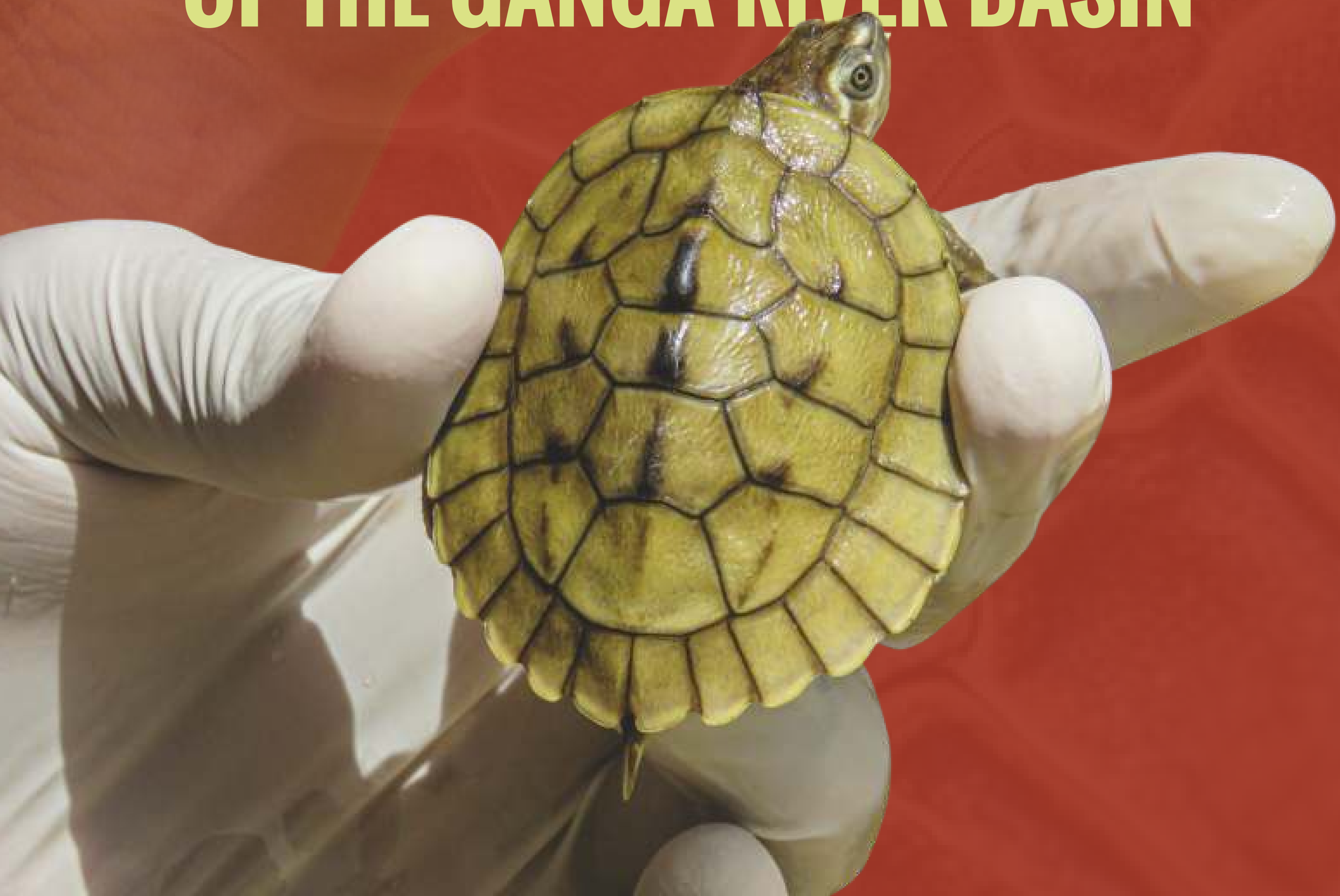
नमामि गंगे

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

BRINGING THE ECOSYSTEM ENGINEERS BACK:

REINTRODUCTION PLAN FOR FRESHWATER TURTLES OF THE GANGA RIVER BASIN



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REINTRODUCTION PLAN FOR FRESHWATER TURTLES OF THE GANGA RIVER BASIN

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Bringing the Ecosystem Engineers Back:
Reintroduction Plan for Freshwater Turtles of the Ganga River Basin

This document is an output of the project "Planning and Management for Aquatic Species Conservation and Maintenance of Ecosystem Services in the Ganga River Basin for a Clean Ganga", sponsored by the National Mission for Clean Ganga, Ministry of Jal Shakti, Government of India, New Delhi.

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C R PATIL

सत्यमेव जयते

Minister of Jal Shakti,
DoWR, RD & Gr, Government of India

message

Civilizations have historically evolved around rivers. They provide support to the human society with a variety of goods and services, however, the continued availability of these goods and services is maintained by the complex biological processes that the biodiversity present in the rivers facilitate. As civilizations evolved from agrarian to industrial societies, uncontrolled human activities and unsustainable extraction practices undermined the survival of this biodiversity and effected the sustained availability of the goods and services essential for human survival.

Among the various species turtles inhabiting the Ganga Basin, freshwater turtles are perhaps the most ecologically and culturally significant. In the current scenario where the human population is growing at an unprecedented rate the need for extraction of resources and development of infrastructure has placed the various turtle species inhabiting the Ganga Basin in a perilous situation.

Recognizing these challenges the Government of India through the Ministry of Jal Shakti has launched an ambitious initiative 'Namami Gange' to integrate development with conservation. The initiative is a flagship program of the Prime Minister. It was launched as an effort to maintain the cultural role and conserve the Ganga Basin for the sustained availability of its rich resources. As a part of this initiative the Wildlife Institute of India has been entrusted with the task of assessing the biodiversity of the Ganga Basin and suggest methods for its effective conservation.

As a part of their efforts the present document showcases their findings on the status of freshwater turtles in the Ganga Basin. The document presents a detailed analysis of the factors that threaten these turtles in the Ganga Basin and the measures necessary for its effective conservation.

I commend the team members for their diligent efforts and hope that their findings are used for effective conservation of freshwater turtles.

(C R Patil)

message

RAJ BHUSHAN CHOUDHARY

सत्यमेव जयते

Minister of State, Jal Shakti
DoWR, RD & Gr, Government of India

The mighty Ganga and its various tributaries form the Ganga Basin. The Basin is home to a highly dense human population alongwith a rich biodiversity. The extremely dense human population has a strong dependence on the rivers since time immemorial and has been using the rivers for extracting various resources for consumption and more importantly for cultural and religious purposes.

The rapid growth of human population over the last 100 years along-with the fast-paced economic development however, have placed the rivers and the biodiversity they support in the basin under extreme stress. As a result, the river is unable to effectively fulfill its ecological and cultural roles.

The Government of India understanding the challenges facing the Ganga River and its tributaries initiated an ambitious programme for the recovery of the Basin under the National Mission for Clean Ganga under the stewardship of the nation's Prime-Minister Shri Narendra Modi. The mission aims to maintain a river that fulfills the economic ambitions of the people inhabiting the river basin while ensuring that its ecological functions are protected.

Keeping this in view the Wildlife Institute of India has been tasked with assessing the biodiversity of the basin and devising steps for its conservation so that its cultural, economic and ecological functions can be maintained. The present report is a part of the lnstitute's effort in this direction.

The present report on the recovery of freshwater turtles of Ganga Basin, documents the status of the species, the factors that threaten their survival and the actions needed for the conservation of the species. I appreciate the efforts of the team and hope that the recommendations made by the team are used for better and more effective conservation actions at the field level.

(Raj Bhushan Choudhary)

V. SOMANNA

सत्यमेव जयते

Minister of State, Jal Shakti
DoWR, RD & Gr, Government of India

message

Indians have a close cultural and religious association with their rivers. The Ganga basin including the mighty Ganga and its various tributaries has an extremely fertile floodplain and supports one of the highest densities of human population on earth along with an equally rich biodiversity. This extremely dense human population besides having close cultural ties with the river basin also uses the resources made available by the basin.

Some of the resource use practices are sustainable and do not harm the ecosystem while a host of others such as poaching, collection of eggs of turtles, discharge of pollutants etc. in the river cause immense harm to the ecosystem of the river basin. This has led to the reduction in populations of a large number of species in vast stretches of the rivers, while certain stretches are faced with local extinction of a number of species.

These animal species facing a sharp reduction in numbers are often encountered in a distressed and/or displaced state requiring human intervention in the form of rescue and rehabilitation. This document records the status of four freshwater turtle species facing imminent threats to their survival and measures for their conservation.

I take this opportunity to express my appreciation of the Wildlife Institute of India's team in undertaking the intensive efforts involved in the preparation of this document and wish the team all success in their future efforts.

(V. Somanna)

SHRI. V. L. KANTHA RAO

सत्यमेव जयते

Secretary, Ministry of Jal Shakti,
DoWR, RD & Gr, Government of India

message

Rivers are the lifelines of human civilization and human life has developed and prospered along freshwater bodies. Freshwater bodies are biologically one of the most diverse ecosystems on the planet earth. This biodiversity through intricate biological relationships has been responsible for ensuring the sustained availability of goods and services from freshwater habitats.

In India rivers have strong cultural and religious bonds with the human population. The Ganga basin comprising of the mainstem Ganga River and several tributaries like Yamuna forms the lifeline of the country. The Ganga basin supports a predominantly agrarian society that is strongly dependent on water for a range of resource requirements.

The resource utilization practices were largely sustainable till quite recent times; however, the rapid human growth in population witnessed an unprecedented surge in resource extraction that led to extensive fragmentation and degradation of the habitat of the rivers. This has been accompanied by a rapid decline in both number of species and individuals within a species. Freshwater turtles are one such group facing local extinction or sharp declines of species in large stretches of the rivers in the Ganga basin. The decline in their numbers is further aggravated by anthropogenic activities like poaching and collection of eggs despite being crucial part of the complex ecosystem.

Planned conservation efforts are needed for ensuring sustainable populations of these imperiled species. The document uses four freshwater turtle species as flagships for the conservation of all turtle species and their habitats in the Ganga Basin. The Wildlife Institute of India with funding support from the National Mission for Clean Ganga has undertaken detailed field surveys and analysis for planning the recovery of these species. The present document is a detailed plan for the recovery of riverine turtles in the Ganga Basin.

I commend the WII team for their efforts and hope that the current document will form a basis for appropriate action in the field for the sustainable conservation freshwater turtles and allied biodiversity in the Ganga Basin.

(Shri. V. L. Kantha Rao)

SHRI RAJEEV KUMAR MITAL

सत्यमेव जयते

Director General (NMCG),
Ministry of Jal Shakti,
DoWR, RD & Gr, Government of India

message

The Ganga Basin with its vast expanse is the lifeline for one of the densest human aggregations on the lone living planet. Around 40% of the country's population inhabits the basin and depends on it either directly or indirectly. The large expanse includes perennial rivers having glacial origins in the Himalayas and monsoonal rivers originating in the Vindhyas and Aravalis. This varied landscape translates into a complex landscape comprising of a mosaic of unique ecosystems. The ecosystem variability has translated into a rich and unique biodiversity present across the Basin that is responsible for ensuring the sustained availability of the ecosystem services and goods derived from the Basin.

This rich biodiversity is juxtaposed with the dense human aggregation that has strong economic and cultural dependence on the resources provided by the Basin. This juxtaposition due increasing human needs on the Basin's resources has resulted in undermining its biodiversity and thereby undermining its sustainability. The resultant loss of biodiversity translates into extinction or near extinction of key components of biodiversity across large stretches of the rivers leading to reduced availability of goods and services.

Freshwater turtles are a key component of the riverscape; however, in the current Anthropocene the unprecedented resource extraction has resulted in a highly fragmented and degraded landscape necessitating conservation interventions. The Wildlife Institute of India under the aegis of the WII-NMCG project has undertaken the task of assessing the threats and develop measures for the conservation of freshwater turtles in the Ganga Basin.

The present document is an outcome of this effort. It is based on intensive field surveys and a review of literature to document the status of turtles in the Basin. The analysis carried out has led to the identification of four species of turtles which can act as umbrella species for the conservation of much of the biodiversity in the Basin.

I congratulate the team for its efforts in developing this document and hope that it will form the basis for the conservation of freshwater aquatic species in the Ganga basin for ensuring sustained availability of goods and services from the Ganga basin.

(Rajeev Kumar Mital)

CONTENT

EXECUTIVE SUMMARY

Freshwater turtles are among the most ecologically important yet highly threatened faunal groups of the Ganga River Basin. These prehistoric animals play a critical role in maintaining aquatic ecosystem health through scavenging, vegetation control, nutrient cycling, and influencing prey-predator dynamics. Decades of habitat degradation, pollution, illegal trade, unsustainable harvesting, sand mining, hydrological alteration, and increasing human pressure have pushed several turtle species, including *Batagur kachuga, Batagur dhongaka, Nilssonia gangetica, Chitra indica,* and others, towards severe population decline.

This document presents a comprehensive, science-based strategy for the reintroduction and long-term recovery of selected freshwater turtle species within the Ganga Basin. The strategy integrates ecological knowledge, conservation practice, habitat suitability modelling, species biology, and captive management strategies to support successful Reintroduction efforts. The compilation draws from extensive field surveys, species distribution modelling (MaxEnt), captive care experience, genetic and health assessments, and community-based conservation frameworks developed under the WII-NMCG project.

The report outlines best practices for site selection, habitat evaluation, pre-release conditioning, quarantine and disease screening, release planning, transport guidelines, and post-release monitoring. Species-specific ecological requirements and natural history information are included to ensure that reintroductions efforts align with biological needs and environmental suitability. Captive management protocols guide enclosure design, health care, nutrition, and handling, which are critical for producing healthy individuals capable of surviving in the wild.

A key component of this document is the use of habitat suitability modelling to identify climate-resilient zones and conservation priority areas across the basin. These spatial analyses guide decision-making by pinpointing suitable release sites, predicting future habitat shifts, and helping mitigate threats such as fragmentation and anthropogenic pressure. Ultimately, successful turtle reintroduction is not a biological exercise alone it requires strong collaboration with local communities, enforcement agencies, and river-dependent stakeholders. The Document emphasize the integration of traditional knowledge, participatory monitoring, and awareness programs to ensure long-term protection of restored populations.

This document serves as a practical field manual and scientific reference for conservation managers, forest departments, researchers, and policy makers. By implementing these guidelines, the Ganga River Basin can move closer to restoring its lost turtle diversity and strengthening the resilience of one of India's most culturally and ecologically significant river systems.

SUMMARY

INTRODUCTION

The Ganga River Basin represents one of the most complex and ecologically important river systems in the world. Spanning multiple biogeographic zones and supporting nearly 40% of India's human population, the basin sustains exceptional biological diversity, including numerous threatened aquatic species. Freshwater turtles form a key component of this biodiversity, with more than 15 turtle species recorded from the basin. Belonging primarily to the families Trionychidae (softshell turtles) and Geomydidae (hardshell turtles), these species play vital ecological roles as scavengers, herbivores, predators, and bioindicators, contributing to water quality maintenance, regulation of aquatic vegetation, nutrient cycling, sediment turnover, and food-web stability.

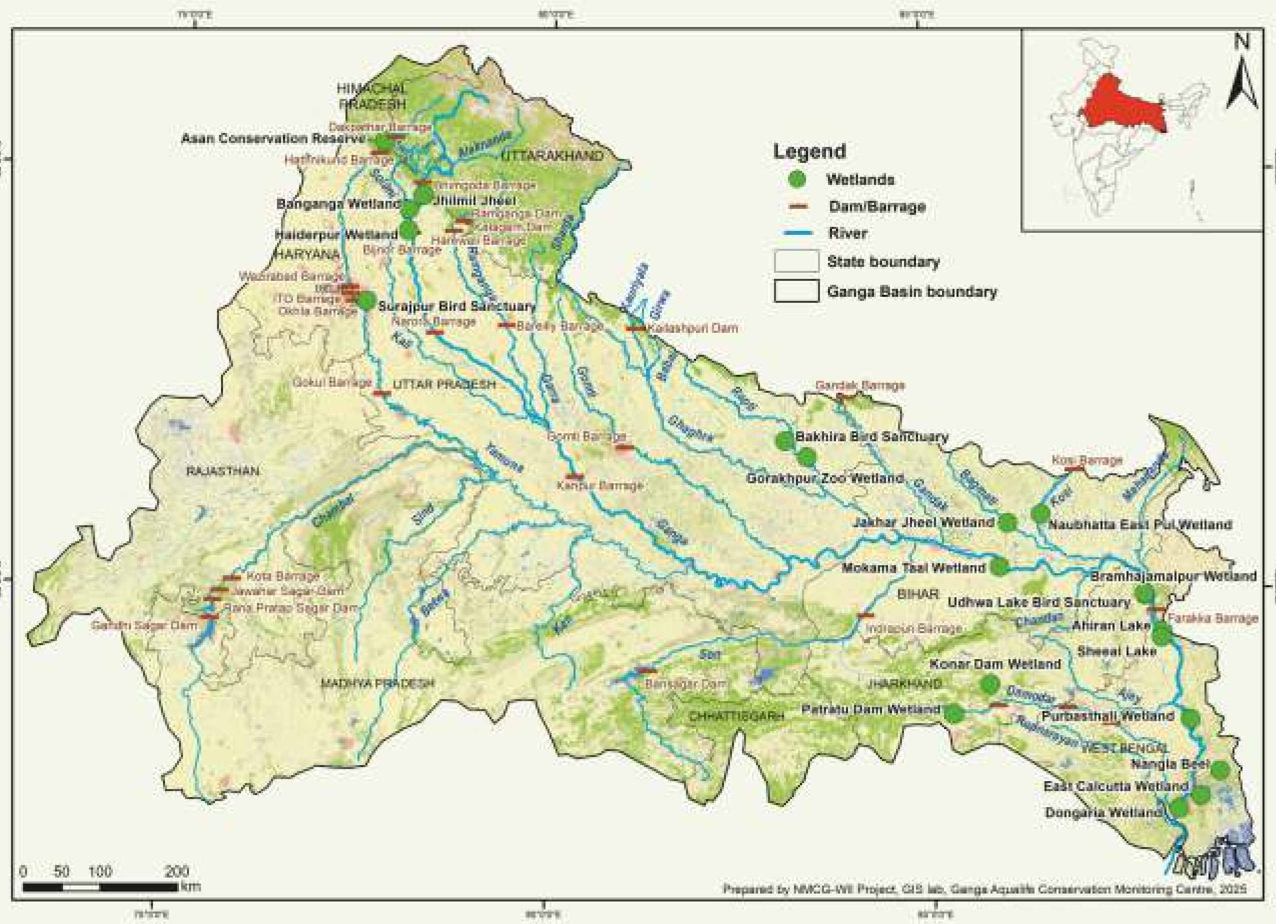


Fig- Distribution of the select wetlands in the Ganga River Basin

Despite their ecological importance and deep-rooted cultural and religious significance in Indian society, freshwater turtles in the Ganga Basin face severe threats. Habitat degradation due to sand mining, river regulation, dam construction, embankments, and floodplain modification has resulted in the loss of critical nesting, basking, and foraging habitats. Pollution from industrial effluents, domestic sewage, agricultural runoff, plastics, and microplastics has further degraded water quality, adversely affecting turtle health, reproduction, and survival. Illegal poaching and trade for meat, traditional medicine, and the pet trade, along with accidental bycatch in fishing gear, continue to drive population declines. These pressures are compounded by climate change, which alters river hydrology, increases temperature variability, disrupts nesting cycles, and threatens population stability through skewed sex ratios arising from temperature-dependent sex determination.

The chapter also highlights the challenges associated with nesting and recruitment, including loss of nesting beaches, predation by feral and wild animals, invasive species, and human disturbance. While several conservation initiatives, such as rescue and rehabilitation, captive breeding, head-starting, habitat protection, and community-based programs like Ganga Prahari, have shown positive outcomes, the scale and intensity of threats necessitate stronger, more integrated conservation responses.

SYSTEMATICS AND TAXONOMY OF FRESHWATER TURTLES

A review of the systematics of the four ecologically and evolutionarily significant species, *Batagur kachuga, Batagur dhongoka, Nilssonia gangetica*, and *Chitra indica*, representing the families Trionychidae and Geoemydidae, outlines how these ancient turtle lineages diversified from the Late Cretaceous onward, shaped by continental drift, palaeoclimatic fluctuations, and the dynamic evolution of South Asian river systems. Trionychidae are presented as highly specialised, fully aquatic softshell turtles, characterised by adaptations such as flexible, leathery shells, cutaneous respiration, and benthic predation. In contrast, Geoemydidae exhibit greater ecological flexibility, combining riverine life with basking and seasonal terrestrial movements. Comparative evolutionary insights emphasise contrasting adaptive strategies that have allowed both families to persist in large river ecosystems.

Integrating fossil evidence, morphology, physiology, and molecular phylogenetics, the document demonstrates strong genetic structuring across river basins, revealing distinct evolutionary lineages and multiple conservation management units. Mitochondrial and nuclear DNA studies support current taxonomic placements and provide critical guidance for conservation planning, captive breeding, and population reinforcement programs.

The ecological sections detail habitat preferences, feeding strategies, reproductive behaviour, and sensitivity to hydrological and thermal regimes, underscoring the dependence of these turtles on undisturbed river channels and sandy nesting banks. The document identifies habitat degradation, sand mining, river regulation, pollution, poaching, and climate change as major threats driving population declines, with Batagur species and *Chitra indica* facing the highest risk of extinction.

NATURAL HISTORY AND SPECIES DESCRIPTION

Detailed morphological descriptions highlight strong sexual dimorphism, ontogenetic variation, and specialised adaptations to riverine environments, including streamlined carapaces, webbed limbs, and physiological traits supporting prolonged submergence. The report documents species-specific habitat preferences, feeding ecology, basking behaviour, and reproductive strategies, demonstrating a close dependence on clean, free-flowing rivers and undisturbed sandy banks for nesting. Long generation times, late sexual maturity, and high nest-site fidelity increase vulnerability to environmental change.

Batagur kachuga (Red-Crowned Roofed Turtle)

Batagur dhongoka (Three Striped Roofed Turtle)

Distributional assessments reveal severe range contractions across India, Nepal, and Bangladesh, with many populations now extirpated or highly fragmented. The Chambal River emerges as the most important remaining stronghold for Batagur species, while Chitra indica and Nilssonia gangetica persist in scattered river stretches across major basins. Anthropogenic pressures, including sand mining, hydrological alterations, pollution, illegal trade, bycatch in fishing gear, and predation of nests, are identified as the principal drivers of population decline.

The report reviews the legal status of these species under the IUCN Red List, the Wildlife (Protection) Act, 1972, and CITES, and documents ongoing conservation interventions such as nest protection, riverside hatcheries, head-starting, captive breeding, rescue and rehabilitation centres, and community-based management. Long-term conservation success is emphasised as dependent on integrated strategies combining habitat protection, scientific monitoring, genetic management, enforcement of wildlife laws, and capacity building of field staff and local communities.

MATERIALS AND METHODS

Field surveys were conducted across the Ganga River Basin, covering approximately 2,280 km of riverine stretches across the mainstem Ganga and 22 tributaries. Boat-based visual encounter surveys were carried out during post-monsoon seasons between 2020 and 2024 using standardized protocols. These surveys provided critical baseline information on turtle occurrence across a wide geographic extent and diverse riverine habitats.

Species occurrence records were compiled from multiple verified sources, including field observations, global biodiversity databases, published literature, and project reports. A total of 2,670 georeferenced records representing 16 freshwater turtle species were used for habitat suitability analysis. To capture ecological and anthropogenic drivers of turtle distribution, 30 environmental variables were incorporated, encompassing bioclimatic parameters, hydrology, elevation, vegetation indices, land use-land cover, infrastructure proximity, protected area coverage, and human influence indices. Both current climate conditions and future projections (2021-2100) under three Shared Socioeconomic Pathways (SSP126, SSP245, and SSP585) were included to evaluate climate change impacts.

Habitat suitability modelling was performed using the Maximum Entropy (MaxEnt) algorithm, a robust machine-learning approach suitable for presence-only data. Spatial filtering was applied to reduce sampling bias, and model performance was evaluated using cross-validation and Area Under the Curve (AUC) metrics. Jackknife analyses were used to identify the relative importance of environmental predictors influencing turtle distributions. Model outputs were classified into high, moderate, and low suitability categories to facilitate interpretation and spatial planning.

Nilssonia gangetica **(Indian Softshell Turtle)**

Chitra indica **(Giant Softshell Turtle)**

The resulting maps provide a comprehensive assessment of current habitat suitability, potential climate-resilient refugia, and areas vulnerable to habitat loss across the Ganga Basin. These outputs offer a scientifically rigorous foundation for prioritizing conservation actions, guiding habitat protection and restoration, and informing adaptive management strategies for freshwater turtles in the face of increasing anthropogenic pressures and climate change.

HABITAT SUITABILITY MODELLING

Habitat suitability for four threatened freshwater turtle species (*Batagur dhongoka, Batagur kachuga, Nilssonia gangetica*, and *Chitra indica*) in the Ganga River Basin was evaluated using ecological niche modelling based on species occurrence records and a wide range of environmental and anthropogenic variables. The models showed high predictive performance, indicating a strong relationship between turtle distribution and the selected predictors.

Temperature-related variables emerged as the dominant drivers of habitat suitability across all species, emphasizing the importance of thermal regimes in influencing activity, nesting, incubation, and overall habitat selection. Hydrological factors such as proximity to rivers, moderate water availability, and low to moderate vegetation cover also played a key role in defining suitable habitats. Areas closer to protected regions consistently showed higher suitability, although certain species displayed tolerance to moderate human influence.

Spatial patterns highlight the Yamuna, Chambal, and Ganga river systems as the most critical landscapes for freshwater turtles in the basin. Suitable habitats for Batagur kachuga and Batagur dhongoka are highly restricted and fragmented, largely confined to the middle Yamuna-Chambal region and limited stretches of the Ganga. In contrast, Nilssonia gangetica exhibits a broader distribution of suitable habitats across the middle and lower reaches of the Yamuna, Chambal, and Ganga rivers, while Chitra indica shows strong dependence on the Yamuna-Chambal system with fragmented suitable areas along the middle Ganga.

CAPTIVE CARE AND MANAGEMENT PROTOCOLS

The protocols emphasize the importance of enclosure design that facilitates natural behaviours such as swimming, basking, and burrowing, supported by appropriate substrates, vegetation, basking platforms, secure fencing, and easy access for caretakers. Maintenance of high-water quality, through regular monitoring, filtration, aeration, and controlled water exchange, is highlighted as a fundamental requirement for maintaining turtle health under captive conditions.

Sanitation, hygiene, and husbandry practices form a central component of the management framework. The chapter details routine cleaning schedules, biosecurity measures including restricted access and footbaths, and the use of enclosure-specific equipment to minimize disease transmission. Daily partial water replacement, periodic deep cleaning, and reliance on biological filtration systems are recommended to maintain hygienic and stable captive environments.

Nutritional management is addressed through an overview of dietary requirements, feeding strategies, and reference nutritional standards derived from farmed freshwater turtles. The importance of balanced, species-appropriate diets is emphasized, along with the use of raw diets for conservation breeding programmes and commercial feeds where appropriate. Feeding regimes based on body weight, life stage, and feeding ecology are recommended to ensure optimal growth, health, and shell development.

The chapter further describes protocols for quarantine and disease management, including mandatory isolation of new or sick individuals, minimum quarantine durations, health screening, and controlled handling by designated personnel. Methods for individual identification, such as tagging and marking, are outlined to support long-term record-keeping and monitoring. Finally, safe handling and transport procedures are detailed to minimize stress and injury during routine management or relocation.

REINTRODUCTION PROTOCOLS

The framework articulates a long-term conservation vision focused on establishing self-sustaining, demographically and genetically viable meta-populations across suitable habitats within the historical range of the four species. The plan adopts an integrated conservation approach that combines habitat restoration and protection, population reinforcement, and carefully planned reintroductions. It is aligned with internationally accepted best practices, particularly the IUCN guidelines on conservation translocations, and is designed to be implemented over a ten-year horizon with clearly defined goals, objectives, timelines, and measurable performance indicators.

A central component of the plan is a rigorous and transparent methodology for reintroduction planning. This includes comprehensive status reviews, threat assessments, and the application of strict site-selection criteria based on ecological suitability, availability of critical habitat features (such as deep pools and sandbanks), hydrological connectivity, threat intensity, and feasibility of mitigation. Equal importance is placed on social feasibility, with strong emphasis on stakeholder consultations, community support, and institutional commitment before site selection. Each potential site is required to undergo detailed baseline assessments to ensure that reintroductions are attempted only where long-term survival and reproduction are realistically achievable.

Population recovery strategies are multifaceted and adaptive. The framework proposes a combination of captive-based head-starting or grow-and-release programmes, using strengthened and standardized ex-situ facilities, and wild-to-wild translocations where appropriate to restore breeding structure and enhance genetic exchange among fragmented populations. Reintroductions are designed to be phased over multiple years, seasonally timed to coincide with favourable river conditions, and preceded by stringent health and genetic screening to minimize ecological and epidemiological risks. Post-release monitoring, including marking and telemetry of released individuals, is emphasized as a critical tool for assessing survival, movement, habitat use, and causes of mortality. Monitoring outcomes are explicitly linked to adaptive management, allowing refinement of release strategies, site selection, and threat mitigation measures based on empirical evidence.

Recognizing that reintroduction success is inseparable from habitat security, the framework places strong emphasis on riverine habitat management and threat mitigation. Priority actions include maintenance of environmental flows in regulated rivers, control of industrial and agricultural pollution, regulation and enforcement against illegal sand mining, management of riverbed agriculture, and reduction of fisheries bycatch through spatial and temporal fishing regulations. The establishment and strengthening of protected river stretches, refugia, and enhanced patrolling regimes are proposed to provide long-term security to reintroduced and existing populations. These habitat-focused interventions are designed to benefit not only the focal turtle species but also a wide range of associated aquatic fauna.

Research and monitoring are identified as foundational pillars of the programme, given the substantial knowledge gaps that persist regarding the ecology, demography, health, genetics, and climate-change vulnerability of the four species. The framework proposes standardized population and habitat monitoring protocols, use of modern tools such as telemetry and geospatial analyses, disease surveillance, and genetic studies to inform evidence-based decision-making. A centralized mechanism for data collation and knowledge dissemination is envisaged to ensure that research outputs are translated effectively into management action.

The framework also highlights the critical role of stakeholder engagement, capacity building, and governance. Active participation of river-dependent communities, frontline forest staff, and multiple line departments is integral to successful implementation. Targeted training, awareness programmes, community-based surveillance, and livelihood-support measures are proposed to foster stewardship and reduce conflict. In parallel, the plan underscores the importance of a supportive policy and legal environment, inter-sectoral coordination, and sustained financial mechanisms to ensure continuity beyond short-term project cycles.

INTRODUCTION

FRESHWATER HABITATS

Freshwater ecosystems cover less than one percent of the planet, but they are among the most diverse and dynamic systems globally (Strayer and Dudgeon 2010). They provide important functions and services such as water purification, carbon sequestration, and flood regulation, thereby supporting human well-being (Russi et al. 2013). At the same time, freshwaters are among the most threatened ecosystems worldwide. They continue to be degraded rapidly, and biodiversity is lost through human activities at unprecedented rates (Davidson 2014, WWF 2016). Indeed, one in three freshwater species is already threatened (IUCN 2016b), and populations are declining faster than in marine or terrestrial realms (Dudgeon et al. 2006, WWF 2016).

Despite their critical state, freshwaters and their unique diversity remain largely overlooked by the general public and within environmental policy (Cooke et al. 2013). Therefore, rivers, lakes, and ground waters receive less conservation investments than most other ecosystems do (Darwall et al. 2011).

Fig – Freshwater ecosystem and threats (Credit- Lakshi Nanda Majumdar)

Fig- Human settlement and infrastructure along the river

FRESHWATER BIODIVERSITY AND ECOSYSTEM SERVICES

Freshwater biodiversity, from fish to frogs and microbes to macrophytes, provides a vast array of services to people. Mounting concerns focus on the accelerating pace of biodiversity loss and declining ecological function within freshwater ecosystems that continue to threaten these natural benefits (Lynch et al 2023).

Rivers are essential to human well-being. River landscapes have served as areas for settlements, infrastructure, and production for several thousand years (Fig).

They provide water for drinking, cooling, and irrigation, fish as food supply or for recreational fishing, areas for flood protection, and they can have cultural and esthetic value. The increasing intensification of land use and the associated channelization, damming, and other radical changes (e.g., through operation of hydropower plants) led to a shift of the functions and related services available in river landscapes (Fig). However, many rivers around the world are severely degraded or at risk, which undermines their ability to provide critical ecosystem services and related benefits.

Fig- Fishing (credit- Dhritiman Mukharjee)

Fig- Dam and Hydropower plants (Credit- Valdiya Ravi)

Leopold et al. (1964) and Welcomme (1979) listed and described eight typical features of flood plain ecosystems, all of which may be utilized by resident turtle species. These include: (1) the main channel and its anabranches which normally retain water throughout the year (although surface flow may cease or even disappear in dry periods in extreme environments such as those of East Africa and Australia thereby forcing its turtle fauna to seasonally move to permanent water or into subterranean estivation); (2) oxbows and disconnected oxbow lakes; (3) point bars; (4) meander scrolls and shallow depressions; (5) sloughs; (6) natural levees adjacent to the channel; (7) swamps and back-swamp deposits; and (8) coarse sand splays deposited by flooding. This mix of permanent, semi-permanent, and ephemeral aquatic habitats and associated terrestrial habitats are constantly changing in extent and character. Welcomme (1979) stated that the organisms inhabiting these flood plain river ecosystems have had to adapt to spatial and temporal fluctuations which are perhaps unique among aquatic environments.

Most natural rivers are flood plain rivers which, in contrast, are those that periodically respond to large seasonal changes in precipitation within their watersheds by overflowing the main channel and inundating the adjacent plain on a regular basis. The great fluctuations in water level result in seasonal cycles of flood and drought and an ever-changing array of ecological conditions and habitats (Welcomme, 1979).

Fig- Flood plain of river (Credit- Government of Uttar Pradesh)

GANGA BASIN

The National River of India - the Ganga and its tributaries and distributaries traverse five distinct biogeographic zones; the Himalayas, the Gangetic Plains, Semi-Arid, Deccan Plateau and the Coastal Zone with each zone supporting a unique assemblage of biodiversity. The Basin extends across India, Tibet (China), Nepal and Bangladesh, with a drainage area of 8,61,452 Sq.km of its total 10,86,000 Sq.km lying in India (approximately 26% of the India's total area) and supports approximately 40% of its human population. The basin includes the states of Uttarakhand, Himachal Pradesh, Uttar Pradesh, Haryana, Delhi, Madhya Pradesh, Rajasthan, Bihar, West Bengal, Jharkhand and Chhattisgarh. It is delimited by Himalayas on the north, Aravalli's on the west, the Vindhyan range and Chottanagpur plateau on the south and by the Brahmaputra Ridge on the east. Climatically, the basin in the higher elevation reaches of the Himalayan ranges experience lower temperatures with some parts being above the snow line. As the basin descends Middle Ganga Plains the mean temperatures rise with occasional winter cold waves and hot summer winds from the west sweeping the middle plains. The lower Ganga plains have a hot and humid monsoonal climate. The middle and lower plains receive most of their precipitation (84% of the total) from the annual south-west monsoons while the higher elevation areas receive winter snows. The western semi-arid region has high summer temperatures and is characterized by reduced precipitation and cool winters (India-WRIS. 2012).

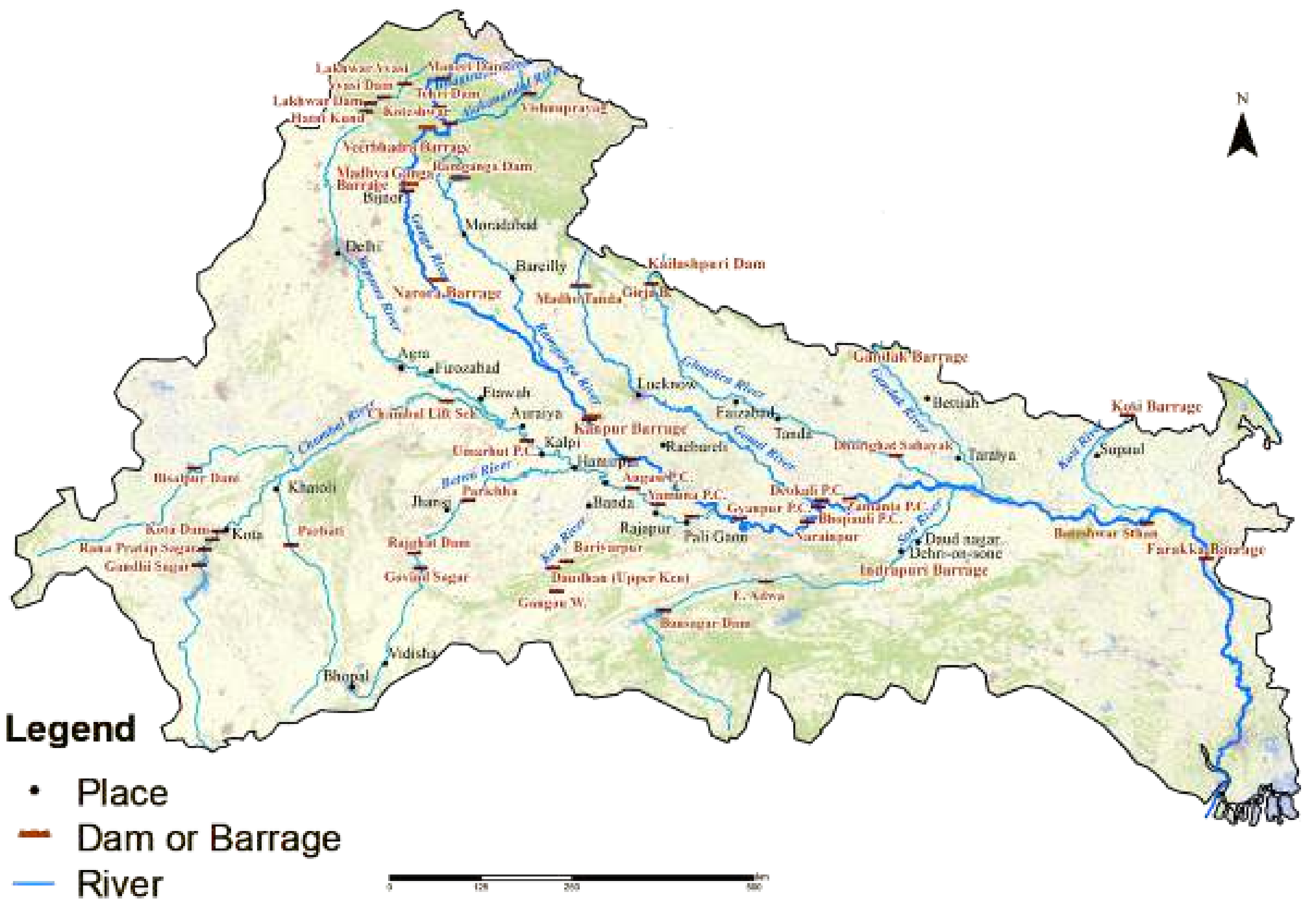


Fig- Ganga river basin (Source- unknown)

This diversity of habitat conditions is reflected in the diverse type of faunal assemblages that exist in the different ecological zones of the basin and adds to the biodiversity of the Basin. It is represented by five species of mammals including the Eurasian otter, Small clawed otter; Smooth-coated otter, Irrawaddy dolphin and Gangetic dolphin, 25 species of reptiles including all the three crocodylian species found in India, at-least 14 chelonian species, twenty-five species of amphibians and along with 236 species of fish. The Ganga river basin also is the home for more than 700 species of birds including 128 species of water birds (WII-GACMAC 2017).

STATUS OF FRESHWATER TURTLES IN THE GANGA RIVER BASIN

The Ganga River basin, one of the world's most ecologically significant and complex river systems, originating from Gaumukh in the Gangotri Glacier of the Indian Himalayas. The river's main stem flows 2,525 km through five states of India and empties into the Bay of Bengal, while its drainage basin includes catchments in 11 states with the largest drainage area in the country of over

1.08 million square kilometres (Bhargava, 1987; Rao, 2001; Sinha, 2015; Jhariya & Tiwari, 2020). The diverse range of aquatic and terrestrial wildlife and resources supported by the basin makes it crucial for the ecological and socio-economic development of the country (Behera et al., 2014; Shukla et al., 2018). The basin sustains over 500 million people, who depend on it for various purposes, including agriculture, fisheries, hydropower, and cultural and religious practices (Sinha, 2015; Khairnar, 2016; Shukla, 2018; Jhariya & Tiwari, 2020).

The river has an immense cultural and spiritual significance in Hinduism with many sacred and ancient cities , including Haridwar, Prayagraj, and Varanasi, along its banks (Bhargava, 1987; Rao, 2001; Jhariya & Tiwari, 2020). Despite its importance, increasing population and resulting urbanization, pollution, and habitat destruction pose a significant threat to the biodiversity and the health of the basin (Bhargava, 1987; Rao, 2001; Buhlmann et al., 2009; Behera et al. 2014; Sinha, 2015; Shukla et al., 2018; Jhariya & Tiwari, 2020; Parihar, 2021).

The rich and dynamic ecosystem provided by the Ganga and its tributaries supports a variety of species, including various endangered and endemic wildlife such as the Ganges River dolphin (*Platanista gangetica gangetica*), Mugger crocodile (*Crocodylus palustris*), Gharial (*Gavialis gangeticus*) (Rao, 2001; Behera et al., 2014; Sinha, 2015; Sharma et al., 2024). The basin also supports several threatened freshwater turtle species, such as the Indian softshell turtle (*Nilssonia gangetica*), Red-crowned roofed turtle (*Batagur kachuga*), Indian peacock softshell turtle (*Nilssonia hurum*), and Indian narrow-headed softshell turtle (*Chitra indica*) (Rao, 2001; Das & Singh, 2009; Das et l., 2010; Behera et al., 2014; Sinha, 2015), leading to the lower Gangetic plain being considered a 'Turtle Conservation Priority Area' (Buhlmann et al., 2009). The basin is also a critical habitat for 177 bird species, as many as 357 fish species, and wetland vegetation that is essential for maintaining ecological balance (Sinha, 2015). Keeping in view the immense ecological and cultural significance of the river basin various initiatives have been launched aiming to restore the habitat for ensuring species conservation (Jhariya & Tiwari, 2020; Dwivedi, 2021). These range from river clean-up to community awareness campaigns to rescue and rehabilitation of aquatic fauna such as freshwater turtles. For the survival of the diverse range of species and the well-being of the millions relying on it, the Ganga River basin requires a holistic sustainable conservation effort (Bhargava, 1987; Behera et al., 2014; Sinha, 2015).

FRESHWATER TURTLES DIVERSITY IN THE GANGA BASIN

In an aquatic habitat, freshwater turtles play a fundamental role in maintaining ecosystem health and balance (Moll & Moll, 2004; Wahab et al., 2012; Lovich et al., 2018). They prevent excessive plant growth by acting as aquatic vegetation controllers, maintaining the water flow and oxygen levels in a water body. As scavengers, they consume dead organisms and organic waste keeping water bodies clean of pollution and preventing disease outbreaks (Moll & Moll, 2004; Wahab et al., 2012; Santori et al., 2020). They also contribute to nutrient cycling by feeding on plants and animals and redistributing organic material. Additionally, some species also assist in seed dispersal, aiding wetland restoration and plant diversity (Brown et al., 2024; Stanford et al., 2020; Wahab et al., 2012). As they occupy the role of both predator and prey, turtles help maintain a balance within a multitude of aquatic food webs, influencing populations of fish, insects, and molluscs (Moll & Moll, 2004; Giri et al., 2022).

In the Ganga River basin, a remarkable diversity of more than 15 species of freshwater turtles and one tortoise species can be seen thriving in the rivers, tributaries, wetlands, and floodplains (Rao, 2001; Sinha, 2015). These turtles belong to two families, viz., Trionychidae (softshells) and Geomydidae (hardshells), with each species playing a vital role in the maintenance of the ecological balance of the riverine ecosystem. The contribution of freshwater turtles to the aquatic vegetation control, nutrient cycle, and habitat health by scavenging makes them keystone species, essential for sustaining the river's biodiversity (Moll & Moll, 2004; Wahab et al., 2012; Sinha et al., 2014; Stanford et al., 2020; Santori et al., 2020).

