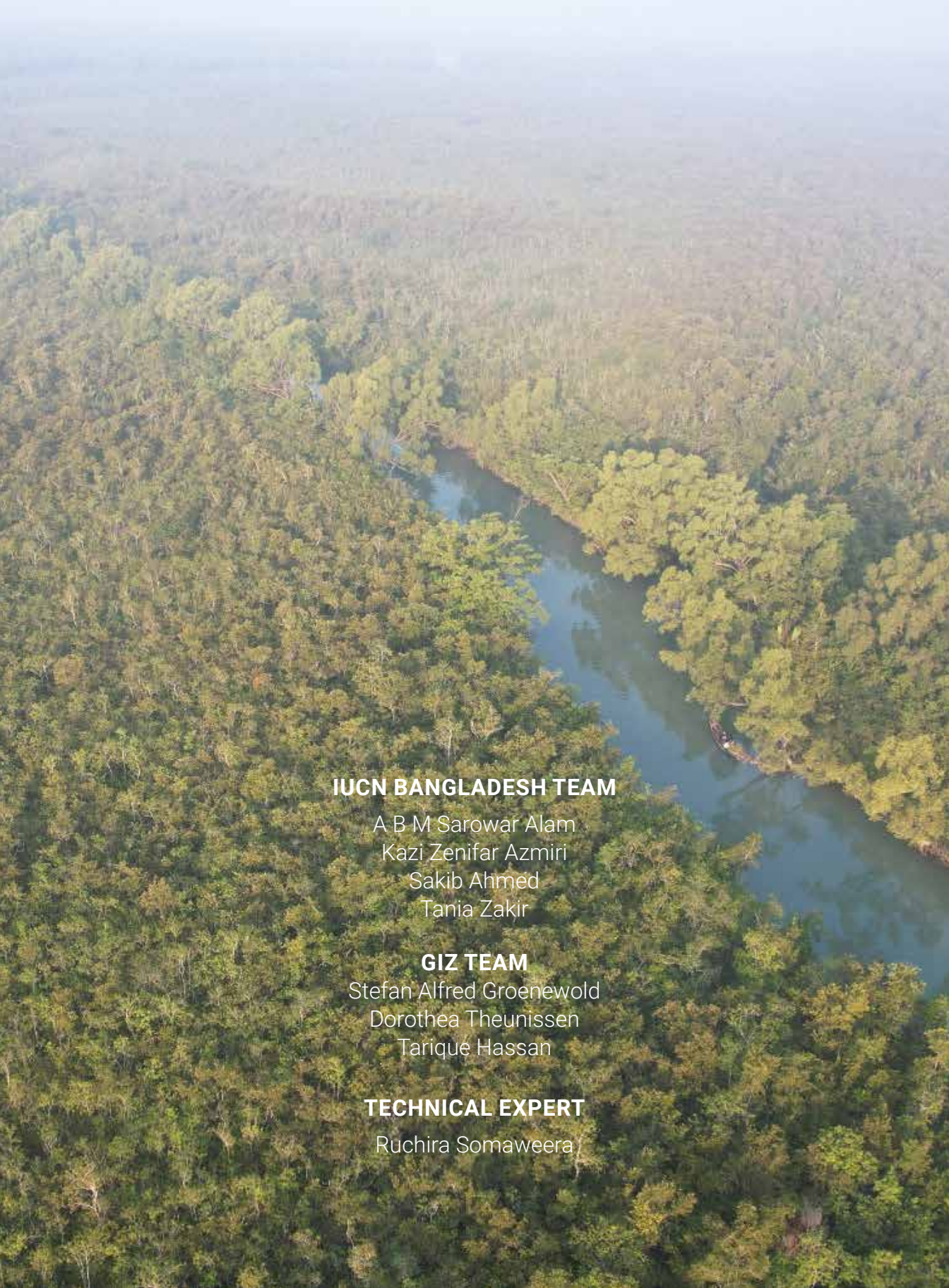


FIELD MANUAL FOR THE STUDY OF CROCODILES IN BANGLADESH



An aerial photograph showing a winding river or stream cutting through a vast, dense forest. The forest is composed of various shades of green, indicating different types of trees and vegetation. The river is a dark blue-grey color, contrasting with the surrounding greenery. The perspective is from a high angle, looking down on the landscape.

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FIELD MANUAL FOR THE STUDY OF CROCODILES IN BANGLADESH

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Salt-water crocodile

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CROCODILES OF BANGLADESH

SPECIES DIVERSITY

Bangladesh is the home to one species of gavialid, the Gharial (*Gavialis gangeticus*), and two species of crocodylians, the Marsh or Mugger Crocodile (*Crocodylus palustris*) and the Saltwater or Estuarine Crocodile (*Crocodylus porosus*).



GHARIAL

This species was historically known to be common in the Padma and Jamuna rivers (Khan 1982), but a drastic population decline due to habitat destruction and change saw the species disappear from most parts of their historical range in Bangladesh. A small number of Gharials continued to be reported into the 1980s. Nesting areas that were known to support a limited number of nests as late as 1985, have recorded no nesting since 1990. During floods, a part of the distribution range on the Padma River is periodically moved into Indian jurisdiction as the river channel changes. The current status of Gharial in Bangladesh is unknown. While some sources suggest that the species is extinct in the wild (Cox and Rahman 1994), others record anecdotal evidences for its existence. For example, based on questionnaire survey data, Rashid *et al.* (2014) reported 21 records of Gharials from Bangladesh between 2009 and 2012. Similarly, between 2000 and 2015, based on questionnaire survey data, IUCN Bangladesh (2016) recorded 58 Gharials from the major rivers of Bangladesh of which 39 were from the Padma River, 17 from the Jamuna River, and one from the Brahmaputra and the Mahananda Rivers each.





MUGGER CROCODILE

Cox and Rahman (1994) reported the mugger crocodile to be extinct in the wild in Bangladesh. Wild populations were extirpated in the Sundarbans during the 1980s. The last known individuals survived in the shrine of Khan Jahan Ali at Bagerhat (~25 km north of the Sundarbans) for several decades but are considered extinct in the wild now. Farming attempts for Muggers in Bangladesh has failed due to lack of breeding in captivity (Masum *et al.* 2012). There are a limited number of individuals in captivity in few zoos in Bangladesh.



