The recruitment pattern and inter-calving interval of the reintroduced greater one-horned rhinoceros (*Rhinoceros unicornis*) population in Manas National Park, Assam, India

Deba Kumar Dutta[1], Amal Chandra Sarmah[2], Amit Sharma[3], Bibhab K Talukdar[1], Anindya Swargowari[4]*

[1]13, Tayab Ali Bi-lane, Bishnu Rabha Path, Guwahati, Assam, 781028, India
[2]House No 38, South Sarania Road, Swahid Anil Deka Path, PO Ulubari, Guwahati, Assam, 781007, India
[3]WWF-India, Block A16, Flat No. 103, Basistha, Guwahati, Assam, 781029, India
[4]House No 18, Sonaighuli Don Bosco; PO Sawkuchi, Guwahati, Assam, 781040, India

*corresponding author: debakumerdutta@gmail.com

Submission date: 25 March 2025; Accepted version 11 June 2025.

Abstract
This study examines the reproductive performance and inter-calving intervals (ICI) of reintroduced greater one-horned rhinoceros (*Rhinoceros unicornis*) in Manas National Park (MNP), India, from 2012 to 2021. The Park's rhino population was previously wiped out due to poaching but has been re-established through the wild-to-wild translocations under Indian Rhino Vision 2020 (IRV2020) and rhino rehabilitation programmes. Our monitoring and analysis reveal that translocated and rehabilitated rhinos have adapted progressively to their new environment, with 35 calves born during the study period (2012–2021). We observed distinct conception patterns among translocated rhinos that conceived before translocation compared with those that conceived after their release in MNP. The average ICI interval for rehabilitated rhinos was 2.12 to 4.41 years, while for translocated rhinos it was 1.99 to 6.30 years. Study findings indicate that the average age at first calving for the first generation (F1) was 5.65 years. Our findings indicate that rehabilitated rhinos tend to calve near human presence, close to the anti-poaching camps, while translocated rhinos preferred more isolated areas. We also observed seasonal calving patterns, with most births occurring during the monsoon (May–September) season. The study highlights the importance of effective monitoring, anti-poaching measures, transboundary collaboration, habitat management and community support for the long-term conservation success of the rhino population in MNP. Our research contributes to the understanding of rhino reproductive biology in re-establishing populations and informs conservation strategies for this threatened species.

Résumé
Cette étude examine les performances reproductives et les intervalles entre les naissances du rhinocéros indien (*Rhinoceros unicornis*) réintroduit dans le parc national de Manas, en Inde, entre 2012 et 2021. Les rhinocéros y avaient été exterminés par le braconnage, mais des opérations de translocations entre populations sauvages sous le plan Indian Rhino Vision 2020, ainsi que des programmes de réhabilitation, ont permis leur retour au sein du parc. Nos suivis et analyses révèlent que les individus issus de translocation et de réhabilitation se sont progressivement adaptés à leur nouvel environnement, comme le montrent les 35 petits nés pendant la période étudiée. Des schémas de conception distincts ont pu être relevés parmi les rhinocéros issus de translocation, entre les individus ayant procréé avant la translocation et ceux ayant procréé après leur introduction dans le parc national de Manas. L'intervalle moyen entre les naissances pour

les rhinocéros réhabilités était de 2,12 ans à 4,41 ans, tandis que celui des individus issus de translocation était de 1,99 an à 6,3 ans. Les résultats de notre étude indiquent que l'âge moyen de la première conception pour la génération F1 était de 5,65 ans. Ils établissent également que les rhinocéros réhabilités tendent à mettre bas à proximité des zones de présence humaine – près des camps anti-braconnage – là où les individus issus de translocation privilégient les zones plus isolées. En outre, nous avons observé des schémas de mises bas corrélées aux saisons, la plupart des naissances ayant lieu entre mai et septembre, pendant la mousson. Cette étude souligne l'importance d'un suivi efficace, de mesures antibraconnage, de la collaboration transfrontalière, de la gestion des habitats et du soutien des communautés pour assurer une conservation de la population de rhinocéros dans le parc de Mana réussie sur le long terme. Nos recherches contribuent à la compréhension de la biologie reproductive des rhinocéros dans le cadre du rétablissement des populations et éclairent les stratégies de conservation de cette espèce menacée.

Introduction

Knowledge of the recruitment rate of wild animals is important for the understanding of population dynamics and can inform conservation and management strategies to ensure the long-term survival of wildlife populations. Population dynamics in herbivorous mammals are governed by the differences between births, deaths, emigration and immigration (Fowler 1981). Vital rates such as the age at sexual maturity (ASM), conception rate, gestation length and intercalving interval (ICI) all influence fecundity, growth potential, and turnover or generation time (Gaillard et al. 1998; 2000). These factors are, in turn, largely influenced by the scaling of vital rates with body size and metabolic rates (Owen-Smith 1988). The minimum age at first conception affects the potential for the population to increase, since earlier ASM equates to longer lifetime productivity (Owen-Smith 1988). Thus, if females attain sexual maturity and start reproducing at an earlier age, the growth rate for the population will increase even if no other vital rates change.

The recruitment rate of greater one-horned rhinoceros (GOH) refers to the rate at which new individuals are added to the population through reproduction. Female GOH in the wild typically reach sexual maturity at around 5–7 years and have a gestation period of 15–16 months (Dutta 1991; Steak 2024). They give birth to a single calf and typically have an ICI of 2–3 years (Owen-Smith 1988; Steak 2024). This slow intrinsic reproductive rate, combined with habitat loss, poaching, disease, and climatic variation, all contribute to low productivity of extant populations (Fowler 1981; Gaillard et al. 1998, 2000).