Softshell turtles have flattened and leathery shells (Rathoure, 2018). They are primarily carnivorous and scavengers, they clean aquatic environments by consuming dead and decaying matter (Moll & Moll, 2004; Santori et al., 2020). One of the key softshell turtle species, the Indian softshell turtle (*Nilssonia gangetica*) is widespread throughout the basin and critical for water quality management by scavenging animal carcasses in the water (Wildlife Institute of India, 2023a). Characterized by its distinct marking, the Indian peacock softshell turtle (*Nilssonia hurum*) is often found in deep rivers, wetlands, and can also be found in lakes, canals, and marshes performing an ecological function similar to *N. gangetica* (Tikader & Sharma, 1985; Hanfee, 1999; Das et al., 2010). The Indian flapshell turtle (*Lissemys punctata*) is a highly adaptable species that thrives in ponds, lakes, marshes, canals, and even agricultural fields while demonstrating its resilient nature to extreme conditions (Bhupathy et al., 2014; Rathoure, 2018). An elusive species, the Indian narrow-headed softshell turtle (Chitra indica) prefers deep river channels with low turbidity, and is a crucial indicator of water quality in the Basin (Das & Singh, 2009). Leith's softshell turtle (*Nilssonia leithii*) is generally found in the peninsular river systems of India, however, it has also been reported from some parts of the Ganga basin (Das et al., 2014; Tikader & Sharma, 1985).

Fig- Indian softshell turtle (*Nilssonia gangetica*)

Hardshell turtles, with domed and rigid shells, are generally herbivorous or omnivorous and have a key role in the control of aquatic vegetation and the dispersal of seeds (Moll & Moll, 2004; Stanford et al., 2020). The Red-crowned roofed turtle (*B. kachuga*), a species included among 25 most endangered turtle list (TCC, 2018), is found in select stretches of the Chambal and Ganga rivers. The males of the species display characteristic red markings on their necks and head during breeding season (Hanfee, 1999). The Three-striped roofed turtle (*B. dhongoka*) is a large herbivore vital for the regulation of aquatic plant populations. The Indian roofed turtle (*Pangshura tecta*) and Brown roofed turtle (*P. smithii*) are smaller, adaptable species found in both flowing and stagnant water bodies, feeding on aquatic plants and insects (Tikader & Sharma, 1985; Wahab et al., 2012; Hossain et al., 2015; Chaudhari & Soni, 2022;). The Spotted pond turtle (*Geoclemys hamiltonii*) has a distinct blackshell with yellow spots and prefers slow-moving water bodies, often seen in wetlands and oxbow lakes near rivers (Safi et al., 2021).

Fig- Spotted Pond turtle (*Geoclemys hamiltonii*)

They prevent excessive plant growth by acting as aquatic vegetation controllers, maintaining the water flow and oxygen levels in a water body. As scavengers, they consume dead organisms and organic waste keeping water bodies clean of pollution and preventing disease outbreaks (Moll & Moll,2004; Santori et al., 2020; Wahab et al.,2012). They also contribute to nutrient cycling by feeding on plants and animals and redistributing organic material. Additionally, some species also assist in seed dispersal, aiding wetland restoration and plant diversity (Wahab et al., 2012; Stanford et al., 2020; Brown et al., 2024). As they occupy the role of both predator and prey, turtles help maintain a balance within a multitude of aquatic food webs, influencing populations of fish, insects, and molluscs (Moll & Moll, 2004; Giri et al., 2022).

THREATS TO FRESHWATER TURTLES IN THE GANGA BASIN

Despite their ecological importance, freshwater turtles face several severe threats in the Ganga basin (Dubey et al., 2025). One of the most significant threats to the turtle population, habitat destruction, is caused by illegal sand mining, dam construction, and river pollution. Poaching and illegal trade have been major conservation concerns for decades (Badola et al 2019; Bajaj et al., 2021; Horne et al., 2022; Liu et al., 2021; Lovich et al., 2018; Polisar & Horwich, 1994; Rais et al., 1997; Rao, 2001; Safi et al., 2024; Sinha, 2015; Stanford et al., 2020), especially for softshell turtles, which are preferred for their soft meat (Wahab et al., 2012). Turtles are also targeted for their shells and used in traditional oriental medicine. Moreover, bycatch in fishing nets causes accidental deaths of turtles (Barhadiya & Singh, 2020; Bodie, 2001; Larocque et al., 2012; Rasal et al., 2009; Stanford et al., 2020; Wahab et al., 2012), and pollution and plastic waste negatively affect their health and survival (Lovich et al., 2018). Additionally, climate change further amplifies these threats to the turtle population and alters fluvial flow patterns and affects the turtle nesting success (Döll & Zhang, 2010; Chessman, 2011; Lovich et al., 2018; Stanford et al., 2020).

Not only is their conservation important for the maintenance of the health of riverine ecosystems but also to ensure a sustainable livelihood for communities that are dependent on the Ganga. A holistic conservation effort involving habitat protection and also community participation is vital for these ancient reptiles with high ecological significance to survive (Behera et al., 2014; Stanford et al., 2020; Rao, 2001).

ECOLOGICAL ROLES OF FRESHWATER TURTLES

The freshwater turtles of the Ganga River basin are crucial to maintaining the river's ecological balance (Sarkar et al., 2003). Their contribution to essential ecological functions such as checking prey population, keeping water clean by consuming dead and decaying matter, and promoting sediment turnover are all important in maintaining a healthy aquatic ecosystem (Santori et al., 2020; Wahab et al., 2012).

The maintenance of the fish population is one of the primary ecological roles of freshwater turtles (Giri et al., 2022; Moll & Moll, 2004). Most turtles are omnivores or carnivores that consume fish, molluscs, and other small aquatic organisms, including the weaker or sick individuals, which helps regulate a predator-prey dynamic (Lagler, 1943;Wahab et al.,2012). This prevents overpopulation of specific species of fish that, if unchecked, could lead to the disruption of the aquatic food web (Munsch et al., 2021).

As scavengers, freshwater turtles play a role in the removal of dead organic matter from rivers (Moll & Moll, 2004; Santori et al., 2020; Wahab et al., 2012). Softshell turtle species such as the Indian softshell turtle (*Nilssonia Gangetica*) and the Indian Peacock softshell turtle (*Nilssonia hurum*) consume dead plants and animals, reducing the accumulation of organic wastes and hence preventing water pollution and outbreak of diseases (Das et al., 2010; Wildlife Institute of India, 2023a; Wildlife Institute of India, 2023b).

Freshwater turtles also contribute to nutrient cycling and sediment turnover (Stanford et al., 2020). Through bioturbination, they tend to disturb the sediment while walking along the riverbed while digging for food or nesting, in turn preventing the excess accumulation of organic matter (Souza & Abe, 2000). This leads to an increased penetration of oxygen in the substrate, which benefits the benthic organism and also maintains the health of the ecosystem. Moreover, turtle waste is a natural fertilizer that enriches water with nutrients, encouraging the growth of aquatic plants and algae (Moll & Moll, 2004).

Most hardshell species, such as the Red-crowned roofed turtle (*Batagur kachuga*) and the Three-striped river turtle (*Batagur dhongoka*) are herbivores that control the growth of aquatic vegetation, which if left unchecked could lead to the accumulation of detritus, the decomposition of which results in depletion of oxygen level and acidification of water resulting in degraded habitat conditions (He et al., 2024). This ecosystem service is specially critical for lentic wetlands and oxbow lakes where fish and other aquatic animal populations are negatively impacted by the overgrowth of plants (Brown et al., 2024).

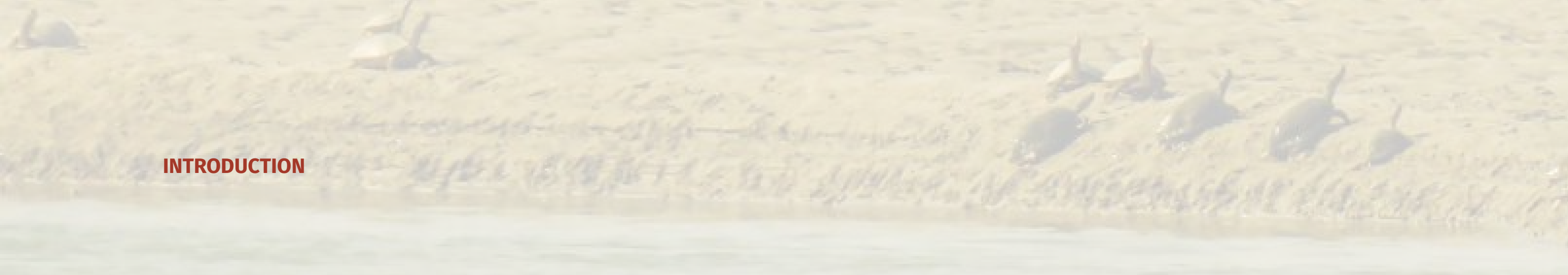
As vital components of the riverine ecosystems, turtles are highly sensitive to pollution, habitat degradation, and changes in water temperature and can act as bioindicators of the quality of water and health of the ecosystem (Wahab et al., 2012). Therefore, a decline in their populations can signify increasing pollution or any degradation in habitat quality (Safi et al., 2020).

RELIGIOUS AND CULTURAL SIGNIFICANCE OF TURTLES

Freshwater turtles hold immense religious and cultural significance in India, particularly in Hinduism and Buddhism. In Hindu mythology, turtles are associated with Lord Vishnu's second avatar, Kurma, who took the form of a giant turtle to support Mount Mandara during the churning of the ocean (Samudra Manthan) (Palmer & Finlay, 2003; Indian Mythology, 2009). This sacred symbolism portrays turtles as divine beings that uphold balance and stability, reinforcing their ecological importance in maintaining riverine ecosystems (Kurma Avatar, 2023; Kurma Avatar Story, 2020). Several temples and sacred water bodies across India house live turtles, where they are revered and fed by devotees. Many temple ponds, known as kunda, serve as sanctuaries for turtles, with communities actively protecting them as sacred animals (Agarwala, 2019; Barhadiya et al., 2020; Giri et al., 2022; Sarkar et al.,2019). In Buddhism, turtles symbolize wisdom, patience, and longevity, and they appear in various teachings and folklore, further strengthening their cultural relevance in the region. Turtles are often released as a form of prayer (Barhadiya et al., 2020; Hwang, 2020).

This deep-rooted spiritual connection can be leveraged for conservation awareness. Engaging religious leaders, temple authorities, and devotees in conservation programs can help instill ethical responsibility towards protecting turtles. Awareness campaigns emphasizing that harming or capturing turtles disrupts nature's balance can influence community perceptions and encourage compassionate conservation (Barhadiya & Singh, 2020; Polisar & Horwich, 1994).

Fig- Samudra Manthan- Religious and Cultural significance of turtles in India (Source- vedicfeed.com)



THREATS TO FRESHWATER TURTLE POPULATIONS

The increased intensity of the multitude of threats faced by freshwater turtle populations in the Ganga River basin is jeopardizing their survival, with many species populations severely declining, earning them the threatened category under IUCN's Redlist. Various factors including habitat degradation, pollution, accidental bycatch mortality, and overexploitation for pet trade, medicinal purposes, and meat and egg consumption, are the leading causes of this decline (Bhupathy et al., 2014; Horne et al., 2022; Johnston et al., 2016; Lovich et al., 2018; Panda et al., 2024; Rasal et al., 2009; Sinha, 2015; Stanford et al., 2020; Wahab et al., 2012). Despite surviving for millions of years and their important role in the ecosystem, these reptiles cannot cope with the changes in their habitat caused by anthropogenic activities (Moll & Moll, 2004; Wahab et al., 2012).

Habitat degradation is the most pressing threat to freshwater turtles. Primarily, anthropogenic activities such as sand mining, deforestation, construction of dams, and river bank modification cause habitats to degrade (Buhlmann et al., 2009; Ishwar, 2003; Moll et al., 2009; Parihar, 2021; Rasal et al., 2009; Sinha, 2015; Stanford et al., 2020). Since many freshwater turtle species use sandy banks for nesting and basking, the excessive extraction of sand leads to the fragmentation of these critical habitats and leads to decreased reproductive success (Moll, 1997; Moll et al., 2009). Additionally, hydel projects including the construction of dams and barrages tend to alter the natural fluvial flow (Behera et al., 2014; Rasal et al., 2009; Sinha, 2015; Stanford et al., 2020; Wahab et al., 2012), which affects the availability of food, breeding cycles, and hatchling dispersal. Moreover, the loss of wetlands, oxbow lakes, and floodplains further reduces the availability of suitable nesting and foraging habitats (Dieter et al., 2014; Stanford et al., 2020).

Fig- Sand mining in the habitat of the critically endangered Red-crowned roofed turtle, Chambal, India
(Credit- Dr. Anish Andheria)

Another major threat to the freshwater turtles of the Ganga basin is pollution. The poor water quality of the rivers of the basin can be attributed to industrial waste, and untreated sewage discharged into them (Behera et al., 2014; Bhargava, 1987; Jhariya & Tiwari, 2020; Lovich et al., 2018; Moll et al., 2009; Parihar, 2021; Rao, 2001; Sinha, 2015; Santy et al., 2020). The aquatic environment is contaminated with pesticides, heavy metals, and plastics, which may harm the turtles directly by ingestion or entanglement (Clukey et al., 2017; Jhariya & Tiwari, 2020; Rai et al., 2010; Stanford et al., 2020). Especially concerning is the microplastic pollution as turtles often mistake debris for food, which may lead to intestinal blockages and malnutrition with eventual death of the individuals (Clukey et al., 2017; Nelms et al., 2015; Stanford et al., 2020).

Fig- River pollution (Source- Business Insider)

Poaching and trading of turtles have been happening for thousands of years, but the unchecked magnitude of these activities has led to near complete depletion of many turtle species. These reptiles are sought for consumption as food, medicine, trophies, decorations, etc. (Barhadiya & Singh, 2020; Bhupathy et al., 2014; Buhlmann et al., 2009; Cheung &Dudgeon, 2006; Liu et al., 2021; Moll & Moll, 2004; Polisar & Horwich, 1994; Rais et al., 1997; Safi et al., 2024; Stanford et al., 2020; Wahab et al., 2012). Softshell turtles are especially preferred for consumption due to their soft meat (Wahab et al., 2012). Species such as the Indian softshell turtle (*Nilssonia gangetica*), Spotted pond turtle (*Geoclemys hamiltonii*) and the Indian flapshell turtle (*Lissemys punctata*) are often poached and illegally traded to both local and international markets (Bhupathy et al., 2014; Chaudhari & Soni, 2022; Das & Bhupathy, 2010; Kharel & Chhetry, 2014; Mendiratta et al., 2017; Rathoure, 2018; Rotmans & Zwartepoorte, 2013; Safietal., 2021; Sinha, 2015; Upadhyay & Upadhyay,2002). Hardshell turtles are often captured for the exotic pet trade. Species such as the Spotted pond turtle (*Geoclemys hamiltonii*) and Indian roofed turtle (*Pangshura tecta*) are some of the most commonly seized species from pet trade (Chaudhari & Soni, 2022; Rotmans & Zwartepoorte, 2013).

Fig- Turtle rescued from illegal trade

Accidental bycatch in fishing gear such as gill nets, trawl nets, and hooks are often used in commercial and artisanal fishing and may unintentionally trap turtles (Stanford et al., 2020; Wahab et al., 2012; Qureshi et al., 2020; Rasal et al., 2009). This may lead to injuries or even drowning as the turtle under duress, struggles to be free and further entangles itself (Polisar & Horwich, 1994). All turtle species have to surface to breathe, therefore when entangled for a long time; they often get asphyxiated (Work & Balazs, 2010). Additionally, practices such as dynamite fishing, electrofishing, and poisoning not only kill fish, but also other non-target animals such as turtles (Hamelin et al., 2017; Wahab et al., 2012).

An emerging threat to turtles that affects both the hydrology of rivers (Döll & Zhang, 2010) and nesting success is climate change. Since turtles have temperature-dependent sex determination (TSD), any change in the temperature of the environment may create an imbalanced sex ratio of the hatchlings (Butler, 2019; Chessman, 2011; Herrera et al., 2020; Laloë et al., 2015; Roberts et al., 2023; Stanford et al., 2020). Since warmer temperatures result in female hatchlings, climate change may cause the populations to become female-dominant over time, resulting in decreased population and genetic diversity (Stanford et al., 2020).

Further adding to the challenges faced by freshwater turtles is the presence of predators and invasive species (Rathoure, 2018; Sinha,2015; Stanford et al., 2020). Jackals, foxes, feral dogs, monitor lizards, crows, and mongoose are often seen consuming eggs from nesting sites, reducing the hatchling success (Chessman, 2011; Rasal et al., 2009). Invasive species such as African catfish (Clarias gariepinus) and Red-eared slider (Trachemys scripta elegans) compete with native turtles for the already depleting resources, and often replace the native species especially in altered environments. Some invasive species also spread diseases or are parasitic (Koo et al., 2020; Sinha, 2015; Stanford et al., 2020; Vyas, 2021).

There are various conservation efforts to protect turtles such as rescue and rehabilitation programs, community engagement, and legal enforcement aimed at curbing illegal trades, restoring habitats, and promoting sustainable management practices (Dewan et al., 2019; Santy et al., 2020). It is essential to strengthen awareness, research, and policies to ensure the long-term conservation of these freshwater turtle species (Barhadiya & Singh, 2020; Bhupathy et al., 2014; Mohan & Kumari, 2008; Stanford et al., 2020).

HABITAT DEGRADATION AND RIVERINE MODIFICATIONS

Freshwater turtles are highly sensitive to changes in their habitats and, therefore, require a stable and undisturbed riparian habitat for survival (Bodie et al. 2000). However, the natural hydrology of rivers, especially the Ganga River in India, is facing the problem of altered natural hydrology due to large-scale infrastructure projects involving the construction of dams, barrages, and embankments (Bhargava, 1987; Rao, 2001; Sinha, 2015). This affects the availability of nesting sites, feeding grounds, and overall suitable habitat for freshwater turtles (Rhodin etal., 2011; Sirsi et al., 2017; Andrade et al., 2023; Wahab et al., 2012). These modifications have led to a disruption in their natural life cycles and created a long-term ecological imbalance.

The construction of hydel projects has disrupted natural water-flow and sedimentation patterns (Behera et al., 2014; Moll et al., 2009; Rao, 2001; Sinha, 2015). Many species, such as the Red- crowned roofed turtle (*Batagur kachuga*) and the Three-striped roofed turtle (*Batagur dhongoka*), rely on seasonal flooding for nesting (Dieter et al., 2014; Stanford et al., 2020). However, the release of water from dams often floods or desiccates the nesting sites unpredictably, causing nesting failures and hatchling mortality. Moreover, these structures obstruct turtle movement between nesting and feeding grounds by fragmenting riverbeds, increasing the risk of decreased genetic diversity and population stability (Behera et al.,2014; Michalski et al., 2020; Moll et al., 2009; Quintana et al., 2019; Sirsi et al., 2017; Stanford et al., 2020).

Flood-controlling embankments and channelization projects further degrade turtle habitats by altering the morphology of rivers, and preventing the formation of sandbars, wetlands, and oxbow lakes. This prevents access to key nesting, foraging and hibernation sites (Dieter et al., 2014). Moreover, embankments also restrict the connectivity of floodplains, hence preventing or limiting access to different nesting or basking sites utilized by turtles at different seasons (Quintana et al., 2019).

One of the major causes of habitat degradation in the Ganga basin is sand mining. Excessive extraction of sand for construction and industrial purposes has destroyed many important nesting sandbars, reducing the availability of breeding grounds (Moll, 1997; Moll et al., 2009). As the removal of riverbed sediments destabilises benthic ecosystems, the turtles that rely on aquatic invertebrates, molluscs, and small fishes, face disrupted food availability (Plummer et al., 2008; Wnek et al., 2013).

Furthermore, alterations in water quality due to these infrastructure projects have indirect yet significant impacts on freshwater turtles. The reduction in the flow of water leads to an increase in pollution concentration in the water, which exposes turtles to pollutants such as heavy metals, toxic chemicals and disease-causing pathogens (Jhariya & Tiwari, 2020; Safi et al., 2020). The high presence of these pollutants often changes the temperature, dissolved oxygen (Bhargava, 1987) and nutrient concentration in water, affecting the metabolism, reproduction and health of turtles (Usuda et al., 2010).

POLLUTION AND ITS EFFECTS ON TURTLES

Being a lifeline that supports millions of people, the Ganga River is increasingly threatened by severe pollution (Jhariya & Tiwari, 2020; Sarkar et al., 2003; Sinha, 2015). There has been a significant deterioration in the water quality due to the uncontrolled discharge of untreated industrial effluents, municipality wastes, and agricultural runoffs, which pose a severe threat to all aquatic species (Behera et al., 2014; Bhargava, 1987; Héritier et al., 2017; Jhariya & Tiwari, 2020; Parihar, 2021; Rao, 2001; Sinha, 2015). Another pollution-causing factor is the throwing of cremation remains, including partially burnt bodies, as well as flowers and statues of gods and goddesses, which contain paints, clothes and toxins, in the Ganga River, which can spread pathogens and harm the biodiversity (Jhariya & Tiwari, 2020). Freshwater turtles are facing health complications, reproductive issues, and population declines due to the accumulation of heavy metals, plastics, and toxic chemicals in the water (Bodie, 2001).

The Ganga River and its tributaries consist of many factories along their banks that release industrial wastes consisting of heavymetals such as mercury, lead, cadmium, and arsenic into the rivers (Rao, 2001). In hatchlings, exposure to persistent organic pollutants (POPs) and other hazardous chemicals often causes neurological disorders, liver damage, and developmental issues (Gupta et al., 2016; Safi et al., 2020; Sposato et al., 2021).

Agricultural runoffs of organic matter, pesticides, fertilizers, and herbicides seep into rivers and contaminate aquatic species and humans. This is enhanced by deforestation, which causes rainwater to move fast and carry wastes and pollutants into the river water (Bhargava, 1987; Ishwar, 2003; Jhariya & Tiwari, 2020; Sinha, 2015). Turtles that consume contaminated prey face hormonal imbalances, metabolic disorders, and reduced fertility (Nelms et al., 2015). Furthermore, excess fertilizer runoffs can cause eutrophication, in which case, algal and cyanobacterial blooms deplete the dissolved oxygen levels in the water (Santori et al., 2020), either forcing turtles to migrate or to suffocate (Ngatia et al., 2019).

In the Ganga River, plastic pollution is extensive and has become one of the most perilous threats to freshwater turtles. They often consume floating plastic, microplastics, and synthetic fibres as they mistake them for food, which leads to intestinal blockages, inability to eat, starvation, and internal injuries. Ingestion of plastic may also lead to chemical toxicity, which affects the reproductive and digestive systems (Clukey et al., 2017; Laist, 1987; Stanford et al., 2020; Vyas, 2015). Furthermore, there have been many instances of turtles getting entangled in plastic bags, fishing nets, and other debris, often leading to injury or fatality by drowning (Schuyler et al., 2012).

The greatest problem of the pollution crisis in the Ganga River basin is the discharge of untreated domestic sewage into the rivers (Jhariya & Tiwari, 2020; Rao, 2001). The sewage that is discharged contains high levels of organic waste, bacteria, and pathogens, which degrade the water quality and increase the risk of disease and infection in turtles and all other animals dependent on the degraded water (Chakraborti et al., 2018; Lovich et al., 2018). Rotting of shells, fungal infections, and parasitic infestation are common in turtles due to contaminated water. Pharmaceutical and personal care products in wastewater contain endocrine-disrupting compounds (EDCs) which affect the reproductive system of turtles by altering hormonal regulation and sex determination in hatchlings (Willingham & Crews, 2000; Yan et al., 2018).

Temperature changes and oxygen depletion caused by pollution harm turtles. Industrial effluents can change the temperature of rivers, often impacting turtle metabolism and nesting behaviour. On the other hand, depletion in oxygen, which is caused by chemical wastes and organic matter decomposition, can create hypoxic conditions, making it hard for turtles, especially those that inhabit stagnant or slow-moving waterbodies, to survive (Safi et al., 2020; Stoot et al., 2013).

ILLEGAL WILDLIFE TRADE AND EXPLOITATION

The illegal wildlife trade for consumption of meat and eggs, traditional medicine, and pet trade, is a significant threat to the freshwater turtle and other vertebrate populations in the Ganga River basin (Barhadiya & Singh, 2020; Cheung & Dudgeon, 2006; Noureen & Khan, 2007; Tortoise and Freshwater Turtles Under Siege, 2019; Rao, 2001; Singh et al., 2023; Stanford et al., 2020; Wahab et al., 2012). With the high demand in domestic and international markets for such illicit trade, there has been a rapid decline in turtle populations in the wild. The threatened status of turtles and their protection, such as that under the Wildlife (Protection) Act, of 1972 creates a bigger demand for poaching and illegal trading (Krishnakumar et al., 2009; Mali et al., 2014; Stanford et al., 2020).

In India, the softshell species that are the most illegally traded are the Indian softshell turtle (*Nilssonia gangetica*), the Indian Peacock softshell turtle (*Nilssonia hurum*), Indian flapshell turtle (*Lissemys punctata*) and the (Das et al., 2010; Badola et al 2019). These species are prized for their soft meat and calipee (cartilage) which are considered delicacies in certain parts of the country. These softshells are often illegally captured from various regions and smuggled to West Bengal and northeastern states, as well as to Southeast Asian countries where turtles are consumed as well as used to make traditional medicine (Bhupathy et al., 2014; Das & Singh,2009; Krishna Kumar et al., 2009; Sinha, 2015; Stanford et al., 2020).Turtle shells and calipee are thought to possess medicinal properties and are often used in the treatment of arthritis and respiratory ailments, and as longevity tonics, further endangering turtles (Polisar & Horwich, 1994; Sihombing et al., 2021).

Fig- Illegal tread of Indian flapshell turtle (*Lissemys punctata*)

The operation of poaching and illegal trafficking networks happens through specific organized smuggling routes with turtles being transported in hidden compartments in vehicles, trains, and even air cargo. The key transit points for turtle trafficking include Indian borders near Nepal, Bangladesh, and Myanmar (Mendiratta et al., 2017; Rotmans & Zwartepoorte, 2013; Sengottuvel et al., 2024). Despite frequent seizures by wildlife enforcement agencies, customs officials, and police, the trade continues to flourish due to high profits and weak law enforcement in some areas.

IMPACT OF CLIMATE CHANGE ON TURTLE HABITATS

For freshwater turtles, an optimum temperature range is required for physiological functions such as metabolism and reproductive success, therefore, a rise in the temperature caused by climate change has a significant impact. Increased river temperature can lead to higher metabolic rates that force turtles to expend more energy, increasing stress and disease (Larocque et al., 2012). Also, since turtles exhibit temperature-dependent sex determination (TSD), a temperature rise may result in more female hatchlings, affecting the sex ratio, disrupting population balance, and reducing genetic diversity (Herrera et al., 2020; Laloë et al., 2015; Morreale et al., 1982; Roberts et al., 2023; Stanford et al., 2020).

Climate change is severely affecting river hydrology, water temperature, and seasonal fluvial patterns, all of which play a crucial part in freshwater turtle survivability. Being ectothermic (cold-blooded), turtles are highly vulnerable to temperature fluctuations and changes in their habitats, which have an impact on their breeding, nesting, and population health and dynamics (Butler, 2019; Döll & Zhang, 2010; Lenhart et al., 2013; Rathoure, 2018; Stanford et al., 2020).

Climate change is also leading to erratic rainfall and glacial melt in the Himalayas, causing a change in river flow and leading to the destruction of habitats used by turtles. The seasonal fluvial flow patterns of the Ganga regulate nesting cycles, food availability and migratory routes of turtles, therefore, irregularity in monsoon patterns, prolonged droughts, and unseasonal floods are disrupting their natural histories (Stanford et al., 2020). Sudden unseasonal flooding can drown nesting sites, eggs, and hatchlings, while extended dry spells cause shrinkage of habitat availability and may lead to food scarcity.

Further threatening the freshwater turtles is extreme weather events including cyclones and heavy storms that destroy riverbanks, sandbars, and wetlands that are utilized by turtles for nesting and foraging (Rhodin et al.,2011). In some parts, turtles are forced to seek alternative, often unsuitable habitats due to the disappearance of traditional nesting sites caused by coastal erosion and increasing water levels (Moll et al., 2009; Quintana et al., 2019).

A major concern in the Ganga basin is the increase in sedimentation and pollution levels in rivers caused by climate-induced land-use changes and deforestation. Heavy rainfall on deforested land causes soil erosion which increases the rate of sediment deposition in riverbeds, degrading the foraging and nesting beaches of turtles (Dubey et al., 2025; Ishwar, 2003; Jhariya & Tiwari, 2020; Kharel & Chhetry, 2014; Parihar, 2021; Sinha, 2015). Furthermore, an increase in temperature leads to accelerated pollutant breakdown in rivers, which increases the toxicity of water.

TURTLE NESTING AND BREEDING CHALLENGES

Freshwater turtles in the Ganga River Basin face numerous challenges when it comes to nesting and successful reproduction. Many species, including the Red-crowned Roofed Turtle (*Batagur kachuga*), the Three-striped Roofed Turtle (*Batagur dhongoka*), and the Indian Softshell Turtle (*Nilssonia gangetica*), depend on undisturbed sandy riverbanks for nesting (Dubey et al., 2025; Sirsi et al., 2017). The reproductive success of freshwater turtles has decreased exponentially due to anthropogenic activities, predation, and the presence of invasive species (Rathoure, 2018; Stanford et al., 2020).

Sand mining is one of the biggest threats to nesting turtles as it decreases the availability of nesting beaches, making it hard for turtles to find suitable habitats to lay eggs (Bodie, 2001; Horneetal., 2022). The excessive extraction of sand from riverbanks leads to a change in river hydrodynamics and sedimentation, which are crucial for the maintenance of nesting sandbars. With disturbed or eroded nesting sites, the mortality rate of eggs and hatchlings has increased, causing a decline in the addition of individuals to the turtle populations (Moll, 1997)

Predation by stray dogs, jackals, and crows prey on turtle eggs and hatchlings, reducing the survivability rate of many turtles into adulthood. In some areas, the presence of human settlements has led to an increase in the population of feral dogs which destroy turtle nests in a whole sand bar overnight (Chessman, 2011; Khan et al., 2015; Khan et al., 2016; Rasal et al., 2009; Stanford et al., 2020). Other predator species including monitor lizards and mongoose also contribute to the high egg mortality.

Fig- Sand mining is the biggest threat to nesting turtles

Various conservation initiatives have been implemented to address these conservation concerns under the joint efforts of the Wildlife Institute of India (WII), the National Mission for Clean Ganga (NMCG), and state forest departments. The rescue and rehabilitation component focuses on the rescue of turtles confiscated from illegal trades, their rehabilitation in the various centres under the project and their eventual release. There are also community engagement and awareness programs such as the Ganga Prahari and the Bal Ganga Prahari that educate the local communities about the importance of turtles and their conservation. In terms of habitat conservation, nesting sites of endangered turtle species such as *Nilssonia gangetica* and *Batagur kachuga* are protected by habitat restoration programs (Talukdar et al., 2018).

Since turtles play a critical role in the maintenance of balance in aquatic ecosystems and are hence considered keystone species, their mass removal from a habitat has severe ecological consequences. Their over-exploitation leads to population and food web imbalance, affecting the health of entire river-systems (Moll & Moll, 2004; Santori et al., 2020; Wahab et al., 2012). To combat this crisis, stronger enforcement of wildlife protection laws, increased patrolling of trade routes, and strict monitoring of markets are essential. Also, community awareness, rescue and rehabilitation, and conservation breeding programs can help mitigate the decline of turtle populations (Bhupathy et al., 2014; Stanford et al., 2020; Rao, 2001). Curbing of illegal trade depends on strengthening international cooperation and policy framework (Horne et al., 2022; Yadav et al., 2021).

CAPTIVE BREEDING AND REHABILITATION EFFORTS

Various conservation programs that focus on combating the decline of the population of turtles have been initiated for many species. With a focus on captive breeding, head-starting, rescue and rehabilitation and community engagement, organizations such as the Wildlife Institute of India (WII) and the state forest departments have played a crucial role in the conservation efforts (Bajaj et al., 2021; Dubey et al., 2025; Dwivedi, 2021; Kumar et al., 2024).

To ensure the survivability of threatened species such as the Red-crowned roofed turtle (*Batagur kachuga*), the Three-striped roofed turtle (*Batagur dhongoka*), and the Indian softshell turtle (*Nilssonia gangetica*), captive breeding programs have been established, where turtles are bred under a controlled environment. Factors such as temperature, food availability, and predation that influence their survival are controlled in these programs (Bajaj et al., 2021; Das & Bhupathy, 2010; Dubey et al., 2025). Once the eggs hatch and the hatchlings reach a certain size, they are released into their natural habitats with increased chances of survival compared to those that hatched in the wild, ensuring they reach adulthood.

Head-starting programs focus on raising turtle hatchlings in protected enclosures for the first few months or years of their lives before releasing them into the wild. This strategy significantly enhances their survival rates, as young turtles are highly vulnerable to predation, disease, and environmental hazards, and hence is an important conservation action (Dubey et al., 2025; Santori et al., 2020; Spencer et al., 2017; Stanford et al., 2020). Facilities such as the Turtle Breeding and Rehabilitation Center in Sarnath serve as crucial hubs for head-starting efforts, research, and conservation education (Talukdar et al., 2018).

COMMUNITY INVOLVEMENT IN TURTLE CONSERVATION

One of the most effective strategies for protecting turtles in the Ganga River basin has been the engagement of local communities in conservation initiatives. Since most of the threats to turtles stem from anthropogenic activities, it has become imperative to involve people and lead a community-based conservation initiative to foster a sustainable coexistence between people and wildlife (Dubey et al., 2025; Jain et al., 2024; Rao, 2001).

Launched under the Namami Gange mission, the Ganga Prahari program has been the most successful initiative in the conservation of turtles. The program focuses on involving communities that depend on the river for a livelihood such as fishermen, boatmen, and farmers in the monitoring, rescue, and protection of freshwater turtles and other aquatic animals. The members of Ganga Prahari are given training to identify turtle species, patrol nesting sites, and report illegal activities such as sandmining and poaching. This program has led to an increase in awareness and a decrease in the exploitation of turtles with the involvement of local communities (Dubey et al., 2025).

A youth-oriented extension of the Ganga Prahari, the Bal Ganga Prahari program focusses on the education of students and youth community members about the importance of freshwater turtles and the health of a river. These young conservationists learn about the ecological role of turtles, threats, and ways to contribute to the conservation through workshops, river clean- up drives, and interactive sessions. Fostering a sense of responsibility and stewardship among the young ensures a long-time commitment to the conservation of the aquatic ecosystem of the Ganga basin and its turtles.

Several community-led conservation initiatives have emerged in different parts of the Ganga basin where local fishermen of some areas voluntarily report accidental bycatch of turtles in their fishing nets. This allows for the timely treatment of injured turtles by rescue teams. Awareness campaigns in regions with prevalent illegal trade of turtles have helped reduce the exploitation of turtles for their meat and eggs while promoting alternate livelihoods for those involved in such trades. Community involvement also helps in habitat restoration and sustainable resource management. Programs that involve communities in conservation encourage sustainable fishing practices, controlled sand mining, and organic farming that in turn reduce the magnitude of habitat destruction and pollution, ultimately benefiting both turtles and river-dependent communities. Additionally, ecotourism initiatives centered on the conservation of turtles, such as guided tours to nesting sites and turtle rehabilitation centres, provide economic incentives for conservation while spreading awareness among visitors (Stanford et al., 2020).

ROLE OF LEGISLATION AND POLICY IN TURTLE PROTECTION

In India, the protection of freshwater turtles amongst other species is governed by legislation and policies. The primary legal framework for the protection and conservation of organisms in the country is the Wildlife (Protection) Act, 1972 (WPA). The category of Schedule I, which provides the highest level of protection to a species in the country, has been given to many freshwater turtle species of the Ganga River basin such as the Red-crowned roofed turtle (*Batagur kachuga*), Indian flapshell turtle (*Lissemys punctata*), Northern river terrapin (*Batagur baska*), and the Indian narrow-headed softshell turtle (*Chitra indica*) (Bhupathy et al., 2014; Moll et al., 2009; Rathoure, 2018; Wildlife Institute of India, 2023c). Many of the freshwater turtle species are also included under Schedule II and Schedule III, protecting them from capture, trade, and illegal hunting or killing (D'Cruze et al., 2015).

In addition to the WPA,1972, international agreements such as the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) protect freshwater turtles from illegal trade (Singh et al., 2023; Basu & Basu, 2024; Stanford et al., 2020). Since India is a member of CITES, freshwater turtles are listed under Appendix I or Appendix II, which regulates or prohibits their international trade. Furthermore, the Environment Protection Act, 1986, and the Biodiversity Act, 2002, also contribute to habitat conservation by controlling pollution, habitat destruction, and illegal exploitation.

Despite these strong legal frameworks, the implementation and enforcement of turtle protection laws face significant challenges (Stanford et al., 2020). While enforcement agencies conduct seizures and rescue operations, the covert nature of the trade, porous borders, and organized wildlife trafficking networks make it difficult to eliminate. Softshell turtles, are particularly vulnerable due to their demand in the meat and traditional medicine trade (Barhadiya & Singh, 2020; Bhupathy et al., 2014; Rathoure, 2018; Singh et al., 2023;Singh & Singh, 2024)

Another major challenge is the lack of public awareness and training among local enforcement agencies, including forest officials, police, and border security personnel (Stanford et al., 2020). Many officers are not adequately trained to identify protected turtle species, leading to ineffective law enforcement. Additionally, corruption and inadequate resources in wildlife crime units further weaken conservation efforts (Cheung & Dudgeon, 2006; Gong et al., 2006; Moll et al., 2009)

To address these issues, stronger inter-agency collaboration and capacity-building programs are needed (Rathoure, 2018). Training workshops for forest rangers, customs officers, and local police can improve their ability to identify, monitor, and act against illegal turtle trade (Wahab et al., 2012). Enhancing wildlife crime intelligence networks and strengthening cross-border collaborations with countries such as Bangladesh, Nepal, and China, where trafficked turtles often end up, will be crucial in breaking illegal trade chains (Safi et al., 2021, 2024)

Policy improvements should also focus on community involvement and habitat protection measures. Strengthening the implementation of the National Plan for Conservation of Aquatic Ecosystems (NPCA) and incorporating freshwater turtle conservation into river management policies can help ensure long-term habitat security. Moreover, better regulation of sandmining, pollution control, and sustainable fisheries management can indirectly benefit turtle populations by preserving their natural habitats (Bodie, 2001; Casale, 2010).

Incorporating technology-driven solutions like GPS tracking of confiscated turtles, AI- powered surveillance for illegal trade detection, and mobile-based community reporting tools can enhance conservation enforcement. Additionally, public awareness campaigns, school education programs, and media outreach can help change attitudes toward turtles, emphasizing their ecological importance over commercial value (Barhadiya & Singh, 2020; Bhupathy et al., 2014; Lovich et al., 2018; Rathoure, 2018)

RESEARCH AND MONITORING EFFORTS

Scientific research and continuous monitoring play a critical role in the conservation of freshwater turtles in the Ganga River Basin. Understanding turtle behavior, migration patterns, and habitat requirements is essential for designing effective conservation strategies (Talukdar et al., 2018). Various methods, including long-term ecological studies, radio telemetry, and habitat suitability modeling, have been employed to study and monitor freshwater turtle populations (Galois et al., 2002; Ohtani et al., 2023; Stanford et al., 2020).

One of the most valuable research techniques is radiotelemetry, which involves tagging turtles with radio transmitters to track their movement patterns, habitat use, and seasonal migrations (Berberi et al., 2024; Ribeiro et al., 2024; Stanford et al., 2020). This technology provides insights into nesting behaviors, feeding grounds, and dispersal routes, which are essential for identifying critical habitats that require protection (Galois et al., 2002; Richards & Seigel, 2009). Radio-telemetry studies have been successfully conducted on several turtle species, helping conservationists understand how these turtles interact with their environment (Sirsi et al 2025)

Additionally, habitat suitability modeling (HSM) has emerged as a powerful tool for predicting the distribution of turtle species based on environmental factors such as water depth, flow velocity, vegetation cover, and human disturbances. Using geospatial data and remote sensing, researchers can map potential habitats and assess how climate change, pollution, and river modifications are impacting turtle populations. Such studies help in prioritizing conservation areas and guiding riverine management policies (Tan et al., 2022)

Long-term ecological studies focusing on population trends, nesting success, and mortality rates are crucial for evaluating the impact of conservation efforts. These studies involve mark- recapture surveys, genetic analysis, and nest monitoring to estimate population sizes and genetic diversity. Understanding nesting ecology, including egg incubation temperatures, predation risks, and hatchling survival rates, is particularly important for species recovery programs.

Citizen science and community-driven monitoring programs, such as those led by Ganga Prahari members, play a significant role in turtle research. These initiatives involve local fishers, boatmen, and students in data collection, helping researchers gather real-time observations on turtle sightings, illegal poaching incidents, and nesting activity. Combining traditional ecological knowledge with modern scientific methods enhances conservation outcomes by bridging the gap between research and community participation.

Despite significant progress, research and monitoring efforts still face challenges, including funding constraints, lack of trained personnel, and difficulties in accessing remote riverine areas (Bennett et al., 2016; Dubey et al.,2025). Strengthening collaborations between research institutions, government agencies, and conservation organizations is essential for expanding monitoring programs and ensuring long-term sustainability of freshwater turtle populations. By integrating advanced scientific tools with community engagement, conservationists can develop more effective strategies to protect these keystone species in the Ganga River Basin (Behera et al., 2013; Rao, 2001)

TRANSBOUNDARY CONSERVATION CHALLENGES

Many freshwater turtle species in the Ganga River Basin have transboundary distributions, particularly along the India-Nepal and India-Bangladesh borders. These shared populations pose unique conservation challenges, requiring coordinated cross-border efforts to ensure their protection. Turtles such as the Indian Softshell Turtle (*Nilssonia gangetica*) and the Indian Flapshell Turtle (*Lissemys punctata*) are frequently found in border rivers, wetlands, and floodplains, where they are vulnerable to illegal trade, habitat loss, and pollution across multiple jurisdictions (Bhupathy et al., 2014; Mallick et al., 2021; Rathoure, 2018).

One of the biggest transboundary threats is the illegal wildlife trade, where turtles are smuggled across borders for meat, traditional medicine, and the exotic pet market (Stanford et al. ,2020; Wahab et al., 2012). Organized transboundary trafficking networks operate along the Indo- Nepal and Indo-Bangladesh corridors, taking advantage of porous borders, weak enforcement, and high market demand in neighboring countries (Mendiratta et al., 2017; Stoner & Shepherd, 2020). The lack of coordinated enforcement between nations allows traffickers to exploit gaps in wildlife protection laws, making international cooperation essential in curbing this crisis.

Another significant challenge is habitat degradation due to shared water resources. Many of the Ganga Basin's tributaries and wetlands that support turtle populations are impacted by upstream activities, including dams, irrigation projects, and industrial pollution (Bhargava, 1987; Shukla et al., 2018; Sinha, 2015; Tiwari et al., 2016). Without bilateral conservation agreements, unregulated water management policies can lead to declining water quality, disrupted nesting sites, and altered river flow patterns, threatening turtle survival.

To address these challenges, regional conservation frameworks must be strengthened. Initiatives like the South Asia Wildlife Enforcement Network (SAWEN) and bilateral agreements between India, Nepal, and Bangladesh should prioritize freshwater turtle protection through joint monitoring, intelligence-sharing, and stricter law enforcement. Collaborative habitat restoration projects and community-driven conservation programs across borders can help safeguard critical nesting and foraging sites.

FUTURE PROSPECTS AND CHALLENGES IN CONSERVATION

Despite significant progress in freshwater turtle conservation in the Ganga River Basin, several challenges remain that threaten their long-term survival. Anthropogenic pressures, such as rapid urbanization, habitat destruction, pollution, and illegal wildlife trade, continue to put immense stress on turtle populations. Climate change further complicates conservation efforts by altering river flow, nesting sites, and seasonal breeding cycles, making long-term sustainability a challenge.

One of the biggest obstacles is the lack of dedicated funding for freshwater turtle conservation. While programs like Namami Gange have made strides in habitat restoration, long-term funding for captive breeding, research, and enforcement remains limited. More financial resources and investment in community-led conservation programs are essential for the continued success of these initiatives.

