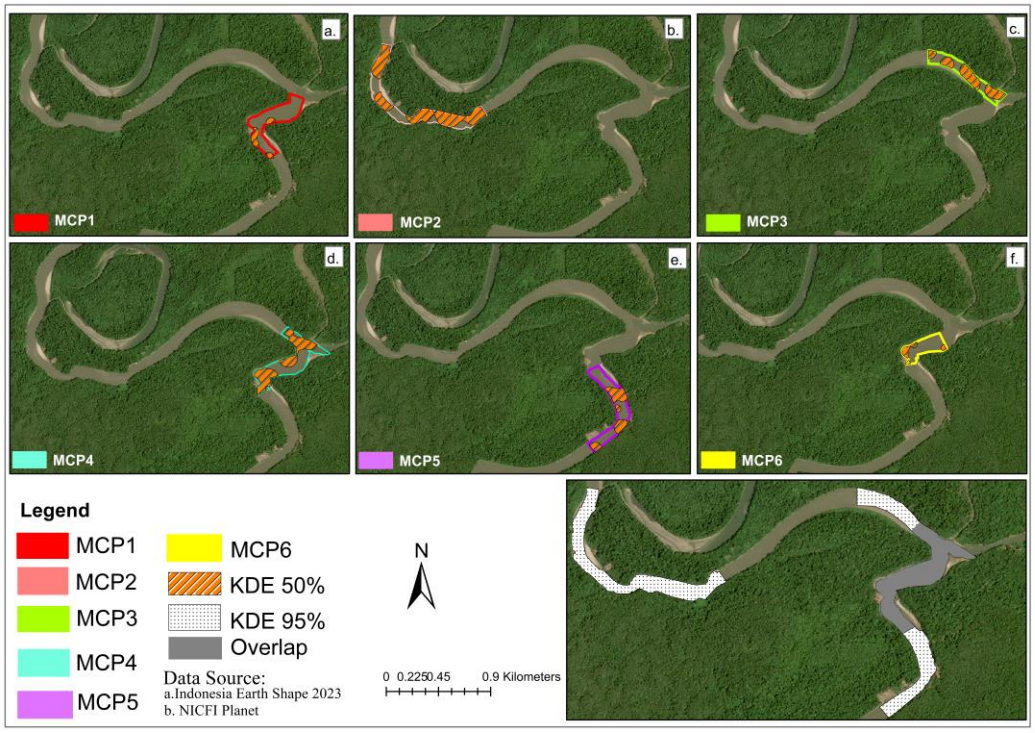

Figure 4. The daily home range of pig-nosed turtles (MCP & KDE) in Kao River, Boven Digoel.

Based on Table 3, the pig-nosed turtles' daily home range for MCP ranges between 12.76–24.59 ha, with an average value of 18.03 Ha. The highest MCP value was observed in females, whereas the smallest MCP value was observed in males. Table 3 shows that the The KDE50% value ranges between 1.56–17.09 ha, and the KDE95% value is between 2.99–23.88 ha. The average daily home range of KDE50% was 7.51 ha, and KDE95% was 12.44 ha. Some *C. insculpta* daily home ranges include multiple core areas, with most having between three and five core areas. Pig-nosed turtles were not confined their space use to a single area within the Kao River region.

Table 3. Pig-nosed turtles Daily home range MCP, KDE50%, and KDE95%.

No code	MCP (ha)	KDE 50% (ha)	KDE95% (ha)
003	16.37	2.55	7.06
004	12.76	7.68	12.74
005	24.59	17.09	23.88
006	19.00	10.21	15.44
007	16.81	6.02	12.55
008	18.67	1.56	2.99
Average (Ha)	18.03	7.51	12.44

Pig-Nosed Turtles Hot-Spot In Kao River

The pig-nosed turtle in the Kao river has a movement hotspot covering 76.16 ha (Figure 5). Hotspot analysis indicated that most of the Muyu River and two adjacent dead rivers were classified as cold spots. No movement of pig-nosed turtles toward the Dead or Muyu rivers was detected during this study. However, as the study was conducted over a short period, the results may vary with long-term monitoring. It is also possible that pig-nosed turtles avoid areas with greater transportation access. Sesnukt Village, which is near the Kao River, can reach via the Muyu River. The avoidance of dead rivers might be due to the river conditions, as they were mostly dry during the study due to the lack of rain. These rivers are typically inundated during rainy seasons.