The Manas National Park (MNP) is one of the pristine natural habitats of the Eastern Himalaya and had around 80–100 rhinos in the 1980s. Tragically, the entire resident GOH population of MNP was wiped out due to poaching in the early 1990s. Subsequently, the Government of Assam, with the support of WWF, the International Rhino Foundation (IRF), United States Fish and Wildlife Service (USFWS), and Bodoland Territorial Council (BTC), launched Indian Rhino Vision 2020 (IRV2020), whose aims included restoring the rhino population in MNP through translocation (Bonal et al. 2009; Dutta 2018). The 22 rhinos were translocated to MNP from Kaziranga National Park (NP) and Pobitora Wildlife Sanctuary (WS) between 2008 and 2021.

In parallel to translocation, a group of rehabilitated rhinos were also reintroduced to MNP from the Centre for Wildlife Rehabilitation and Conservation (CWRC), located near Kaziranga NP (Barman et al 2014; Dutta 2023). Rehabilitation refers to the process of rescuing, treating, and gradually reintroducing injured, orphaned, displaced, or otherwise distressed animals back into their natural habitats (Emslie et al. 2009; Barman et al. 2014). The CWRC has played a pioneering role in the rhino rehabilitation process in the North Eastern Region of India, and 20 rehabilitated rhinos were introduced to MNP from CWRC between 2006 and 2021, because MNP was considered a more suitable natural situation than the rehabilitation centre.

The aim of these translocations and rehabilitation is to re-establish a self-sustaining rhino population in MNP. Knowledge of recruitment rates is vital for assessing the health and future prospects of this newly established population. This study was undertaken to fulfil this need.

Study area

MNP is located in the northern part of the Brahmaputra valley, in the foothills of the Eastern Himalayas. The Park is located in the districts of Chirang and Baksa of Assam in north-east India and shares its borders with the Royal Manas NP of Bhutan to the north. The southern boundary of the Park is adjacent to densely populated agricultural areas and human settlements. Agriculture is the primary economic activity in these areas.

MNP has a tropical climate with an annual rainfall of 3,000–4,000 mm and average annual temperatures ranging between ~20° and 27°C. The climate can be divided into four distinct seasons: pre-monsoon (March–May), a transitional season marked by dryness, humidity and steadily increased temperatures; the monsoon season (June–September), which is the wettest and hottest time of year; retreating monsoon (October–November); and winter (December–February), when it is cold and foggy (Borthakur 1986). Humidity ranges between 70% to 80% and is highest during the monsoon and retreating monsoon seasons. The Park consists of alluvial grasslands, semi-evergreen forests, and moist and dry deciduous forests. As one of the largest north bank tributaries of the Brahmaputra River, the Manas–Beki River system provides perennial water for the Park and habitats for freshwater fish, aquatic migratory birds, and wild buffalo.

The MNP is renowned for its rich fauna and flora biodiversity, which includes, in addition to rhinos, species such as tiger (*Panthera tigris tigris*), pygmy hog (*Porcula salvania*), golden langur (*Trachypithecus geei*), hispid hare (*Caprolagus hispidus*), Bengal florican (*Houbarogsis bangalensis*), and white-winged wood duck (*Asarcornis scutulata*).

Methodology

We analysed rhino monitoring data from 1 September 2012 to 31 December 2021. During this period, rhinos were monitored by using radio-telemetry systems, comprising VHF radio collars, directional antennae (Telonics RA-14K antennae, 148–152 MHz) and a VHF radio receiver to record the data (Communication Specialists, R-1000 receiver, 148–152 MHz) (Dutta 2023). Directional compasses and windows software, Locate II and Locate III (Dutta 2018), were used to triangulate locations of rhinos. We also used camera traps to observe the rhinos in inaccessible areas. Translocated rhinos were ear-notched as per IUCN/SSC-AsRSG methods at the capture site for ease of identification. The rehabilitated rhinos did not have ear notches, so we recorded their unique body features (Fig. 1) in a Master ID file to assist their identification during monitoring (Dutta et al. 2019). The likelihood of misidentification of these individuals was minimal; however, identifying F1 generation rhinos (the offspring of translocated and rehabilitated individuals) was more challenging due to the lack of prior documentation and overlapping features.

We estimated the birth dates of calves of translocated, rehabilitated, and F1 generation females based on their first recorded sightings with newborn calves. We did not assume that the date of first calf sighting equalled the actual birth date without validation (Dutta 2018). In nearly all cases, calves were detected

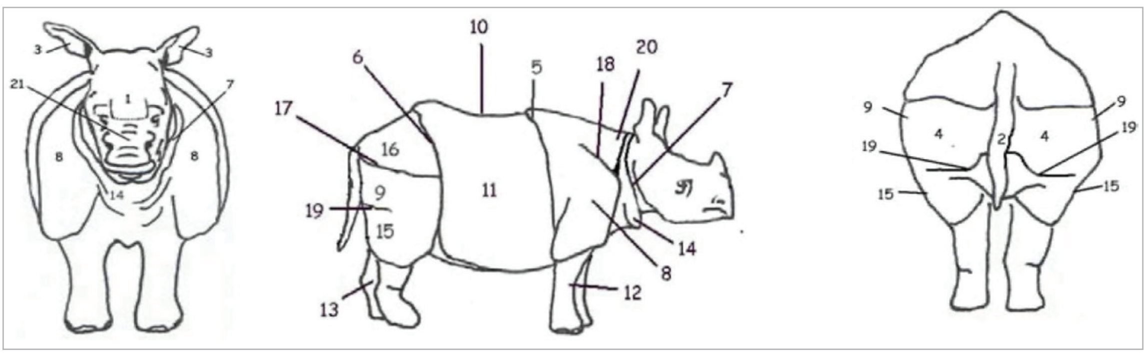

Figure 1. The unique identification features of GOH rhinoceros: 1) horn, 2) tail, 3) ear, 4) anal plate, 5) front cross fold, 6) rear cross fold, 7) neck fold, 8) shoulder plate, 9) upper right thigh plate, 10) prong (spines), 11) ribs, 12) front leg, 13) hind leg, 14) lower neck fold, 15) lower thigh plate, 16) back plate, 17) upper back corner, 18) shoulder cross fold, 19) lower back corner, 20) upper neck, 21) face.