Limited policy focus on freshwater turtles compared to other charismatic species like tigers and elephants also hinders conservation progress. Strengthening legal frameworks, improving enforcement of the Wildlife Protection Act (1972), and enhancing transboundary cooperation with Nepal and Bangladesh are necessary to curb illegal trade and habitat destruction.

On a positive note, future conservation efforts can benefit from advancements in scientific research and technology-driven monitoring. Tools such as radio telemetry, satellite tracking, and habitat modeling can provide deeper insights into turtle ecology, movement patterns, and habitat requirements (Galois et al., 2002; Stanford et al., 2020). Additionally, integrating local communities into conservation efforts through sustainable livelihood programs and eco- tourism initiatives can help foster long-term stewardship.

Ultimately, the future of freshwater turtles in the Ganga Basin depends on strengthening conservation policies, increasing public awareness, securing funding, and fostering international collaboration (Sinha, 2015). With enhanced scientific research, community engagement, and stronger enforcement measures, the conservation of these keystone species can be scaled up for long-term success.

THE NEED FOR INTEGRATED CONSERVATION EFFORTS

Protecting freshwater turtles in the Ganga River Basin requires a holistic, multidisciplinary approach that combines scientific research, habitat restoration, strong law enforcement, and active community participation. Given their critical role in maintaining riverine ecosystem health, freshwater turtles must be prioritized in conservation policies and management strategies.

Research and monitoring are essential to understanding turtle behavior, habitat requirements, and threats, enabling data-driven conservation actions. Studies involving radio telemetry, habitat suitability modeling, and genetic analysis can provide valuable insights for species- specific conservation measures (Stanford et al., 2020). Strengthening habitat restoration by curbing pollution, regulating sand mining, fishing practices, and ensuring natural river flow is crucial to maintaining suitable nesting and foraging grounds for turtles.

There must be strict enforcement of laws and policies, which play a vital role in tackling threats such as illegal wildlife trade, accidental bycatch, and habitat encroachment. Strengthening inter-agency collaboration, enhancing anti-poaching efforts, and improving transboundary conservation agreements with Nepal and Bangladesh are necessary steps toward curbing illegal trafficking and protecting shared turtle populations (Rathoure, 2018).

Engaging local communities is a key factor in long-term conservation success. Initiatives like Ganga Prahari and Bal Ganga Prahari have shown that involving riverine communities in turtle rescue, habitat protection, and awareness campaigns can lead to significant conservation gains. Expanding such community-driven programs and integrating sustainable livelihood options will ensure that conservation efforts are socially inclusive and economically viable (Jain et al., 2024). Moving forward, a collaborative conservation framework that brings together government agencies, research institutions, NGOs, and local communities is essential for securing the future of freshwater turtles in the Ganga River Basin. By addressing current challenges and leveraging scientific advancements, we can ensure that these ancient, ecologically important species continue to thrive in their natural habitats for generations to come.

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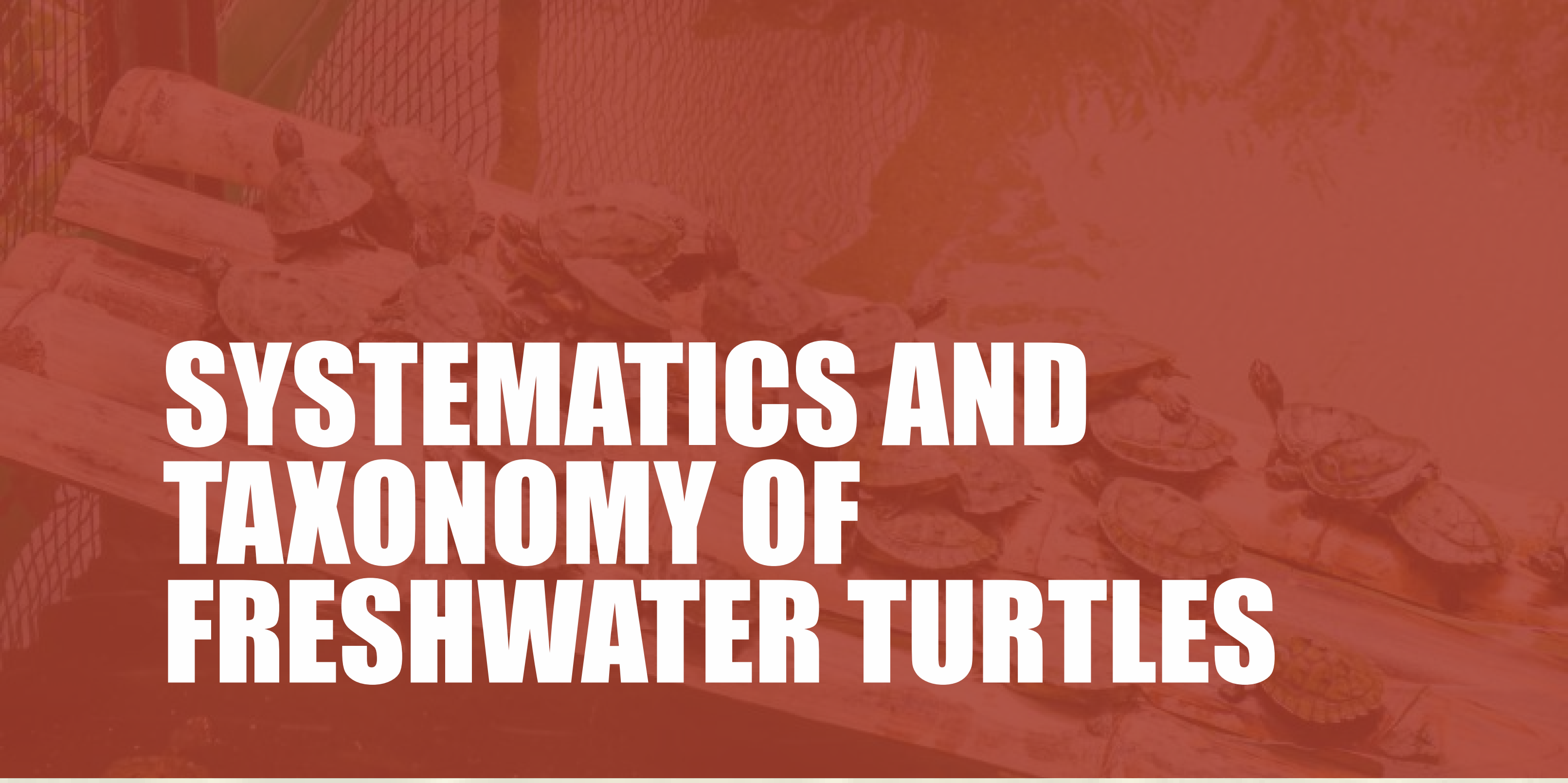

SYSTEMATICS AND TAXONOMY OF FRESHWATER TURTLES

Family Geoemydidae

***Batagur kachuga* (Gray, 1831) - Red-crowned Roofed Turtle**

Kingdom: Animalia | Phylum: Chordata | Class: Reptilia | Order: Testudines | Family: Geoemydidae

***Batagur dhongoka* (Gray, 1832) - Three-striped Roofed Turtle**

Kingdom: Animalia | Phylum: Chordata | Class: Reptilia | Order: Testudines | Family: Geoemydidae

Family Trionychidae

***Nilssonia gangetica* (Cuvier, 1825) - Indian Softshell Turtle**

Synonym: *Aspideretes gangeticus* (Cuvier, 1825)

Kingdom: Animalia | Phylum: Chordata | Class: Reptilia | Order: Testudines | Family: Trionychidae

***Chitra indica* (Gray, 1830) - Indian narrow-headed softshell turtle**

Kingdom: Animalia | Phylum: Chordata | Class: Reptilia | Order: Testudines | Family: Trionychidae

Freshwater turtles of the Indian subcontinent represent some of the most ancient and ecologically significant reptilian lineages, contributing to riverine biodiversity and ecosystem stability (Das & Singh, 2009; Rhodin et al., 2018). Their diversity, particularly within the families Geoemydidae, Trionychidae, and Testudinidae, reflects a long evolutionary history shaped by continental drift, paleoclimatic fluctuations, and the dynamic river systems of South Asia (Pritchard & Trebbau, 1984; Naylor et al., 2008).

The Ganga Basin, one of the world's largest and most ecologically diverse river systems, serves as a critical refuge for several endangered and critically endangered species, including *Chitra indica, Nilssonia gangetica, Batagur kachuga*, and *Batagur dhongoka* (Singh et al., 2019; Safi et al., 2025).

SYSTEMATICS AND TAXONOMIC OVERVIEW

Family Trionychidae

The Trionychidae (softshell turtles) are recognised by their flattened, flexible bodies, cartilaginous shells, and elongated snorkel-like snouts, adaptations that enable a fully aquatic lifestyle (Spinks & Shaffer, 2005). Distributed across Asia, Africa, and North America, Trionychids exhibit high morphological and behavioural specialisation for predation and submersion.

The family is divided into two subfamilies:

1. **Trionychinae** - Asian genera including *Chitra, Nilssonia, Amyda,* and *Pelochelys*
2. **Apaloneinae** - North American genus *Apalone*

Key Ganga Basin Representatives:

- ***Chitra indica*** - Notable for elongated snout and benthic predation specialization.
- ***Nilssonia gangetica*** - Adapted for deep riverine habitats, with strong swimming capability.

3.1.2. Family Geoemydidae

The Geoemydidae is the most species-rich turtle family in Asia, encompassing genera such as *Batagur, Pangshura, Cyclemys, Mauremys,* and *Geoemyda*. These turtles occupy rivers, marshes, and ponds, exhibiting diverse shell morphologies, feeding strategies, and behavioural adaptations (van Dijk et al., 2011; Zhang et al., 2013).

key ganga basin representatives

Many species within Geoemydidae are critically threatened, surviving in fragmented river sections due to habitat degradation and anthropogenic pressures (Wang et al., 2004; Jiang et al., 2018).

- ***Batagur kachuga*** - Males display bright red head colouration during breeding; reliant on deep, slow-flowing river channels.
- ***Batagur dhongoka*** - Slightly smaller, with longitudinal carapace stripes; inhabits sandy substrates of medium-sized rivers.

EVOLUTIONARY HISTORY AND PALAEONTOLOGY

3.2.1. Trionychidae Evolution

Softshell turtles (Trionychidae) originated during the Early Cretaceous (~100 Ma) (Sterling et al., 2011). Fossil and molecular evidence indicate that ancestral forms possessed heavily ossified shells, which gradually evolved into the modern leathery condition, facilitating rapid movement and ambush predation.

Key evolutionary adaptations:

- Flattened, hydrodynamic morphology for fast swimming and burrowing
- Elongated neck and snorkel-like snout for benthic predation
- High genetic structuring across river basins, reflecting historical isolation and river capture events (Li et al., 2017; Liu et al., 2019)

3.2.2. Geoemydidae Evolution

Geoemydids diverged from the superfamily Testudinoidea in the Late Cretaceous (~60-70 Ma) (Naylor et al., 2008). Fossil records suggest early diversification occurred across Asia and Europe, with continental drift facilitating allopatric speciation (Pritchard & Trebbau, 1984).

Adaptive traits include:

- Webbed feet and streamlined shells in aquatic habitats
- Semi-terrestrial flexibility in genera such as *Batagur*, allowing movement between feeding and nesting sites

Phylogeographic studies reveal:

- Isolation across South and Southeast Asia shaped by mountain ranges (Himalayas) and major rivers (Yangtze, Ganges)
- Pleistocene climatic fluctuations and river formation influenced genetic diversification (Fu et al., 2006; Jiang et al., 2018)

Comparative Insight:

- While both families diverged in the Cretaceous, Trionychidae evolved as fully aquatic specialists, whereas Geoemydidae retained ecological flexibility, allowing occupation of both aquatic and semi-terrestrial niches.

MORPHOLOGY AND FUNCTIONAL ADAPTATIONS

Trionychid Morphology

- Leathery, flexible shell aiding manoeuvrability
- Flattened carapace and plastron reducing hydrodynamic drag
- Elongated neck and pointed snout for ambush hunting
- Cutaneous respiration supporting prolonged submersion (Spinks & Shaffer, 2005)

Chitra indica shows extreme snout elongation, allowing prey capture in riverine substrates.

Geoemydid Morphology (*Batagur* spp.)

- Hard, domed carapace for stability in flowing rivers
- Webbed limbs for effective swimming
- Sexual dimorphism and seasonal breeding coloration
- Reliance on basking behavior for thermoregulation

PHYSIOLOGY

Softshell turtles utilise cutaneous and cloacal respiration, have low oxygen consumption, and adjust metabolism to temperature variations. Geoemydids rely on pulmonary respiration but exhibit coordinated basking to regulate body temperature (Pough et al., 2016). Both families are highly sensitive to water quality, flow rate, and temperature, making them vulnerable to anthropogenic disturbances.

MOLECULAR PHYLOGENETICS AND MITOCHONDRIAL GENOME STUDIES

Mitochondrial DNA markers (cytochrome b, 16S rRNA, complete mtDNA) reveal:

- *Chitra* and *Nilssonia* form a well-supported Trionychinae clade (Liu et al., 2019)
- Geographic isolation drives high genetic divergence in populations of *Batagur* species (Jiang et al., 2018)
- Deep genetic splits in northern and northeastern river populations indicate multiple management units for conservation

These findings provide molecular evidence for evolutionary relationships and inform *in situ* and *ex situ* conservation strategies (Cui et al., 2020).

ECOLOGY AND BEHAVIOUR

Habitat Preferences:

- **Trionychids:** Sandy riverbeds, oxbows, and deep pools
- ***Batagur* spp.:** Slow-moving rivers with sandbanks for nesting

Feeding Ecology:

- **Trionychids:** Carnivorous, consuming fish, molluscs, and crustaceans
- ***Batagur* spp.:** Primarily herbivorous, with seasonal shifts to fruits and aquatic vegetation

Reproductive Behaviour:

- Nesting on undisturbed sandy banks
- Dependent on river flow, sediment deposition, and temperature
- Site fidelity observed in *Batagur* species, emphasizing vulnerability to river modification

Human activities such as sand mining, damming, and poaching severely affect reproductive success (Rhoads et al., 2010; Singh et al., 2019).

CONSERVATION CHALLENGES AND MANAGEMENT STRATEGIES

Major Threats:

- Habitat destruction due to sand mining and urbanisation
- Water pollution from industrial and agricultural sources
- Poaching for meat, traditional medicine, and the pet trade
- Altered river hydrology from dams and irrigation
- Climate change is affecting nesting and foraging habitats

Conservation Priorities:

- ***In situ* protection:** Nesting beaches, river sanctuaries, and strict anti-poaching measures
- ***Ex situ* programs:** Captive breeding, genetic management, and population augmentation
- **Community involvement:** Education programs and local surveillance
- **Scientific monitoring:** Genetic surveys, population modelling, and satellite telemetry

Effective strategies integrate molecular genetics, field ecology, and social participation to maintain population viability (Praschag et al., 2012; Safi et al., 2025).

CONCLUSION

The families Trionychidae and Geoemydidae illustrate the remarkable evolutionary, morphological, and ecological diversity of South Asian freshwater turtles. Their adaptations-from softshell respiration to riverine migration-reflect millions of years of evolution shaped by dynamic river systems. Preserving these species requires a multi-disciplinary approach integrating taxonomy, molecular phylogenetics, behavioural ecology, and habitat conservation. Such strategies are essential for maintaining the ecological integrity of the Ganga Basin and the broader freshwater ecosystems of South Asia.

SPECIES ATTRIBUTES

Batagur kachuga (Red-Crowned Roofed Turtle)

Systematics and Taxonomy

Kingdom: Animalia

Phylum: Chordata

Class: Reptilia

Order: Testudines

Family: Geoemydidae

Genus: Batagur

Species: *B. kachuga*

Batagur kachuga is a medium-to-large freshwater turtle distributed in northern India and Bangladesh. The species is characterized by a distinct keel along the carapace, giving it a "roofed" appearance, and sexual dimorphism during the breeding season (Fritz et al., 2003; Praschag et al., 2012).

Phylogeny

Phylogenetic studies indicate that *B. kachuga* is closely related to *B. dhongoka*, forming a monophyletic group within Geoemydidae (Rhodin et al., 2018). Divergence correlates with Pleistocene river system shifts, which created isolated populations and facilitated speciation (Safi et al., 2025).

Phylogeography

Populations are restricted to specific river systems, and geographic isolation due to river fragmentation has resulted in limited gene flow. The Ganges and Brahmaputra basins harbor genetically distinct subpopulations (Jiang et al., 2018).

Evolution

Adaptive traits include omnivorous feeding habits, seasonal migration to nesting sites, and the keeled carapace which provides mechanical protection in riverine habitats. These traits reflect strong selective pressures from river dynamics and predation (Pough et al., 2016).

Conservation and Evolutionary Significance

B. kachuga is Critically Endangered, threatened by river pollution, sand mining, and illegal harvesting. Conservation strategies integrating genetic and phylogenetic data are essential to protect distinct evolutionary lineages (IUCN SSC, 2021; Singh et al., 2019).

Batagur dhongoka (Three Striped Roofed Turtle)

Systematics and Taxonomy

Kingdom: Animalia

Phylum: Chordata

Class: Reptilia

Order: Testudines

Family: Geoemydidae

Genus: *Batagur*

Species: *B. dhongoka*

Batagur dhongoka is a large freshwater turtle native to the Ganges-Brahmaputra river system, particularly in India and Bangladesh. Its carapace is moderately domed, olive-brown, with a yellowish plastron. Adults reach 50 cm in carapace length, with sexually dimorphic features more pronounced during the breeding season (Das & Singh, 2009; Praschag et al., 2012).

Phylogeny

Molecular phylogenetic analyses place *B. dhongoka* within the Batagur clade, diverging from its congeners during the late Miocene (~10-15 million years ago) (van Dijk et al., 2011; Safi et al., 2025). Its lineage represents a unique evolutionary adaptation to fast-flowing rivers of the Indian subcontinent.

Phylogeography

The species' populations are fragmented by natural and anthropogenic barriers, including river engineering, pollution, and habitat loss, resulting in isolated genetic units (Rhoads et al., 2010). Localized river populations suggest that historical river course changes influenced the distribution and genetic structuring of the species.

Evolution

B. dhongoka exhibits omnivory, feeding on aquatic vegetation, invertebrates, and small fish. Its moderately domed carapace and strong limbs are adaptations for maneuvering in fast-flowing water, while nesting behavior is synchronized with seasonal river dynamics (Pritchard & Trebbau, 1984).

Conservation and Evolutionary Significance

Classified as Critically Endangered, *B. dhongoka* is threatened by habitat destruction, pollution, and illegal collection. Conservation initiatives require habitat protection, population monitoring, and captive breeding programs to maintain evolutionary diversity (Singh et al., 2019; IUCN SSC, 2021).

Nilssonia gangetica (Indian Softshell Turtle)

Systematics and Taxonomy

Kingdom: Animalia

Phylum: Chordata

Class: Reptilia

Order: Testudines

Family: Trionychidae

Genus: *Nilssonia*

Species: *N. gangetica*

Nilssonia gangetica inhabits large river systems across India, Bangladesh, and Myanmar. The species exhibits a moderately flattened carapace with a smooth, leathery surface and variable coloration from olive to dark brown (Jiang et al., 2018). Sexual dimorphism is pronounced, with females larger than males, reflecting the species' reliance on abundant energy reserves for reproduction (Aaranyak, 2010). This species prefers deep river pools and slow-moving sections of rivers with sandy or muddy substrates suitable for burrowing (Aaranyak, 2010).

Phylogeny

Molecular studies indicate that *N. gangetica* represents a basal lineage within Trionychidae, diverging early from the Chitra lineage approximately 60 million years ago (Zhang et al., 2013; Sterling et al., 2011). Within the genus Nilssonia, *N. gangetica* is closely related to *N. hurum* and *N. leithii*, sharing traits such as burrowing behaviour, broad plastron, and a carnivorous-omnivorous diet. Its genetic distinctiveness highlights the evolutionary importance of South Asian River turtles (Naylor et al., 2008).

Phylogeography

The species' distribution is strongly linked to the Ganges-Brahmaputra-Indus river systems. Rivers act as both dispersal corridors and barriers, with populations separated by dams, natural waterfalls, and seasonal dry zones, contributing to limited gene flow (Wang et al., 2004). Genetic studies indicate distinct lineages corresponding to river basins, underlining the importance of localized conservation strategies (Liu et al., 2019).

Evolution

Evolutionary adaptations of *N. gangetica* include a streamlined body for rapid swimming, burrowing in sandy or muddy substrates for protection, and specialized suction feeding for capturing prey (Pough et al., 2016). Its large size and long lifespan are adaptive strategies for riverine environments with seasonal variability (Li et al., 2017).

Conservation and Evolutionary Significance

Nilssonia gangetica is classified as Vulnerable due to habitat fragmentation, river pollution, and human exploitation (IUCN SSC, 2021). Conservation programs emphasizing river habitat restoration and captive breeding aim to preserve evolutionary lineages and prevent loss of genetic diversity (Wang et al., 2004; Safi et al., 2025).

Chitra indica (Giant Softshell Turtle)

Systematics and Taxonomy

Kingdom: Animalia

Phylum: Chordata

Class: Reptilia

Order: Testudines

Family: Trionychidae (Softshell turtles)

Genus: *Chitra*

Species: *C. indica*

Chitra indica is among the largest softshell turtles in the world, reaching lengths up to 2 meters in some populations (Spinks & Shaffer, 2005). The species is characterised by a flattened, leathery carapace, elongated snout, and sharp, hooked jaws adapted for a carnivorous diet (Fritz & Havas, 2007). The genus *Chitra* is strictly aquatic, preferring large, fast-flowing rivers with sandy or muddy bottoms. Morphologically, *C. indica* shows sexual dimorphism, with males having smaller, narrower carapaces and longer tails relative to females (Li et al., 2017).

Phylogeny

Molecular phylogenetic analyses place *C. indica* firmly within the Trionychidae family, forming a distinct clade with other *Chitra* species. Mitochondrial DNA and nuclear gene studies suggest that the genus diverged from other Asian softshell turtles approximately 50-60 million years ago, making it an ancient lineage of riverine turtles (Spinks & Shaffer, 2005; Li et al., 2017). The genus is closely related to *Chitra chitra*, with genetic evidence supporting lineage divergence corresponding to geographic separation across river basins (Liu et al., 2019).

Phylogeography

Populations of *Chitra indica* are largely restricted to major Indian and Bangladeshi rivers, including the Ganges, Brahmaputra, and Godavari. Phylogeographic studies suggest that historical river shifts and climatic fluctuations have led to population fragmentation, resulting in distinct genetic lineages (Pawar & Mistry, 2021). The distribution of *C. indica* also correlates with the presence of suitable nesting habitats along sandy riverbanks, which are increasingly threatened by human activities.

Evolution

Adaptations of *C. indica* include a hydrodynamic carapace, an elongated snout for suction feeding, and powerful forelimbs for rapid swimming and digging nests in sandy substrates (Li et al., 2017). Its evolutionary history reflects specialisation for large river systems, a trait that distinguishes it from smaller, more flexible softshell turtles like Pelodiscus sinensis (Spinks & Shaffer, 2005). Fossil evidence indicates that the lineage of *Chitra* has existed in South Asia since the Late Cretaceous, suggesting a long evolutionary history of adaptation to riverine environments.

Conservation and Evolutionary Significance

Chitra indica is classified as Critically Endangered due to habitat destruction, sand mining, pollution, and exploitation for local consumption and trade (Fritz & Havas, 2007). Conservation efforts focused on protecting nesting sites, captive breeding, and genetic management are critical to preserving this ancient lineage (Pawar & Mistry, 2021). Its evolutionary significance lies in its long, independent history within Trionychidae, providing insights into softshell turtle diversification in South Asian river systems.

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NATURAL HISTORY AND SPECIES DESCRIPTION

RED CROWNED ROOFED TURTLE (*Batgur kachuga*)

The species is classified as Critically Endangered in the IUCN Red List, Schedule I in the Wildlife (Protection) Act, 1972, and Appendix II in CITES. There are approximately 500 breeding females in the wild (Hanfee, 1999; van Dijk et al., 2000; Turtle Conservation Fund, 2002; Moll & Moll, 2004; Kishwan & Venkataraman, 2011; van Dijk et al., 2012; Ahsan et al., 2015; Praschag et al., 2019).

DESCRIPTION

Strong sexual dimorphism is displayed by the turtle. Males have ventrally yellow to creamy white, dorsally red, and laterally bluish-grey body colour, while females have olive-blue body colour. The dorsal part of the neck and the throat are white. There is an oval patch of orange colour on both sides of the throat. Webbed limbs are thick with narrow scales that are transverselylarge. Five claws are found on the forelimbs and four on the hindlimbs (Smith, 1932; Moll, 1986; Hanfee, 1999; Moll & Moll, 2004; Praschag et al., 2008).

Fig- Sexual dimorphism in *Batgur kachuga*

The head bearing a temporal arch is slightly long with a pointed and upturned snout that projects beyond the lower jaw but not the orbit. In adult males, the head is dark to bluish-black, with a crimson crown that begins at the snout and becomes more prominent during mating season (Acharji, 1955; Kishwan & Venkataraman, 2011).

There are a few stripes of different hues that run from the head to the neck. There are two lateral stripes of a light orange-yellow hue, one from the eye over the tympanum to the neck, and the other from the snout, above the mandible, below the tympanum to the neck. There is a grey stripe that runs from behind the eye, over the mandibles, and below the tympanum to the neck, sandwiched between the orange-yellow stripes. Athin light grey stripe is present inside the dark grey stripe that only goes to the tympanum (Moll, 1986). Six red lines, four of which extend from the crown, are seen on the dorsal white section of the neck (Tikader & Sharma, 1985; Aryal et al., 2010).

Fig- Adult male *Batagur kachuga*

There are little shields on the back of the head. The jaws are broad, bright yellow, bicuspid, and serrated, with mostly broad alveolar surfaces. Between the inner and outer edges of the upper jaw, there is a noticeable median ridge. Male eyes range from yellow to orange, whereas female eyes are brown. The tail is fairly short, and there is no variation between juveniles and adults in this regard (Hanfee, 1999; Tikader & Sharma, 1985; Moll, 1986).

The body colour of juvenile turtles is duller than that of adult turtles. The head is grey, with a cream-coloured dorsolateral stripe extending from the upper corner of the eye, across the tympanum, and ending at the neck. Six grey stripes cover the neutral grey-hued neck in place of the colourful ones. The rest of the mandible is olive-grey, with the tomium being either orange or yellow. The limbs are white in the posterior region and olive-grey in the anterior region, respectively (Moll, 1986).

Fig- Juvenile *Batagur kachuga*

For females, the largest reported carapace length is 56 cm (Moll, 1986; Praschag et al., 2019), while for males it is 30cm (Aryal et al., 2010). In females, the average range of carapace width is 35-37cm. According to a report, the carapace's length-to-width ratio is 1.32 (Rao & Singh, 1987a). The carapace length and width of hatchlings are approximately 6 cm and 5 cm, respectively (Moll, 1986). The carapace is smooth and elliptical with a wider middle portion. It is dorso-ventrally depressed and unicarinate (Acharji, 1955; Hanfee, 1999), and grey to olive brown in colour and in males the anterior portion along the midline has a reddish hue (Acharji, 1955; Aryal et al., 2010). Juveniles have interrupted vertebral keels, most prominent in the second and third vertebral shields, which gradually decrease with age. There is the presence of lateral keels as weak ridges on the pleural shields. In adults, the rim is smooth, but in hatchlings and juveniles, it is bluntly but profoundly serrated in the eighth to twelfth marginal shields, and severely serrated from the fifth to seventh marginal shields (Smith, 1931; Moll, 1986; Tikader & Sharma, 1985).

Fig- Adult female *Batagur kachuga*

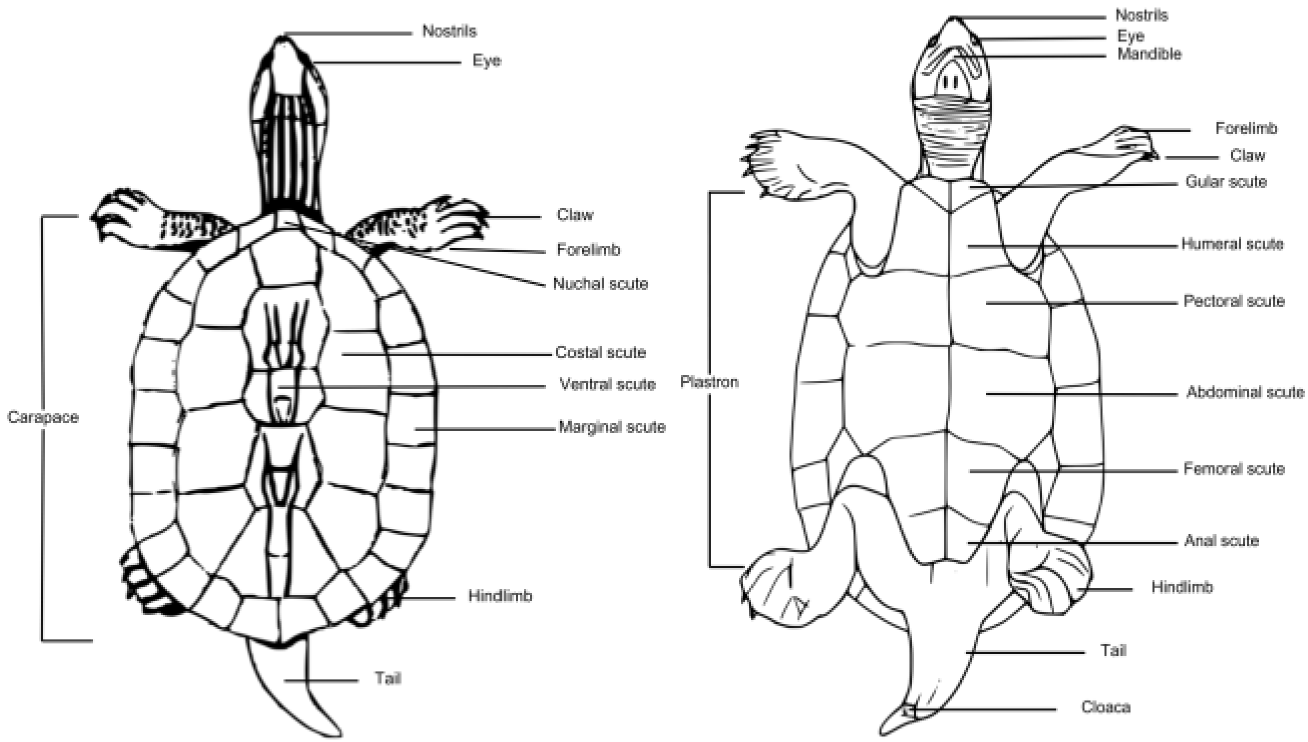

Fig:- Carapace of *Batagur kachuga* (Source- Tikader & Sharma, 1985)

The Nuchal is posteriorly broad. The first and second vertebrae are both similarly long and broad, while the latter is wider than long in juveniles. The posterior border of the second vertebral is straight. The third vertebral is shorter than the second, while the fourth is the longest vertebral shield. The third forms a transverse suture and a broad suture with the second and fourth vertebral, respectively (Smith, 1931; Tikader & Sharma, 1985; Aryal et al., 2010).

The anteriorly truncated, long and narrow plastron has a little anal notch and is coloured orange, cream, or pale yellow. In females, the plastron measures 43-46 cm in length. The posterior portion protrudes beyond the carapace (Acharji, 1955; Moll, 1986; Rao & Singh, 1987a). The shell opening is broader than the plastron, and the breadth of the bridge is more than the length of the posterior part of the plastron. Gular, humeral, axillary, pectoral, abdominal, inguinal, femoral, and anal shields are all paired. The sutures of the plastron are obtusely curved between the humeral and pectoral shields, while the shortest and longest sutures are located between the gular and abdominal shields, respectively. A juveniles' plastron exhibits lateral angulation (Smith, 1931; Tikader & Sharma, 1985).

DISTRIBUTION

It is distributed in India, Nepal, and Bangladesh. In India, it has been reported from Ganges-Brahmaputra flood plains in the states of Assam, West Bengal, Chhattisgarh, Jharkhand, Bihar, Madhya Pradesh, Uttar Pradesh, Uttarakhand, Haryana, and Rajasthan. However, its report from the Brahmaputra River has not been confirmed. It might exist in Myanmar as well (Dipu, 2013). In Bangladesh, it has been regarded as extinct since 2010. Only the lower Chambal River inside the National Chambal Sanctuary is home to the remaining viable wild population, with roughly 50 nests over a spread of 100km (Praschag et al., 2019). Even this sanctuary is vulnerable to sand mining (Acharji, 1955; van Dijk et al., 2000; Moll & Moll, 2004; Aryal et al., 2010; Chakraborty & Mirza, 2010; van Dijk et al., 2012; Nair & Krishna, 2013; Sirsi et al., 2017; Fong & Sung, 2017; Turtle Conservation Coalition, 2018; Singh et al., 2024).

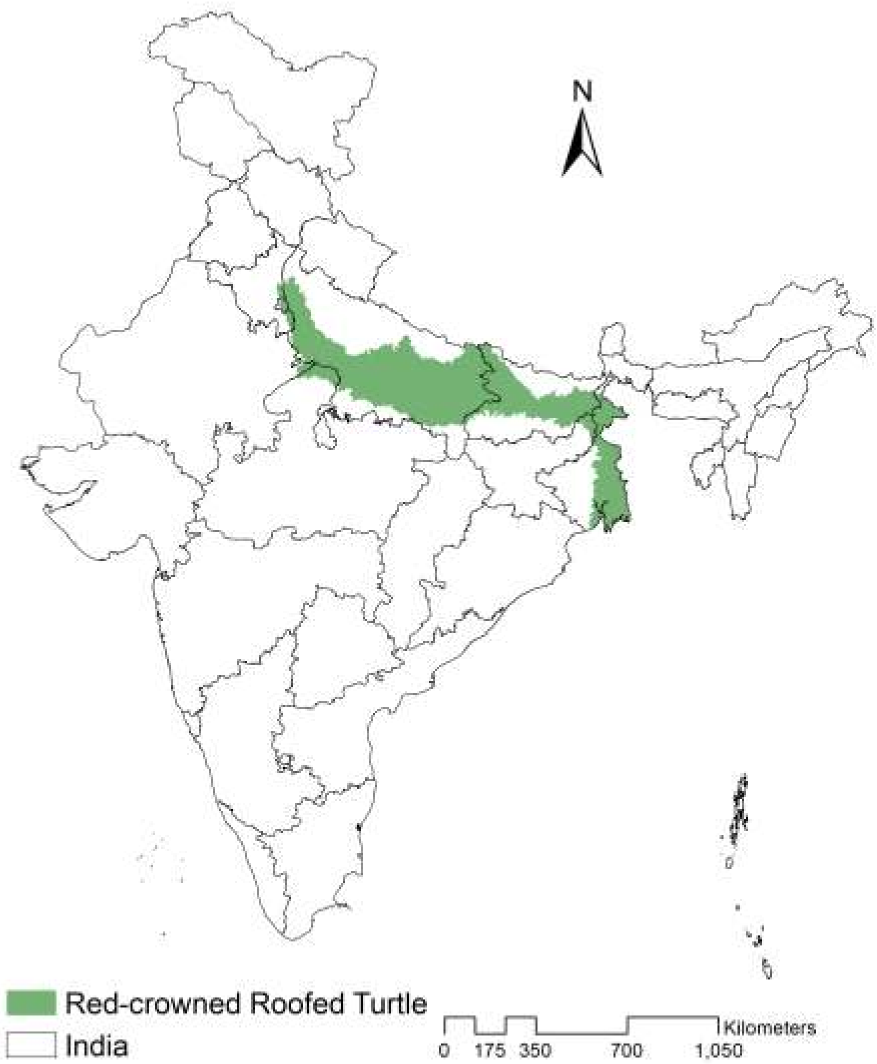

Fig:- Map of distribution of *Batagur kachuga* (Source- IUCN Red List, 2023)

DIET

Adults are herbivorous, while juveniles are omnivorous. They consume aquatic plants and fruits from littoral zones or banks (Moll, 1986; Aryal et al., 2010; Taigor & Rao, 2010; Praschag et al., 2019).In captivity, they have been fed fish, soya, cucumber pumpkin, leaves of mulberry, bottle gourd, aquatic macrophytes, and even a feed made of a mixture of fish, Pedigree dog food and supplements (Singh et al., 2024).

ECOLOGY AND BEHAVIOUR

The species is elusive in nature and tends to dive in water with the slightest disturbance. This makes it harder to know the population status. They prefer deep-flowing clean inland rivers and lakes with sandy bottoms and watersheds (Acharji, 1955; Prashchag et al., 2008; Aryal et al., 2010; Praschag et al., 2019). They are seen basking on snags, and rocks, and also sometimes on sand or hard soil. In the winter, basking occurs from 0900 to 1730 hours, while in the summer, it occurs from around 0530 to 1130 hours. Some bask for a second time in the evening at about 1630 hours. While basking they have their head tilted at an angle of 45o and when they are relaxed enough they stretch out their limbs. They have overlapping habitats with Gharials, but they occupy different niches (Rao & Singh, 1987c; van Dijk et al., 2000).

The species has a generation time of over 25 years with both sexes attaining maturity at about 18 years (Praschag et al., 2019). The breeding period starts in December with nesting commencing from mid-February with peak activity during the months of March and April during which the minimum and maximum temperature ranges from 16.2°C to 40.1°C. Although the females are occasionally observed building nests in the winter, in these instances the embryo either dies or remains dormant until the warmer months. Nesting sites that are selected are flat or gently sloped at about 3-60m away from water in a part of the river with the lowest depth, and are usually covered with fine sand rather than gravel (Rao & Singh, 1987a; Rao & Singh, 1987b; Rao & Singh, 1987c; Aryal et al., 2010; Sirsi et al., 2017).

With rare exceptions, most nesting occurs at night, depending on the temperature or the experience of predator intervention(Rao & Singh, 1987b). The females come out of the water and make a direct path towards the nesting place. They throw sand up to 1-2m in all directions while digging the pits. They dig little chambers to test the quality of the sand and confuse predators before creating the main nest. They favour fine particles of sand. The scattered sand from their digging, the numerous fake nests, along the marks from crawling in loops may confuse the predators. There is no uniform distance between the pits. The depth and width of nests are usually 15cm and 34.6cm, respectively. (Rao & Singh, 1987a; Pareek et al., 2024).For ovulation, the midway temperature should be high. The nesting season is controlled by that and the availability of sand banks for nesting (Ganzhorn & Licht 1983 cited in Sirsi et al., 2017).

Fig- Basking behaviour of *Batagur kachuga*

Reddish-coloured eggs with dimensions of 6.6-7.5 cm, 3.7-4.5 cm, and 56-58 g are laid in one or two clutches of six to thirty-one eggs each (Rao & Singh, 1987a; Sirsi et al., 2017; Praschag et al., 2019). The eggs are either rigid or expandable (Moll, 1986).

After laying eggs, the females take a steep turn back to the water near the point of emergence (Pareek et al., 2024). 27.5-32°C is the optimum nest temperature for the incubation of the eggs, which hatch after approximately 60 days (Rao & Singh, 1987a). The magnitude of the monsoon has no significant correlation with clutch size but has a negative correlation to the number of nests. Hatching usually occurs in the months of May to June, before the start of monsoon rains (Sirsi et al., 2017).

CONSERVATION EFFORT

It is one of the world's 25 most endangered Testudines (Turtle Conservation Coalition, 2018). The main reason for the drastic decline in the population size of the species is hunting for international trade. They are sold in the International market as pets, food, and medicine, despite having no special nutritive or curative properties. The amount of hydrological projects, sand mining operations, and agricultural drainage systems has expanded recently. These activities have altered the course of rivers, which is problematic for this species because it requires sandy beaches with shallow freshwater for nesting. The usage of chemicals has led to the spread of water pollution, which has caused health issues. Turtles usually have a large life span, which contributes to the bio-magnification of dangerous substances like mercury. Ghost fishing nets that are abandoned in rivers after fishing have caused many deaths by entanglement. Removal of huge rocks and floating snags for boating and aesthetic reasons results in the loss of basking spots. (IUCN/SSC Tortoise, & Freshwater Turtle Specialist Group,1989; van Dijk et al., 2000; Turtle Conservation Fund, 2002; Moll & Moll, 2004; Meiling et al., 2008; Aryal et al., 2010; Chakraborty & Mirza, 2010; Kishwan & Venkataraman, 2011; van Dijk et al., 2012;Turtle Conservation Coalition, 2018; Rivera, 2013; Fong & Sung, 2017; Praschag et al., 2019; Stanford et al., 2020; Singh, 2021; Badola et al., 2021; Singh et al., 2024). Due to the dispersed and isolated distribution of the few living small populations, the species may suffer from declining genetic diversity (Kumar et al., 2021).

It has been added to CITES Appendix II, which protects it from wildlife trade without an export certificate. It has also been put under Schedule I of the Wildlife (Protection) Act of 1972 of India which gives it the utmost protection from trading and poaching. Due to its rapidly declining population, it has been added under the category of Critically Endangered in the IUCN Red List 2023. It has also been added as Critically endangered in the Bangladesh Wildlife Protection Act 1974 (van Dijk et al., 2000; Turtle Conservation Fund, 2002; Moll & Moll, 2004; Kishwan & Venkataraman, 2011; van Dijk et al., 2012; Ahsan et al., 2015; Praschag et al., 2019).

In 2006, a Turtle Conservation Centre for *Batagur kachuga* and *B. dhongoka* was started in the Chambal River in the National Chambal Sanctuary. There, the species is protected in their nests, raised in hatcheries by riversides, released as hatchlings, given head starts, and managed at the community level by the guidelines of the "Conservation Action Plan for Endangered Freshwater Turtles and Tortoises of India". Every year, during the months of February to May, a Batagur nest protection programme is held. From 2006 to 2020, this programme has protected more than 768 nests of *B. kachuga* and 66 *B. dhogoka*. Captive colonies have been established in the regional zoological parks of Kanpur and Lucknow. There is also a captive-bred population at Kukrail Gharial Rehabilitation Centre in Lucknow and Madras Crocodile Bank Trust in Tamil Nadu (Singh et al., 2024). There have also been attempts at captive breeding in Morena, Madhya Pradesh (van Dijk et al., 2000; Turtle Conservation Coalition, 2018).

According to the Global Action Plan created by the Turtle Conservation Fund, species such as *B. kachuga*, whose population in the wild is low, must be protected by the creation of assurance colonies to increase their population. Then, there should be research on the species and surveys on its natural history. Capacity building, trade monitoring, the establishment of rescue centres, and ecological turtle farming will help in the long-term conservation of the species (Turtle Conservation Fund, 2002).

There should be the release of head-starting juveniles in the wild instead of newly hatched ones (Buhlmann et al., 2015). It is crucial to stop local communities from hunting turtles for meat. This can be achieved by educating the public about the laws that protect turtles and by implementing stricter fishing regulations. The Wildlife (Protection) Act, 1972's rules should be updated, and forest personnel should receive the necessary training. There is a need for the establishment of sanctuaries, implementation of seasonal closures and ban on construction that are harmful to the ecosystem (IUCN/SSC Tortoise, & Freshwater Turtle Specialist Group, 1989; Chakraborty & Mirza, 2010). Lakes, Ponds, rivers, and their tributaries should be surveyed in their historical range to learn about the current population status in India followed by extensive preservation and research of the habitat with the presence of the species, especially the Upper Gangetic Plains (Buhlmann et al., 2009) before the population declines beyond repair. Knowing the locations of the existing populations may also help down illegal hunting practices (Fong & Sung, 2017).