The area of hotspot movement for pig-nosed turtles in the Kao River is concentrated near the sandbanks used for nesting, as well as in areas of shrubland, primary dryland forest, secondary dryland forest, and mixed farming. Figure 5 shows that the turtle movements are close to these nesting sandbanks, possibly because the study took place during the nesting season. Figure 6 show several wood logjams and isolated wood logs on the riverbank around the hotspot area. Pig-nosed turtles are suspected of using these microhabitats in addition to sand.

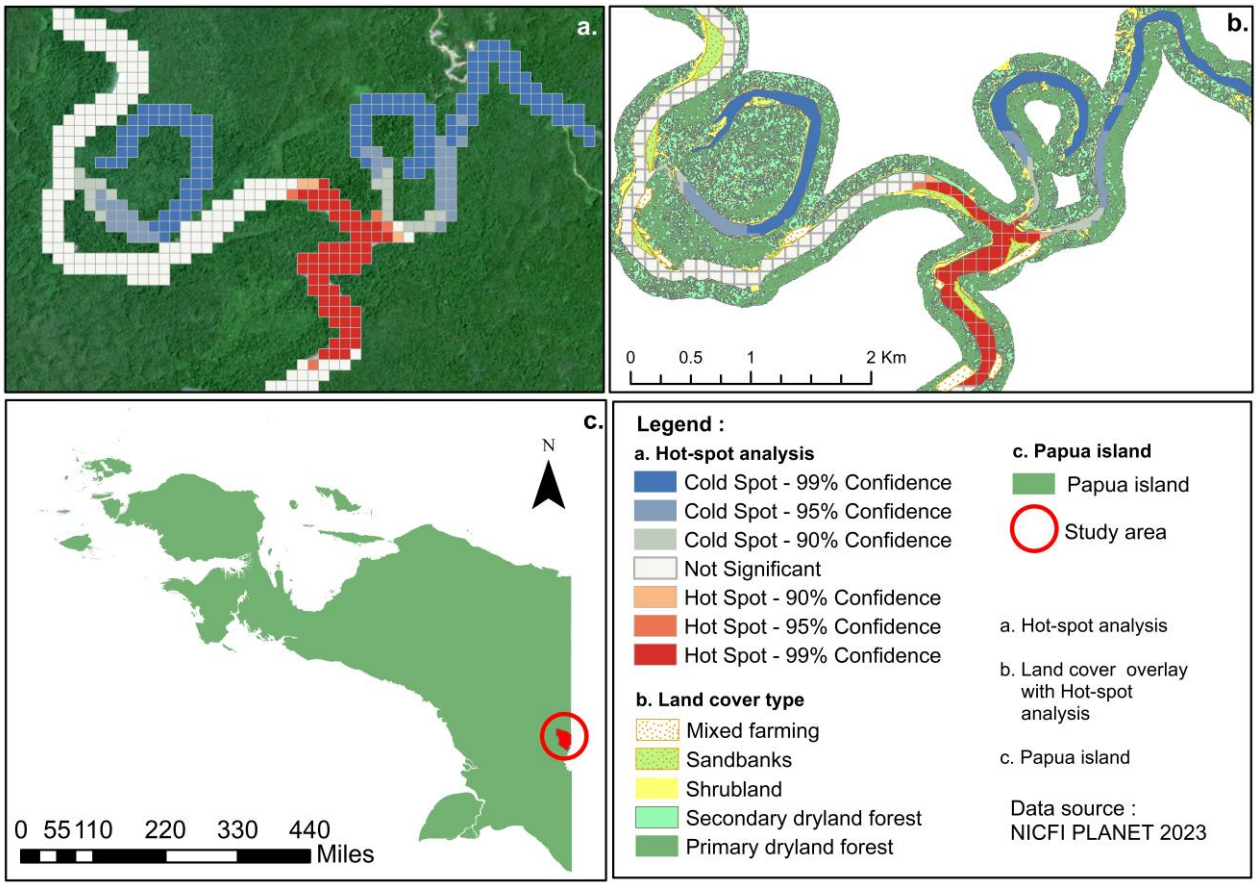

Figure 5. Land cover type and hot-spot analysis of pig-nosed turtle in Kao river, Papua.

Figure 6. Isolated log jam (A), Isolated log in the study area (B).