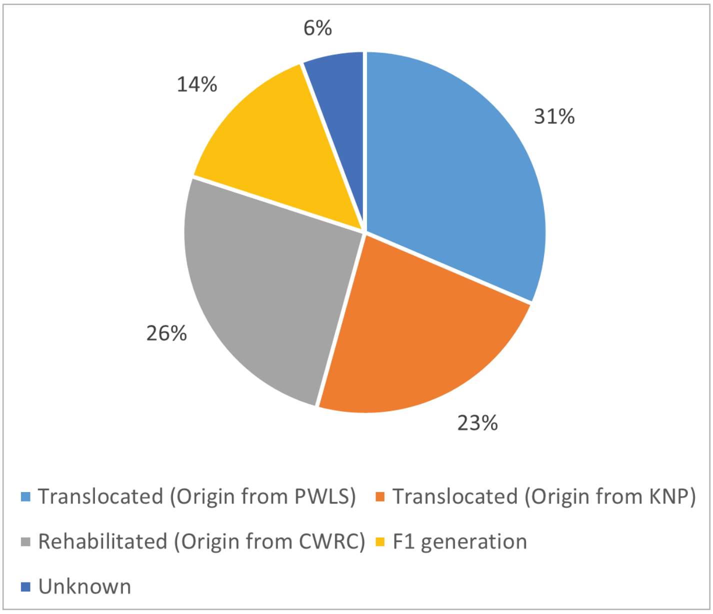

Figure 2. Proportions of the calving at Manas NP by females of different source populations.
PWLS = Pobitora WS; KNP = Kaziranga NP

within 4–5 days of birth due to the existence of rigorous, field-based monitoring protocols. Adult females—especially those close to parturition—were closely tracked, and behavioural indicators such as temporary isolation (Dutta 2018) were used to anticipate calving events. Additionally, most rehabilitated females and their F1 offspring gave birth near anti-poaching camps in open areas, improving visibility and facilitating early detection. Thus, the birth dates used to calculate female ages at first calving and ICI are based on direct, near-immediate post-birth observations.

Translocated rhinos were manually stratified into two groups (conception pre- and post-translocation), using the rhinos' estimated average gestation period of approximately 480 days based on findings of other studies (Laurie 1978; Schwarzenberger and Hermes 2023). A Chi-square test of independence was used to evaluate the association between season of birth and rhino origin (Rehabilitated, Translocated, F1, Unknown). This and all other data were analysed using Excel. Spatial data was plotted and analysed using ArcGIS 9.2 and ArcView 3.2a (ESRI 2006). A non-parametric technique, Maximum Convex Polygon (MCP) (Mohr 1947), was used to estimate overall home range size.

Results

Between September 2012 and December 2021, 35 rhino calves were born in MNP. Nine calves were born to rehabilitated rhinos, while 19 were born to translocated rhinos. Five calves were from the F1 generation, and the mothers of two rhinos born in inaccessible areas could not be identified. A total of eight translocated adult female rhinos (five from Pobitora WS and three from Kaziranga NP), four rehabilitated adult female rhinos (all from CWRC), five F1 generation female rhinos, and two unidentified adult female rhinos contributed to the growth of the rhino population in MNP during this period (Fig. 2).

Conceiving patterns of translocated females

Among translocated rhinos, adult female rhinos R3, R6, R8, R13, and R15 gave birth more than 480 days (1.314 years) after translocation and were therefore assumed to have conceived after they arrived in MNP. In contrast, rhinos R10, and R17 gave birth within 480 days of their release in MNP (R10: 261 days post-release; R17: 415 days post-release), which implies that these rhinos likely conceived in their source areas before the translocation. The translocation process did not appear to affect the pregnancy process of these two already pregnant females (Table 1).

Table 1. Translocation and birth of first calves after release of translocated female rhinos in MNP. Females giving birth less than 480 days (1.314 years) after conception were assumed to be pregnant on arrival at Manas NP.
All rhinos were captured one day prior to release in Manas NP. PWLS = Pobitora WS or KNP = Karizanga NP.

Rhino code	Origin	Estimated age at capture (years)	Estimated date of birth	Release date	Date of birth of first calf at MNP	Years to first conception at MNP	Years to birth of first calf at MNP
Females Pregnant on Arrival at Manas NP							
R10	PWLS	9	07/01/2003	09/01/2012	26/09/2012	n/a	0.71
R17	KNP	10	10/01/2002	12/01/2012	02/03/2013	n/a	1.14
Females not Pregnant on Arrival at Manas NP							
R3	PWLS	12	27/10/1998	28/12/2010	27/09/2013	1.43	2.75
R6	PWLS	10	16/01/2001	18/01/2011	14/05/2013	1.00	2.32
R8	PWLS	7	17/01/2004	18/01/2011	23/03/2013	0.86	2.18
R9	PWLS	8	08/01/2004	09/01/2012	03/04/2014	0.92	2.23
R13	KNP	11	18/01/2001	20/01/2012	27/09/2013	0.37	1.69
R15	KNP	9	10/01/2003	12/01/2012	02/11/2013	0.49	1.81

Conceiving patterns of rehabilitated females

The first-calving ages of rehabilitated female rhinos raised in MNP were estimated at 9.2 years based on their birth date during the time of rescue at Kaziranga NP, also estimated (Table 2). Manas RC = Manas Rehabilitation Centre (Popularly known as Rhino Boma area).

Conceiving patterns of F1 females born at Manas NP

The F1 generation, which represents the first filial generation resulting from an on-site mating and conception at MNP, comprised four rhinos—Ganga A, Jamuna A, Mainao A, and Mainao B—that were the offspring of rehabilitated mothers, while R3A was the only one born to a translocated mother (R3). The average age at first calving of the four F1 rhinos born to rehabilitated mothers ranged between 4.58 and 6.17 years, and R3A also calved at a comparably early age (6.25 years). Thus, all F1 females gave birth to their first offspring at a much earlier age than the rehabilitated rhinos, based on their estimated ages (range 7.85–10.61 years; Table 2).