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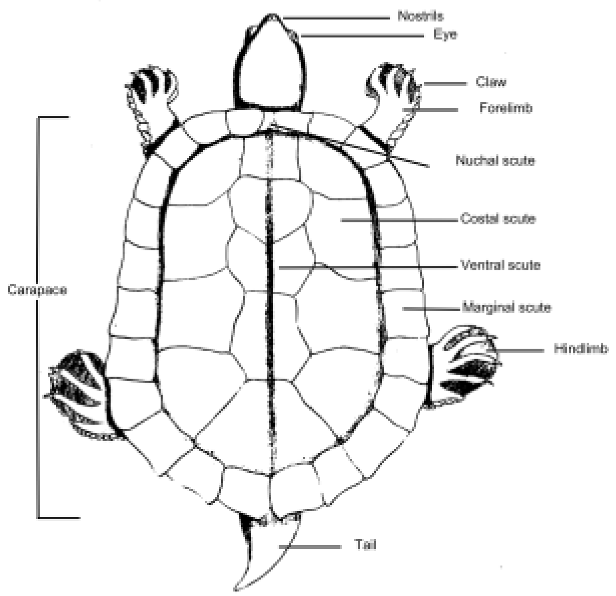
THREE-STRIPED ROOFED TURTLE (*Batagur dhongoka*)

SPECIES DESCRIPTION

The species has olive to brown, unicarinate carapace with three characteristic black stripes, one vertebral and two lateral. Females have a recorded maximum carapace length of 48 cm (Rao & Singh, 1987a). Males are smaller than females with a maximum carapace length record of 26 cm (Smith, 1931). The elliptical carapace is wide in the middle and is posteriorly smooth, depressed with blunt serrations. The nuchal is posteriorly wide. The 1st vertebral shield is broader than long and narrow in the middle. The 2nd vertebral is wide in juveniles, and in adults, it is long and posteriorly narrow. Its posterior margin fits into the 3rd shield's emargination. Shorter than the 2nd and 4th vertebral, the 3rd shield forms a suture with the longest 4th shield. The vertebral keel is interrupted and most prominent in the 2nd and 3rd vertebral shields. It decreases in size with age (Theobald, 1876; Murray, 1884; Smith, 1931; Tikader & Sharma, 1985; Hanfee, 1999; Devaprakash, 2015).

The plastron is yellow, anteriorly truncated, posteriorly notched, and narrower than the width of the opening of the shell but posteriorly protrudes beyond. In juveniles, the plastron is laterally angulated, and each plastron shield has a large reddish patch (Smith, 1931; Tikader & Sharma, 1985; Rao & Singh, 1987a; Hanfee, 1999). Shields include paired gulars, humeral, axillary, abdominal, inguinal, femoral and anal. Median suture is the largest and smallest in abdominal and gular shields, respectively. The suture between the humeral and pectoral shields is straight (Smith 1931; Tikader & Sharma, 1985).



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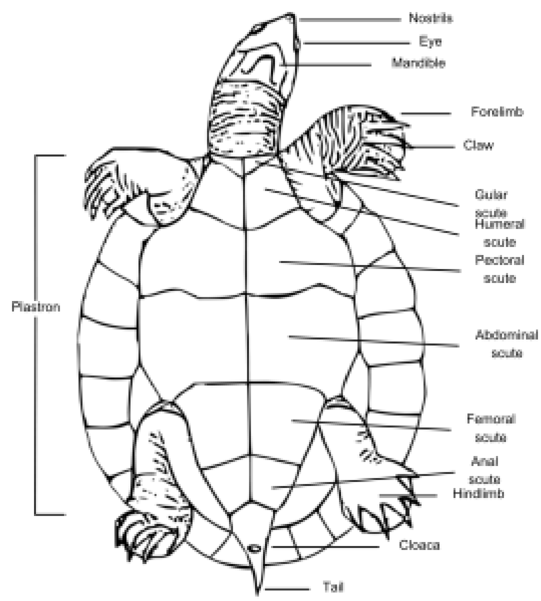

Fig-

Fig-
Batagur dhongoka Hatchling (left) and Yearling (Right)

The moderately sized head has a snout that projects beyond the lower jaw. Skin is olive or yellow with a yellow stripe running along the side of the head, from the nostrils passing above the eye and tympanum. The skull has a temporal arch (Theobald, 1876; Murray, 1884; Smith, 1931; Tikader & Sharma, 1985; Hanfee, 1999). Limbs are 5 clawed and webbed. The tail is short and doesn't distinguish between juvenile and adult (Tikader & Sharma, 1985; Hanfee, 1999).

ECOLOGY OF *BATAGUR DHONGOKA*

The species nests on sand banks with specific habitat requirements for nesting. However, excessive sand mining, hydrological projects, shrimp farming, and riverbank agriculture have changed the course of rivers or degraded sandbanks (Rao & Singh, 1987b). Other factors such as the illegal trafficking of eggs and adults for food, medicine and pet trade, natural predators, and the long generation period, have caused the population of *Batagur dhongoka* to drop (Tikader & Sharma, 1985; Rao & Singh, 1987b; Jenkins, 1995; Choudhury et al., 2000; Rashid & Khan, 2000; Turtle Conservation Fund, 2002; Horne, 2011; Devaprakash, 2015; Sirsi et al., 2017; Lovich et al., 2018; Bajaj et al., 2020; Chakraborty et al., 2020; Stanford et al., 2020; Singh, 2021; Badola et al., 2021.

B. dhongoka inhabits deep, clean freshwater rivers or large wetlands with an upper elevation limit of 140 m asl (Rashid & Khan, 2000; IUCN, 2019). The species is often seen basking on sandbanks, snags, and rocks (Devaprakash, 2015).

FORAGING AND NUTRITION

It is an omnivorous species but males are more carnivorous. In free ranging conditions they have been observed to consume aquatic plants, mussels, etc., while in captive colonies, they are fed pumpkin, bottle gourd, leafy vegetables, cucumbers, tomatoes, carrots, apple, watermelon, seasonal fish, shrimp, and feed concentrates (Bajaj et al., 2020; Devaprakash, 2015).

REPRODUCTION

The species is oviparous females lay 30-35 dull brown to yellowish-white eggs in 1-2 clutches at an average interval of 20 days (Devaprakash, 2015; Sirsi et al., 2017). The species starts nesting in mid-December and lasts till April, with peak activity in March and April (Rao & Singh, 1987; Rao & Singh, 1987b). Hatching occurs from May to June after an incubation period of 2 months (Devaprakash, 2015; Pareek et al., 2024). Nests are made nocturnally and irregularly distanced (Rao & Singh, 1987) in sandbanks and islands near rivers with steep slopes and fine sand where depth has started lowering (Rao & Singh, 1987b; Sirsi et al., 2017; Pareek et al., 2024). Nesting does not correlate with rainfall, but peak activity is seen when the nesting habitat is most available and the temperature is high (Rao & Singh, 1987b; Sirsi et al., 2017). The nesting crawls of females differ a lot. Females move in a straight line towards the nesting site, deposit eggs, and then return to the water 3-5m away from the point of emergence. They might also move to the nesting site, lay eggs, cross the emergence path, and re-enter the river 5-15m away from the emergence point. Females might also emerge and crawl parallel to the river, lay eggs, and then return in a straight line 3-15m away from the point of emergence (Pareek et al., 2024).

While digging holes for nesting, they throw 15-30m of sand in one direction (Pareek et al., 2024). After which, females lay 20-25 yellowish-white that are 5.1-6.6 cm, 3.2-4.1 cm, and 36.5-57.3 g in length, breadth, and weight, respectively (Smith, 1931; Rao & Singh 1987). During peak nesting time, 6-7 females make nests in a single sandbar, filled with marks of crisscross pathways (Devaprakash, 2015; Pareek et al., 2024). Parental care is minimal, with the females leaving the nest after laying the eggs. The eggs incubate in the nest unprotected (Pareek et al., 2024).

DISTRIBUTION AND POPULATION CONNECTIVITY

Historical

The species was reported to be found in India, Bangladesh, and Nepal (Theobald, 1876; Murray, 1884; Choudhury et al., 2000; van Dijk, 2000; Rashid & Khan, 2000; Dipu, 2013; Devaprakash, 2015). It was formerly widespread in the Ganga Brahmaputra Basin, however, the species is nearing extinction in the wild and has vanished from the majority of its natural range (Smith, 1931; Tikader

& Sharma, 1985; Hanfee, 1999; Ahmed & Das, 2010; Devaprakash, 2015). In India, it was once found throughout the Ganga and Brahmaputra River Basin in the states of Assam, West Bengal, Jharkhand, Chhattisgarh, Bihar, Madhya Pradesh, Uttar Pradesh, Haryana, and Rajasthan (Smith, 1931; Tikader & Sharma, 1985; Hanfee, 1999).

Current

The Three-Striped Roofed Turtle (*Batagur dhongoka* Gray, 1832) is a freshwater turtle of the family Geoemydidae (Turtle Taxonomy Working Group, 2012).It has been recorded from India, Bangladesh, and Nepal (Theobald, 1876; Murray, 1884; Choudhury et al., 2000; van Dijk, 2000; Rashid & Khan, 2000; Dipu, 2013; Devaprakash, 2015). Devaprakash, 2015). But the species has become extirpated from most of its native range and is on the brink of extinction in the wild. The largest wild population is found in the Chambal River inside the National Chambal Sanctuary (Rao & Singh, 1987; Nair & Krishna, 2013; Sirsi et al., 2017; Singh et al., 2024), and a population has also been reported from Farakka in West Bengal (Ismail et al., 2022). In 2020, a single individual was also recorded in the Yamuna River of Delhi NCR (Barhadiya et al., 2020).

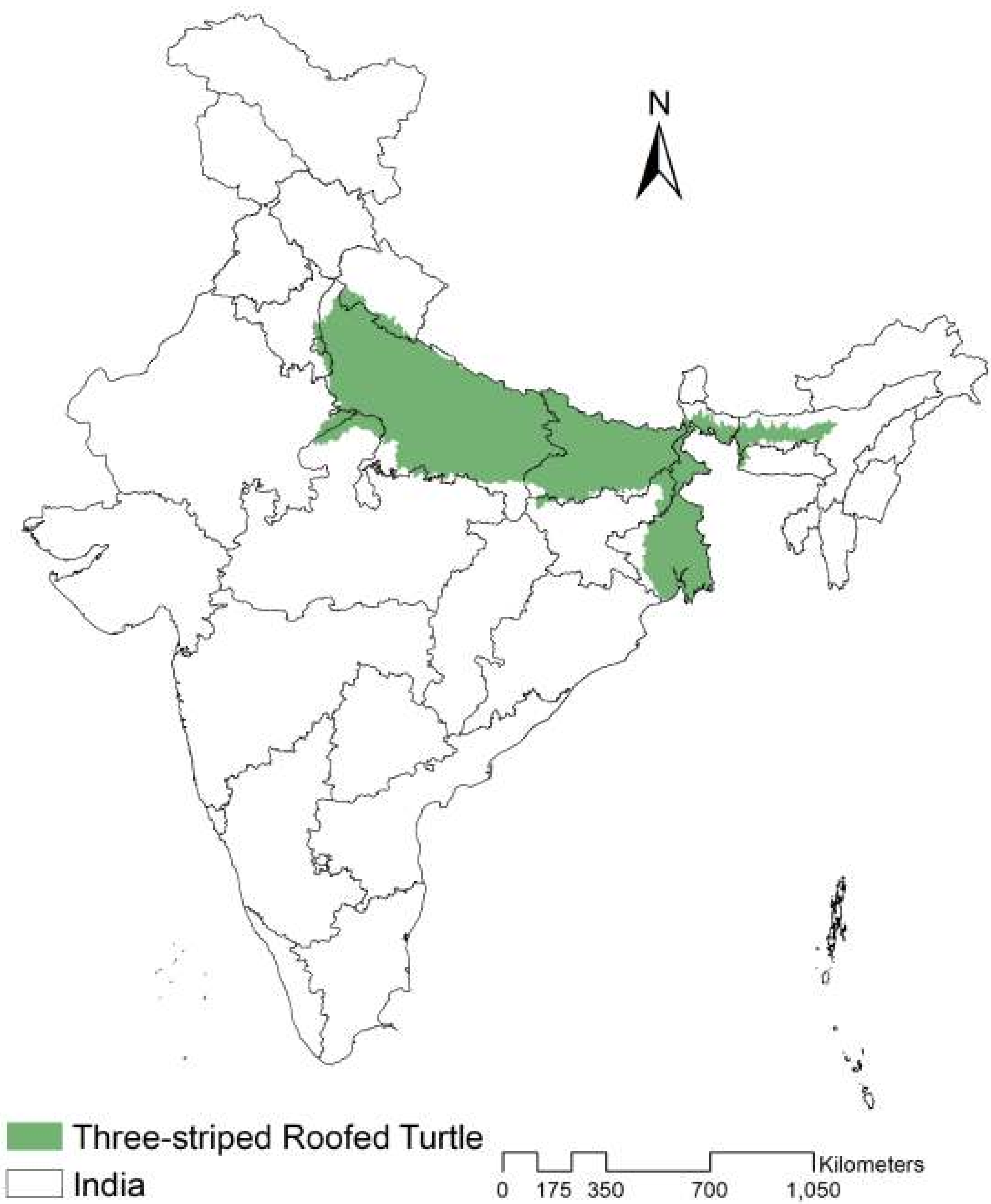

Fig- Map of distribution of *Batagur dhongoka* (Source- IUCN Red List)

Threats

The species is facing imminent threats from hydrological projects, sand mining, deforestation and pollution that have fragmented and degraded the habitat of the species. additional threats include getting entangled in fishing nets, ghost nets, poaching and illegal trade and predation of eggs by feral dogs and wild predators such as jackals. (Tikader & Sharma, 1985; Rao & Singh, 1987b; Jenkins, 1995; Choudhury et al., 2000; Rashid & Khan, 2000; Turtle Conservation Fund, 2002; Horne, 2011; Devaprakash, 2015; Sirsi et al., 2017; Lovich et al., 2018; Bajaj et al., 2020; Chakraborty et al., 2020; Stanford et al., 2020; Singh, 2021; Badola et al., 2021).

Accurate population estimates for the species are unavailable; however, due to loss of habitat along with other anthropogenic drivers it is believed that the species has faced sharp declines.

Data on the current population size of the species is not available (Ahmed & Das, 2010). But there is a population in the Chambal River of the National Chambal Sanctuary (Rao & Singh, 1987; Nair & Krishna, 2013; Sirsi et al., 2017; Singh et al., 2024). Because there are few reports on the species from the wild, and markets, and due to excessive habitat degradation, it is thought that the population has declined significantly (IUCN. 2019; Badola et al., 2021).

CONSERVATION STATUS AND ONGOING CONSERVATION ACTIONS

The species because of threats described above is placed under Schedule I of the Wildlife Protection Act (1972) and is listed as Critically endangered in the IUCN Redlist of Threatened Species (Das et al 2019) and Appendix II of CITES.

Despite a lack of data on the population size of the species, a decline in the number of individuals from the wild, food markets, and the degradation of suitable habitat has qualified the species to be placed in CITES Appendix II and to be classified as Critically Endangered in the IUCN Red List since 2018 (IUCN. 2019; Badola et al., 2021), and as Critically Endangered under the Bangladesh Wildlife Protection Act of 1974 (Rashid & Khan, 2000; Horne, 2011; Devaprakash, 2015).

Since 2006, the "Conservation Action Plan for Endangered Freshwater Turtles and Tortoises of India" has used the National Chambal Sanctuary as a location for riverside hatcheries, nest protection, head-starting, and colonization (Singh et al., 2024). The species is maintained in captive colonies in Nawab Wazid Ali Shah Zoological Park, Lucknow, Kanpur Zoological Park, Madras Crocodile Bank Trust & Centre for Herpetology, Kukrail Gharial Rehabilitation Centre in Lucknow, Ganga Aqualife Rescue and Rehabilitation Centre in Narora and Varanasi in Uttar Pradesh, and Barhi and Morena in Madhya Pradesh. Through these colonies, head-starting and reintroductions are performed (Choudhury et al., 2000; Buhlmann et al., 2009; Devaprakash, 2015; Bajaj et al., 2020; Madras Crocodile Bank Trust & Centre for Herpetology, 2022; UPFD Endangered Species Project, 2023; Singh et al., 2024).

Technological advances and media have made the sharing of data and news related to conservation easier. UNODOC Wildlife Seizure database and C4AD Wildlife Seizure database help collect data regarding illegal activities (Badola et al., 2021).

The Wildlife Institute of India (WII) has played a major role in conserving turtles and tortoises found in the Ganga River Basin. The Institute has studied the diversity of the turtles and tortoises in Ganga (Talukdar et al., 2019). Growth patterns (Talukdar et al., 2021b), and hematology and serum chemistry (Talukdar et al., 2021a) of *Batagur dhongoka* have been studied. There has also been a study on the relationship between diseases and the trade of animals (Talukdar & Nigam, 2014). The reliability of software such as ImageJ has been tested to take digital morphometric measurements (Panda et al., 2024).

The Institute and the Ministry of Jal Shakti of the Government of India started a project to rejuvenate the Ganga River and conserve its biodiversity. Capacity-building workshops, the rescue and release of species, the establishment of rescue and rehabilitation centres, the identification of release sites (Bajaj et al., 2018), and the development of guides for conservation are a part of this project (Mallapur et al., 2019). Turtle rearing, rescue, and rehabilitation centres were established in Sarnath in Varanasi district (Talukdar et al., 2020) and Narora in Bulandshahr district of Uttar Pradesh (Bajaj et al., 2020), and Bhagalpur district of Bihar. In these centres, details of turtle pond enrichment and various methods related to rehabilitation and health assessment of the turtles have been studied (Nigam et al., 2019).

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INDIAN SOFT-SHELLED TURTLE (*Nilssonia gangetica*)

Nilssonia gangetica (Cuvier, 1825), commonly known as the Indian soft-shelled turtle, is a large freshwater turtle species distributed across South Asia, including India, Bangladesh, and Nepal (Das, 1995; Smith, 1931). Within India, populations are reported across major river basins, such as the Ganga, Narmada, Godavari, Mahanadi, and Brahmaputra (Das, 1995; Choudhury & Bhupathy, 1993). The species predominantly inhabits rivers and streams but is also found in lentic water bodies, including oxbow lakes, floodplain wetlands, irrigation canals, and stagnant ponds, demonstrating remarkable habitat plasticity (Moll & Moll, 2004; Das, 1995). *N. gangetica* shows a preference for areas with soft sandy or muddy substrates, which support burying and ambush behaviours (Moll & Moll, 2004).

Morphologically, *N. gangetica* exhibits adaptations characteristic of trionychid turtles that enable efficient aquatic life. Its dorsoventrally flattened, leathery carapace reduces hydrodynamic drag, facilitating movement in water (Ernst & Barbour, 1989; Moll & Moll, 2004). Fore- and hind limbs are fully webbed, providing propulsion for swimming, digging, and substrate manipulation (Moll & Moll, 2004). The species possesses a long, tubular neck and snout, allowing surface respiration while the body remains submerged, minimising predation risk and aiding ambush predation (Moll & Moll, 2004). Adults are among the largest freshwater turtles in India, attaining carapace lengths of 70-90 cm (Das, 1995). The carapace is flexible and partially ossified, facilitating ease in complex riverine habitats and burrowing behavior (Moll & Moll, 2004; Ernst & Barbour, 1989).

Fig- *Nilssonia gangetica* Yearling (Left) and Adult (Right)

Behaviorally, *N. gangetica* is primarily benthic, spending extended periods buried in substrate or lying motionless in deep water, a strategy linked to ambush predation and predator avoidance (Moll & Moll, 2004). The species is an opportunistic omnivore, consuming fish, amphibians, crustaceans, molluscs, aquatic insects, aquatic plants, and carrion (Moll, 1980; Vivekanandan & Rajagopalan, 2009). Through predation, it regulates prey populations, while scavenging contributes to nutrient cycling and organic matter decomposition in riverine ecosystems (Moll & Moll, 2004). Seasonal monsoon-driven hydrological changes stimulate increased movement, foraging, and potential dispersal. While largely aquatic, occasional basking occurs for thermoregulation (Whitaker, 1997).

The reproductive ecology of *N. gangetica* is closely linked to seasonal hydrology. Females migrate to exposed sandy banks above the flood line during the dry season to lay eggs (Rao & Singh, 1987; Whitaker, 1997). Clutch sizes typically range from 20-50 eggs, and incubation lasts approximately 260 days (Vyas & Patel, 1992). Hatchlings emerge with the onset of monsoon, moving into shallow vegetated areas that protect them from predators before gradually dispersing into deeper channels as they grow. Growth is slow, with sexual maturity reached only after several years, and adults are long-lived, often surviving for multiple decades (Moll & Moll, 2004).

Culturally, *N. gangetica* is revered in India as "Kurma," the reincarnation of the Hindu god Vishnu, resulting in its frequent presence near sacred water bodies and historically reduced hunting pressure in some areas (Whitaker, 1997). Despite this, cultural reverence alone does not shield populations from habitat degradation and exploitation (Whitaker, 1997; Choudhury & Bhupathy, 1993).

Anthropogenic threats to *N. gangetica* are extensive. Habitat alteration caused by dam construction, river channel modification, sand mining, and water pollution significantly reduces suitable nesting and foraging areas

Fig- N. gangetica hatchlings

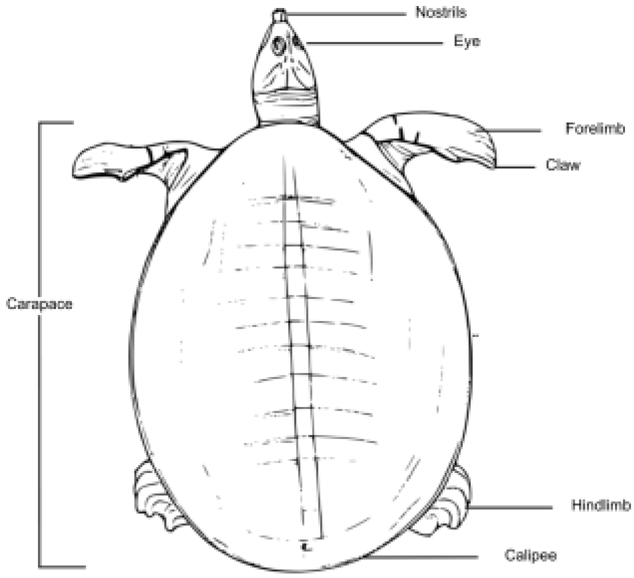
and disrupts seasonal cues essential for reproduction and dispersal (Choudhury & Bhupathy, 1993; Vivekanandan & Rajagopalan, 2009). Overexploitation for meat and traditional medicine persists across its range, exacerbating population declines (Rahman et al., 2015; WWF-India, 2019). These pressures have led to its classification as Vulnerable on the IUCN Red List and its inclusion in CITES Appendix I, highlighting its global conservation significance (IUCN, 2021).

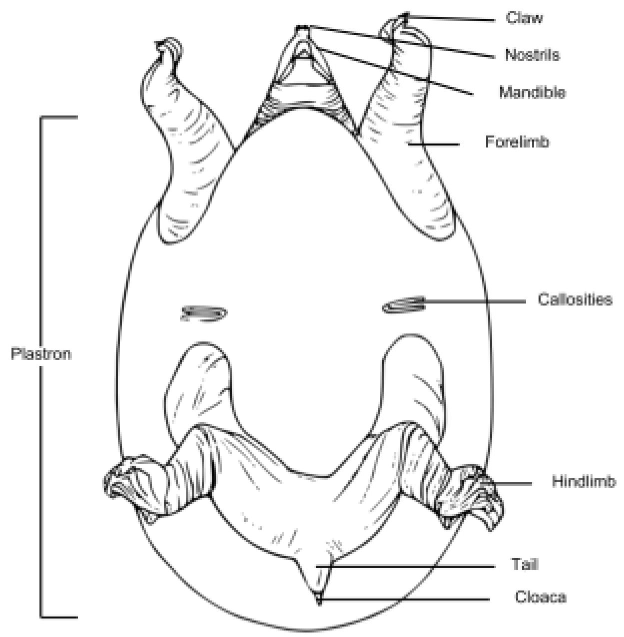
Conservation initiatives targeting *N. gangetica* include captive breeding programs, community-based protection, and public awareness campaigns aimed at reducing hunting and protecting riverine habitats (Rahman et al., 2015; WWF-India, 2019). However, ongoing threats such as accidental mortality in fishing gear, uncontrolled habitat modification, and pollution necessitate comprehensive, landscape-level conservation strategies (Vivekanandan & Rajagopalan, 2009; WWF-India, 2019). Habitat restoration, maintenance of natural river flow regimes, and strict enforcement of protective legislation are critical for the long-term survival of the species (Choudhury & Bhupathy, 1993; Rahman et al., 2015).

Given its ecological role as both predator and scavenger, cultural importance, and vulnerability to anthropogenic threats, *N. gangetica* represents a key species for research linking freshwater biodiversity conservation, ecosystem function, and human dimensions. Further studies on its distribution, population dynamics, habitat requirements, and reproductive biology are essential to inform effective management and conservation planning. Protecting *N. gangetica* ensures not only the survival of a culturally and ecologically important freshwater species but also the integrity and resilience of the riverine ecosystems it inhabits (Moll & Moll, 2004; Rahman et al., 2015).

DISTINGUISHABLE FEATURES

Despite the shared characteristics among members of the family Trionychidae, *Nilssonia gangetica* exhibits several distinctive morphological features. The species possesses a greenish head marked by black oblique lines, often forming a forward-directed 'Y' pattern; in some individuals, these lines may be broken or incomplete,





indicating intraspecific variation. The head is broad, with a snout approximately equal in diameter to the orbit, while the interorbital region in adults is narrower than the nasal fossa. The upper jaw lacks ridges but bears fleshy excrescences or extensive pads along both jaws, which assist in the efficient grasping and manipulation of prey. Additionally, the inner edges of the alveolar surface of the mandibles are elevated, forming a pronounced ridge that further enhances prey capture. (Boulenger 1980). The carapace of *N. gangetica* is soft yet robust, featuring eight pairs of costal plates, of which the last pair is particularly well-developed. These plates are coarsely pitted, providing structural support while maintaining flexibility. Two neural plates are present between the first pair of costals, a characteristic shared among soft-shelled turtles. The plastron exhibits very large callosities, typically numbering around five, which likely serve a protective function during substrate digging and interactions with other individuals. (Boulenger 1980) The overall morphology-including a flattened body, large head, and specialised jaw structures-reflects the species' adaptation to a predominantly aquatic, benthic, and ambush-based lifestyle, enabling it to efficiently capture a wide range of prey and thrive in varied freshwater habitats.

Fig- Forward-directed 'Y' pattern on the head of a *Nilssonia gangetica* yearling

Description of the species

Nilssonia gangetica is a large freshwater turtle, with historical records reporting individuals reaching up to 94 cm in total carapace length (The Reptiles of British India, 1890). As a member of the family Trionychidae, it exhibits several adaptations to an aquatic lifestyle: the head and neck are fully retractable, and the carapace is only partially ossified, lacking bony scutes and instead covered by a leathery, pliable outer layer. (Günther 1864) The bony elements are prominent along the central region of the carapace but are reduced along the periphery, giving flexibility to the margins. The carapace is longer than broad and displays a slight anterior swelling along the vertebral line, while the overall shape ranges from round to oval. Its colouration is typically olive or green, occasionally marked with black reticulations, and the shell is moderately domed. (Günther 1864)

The head is wide, slightly downward-turned, and green, adorned with black lines across the forehead and sides of the neck; the intensity and pattern of these lines vary with age and among individuals (Whitaker, 1997). Juvenile carapaces differ markedly from adults, featuring a low vertebral ridge, 12-13 longitudinal rows of tubercles on each side, and 4-6 ocelli that are brown with red and black central ridges. Young individuals also display round yellow spots behind the eyes, nostrils, and at the angle of the mouth, with multiple yellow spots along the soft carapace ridges. The snout ends in a pair of proboscis-like nostrils, facilitating surface breathing while submerged. The tail is short but clearly visible, and both forelimbs and hind limbs are fully webbed, aiding in swimming and burrowing behaviours (Boulenger, 1890).

Fig- Ocelli on the carapace of a juvenile *N. ganagetica*

Habitat

Nilssonia gangetica is a large freshwater turtle species distributed across South Asia, with confirmed records from major river basins including the Ganga, Brahmaputra, Godavari, Mahanadi, Narmada, Chambal, Gandak, and Ghaghara rivers (Das, 1995; Choudhury & Bhupathy, 1993). The species primarily inhabits slow- to moderately flowing rivers and streams, where soft sandy or muddy substrates facilitate burrowing, concealment, and ambush predation (Moll & Moll, 2004).

In the Chambal River, individuals are frequently observed in deep pools and eddies along river bends, with sandbars serving as critical nesting sites and submerged vegetation providing shelter and foraging grounds (Whitaker, 1997). In the Gandak River, the species utilizes floodplain wetlands and oxbow lakes created by meandering channels, often inhabiting shallow vegetated areas during the monsoon season (Vivekanandan & Rajagopalan, 2009). In the Ghaghara River, turtles are found in stretches with moderate water flow and soft sandy substrates, particularly near confluences and low-turbulence zones, providing both protection and abundant prey (Moll & Moll, 2004). In the Brahmaputra River, *N. gangetica* has been recorded in deep channels and riverine floodplain wetlands, taking advantage of the large, sandy banks for nesting and submerged vegetation for foraging and refuge (Das, 1995; Rao & Singh, 1987).

Beyond natural riverine habitats, *N. gangetica* also inhabits irrigation canals, large ponds, and seasonal wetlands, demonstrating considerable ecological plasticity. The species is frequently recorded in stagnant water bodies and temple ponds across India, where cultural and religious protection reduces hunting pressure and allows persistence in human-modified environments (Whitaker, 1997; Choudhury & Bhupathy, 1993).

Seasonal hydrological fluctuations, particularly monsoon-driven floods, influence movement and distribution, with adults migrating to exposed sandy banks for nesting during the dry season. Habitat selection is closely tied to water depth, substrate type, availability of prey, and shelter opportunities, reflecting the species' ecological role as a benthic predator and scavenger in freshwater ecosystems (Moll & Moll, 2004). Conservation of both natural riverine systems and culturally protected stagnant water bodies is therefore critical for the persistence of *N. gangetica.*

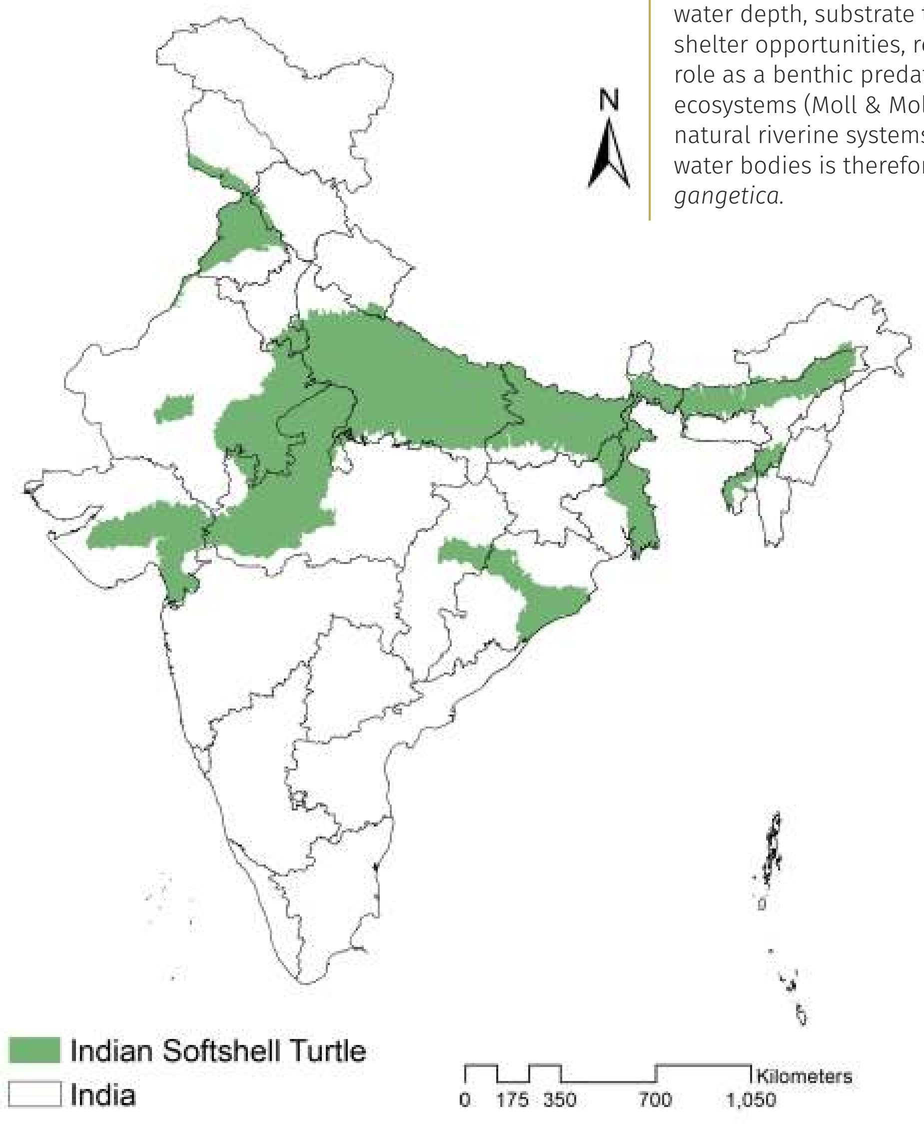


Fig-
Map of distribution of *Nilssonia gangetica* (Source- IUCN Red List)

NATURAL HISTORY

Nilssonia gangetica exhibits pronounced defensive behaviour when disturbed. Individuals are known to be aggressive, readily biting potential threats, and have been observed producing low cackling or grunting vocalisations when cornered, which may serve as an anti-predator response (Boulenger, 1890). This species shows clear thermoregulatory behaviours, often basking on sandy or muddy riverbanks during cooler winter months to elevate body temperature, while retreating into water or burrowing into substrate during hot or dry periods to prevent desiccation and maintain hydration (Das, 1995). Burrowing into sand or soft mud also allows the turtles to hide from predators and survive seasonal droughts, reflecting their adaptability to fluctuating riverine environments.

Reproduction is dependent on the season, and courtship typically commences with the onset of the monsoon, when rising water levels and increased prey availability provide favourable conditions for mating (Whitaker, 1997). Nesting occurs primarily between October and November, coinciding with receding water levels that expose sandy banks suitable for oviposition. Clutch sizes are variable, ranging from 8 to 32 eggs, with each egg measuring approximately 23-32 mm in diameter. The eggs are hard-shelled, spherical, and white, adaptations that provide protection against desiccation and predation in nest sites (Das, 1995; Whitaker, 1997).

These behavioural and reproductive traits, including basking, burrowing, and seasonal breeding, demonstrate the species' close ecological link to riverine habitats. Their survival is strongly dependent on the availability of sandy banks for nesting and soft substrates for burrowing, emphasising the importance of conserving natural riverine systems and seasonal wetlands to sustain viable populations.

DIET

Nilssonia gangetica, a large softshell turtle inhabiting South Asian rivers, exhibits opportunistic and omnivorous feeding behaviour, with diet composition varying across age classes, seasons, and habitat conditions. Adults are primarily carnivorous, consuming a wide variety of prey, including fish, amphibians, crustaceans, molluscs, aquatic insects, and occasionally carrion. By preying on a range of organisms and scavenging, adults play a critical role in regulating prey populations and recycling nutrients within freshwater ecosystems (Das, 1995; Whitaker, 1997). Adult turtles typically employ ambush predation, partially burying themselves in sand or mud and striking rapidly with their long, flexible necks. Morphological adaptations, such as fleshy pads along the mandibles and sharp alveolar ridges, facilitate the capture and processing of slippery or hard-bodied prey (Boulenger, 1890).

Juveniles are more opportunistic, feeding on smaller invertebrates, aquatic insects, plant matter, and,

Fig- Burrowing into mud

occasionally, conspecific eggs or hatchlings, indicating instances of cannibalism under resource-limited conditions (Whitaker, 1997). Juveniles often forage in shallow water or near river margins, where prey is more accessible, and their smaller size limits consumption of larger prey items. Like adults, juveniles utilize ambush strategies but supplement this with active foraging among benthic substrates and aquatic vegetation (Das, 1995).

During the monsoon, increased water flow and turbidity disperse prey, prompting a combination of active and ambush foraging. In the dry season, turtles concentrate in residual pools and channels, intensifying predation and scavenging activity. The dietary flexibility of *N. gangetica*, including occasional cannibalism, enables it to survive in diverse habitats such as rivers with altered flow regimes, oxbow lakes, temple ponds, and anthropogenically impacted water bodies (Moll & Moll, 2004).

Overall, *Nilssonia gangetica* demonstrates a combination of behavioural strategies and morphological adaptations that enable efficient exploitation of available food resources across ontogenetic stages. Its predatory and scavenging behaviour, combined with opportunistic cannibalism in juveniles, underscores its ecological importance in South Asian freshwater ecosystems.

Fig- Nilssonia gangetica yearling having fish.

THREAT

Nilssonia gangetica is the fourth most frequently seized turtle species listed under CITES, reflecting its high level of exploitation. The species is extensively hunted for its meat and is also targeted for the calipee, the outer rim of the carapace, which is considered a delicacy in several countries. Large volumes of this species are illegally traded to East Asian markets, primarily for use in traditional Chinese medicine. Between 2000 and 2015, approximately 16,400 individuals were confiscated from illegal trade networks, highlighting the scale of exploitation (CITES, 2016).

In addition to targeted harvesting, the large body size of *N. gangetica* makes it highly susceptible to accidental mortality, as individuals frequently become entangled in fishing nets and often die as a result. Egg collection is another major threat across its range, with local communities harvesting clutches for human consumption, thereby reducing recruitment and further exacerbating population declines (TRAFFIC, 2019).

These combined pressures-illegal trade, bycatch mortality, and egg harvesting-pose serious risks to the long-term persistence of the species, emphasising the urgent need for effective conservation interventions, including stricter enforcement of wildlife protection laws, regulation of trade, and community-based nest protection programs.

Fig- Illegal trade of Nilssonia gangetica

CONSERVATION INITIATIVE

As part of the Ganga Action Plan (GAP), *Nilssonia gangetica* was included in a large-scale conservation and river-restoration initiative aimed at improving ecological conditions in the Ganga basin. Under this program, eggs were collected from the wild, artificially incubated, and hatchlings were reared at the Kachua Punarvas Kendra (Turtle Rehabilitation Centre) in Sarnath, Uttar Pradesh (WII, 1997; Uttar Pradesh Forest Department, 2005). Over the course of the initiative, more than 40,000 softshell and hardshell turtles, including *N. gangetica*, were released into the Sarnath Turtle Sanctuary, a protected stretch of the river designated to support riverine biodiversity and enhance biological scavenging functions (WII, 1997; Sarkar et al., 2012). The releases were intended to strengthen depleted turtle populations and to facilitate natural organic waste removal, capitalising on the scavenging habits of softshell turtles.

Despite its initial scale, the program faced administrative and logistical constraints, and the turtle-release operations were halted after 2007, with limited subsequent monitoring or evaluation of released populations (Uttar Pradesh Forest Department, 2005; Sarkar et al., 2012). Long-term data on survival, dispersal, and ecological impact remain scarce, underscoring the need for systematic post-release assessments to more accurately evaluate the conservation outcomes of the GAP turtle program.

Fig- Artificially incubated and hatchlings were reared at the Kachua Punarvas Kendra

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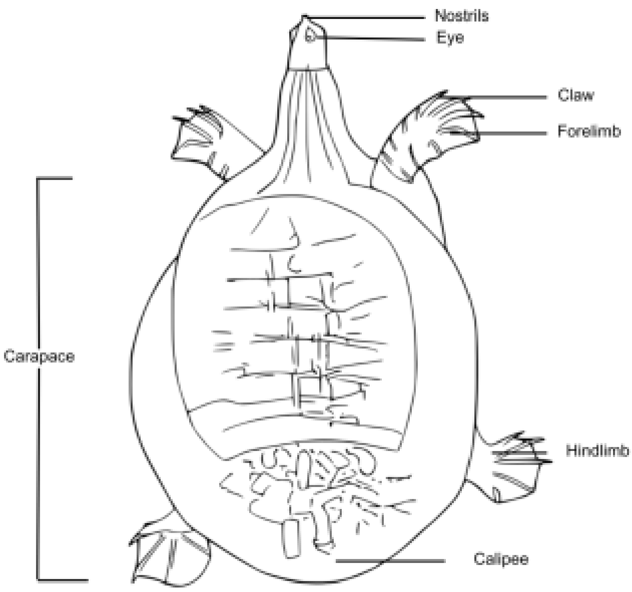
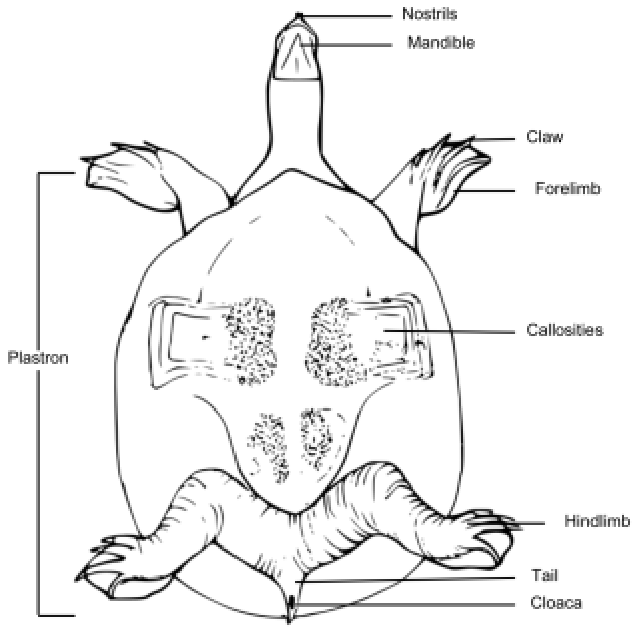
THE NARROW-HEADED SOFTSHELL TURTLE, *Chitra indica*

The Narrow-headed Softshell Turtle, *Chitra indica* (Grey, 1830), is a large freshwater chelonian endemic to South and Southeast Asia and is among the largest softshell turtles in India. Unlike most hard-shelled turtles, softshell turtles possess a flexible, leathery carapace instead of a rigid, ossified shell. This adaptation confers increased agility in aquatic habitats and allows them to burrow into sandy substrates for ambush predation (Das & Singh, 2009). *C. indica* is characterised by an elongated, flattened head, streamlined neck, and pointed snout, with dorsally positioned nostrils enabling efficient surface breathing while mostly submerged. These turtles are capable of cutaneous and pharyngeal respiration, which allows them to absorb oxygen directly through the skin and lining of the throat, facilitating extended submersion (Das & Singh, 2009).

Adult carapace lengths can reach up to 110 cm, with body masses approaching 250 kg (Das & Singh, 2009; Sachsse, 1971). *C. indica* is primarily carnivorous, preying on fish, frogs, crustaceans, and molluscs. These turtles exhibit aggressive defensive behaviours; when threatened, they rapidly extend their necks and strike, sometimes inflicting injury to humans and damaging small watercraft. Handling also induces the secretion of a characteristic musky odour (Das & Singh, 2009).





TAXONOMY

Kingdom: Animalia

Phylum: Chordata

Class: Reptilia

Order: Testudines

Family: Trionychidae

Genus: *Chitra*

Species: *indica*

COMMON NAMES

Assamese - Baghiakaso, Dhushkachim

Bengali - Chitra, Chhim, Dhushkachim, Gotajil

English - Indian Narrow-headed Softshell Turtle

English, Old (ca.450-1100)- Narrow-headed Softshell Turtle, Chitra Turtle, Short-headed Softshell Turtle, River Softshell Turtle, Asian Softshell Turtle

Hindi - Chitra, Seem, Seonthar, Sitra, Sewtree

Nepali - Chitra

Oriya - Balerakainchha, Chitra kainchha

NATURAL HISTORY

Appearance

The narrow-headed softshell turtle, *Chitra indica*, tends to be relatively large, with a carapace of up to 1.10 m. The carapace tends to be bluish-grey or olive with intricate wavy reticulations. This pattern is also present on the neck and forelimbs.

Figure 2. *Chitra indica* juvenile (Source- cherepahi.ru)

Numerous small epidermal bumps and vertebral keel are present on the carapace of the juvenile and absent in adults. The shell is oval, flattened and soft, with eight pairs of costals and four plastral callosities. Between the first pair of costals, a single neural is present. The head is long and narrow, with a short proboscis. The plastron is pink or cream in colour.

Males usually have a longer tail when compared to females; however, females tend to achieve a greater overall size. In an adult, carapace length reaches up to 110cm.Hatchlings have a carapace length of 39-40mm and a mass of 7-10 grams. Overall mass can be up to 250 kg (Das and Singh, 2009; Sachsse, 1971https:/ /animaldiversity.org/accounts/Chitra_indica/ - A95589C5-E54B-11E4-AE5E-002500F14F28).