Adult Mugger Crocodile from Sri Lanka

© Ruchira Somaweera

SALTWATER CROCODILE

The saltwater crocodile, *Crocodylus porosus*, is one of the most notable apex predators of aquatic ecosystems of the Sundarbans mangrove landscapes. In the past, saltwater crocodiles were abundant across the southern coast of Bangladesh, but heavy exploitation for skins until 1970s greatly depleted their populations (Whitaker 1982). Locally listed as Endangered, this species has received very little attention in previous investigations, thus



limited data exists on their population status, distribution and condition (Tamang 1993, Hussain and Achargya 1994, Halder and Deodatus 2003, Aziz and Islam, 2018). Aziz and Islam (2018) surveyed approx. 351 km of rivers of the Bangladesh Sundarbans during daytime between 2014 and 2015, and recorded a total of 42 individual crocodiles. Based on this estimate, it is inferred that a population of approximately 140 individuals could occur in the Bangladesh Sundarbans (Aziz and Islam, 2018). An in-depth understanding of the population status and the habitat use by this species within the Sundarbans mangroves would provide vital data for improved management and conservation of this poorly-known species.

Arguably, one of the most significant threats to this species is disturbances from and interactions with human activities, particularly resource collectors (e.g., *Nypa* palm harvesting, extensive fishing, honey collection, etc.) and cargo vessels navigating through different channels within the Sundarbans. These encounters have also given rise to a crocodile-human conflict in parts of the Sundarbans area (Das and Jana, 2017).

An improved understanding of the movement patterns, thus the habitat use of saltwater crocodiles, therefore, would be a key requirement to minimize and mitigate the threats from human activities and minimize the human-crocodile conflict. With the objective of studying the spatial distribution and home ranges of the saltwater crocodiles across the Bangladesh Sundarbans, satellite transmitters will be deployed on a group of crocodiles and monitor their movements over time. The tagged crocodiles would help quantify home range size, identify activity hotspots, understand daily and seasonal movement patterns, identify correlation between movement and meteorological variables, and identify locations of interactions with humans.

Large scale commercial exploitation for crocodile skins up to the 1970s depleted the Saltwater Crocodile population from most part of their historical range in Bangladesh. Currently, the known populations are restricted to the Sundarbans (Ganges delta). Population surveys however suggest low numbers in the wild. In 1982, four crocodiles and 20 tracks were recorded during daytime (450 km) and nighttime (95 km) surveys. Between 1980-1983, 62 sighting were report by Sarker (1983) and 40 by Sarker and Shafi (1994). In 2014–2015, daytime surveys in ~351 km of river recorded 42 crocodiles (Aziz and Islam 2018). In 2016, 60 crocodiles and 31 tracks were recorded during the day in 1,893 km of river. The population in Bangladesh was estimated to be 150–200 individuals in 1985, 250–300 adults in 2000, 100–150 adults in 2012 (Rashid 2013). Although insignificant compared to tigers, Saltwater Crocodiles also do fatal attacks to humans in Sundarbans (Ferdiousi and Khan 2021).



CONSERVATION

All species of crocodiles in Bangladesh are protected by the Bangladesh Wildlife Act 1974 (Deodatus 2003) and revised Wildlife Act 2012. The Gharial is listed Critically Endangered, while the Saltwater Crocodile is listed Endangered, and also listed in the Appendix I of the CITES (Convention on International Trade in Endangered Species). Crocodylians also have a spiritual value in Bangladesh society (Mukul *et al.* 2012).

While hunting crocodiles for skin could have been the main threat for populations in Bangladesh historically (Halder and Deodatus 2003), it is possibly an insignificant threat now, and is likely limited to localized hunting for meat (Uddin *et al.* 2022). The protected status of crocodylians since 1973 apparently did not result in a population recovery within the country. Currently, disturbance by a growing number of resource collectors (e.g., *Nypa* palm harvesting, extensive fishing, honey collection, etc.) within the Sundarbans is likely the key threat to the Saltwater Crocodile population. Reports show that approximately 3.5 million local people enter the forest annually for collecting fish, crabs, honey and non-timber forest products (Hoq 2007). Disturbances by cargo vessels navigating through different channels, entangling and drowning in fishing nets, water pollution related to cargo accidents and oil spills could be other threats for crocodiles in the Sundarbans (Aziz 2017).



Adult female Saltwater Crocodile from Sundarbans, Bangladesh

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Crocodile Breeding Centre: The Karamjal Crocodile Breeding Centre (KCBC) was established in 2000, and by early 2017 keep conservation in mind, its total stock comprised 215 crocodiles. Although one of its goals was to make animals available for release into the wild, by early 2016, only about 19 Saltwater Crocodiles had been released into canals and rivers of the Sundarbans (Webb *et al.* 2010).

Bangladesh started crocodile farming with F2 generation in the year 2004. Starting with 75 individual crocodiles, Reptiles Farm Ltd (RFL). now has approximately 1500 Saltwater Crocodiles. RFL got registered with CITES in 2007 and made its first export in 2010 (Ahmed 2014). Commercial farming however seems to be progressing well with several studies reporting details of production and health aspects (Arif *et al.* 2010, Hossain *et al.* 2012, Hossain *et al.* 2013, Sultana *et al.* 2012)



Sundarbans during monsoon

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SURVEY METHODOLOGIES FOR CROCODYLIANS

Standardized nighttime spotlight surveys are an integral part of long-term monitoring of crocodylians. They are an effective method of collecting information on population trends over time, habitat use, population demographics etc., and could be conducted without having to physically catch the animals. Below is a list of factors to consider when designing and conducting a spotlight survey. More detailed information could be found in Fukuda *et al.* (2013b) and Bayliss (1987).