Table 3. Age at first calving F1 generation female rhinos born in MNP

Name	Date of birth	Date of birth of first calf	Age at first calving (years)
Ganga A	04/05/2013	03/12/2017	4.58
Jamuna A	07/04/2013	07/06/2019	6.17
Mainao A	06/02/2013	07/12/2018	5.83
R3 A	14/05/2013	13/08/2019	6.25
Mainao B	12/08/2015	10/01/2021	5.42
		Average	**5.65**

Inter-calving intervals of rehabilitated rhinos

Among rehabilitated rhinos, Mainao subsequently gave birth again in 2015, 2.5 years after the birth of the fist calf. She died a natural death in 2016. Ganga gave birth again three times until 2021, with the ICI increasing from 2.21 years to 2.41 years and then 3.69 years. Jamuna gave birth again in 2017, 4.41 years after the birth of the first calf. The younger female Purabi gave birth once in the study period, in 2020. The average ICI for rehabilitated rhinos was 3.03 years (Table 4).

Table 2. Rescue history and First-calving records of rehabilitated females in Manas NP.

Rhino name	Estimated age at rescue (months)	Estimated date of birth	Date of rescue	Arrived at MRC	Released into wild at MNP	Estimated age at release into wild (years)	Date of birth of first calf at MNP	Years to conception after release	Years to first birth after release	Est. age at first calving (years)
Mainao	1	27/06/2002	28/07/2002	20/01/2006	28/11/2008	6.42	06/02/2013	2.88	4.19	10.61
Ganga	4	14/03/2004	14/07/2004	28/01/2008	27/11/2008	4.71	04/05/2013	3.12	4.43	9.14
Jamuna	6	21/01/2004	22/07/2004	28/01/2008	27/11/2008	4.85	07/04/2013	3.04	4.36	9.21
Purabi	3	27/03/2012	27/06/2012	23/09/2013	16/02/2016	3.89	02/02/2020	2.65	3.96	7.85
								Average		**9.20**

Table 4. Inter-calving intervals (ICI, values in years) of rehabilitated females at MNP.

Name	1st calf	2nd calf		3rd calf		4th calf		Date of death	Average ICI
	Date of birth	Date of birth	ICI	Date of birth	ICI	Date of birth	ICI		
Ganga A	06/02/2013	12/08/2015	2.51					2016	2.51
Jamuna A	04/05/2013	18/06/2015	2.12	15/11/2017	2.41	24/07/2021	3.69		2.74
Mainao A	07/04/2013	03/09/2017	4.41						4.41
R3 A	02/02/2020								n/a
								Overall average (n = 5)	**3.03**

Table 5. Inter-calving intervals (ICI, values in years) of translocated female rhinos at MNP

Number	1st calf	2nd calf		3rd calf		4th calf		Date of death	Average ICI
	Date of birth	Date of birth	ICI	Date of birth	ICI	Date of birth	ICI		
R3	27/09/2013	15/01/2020	6.30						6.30
R6	14/05/2013	10/05/2015	1.99	15/10/2018	3.44	04/11/2021	3.06		2.83
R8	23/03/2013							2013	n/a
R9	03/04/2014	28/04/2018	4.07	19/09/2021	3.40				3.73
R10	26/09/2012							2013	n/a
R13	27/09/2013	28/04/2018	4.58	21/10/2020	2.48				3.53
R15	02/11/2013	18/09/2017	3.88	26/08/2019	1.94	14/11/2021	2.22		2.68
R17	02/03/2013							2013	n/a
								Overall average (n = 11)	**3.40**

Inter-calving intervals of wild-to-wild translocated rhinos

Among translocated female rhinos, five individuals (R3, R6, R9, R13, and R15) gave birth to two or more calves. Three others (R8, R10 and R17) were killed by poachers following the birth of their first calf in MNP. ICI values for rhinos calving more than once ranged from 1.94 to 6.30 years, with a mean of ~3.40 years. The ICI between the first and second calf born to R3 was unusually long at 6.30 years (Table 5).

Seasonal calving patterns

The analysis revealed that there are distinct seasonal patterns in rhino reproduction in MNP. The highest number of births, 14, took place in the monsoon season. Nine births took place in the pre-monsoon period, and nine in the retreating monsoon, with only three births during the winter season.

Differences of calving patterns of translocated and rehabilitated rhinos

Two of nine births during the pre-monsoon season were from rehabilitated rhinos and seven from translocated rhinos. Out of the total of 14 births during the monsoon season, five were from rehabilitated rhinos, seven from translocated rhinos and two from F1 generations. Among the nine births in the retreating monsoon five were from translocated rhinos two from F1 generations, with two births recorded from unknown rhinos. Out of three birth records in the winter season, two were from translocated rhinos and one was from the F1 generation (Fig. 3). A chi-square test of independence (χ^2 2 = 15.05, df = 9, p = 0.089) showed that there was no significant association between the mother's origin and season of birth.

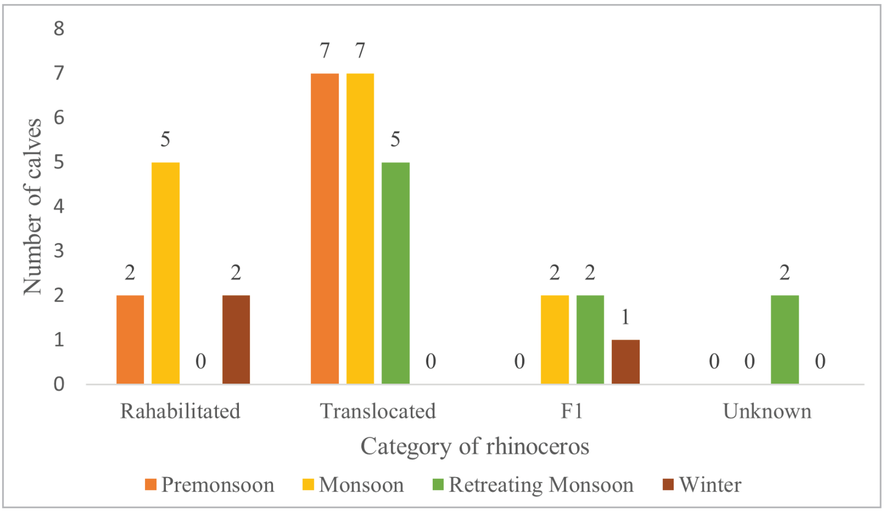

Figure 3. The calving patterns among different category of rhinos in different seasons.