INTERNAL ANATOMY

Trachea: the windpipe, which connects the larynx and bronchi of the tortoise

Lung: respiratory organ of the tortoise

Stomach: part of the digestive tract of the tortoise between the esophagus and the intestine

Rectum: the final part of the digestive tract

Cloaca: outlet of the digestive tract, disposes of waste and lays eggs

Bladder: pocket in which urine collects before it is evacuated

Intestine: part of the digestive tract of the tortoise after the stomach

Liver: bile-producing digestive gland

Heart: blood-pumping organ of the tortoise

Esophagus: part of the digestive tract of a tortoise between the mouth and the stomach

DISTRIBUTION

The narrow-headed softshell turtle, *Chitra indica*, is widely distributed throughout south Asia. In the Indian subcontinent, it can be found within the river systems of the Indus, Ganga, Godavari, Kaveri, Mahanadi and Padma rivers. Distribution is extensive in peninsular India but can be irregular and restricted. This may result from its large body size and specialized habitat requirements (Das,1995; Das and Singh, 2009).

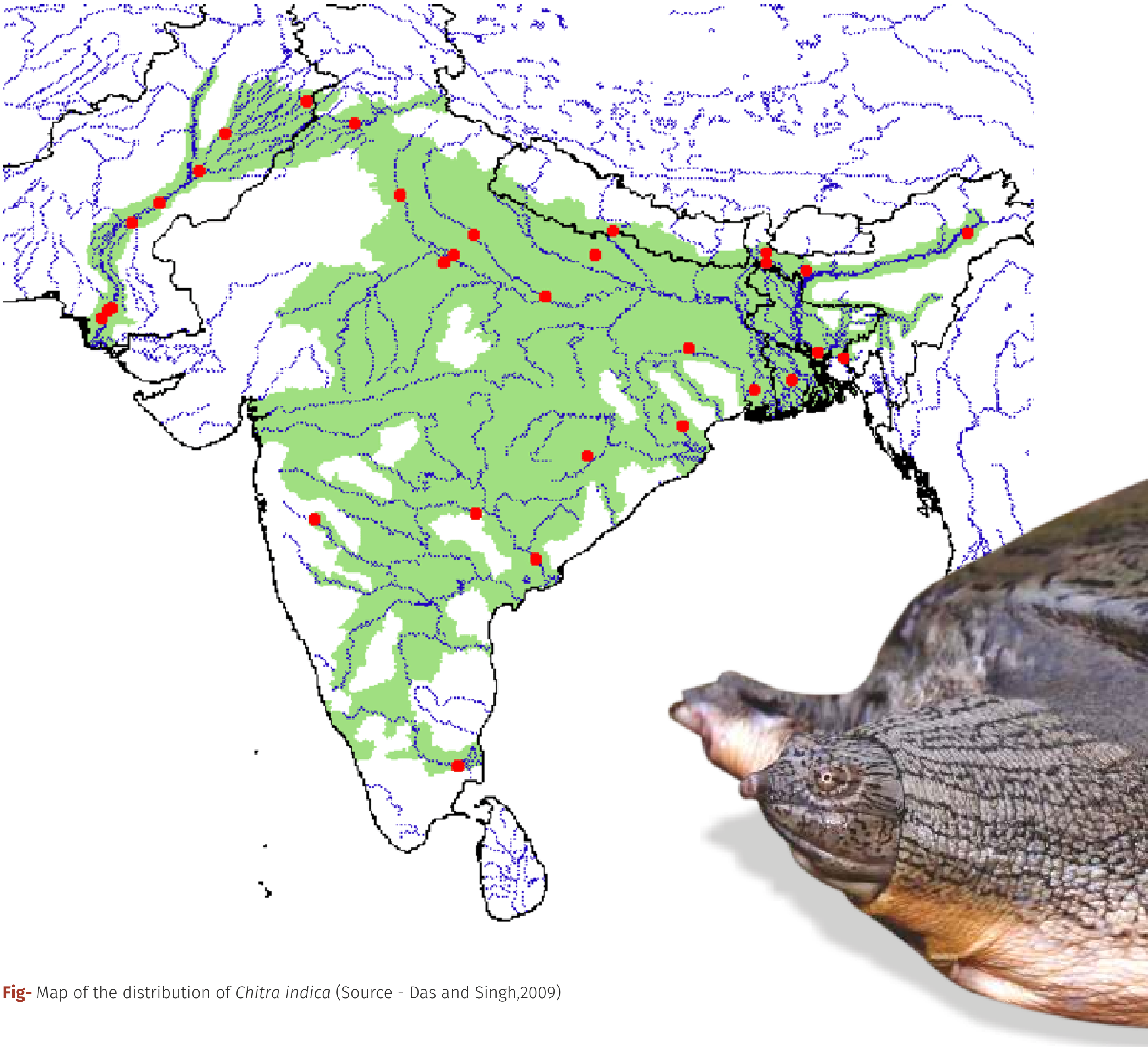


Fig- Map of the distribution of *Chitra indica* (Source - Das and Singh,2009)

HABITAT ECOLOGY

This species prefers moderate to large rivers with low turbidity and sandy bottom and spends most of the time submerged under the sandy bottom. They prefer flat-topped sandbanks with inclined shore-lines bordering fast-moving water at least 50cm deep for basking (Rocha & Molin A, 1990; Rao,1990)

Chitra indica nests at different times of the year, depending on the area. In the Ganga River system, nesting occurs during peak monsoons, usually from late August to mid-September. During the egg-laying period, the females emerge on sandy or sandy loam substrate, and eggs are tightly compacted in the sub-soil after laying. Nests are flask-shaped with an egg chamber typically 15 X 23 cm. The nests are located at a distance of 8 - 135 m from the water edge (Bhadauria et al. 1990).

Chitra indica is an ambush predator, which burrows itself in the substrate with only the eye and tip of the snout exposed outside to catch passing prey. This species is a specialised fish eater but may also ingest macroinvertebrates. Based on some studies of the digestive tract of the species; it appears that it primarily feeds on fish, frogs, crabs, shrimp and molluscs (Rashid and Swingland, 1997; Das and Singh,2009).

DIET IN CAPTIVITY

Feeding of hatchling- fish *Chela cachius* and *Punctius sophore*, earthworm (*Pheretima posthuma*) and pila (*Pila globosa*) preferred fish fingerlings. Feed was given after one week of hatching and only in the morning. (Singh and Singh, 2022https://animaldiversity.org/ accounts/ Chitra_indica/ - A95589C5-E54B-11E4-AE5E-002500F14F28)

REPRODUCTION

Sexual maturity in *Chitra indica* is determined by both body length and mass, with individuals typically reaching maturity at 44-55 cm in length and 12-16 kg in mass (Aryal et al., 2010; Ernst et al., 2015; Das & Singh, 2009). The species exhibits moderate fecundity, with clutch sizes ranging from 65 to 193 eggs per reproductive event. Eggs are spherical, brittle-shelled, unpigmented, and appear translucent white upon laying (Bhadauria et al., 1990).

Fig- *Chitra indica* (Source- Reddit)

Oviposition occurs on sandy or sandy-loam substrates along riverbanks. Following deposition, eggs are carefully covered with sand, providing protection and maintaining a suitable microenvironment for embryonic development. Incubation periods range from 40 to 70 days, influenced by ambient temperatures between 25.5°C and 36°C. The sand covering not only stabilises moisture levels but also buffers against temperature fluctuations, both of which are critical for successful embryogenesis.

Fig- Nest of *Chitra indica* on the sandy river bank (Source- Khadka et al. 2022)

THREATS AND CONSERVATION

The narrow-headed softshell turtle is hunted mainly for their calipee. The outer leathery part of this species shell, eggs, and flesh is consumed by the local community of the Ganga river. Poachers prefer large adults of this species less due to their high-fat content, resulting in lower calipee quality. Juveniles are hunted more for their calipee (Das and Singh, 2009).

Extensive development in the river area, construction of dams, deforestation, aquatic pollution, and overfishing in the range of this species are affecting their survival of the species (Choudhary and Bhupathy 1993)

Chitra indica is listed as endangered on IUCN Red List, Schedule II (Asian Turtle Trade Working Group, 2000) in Indian Wildlife Protection Act 1972 and Appendix II in CITES (Das and Singh, 2009).

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MATERIALS AND METHODS

INTRODUCTION

Freshwater turtles are among the most threatened vertebrate groups in riverine ecosystems, yet effective conservation planning for many species remains constrained by critical information gaps. In the present context, there is a pronounced lack of reliable data on the current distribution and population status of four priority turtle species, *Batagur kachuga, Batagur dhongoka, Nilssonia gangetica*, and *Chitra indica*. These deficiencies significantly impede the formulation of scientifically robust and spatially explicit conservation strategies.

During the tenure of the project, comprehensive field-based data on the present distribution and population trends of these species could not be generated. This limitation arose primarily due to difficulties in accurate field identification, the cryptic and wary behaviour of the species, and logistical and environmental constraints inherent to large river systems. Despite these challenges, expert assessments and available evidence consistently suggest a decline in both the extent of area under occupancy and overall population size of these taxa, underscoring the urgency for targeted conservation interventions.

In view of these constraints, the present study adopts a modelling-based approach to conservation planning. Secondary data, along with information generated during Phase I and Phase II of the project, were integrated to develop predictive distribution models and identify potential priority areas for conservation. Within this framework, *Batagur kachuga* and *Batagur dhongoka* were selected as umbrella species representing the Geoemydidae turtles. At the same time, *Nilssonia gangetica* and *Chitra indica* were used as umbrella species for the Trionychidae turtles. This umbrella-species approach allows for broader ecosystem-level conservation benefits while addressing the needs of multiple co-occurring taxa.

The following sections detail a stepwise and systematic methodology adopted for conservation prioritization, aimed at overcoming data limitations and facilitating informed decision-making for the long-term conservation of these imperilled freshwater turtle species.

STUDY AREA

The study was conducted within the Ganga River Basin, one of the largest and most ecologically diverse river systems in the world. The study was carried out in the tributaries and sub-tributaries of the Ganga River. We carried out boat-based visual encounter surveys in ten rivers, covering a total linear stretch of 2280 km, viz 22 tributaries including the mainstem Ganaga. The surveys were carried out during the post-monsoon seasons (November -February) of 2020 and 2024 using an inflatable rubber boat fitted with 25hp Yamaha engine.

The Ganga River, India's national river, originates from the Gangotri Glacier in Uttarakhand and flows approximately 2,525 km before draining into the Bay of Bengal. The basin covers an area of about 1,117,000 km², extending across India, Tibet (China), Nepal, and Bangladesh. Of this, 861,390 km² lies in India, accounting for nearly 26% of the country's total geographical area. Collectively, these regions support more than 40% of India's population, which depends on the river for water, agriculture, and livelihoods (Kumar et al., 2023; Rai, 2013; Salman & Uprety, 2021; Singh, 2018; WII-NMCG, 2019).

SPECIES OCCURRENCE DATA AND ENVIRONMENTAL VARIABLES

Occurrence data for freshwater turtles across India were compiled from multiple sources, including the Global Biodiversity Information Facility (GBIF), peer-reviewed literature, and project reports. A total of 2,670 verified georeferenced records representing 16 turtle species known to occur within the Ganga River Basin were used for habitat suitability modelling. A total of 30 environmental variables were selected for model development. These included 19 bioclimatic, topographic, land cover, vegetation, hydrological, anthropogenic, and future climate variables. Bioclimatic data (BIO1 to BIO19) were obtained from WorldClim Version 2, representing the 1970-2000 baseline period, at 30-arc second (~1 km²) resolution. Elevation data were extracted from the Shuttle Radar Topography Mission (SRTM) dataset available in WorldClim Version 2.1. Future climate projections (2021-2100) were sourced from the HadGEM3-GC31-LL Global Climate Model (GCM) under the Coupled Model Intercomparison Project Phase 6 (CMIP6). Three Shared Socioeconomic Pathways (SSPs) SSP126 (low emissions), SSP245 (moderate emissions), and SSP585 (high emissions) were considered to represent a range of potential future scenarios.

Land Use Land Cover (LULC) data at a resolution of 300 m for the year 2020 were obtained from the European Space Agency Climate Change Initiative (ESA CCI). Vegetation and water indices, namely the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), were derived from MODIS satellite imagery. Road network data were obtained from OpenStreetMap and used to calculate Euclidean distances to the nearest road, serving as a proxy for linear infrastructure influence. Euclidean distance layers to rivers were generated from HydroSHEDS, while protected area boundaries were derived from the World Database on Protected Areas (WDPA). The Human Influence Index (HII) was sourced from the Global Human Settlement Layer - Settlement Model Grid (GHS-SMOD), which classifies regions based on human settlement intensity and typology. All variables were resampled to a uniform spatial resolution of 1 km and clipped to the Ganga River Basin extent in ArcGIS and QGIS for analysis.

HABITAT SUITABILITY MODELLING

Habitat suitability was modelled using the Maximum Entropy (MaxEnt) algorithm, a machine learning approach designed for presence-only species distribution dataError! Hyperlink reference not valid. MaxEnt estimates the probability distribution of species occurrence across a landscape based on the principle of maximum entropy, constrained by environmental predictorsError! Hyperlink reference not valid.. This approach is especially suitable for species with limited absence data, such as freshwater turtlesError! Hyperlink reference not valid..

All occurrence records were spatially filtered at a 1 km resolution using SDMtoolbox in ArcGIS to minimize spatial autocorrelation and sampling biasError! Hyperlink reference not valid.. The 30 predictor variables were standardized and resampled to 1 km² resolution, ensuring compatibility across all datasets. Model runs were performed in MaxEnt version 3.4.4 using default feature settings with multiple replicates. Cross-validation was used to partition the data into training and testing subsets for model evaluationError! Hyperlink reference not valid.. The area under the curve (AUC) of the receiver operating characteristic (ROC) was used as the primary metric for assessing model performance. Jackknife tests within MaxEnt were used to determine the relative contribution and importance of each variable to the final modelError! Hyperlink reference not valid..

For future habitat projections, the same modelling framework was applied using bioclimatic layers corresponding to the three Shared Socioeconomic Pathways (SSP126, SSP245, and SSP585) to predict changes in potential turtle habitat distribution under different climate change scenarios up to 2100Error! Hyperlink reference not valid.. The continuous suitability outputs generated by Maxent were classified into three habitat suitability categories: high, moderate, and low, using equal interval classification in GISError! Hyperlink reference not valid.. These maps were then used to visualize spatial patterns of current and future potential habitats for freshwater turtles across the Ganga Basin. The final outputs provided a comprehensive assessment of present-day and projected turtle habitat suitability, identifying areas of high conservation priority, climate-resilient refugia, and regions vulnerable to habitat loss due to anthropogenic and climatic pressures. The results form a spatial basis for developing management strategies aimed at the long-term conservation of freshwater turtles in the Ganga River Basin.

Table 1: Environmental variables and their abbreviations used for habitat suitable modelling of turtles

Variables	Details
1	bio1 (Annual mean temperature)
2	bio2 (Mean diurnal temperature range [mean of Monthly (max temp-min temp)])
3	bio3 (Isothermality (P2/P7) (×100))
4	bio4 (Temperature seasonality (standard deviation×100))
5	bio5 (Max temperature of warmest month)
6	bio6 (Min temperature of coldest month)
7	bio7 (Temperature annual range (P5-P6))
8	bio8 (Mean temperature of wettest quarter)
9	bio9 (Mean temperature of driest quarter)
10	bio10 (Mean temperature of warmest quarter)
11	bio11 (Mean temperature of coldest quarter)
12	bio12 (Annual precipitation)
13	bio13 (Precipitation of wettest month)
14	bio14 (Precipitation of driest month)
15	bio15 (Precipitation seasonality (coefficient of variation))
16	bio16 (Precipitation of wettest quarter)
17	bio17 (Mean temperature of wettest quarter)
18	bio18 (Mean temperature of driest quarter)
19	bio19 (Precipitation of coldest quarter)
20	EUC_RIVER_1 (Euclidean distance to river)
21	EUC_PA_1 (Euclidean distance to protected areas)

Variables	Details
22	EUC_ROAD_1 (Euclidean distance to roads)
23	NDVI_1 (Normalized Difference Vegetation Index)
24	NDWI_1 (Normalized Difference Water Index)
25	elev (Elevation)
26	HII_1 (Human Influence Index)
27	LULC (Land Use Land Cover)
28	FBIO126 (Future climatic variable SSP 126)
29	FBIO245 (Future climatic variable SSP 245)
30	FBIO585 (Future climatic variable SSP 585)

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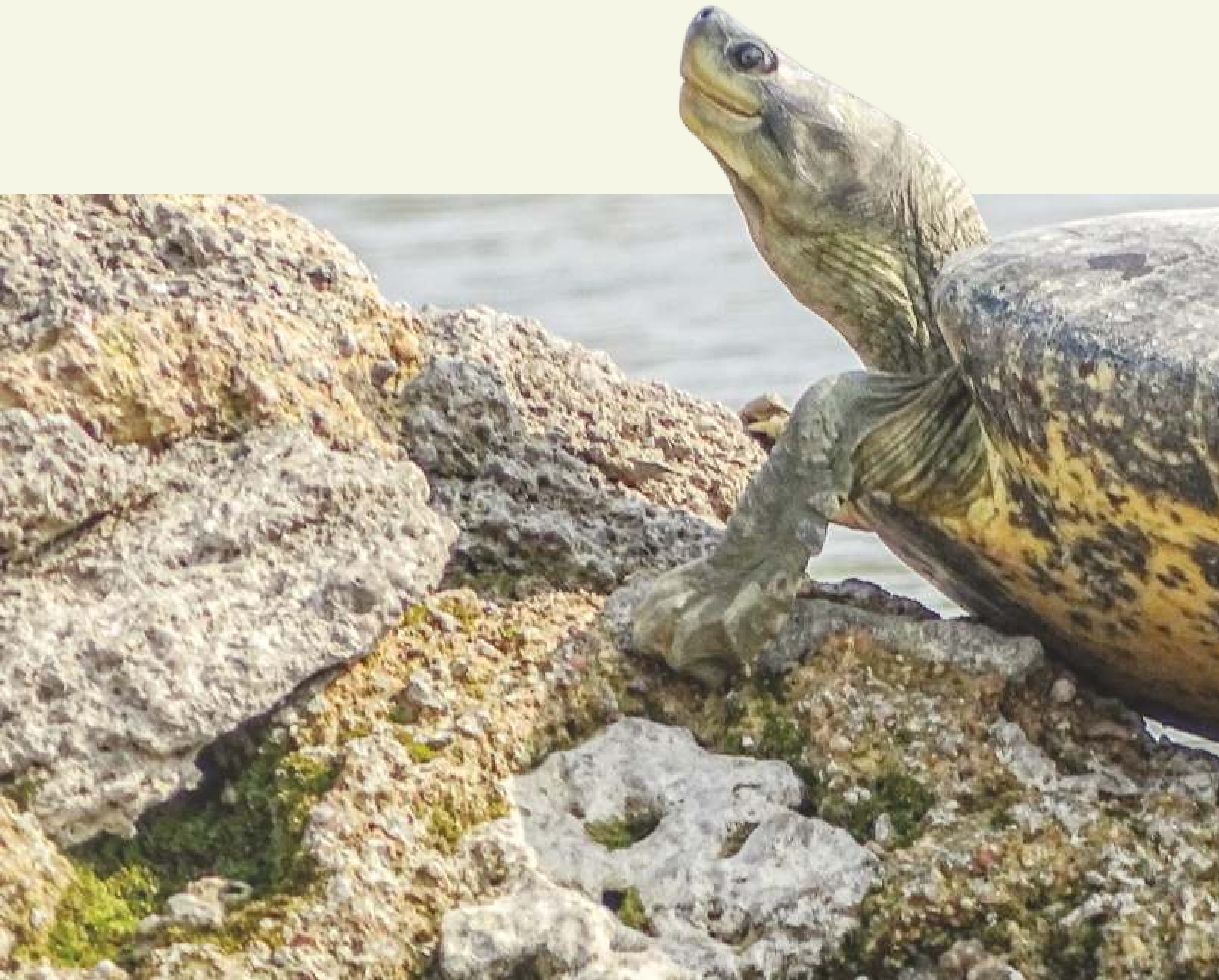

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RESULT AND DISCUSSION

Batagur dhongoka

A species-wise spatial and environmental analysis was performed in MaxEnt software for the 4 turtle species found in the Ganga River basin, including *Batagur kachuga, Batagur dhongoka, Nilssonia gangetica* and *Chitra indica* The occurrence points of all the species and the collected data on environmental variables were used to predict the areas with the most suitable habitat for each of the species, with an aim to better understand their distribution, ecology, and conservation requirements.

The selected 30 bioclimatic variables, including climatic factors, future climatic factors, elevation, land use, human activity, and proximity to protected areas, rivers and roads, were incorporated by the model in making habitat suitability maps. The results provide an understanding of what factors drive each species to select a habitat as suitable based on the current distribution of the species and represent it in the form of a spatial pattern that highlights the areas with the most to least suitability. These results will guide in planning conservation strategies by showing sites critical for each of the species. Additionally, it will also help in mitigating threats such as habitat fragmentation, pollution, and anthropogenic disturbances in the predicted distribution of the species.

The MaxEnt model for *Batagur dhongoka* has produced a regularized training gain of 1.036, which shows that the model is a fit to the training data. As the magnitude is greater than 1, it can be said that the environmental factors that influence the habitat suitability of the turtle species were identified. With an AUC of 0.899, the model is reliable and

Model Performance Analysis

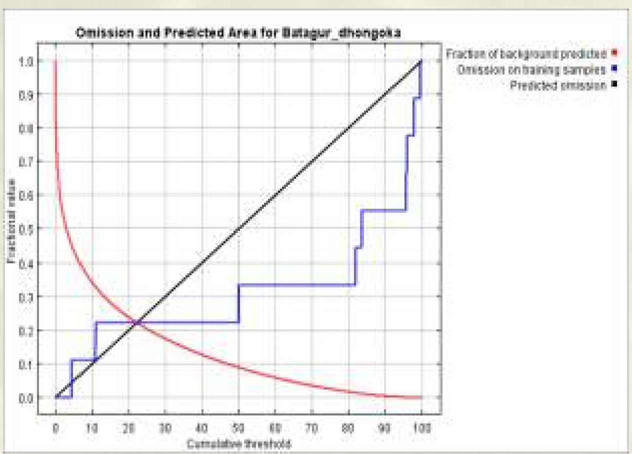


Figure 8: Average omission and predicted area for *Batagur dhongoka* in the Ganga basin

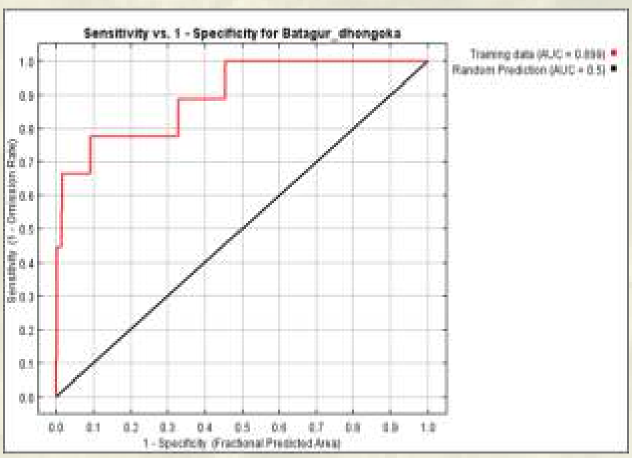


Figure 9: ROC curves for models of *Batagur dhongoka* in the Ganga basin

shows its ability to separate presence and background points (Fig. 9). The value for unregularized training gain is 1.834, which is greater than the regularized training gain, representing the fact that the model is complex with regularizations to avoid overfitting. The algorithm used in the model converged after 240 iterations, with the completion of the run in 0 seconds. The results indicate that the selected environmental factors, which were used in the model, are good predictors of habitat suitability of the species.

Table 2. Contribution of environmental variables in the model building for *Batagur dhongoka*

Variable	Percent contribution	Permutation importance
bio4	31.8	63.9
bio7	30.7	0
bio8	12.7	0
NDVI_1	8.7	15.4
bio3	4.9	0.9
bio10	4	6.1
bio1	3.2	0

Key Environmental Variables

The model identified 7 of the selected factors as major contributors to the distribution of *Batagur dhongoka* (Table 2). The factor that influences the suitability of habitat of the species the most is temperature seasonality (bio4), which makes a contribution of 31.8% to the model, suggesting that areas that have a specific pattern of seasonal temperature are critical for the species. Another great contributor is the temperature annual range (bio7), which accounts for 30.7% of the output. This implies that the species is highly sensitive to changes or variations in the temperature. The mean temperature of wettest quarter (bio8) plays a role of 12.7% in the predictions, which suggests the preference for specific temperatures in monsoons. Normalized Difference Vegetation Index (NDVI_1) has an impact of 8.7%, which indicates the importance of vegetated areas, likely related to foraging and thermal regulations. Other factors, such as isothermality (bio3), mean temperature of the warmest quarter (bio10), and annual mean temperature (bio1), have a minor impact on the predictability of the model with contributions of 4.9%, 4%, and 3.2%, respectively. This further emphasized the importance of temperature in the distribution of *Batagur dhongoka*.

The relative influence of each of the factors is evident in their permutation importance values. The temperature seasonality (bio4), which has the highest percent contribution, also has the greatest permutation importance of 63.9%, which highlights the factor's ability to predict suitable habitats and the fact that its removal from the model will reduce the performance of the model the most. However, some of the factors, such as temperature annual range (bio7) and mean temperature of wettest quarter (bio8) that had high percent contributions have zero permutation importance. This shows that these factors contributed during the training of the model, but their ability to predict the habitat of the species is low, which might be caused by overlapping with other factors that are better predictors (e.g., bio4). On the other hand, the Normalized Difference Vegetative Index (NDVI_1), which made moderate contributions to the model, has a permutation importance of 15.4%. Other variables, such as isothermality (bio3), mean temperature of the warmest quarter (bio10), and annual mean temperature (bio1) have low permutation importance of 0.9%, 6.1%, and 0%, indicating their limited role in the prediction of habitat suitability.

Jackknife test of variable importance

From the result of the jackknife test of regularized training gain, it is evident that the mean temperature of wettest quarter (bio8) accounts for the highest gain in isolation, showcasing its predictive information. This is followed by the high individual gains of temperature seasonality (bio4), which is closely followed by temperature annual range (bio7), which confirms their importance in habitat prediction. Another factor that provides a high gain is the mean temperature of warmest quarter (bio10). Additionally, the maximum temperature of warmest month (bio5), annual precipitation (bio12), and mean diurnal temperature range (bio2) are weak predictors, while the other remaining factors have negligible gain towards the prediction of suitability (Fig. 10).

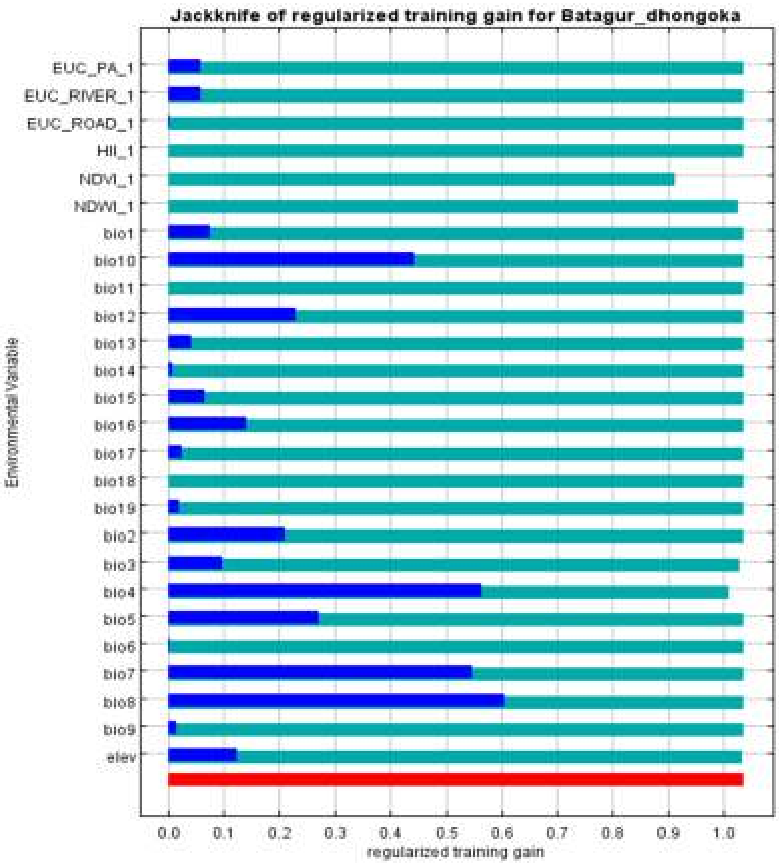


Figure 10: Jackknife test of variable importance for *Batagur dhongoka*

Response curves and variable relationships

Through the marginal response curves, it can be understood that Annual mean temperature (bio1), mean temperature of warmest quarter (bio10), temperature seasonality (bio4), and elevation (elev) play a major role in the habitat suitability when all the other factors are held constant (Fig. 11). The suitability of a habitat for *Batagur dhongoka* increases with an increase in the annual mean temperature (bio1), mean temperature of warmest quarter (bio10), temperature seasonality (bio4), and a decrease in elevation (elev). In terms of variables that are influenced by humans, the suitability increases with a decrease in Euclidean distance to protected areas (EUC_PA_1), Euclidean distance to rivers (EUC_RIVER_1), while there is a slight preference away from areas with roads (EUC_ROAD_1) and Human Influence Index (HII_1). There is also a moderate preference to habitats with vegetation (NDVI_1) which decreases as the density of vegetation increases more, and a preference to the presence of water bodies (NDWI_1). Additionally, there is a negative trend to an increase in isothermality (bio3). Other bioclimatic variables have negligible impact on the selection of habitats.

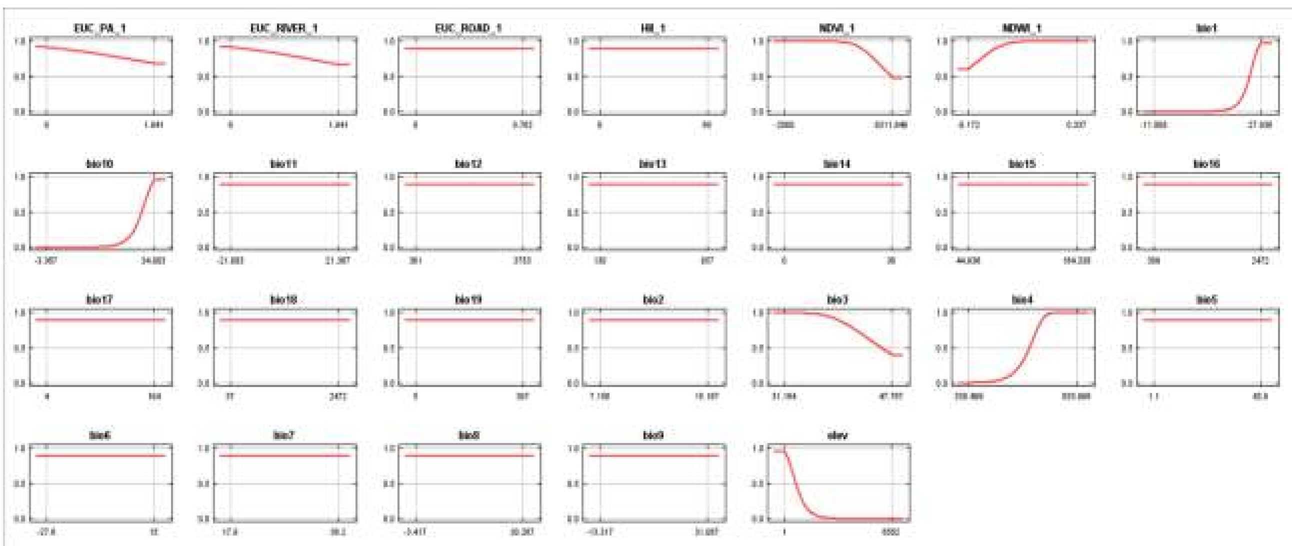


Figure 11: Marginal response curves showing the effect of the removal of individual environmental factors on *Batagur dhongoka* habitat suitability

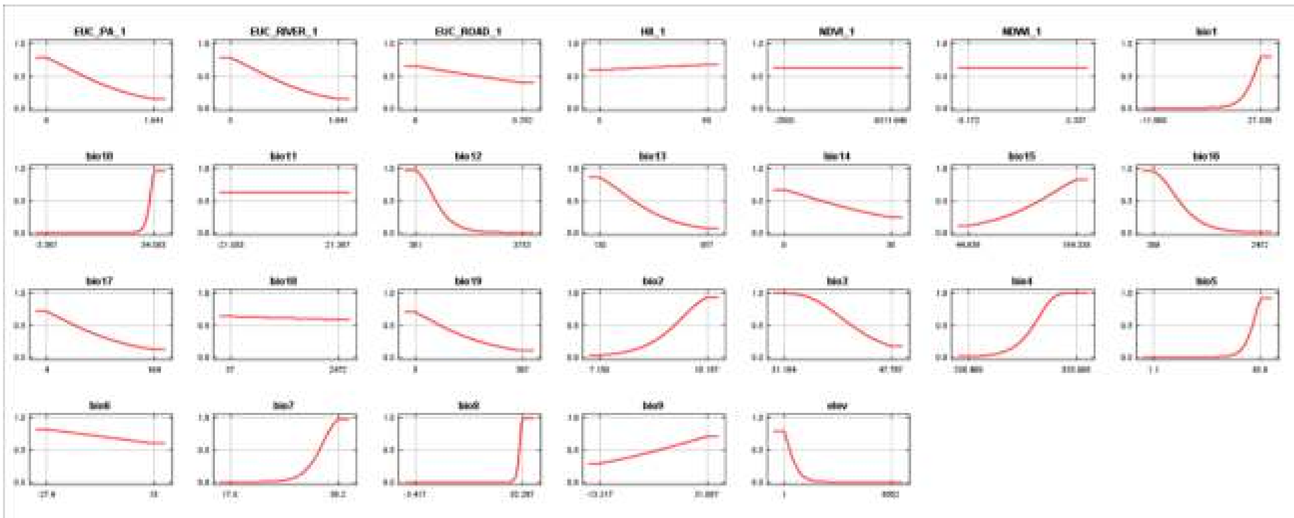


Figure 12: Single-variable response curves showing the effects of individual variables on *Batagur dhongoka* habitat suitability

When used in the model individually, the suitability of an area as a habitat increases with a decrease in Euclidean distance to protected areas (EUC_PA_1), to rivers (EUC_RIVER_1), and surprisingly, with a decrease in Euclidean distance to roads (EUC_ROAD_1) and increase in Human Influence Index (HII_1) (Fig. 12). Amongst the bioclimatic variables, there is an increase in the suitability with an increase in annual mean temperature (bio1), mean temperature of warmest quarter (bio10), precipitation seasonality (bio15), mean diurnal temperature range (bio2), temperature seasonality (bio4), max temperature of warmest month (bio5), temperature annual range (bio7), mean temperature of wettest quarter (bio8), and mean temperature of driest quarter (bio9), which shows that the species is sensitive to cold temperatures. Moreover, increase in factors such as annual precipitation (bio12), precipitation of wettest month (bio13), precipitation of driest month (bio14), precipitation of wettest quarter (bio16), precipitation of driest quarter (bio17), precipitation of coldest quarter (bio19), isothermality (bio3), min temperature of coldest month (bio6) and elevation (elev) leads to a decrease in suitability, which indicates that the species prefers warmer temperatures and less precipitation, likely due to flooding related to rain.

Threshold Selection and Omission Rates

The threshold analysis for the species explains how changing the threshold values of the model affects the predicted suitable habitat area and the chance of missing real areas where the species is distributed. At the "Minimum Training Presence" threshold, the omission rate was 0%, and the predicted area was 45.6% of the total area, which indicates that all the presence locations were taken without omissions, representing a broad habitat range. On the other hand, for the "Maximum Training Sensitivity Plus Specificity" threshold, the omission rate was 22.2%, and the predicted area was only 9%, which shows model specificity but by omitting a large portion of potential habitats.

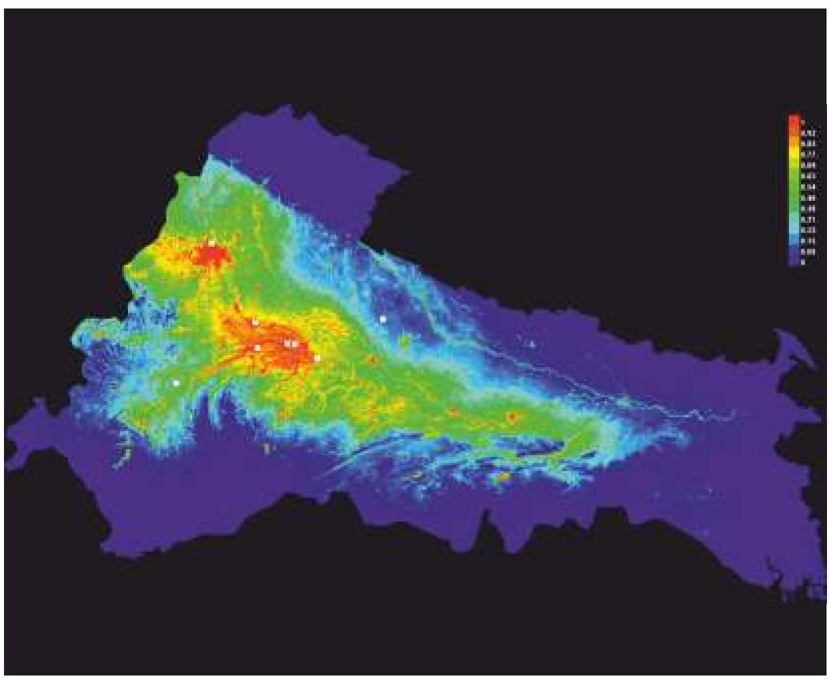


Figure 13: Species distribution map of *Batagur dhongoka* in the Ganga basin

Model Explanation and Conservation Implications

The habitat suitability model of *Batagur dhongoka* achieved an AUC of 0.899, a regularized training gain of 1.036, and an unregularized training gain of 1.834. These values indicate the high accuracy and efficiency with which the model identified the distribution pattern of the species and the factors that determine them.

The factors temperature seasonality (bio4), temperature annual range (bio7), mean temperature of wettest quarter (bio8), Normalized Difference Vegetation Index (NDVI_1), isothermality (bio3), mean temperature of the warmest quarter (bio10), and annual mean temperature (bio1) play significant roles in defining the species' distribution. Through the analysis of the marginal response curves of each of these factors, it was known that the species is distributed in areas that have high seasonal temperature variations with a preference for warm weather, which could be because seasonal changes in temperature influence nesting as described by Sirsi et al. (2017), and other biological processes.

The species also prefers areas with low to moderate vegetation density, as even though they require vegetation for thermal regulation and foraging, excess vegetation can restrict movement and access to water bodies. Despite being considered important, bio7 and bio8 showed limited effect on the predictions of the habitat suitability, indicating their weak overall impact when compared to other factors or the species can tolerate a wide range of such factors.

The generated habitat suitability map (Fig. 14) highlights the key regions that provide optimal conditions for the distribution of *Batagur dhogoka*. The suitability was maximum in the middle stretches of the river Yamuna and the middle and lower parts of Chambal and Sind. From the middle to the lower Betwa and Ken rivers and lower Yamuna, the map shows a mosaic of high to medium suitability. In the Son, the area near the Bansagar Dam shows high suitability, while the rest of the river shows medium suitability. The upper stretches of Yamuna have medium suitability, with some nearby water bodies showcasing high levels of suitability. The whole of Gomti, Ghagra, and Kauriyala, and some parts of Girwa and Rapti rivers show low to medium suitability. There are moderate

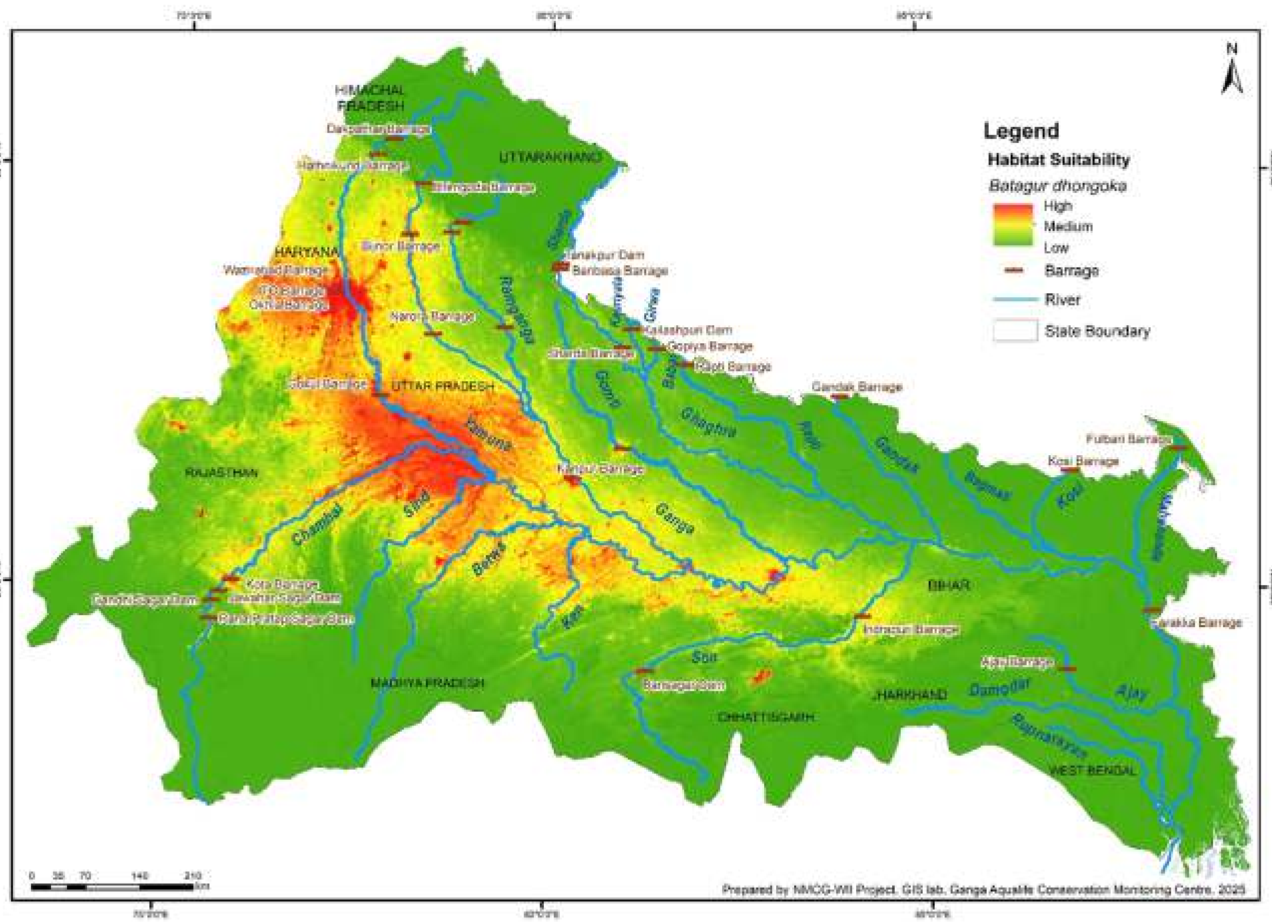


Figure 14: Habitat suitability map of *Batagur dhongoka* in the Ganga basin

levels of suitability in the area where the Gandak River meets the mainstream Ganga. Other tributaries and areas in their proximity do not show suitability which can be accounted to the presence of less favourable conditions or human activities.

The key threats to the species are habitat degradation and fragmentation caused by an altered sandbank topography and siltation of rivers due to dam construction, sand mining and deforestation, overexploitation of adults and eggs for food and commerce, and pollution. Due to the combined effect of these threats on the population of the species, it is categorised as Critically Endangered under IUCN's Red List of threatened species.

Conservation strategies should prioritize areas with high suitability. These strategies should involve sustainable land use, preventing further habitat fragmentation and implementing habitat restoration programs, monitoring water flow from dams and controlling unseasonal flooding, and enforcing stricter laws on sand mining and industrial waste runoffs. It is also pertinent to add to the genetic pool of the wild population to enhance genetic diversity. This could be achieved through captive breeding programs and the reintroduction of captive-bred individuals into habitats that are restored or safe from threats.

For long-term conservation, local communities should be involved through awareness programs, sustainable livelihood alternatives should be promoted, and research and monitoring of critical habitats and present wild populations should be performed regularly to keep ecological databases updated, which could help in adaptive conservation of the species. Technological tools, including satellites and drones, can enhance surveillance in places that are hard to access, ensuring a more comprehensive approach to conservation.