- a) **Environmental Context:** Tides are an important consideration as low tides may restrict access and highest tides may expand the water body significantly. Smoke, fog, mist or rain reduce the visibility, so surveys should not be carried out under these conditions. As cold-blooded animals, the basking and in-water activities of crocodiles are largely governed by temperature. New moon nights (no moonlight) are ideal for spotlight surveys as the darker conditions increase the possibility of seeing eye shines.
- b) **Pilot Survey:** When surveying a river for the first time, a pilot survey should be first conducted at low tide during daytime to check conditions of the water body including access to a boat ramps, location of barriers and risks such as rocks, sand bars and logs etc. so that the nocturnal spotlight survey can be done safely.



Low tide is best for crocodile survey

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- c) **Timing:** Repeated surveys over years should be conducted in the same month, ideally within the same two-week period to minimize variations due to seasons. The exact date and time of a survey will depend on the tide. Surveys are ideally conducted during a low tide at night, usually in mid to late winter/ dry season. When water temperatures are higher than air temperatures, most crocodiles are in the water at night where they can be spotted at low tide. The start and end points of each survey must be exactly the same between years.
- d) **Survey Vessel:** The survey vessel needs to be large enough to accommodate at least three people (spotter, recorder and skipper) and the survey gear, but also small enough to operate at low tide in shallow and/or narrow streams. In most surveys in tropical Australia, ~4 m long aluminum dinghies with a ~30 horse power (hp) engine is used to survey small rivers, and 5-6 m boats powered by 50-60 hp engines are used in large rivers and lakes.
- e) **Speed:** Survey speed depends on the condition of the river (water depth, crocodile density, visibility through vegetation, etc), but 8-10 km/h is an ideal speed if there is a medium to high density of crocodiles (>5 eye-shines per kilometre). If the density is lower, a speed of 15-25 km/h appears suitable. The boat is driven upstream in the middle of the river, but when a crocodile is spotted, the boat slows down gradually approach the animal as closely as possible for species identification and size estimation. Boat speed should be reduced gradually as sudden change in engine noise can disturb the crocodile. Larger rivers are surveyed one bank at a time, where the boat is driven closer to one bank on the way upstream and the opposite bank on the way downstream. Smaller creeks where you can see both banks with the spotlight are only surveyed once while travelling upstream.
- f) **Spotlight:** A hand-held spotlight of at least 100W (200 000 candlepower), powered by a lead-acid battery (12 V, 100 Ah) is recommended for spotlighting for crocodiles. The spotter stands/ sits at the very front of the boat with the spotlight held near eye level. Spotter scans the water surface, water edge, banks and vegetation with the light, in a zigzag manner from one side of the river to the other searching for the eye-shine of a crocodile. An eye-shine of a crocodile glows red, orange or pink in the light and can be often seen from a long distance away. Larger fish, mammals, large spiders and frogs also reflect eye-shine in the spotlight, but these animals can be easily distinguished from a crocodile with some experience, because they have different colours in the eye-shine (e.g. whitish or bluish shines by spiders). When a crocodile eye-shine is noted, the boat should continue to move upstream, in midstream, while the spotter ensures no other crocodiles are being



After sunset to sunrise is best time to survey the crocodiles

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missed on either side. The spotter then directs the boat towards the spotted crocodile, with the aim of a close approach to estimate crocodile species and size. Approaching from midstream at near right angles to the crocodile maximises the chance of getting a clear view of the crocodile before it moves away. The spotter controls the speed and direction of the boat through a combination of light and hand signals.

- g) Size Estimation:** Total length (TL) of a crocodile refers to the distance from the tip of the snout to the tip of the tail and is usually estimated using 30 cm (0.3 m or 1 foot) intervals. In most cases only the crocodile's head and anterior neck are visible in the water, and spotters need to estimate the TL from the head length. In Saltwater Crocodiles up to ~4.2 m long, TL is around 7 times head length. In crocodiles larger than ~4.2 m, the TL is around 8 times head length (Fukuda *et al.* 2013a). For example, if the spotter estimates the head length to be 0.6 m (2 feet long), the total length of the crocodile is estimated at 4.2 m long (0.6 x 7). Saltwater Crocodiles usually ranges from 0.3 to 5.4 m (1 to 18 feet) and those smaller than 0.6 m (2 feet) in TL are often recorded as "hatchlings of the year". If the crocodile escape before a size estimation is made, it is recorded as a "eye shine only".



A spotter sitting in front of the boat using a hand-held spotlight to scan the bank

© Ruchira Somaweera

h) Data recording: When a crocodile is observed, and a size estimation is made, the spotter calls out the record to the data recorder who sits adjacent to or behind the spotter in the boat. The data recorder uses a hand-held GPS to record coordinates for each crocodile. To record the location faster and minimize errors, only a waypoint number is written down/ entered in the field rather than the full coordinates. Later, when the GPS data is downloaded, the waypoint numbers could be matched. The standard data to be recorded for each animal includes

- a. Species : if multiple species co-exists
- b. Total Length : estimated length in metres or as “hatchlings of the year” or “eye shine only”
- c. Position : mid stream (MS), shallow water on edge (SWOE), on bank (OB), on rocks (OR) etc.
- d. GPS waypoint number
- e. Any comments : e.g. observation of feeding, missing body parts etc

Data recorder should be only using a red light (head lamp) to minimize disturbances. Data recording could be done manually on paper or digitally on a mobile phone/ Personal Digital Assistant (PDA) with a custom-made data form. A continuous GPS track for the entire survey should be recorded, along with the coordinates of each crocodile approached and recorded.



An example of a standard data sheet is given below.

Crocodile Spotlight Survey Data Sheet

Location			Date		
Spotter			Recorder		
Skipper			Vessel and Engine Size		
Start Time			Start Point		GPS location
End Time			End Point		GPS location
Notes		Weather, tides, river conditions etc.			
#	Species	Size	Position	GPS	Notes
1	C. porosus	Hatchling	SWOE	012	
2	C. porosus	3.9 m	MS	013	Attack response
3					
4					



A saltwater crocodile hatchling

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STUDIES WITH CAPTURE

While spotlight surveys provide information on population size, demographics, distribution and habitat use of crocodiles, sometimes individuals need to be caught for various purposes including for telemetry studies, relocations and translocations, captive breeding programs, removal of problem crocodiles, marking etc. The following sections summaries various techniques and considerations in capture, restraining, marking and transporting crocodylians.