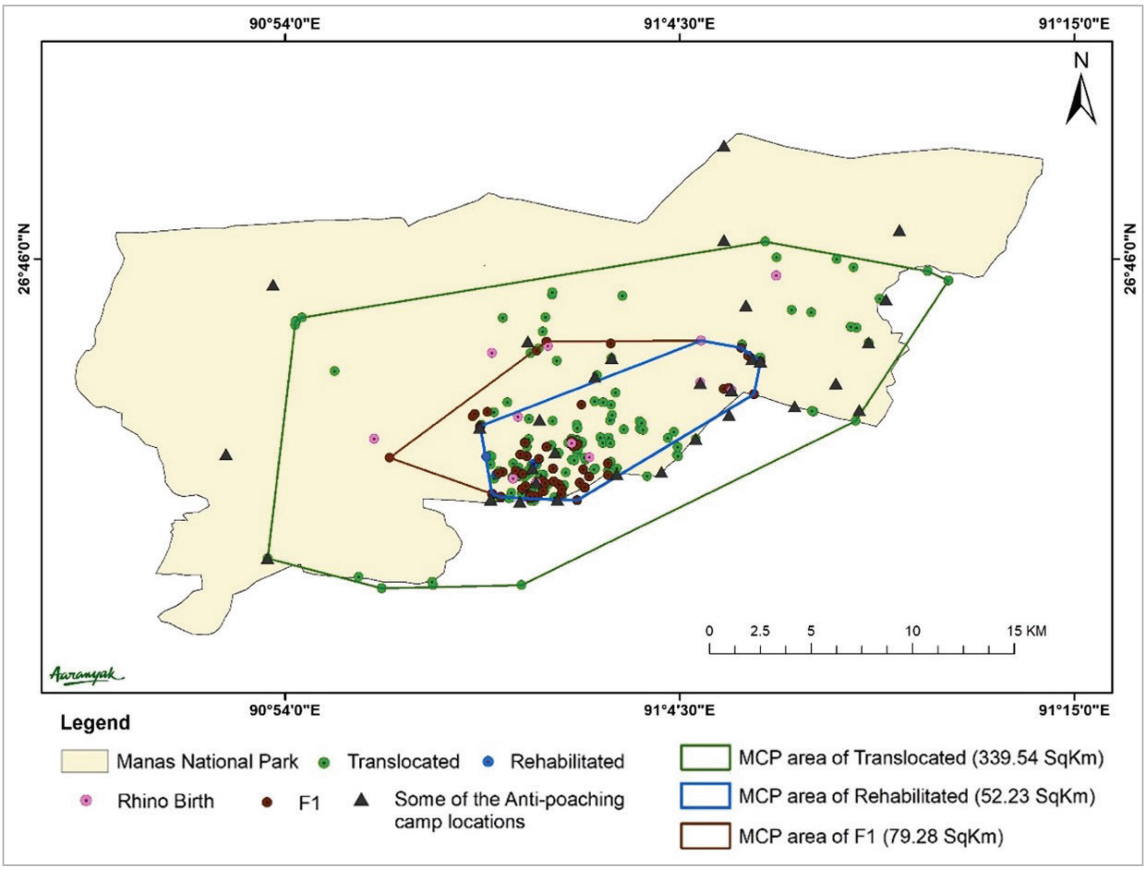

Figure 4. Overall home ranges of translocated, rehabilitated and F1 females with calving sites in MNP.

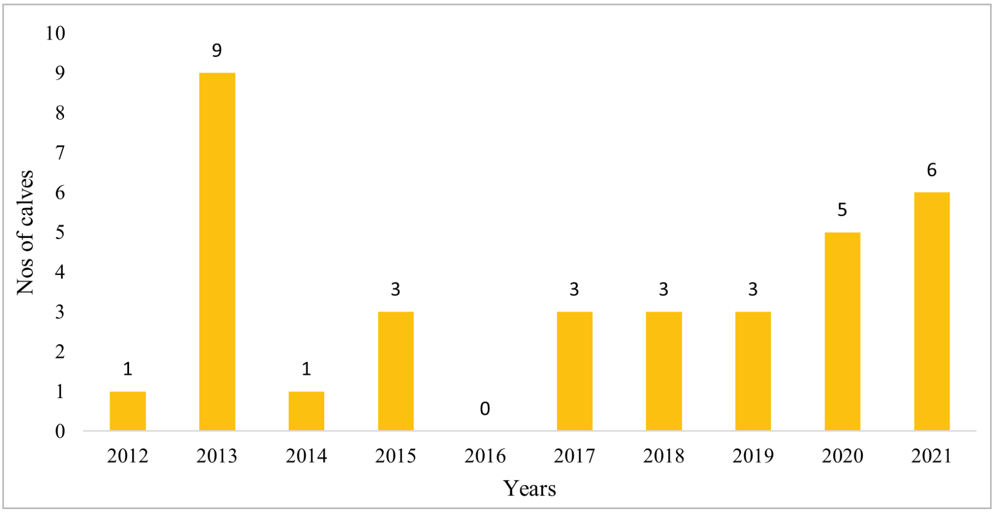

Figure 5. Numbers of calves born each year (2012–2021) Manas NP.