Discussion

Pig-Nosed Turtle Daily Movement

Six turtles were used in this study. The limited availability of the devices was a significant reason for using only six turtles. The cost of the devices is a primary obstacle. However, GPS tracking remains relatively expensive, with costs per unit ranging from $2,000 to $ 8,000, excluding additional charges for data download networks [24]. The small sample size naturally limits the findings of the study; however, this study was able to provide data on daily movements and daily home range. This study is part of research testing a cost-effective GPS tracker for turtles, created and developed by the pig-nosed turtle team from the Faculty of Forestry at IPB University. This device is still in the testing and development stages. The use of GPS tracking devices on pig-nosed turtles is a part of testing the device to observe its performance in the wild.

The research findings showed that pig-nosed turtles tend to move from one location to another and do not stay in one place. Figure 3 shows that pig-nosed turtles in the Kao River tend to move from one location to another, indicating that they are active in their movement. Research conducted in the Daly River also found similar results, showing that male and female pig-nosed turtles moved upstream and downstream [17]. A previous study in the Daly River revealed that ten turtles have different movement patterns: seven made upstream movements, one moved downstream, and two moved in both directions [16]. The research findings show that pig-nosed turtles tend to move along the riverbanks. The varied movement directions (upstream and downstream) suggest that the turtles actively forage across different habitats within the river, potentially exploiting the diverse food resources available throughout the river system [25]. Turtles feed along riverbanks, where they cross plants, insects, crustaceans, and other small creatures. Riverbanks serve as a transitional zone between aquatic and land habitats and offer various food sources and shelters [17]. This study was conducted during the dry season. Based on observations, there was one instance of river rise from November 26 to 29, 2023. This rise caused the original small river to expand. Observations showed that the movement of pig-nosed turtles tended to remain along riverbanks, regardless of whether they were during high or low tide. This suggests that their movement behavior is not significantly influenced by tidal changes, considering that pig-nosed turtles are aquatic animals. However, the daily movement range and home range size could change, as the fluctuations in river size due to tides may affect it.

Daily movement data in North Australia showed that *C. insculpta* inhabits distinctively and generally well-separated locations during the day and night [17]. In the Kao River, we found that pig-nosed turtles actively moved during both day and night, as indicated by the displacement from the previous positions where the turtles were found. In the Daly River, pig-nosed turtles exhibit activity both day and night, with extended activity periods likely reflecting the need to optimize food intake in an energy-constrained environment [16,26,27]. The interpretation of this behavior in the Kao River is that pig-nosed turtles are likely to be active both day and night to optimize food intake, similar to their behavior in the Daly River. This suggests that turtles in the Kao River may also face environmental pressures that require them to maximize their foraging time. The difference between the research in the Kao and Daly rivers lies in the duration of data collection. In the Kao River, movement data were collected over three days for each individual, whereas in the Daly River, movement data were gathered over three months and 22 days.

The mean daily movement of pig-nosed turtles in the Kao River ranged from 360.54–682.32 m. According to a previous study in Daly River, North Australia, the distance per movement of pig-nosed turtles ranged between 210.0–2,370.78 m [16]. Differences in these results occurred because of the varying durations of data collection, as previously mentioned. There were some missing data points in Table 2 (indicated by "-"), which might be due to the possibility of deep diving of the turtle. Based on a pilot test at IPB University, the transmitter cannot send data to the receiver if the tracking device is submerged up to 3 m deep underwater [23]. The results in Table 2 show that turtle 006 had a higher mean daily movement value than turtle 007. The SCL and mass of female turtle 007 (SCL:47 cm, 12 kg) were greater than those of the female turtle 006 (SCL:41 cm, 7.2 kg). This may indicate that the body size of adult pig-nosed turtles does not affect movement values. Previous studies on the Daly River have reported similar results. Female turtles with an SCL of 43 cm have a distance per movement of 523.4 ± 868.82 m, while female turtles with an SCL of 46.2 cm have a distance per movement of 489.0 ± 1,019.72 m. A female turtle with an SCL of 40.2 cm had a distance per movement of 775.3 ± 1,324.20 m, while a female turtle with an SCL of 44.5 cm had a distance per movement of 463.0 ± 1,052.73. In turtles, variations in home range and movement patterns have been documented both within and between species [7]. External factors such as weather conditions, seasonal changes, the dimensions of wetlands, and the surrounding environment can significantly influence these patterns.