CAPTURE

Various methods are used to capture wild crocodylians, and the choice between options depends on the species, size, location, habitat type, experience of the researcher, and also the reason for capture. However, during every capture, the collective safety of both the crocodile and research team must be paramount above all other objectives. Most counties regulate the methods used to capture, therefore it is important that proper discussions with the relevant authorities takes places priori to designing a project.

Unlike any other reptile group, crocodylians can experience anaerobic metabolism when struggling during capture leading to acidosis and death (Bennett *et al.* 1985, Seymour *et al.* 1985). Therefore, when capturing crocodiles, particularly large individuals (>4 m), all attempts must be made to limit undue stress and struggling. More so, the condition of restrained animals must be monitored regularly.

The table below summarizes capture methods used for crocodylians based on circumstance and size. Only live capture methods are listed.

Method	Summary	Size range	Example references
Crocodile within reach			
Hand capture	Animal grasped behind the neck and constrained using both hands	<0.8 m	Combrink <i>et al.</i> (2012)
Tongs	'Plucking' crocodiles from water using large tongs (e.g. 'Pilstom' tongs)	<1.2 m	Webb and Messel (1977)
Hand nets	Animal scooped using hand nets by wading in shallow water or from a boat	<1.6 m	Webb and Messel (1977)



Method	Summary	Size range	Example references
Noosing	Either a self-locking, non-slipping cable or rope tied to a long pole (for large animals) or use of a Ketch-All pole (or alike) for small animals. The noose is ideally secured over upper jaw (for wide snouted species) or neck (for slender snouted species). The latter needs immediate restraining and removal of noose from the neck. Often used from a boat at night combined with a spotlight or wading in shallow water.	1-6 m	Combrink <i>et al.</i> (2012)
Electric stunning	Delivering an electric charge for ~5 seconds (depending on size and body condition of the crocodile) via a set of metal forks placed on the skin on the back of the crocodile's neck. Limited to use in smaller and shallow water bodies, but frequently used in captivity e.g., crocodile farms.	1 - 2 . 4 m	Peucker <i>et al.</i> (2004)
Skin harpooning	Attaching a barbed detachable harpoon head and line to the skin on the neck or base of tail of a crocodile using a pole. Harpooning is the preferred method of capture for most crocodile management programs in Australia. The harpoon head can also be modified to obtain biopsy samples without having to capture and restrain the crocodile.	>2 m	Barrow and Halford (2019), Walsh (1987), Webb and Messel (1977)
Darting with chemical immobilizers	Use of muscle relaxants (e.g. gallamine triethiodide, pancuronium bromide, succinylcholine chloride, atracurium besylate), opioids (e.g. etorphine hydrochloride), dissociative anesthetics (e.g. ketamine hydrochloride, tiletamine and zolazepam) or other drugs to induce immobilization. Usually targeted the lateral aspect of the base of the tail behind the hindlegs. The effects of most muscle relaxants can be reversed by neostigmine methyl sulphate after restraining/ transportation.	>2 m	Bennett (1991), Brien and Manolis (2016), Fleming (2014), Olsson and Phalen (2012)