Spatial pattern of calving sites

Based on home range analysis, the three rhino groups—translocated, rehabilitated, and F1 generation—show overlapping yet distinct patterns of space use across MNP. Translocated rhinos occupied significantly larger areas, with an average home range of 339.54 km², often using remote and less-disturbed habitats throughout the Park. In contrast, rehabilitated rhinos had smaller home ranges averaging 52.23 km², primarily concentrated in the central and limited eastern zones of the Park. F1 individuals displayed intermediate range sizes (79.28 km²) and were largely clustered around the same core areas as the rehabilitated group (Fig. 4).

Yearly calving patterns

In 2013, nine rhino calves were born in a single year, the most ever. The number of rhino calves born in the following years declined and only one calf was born in 2014, with three in 2015, and no calves were born in 2016. In the years 2017–2019, rhino calf births increased again, with a total of three calves born each year. The number of rhino calves born increased to five in 2020 and seven in 2021. Hence calving numbers were not uniform during the period of study (Fig. 5).

Discussion

The reintroduction of rhinos in MNP is regarded as one of India's most significant conservation successes, contributing approximately 1% to the global wild rhino population, estimated at ~4,000 animals (Sharma 2022). During the period covered by this study, a total of 35 calves were born in the Park. Of these, translocated rhinos gave birth to 19 calves, rehabilitated rhinos produced nine, and F1 generation rhinos accounted for five births, while the mothers of two calves remain unidentified. This reproductive success highlights the species' ability to adapt well to both translocation and rehabilitation efforts and to new environments despite the stresses involved (Dutta 2018; Dutta 2023). While this is a commendable outcome, a closer look at the female reproductive pool and ICI dynamics suggests that the population has not yet reached its full reproductive potential.

Under average field conditions, female rhinos are expected to have their first calf before 7.5 years of age and produce one calf every 2–3 years on average. (K Adcock *in prep*) However, actual recruitment during the study period was slightly lower than expected. This shortfall was likely due to i) the rehabilitation process resulting in delayed sexual maturity in rehabilitated females; ii) poaching eliminating many adult males and some females early in the study, which limited and disrupted successful breeding; and iii) undetected calf mortality.

This study also highlights the need for a comparative assessment with source populations in Kaziranga NP and Pobitora WS to better understand reproductive rates, ICI patterns, and recruitment success under varying ecological and management conditions. Such comparisons will help inform adaptive strategies for future translocations and population reinforcement efforts.

The study identified that some females were already pregnant at the time of capture, suggesting that current capture and translocation protocols are generally well-managed to support ongoing pregnancies. However, pregnancies were not identified prior to translocation, and it is possible that early pregnancies went undetected or that foetal losses occurred in other individuals. Though translocation protocols are being adhered to, there may still be a high risk of stress-induced foetal loss in pregnant adult females. This highlights the need for improved pregnancy detection tools suitable for field use, especially in wild conditions. Assessing pregnancy status before translocation would allow for a more accurate evaluation of reproductive outcomes, including the proportion of births in relation to the number of females confirmed as pregnant at capture.

According to Milner et al. (2007) and Wittemyer et al. (2014), the poaching of breeding males can disrupt sex ratios and hinder recruitment processes in large mammal populations. This phenomenon was observed in MNP between 2012 and 2016, when all dominant adult male rhinos were killed by poachers (Dutta 2018). However, the implementation of stronger anti-poaching measures significantly improved protection, halting further male losses. In a positive development, some subadult males (R7, R14, and R18) survived and later reached sexual maturity, eventually contributing to breeding (Dutta 2023). While this marks a hopeful shift toward population recovery, it also raises concerns about potential inbreeding, particularly in a small, recovering population. If maturing males are closely related to existing females, so that male rhinos mate with mothers or related female offspring, it could lead to genetic bottlenecks and reduced genetic diversity over time. This underscores the importance of monitoring genetic relationships within the population and considering future introductions of unrelated individuals to maintain long-term genetic health.

The ICI of the two groups of rhinos showed distinct reproductive trends. Rehabilitated rhinos had a relatively consistent ICI (2.12 to 4.41 years). Their smaller home ranges (Fig. 5), which overlaps with the ranges of all dominant bulls, might contribute to this consistency. The translocated adult females' rhinos (R3, R6, R9, R13, R15) exhibited a mean ICI of 1.99 to 6.30 years, with noticeably greater variability. These rhinos typically roam more widely in the Park and tend to avoid locations with frequent human presence. Notably, R3 had an ICI exceeding six years. Following calving, R3 was observed moving further north towards the India–Bhutan border, where she stayed with her calf. Movement to these remote areas may take female rhinos outside the territories of dominant bulls, to areas where there is a low male–female sex ratio. These factors might help explain the larger ICI gap among the translocated females.

The F1 generation of rhinos has started contributing to population growth and, by the end of the study period, five F1 females had given birth, including Ganga A, Jamuna A, Mainao A, and Mainao B, all female calves from rehabilitated females, as well as R3A, the only known female calf of a translocated female (R3). The average age at first calving for these five females was around 5.65 years, showing that they reached maturity and bred at a relatively young age. Interestingly, R3A calved at 6.25 years, which is almost the same as the gap between her own birth and her mother's next calving.

There were two calves whose mothers were not identified. Since most F1 females born to rehabilitated rhinos tend to stay in areas closer to anti-poaching camps, where calf sightings are more frequent, the unidentified mothers of these calves observed in more remote, less-monitored areas of the Park are likely to be F1 females born to translocated mothers. The possibility that they were born to translocated adult females can be ruled out, as all translocated rhinos are individually identifiable by ear notches and unique ID markings. Further field monitoring and genetic analysis will be essential to confirm the maternal identity of these calves.