Additionally, study in Daly river also showed a male turtle with an SCL of 37.5 cm had a distance per movement of 276.0 ± 434.16 m, while a male turtle with an SCL of 40.1 cm had a distance per move of 212.4 ± 362.67 m [16]. Intrinsic factors such as size or sex did not affect the movement distance, which has been reported in other species, such as *Kinosternon abaxillare* in Central Chiapas [28], *Phrynops geoffroanus* in Brazil [29], *Terrapene bauri* in Florida [30], and the amur soft-shell turtle (*Pelodiscus maackii*) in China [31]. Limited movement can be influenced by turtle behavior and abiotic factors. In this study, we were unable to observe the behavioral factors restricting movement due to the murky conditions of the Kao River. Based on previous research findings, water temperature is one of the factors affecting the movement of pig-nosed turtles [32]. Freshwater turtles are unable to regulate their body temperature internally; thus, they depend on environmental temperature for regulation [9,33,34]. In other species such as *A. mutica*, *S. depressus*, and *P. maacki*, water temperature greatly affects movement [31,33,35]. In some subtropical regions, the winter season affects turtle behavior, resulting in limited movement. In China, the hibernation period for Reeves' turtles, scientifically known as *Mauremys reevesii*, typically starts from mid-November and extends into December, gradually concluding by March or April [36]. On the other hand, hawksbill turtles display a behavior known as quiescence, which spans an average of 11.3 days during each internesting phase. This quiescence is marked by the least amount of activity, with the shortest movement distances and the longest duration overall [37].

Pig-Nosed Turtle's Daily Home Range

The pig-nosed turtles' daily home range for MCP ranges between 12.76–24.59 ha, with an average value of 18.03 ha. The highest MCP value was observed in females, whereas the smallest MCP value was observed in males. Results from studies about pig-nosed turtles in Daly River showed that home range in females (43.7 ± 17.27 ha, N = 13) are higher than males (16.2 ± 6.58 ha, N = 5). Pig-nosed turtles in the Kao River area have a relatively sizeable daily home range despite the short observation period, which is influenced by the size of the Kao River. The width of the Kao River has a width ranging from 20–360 m. Our findings align with earlier research indicating that the home range sizes of aquatic turtles expand with the size of water bodies [38]. Factors such as river size, habitat, and search for food and mates may influence the home range size and shape of river turtles [39–41]. River size may affect the home range size, as shown in the example of the softshell turtle *Apalone mutica*. Individual *A. mutica* that live in smaller upstream areas utilize confined spaces that live in more extensive downstream reaches. This causes the home range of *A. mutica* in the downstream river to be larger than that in the upstream river [35].

The KDE50% value ranges between 1.56–17.09 ha, and the KDE95% value is between 2.99–23.88 ha. The average daily home range of KDE50% was 7.51 ha, and KDE95% was 12.44 ha. Some daily home ranges of *C. insculpta* include multiple core areas, with the majority having between three and five. Pig-nosed turtles did not limit their space to single areas of the Kao River area. Previous studies on the Daly River also found no significant differences in home ranges among gravid and non-gravid female turtles. However, they found that females were more active, moved further, and occupied a more extensive home range than males. However, in the present study, we found that the MCP of four turtles overlapped (turtles 003, 005, 006, and 008). Both male and female turtles had overlapping areas. The total area overlap was 30.64 ha with an average valueofs of 6.12 ha. This result shows that pig-nosed Kao River turtles use the same space to fulfill their needs. In

comparison, previous studies have shown that home ranges overlap between pig-nosed turtle species. In the Daly River, a high proportion of turtles shared the same river stretch with a given turtle, with 96.8% females and 84.6% [16]. It is also common for male and female group of turtles to overlap [17].

Pig-nosed overlap occurs because this social species has been observed to engage in group activities such as feeding, aquatic basking, and nesting [15,17,22,42]. Although tortoises are mostly solitary creatures, they rely on olfactory signals for social communication. Various tortoise species utilize these scent cues to identify the identity, gender, and reproductive condition of their fellow species [41]. Turtles and tortoises use a combination of visual and chemical signals during social interactions involving the head and displaying patterns and colors on the front limbs, neck, and head [43]. Additionally, pig-nosed turtles are not territorial animals. If wild animals do not exhibit territorial behavior, their movements and home ranges may overlap [44]. Other turtle species, such as *Glyptemys insculpta*) [27] and *Glyptemys muhlenberg* in the Southern Appalachians (USA), have overlapping home ranges [45]. The reason pig-nosed turtles in the Kao River use the same space can be influenced by the availability of food. Pig-nosed turtles are omnivorous, so there is little likelihood of competition for food.