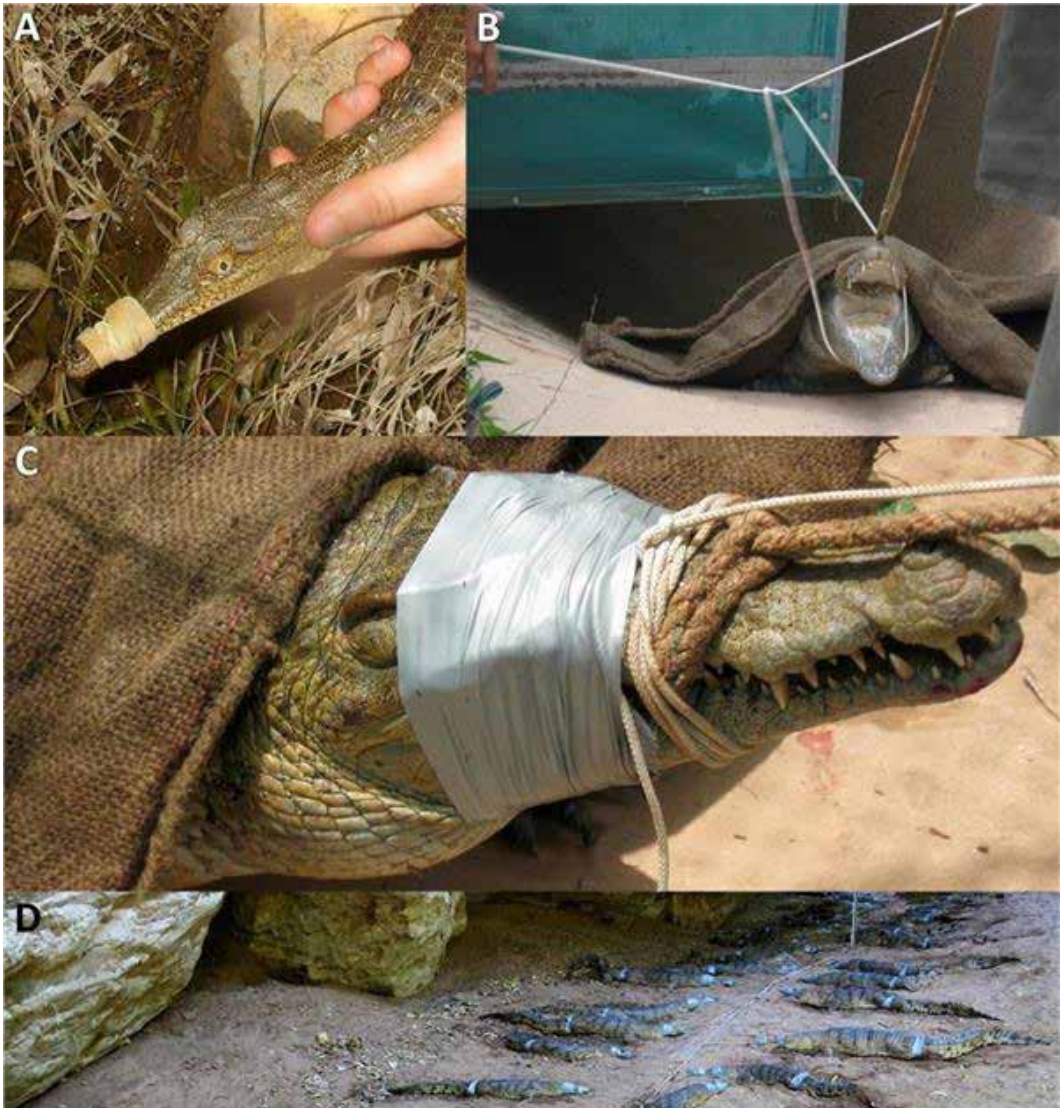


Method	Summary	Size range	Example references
Crocodile not within reach but can be seen			
Weighted hooks	Weighted treble hooks attached to a fishing rod and reel casted over the crocodile and rapidly retrieved so the hook is embedded into the epidermal scales of the animal. The barbs of the treble hook should be removed to assist the hook in penetrating the skin.	1.2-3.5 m	Combrink <i>et al.</i> (2012)
Drone/ UAV based capture	Baited self-locking wire noose attached to an activated payload release mechanism of a UAV and letting the crocodile bite the bait before retrieving the animal and restraining.	2-3 m	Brien <i>et al.</i> (2020)
Crocodile cannot be seen (passive captures)			
Netting	Setting long gill nets across water bodies and retrieving the entangled crocodiles. Nets should be continuously and thoroughly checked for movements and entangled crocodiles should be removed as soon as they are found.	>0.5 m	Webb and Messel (1977)
Trapping	Large variety of metal, rope and pipe traps available to use based on targeted size, location and budget. Traps baited and checked as early as possible in the day to minimize the time a crocodile spent in the trap. Traps set in tidal waters should have adequate flotation so the captured crocodiles do not drown. Traps can also be fitted with radio-alarm devices that indicate when a crocodile has been captured.	2-6 m	Kofron (1989), Saumure <i>et al.</i> (2002), Walsh (1987), Webb and Messel (1977)
Baited hooks/ Snaring	Usually only used when any other capture method is not possible or appropriate, or when there is an urgency of capture. It is crucial that the captured crocodiles have access to shade or permanent water so that they do not overheat, dehydrate or drown after capture. Snares should be checked as often as practicable but, as a minimum, must be checked at first and last light on a daily basis.	1-6 m	Brien and Manolis (2016), Combrink <i>et al.</i> (2012)



Examples of capture methods for crocodiles includes A) hand netting, B) noosing (note the non-slipping and self-locking Ketch-all pole with a rope noose on snout), C) harpooning, D) netting, and E) floating baited cage traps (all images © Ruchira Somaweera).

Care should be taken when collecting and handling crocodylian eggs. To minimize deposition of human scent, it is advisable to wear rubber boots and latex gloves, and place equipment on plastic drop sheets rather than on the soil surface. Eggs can be marked and numbered on the dorsal-most surface using lead pencils to allow correct replacement and orientation within the clutch cavity.



Restraining crocodiles. Rubber bands can be used to easily restraining smaller crocodiles (A). Care should be taken not to cover the nostrils. Larger crocodiles are best restrained using rope (B). Eyes are covered to minimize visual stimulants and it is advisable to leave the mouth slightly open (in this case using the same rope) to allow any regurgitated material to drain out. Duct tape is an easier and faster method when catching and restraining a large number of crocodiles (D). When holding them temporarily till processing, it is crucial that the animals are kept in the shade and hydrated. (all images by Ru Somaweera).

RESTRAINING

All crocodylians are capable of inflicting serious damage by ether biting or lashing out with tails. It is crucial that in every capture scenario involving juvenile and adult crocodiles, the



head is controlled and jaws are securely tied/tethered to prevent injury to handlers and to the animal itself. Based on the size of the animal rubber bands (<1m), cable ties (>1 m), duct tape (>1m) or ropes or cord (>1m) could be used for securing the jaws. Generally, for large animals (>2 m), one or more snout ropes are placed over the top jaw behind the largest teeth, and after closing the jaws, cord or tape is tied around both jaws. The diameter of the snout rope should be appropriate to the size of the crocodile, have a spliced loop, and be applied as a noose. This way the rope can be tightened and undone easily and without knots. If large cable ties are being used, it is advisable to attach it to a rope fed through a hollow PVC pipe of at least 1.5 m and then place the loop over the snout (so the researcher is not close to the crocodile when restraining). Alternative restraining methods includes placing them in capped round PVC pipes (diameter of the pipe is determined by the size/girth of the crocodile) or wrapping in stout cloth sheets or blankets, or using immobilizing drugs such as Pavulon.

Some practical considerations include:

1. Do not use electrical/insulation tape as they can slip off under wet conditions.
2. Always check whether the nostrils are not covered.
3. Ensure that the restrain is not too tight restricting blood flow and causing local cutaneous necrosis.
4. If the mouth is been taped close, feed a small rope through the duct tape and attach to a longer rope. With this setup the duct tape can be slit right before release and pulled away from the snout using the rope from a safe distance.

Once the jaws are securely closed, place a blindfold (a heavy damp cloth or hessian bag) over the eyes to eliminate visual stimuli. Tape could be used on smaller animals, but extreme care should be taken that the eyes are 'sunk' into the skull to prevent any damage before applying tape over.

Upon capture some individuals regurgitate water or food and it is important to prevent them flowing back into the esophagus and choking the animal. Ideally the animal should be places with the head higher than the body. If not, it is advisable to keep the mouth slightly open with a rubber pipe, thick rope or a padded tube placed between the jaws before they are tied so the regurgitates material can drain out.