Batagur kachuga

Model Performance Analysis

The MaxEnt model for *Batagur kachuga* shows high fit to the training data, which is represented in the regularized training gain of 4.125. With an AUC of 0.997 (Fig. 16), the model shows great capability to differentiate between presence and pseudo-absence points. The unregularized gain of 4.776, which is slightly higher than the regularized training gain, implies the fact that regularization made minimal changes in the complexity of the model. Moreover, the model saw a convergence within 500 iterations, taking 12 seconds to complete the run. This shows that the model has a high ability to predict the suitability of habitats for the species. However, the combined high AUC value and regularized training gain value might indicate overfitting of the model to the training data.

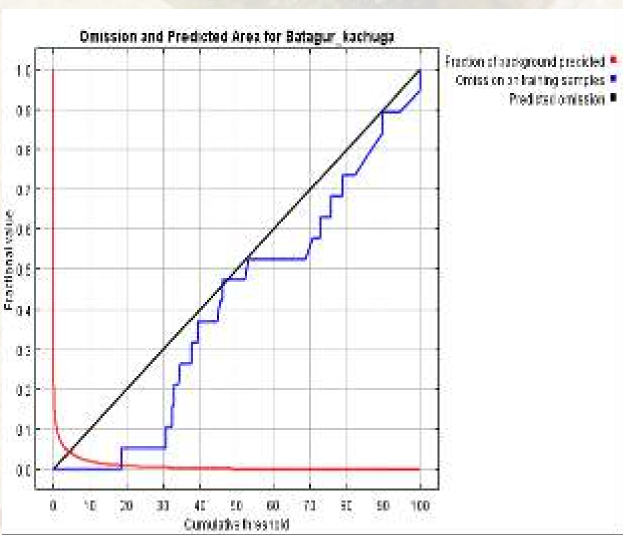


Figure 15: Average omission and predicted area for *Batagur kachuga* in the Ganga basin

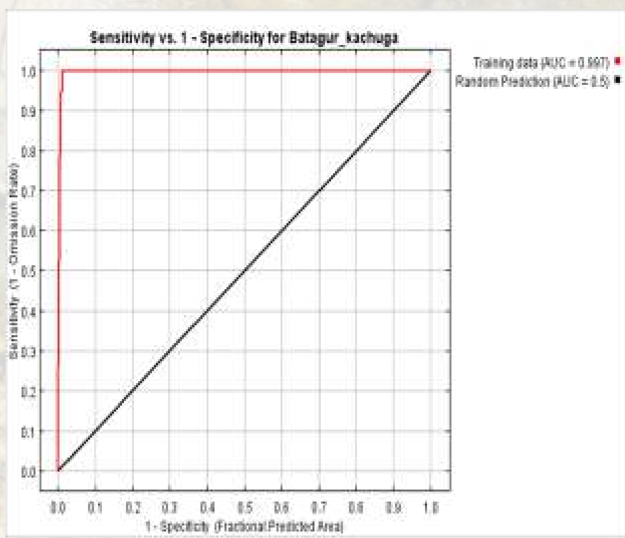


Figure 16: ROC curves for models of *Batagur kachuga* in the Ganga basin

Table 3. Contribution of environmental variables in the model building for *Batagur kachuga*

Variable	Percent contribution	Permutation importance
bio7	43.4	0.1
EUC_PA_1	19.5	1
bio8	8.2	6.3
bio10	7	59.6
elev	5.3	0
NDWI_1	5.2	13.5
bio13	2.9	9
bio17	2.9	2.7
NDVI_1	2	0

Key Environmental Variables

A total of 9 variables were identified by MaxEnt to affect the habitat suitability of *Batagur kachuga* the most (Table. 3). Out of all, the temperature annual range (bio7) had the highest impact with a contribution of 43.3% to the model, which implies that the species is temperature sensitive and prefers a stable temperature range. The Euclidean distance to protected areas (EUC_PA_1) also has a major influence, accounting for 19.5% of the output. This indicates that the species has a preference towards human-managed areas with undisturbed habitats. Mean temperature of wettest quarter (bio8) and mean temperature of warmest quarter (bio10) impact the model with a value of 8.2% and 7%, respectively, which further highlights the sensitivity of the species to variations in temperature. Additionally, elevation (elev) and Normalized Difference Water Index (NDWI_1) have almost similar impact on the suitability with values of 5.3% and 5.2%, respectively. Moderately contributing to the model are precipitation of wettest month (bio13), precipitation of driest quarter (bio17), and Normalized Difference Vegetation Index (NDVI_1) with respective contributions of 2.9%, 2.9%, and 2%, which represents the species' susceptibility to monsoon and presence of vegetated habitats.

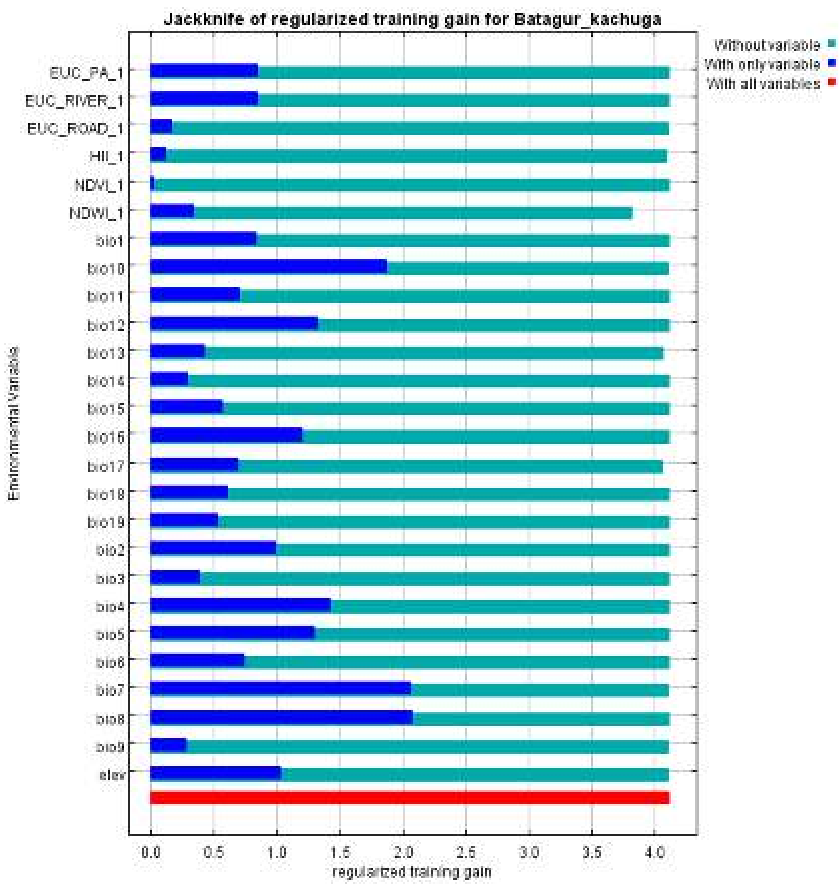


Figure 17: Jackknife test of variable importance for *Batagur kachuga*

Despite showing a lower contribution to the model, mean temperature of warmest quarter (bio10) has the highest permutation importance with a value of 59.6%, and the highest percent contributor, temperature annual range (bio7) has a negligible permutation importance of 0.1%. Euclidean distance to protected areas (EUC_PA_1), another major percent contributor has a permutation importance of only 1%. The factor with the second and third highest permutation importance of 13.5% and 9% are Normalized Difference

Water Index (NDWI_1) and precipitation of wettest month (bio13), respectively, showcasing their important role in the prediction in the model. Additionally, mean temperature of wettest quarter (bio8) and precipitation of driest quarter (bio17) have a low value of 6.3% and 2.7%, respectively, while elevation (elev) and Normalized Difference Vegetation Index (NDVI_1) have no permutation importance. The contrast between the percent contribution and the permutation importance can be due to shared information or co-linear variables.

Jackknife test of variable importance

The jackknife test showcases mean temperature of wettest quarter (bio8) as having the highest gain in isolation, followed closely by temperature annual range (bio7), which means that they have provided the most to the prediction of suitability. Mean temperature of warmest quarter (bio10) was the third highest contributor to the search of habitat. Additionally, factors such as temperature seasonality (bio4), annual precipitation (bio12), max temperature of warmest month (bio5), precipitation of wettest quarter (bio16), and elevation (elev) also have played a role in the model, while the other factors have minor role in the prediction of the suitable habitat (Fig. 17).

Response curves and variable relationships

As seen in the marginal response curves, an increase in Euclidean distance to protected areas (EUC_PA_1) shows a sharp decline in habitat suitability, while it decreases slightly with an increase in Euclidean distance to river (EUC_RIVER_1). In the case of Euclidean distance to roads (EUC_ROAD_1), the suitability is highest at a specific distance from the road, but surprisingly, the suitability decreases with an increase in distance from roads. *Batagur kachuga* shows a slight tolerance to the Human Influence Index (HII_1), which shows its distribution in moderately encroached areas. The species also shows a preference for moderately vegetated areas. The suitability is the highest at a specific level of water availability, with a sharp decline in the case of lack or too much of the presence of water bodies. The model shows an increase in the suitability with an increase in annual mean temperature (bio1), mean temperature of warmest quarter (bio10), precipitation of wettest month (bio13), precipitation of driest quarter (bio17), temperature seasonality (bio4), mean temperature of wettest quarter (bio8), and mean temperature of driest quarter (bio9). Additionally, an increase in annual precipitation (bio12) shows a decline in the suitability (Fig. 18). Other factors have a consistent suitability, which indicates that they do not have any significant influence on the distribution of the species.

The habitat suitability of the species shows a sharp decline as the Euclidean distance to protected areas (EUC_PA_1), to rivers (EUC_RIVER_1), and roads (EUC_ROAD_1) increases, but with the highest suitability at a specific distance from all. In the case of the Human Influence Index (HII_1), the graph shows that the suitability increases with its increase, which indicates that the species has a high tolerance to human activity. There is also an increase in the suitability with the Normalized Difference Vegetation Index (NDVI_1) up to a specific point before a sharp decline. For the other factors, the species has a sharp suitability peak at specific ranges. Low annual precipitation (bio12), precipitation of wettest month (bio13), precipitation of driest month (bio14), precipitation of wettest quarter (bio16), precipitation of driest quarter

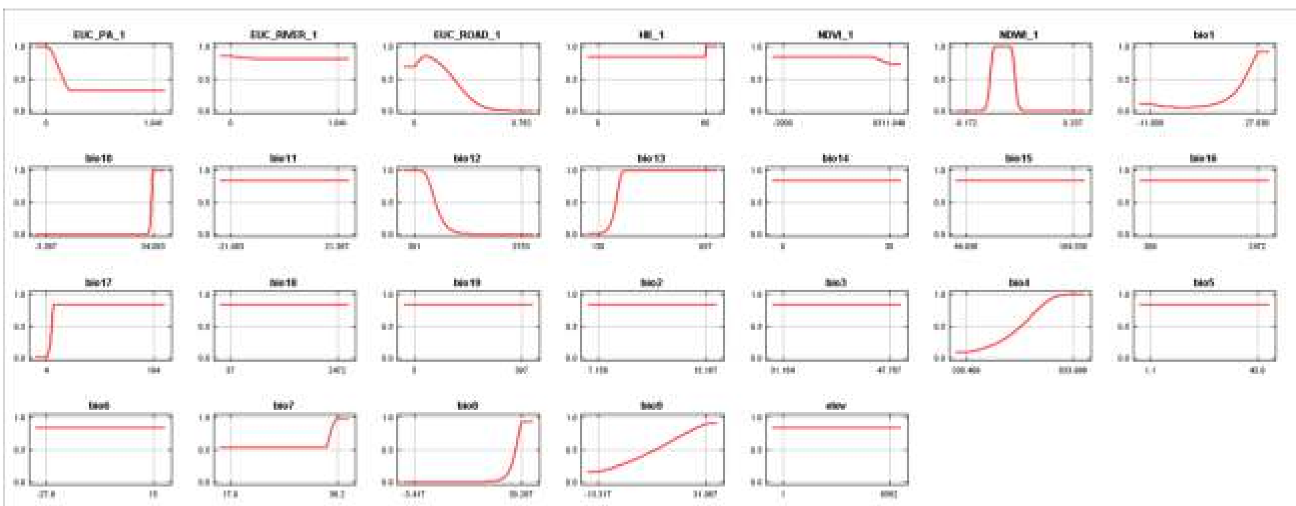


Figure 18: Marginal response curves showing the effect of the removal of individual environmental factors on *Batagur kachuga* habitat suitability

(bio17), precipitation of coldest quarter (bio19), and elevation (elev) have the highest suitability. On the other hand, high annual mean temperature (bio1), mean temperature of warmest quarter (bio10), mean temperature of coldest quarter (bio11), precipitation seasonality (bio15), mean diurnal temperature range (bio2), temperature seasonality (bio4), max temperature of warmest month (bio5), min temperature of coldest month (bio6), temperature annual range (bio7), mean temperature of wettest quarter (bio8), and mean temperature of driest quarter (bio9) showcase the highest suitability. Additionally, the suitability peaks at moderate level of isothermality (bio3), and also shows increased suitability in two specific low ranges of precipitation of warmest quarter (bio18) (Fig. 19). These single-variable response curves make it evident that *Batagur kachuga* has strong preferences to specific climatic, hydrological, and topographical conditions.

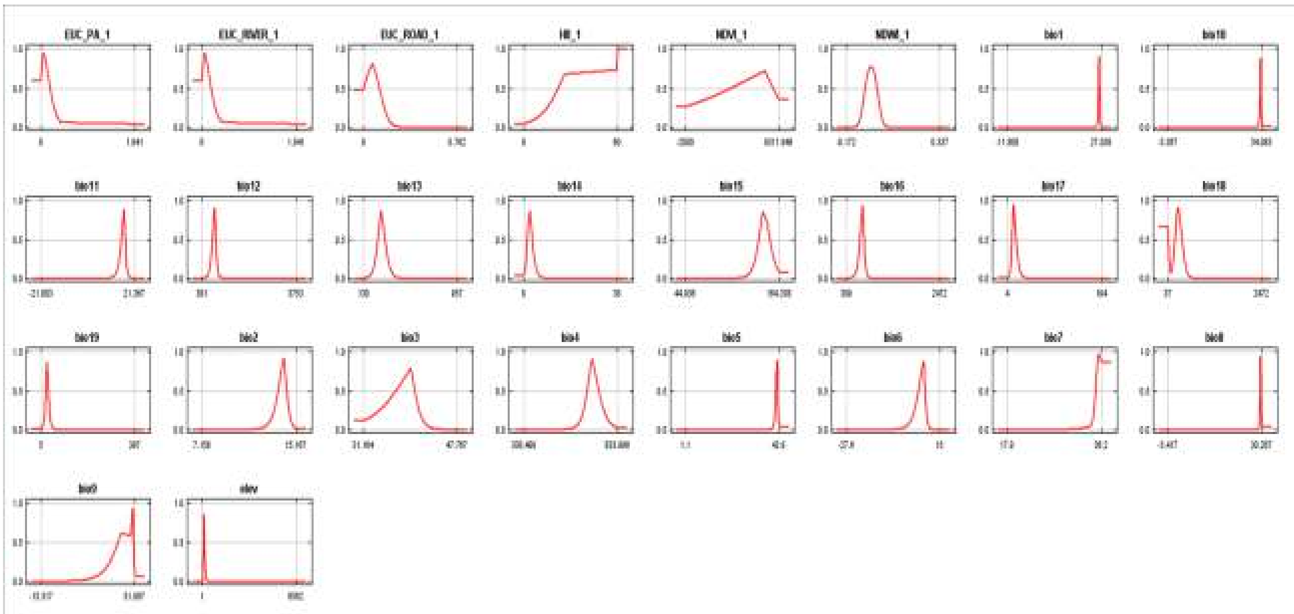


Figure 19: Single-variable response curves showing the effects of individual variables on *Batagur kachuga* habitat suitability

Threshold Selection and Omission Rates

An analysis of the threshold values for *Batagur kachuga* was performed to assess habitat suitability. Both the "Minimum Training Presence" threshold and the more precise "Maximum Training Sensitivity Plus Specificity" threshold saw a predicted area of 1.1% of the total area of the Ganga river basin as suitable habitat, and an omission rate of 0%, which means that all occurrences are included in the predicted distribution. The species' suitable habitat is limited, emphasizing the need for conservation measures.

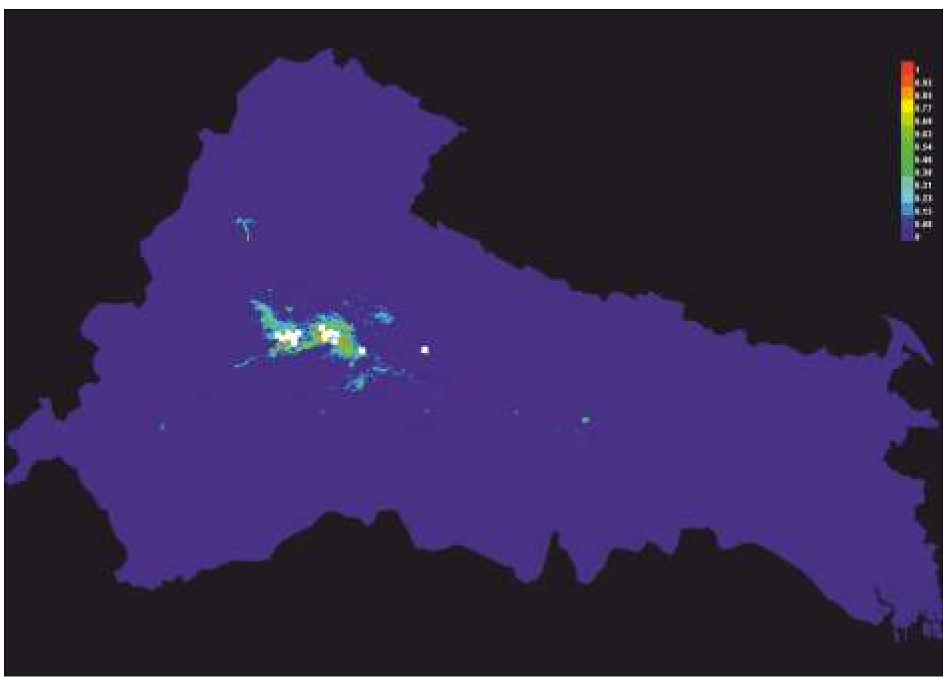


Figure 20: Species distribution map of *Batagur kachuga* in the Ganga basin

Model Explanation and Conservation Implications

In the case of *Batagur kachuga*, the suitability model attained an AUC of 0.997 with a regularized training gain of 4.125 and an unregularized training gain of 4.776. This shows that the model demonstrated a high predictive accuracy and ability to find suitable areas for the species. The selected environmental variables were good contributors to the distribution of the species. The model is a reliable tool for targeted conservation planning.

The model highlighted temperature annual range (bio7), Euclidean distance to protected areas (EUC_PA_1), mean temperature of wettest quarter (bio8), mean temperature of warmest quarter (bio10), elevation (elev), Normalized Difference Water Index (NDWI_1), precipitation of wettest month (bio13), precipitation of driest quarter (bio17), and Normalized Difference Vegetation Index (NDVI_1) as the key environmental factors that participated in the prediction of areas with suitability.

The species shows a preference towards habitats that have a high range in temperature with warm monsoons and summers, which could be accounted to the need for seasonal variations in climate for biological processes such as incubation, breeding, and nesting, among others. These suitable habitats must also have moderate to high rainfall, especially in monsoons and dry months, emphasizing the importance of water availability for the species. The species was seen to be distributed in areas that are within or are close to protected areas. This could be attributed to the high decline in the populations in areas with human presence as they are often poached or harmed by anthropogenic activities in such places. The species shows a high adaptability to a range of elevation and vegetation, or it is possible that the factors of elevation and vegetation, when compared to other factors, are not that important of predictors. A suitable habitat for the species must have a moderate water availability in the form of water bodies, as the species can not thrive in extremely dry places or places with extreme water availability, as the species requires water for thermoregulation, foraging and maintaining overall health, but too much presence of water bodies could lead to flooding of areas that could destroy nests and harm hatchlings.

The habitat suitability map of the species shows the

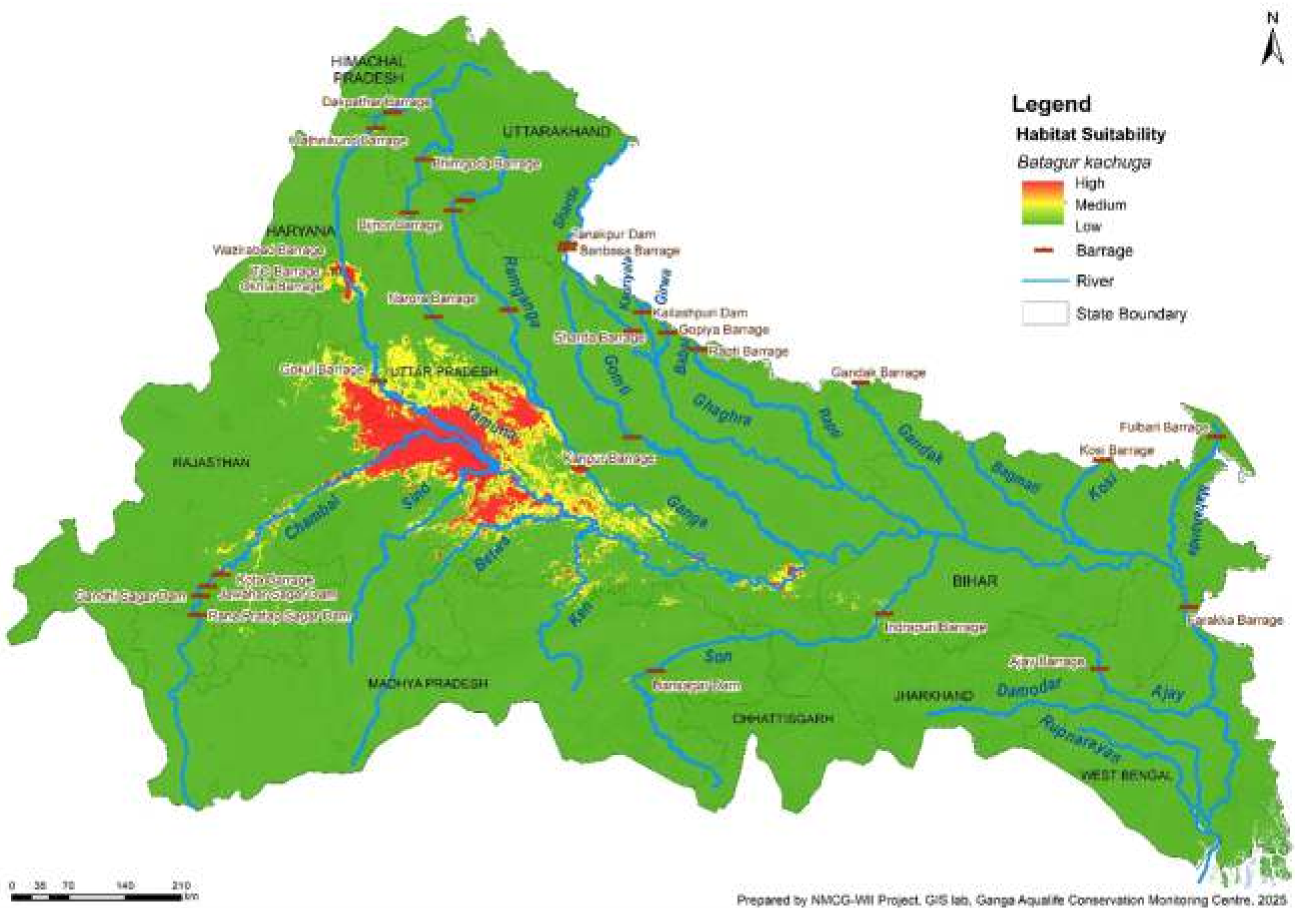


Figure 21: Habitat suitability map of *Batagur kachuga* in the Ganga basin

highest suitability in the middle Yamuna, where the confluence of the river with Chambal and Sind Rivers occur. The peripheral parts of this high suitability area showed a moderate amount of suitability. A mosaic of high and moderate suitability was found in the region between the Sind and Betwa rivers, the middle to lower Ken till it joins the Yamuna, and portions of Uttar Pradesh between the Yamuna and the Ganga. In Delhi, near the ITO Barrage, the area near the river Yamuna showed high suitability while its peripheral regions showed medium suitability. The Hathnikund Barrage in the Yamuna of Haryana had a small area with medium suitability. The area along the Bansagar Dam and Indrapuri Barrage of the Son River showed medium suitability with a few small areas of high suitability (Fig. 21).

Considered one of the world's 25 most endangered turtles according to the Turtle Conservation Coalition (2018) and considered a Critically Endangered species by IUCN's Red List, *Batagur kachuga* faces various threats. Threats such as habitat degradation and fragmentation are caused by numerous factors, including construction of hydel projects, sand mining, pollution caused by disposal of untreated municipality and industrial wastes, poaching of adults and eggs for food and pet trade, and accidental entrapment in ghost nets are resulting in drastic population declines. Due to reduced numbers in the wild, the species also faces the danger of a shallow gene pool.

It is relevant to take targeted conservation efforts in the currently occupied areas of the species. Habitats degradation and fragmentation, if not completely mitigated, can be reduced through the enforcement of stricter laws on the fluvial flow regulation, sand mining, and waste disposal. Monitoring of sites, anti-poaching patrols, and nest protection need to be established in all the highlighted areas of high habitat suitability. Local fishermen should be educated on sustainable fishing methods and procedures to follow if there is any accidental entanglement of turtles in their fishing nets. Moreover, it has become necessary to increase the size of the population in the wild, which can be achieved through captive breeding programs with reintroduction in suitable habitats. Additionally, since data on the current population status of the species is lacking, it is crucial to perform population surveys before designing and implementing conservation strategies.

Chitra indica

Model Performance Analysis

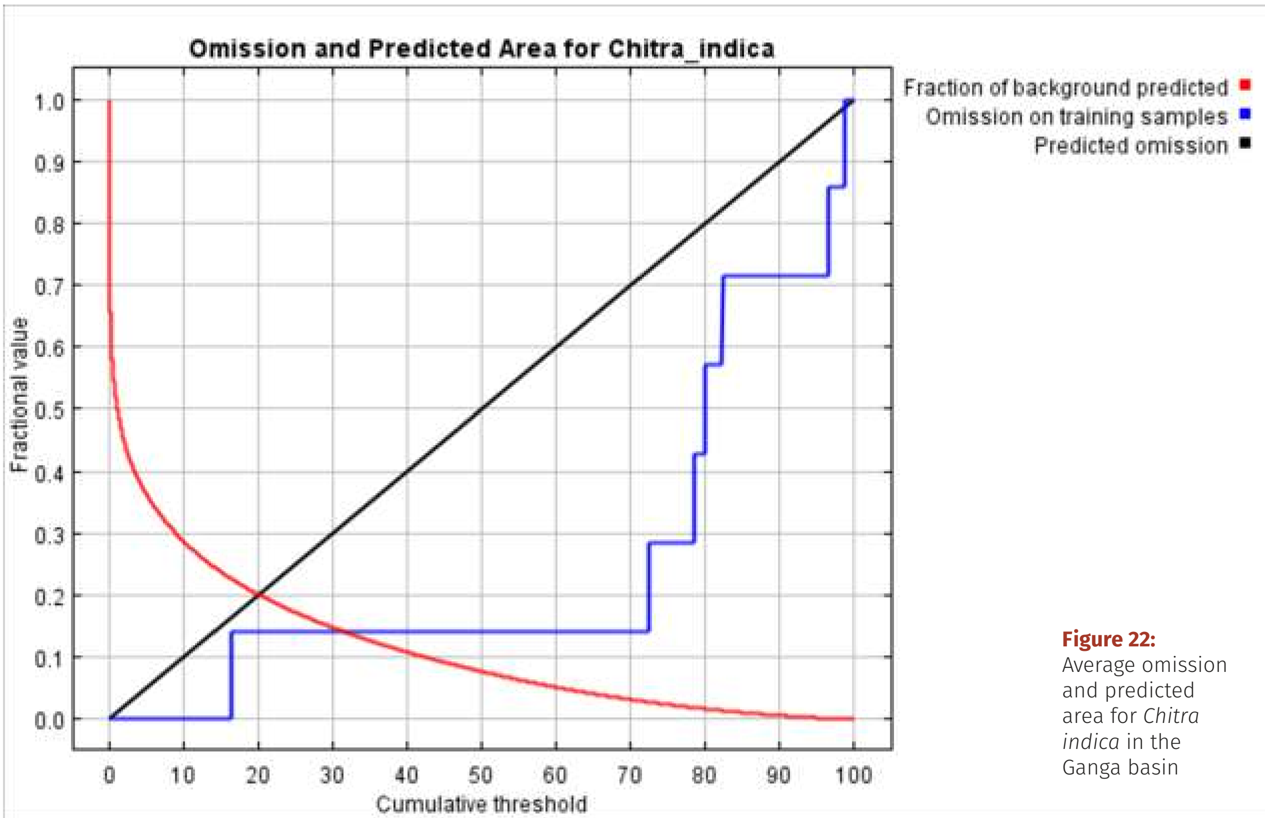


Figure 22: Average omission and predicted area for *Chitra indica* in the Ganga basin

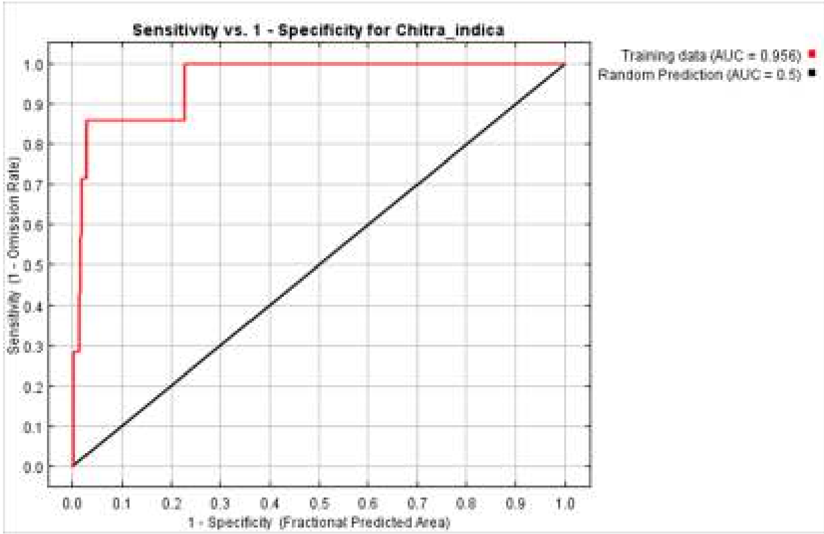


Figure 23: ROC curves for models of *Chitra indica* in the Ganga basin

In the case of *Chitra indica*, the MaxEnt model produced a regularized training gain of 1.186 and an AUC of 0.956, which highlights that the model has a fit to the training data and has the ability to identify the environmental factors that influence the habitat suitability of *Chitra indica*, and it can find the difference between presence and pseudo-absence points (Fig. 23). A magnitude of 2.051 of the unregularized training gain is greater than the regularized training gain, indicating the high complexity of the model and absence of overfitting through regularizations. After 200 iterations, the algorithm of the model converged. The run was completed in 0 seconds. The environmental factors were able to predict the habitat suitability of the species precisely.

Key Environmental Variables

The MaxEnt model identified 8 environmental factors that played a significant role in predicting the habitat suitability of *Chitra indica* (Table 2). Among all the factors, temperature seasonality (bio4) was found to be the most influential with a contribution of 45.1% to the model, which highlights that temperature variations play a crucial role in the distribution of *Chitra indica*. Mean temperature of the wettest quarter (bio8) and elevation (elev) were the second and third highest contributors, accounting for 16.8% and 15.6%, suggesting that the species is also dependent on specific temperature conditions during the monsoon and occupies certain altitude. The Normalized Difference Water Index (NDWI_1) has a contribution of 14.9%, which underscores the importance of proximity to water in defining the species' habitat suitability. Other factors, such as isothermality (bio3) and temperature annual range (bio7), contributed 2.6% and 2.2%, respectively, indicating a minor yet notable influence on the distribution of the species. Similarly, Normalized Difference Vegetation Index (NDVI_1) and distance to river (EUC_RIVER_1) also had minimal contributions of 2% and 0.4%, respectively, suggesting that vegetation cover and proximity to rivers are relevant but not critical in predicting the suitability of habitat.

When analyzing the permutation importance, elevation (elev) stood out as the most important predictor with a permutation importance of 36.7%, which suggests that even though other factors contributed more during model training, elevation holds an important role in final habitat prediction. Temperature annual range (bio7) also had a high permutation importance with a value of 28.9%, despite its lower percent contribution, emphasizes that the species is sensitive to variations in temperature. NDWI_1 also showed a substantial permutation importance of 18.5%, signifying the importance of presence of water bodies in habitat selection. Interestingly, temperature seasonality (bio4) and mean temperature of the wettest quarter (bio8), which were top contributors during training, had no permutation importance, indicating that while they shaped the model, their removal would not significantly affect its predictive capacity, which could be contributed to possible correlation with stronger predictors. Factors such as NDVI_1 (4%) and bio3 (0.4%) showed limited importance in determining habitat suitability with values of 4%, and 0.4%, respectively. EUC_RIVER_1 (0%) had no permutation importance indicating the lack of role in prediction.

Table 4. Contribution of environmental variables in the model building for *Chitra indica*

Variable	Percent contribution	Permutation importance
bio4	45.1	0
bio8	16.8	0
elev	15.6	36.7
NDWI_1	14.9	18.5
bio3	2.6	0.4
bio7	2.2	28.9
NDVI_1	2	4
EUC_RIVER_1	0.4	0

Jackknife test of variable importance

Based on the results of the jackknife test for regularized training gain, it is seen that mean temperature of the wettest quarter (bio8) is the most important factor with the highest gain in isolation. When omitted it creates the greatest reduction in the performance of the model. The temperature seasonality (bio4) has the second highest individual gain, followed by the temperature annual range (bio7). Elevation (elev) has a moderately important role in predicting the presence of suitable habitat in the Ganga basin. All the other factors have mild to negligible gains, which means that they don't have much role in deciding which area is suitable for the species' distribution (Fig. 24).

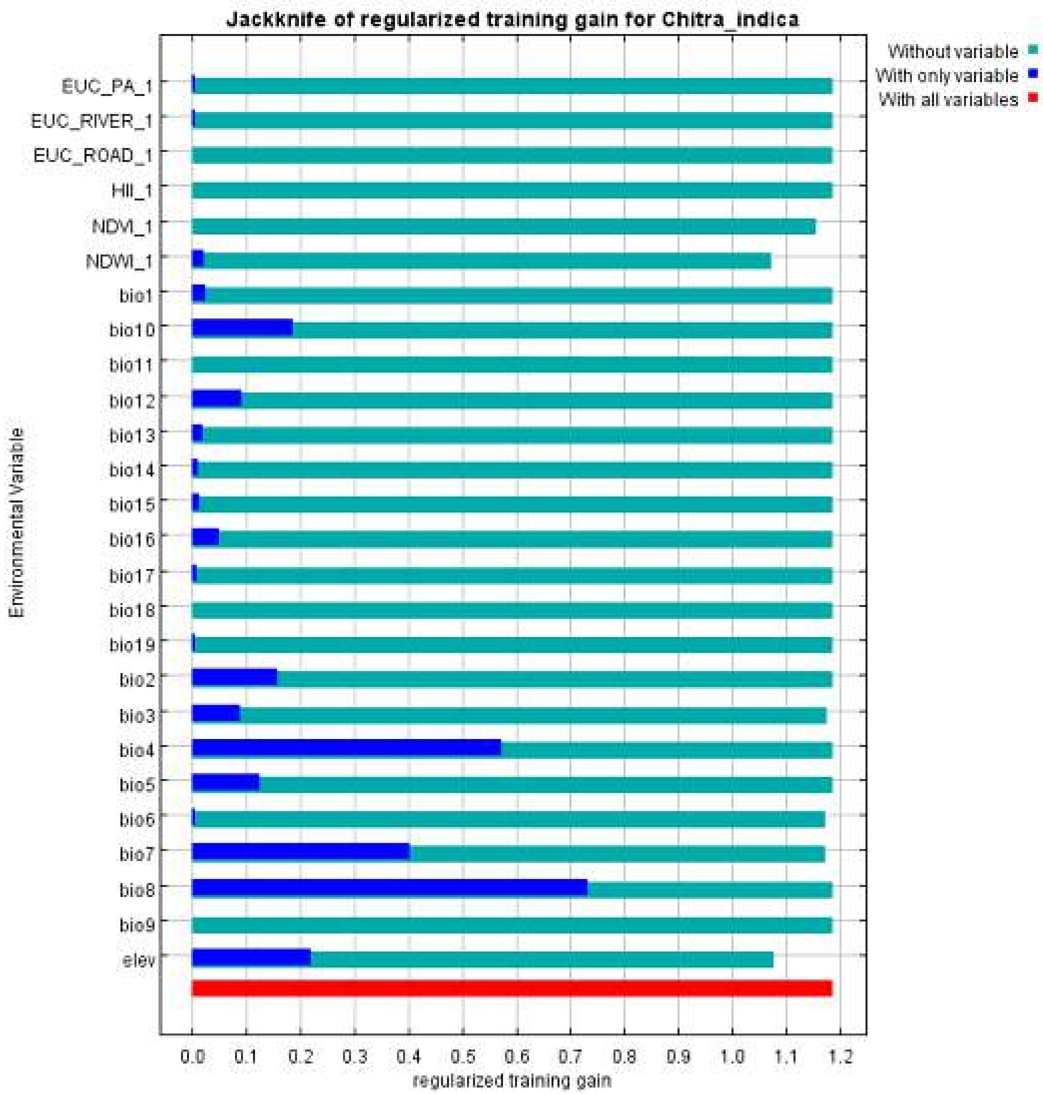


Figure 24: Jackknife test of variable importance for *Chitra indica*

Response curves and variable relationships

The marginal response curves plotted by the model for *Chitra indica* suggest that Normalized Difference Water Index (NDWI_1), min temperature of coldest month (bio6), temperature annual range (bio7), and elevation (elev) influence the habitat suitability the most (Fig. 25). The suitability increases with an increase in proximity to water bodies, and temperature. However, it decreases with a drop in temperature and with an increase in elevation. Increment in Normalized Difference Vegetation Index (NDVI_1) and isothermality (bio3) negatively impact the suitability of a habitat, but not critically. Euclidean distance to protected areas (EUC_PA_1), rivers (EUC_RIVER_1), and roads (EUC_ROAD_1) have only a slight impact on the suitability with the former two decreasing the suitability with their increase, while the latter increasing the suitability. An increase in the mean temperature of wettest quarter (bio8) slightly increases the suitability. The habitat suitability of *Chitra indica* remains constant for the other factors, showing their limited impact.

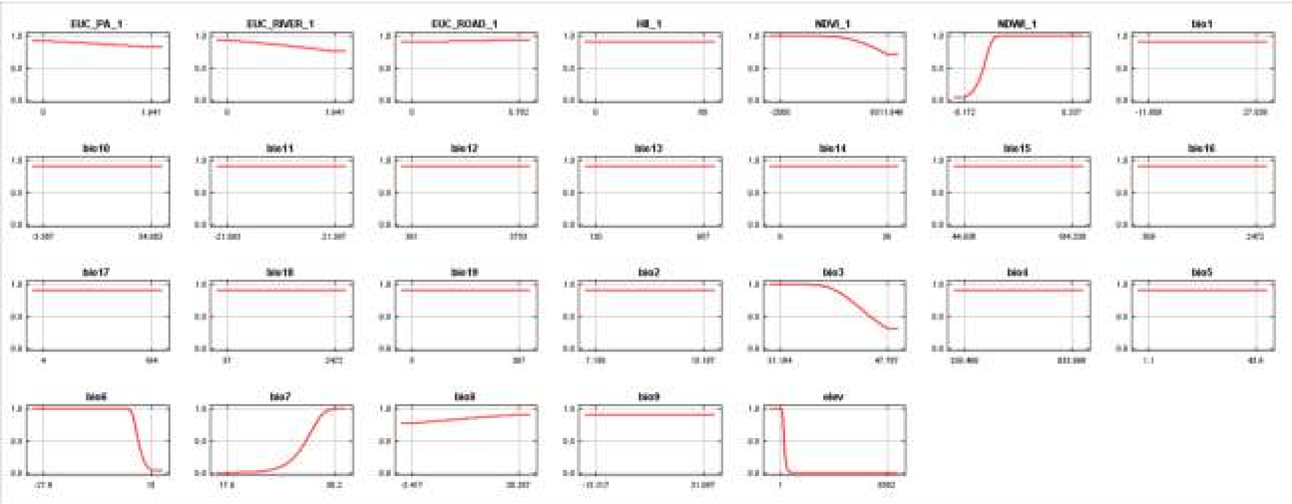


Figure 25: Marginal response curves showing the effect of removal of individual environmental factors on *Chitra indica* habitat suitability

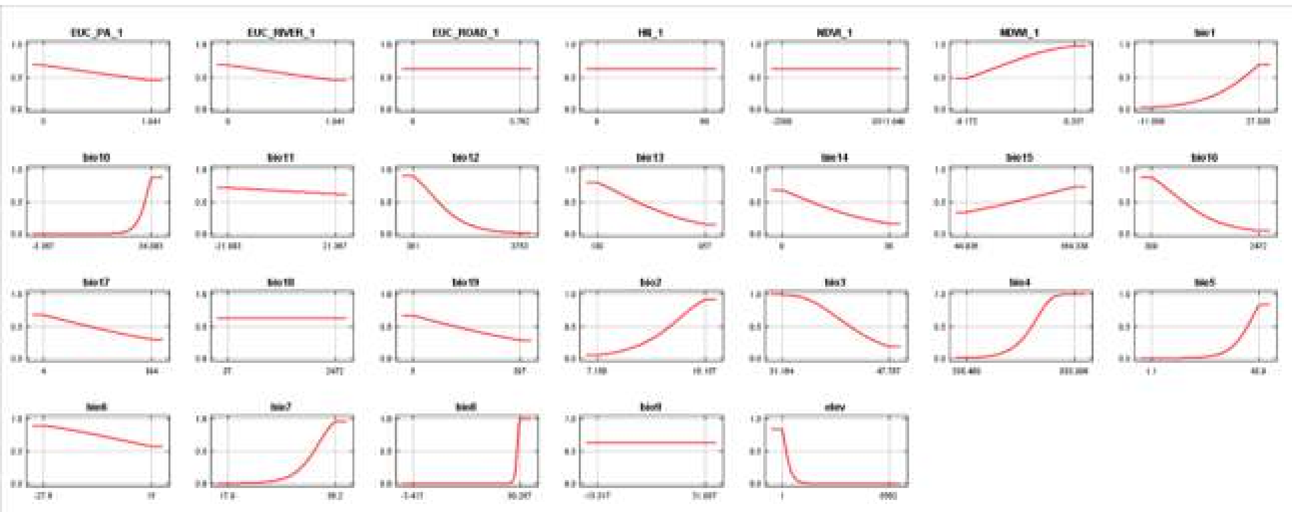
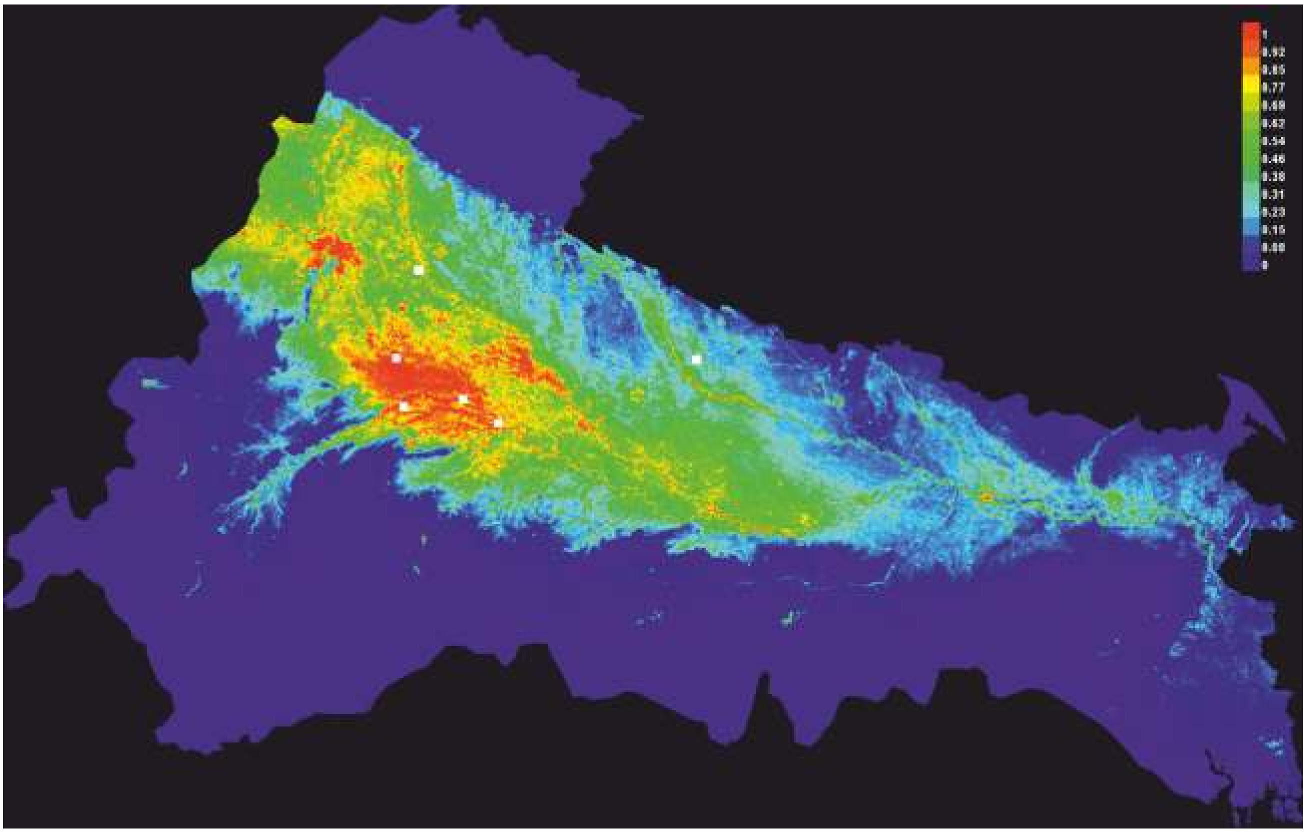


Figure 26: Single-variable response curves showing the effects of individual variables on *Chitra indica* habitat suitability

The single-variable response curve for the species shows that increase in distance to protected areas (EUC_PA_1), rivers (EUC_RIVER_1), annual precipitation (bio12), precipitation of wettest month (bio13), precipitation of driest month (bio14), precipitation of wettest quarter (bio16), precipitation of driest quarter (bio17), precipitation of coldest quarter (bio19), isothermality (bio3), min temperature of coldest month (bio6), and elevation (elev) creates a negative trend. This demonstrates the unsuitability of a habitat in a higher elevation with heavy rainfall and high variation in temperature. On the other hand, factors including Normalized Difference Vegetation Index (NDVI_1), annual mean temperature (bio1), mean temperature of warmest quarter (bio10), precipitation seasonality (bio15), mean diurnal temperature range (bio2), temperature seasonality (bio4), max temperature of warmest month (bio5), temperature annual range (bio7), and mean temperature of wettest quarter (bio8) have a positive impact on a habitat's suitability with their increase. This highlights the species' preference to warmer temperatures, presence of vegetation, and seasonal rainfall. Other factors have slight impact on the suitability.