Based on field observations of pig-nosed turtles in the Kao River, their diet consists of breadfruit (*Artocarpus altilis*), matoa fruit (*Pometia pinnata*), and genitri fruit (*Elaeocarpus angustifolius*). The animals they eat include shrimp and several types of clams [17]. These findings are consistent with research conducted in Papua New Guinea and Australia, which also indicates that pig-nosed turtles are omnivorous [17]. In Papua New Guinea, pig-nosed turtles consume fruits from *Xylocarpus species*, *Nypa fructicous*, *Canarium indicum*, *Antrocarpus incisor*, and the *Saccharum robustum*. Their animal-based diet includes mollusks such as *Batissa violacea*, *Nerita species*, and *Centhidea species*, along with the crustacean *Scylla serrata*. In Australia's Alligator River system, these turtles eat various parts of riparian plants, including *Ficus racemosa*, *Syzygium forte*, and *Pandanus aquaticus*. They also consume aquatic insect larvae, crustaceans, mollusks, fish, and possibly carrion from mammals. Aquatic plants like *Vallisneria sp,* and *Najas tenuifolia* are also part of their diet. During the dry season in the Daly River, their diet primarily consists of *Vallisneria sp*, with smaller amounts of green algae, snails, and figs [15,17].

Pig-Nosed Turtles Hot-Spot In Kao River

Hotspot analysis indicated that most of the Muyu River and two adjacent dead rivers were classified as cold spots. No movement of pig-nosed turtles toward the Dead or Muyu Rivers was detected during this study. However, as the study was conducted over a short period, the results may vary with long-term monitoring. It is also possible that pig-nosed turtles avoid areas with greater transportation access. Sesnukt Village, which is near the Kao River, can reach via the Muyu River. The avoidance of dead rivers might be due to the river conditions, as they were mostly dry during the study due to the lack of rain. These rivers are typically inundated during rainy seasons. The movement hotspots of pig-nosed turtles in the Kao River are concentrated near the sandbanks used for nesting, as well as in areas of shrubland, primary dryland forest, secondary dryland forest, and mixed farming. This is in line with the daily movement findings, which show that most turtles move along the riverbanks.

The movements of the turtles are close to these nesting sandbanks, possibly because the study was conducted during the nesting season. In the Kao River area, the pig-nosed turtle nesting season occurs from October to November [18]. During the nesting and post-nesting periods (August to December) in the Daly River, 346 observations found that females use sand as a microhabitat and movement is associated with the nesting season [16]. Female *C. insculpta* move together around the nesting beach along the river during the nesting season [46]. This research found that a total of 105 and 115 observations used isolog wood and logjam wood respectively [16]. The Kao River serves as a habitat for pig-nosed turtles; however, hot-spot analysis indicates that there are areas that are more frequently used by pig-nosed turtles. Information about hotspots can provide insights into the characteristics of the habitats used by pig-nosed turtles. Additionally, this information can assist local governments in policymaking and management programs for pig-nosed turtles in the Kao River, specifically in spatial planning and area management. This research found that a total of 105 and 115 observations used isolog wood and logjam wood respectively [16].

Conservation Implication

The pig-nosed turtle is listed as EN in the IUCN Red List of Threatened species [15]. The greatest threat to the existence of pig-nosed turtle cames is from humans. Humans cause various ecological problems; human activities that have led to the endangerment or event extinction of certain wildlife species include hunting/capturing, habitat destruction, and forest conversion [44]. The core of managing each species is the

maintenance of an appropriate habitat [44]. Information regarding the movement and home range of pig-nosed turtles in the Kao River can provide insights into their habitats. The local communities in the Kao river area posses family inheritance hunting areas or customary lands known as *hak ulayat*. At least 23 clans from two tribes (Mandobo-Muyu and Muyu-Mandobo) have traditional ownership of pig-nosed turtle breeding areas on the Kao River [18].