Based on the size of the crocodile, the time intended to hold the crocodile in captivity, the placement of the crocodile and the number of personnel involved, the front and back legs



can then be secured ('handcuffed') using bands, duct tape or rope. In doing so, caution that:

1. restraining legs in abnormal positions (e.g. pulled too far in a dorsal position) can easily dislocate joints,
2. restraining legs for long periods (>4 hours) can cause severe oedema of the pectoral and pelvic joints.

Crocodiles with legs retained should be monitored for swelling in the legs at regular intervals and the restrains immediately loosened or removed if swelling is noticed.

Animals should be always restrained in shady locations away from direct sun. Animals should be regularly examined for exposure to direct sun and also biting insects, especially ants. Depends on the situation, they may require to be doused with water to avoid dehydration. The time a crocodile is restrained should be kept to a practically absolute minimum. Captured crocodiles can become unconscious and drown after release if not allowed to rest after prolonged physical restraint (Sedgwick 1986).



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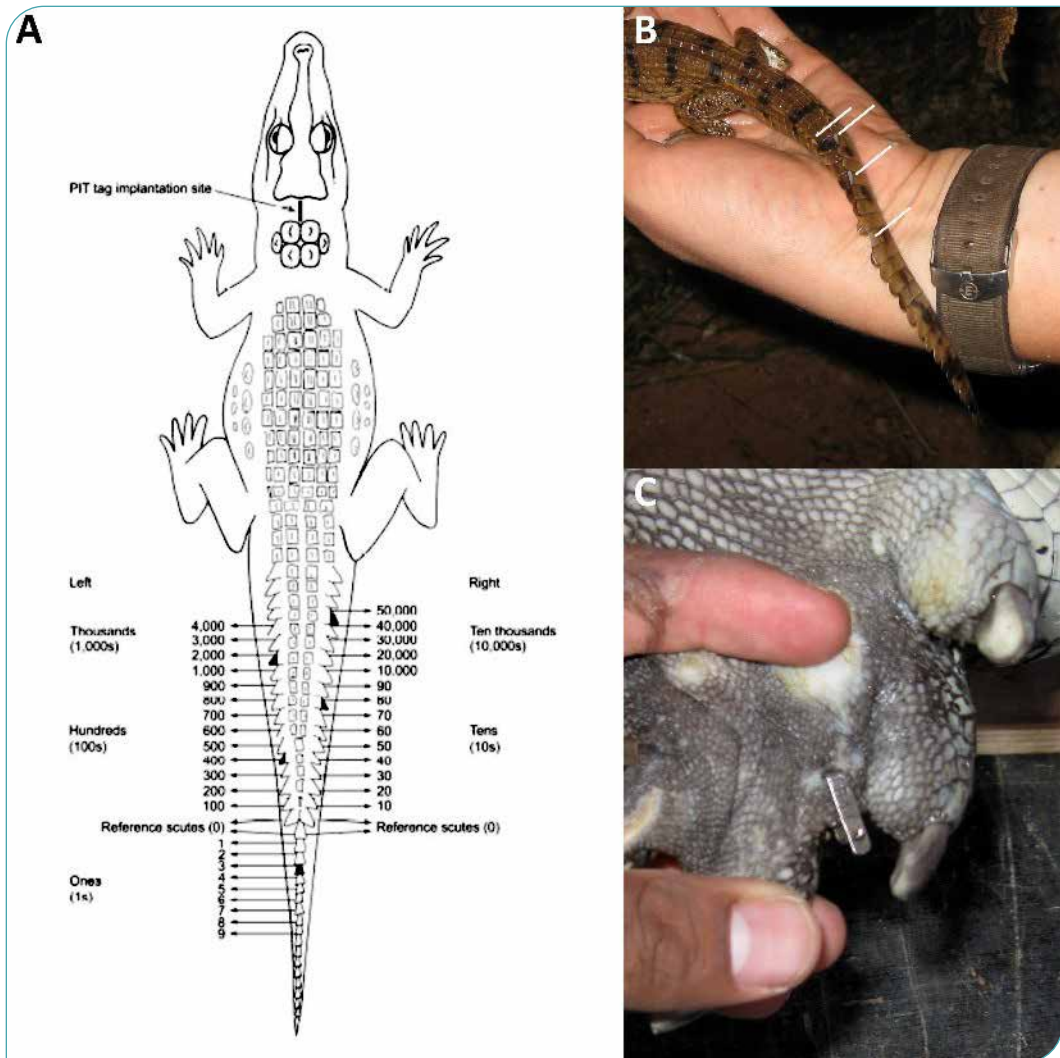
MARKING

Soon after properly restraining the animal, check thoroughly for any previous markings (tags, scute clips etc.). If it is an unmarked animal, and if marking is required, the following table summarizes the standard methods used.

Method	Suitable sizes	Example of studies
Scute clipping Raised scutes along the tail cut using a pair of sterilized scissors or scalpel (for small animals) or a sharp knife (for larger animals), dipped in 70% ethanol and dried using a clean tissue, according to a predetermined numbering system. It is advisable to apply an infection control (e.g. Necrospray) to the cut-site immediately. A sample of the tissues resulting from scute clipping can be used for genetic analysis.	All sizes including hatchlings	Bustard and Choudhury (1981), Somaweera et al. (2011)
PIT tagging Implanting a Passive Integrated Transponder (PIT) tag subcutaneously along the dorsal mid-line between the posterior margin of the cranial platform and the nuchal scales, or at the base of the tail adjacent to the cloaca.	Juveniles and adults	Briggs-Gonzalez et al. (2017), Kay et al. (2004)
Web tagging A small metal tag with a unique identity numbers 'clipped' to the web skin between digit 1 and 2 in the right front limb	Juveniles and adults	Elsay and Aldrich (2009)
Plastic tags Colour plastic tags such as cattle ear tags or anchor fish tags with unique identity numbers or/and colors attached to the nuchal scales or tail scutes	Larger individuals	Bayliss (1987)



Sexing crocodylians is very difficult when they are juveniles as the external genitals are very similar in shape and size between the two sexes (Webb et al. 1984). When they are adults, the penis of the male can be felt and protruded from the cloaca. The largest Saltwater Crocodiles are sexually dimorphic with males reaching exceptional girths with very thick necks.