Threshold Selection and Omission Rates



Model Explanation and Conservation Implications

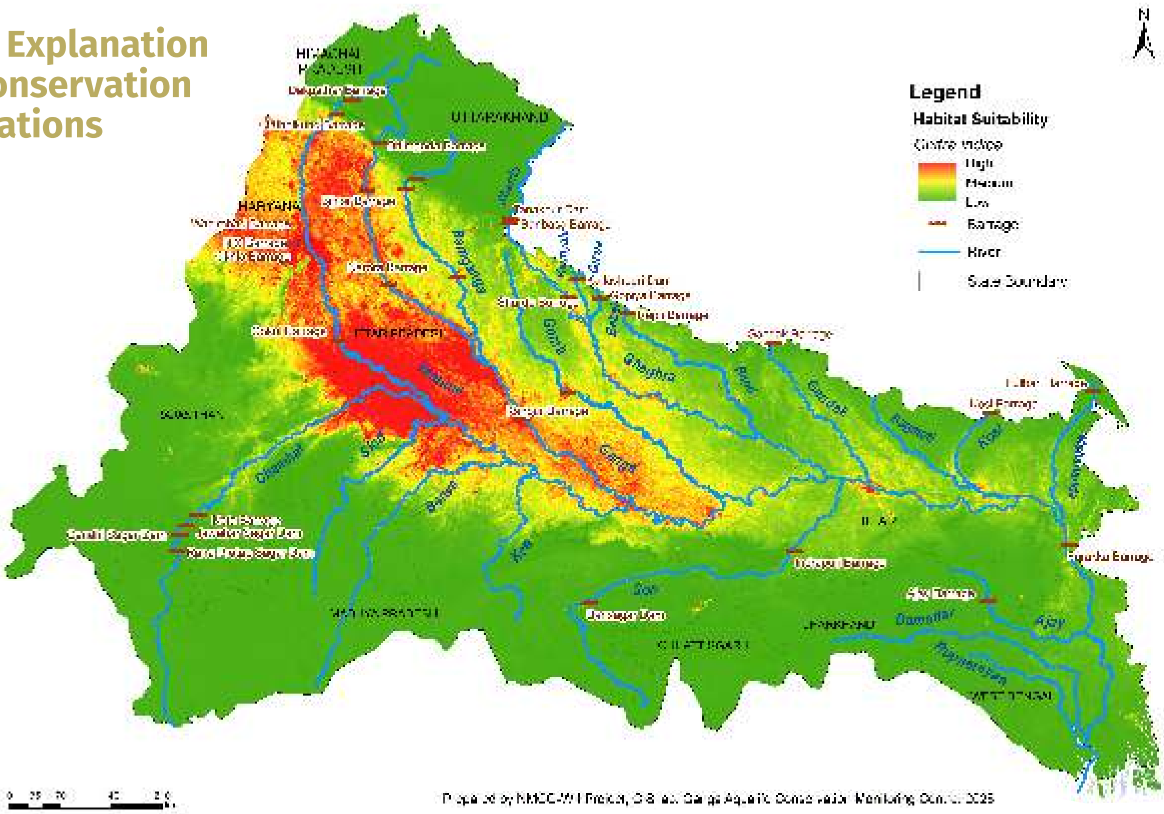


Figure 27: Habitat suitability map of *Chitra indica* in the Ganga basin

Nilssonia gangetica

Model Performance Analysis

The MaxEnt model effectively predicted *Nilssonia gangetica* habitat suitability, as evidenced by a regularized training gain of 2.470, indicating a strong relation between turtle presence and the selected environmental factors. This gain which exceeds 1, confirms the model's ability to identify key predictors. Furthermore, the model demonstrated high accuracy, with an AUC of 0.962, signifying its excellent capacity to separate presence and background points (Fig. 78). The unregularized training gain is 2.781, which exceeds the regularized training gain, indicates that the model is complex and uses regularization techniques to prevent overfitting. The algorithm used in the model converged after 500 iterations, completing the run in 20 seconds, and showing efficient processing by the model. Hence, overall results indicate that the selected environmental factors are good predictors of *Nilssonia gangetica* habitat suitability.

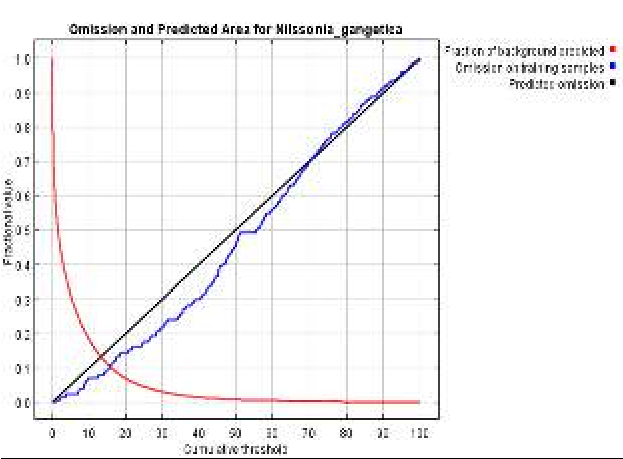


Figure 77: Average omission and predicted area for *Nilssonia gangetica* in the Ganga basin

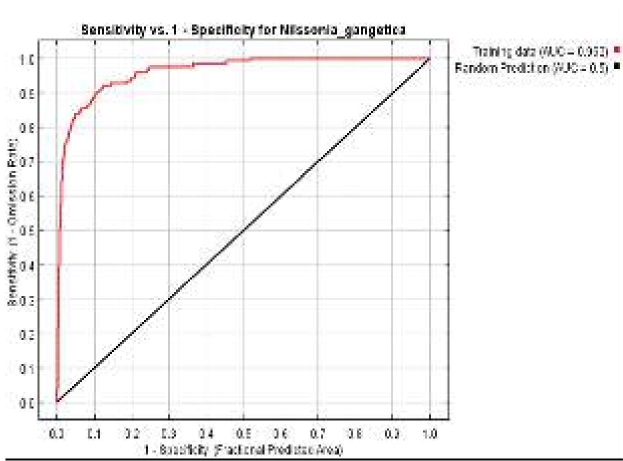


Figure 78: ROC curves for models of *Nilssonia gangetica* in the Ganga basin

Table 12. Contribution of environmental variables in the model building for *Nilssonia gangetica*

Variable	Percent contribution	Permutation importance
bio7	36.7	0
EUC_PA_1	21.9	10
bio8	14.5	6.9
bio13	3.7	6.1
bio18	3.2	7.1
bio5	2.8	0

6 key variables were identified by the model, which significantly influenced the distribution of *Nilssonia gangetica* (Table 12). Out of all, the temperature annual range (bio7) emerged as the most influential factor, contributing 36.7% to the model, highlighting the species' high sensitivity to temperature fluctuations. Euclidean distance to protected areas (EUC_PA_1) also played a considerable role with contribution of 21.9%, indicating the importance of protected areas in shaping the species distribution pattern. Likewise, the mean temperature of the wettest quarter (bio8), accounting for 14.5%, indicates a preference for specific monsoon temperatures. Other factors such as precipitation of wettest month (bio13), precipitation of warmest quarter (bio18), and max

temperature of warmest month (bio5) have a minor influence on the predictability of the model with contributions of 3.7%, 3.2%, and 2.8%, respectively. This further emphasizes the importance of temperature and precipitation in determining *Nilssonia gangetica* habitat suitability.

The study revealed considerable differences between the percent contribution and permutation importance. The temperature annual range (bio7), despite having the highest percent contribution, showed zero permutation importance, implying that its strong influence during model training was not correlated to independent predictive power. This could possibly be due to the overlapping with other better predictors. On the other hand, the permutation importance of the euclidean distance to protected areas (EUC_PA_1) of 10% suggested the important role of this feature in influencing the habitat suitability of the species. The mean temperature of wettest quarter (bio8), had a permutation importance of 6.9%, suggesting a moderate independent contribution. Precipitation of wettest month (bio13) and precipitation of warmest quarter (bio18) showed minor percent contributions but had permutation importance values of 6.1% and 7.1%, respectively, showing a slightly higher independent predictive role than suggested by their contribution during training. Furthermore, the maximum temperature of warmest month (bio5) with a minimal percent contribution also registered a no permutation importance, indicating its limited ability to predict the habitat of the species.

Jackknife test of variable importance

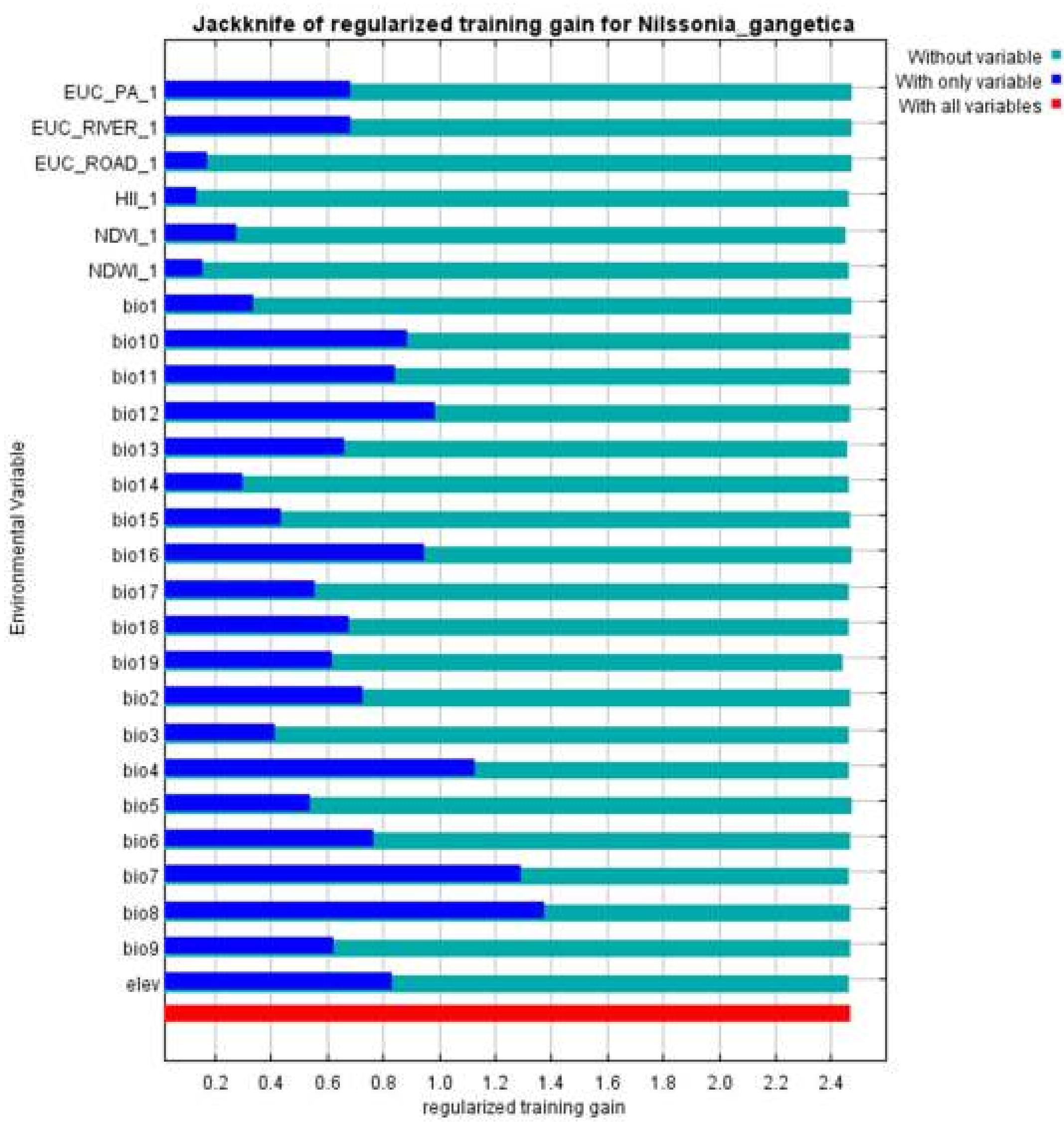


Figure 79: Jackknife test of variable importance for *Nilssonia gangetica*

From the result of the jackknife test of regularized training gain, it is evident that the mean temperature of wettest quarter (bio8) accounts for the highest gain in isolation, showcasing its predictive information. This is followed by the high individual gains of temperature annual range (bio7), and temperature seasonality (bio4) which confirms their importance in the habitat prediction. It is further followed by annual precipitation (bio12), precipitation of wettest quarter (bio16), mean temperature of warmest quarter (bio10), mean temperature of coldest quarter (bio11), min temperature of coldest month (bio6), mean diurnal temperature range (bio2), precipitation of warmest quarter (bio18), precipitation of wettest month (bio13), mean temperature of driest quarter (bio9), precipitation of coldest quarter (bio19), euclidean distance to protected areas (EUC_PA_1), and euclidean distance to rivers (EUC_RIVER_1), which act as moderate predictors. Additionally, precipitation seasonality (bio15), precipitation of driest quarter (bio17), isothermality (bio3), and maximum temperature of warmest month (bio5), are weak predictors, while the other remaining factors have negligible gain towards the prediction of suitability (Fig. 79).

Response curves and variable relationships

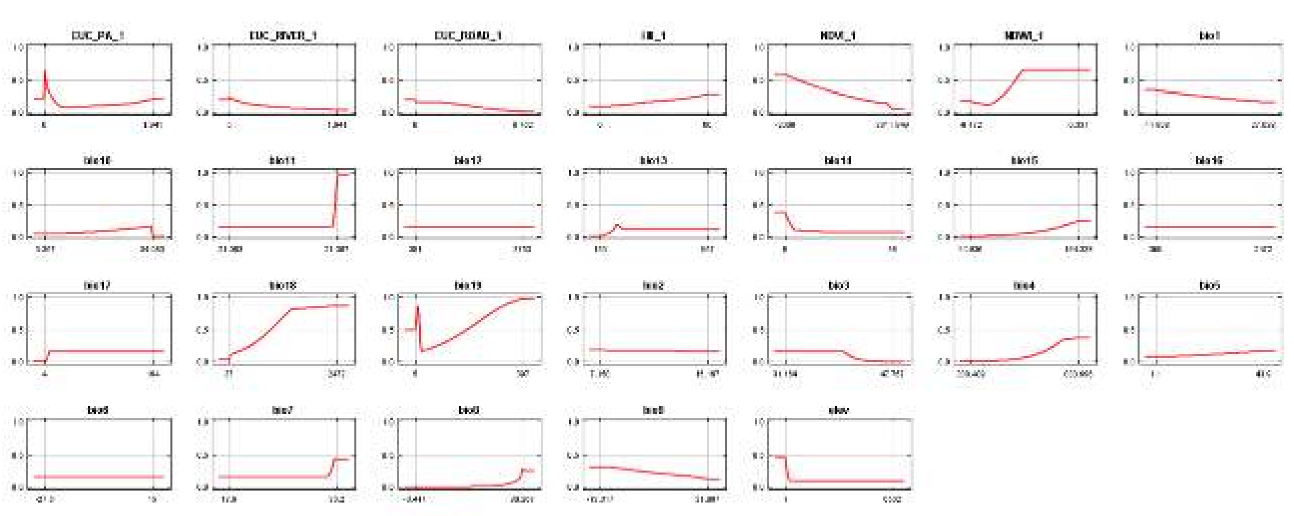


Figure 80: Marginal response curves showing the effect of removal of individual environmental factors on *Nilssonia gangetica* habitat suitability

Through the marginal response curves the impact of removing individual environmental factors on the habitat suitability of *Nilssonia gangetica* can be understood (Fig. 80). A significant decrease was observed with the Euclidean distance to protected areas (EUC_PA_1) in relation to the habitat suitability of the species, suggesting that the species prefers environments adjacent to protected areas. Also, a decrease in suitability was observed with increasing distance to rivers (EUC_RIVER_1), and roads (EUC_ROAD_1). However, contrary to that, a positive trend was observed with Human Influence Index (HII_1), indicating the species' tolerance or preference for areas under human influence. The Normalized Difference Vegetation Index (NDVI_1) showed a decline in suitability with the increase in vegetation density, while the Normalized Difference Water Index (NDWI_1) peaked at moderate values, suggesting a preference for specific water body conditions. Amongst the bioclimatic variables, there is an increase in the suitability with an increase in maximum temperature of the warmest month (bio5), annual temperature range (bio7), mean temperature of the wettest quarter (bio8), and mean temperature of the warmest quarter (bio10), implying that suitability increases with the increase in temperature levels. In contrast, the annual mean temperature (bio1), and mean temperature of the driest quarter (bio9) decreased in the suitability as temperature increased. The Isothermality (bio3) decreased in suitability as temperature stability increased, indicating that such situations should be avoided. The mean diurnal temperature range (bio2) revealed peak suitability within specific ranges, showing a preference for moderate temperature changes. In case of temperature seasonality (bio4), the habitat suitability increases with temperature seasonality, indicating a preference for areas with distinct seasonal temperature changes. The precipitation of the wettest month (bio13), and precipitation of the driest month (bio14) showed a decrease in suitability with increasing precipitation, suggesting an avoidance of wetter conditions. The precipitation seasonality (bio15), precipitation of the driest quarter (bio17), and mean temperature of the coldest quarter (bio11) showed peak suitability within specific ranges of values. While the precipitation of the coldest quarter (bio19) revealed fluctuations showing a steep decline initially in the habitat suitability with the increase in precipitation and then gradually taking a positive trend. The rest of the bioclimatic variables showed relatively minor or flat lines, suggesting that their removal has minimal impact on habitat suitability. Furthermore, elevation (elev) revealed a sharp decline in suitability with increasing altitude, indicating a strong preference for lower elevations.

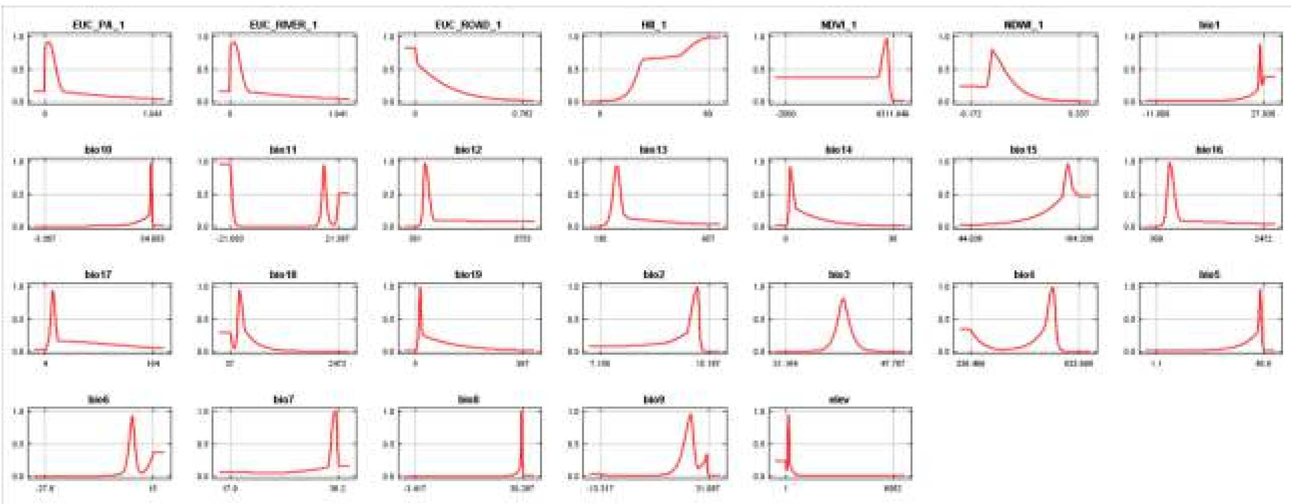


Figure 81: Single-variable response curves showing the effects of individual variables on *Nilssonia gangetica* habitat suitability

Threshold Selection and Omission Rates

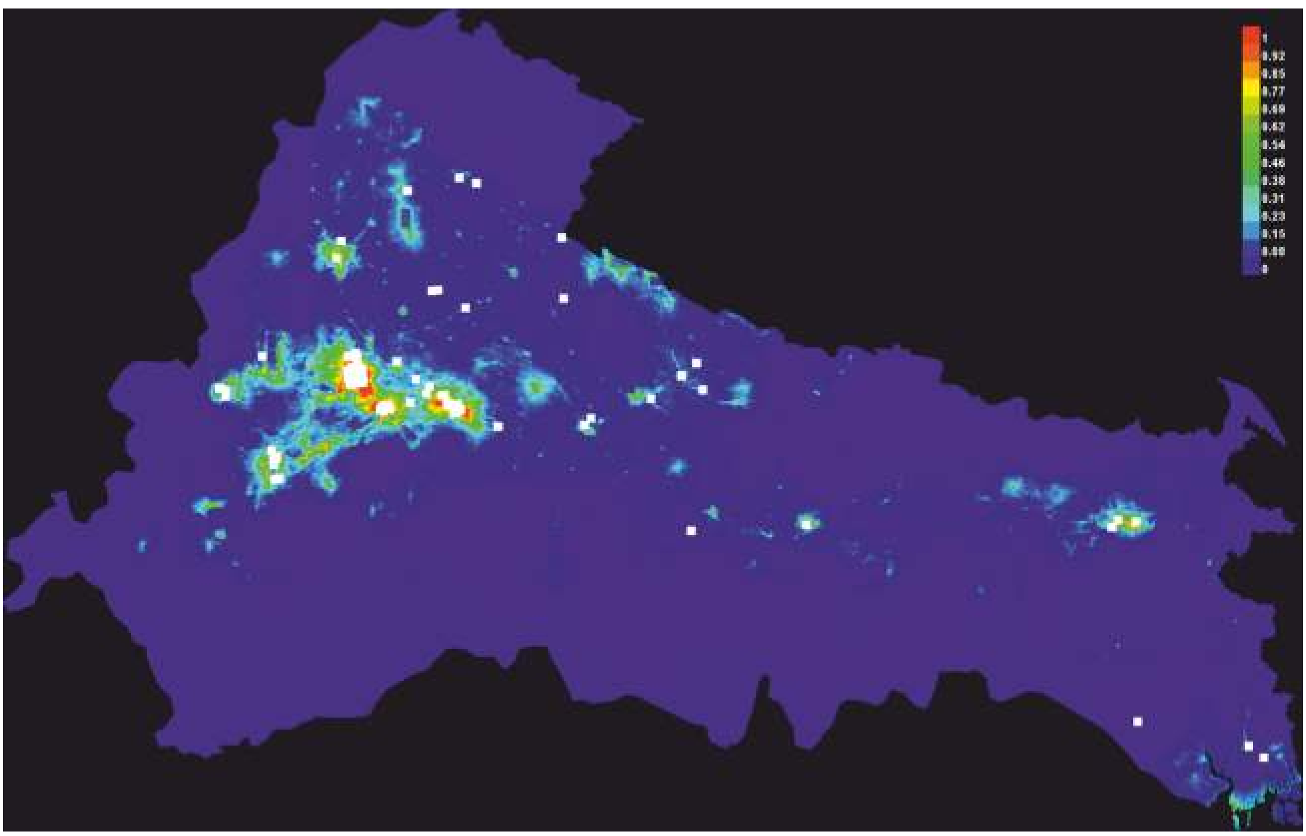


Figure 82: Species distribution map of *Nilssonia gangetica* in the Ganga basin

The single-variable response curves reveal the influence of individual environmental variables on *Nilssonia gangetica* habitat suitability (Fig. 81). Habitat suitability was highest at distances closer to protected areas (EUC_PA_1) and rivers (EUC_RIVER_1), decreasing as distance increases, signifying a preference for proximity to these features. On the other hand, the model also revealed that the habitat suitability of the species increases with decreasing distance to roads (EUC_ROAD_1) and increasing Human Influence Index (HII), suggesting a tolerance for human-altered landscapes. Moreover, the Normalized Difference Vegetation Index (NDVI_1) showed peak suitability at lower densities, which decreases as density increases. The Normalized Difference Water Index (NDWI_1) showed peak suitability at moderate values. The annual mean temperature (bio1) and mean temperature of the warmest quarter (bio10) both showed increasing suitability with higher temperatures, suggesting the preference of species for warmer temperatures. The precipitation and temperature variables ranging from bio11 to bio19 showed varying, often peaking, responses, indicating preferences for specific ranges of conditions. Also, the mean diurnal temperature range (bio2), isothermality (bio3),

temperature seasonality (bio4), maximum temperature of the warmest month (bio5), minimum temperature of the coldest month (bio6), temperature annual range (bio7), mean temperature of the wettest quarter (bio8), and mean temperature of the driest quarter (bio9) all exhibit peak suitability within certain ranges. Furthermore, the habitat suitability was observed to decrease with increasing elevation (elev), indicating a preference for lower altitudes.

Model Explanation and Conservation Implications

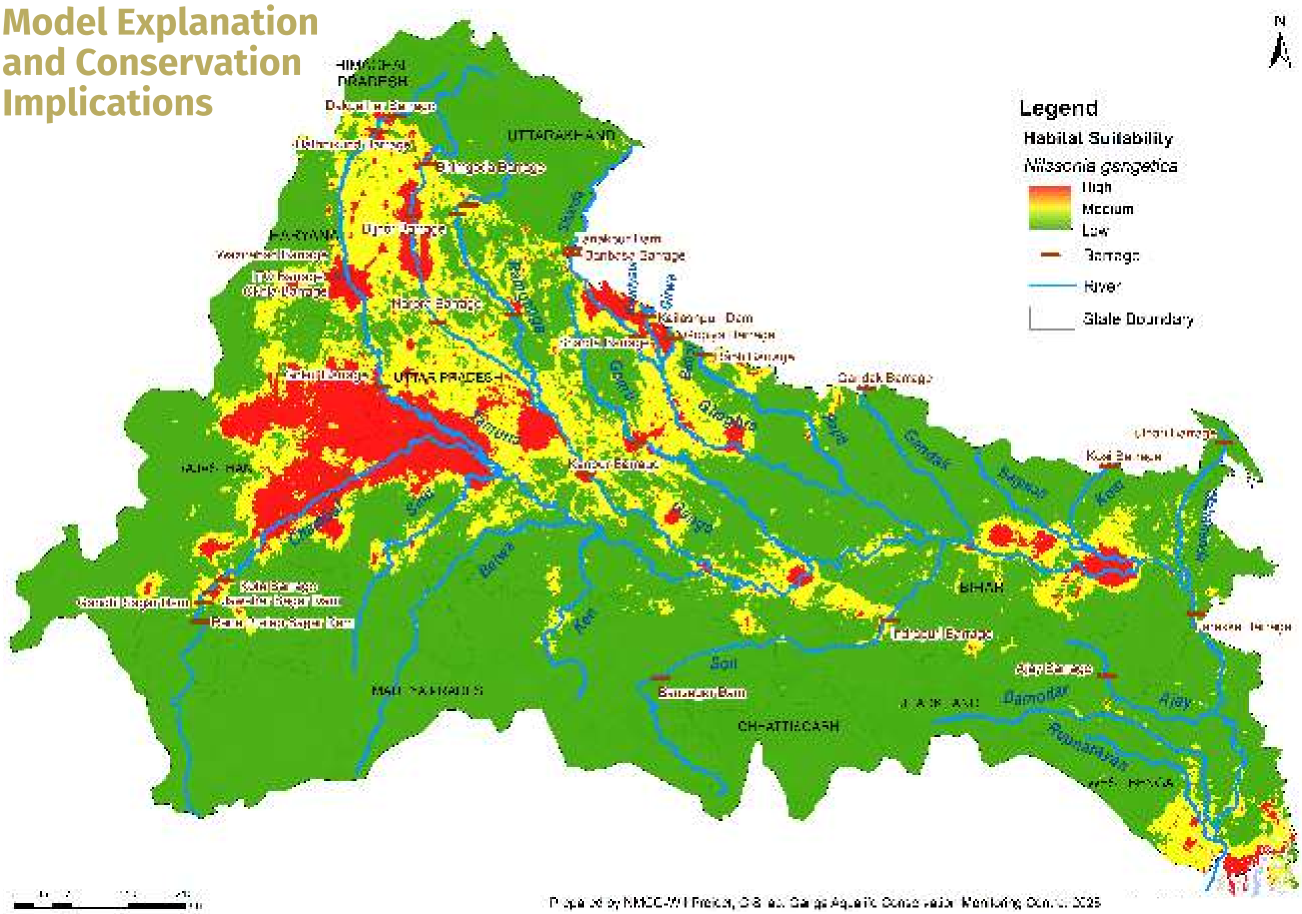


Figure 83: Habitat suitability map of *Nilssonia gangetica* in the Ganga basin

CONCLUSION

The present study provides a comprehensive, species-wise assessment of habitat suitability for four threatened freshwater turtle species, *Batagur kachuga, Batagur dhongoka, Nilssonia gangetica,* and *Chitra indica*, within the Ganga River Basin using MaxEnt-based ecological niche modelling. The results demonstrate that the selected environmental and anthropogenic variables are robust predictors of habitat suitability, as reflected by consistently high model performance metrics (AUC values ranging from 0.899 to 0.997 and regularized training gains exceeding unity for all species). This indicates that the modelling approach effectively captures the ecological preferences and constraints governing the distribution of these species.

Across all four turtles, temperature-related variables emerged as the dominant drivers of habitat suitability. Parameters such as temperature seasonality (bio4), temperature annual range (bio7), mean temperature of the wettest quarter (bio8), and mean temperature of the warmest quarter (bio10) consistently influenced species distributions, underscoring the strong sensitivity of freshwater turtles to thermal regimes. This reflects the importance of temperature in regulating key biological processes such as metabolism, activity patterns, nesting, incubation, and sex determination. In contrast, higher elevations, excessive precipitation, and extreme hydrological conditions were generally associated with reduced habitat suitability, indicating a preference for lowland river stretches with stable yet seasonally variable climatic conditions.

Hydrological and landscape variables also played a significant role. Proximity to rivers, moderate availability of water bodies (as indicated by NDWI), and low to moderate vegetation density were important determinants of suitable habitats. All species showed strong associations with areas close to protected areas, highlighting the role of reduced anthropogenic pressure and better habitat integrity in sustaining turtle populations. At the same time, certain species exhibited tolerance to moderate levels of human influence, suggesting that conservation interventions in human-dominated landscapes remain feasible if key threats are managed

The habitat suitability analysis reveals distinct yet overlapping river-specific patterns for the four focal freshwater turtle species within the Ganga Basin, collectively highlighting the central importance of the Yamuna, Chambal, and Ganga rivers. For both *Batagur kachuga* and *Batagur dhongoka*, suitable habitats are primarily concentrated in the middle reaches of the Yamuna and Chambal rivers, with the Yamuna-Chambal confluence emerging as a key stronghold. Additional suitable stretches along the Ganga mainstem near Kanpur further underscore the significance of this region for turtles.

In contrast, *Nilssonia gangetica* exhibits a broader distribution of highly suitable habitats, extending across the middle and lower reaches of the Yamuna, Chambal, and Ganga rivers, including downstream stretches in eastern Uttar Pradesh, Bihar, and parts of West Bengal. This pattern reflects the species' wider ecological tolerance and dependence on large, lowland river systems.

For *Chitra indica*, suitable habitats are more spatially restricted, with strong concentration in the Yamuna-Chambal system and fragmented yet important stretches along the middle Ganga. Collectively, these results emphasize that conservation priorities for freshwater turtles in the Ganga Basin should focus on protecting and managing key river stretches within the Yamuna, Chambal, and Ganga systems, as these areas support the highest habitat suitability and represent critical landscapes for the long-term persistence and recovery of all four species. The generated habitat suitability maps identify distinct spatial patterns across the Ganga Basin, highlighting river stretches such as the Chambal-Yamuna system, parts of the Sind, Betwa, Ken, Son, and select tributaries as priority landscapes for conservation action. However, the analysis also reveals that suitable habitats are fragmented and limited in extent, particularly for *Batagur kachuga,* emphasizing the urgency of targeted and site-specific conservation measures. Overall, the results reinforce that habitat degradation, fragmentation, altered flow regimes, sand mining, pollution, and exploitation remain the primary drivers of decline, and that without strategic intervention, the long-term persistence of these species in the wild is unlikely.

RECOMMENDATIONS

Based on the results of the habitat suitability analysis, the following recommendations are proposed to guide conservation planning and management of freshwater turtles in the Ganga River Basin:

Prioritization of High-Suitability Areas

Conservation actions should be spatially prioritized in river stretches identified as having high and medium habitat suitability for each species. These areas should be treated as critical conservation landscapes for focused protection, monitoring, and management interventions.

Habitat Protection and Restoration

Immediate measures are required to prevent further degradation of suitable habitats through the strict regulation of sand mining, riverbed agriculture, and unregulated fishing. Restoration of degraded sandbanks, maintenance of deep pools, and protection of nesting and basking sites should be undertaken in priority areas.

Maintenance of Environmental Flows

Given the strong influence of temperature and hydrology on habitat suitability, river flow regulation should aim to maintain ecologically meaningful environmental flows. This includes avoiding sudden or unseasonal releases from dams that may inundate nesting sites or alter thermal regimes critical for reproduction.

Strengthening Protected Area Networks

River stretches with high suitability that fall outside existing protected areas should be considered for enhanced legal protection through conservation reserves, eco-sensitive zones, or site-specific management regulations. Integration of turtle conservation objectives into existing protected area management plans is strongly recommended.

Population Reinforcement and Reintroduction

For species with severely fragmented or depleted populations, particularly *Batagur dhongoka* and *Batagur kachuga*, captive breeding, head-starting, and scientifically guided reintroduction programmes should be implemented in identified suitable habitats. Genetic considerations and health screening must be integral to such efforts.

Community Engagement and Threat Mitigation

Local fishing and river-dependent communities should be actively involved through awareness programmes, promotion of turtle-friendly fishing practices, and mechanisms for reporting accidental bycatch. Alternative livelihood options and incentive-based conservation models should be promoted in priority areas.

Long-term Monitoring and Research

Regular population surveys, nest monitoring, and habitat assessments should be carried out in both currently occupied and predicted suitable habitats to validate model outputs and track population trends. Telemetry, remote sensing, drones, and other technological tools should be used to enhance monitoring in inaccessible river stretches.

Adaptive Management under Climate Change

Given the strong climatic sensitivity revealed by the models, conservation planning must explicitly account for future climate variability. Long-term monitoring of temperature, precipitation, and hydrological changes should inform adaptive management strategies to buffer populations against climate-driven risks.

Policy Integration and Inter-agency Coordination

Effective conservation of freshwater turtles requires coordination among forest, fisheries, irrigation, and pollution control authorities. The results of this study should be mainstreamed into river basin management, fisheries regulations, and biodiversity action plans at the state and basin levels.

CAPTIVE MANAGEMENT AND HUSBANDRY PROTOCOLS

INTRODUCTION

Freshwater turtles are among the most threatened vertebrate groups globally, with many species experiencing severe population declines due to habitat degradation, exploitation, incidental mortality, and alteration of riverine and wetland ecosystems. Captive management has therefore become an integral component of freshwater turtle conservation, particularly in the context of rescue, rehabilitation, confiscation, head-starting, and conservation breeding programmes.

Effective captive care and management are essential to ensure animal welfare, prevent disease transmission, reduce stress, and maintain the physiological and behavioural fitness of individuals housed under controlled conditions. Captive facilities also play a critical role in supporting field conservation initiatives by providing temporary or long-term care to injured, sick, or displaced turtles, as well as safeguarding individuals until release or translocation is feasible.

The protocols outlined in this section describe standardized practices for enclosure design, sanitation and hygiene,

husbandry, nutrition, quarantine, health management, identification, and transport of freshwater turtles maintained in captivity. These guidelines are intended to support uniformity in management practices across conservation facilities and apply to a wide range of freshwater turtle species. Where necessary, protocols may be modified based on species-specific ecological requirements, life-history stages, and site-specific logistical constraints.

Enclosure Design and Environmental Enrichment

Freshwater turtles are predominantly aquatic and require enclosures that ensure continuous access to clean and fresh water. Enclosures must be designed to facilitate natural behaviours such as swimming, basking, and burrowing, while ensuring animal safety and ease of management.

A layer of clean sand should be provided at the bottom of ponds to allow turtles to burrow and remain concealed. Enclosures must be securely fenced to prevent escape and to protect turtles from predation or disturbance by other animals. An open terrestrial area, either along the periphery or as an island within the pond, should be provided for basking. Proper vegetation should be maintained inside and around enclosures to simulate natural habitat conditions and improve microclimate. A walkway along the edge of the enclosure is essential to provide caretakers with safe and complete access for feeding, monitoring, cleaning, and routine maintenance.

Fig: plants to provide natural habitat

Fig: Basking Platforms

Water quality is a critical requirement in freshwater turtle enclosures. Regular monitoring of water parameters is essential. Water should be free of chlorine, slightly acidic to neutral (pH 6.5-7.0), adequately filtered, and well oxygenated. Maintenance of water quality requires an efficient filtration system and regular water exchange.

Sanitation and Hygiene

Separate cleaning equipment and accessories must be designated for each enclosure to prevent cross-contamination. Personnel entering enclosures should wear appropriate protective clothing such as gloves, boots, and dedicated work attire. Separate clothing and protective gear must be used for quarantine enclosures.

Routine sanitation protocols should be strictly followed. Leftover food and organic debris must be removed daily. During cleaning operations involving disinfectants, turtles must be temporarily shifted out of the enclosure to avoid exposure.

Husbandry Practices

Maintenance of sanitation and hygiene is essential for effective captive conservation, as it helps prevent the majority of infectious diseases. Pond sanitation is achieved by replacing approximately 10% of the total water volume daily. Monthly scrubbing and thorough cleaning of ponds should be carried out, along with regular cleaning of the surrounding premises.

Water quality must be maintained using natural or biological filtration systems, and the use of chemical additives should be avoided. Key water quality parameters such as pH, temperature, dissolved oxygen levels, and bacterial load must be monitored regularly.

Restricted entry protocols are followed within the facility. All personnel entering turtle enclosures must pass through footbaths containing diluted potassium permanganate solution. Footbaths are installed at each enclosure entrance as a preventive biosecurity measure to inactivate viruses, bacteria, and protozoans.

Diet and Nutritional Requirements

Freshwater turtles exhibit considerable variation in diet and feeding strategies due to their wide distribution across diverse aquatic habitats (Bonin et al., 2006). Their slow metabolism may account for a relatively high tolerance to dietary imbalance (McWilliams, 2005). In the wild, turtles may experience starvation or malnutrition due to competition, overpopulation, or adverse climatic conditions.

Wild freshwater turtles function as opportunistic carnivores or omnivores, consuming invertebrates, small vertebrates, and vegetation to meet nutritional requirements (Rhodin et al., 2008). In captivity, inappropriate or imbalanced diets may lead to nutritional deficiencies, while excessive feeding may result in obesity. Due to their longevity and the energetic demands of shell mineralization, turtles are particularly susceptible to long-term nutritional deficiencies (McWilliams, 2005).

Nutritional requirement of young Chinese soft shell turtle

Nutrient components	Levels/ percentage	Reference
Protein: Energy	32-36 mg/Kj-1	Zhou et al., 2013
Protein	39.0- 46.5%	Jia at el., 2005, Zhou et al., 2013
Fat	8.8%	Huang et al., 2005
Calcium	5.7%	Huang et al., 2003
Phosphorus	3.0%	Huang et al., 2003
Methionine	1.03%	Huang and Lin 2002
Methionine	2.48% of protein	Huang and Lin 2002
Cysteine	0.25%	Huang and Lin 2002
Cysteine	0.6% of protein	Huang and Lin 2002
Taurine	0.9 %	Hou et al., 2013
Magnesium	970- 980 mg/kg	Chen et al., 2014
Iron	266-325 mg/kg	Chu et al., 2007
zinc	35-46 mg/kg	Huang et al., 2010
Copper	4-5mg/kg	Wu and Huang 2008
Carotene	49-89 mg/kg	Chen and Huang 2011
Vitamin C	2500 - 5000 mg/kg	Zhou et al 2002
Vitamin A	2.58- 3.48	Chen and Huang 2014
Vitamin E	40 IU/Kg-1	Huang and Lin 2004

Nutritional composition of commercial foods for turtles (nonspecific food) Rawski, M., et al. (2013)

Crude protein (%)	Fat (%)	Fibre (%)	Ca (%)	Phosphorous (%)
38 (min)	7.4 (min)	3.4 (max)	2.2 (min)	1.2 (min)

There are no standardized nutritional requirements available for freshwater turtles. Therefore, nutritional standards developed for farmed freshwater turtles are used as reference. Newly hatched turtles do not require external feeding for the first few days post-hatching, as nutrition is derived from absorption of the yolk sac (Mitchell and Tullu, 2009).

Feeding Strategies and Nutritional Management

When turtles are maintained as breeding stock under conservation breeding or reintroduction programmes, raw diets are considered most appropriate. Raw diets consist of live, fresh, dried, or frozen food items and are provided without numerical nutrient calculations. A wide range of invertebrates, vertebrates, and plant matter may be included. Food items must be fresh or singly frozen to prevent microbial contamination and nutrient degradation.


Virgo
TARE
PCS
350
V510
ON/OFF
weighing scale

Insects provide high-quality protein and essential amino acids, though calcium and vitamin supplementation is required. Fish provide vitamins (A, B complex, D?), minerals (Ca, P, Fe, S), and long-chain polyunsaturated fatty acids (Tacon and Matein, 2013). Plant matter is also important to simulate natural feeding behaviour, and aquatic plants such as duckweed and pondweed may be maintained permanently in enclosures.