The results of the study on the movement of pig-nosed turtles showed that turtles move close to sand banks or breeding sites, which means that the turtle also moves within the traditional areas of clan *Karut 1, Karut 2*, and *Jononggoh*. Utilization of pig-nosed turtles, especially eggs, provides economic benefits for the local community and holds promise for future prosperity. *Hak ulayat* indicates that the local community around the Kao River regards pig-nosed turtles as having very promising benefits. The values associated with pig-nosed turtles should align with harmonious conservation management. However, the findings of this study show that the community continues to engage in excessive utilization, particularly in the harvesting of eggs, without any notable conservation efforts.

The success of the protection and conservation efforts for pig-nosed turtles is greatly influenced by the level of awareness and participation of the community, including all government officials, towards pig-nosed turtle protection and preservation programs. Information on the movement and home range of pig-nosed turtles in the Kao River can provide a basis for local governments to consider when formulating policies related to priority areas for the sustainable use and protection of pig-nosed turtles as well as the involvement of sand-nesting ground owners in the management of pig-nosed turtles. The habitat of the pig-nosed turtle in the Kao river needs protection through government regulation, either in the form of *Peraturan Daerah* (regional regulation) or *Peraturan Desa* (village regulation or village decree). We recommend to the regional government that turtle conservation strategies include buffer zones ranging from 150 to 300 m from streams to keep the vegetation around the pig-nosed turtle habitat [47]. Integrating human activities into zoned areas would be better than strictly prohibiting accessibility to these areas. Granting restricted access to local communities in specific zones will facilitate resource monitoring and ensure that all activities are well-controlled [48].

The success of conservation is highly dependent on community involvement, awareness, and management [49]. We recommend that elaborations be specifically carried out through collaboration between the government, the clan owners of the sand nesting grounds, and nearby companies to jointly participate in the conservation management of pig-nosed turtles and their natural habitat directly, including their movement habitat and nesting habitats. Possible actions include raising community awareness by conducting extension and educational activities to inform about the importance of conserving pig-nosed turtles and their habitats. These initiatives may include campaigns, workshops, and educational programs integrated into school curricula, aimed at boosting the human resource capacity of clan representatives to collaboratively participate in conservation efforts for the habitats and nesting areas of pig-nosed turtles. This involves training each clan representative responsible for sand nesting sites to preserve forest conditions and vegetation around rivers and nesting habitats, ensuring the ecosystem remains balanced. The action plan is aimed to be collaboration and elaboration among the government, local communities and nearby companies to help in ongoing efforts to better understand and conserve this unique but critically endangered turtle.

Conclusions

Our study has important implications for studying pig-nosed turtles in Indonesia, particularly in the Papua Region. The daily movement of pig-nosed turtles in the Kao River ranges between 84.95 m and 648.77 m. The daily home range estimated use minimum convex polygon ranges between 12.76–24.59 ha, with an average value of 18.03 ha. The daily home range estimated using kernel density of 50% ranges between 1.56–17.09 ha, and kernel density of 95% ranges between 2.99–23.88 ha. The hot-spot movement area of pig-nosed turtles in the Kao River is 76.16 ha; and hot-spot analysis revealed that the movement of pig-nosed turtles in the Kao River is located near sandbanks, shrublands, primary dryland forests, secondary dryland forests, and mixed farming. Elaboration between stakeholders and the local community can be conducted to conserve pig-nosed turtles. Efforts to safeguard the pig-nosed turtle's habitat can include initiatives such as campaigns, workshops, and educational programs in schools for communities near the Kao River. Additionally, policy-making through government regulations, like *Peraturan Daerah* (regional regulation) or *Peraturan Desa* (village regulation or village decree), can play a crucial role in this endeavor.

Author Contributions

MWLS: Conceptualization, Analysis, Methodology, Software, Investigation, Writing-original draft; **MDK**: Project Administration, Supervision, Validation, Writing-Review & Editing; **LBP**: Supervision, Validation, Writing, and Editing; and **RM**: Conceptualization, Analysis, Software.

Conflicts of interest

There are no conflicts to declare.

Acknowledgments

We sincerely thank all institutions and individuals who supported this research. This study was performed with assistance from the Korindo Group (PT. Tunas Sawa Erma, PT. Tunas Timber Lestari & PT. Inocin Abadi) under the MoU between PT. Tunas Sawa Erma and the Faculty of Forestry and Environmental Studies, IPB University (No. 0101/KG-TSE/JKT/VII/2022).

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