Marking crocodiles. Scute clipping is the most common method used in field studies in Australia and involves cutting the raised tail scutes according to a predetermined numbering system (A and B). PIT tags can be either inserted in the neck (A) or base of tail, and metal web tags can be clipped to the web skin between digits (C). (all images by Ruchira Somaweera diagram from DBCA 2017).



TRANSPORT

The method of transportation depends on the size of the animal, distance transported, area of transport (remote Vs urban) and logistics available (vehicle, manpower). Hatchlings are best transported in tubs with a wet towel on the bottom while juveniles can be placed in individual tubes or PVC pipes to suit the size (e.g. Wilson 1994). Larger animals are usually tied to “carry boards” to prevent excessive struggling during transport. Carry boards also make loading and unloading animals easier. Larger crocodiles can also be transported in custom-built ventilated crates.



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Transporting crocodiles. When manually transporting crocodiles, it is crucial to adequately support the body of the animal and also to firmly secure the head to prevent injuries to the researcher and the crocodile. Larger animals are best transported tied.



General considerations to the welfare of the crocodile during transporting includes:

1. To prevent physical damage to the crocodile, ensure all ropes around the body are locked and not slip knots that can continually tighten, ensure that no sharp or abrasive surfaces are in contact with the crocodile, and the animal is not exposed to excessive heating or cooling.
2. To prevent the animals vomiting and choking, make sure the head is placed higher than the body or/and the mouth slightly open as described in the retraining section.
3. To minimize visual stimulation, cover the eyes (larger animals) or by keep the crocodile in a dark tub/ pipe (smaller animals).
4. To prevent dehydration and excessive heating, regularly douse the crocodile with water if transporting for long durations or under hot conditions.
5. If transposing on boxes or tubes, use padding between the containers and under to reduce vibrations and also to insulate from heat from the body of the vehicle.

SEDATION

Handling large crocodiles for measuring, attachment of telemetry gear and transportation is stressful for the animal and could be extremely risky for the handlers. Therefore, anesthesia or sedation of the crocodiles are sometimes undertaken to minimize risks and damage. However, these procedures should be only undertaken by trained personnel with a proper understanding about crocodylian behaviors, physiology, drug dosages and handling techniques. Mismanagement or inaccurate dosage of drugs could result in accidents due to insufficient doses, prolonged recoveries and deaths of crocodiles.

While a range of drugs are being used in the crocodile husbandry industry, cases of drug usage under field conditions are limited. Currently, for Saltwater Crocodile studies in Australia, Midazolam and Diazepam in combination is used for sedation, with Lignocaine used for localised pain reduction (Paul Beri, pers. comm, 2024). Midazolam is a short acting, water soluble, benzodiazepine with sedative, anticonvulsant, amnestic, anxiolytic, and skeletal muscle relaxant properties. Midazolam effectively works by slowing activity in the brain to allow relaxation and decreased consciousness, and can provide muscle relaxation for 40-60 minutes. Diazepam is a benzodiazepine. It exerts anxiolytic, sedative, muscle- relaxant, anticonvulsant and amnestic effects. Mixing a small volume of Diazepam with Midazolam has shown to induce a smoother induction of sedation. The animal seems less likely to be stressed as it becomes sedated and as it comes out of sedation. Lignocaine is a local anesthetic reducing local pain. Lignocaine is also an antiarrhythmic drug which restore irregular and/or rapid heartbeat to a regular beat. The dosages and administration of these drugs are not discussed herein as they should not be undertaken by anyone without proper training.



HUMANE EUTHANASIA

Based on the recommendations of the Veterinary Science Group of the IUCN Crocodile Specialists Group (CSG), the following methods are in-line with the Codes of Practice and guidelines for humane euthanasia of crocodiles under captive conditions.

1. Captive-bolt pistol: Destruction of brain with a stunner placed behind the eyes followed by pithing if needed (Nevarez *et al.* 2014).
2. Shooting: Destruction of brain using an appropriate caliber bullet for the size of the animal and in line with relevant legislation of the state, training and safety protocols (Huchzermeyer 2003). Pithing to follow if needed.
3. Chemicals: Administration of an euthanizing agent such as Sodium Pentobarbital by an experienced/trained person (Rodrigues *et al.* 2008). Carcasses after drug administration should not be left in the environment for scavengers to feed on.
4. Blunt force trauma: Delivering a sharp blow to the head with a hard implement resulting in brain damage and immediate unconsciousness (Strain *et al.* 2014). Immediately followed by pithing if needed.
5. Cervical severance: Transectioning the spinal cord with a sharp tool followed immediately by pithing (Strain *et al.* 2014).

Freezing, heating, exsanguination, drowning or inhalation of toxic gases are unacceptable methods of euthanasia for crocodylians.

TELEMETRY STUDIES

Movement patterns and home range of crocodiles are best assessed via telemetry studies where electronic tracking devices (VHF, satellite, GPS, etc.) are attached to the crocodile. Several methods of device attachments have been used/ tested including neck collars, back harnesses, surgical implantation, ingestion, and direct attachments to parts of the body. Of these methods, direct attachment is currently the most widely used method for large Saltwater Crocodiles, and attachments are done to either the head, neck or tail using pins, wires or nylon line, usually inserted through holes drilled in the keeled scutes or osteoderms.

The method described herein is currently followed by the Queensland Parks and Wildlife Services in Australia for large Saltwater Crocodiles (Paul Beri, pers comm, 2024). Other methodologies are reviewed in Mascarenhas-Junior *et al.* (2023) and a variation of the system discussed below in which the wire runs under the length of the nuchal rosette rather



than drilled through the scutes is discussed in-detail by Brien *et al.* (2010).

The following protocol is particularly customized for crocodile-specific tags such as SPOT-258 designed by Wildlife Computers. Attachment of other sensors could differ. The protocol also assumes that the crocodile is appropriately sedated, and pain killer drugs have been administered to the local area.



SPOT-258 satellite tracker designed by Wildlife Computers.

Checklist of items required

The following items needs to be prepared in-advance of the tag attachment.