The study also reveals that rehabilitated female rhinos had their first calves at a later age than F1 females. This may be due to early-life captivity, stress from the rehabilitation process, delayed adaptation, and differences in nutrition and social integration. The F1 females, raised entirely in the wild, tended to mature and reproduce more naturally and quickly. The F1 generation also had more chances to mate with adult males than their mothers did. The fact that F1 females were found to reach sexual maturity and calve earlier is a positive sign, which suggests that the population is adapting well and growing in a healthy, self-sustaining way.

The results show year-on-year variations in calf births from 2013 to 2021. There was a peak of nine calves born in 2013, followed by a sharp decline in subsequent years, with only one recorded birth in 2014 and none in 2016. However, calf numbers began to recover between 2017 and 2019, with three births per year; this number increased to five in 2020 and seven in 2021. These fluctuations suggest complex ecological and biological influences. It is possible that the reproductive cycling among females was disrupted during the early years post-translocation, as individuals adjusted to their new environments. Similar trends have been documented in African rhino populations (Schwarzenberger and Hermes 2023). Additionally, the loss or temporary unavailability of mature breeding males—particularly due to poaching incidents between 2012 and 2016—as well as poaching and natural deaths of breeding females, were contributing factors to the downturn of births during this period.

Additionally, some calves may have been born but lost before detection due to early mortality or limited monitoring capacity in dense habitats. It is also possible that the initial spike in births in 2013 reflected the release of reproductively active females who had conceived either shortly before or did so soon after translocation. Overall, these fluctuations underscore the need for continuous investigation covering all the factors mentioned.

There were clear differences in calving site preferences and home range patterns among rehabilitated, translocated, and F1 rhinos in MNP. Rehabilitated females Mainao, Ganga, Jamuna, and Purabi had smaller average home ranges of approximately 52.23 km² and consistently gave birth in areas close to anti-poaching camps and zones with regular human presence. This behaviour likely reflects a degree of human imprinting from their early lives in captivity and the rehabilitation process (Barman et al. 2014). These human-inhabited areas, while more disturbed, may offer protective benefits. The presence of forest staff may reduce poaching threats, while the proximity to human activity could also deter large predators such as tigers, potentially enhancing calf survivability.

In contrast, translocated rhinos showed the largest average home ranges, covering about 339.54 km², and generally calved in remote, less-monitored locations within the Park. This calving behaviour may indicate a preference for isolation or reflect typical wild rhino behaviour, as noted in earlier studies (Dutta 2018). While such remote areas may be ecologically suitable, they could pose greater risks to calves, including exposure to predators, environmental stress, or undetected mortality due to limited surveillance and poaching. The larger spatial movement of translocated rhinos may also delay the detection of reproductive events, making monitoring more challenging.

The F1 generation rhinos, born and raised entirely in the wild, showed intermediate home range sizes averaging 79.28 km². F1 females Ganga A and Jamuna A chose calving sites that overlapped with the areas previously used by their rehabilitated mothers. This suggests potential intergenerational transmission of habitat use. Given their exposure to both wild conditions and moderate human proximity, F1 rhinos may serve as an important behavioural bridge between rehabilitated and wild translocated individuals.

Overall, these findings highlight how home range size and calving site location, influenced by rhino origin, may influence the calving patterns. Further spatial and behavioural studies, including in other rhino-bearing areas of Assam, to better inform future reintroduction efforts and adaptive habitat management strategies, are recommended.

The prime grassland habitat in Manas is currently facing the onslaught of alien invasive species (weeds) that have increased in extent due to several anthropogenic factors, including increased livestock grazing, human movement and dispersal, and uncontrolled fires Lahkar et al. (2011) and Dutta (2018). Invasive species (including *Chromolaena odorata*, *Leea asiatica*, *Ageratum conyzoides* and *Mikania spp.* along with a succession of woody species) have been observed wherever disturbances such as grazing and the creation of openings in grassland for roads, camps, bomas, etc. occur.

Wallow sites and marshes that provide green food during dry seasons are critical for rhinos and are affected by changes in flood patterns and rainfall, as well as silting. Also, there are complex hydrological changes in the ever-changing Brahmaputra River, and a changing climate affecting monsoon patterns. (Dutta

2018) These findings highlight the urgent need for a comprehensive and scientific approach to habitat management focusing on both grasslands and water bodies, alongside strengthened anti-poaching measures. Such strategies are essential for ensuring the long-term survival of rhinos in the Park. The conclusions drawn from this study are crucial for developing a robust model to predict rhino population trends and movements within MNP. Gaining a deeper understanding of reproductive timing, ICI and habitat preferences will help inform more effective conservation and management strategies to support the survival and growth of the species. The purpose of this approach is not only to advance proactive management, but also to recognize that essential habitats are vital to the persistence of rhinos.

Recommendations

This analysis reinforces the need for continued reproductive monitoring, balancing sex ratios, and targeted management to maximize calf recruitment to support long-term demographic viability in MNP. Genetic analysis of the MNP rhino population is needed to confirm the species' integrity and long-term genetic viability following losses of many males from poaching. Similar analyses to this Manas study should be undertaken in source populations in Kaziranga NP and Pobitora WS to better understand reproductive rates, ICI patterns, and recruitment success under varying ecological and management conditions across India. Such comparisons will help inform adaptive strategies for future translocations and population reinforcement efforts.

To accelerate the growth of the rhino population in MNP, additional individuals may be considered for reintroduction from donor sites such as Kaziranga NP, Orang NP and Pobitora WS. However, any future translocations should be preceded by enhanced security measures and robust monitoring systems. It is also essential to ensure that sufficient resources, both human and financial are available to support long-term protection and population stability. Additionally, it is crucial to monitor the impact of translocations/reintroductions on both reproductive success and the behavioural stability of the population.

MNP shares its northern boundary with the Royal MNP in Bhutan, and rhinos have been observed using these transboundary areas (Dutta 2018). Therefore, both India and Bhutan need to enhance cross-border collaboration to ensure the effective conservation of rhinos and other wildlife that move across the international boundary. On the southern side, MNP is bordered by densely populated human settlements. This highlights the need to strengthen community-based conservation efforts and regular awareness programs to foster coexistence and ensure long-term conservation success.