Turtles may consume food quantities up to 12% of their body weight. In India, standard feeding protocols include 10-12% of body weight for herbivorous turtles and 7-10% for omnivorous or carnivorous turtles (Baghel, 2016).

Commercially manufactured feeds represent an alternative feeding strategy and are commonly used for pet or farmed turtles. These feeds are plant- or animal-based, extruded or pelletized, and formulated to meet crude protein and fat requirements. When plant-based feeds are used for carnivorous species, supplementation with calcium, magnesium, and phosphorus is required. Feed selection should be based on the growth stage of the animal.

A balanced diet maintains metabolic equilibrium without net gain or loss of nutrients (Baghel, 2016). Diet formulation must consider nutrient content, energy value, digestibility, and species-specific requirements that vary with age, sex, season, and reproductive status. Feed efficiency is assessed through body weight measurements and monthly morphometric analysis.

Quarantine and Disease Management

Quarantine involves the isolation of animals with no direct or indirect contact with resident individuals. During quarantine, diagnostic testing and treatment protocols are implemented. Facilities must allow adequate visual access for clinical examination, sampling, restraint, and effective isolation.

A single designated caretaker should manage quarantine enclosures. Regular disinfection using appropriate disinfectants must be ensured. The minimum quarantine period should be 30 days, during which comprehensive health assessments are conducted.

Identification Methods

Individual identification is essential for record maintenance and health monitoring. Metal tags may be attached to the carapace or hind limbs for identification. Temporary identification may be carried out using non-toxic paint applied in small quantities. Passive Integrated Transponder (PIT) tags may be used for permanent identification.

Handling and Transport

Small to medium-sized turtles can be handled by securely holding the shell on either side between the fore and hind limbs. Larger softshell turtles are aggressive and should be restrained firmly from the rear portion of the carapace using both hands.

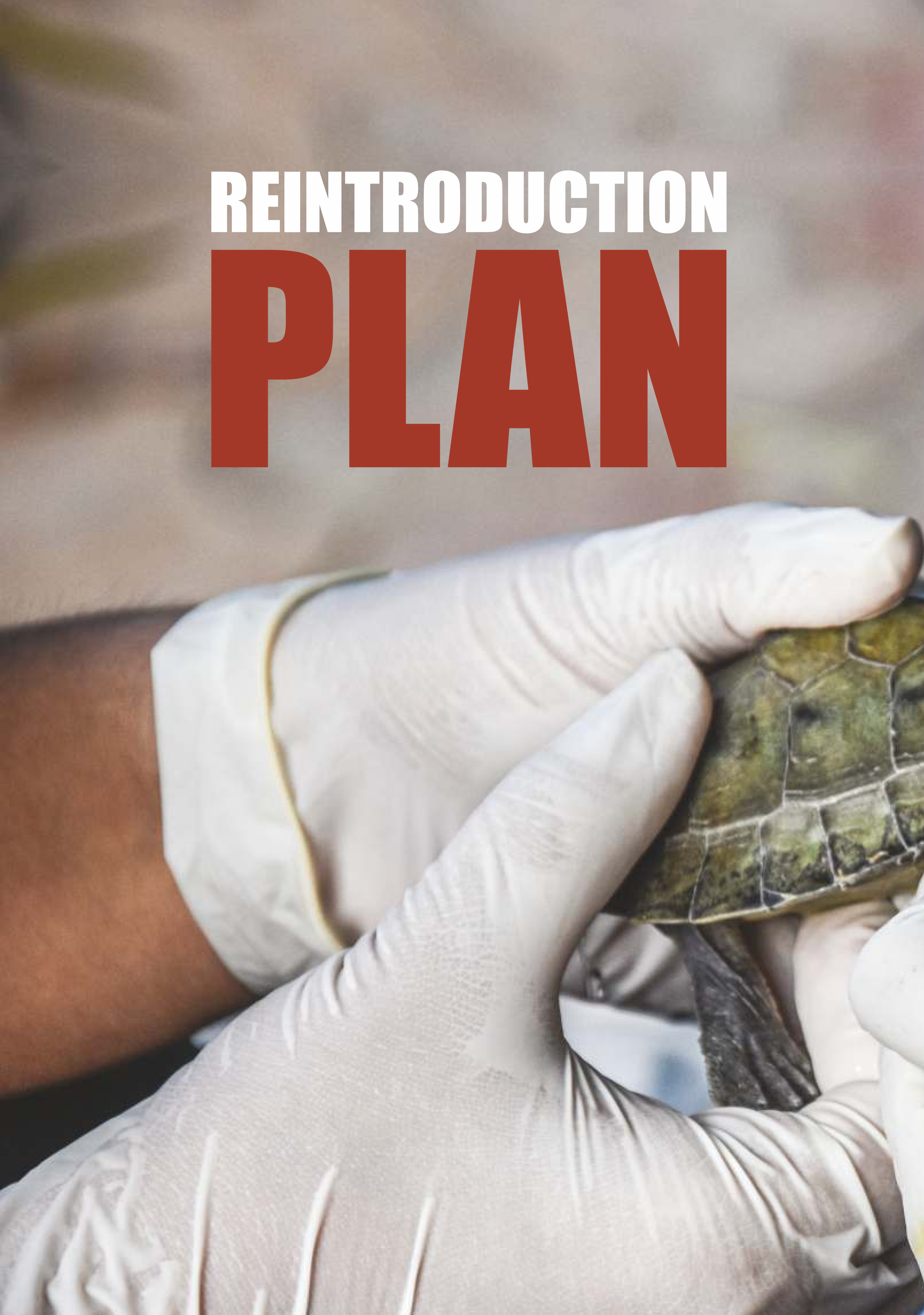
Fig: Handling small turtles

Fig: Handling medium to large turtles

Transportation should be conducted during cooler periods of the day. Transport containers must be securely positioned, maintained upright, and designed according to species and size. Containers may be constructed from wood, cardboard, or polystyrene and must be well ventilated and free of sharp edges. Aggressive individuals should be transported separately.

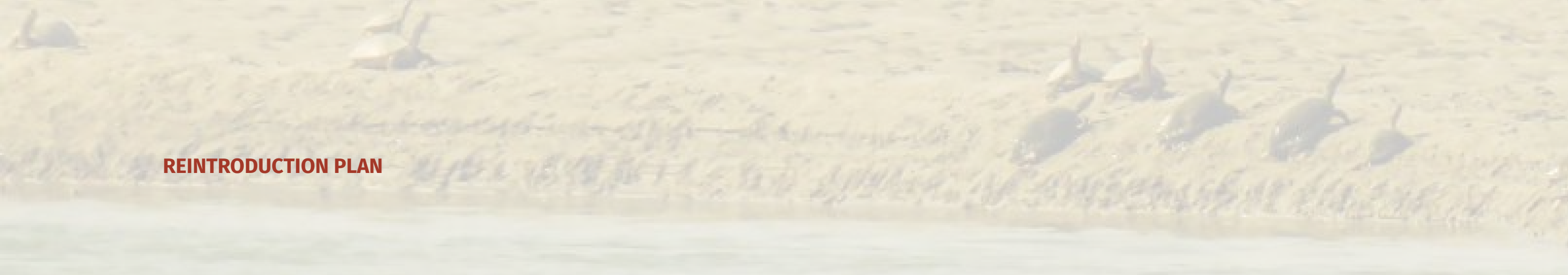
Fig: Transportation of turtles

REINTRODUCTION PLAN



INTRODUCTION

Freshwater turtles are facing increasing challenges for their sustained survival at a global level. The 14 species inhabiting the Ganga Basin are facing similar challenges as their global counterparts with an added challenge in the form of the human anthropogenic pressure being exerted on the riverine system by one of the densest human population aggregations on the earth. The present document includes four species two hardshell (*Batagur kachuga* and *B. dhongoka*) and two softshell species (*Chitra indica* and *Nilssonia gangetica*). The species have been selected as they are facing severely threatened in their present habitats and are restricted to only the Indian subcontinent, additionally, they are umbrella and indicator species and their conservation would lead to the conservation of the rich biodiversity of which they are an integral part.



Anthropogenic factors such as rapid industrial growth, development of linear infrastructure, fragmentation and degradation of freshwater habitats over the last hundred years has resulted in fragmented and declining populations. The species have become extirpated from a large part of their historical range despite efforts in the form of establishment of protected areas, dedicated rearing facilities and improved protection and community outreach. It thus becomes imperative to initiate systematic, science-based reintroduction programs for their sustained conservation has become increasingly urgent. This reintroduction plan aims to re-establish, reinforce, and expand populations of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* in suitable habitats across their historical range in the Ganga Basin. Habitat restoration, enhanced protection efforts, reinforcement of existing populations and reintroduction in suitable habitats are complimentary strategies that are the key to success for ensuring species recovery of the four species.

GOALS, OBJECTIVES AND ACTIONS

To achieve a self-sustaining, viable populations of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* in suitable habitats across their historical range in the Ganga Basin through scientifically guided reintroduction and integrated conservation strategies.

Objectives:

- To identify, protect and restore critical habitat of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* by species appropriate threat mitigation strategies.
- To reestablish and augment populations of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* in suitable habitats across their historical range in the Ganga Basin in suitable habitats and increase the number of breeding individuals and expand the current distribution expanse.
- To establish viable meta-populations with multiple sub-populations for ensuring long-term sustainable conservation.
- To enhance scientific knowledge of ecology of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* through planned research and intensive monitoring programs.
- Regular surveys and nest monitoring of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* populations for assessing progress of species recovery.

The above objectives are aligned with the goal of maintaining multiple self-sustaining populations of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* for achieving identified conservation goals. The document discusses the achievement of specific targets for each objective through measurable performance indicators.

METHODOLOGY

The development and implementation of this reintroduction plan follow a science-based, participatory methodology consistent with IUCN guidelines for reintroductions and other conservation translocations. The planning includes thorough status review and threat assessment: compiling all available information on *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* distribution, ecology, and threats in India. Relevant published and unpublished literature was reviewed alongside field data from ongoing ecological assessment of rivers in the Ganga River Basin. The plan is structured into clear components: a vision for the species long-term future in India, a set of goals and measurable objectives with indicators to guide progress, and a detailed action plan outlining the strategies and activities needed to achieve those objectives. The vision and goals articulate an achievable desired future state such as self-sustaining viable the four identified turtle species populations across river systems. A stepwise adaptive management approach is also proposed: pilot releases are monitored to inform subsequent efforts, and the plan provides for feedback loops to refine techniques over time. By combining robust scientific methods with stakeholder engagement at every stage, the plan maximizes the likelihood of successful reintroduction outcomes and sustained conservation impact.

The methodology for reintroduction itself is based on the IUCN best practices for conservation translocations. This means that prior to any release or translocation, rigorous feasibility assessments are done ensuring habitat suitability, threat control, and genetic/health screening of stock. Following components are proposed:

Site selection

Identification of suitable release sites is fundamental to the success of reintroduction of the four identified turtle species. The plan establishes specific site selection criteria to evaluate potential reintroduction or restocking sites, ensuring that resources are focused on within the areas where highest recover can be achieved.

- The reintroduction site should lie within the historical and current range, with records of past occurrence or nearby existing populations. Priority should be given to river stretches where breeding of was earlier recorded, or adult population thrived but are now depleted or locally extinct.

- The release site, if no turtle is recorded from the site in last 10 years or over, the habitat must meet the species ecological requirements deep pools, sandbanks for basking and nesting, and abundant prey base. A minimum of 10 km contiguous suitable stretch is recommended to support a viable home range and movement.
- The release sites should be lower threat environments free of any intensive human disturbances such as water abstraction projects, sand mining, fishing activities. Site need to be assessed for the intensity of threats and the feasibility of mitigating them and sites with manageable threats where interventions, patrolling, community programs, alternate livelihoods for sand mining and fishing can be also included. Sites with presence of any catastrophic threats such as point source pollution and incident of wildlife poaching should be excluded.
- Preference should be given to river stretches that fall within or adjacent to existing protected areas such as Wildlife sanctuaries and National parks or those that can be declared as Eco-sensitive zones. In case of unprotected stretches those are suitable for release, strong commitment from local authorities to enforce conservation measures is a prerequisite.
- The site considered for release should contribute to a larger meta-population. For example, if suitable sites are chosen in tributaries where the population is already present in the mainstem river will facilitate genetic exchange if natural movement is possible. While dams and barrages fragment many rivers, sites that are relatively connected or where corridors can be restored/managed are prioritized. If, required human assisted movement of animals to facilitate geneflow can be carried out.
- At the end the attitude and support of local communities and stakeholders are critical. Sites where local communities are cooperative or can benefit from turtle conservation through ecotourism or community fishing regulations are favoured. Prior to selection, extensive awareness campaigns and consultations are conducted to ensure stakeholder buy-in and to identify any social challenges that need addressing.
- Each of these identified sites needs to undergo a detailed feasibility study before reintroduction, including baseline surveys of prey fish populations, habitat quality, and threat mapping. By applying rigorous site selection criteria, the plan ensures that reintroductions are attempted only where the four turtle species have the best chance of survival and reproduction.

Reintroduction Strategy

- The reintroduction strategy outlined in this plan is a multifaceted approach encompassing captive breeding and grow and release, wild-to-wild translocations, and careful post-release management. The goal is to restore *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* populations in targeted rivers through phased releases while maximizing survival and integration into the wild ecosystem.

Fig- Captive reared turtles released into the wild.

- **Grow and release:** The success of population recovery efforts for the four species hinges on the effective implementation of a grow and release strategy, wherein wild-collected eggs or hatchlings are captive-reared and later released into the wild at a size less vulnerable to natural threats. This approach enhances early survival and facilitates the re-establishment of the four identified turtle species populations in suitable habitats. Facilities including the Turtle breeding Centre, Sarnath, Varansi, Turtle Rearing Centre, Barhi, Bhind, Deori Gharial Rearing Centre (Morena) and the Gharial Rehabilitation Centre in Kukrail (Lucknow), can be further strengthened and expanded.

  It is also essential to develop Standard Operating Protocols (SOPs) for grow and release, nest site protection, nest rescues, husbandry practices, diet, health monitoring screening, size/age at release to improve post-release success.

- **Wild-to-wild translocations:** In addition to captive releases, the strategy employs translocation of wild Turtles in certain scenarios. For example, adult or subadult turtles of the identified species from established population such as Chambal population can be translocated to augment smaller populations that lack sufficient breeders such as in mainstem Ganga. Such reinforcement translocations should be carefully planned to ensure source populations are not harmed.

- Reintroductions should be conducted in phases over multiple years, rather than a one-time release. A moderate number of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* (approximately 100) juveniles should be released initially and survival should be monitored. Subsequent batches can be released in following years based on the success of earlier releases and capacity of the habitat. Timing of releases should generally coincide with favorable river conditions for instance, post-monsoon season (November to February) when water levels stabilize and prey availability is high, giving the young turtles time to disperse and feed before the next monsoon. Release timing should will also avoid the peak breeding/nesting season to prevent disruptions to any resident turtles of the four species.

- Prior to release or translocation, all individuals should undergo thorough health examinations and, if possible, genetic screening. This is to prevent introducing any pathogens to wild populations and to maintain gene pool.

- Every reintroduction site should have a detailed post-release monitoring program. Released turtles need to be marked before release to track their movements, survival, and behavior. Field monitoring is crucial to detect any mortalities if any. Information on survival will be used to develop adaptive management strategies. For example, if high mortality is observed due to fishing nets, more intensive patrolling or community engagement will be triggered in that area. If released juveniles tend to disperse out of the identified release site, no release should be done on same area and alternative release sites must be for future releases might try or methods to improve site fidelity. The reintroduction strategy is thus explicitly adaptive, learning from ongoing results to refine release numbers, age-classes, or techniques for maximum success.

- Overall strategy of combined captive restocking and strategic translocations is designed to rebuild populations of the four turtle species in multiple rivers while safeguarding the source populations. It also ensures that reintroduction does not occur in isolation and each release is accompanied by habitat protection and community awareness efforts so that the rivers are safe for the juvenile turtles being reintroduced. Over time, as these efforts bear fruit, we envision currently unoccupied rivers once again supporting breeding populations of *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica*, contributing to a meta-population population across the distribution range.

HABITAT MANAGEMENT AND PROTECTION

- Long-term recovery of the four identified turtle species depends on suitable river habitats and the mitigation of threats that have historically decimated the species. Therefore, removing threats, habitat management and protection measures in tandem with reintroductions are key to the success of the reintroduction program. The focus is on creating secure river stretches where *Batagur kachuga, B. dhongoka, Chitra indica* and *Nilssonia gangetica* can breed, feed, and disperse with minimal human-induced pressures. The key strategies outlined are:
- **Environmental flows (e-flows):** Altered water flow regimes due to dams and water extraction have greatly impacted riverine habitats by fragmenting rivers and reducing deep pools. While large dams cannot be removed, it is important to maintain flow at adequate level suitable for the four turtle species in regulated rivers. Managing water discharges that mimic natural flows to some degree, maintaining sufficient depth and flow especially in the dry season. A study for determining the critical e-flow for the four turtle species needs to be conducted across the rivers in the distribution range for identifying suitable existing habitats and management of sub-optimal habitats that can be converted into optimal habitats through planned interventions.
- **Pollution Control:** The four turtle species thrive in clean, unpolluted rivers. Pollution from industrial effluents, agricultural runoff leading to high pesticide levels can deplete fish prey and impact recovery of the four turtle species. Periodic monitoring of water quality at designated sites and the establishment of permanent water quality monitoring stations in the their habitats will facilitate monitoring of contaminants that affect aquatic life and implementing appropriate ameliorative strategies through better waste management and effluent treatment.
- **Mitigating sand mining:** Illegal sand mining on riverbanks is identified as one of the most severe threats to turtle habitat, particularly *Batagur dhongoka* and *B. kachuga* as it destroys sandbanks used for nesting and basking. The plan calls for strict enforcement of mining in critical turtle habitats, especially in and around identified nesting sites. Coordination with mining departments and local authorities need to be strengthened to designate "No-go zones" for mining (particularly in known nesting stretches) and to prosecute violations. Community surveillance involving local communities/ Ganga Praharis will stregthen official patrolling to curb illegal mining. Additionally, restoration of degraded sandbanks where possible through rebuilding or reprofiling banks before the nesting season.
- **River bed agriculture:** One of the major threats to turtle habitat in majority of the range rivers is the widespread practice of riparian agriculture, particularly in sandbanks and islands. Associated activities such as water abstraction using pumps, continuous human presence for pump operation and crop protection, and the use of agro-chemicals (pesticides and fertilizers) significantly contribute to pollution. Assessment of habitats under the WII-NMCG project has documented extensive bankside cultivation, often occupying entire riverbanks right up to the shoreline. This results in the loss of critical basking and nesting sites essential for the thermoregulation and reproduction of turtles particularly *Nilssonia gangetica* and *Chitra indica*. Such encroachment not only reduces available habitat but also increases the likelihood of human-wildlife conflict. For effective reintroduction and long-term survival of the four identified turtle species, it is imperative that riparian agriculture be regulated within critical habitats. It is recommended that a combination of habitat demarcation, legal enforcement, alternative livelihood support, and community engagement to minimize this threat.
- **Regulating fishing and reducing bycatch:** Unsustainable fishing practices are a critical factor undermining turtle populations getting entangled and drowning in gill nets. To address this, it is crucial to designate "fishing-free refuges" along key nesting sites and stretches with high turtle abundance with no-fishing zones. Traditional artisanal fishermen being impacted by loss of livelihood may be compensated by inclusion in the conservation efforts and monetarily.

- **Community-based regulation:** Promoting fishing communities to adopt sustainable turtle-friendly practices such seasonal fishing closures during the turtle breeding season, avoiding the use of certain net types such as fine monofilament gill nets and creation of awareness among fishermen on how to safely release entangled individuals and report any incidents compromising the safety of turtles.
- **Rescue and response:** Capacities of Ganga Praharis have been strengthened in the rescue of turtles; they should be suitably incentivized to rescue any turtles found trapped in nets.
- **Protected area Management and patrolling:** All proposed turtle reintroduction sites should be within the existing protected area network for enhanced protection. The protected area managers need to prioritize the protection and management of aquatic habitats in their PAs through enhanced patrolling of riverine stretches, nest and basking site protection and mobilizing community support.

Intensive protection and management of critical turtle habitats that include nesting and basking beaches by reducing the operational threats such as sand-mining unregulated fishing, riverbank agriculture and ensuring maintenance of critical e-flows can ensure a sustainable future for the freshwater turtles inhabiting the Ganga Basin. The efforts will also ensure the conservation of the remaining turtle species that are presently not so severely threatened and other allied biodiversity inhabiting turtle habitats. It will also help in ensuring healthier rivers for the human society that provide sustainable resources for the riverside communities.

RESEARCH AND MONITORING

Extensive gaps in knowledge exist on all the four identified turtle species that includes population dynamics, dispersion patterns, disease susceptibilities, habitat ecology to name a few. The success of any reintroduction and conservation effort hinges on developing adaptive strategies based on habitat requirements and ability to address susceptibilities of the species to adverse environmental conditions. A strong science-based monitoring program that is aimed at addressing lacunae in knowledge is the key to effective conservation. The suggested monitoring and research framework includes:

- **Population and habitat monitoring:** All sites with existing or reintroduced populations should be monitored using standardized protocols that are uniform across the range. It includes regular population surveys based on basking counts and nest counts during the breeding season assessing the number of adult nesting females. The annual census of Gharials in the National Chambal Sanctuary, conducted jointly by state forest departments in collaboration with WII and other agencies can form a basis for this population monitoring exercise. These surveys will provide crucial information on population trends and reproductive success. Additionally, habitat monitoring using modern geospatial tools, Unmanned Aerial System (UAS) and acoustic doppler current profiler (ADCP) to track changes in the physical habitat (sandbank availability, water depths in critical pools), water quality parameters aquatic vegetation community analysis in the river and along the banks. The information obtained from these studies will form the basis for assessing the success of ongoing conservation efforts, identifying shortcomings and developing mid-course corrections.

  Involving local communities in the monitoring effort besides these planned studies will support conservation efforts by carrying out regular monitoring and reporting of sightings in their areas besides providing support for protection of nests and mobilizing community support for the conservation effort.

- Post-release monitoring and adaptive management: Any effort aimed at conservation of a species of which reintroduction and/or translocation are a major part requires intensive monitoring for measuring success of the effort. The monitoring effort is focused on assessing success of colonization by the released animals in their new habitat and their ability to establish breeding colonies that can re-establish/augment the population of target species. Radio/satellite/GSM/acoustic telemetry transmitters mounted on a representative sample of individuals from each batch of released animals facilitate the collection of fine-scale data on survival, movement patterns and habitat use of the released animals. This information is invaluable for assessing the success of the reintroduction effort wherein high survival rates and site fidelity indicate a good match of the species with the release site and vice versa. Positive results indicate a successful effort while negative results call for developing alternate strategies and identification of alternate sites. This supports the development of an adaptive management loop where data from monitoring on survival rates, causes of mortality, magnitude of disturbance provide the necessary feed-back for decision-making. If monitoring data for example indicates dense aggregation of released individuals in particular areas or an increased mortality through fish-net entanglement or the adverse impacts of agro-chemicals, measures designed to address the newly identified patterns or threats can be rapidly implemented. A mid-term evaluation by concerned stakeholders (after ~2 years) for reviewing monitoring data and adjust strategies numbers released, methods, site choices as needed can facilitate implementation of adaptive management strategies.

STAKEHOLDER INVOLVEMENT AND CAPACITY BUILDING

Every conservation effort has multiple stakeholders and freshwater turtles inhabiting rivers involving complex linear habitats with multiple users have a large number of stakeholders that includes but is not limited to State Forest and Irrigation Departments, Local Communities, Policy planners and Administrators etc. Understanding and addressing the needs of individual stakeholders and sensitizing them to the overall conservation plan are key initial steps in involving the multiple stakeholders in the conservation of the identified species. Fostering a collaborative stewardship model where stakeholders are informed, empowered, and motivated to contribute to recovery of the identified turtle species is basis for effective conservation. Key strategies include:

- **Community participation and awareness:** Local communities, especially river-dependent communities, are both affected by and crucial to the success of conservation of the identified four turtle species. Extensive education and awareness programs in villages and towns near identified priority turtle habitats are proposed to be taken up through outreach campaigns as communities need to be sensitized to the ecological role of freshwater turtles and the benefits of conserving them. Highlighting local success stories can support creating empathy in community members. These sensitized community members should also be involved in practical conservation actions including monitoring and protecting nests and reporting illegal activities. Eco-development committees can be the focal point for such programs. The incentivizing of community involvement through alternate skilling for reducing dependence on resources from the river can be an important part of promoting local community support for the conservation of turtles at the sites selected.

Fig- Awareness program with river side local community.

- **Capacity building of frontline forest staff:** Frontline staff of state Forest Departments are the implementers of actions on ground. Regular training programs for enhancing their capacity in turtle-specific conservation and monitoring techniques is integral to the overall conservation effort. It includes skill enhancement in turtle handling and rescue for safely capturing and relocating animals when needed, nest protection, nest rescue for securing them from predation or flooding. Programs across range states enable dissemination of knowledge on turtle biology, threats, and mitigation measures for creating a well-informed and aware line of defense involved in the conservation of turtles. The capacity building efforts can be strengthened through cross-site visits to areas where ongoing successful programs are operating. The plan envisions creating a network of trained practitioners who can implement conservation of identified turtle species across states.

Fig- Capacity building of frontline forest staff

- **Inter-sector-state coordination platforms:** Conservation of the identified turtle species involves multiple sectors, agencies and states with limited communication channels. Effective conservation of the identified turtle species can be strengthened by creating working groups or task forces including representative stakeholders across the range. At a local level for implementation and monitoring purposes such groups may include members from the local communities, forest, irrigation and law enforcement officials. Such groups should preferably also include voluntary organizations in the area that are working in similar fields. While at an interstate level a steering committee comprising of representatives from stakeholder agencies, scientific organizations can meet for designing and implementing actions that facilitate conservation while supporting the needs of the stakeholders.
- **Outreach and advocacy:** Often the immediate stakeholders are unable to achieve conservation goals by themselves and require a broader public support for creating a supportive environment for conservation of the identified turtle species. An outreach to broader audiences and policymakers can better support conservation by sensitizing them through outreach and advocacy programs. Public campaigns in cities using media and other means can highlight the plight of the identified turtle species and the ongoing and planned Government efforts for their conservation. Such activities can generate public goodwill and create empathic conditions for support from policy makers.

POLICY AND LEGAL FRAMEWORK

- A strong legal basis underpins the conservation of any successful conservation effort and the conservation of the identified turtle species is no different from this. The four turtle species are accorded the highest legal protection in India through their inclusion in Schedule I of the Wild Life (Protection) Act, 1972, which prohibits their killing or capture and provides for strong penalties, further ratification of internation conservation treaties can strengthen protection measures through improved information sharing and better prosecution of offences. Additionally, as most populations exist outside the Protected Area network due to the dynamic nature of their riverine habitats their effective conservation requires habitat protection outside the PA network. An integrative approach that addresses the complex challenges of conservation of riverine fauna is thus required. This plan thus advocates several policy and legal measures for the effective conservation of these turtle species.
- **Strengthening protected area networks:** An expansion of the existing Protected Area network to include key habitat stretches that provide suitable reintroduction sites necessitates their being afforded legal protection through notification of new PAs viz. as a Conservation Reserve or Sanctuary under the WPA, or minimally declaring such sites as an Ecologically Sensitive Area under the existing environmental laws. This legal designation would facilitate better regulation of threats like discharge of effluents, fishing and sand mining. The Ganga Basin has an extensive network of Protected Areas designated for conservation of charismatic terrestrial fauna. Most of these PAs have an extensive riverine network traversing through them or forming their boundaries. Existing management interventions are focused on the conservation of terrestrial fauna with a limited emphasis on aquatic fauna. Upgrading the management plan of these PAs to also focus on conservation of the four turtle species and other aquatic fauna would strengthen conservation efforts and provide additional areas for establishing self-sustaining populations.
- **Integration with water and fisheries policies:** One of the primary threats aquatic fauna faces is from habitat fragmentation caused by construction of water diversion structures and allied linear infrastructure. These activities are not regulated by the Forest departments of the concerned states, rater they are regulated by the irrigation and fisheries department with a totally different set of objectives. They are one of the key stakeholders involved in the use of riverine resources. Their integration into conservation activities is of critical importance for any meaningful conservation effort. Inland fisheries policies of the states may be modified to declare habitats critical for these four turtle species as no fishing zones. The plan also embraces the National Mission for Clean Ganga (NMCG) and similar river rejuvenation programs, ensuring that biodiversity considerations aimed at protecting key aquatic habitats become one of the success metrics of those missions. By influencing these sectoral policies, the plan aims to create a policy environment supportive of conservation of these four turtle species integrating it as a part of sustainable river management.
- **Enforcement and judicial support:** Despite laws in place for conservation of habitats and species, enforcement on large rivers can be challenging due to multiple stakeholders. Extensive environmental legislation aimed at protecting freshwater habitats are in place. The same are however, in a continuous state of conflict with escalating economic

development needs. An informed and sensitive judiciary that is able to balance economic development goals with conservation concerns is key to striking a balance of economic growth with conservation. Additionally, offences against turtles are a big challenge in their conservation. The document proposes sensitization programs for judicial officers for enhanced enforcement mechanisms besides special wildlife crime control units dedicated to riverine habitats. Additional support as required may be provided by local police and revenue authorities.

- **Policy for ex-situ support:** The entire reintroduction paradigm is based on the availability of individuals for the reintroduction/ translocation programs. The judiciousness of extracting individuals from already depleting populations would further exacerbate declines in a population already in a perilous state. Head-starting programs for turtles with eggs collected from nests that face predation, anthropogenic or other threats form a basis for developing populations for release in restored/ suitable habitats. The existing ex-situ policy framework under the WPA empowers Central Zoo Authority to regulate the functioning of zoos and other captive wild animal facilities including conservation breeding centres. The existing regulatory framework however, is inadequate in addressing the needs to address the challenges in managing head-starting facilities. Additionally, the larger zoos and specialized breeding centres in the natural range of the four turtle species need to establish breeding colonies of the four turtle species. The work is currently being undertaken at Gharial rehabilitation centre, Morena, Nawab Wazid Ali Shah Zoological Park, Lucknow, Kukrail Gharial rearing Centre.

  Sensitization programs that develop skills of the personnel involved in managing these facilities for addressing, genetic, health concerns so that they are able to produce surpluses for reintroduction is key to the success of the ex-situ aspects of the overall conservation effort. Additionally, standardized housing and husbandry practices that facilitate management of the animals while ensuring that they retain natural behavioural traits for adapting to free ranging conditions on release need to be adopted at these centres.

- **Securing funding and incentives:** Policy support and community participation ensures sustained financial support mechanisms that are key to these conservation efforts. The plan urges the government to allocate dedicated funding for aquatic biodiversity conservation - possibly as species recovery programs funded through the Ministry of Environment, Forest and Climate Change or through NMCG's biodiversity component. Dedicated funding support to ensure continued salaries of field personnel and other establishment expenses, equipment, research and community compensation over the plan period needs to be available. Additionally, innovative funding mechanisms such as corporate social responsibility (CSR) funds for specific components like sponsoring a breeding center upgrade or community livelihood projects may also be considered. The policy could provide incentives or recognition for communities contributing to conservation. By institutionalizing long-term sustainable funding sources and incentives, the plan ensures longevity beyond short-term project cycles.

  The Policy and Legal Framework for turtle reintroduction as envisaged in the current document would facilitate integrating the policies regulating riverine water usage and management across multiple agencies and stakeholders besides providing a strong legal mandate for its implementation. It focusses on better implementation of the existing policy framework while leveraging for increased inter-agency cooperation. It also attempts to address the issue of critical issue of flow of essential for achieving effective conservation goals. A supportive policy empathetically enforced with appropriate on-ground actions like protection and monitoring can help in bringing these four turtle species and other associated fauna back from the brink.

Research

The document looks at key gaps in existing information on the four turtle species and identifies priority areas for research focus to facilitate evidence-based conservation initiatives. These include:

- **Ecology and demography:** Limited information on the life history strategies in the wild such as population growth rates and size/age class specific mortality, home range sizes, seasonal movements, and natural mortality factors regarding the four turtle species exists. Additionally, while existing studies broadly outline the ecological requirements of the four species, limited information on how they are able to coexist in similar habitats is available. Keeping in view the perilous state of their populations and the declining habitat availability strong ecological evidence for more efficient conservation planning is required.

- **Husbandry, housing and health care:** A limited body of information based on experiential learning from captive facilities on housing, husbandry and health-care of the four turtle species exists. If ex-situ conservation is to be an integral part of the overall reintroduction plan of the four turtle species standardized husbandry, housing and health-care practices based on empirical knowledge obtained from captive and field studies is essential. As a case in point limited information on the dietary habits of these turtles in free ranging conditions exists, yet this information is crucial for devising captive diets for ensuring optimal growth and foraging strategies in the turtles. Gut content analysis of individuals of the four turtle species, necroscopic examination of carcasses encountered can all provide crucial information that can facilitate more effective captive management practices.

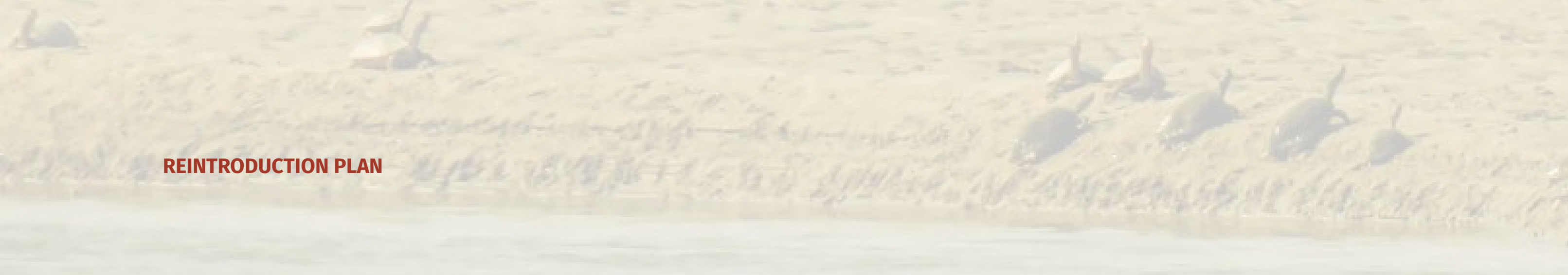
Fig- Captive management

- Health and disease surveillance: Turtles are believed to be hardy species, however climate change, increasing pollution and declining habitat quality render them vulnerable to disease outbreaks. Limited information on these aspects of the four turtle species exists from free ranging conditions. The limited information available is from captive studies or treatment records of animals in rehabilitation. An intensive disease surveillance program for pathogens and contaminants based on necropsy of any carcasses encountered from free ranging conditions, disease screening of biological samples collected from rescued individuals can form a basis for these studies. The information thus generated across centres and states can be pooled and analysed for disease dynamics of the four turtle species identified for reintroduction in the Ganga Basin.

Fig- Healthcere management

- **Genetic research:** The increasing fragmentation of habitats has strong genetic consequences for populations leading to concerns of genetic erosion and loss of functional diversity in populations. The four turtle species identified for reintroduction are no different, The reintroduction plan supports genetic studies to assess the genetic health of each population and the relationships between them. This will lead to informed translocation decisions and aid in selection of source populations for reinforcement and reintroduction.

- **Impact of climate-change:** Climate change poses a growing threat to riverine ecosystems and species with temperature-sensitive life histories, such as these four turtle species. Rising ambient and surface temperatures, coupled with altered precipitation and hydrological regimes, can significantly impact nesting success, sex ratios, and hatchling survival besides impacting habitat availability. Since turtles exhibit temperature-dependent sex determination (TSD), even slight variation in incubation temperatures leads to skewed sex ratios, undermining population sex ratios and potentially compromising future reproductive viability. As a part of the reintroduction and conservation strategy, research focused on evaluating the impacts of climate-induced temperature rise on the ecology and population dynamics of the four turtle species is imperative for ensuring long-term conservation success.



A centralized facility such as The GACMAC developed with funding support from NMCG, at the Wildlife Institute of can act as the coordinating agency for collation and dissemination of information and facilitating inter stakeholder/ agency cooperation. This would facilitate translation of research into conservation action.

IMPLEMENTATION TIMELINE

The reintroduction plan for *Batagur kachuga, B. dhongoka, Nilssonia gangetica* and *Chitra indica* is envisaged as a staged process over the next decade. This would be based on strong inter-state and inter-departmental cooperation and collaboration with committed financial and policy support and periodic monitoring. This section presents a roadmap with timelines for specific actions and the agencies/ stakeholders responsible for the same.

Phase	Activities	Timeline (in Years)	Agencies
Phase I: Preparation	Institutional setup	1-2	State wildlife agencies, Zoos, Breeding Centres,
	Source identification and stock development		
	Site selection and baseline assessment		
	Capacity building		
	Reinforcement of existing population		
Phase II: Reintroductions and Site Interventions	Habitat management and restoration	3-6	State wildlife agencies, Zoos, Breeding Centres,
	Start reintroductions activity		
	Mid-term evaluation		
Phase III: Consolidation and Expansion	Long-term protection measures	6-10	State wildlife agencies, Zoos, Breeding Centres, Wildlife Institute of India
	Coordination		
	Evaluation and next action plan		

PHASE I: PREPARATION AND CAPACITY BUILDING (YEAR 1-2)

- **Institutional setup:** Creation of dedicated central coordinating body for the conservation of the four turtle species at the national level comprising representatives from the Ministry (MoEFCC), state wildlife departments of range states, WII scientists, and Voluntary Organizations partners for overseeing the plan's rollout. It will meet regularly to review progress, facilitate inter-state cooperation, and troubleshoot issues. Similarly, site-level working groups or steering committees will be constituted for each priority river, involving local stakeholders.

- **Source identification and stock development:** Established breeding and rearing facilities such as the Turtle Breeding Centre, Sarnath Varanasi, Turtle Breeding Centre, Barhi, Bhind, Deori Gharial Rearing Centre (Morena) and the Kukrail Gharial Rehabilitation Centre (Lucknow) can act as the primary sources of developing and maintaining captive stock for reinforcement and reintroduction efforts. The existing infrastructure at the centres needs to be upgraded keeping in line with existing best practices for captive management of turtles that address species specific behavioural and ecological needs. Animals in the size classes identified for release should be housed in enclosures that facilitate natural foraging and predation for *Nilssonia gangetica* and *Chitra indica* while predator avoidance behaviours should be incorporated into the behavioural training of all animals as predation of released animals has long been identified as one of the major causes for failure of the animals to establish viable breeding populations on release.

  Standardized protocols for capture, handling and transport of animals should be developed and implemented. *Nilssonia gangetica* and *Chitra indica* are carnivorous turtles and are known to exhibit cannibalistic tendencies. Housing practices and transport containers should address these concerns.

In addition, wild-to-wild translocations may be considered where appropriate, particularly in cases where reintroduction sites possess depleted breeding groups. In such cases, the translocation of subadult or adult animals from robust wild populations can help re-establish functional population structures and promote genetic exchange between isolated groups.

The genetic concerns of loss of genetic diversity due to isolation needs to be addressed, additionally the issue of genetic swamping that is sourcing all animals for reintroduction from the same population should be avoided. Existing best practices for genetic health assessment of populations identified for translocation/reintroduction should be incorporated into the program.

- **Baseline assessment:** Comprehensive baseline habitat assessments should be conducted at all identified reintroduction sites prior to the release of turtles. The surveys of should asses aquatic fauna, with a focus on prey/forage diversity and abundance; habitat quality mapping, including sandbank availability, water depth profiles, and flow regimes; threat mapping, identifying locations and intensity of sand mining, fishing pressure, pollution sources, and other anthropogenic disturbances and socio-economic surveys of local communities to understand dependency on riverine resources, attitudes towards conservation, and potential for community engagement.
- **Capacity building:** Frontline-forest personnel engaged in protection measures and local community youth empathetic to the conservation effort should be trained on population monitoring and protection measures. Also, initiate community engagement in target areas i.e. initiate awareness programs create empathy for the reintroduction effort and create channels of communication for community reporting of sigtings of released animals and any crimes against the released population.

PHASE II: REINTRODUCTIONS (YEAR 3-6)

- **Start reintroductions activity:** The steps undertaken during Phase I should ensure the availability of adequate animals for release in suitable habitats preferably at multiple sites in the protected area network. Three protected areas that are specifically dedicated for the conservation of aquatic species viz. National Chambal Sanctuary flowing between the states of Rajasthan, Madhya Pradesh and Uttar Pradesh, the newly designated Turtle Sanctuary downstream of Prayagraj and Vikramshila Dolphin Sanctuary in Bihar can be used for establishing source populations if monitoring efforts indicate it. Locations that demonstrate high ecological readiness (meet critical habitat requirements of the species identified for release at the site), a supportive local community and where key threats have been addressed are to be preferred. Subsequent releases at these and additional sites should be carried out in Years 4, 5, and beyond, depending on site-specific monitoring of released individuals and habitat conditions. Each release event should be adequately planned to align with optimal seasonal conditions typically post-monsoon (November to February) to maximize survival of the released turtles and facilitate dispersal. These events outreach and community engagement strive to raise awareness, build local support, and foster stewardship for conservation of these turtle species and their aquatic habitats.
- **Habitat management and restoration:** The information obtained from the monitoring program can form a basis for additional habitat management, threat mitigation, and ecological restoration as required to be undertaken at the identified release sites. This should further strengthen the conservation efforts by improving ecological functionality of the habitats through mid-term correction for better ensuring long-term survival, growth, and reproduction. Stretches that are capable of supporting dense turtle populations should be declared no fishing and riverine agriculture zones through available legal measures and through community mobilization accompanied by compensation for livelihood losses. Historical and current data on basking and nesting sites can form the basis for identification of these stretches. Community-based surveillance mechanisms, including trained local volunteers and river watchers, should be established to monitor compliance and reduce incidences of bycatch, entanglement, and disturbance during the breeding season.
- **Mid-term evaluation:** Acritical review of activities undertaken and sites selected should be conducted during Year 5 or 6 as mutually acceptable to key stakeholders. The dedicated central coordinating body may assess the effectiveness of the reintroduction plan, following IUCN guidelines and existing best practices for similar species globally. The review will help determine the efficacy of interventions and the ecological outcomes achieved. The findings may be used for required modifications in the plans/ protocols being implemented. If any site is unable to achieve desired outcomes due to unforeseeable reasons alternate suitable sites may be considered or the resources allocated for supporting efforts may be transferred to sites that are meeting targets.

PHASE III: MONITORING, CONSOLIDATION AND EXPANSION (YEAR 6-10)

It is anticipated that the translocated/ reintroduced populations should ideally be reaching reproductive maturity and be possibly breeding. These are the key signs that the translocated/ reintroduced population has established in the site and future efforts should focus on protecting future nesting and hatchlings. If field observations suggest that natural survival may be uncertain, a portion of the eggs/hatchlings may be transferred for captive rearing. Additional reinforcement releases can be continued if needed to balance sex ratios or introduce fresh genes into the population.

- **Long-term protection measures:** If success has been achieved during the first two phases, the third phase should focus on consolidation of the conservation gains achieved by recognizing community and other stakeholder efforts. The success at one site may be attempted to be replicated at other sites. An additional challenge that needs to addressed is the continued financial viability of the program beyond the planned period through budgetary allocations through the state forest depart, CSR funding or even community conservation models based on ecotourism and river safaris.
- **Evaluation and next action plan:** by the beginning of the tenth year, a comprehensive evaluation needs to initiated to measure the plan's impact. Success indicators would be total number of nests of the designated turtle species at the site compared to that observed at the beginning, number of populations/ meta-populations established, decline in threat perception and community outcomes. The information obtained may be analyzed using predictive models by trained scientists. The outcomes of the analyses carried out and stakeholder feedback should be the basis for the future course of action till the population has stabilized and is self-sustaining.
- **Responsibilities and coordination:** The responsibility for implementation will primarily lie with the concerned state forest department in coordination with other line agencies and voluntary organizations. roadmap clarifies who leads each action. The dedicated central coordinating body for the conservation of the four turtle species will coordinate activities at the national level and facilitate cooperation from other state line agencies through establishment of mutually acceptable dispute redressal mechanisms, make available funding from its own resources or through mobilization from other sources, and handle inter-state or national-level tasks. The WII and other scientific bodies will lead research and monitoring components and community outreach programs.

नमामि गंगे

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