1. 100% Ethanol
2. Wipes/ clean rags
3. Wire Brush/ Scouring pad
4. Antiseptic cream
5. Betadine swabs
6. 30cm lengths of trace wire x15
7. Crimps x 40
8. Lumo Tubes x 30
9. Selleys Knead-it Aqua x 15 Tubes (black)
10. Turpentine x 1L
11. Crimping Pliers x 2
12. Electric drill with drill bits (+ batteries x2 and charger)
13. Locking pliers x 4
14. Rubbish bags small x 5
15. Disposable plastic gloves (appropriate sizes)
16. Silicone
17. Rolls of electrical tape x 2
18. Whiteout pen
19. Side cutters x 2



Procedure

1. After capture, immobilize and restrain the crocodile in a shaded location.
2. Prepare all attachment equipment in accessible location.
3. Cover the wet/dry sensors of the unit with electric tape and fastlock the antenna. Ensure the rubber communication port covers are in with silicone added as a sealant.
4. Clean nuchal shield with ethanol and scouring pad/ wire brush. Wipe clean and dry attachment location and surrounds.
5. Disinfect the nuchal shield area with Betadine and inject local anaesthetic agent. Add antiseptic cream to the location.



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Measurement for tag attachment



6. Rest tag with aerial facing backwards on the shield and mark 4-6 locations on the scutes that align with the holes in the tag with a marker.
7. Remove the tag and drill the scutes using drill bits cleaned in 100% ethanol.
8. Make a 20mm high bed of Kneedit Aqua in center of shield.
9. Add lumo tubes and crimps to trace wires.
10. Run trace wires and tubing through holes on the scutes and tag, pull around and tighten. Locate crimps to top/ side of tag to enable easier crimp access.
11. Pull wire tight through crimps using locking pliers. Cut excess wire ends with side cutters.
12. Place rolled sections of Kneedit Aqua around edges of the tag and build up to a 45 degree to be flush with top of tag.
13. DO NOT cover wet dry sensor or communication ports on top or the side with Kneedit Aqua.
14. Remove ALL electric tape covering the sensors.
15. Wipe clean sensors with ethanol and clean cloth.

It is absolute paramount that sufficient time is given for the crocodile to recover from the procedure and sedation before release.



A tag being attached to the nuchal shields of a large Saltwater Crocodile. Note the tape covering the sensors and lumo tubes added to the trace wire that goes through the holes drilled in the scutes.



First Sattelite tagged crocodile "Juliet"

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CASE STUDY FROM BANGLADESH: DO CAPTIVE-REARED CROCODILES KNOW WHERE "HOME" IS?

WHAT WAS DONE

The study detailed in Somaweera et al (2026) evaluated whether mature captive-reared saltwater crocodiles can be successfully released into the wild without attempting to



return to captivity, and how their movement behaviour compares with wild-caught and translocated individuals. The work addressed a critical gap in crocodile conservation: whether releasing adult captive-reared animals is a viable strategy for reinforcing depleted populations, particularly in Bangladesh's Sundarbans mangrove system.

Five subadult and adult saltwater crocodiles were tracked following release, including three long-term captive-reared females, one wild-caught individual released at its capture site, and one wild-caught individual translocated over 130 km.

HOW IT WAS DONE

Crocodiles were fitted with satellite GPS transmitters and monitored for 53–127 days after release. Movement paths were analysed using state-space models and Brownian bridge movement models to estimate daily displacement and activity space (home-range size). This approach allowed robust comparison of post-release behaviour across different life histories in one of the world's most complex tidal landscapes.

KEY FINDINGS

- **Captive-reared crocodiles did not show homing behaviour.** Despite spending many years in captivity, none attempted to return to husbandry facilities, nor did they exhibit excessive or erratic post-release movements.
- **Movement patterns of captive-reared crocodiles closely resembled wild crocodiles released at their capture site,** with modest daily movements and relatively small, stable activity spaces (14–38 km²).



Transporting a tagged crocodile from Karamjol

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- **The translocated crocodile behaved very differently**, moving up to 34 km per day and occupying an exceptionally large activity space ($>2,500 \text{ km}^2$), consistent with strong exploratory or homing responses documented globally in translocated crocodilians. These results indicate that homing behaviour is strongly associated with prior experience in the wild, not with long-term captivity.

WHY THIS MATTERS BANGLADESH AND THE GLOBAL PICTURE

In Bangladesh, saltwater crocodiles persist at low population sizes, with little evidence of recovery despite decades of protection. Releasing hatchlings and juveniles carries high predation risk and long delays before reproduction. This study provides rare empirical evidence that releasing mature captive-reared crocodiles can possibly immediately contribute to population recovery without triggering maladaptive homing behaviour

Globally, the findings challenge long-held assumptions that adult releases are risky or ineffective. They demonstrate that captive-reared crocodiles can integrate into wild systems, while reaffirming that translocation of wild adults is often ineffective and potentially counterproductive for both conservation and human–crocodile conflict management. More broadly, this work advances understanding of animal navigation, spatial memory, and reintroduction biology, with implications extending well beyond crocodilians.

KEY RECOMMENDATIONS ARISING FROM THE STUDY

1. Prioritise release of subadult and adult captive-reared crocodiles in systems where natural recruitment is low, to accelerate population recovery.
2. Avoid routine translocation of wild problem crocodiles, as it is unlikely to provide lasting conflict mitigation and may increase risk during long-distance movements.
3. Select high-quality, low-disturbance release sites, where prey availability and habitat complexity reduce incentives for wide-scale dispersal.
4. Incorporate soft-release strategies (e.g. semi-natural holding, gradual acclimatisation) for captive-reared animals to further improve post-release success
5. Embed satellite telemetry into reintroduction programs as standard practice, enabling evidence-based evaluation of survival, movement, and settlement
6. Scale up sample sizes and monitoring durations in future programs to assess long-term survival, breeding, and population-level outcomes.



7. Use captive-reared adult releases as part of an integrated national recovery strategy for saltwater crocodiles in Bangladesh, aligned with habitat protection and conflict-prevention measures.



A captive saltwater crocodile at karamjol

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