MNP authorities need to enhance anti-poaching measures, capacity building of park staff in scientific monitoring of rhinoceros, and the integration of modern technology to improve management practices. Continuous behavioural monitoring of rhinos, along with regular training of staff in both monitoring techniques and anti-poaching strategies, is essential for long-term conservation success.

Acknowledgements

The authors acknowledge the support of the Government of Assam, the Chief Wildlife Warden of Assam and the Bodoland Territorial Council, the Rhino Task Force and Translocation Core Committee (TCC). Special thanks to IRF and WWF–India for their support for undertaking these studies and conservation procedures. The College of Veterinary Science Khanapara, Aaranyak, USFWS and WTI are acknowledged for their contribution towards the programme. Thanks to Dr Parikshit Kakati, Dr. Bhaskar Choudhury and Sri Munin Gogoi for their help in compiling the field database. In addition, the authors acknowledge the rhino monitoring teams of the MNP and of Sri Arup Kumar Das and Mrs. Madhumita Borthakur Aaranyak. Sincere thanks go to Sri Sushanta Borthakur, Sri Sonit Kumar Das, Sri Bipul Chandra Nath, Sri Sande Doimary, Mr Iusuf Khan, Mr. Jamir Ali, mahouts, boatmen, drivers, service providers, and all the domesticated elephants of the MNP.

This manuscript is dedicated to Mainao (adult female rhino), Giribala (adult female rhino R8), Odangshi (adult female rhino R10) and Hainari (adult female rhino R17) and local communities living in the adjacent villages of Rajabeel and Gosaivitha (Katajhar).

References

Barman R, Choudhury B, Ashraf NVK, Menon V. 2014. Rehabilitation of greater one-horned rhinoceros' calves in Manas National Park, a World Heritage Site in India. *Pachyderm* 55: 78–91.

Bonal BS, Talukdar BK, Sharma A. 2009. Translocation of rhino in Assam. *Tiger Paper* 36 (1): 91.

Borthakur M. 1986. Weather and climate of North East India. *North East Geographer* 18 (1–2): 20–27.

Dutta AK. 1991. *Unicornis: The great Indian one-horned rhinoceros*. Konark Publishers, New Delhi.

Dutta DK and Mahanta R. 2015. *A study on behaviour and colonisation of translocated greater one-horned rhinoceros in Manas National Park, Assam, India*. NeBIO 6 (2): 26–30.

Dutta DK. 2018. A study on translocated rhinos (*Rhinoceros unicornis*) behaviour and habitat preferences at Manas National Park, Assam, India. PhD thesis. Gauhati University, Guwahati, Assam.

Dutta DK, Malakar NK, Dewan A, Brahma B, Bodo K, Nath B, Doimary S. 2019. Greater one-horned rhinoceros in Manas National Park, Assam, India: a unique identification. Published by the Field Directorate, Manas Tiger Project, Assam.

Dutta DK. 2023. Behaviour and habitat preferences of translocated rhinos (*Rhinoceros unicornis*) at Manas National Park, Assam, India. *Pachyderm* 64: 92–106. https://doi.org/10.69649/pachyderm.v64i.524

Emslie RH, Amin R, Kock R. 2009. Guidelines for the in-situ reintroduction and translocation of African and Asian rhinoceros, Gland, Switzerland.

ESRI. 2006. An Overview of Model builder ArcGIS 9.2 Desktop Help, Environmental System Research Institute Inc. http://webhelp,esri.com/arcgisdesktop/9.2/index.cfm?TopicName=An_overview_of_Modelbuilder

Gaillard JM, Festa-Bianchet M, Yoccoz NG. 1998. Population dynamics of large herbivores: Variable recruitment with constant adult survival. *Trends in Ecology & Evolution* 13 (2): 58–63. https://doi.org/10.1016/S0169-5347(97)01237-8

Gaillard JM, Festa-Bianchet M, Yoccoz NG, Loison A, Toïgo C. 2000. Temporal variation in fitness components and population dynamics of large herbivores. *Annual Review of Ecology and Systematics* 31: 367–393. https://doi.org/10.1146/annurev.ecolsys.31.1.367

Lahkar PB, Talukdar KB, Sarma P. 2011. Invasive species in Grassland Habitat: and Ecological threat to greater one-horned rhino (*Rhinoceros unicornis*). *Pachyderm* 49: 33–39.

Laurie WA. 1978. The Ecology and Behaviour of the greater one horned rhinoceros. PhD dissertation. Cambridge University 10–486.

Milner JM, Nilsen EB, Andreassen HP. 2007. Demographic side effects of selective hunting in ungulates and carnivores. *Conservation Biology* 21: 36–47. https://doi.org/10.1111/j.1523-1739.2006.00591.x

Mohr CO. 1947. Table of equivalent populations of North American small mammals. *American Midland Naturalist* 37: 223–249.

Owen-Smith RN. 1988. *Megaherbivores: The Influence of Very Large Body Size on Ecology*. Cambridge University Press, Cambridge.

Schwarzenberger F and Hermes R. 2023. Comparative analysis of gestation in three rhinoceros species (*Diceros bicornis; Ceratotherium simum; Rhinoceros unicornis*). *General and comparative Endocrinology*, 334p https://doi.org/10.1016/j.ygcen.2023.114214

Sharma A. 2022. The Population status of the greater one-horned rhino in India and Nepal, and the importance of regular monitoring. *Pachyderm* 63: 176–178.

Steak BL. 2024. *International Studbook for the Greater One-horned Rhinoceros 2023*. Zoo Basel, Switzerland.

Wittemyer G, Northrup JM, Blanc J, Hamilton-Douglas I, Omondi P, Burnham PK. 2014. Illegal killing for ivory drives decline in African elephants. *Biological Sciences* 111 (36): 13117–13121. https://doi.org/10.1073/pnas.1403984111