suring valuable economical and biological investments, and it helps maximize sample size. It may be useful in studies of endangered species, where loss of or injury to animals may lead to termination of research.

Acknowledgments.—We thank J. Roof, D. Land, M. Roelke, and R. McBride for assistance in the field. F. Van Dyke, N. R. Holler, J. Roof, and K. A. Logan made helpful comments on an earlier draft. This is a contribition of Federal Aid to Endangered Species Program, Florida Endangered Species Project E-1.

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Received 19 April 1989.
Accepted 3 August 1989.

***Wildl. Soc. Bull.* 18:36–41, 1990**

CAPTURE, CHEMICAL IMMOBILIZATION, AND RADIO-COLLAR LIFE FOR GREATER ONE-HORNED RHINOCEROS

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Greater one-horned rhinoceros (*Rhinoceros unicornis*; hereafter *R. unicornis*) were once abundant in South Asia, ranging from the Brahmaputra valley in the East to the Indus River in the West (Laurie 1978, Dinerstein and McCracken, unpubl. data). Today, free-ranging populations of >80 individuals are limited to 2 reserves: Royal Chitwan National Park, Nepal, and Kaziranga National Park, Assam, India, and it is likely that <1,500 *R. unicornis* survive in the wild (Dinerstein and Price, unpubl. data). We immobilized and radiocollared *R. unicornis* to facilitate a study of population ecology, genetics, social organization, and dispersal ecology (Dinerstein and Wemmer 1988; Dinerstein and McCracken, unpubl. data). Other immobilizations in Chitwan were part of a program to reestablish populations elsewhere in Nepal and India. Thirteen individuals were sent to Royal Bardia Wildlife Reserve, Nepal, and 4 individuals to Dudhwa

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National Park, Uttar Pradesh, India (Mishra and Dinerstein 1987). Prior to our efforts, *R. unicornis* had seldom been immobilized in the wild, although protocol for anesthesia of black rhinoceros (*Diceros bicornis*) and white rhinoceros (*Ceratotherium simum*) is well documented (Harthoorn 1973).

The purpose of our paper is to provide data on chemical immobilization and radio-collaring techniques for *R. unicornis*. Such data are essential as South Asian biologists and managers develop long-term relocation and research programs to restock other reserves with *R. unicornis* and monitor the fate of founder populations. With protection from poaching and habitat destruction, most free-ranging populations of *R. unicornis* are slowly increasing (Dinerstein and Price, unpubl. data) suggesting that "surplus" animals will soon be available for translocation to well-protected parks where *R. unicornis* used to occur. In addition, immobilization techniques used on this species should be applicable to captive animals and other Asian rhinoceratids.

STUDY AREA AND METHODS

We captured *R. unicornis* in the floodplain grasslands and riverine forests bordering the Rapti River in and around Royal Chitwan National Park (84°20′E; 27°30′N). These grasslands rank among the world's tallest; 4 common species reach 4 m, and 2 species exceed 6 m in height. We estimated the population of *R. unicornis* in 1988 to be between 386 and 410 animals (Dinerstein and Price, unpubl. data). More detailed information on the vegetation of Chitwan and *R. unicornis* can be found elsewhere (Dinerstein et al. 1988; Dinerstein and Wemmer 1988; Dinerstein 1989, 1990; Lehmkuhl 1989; Laurie 1978).

Because of dense vegetation and the aggressive nature of *R. unicornis*, we used trained elephants (*Elephas maximus*) in our efforts to locate, capture, and monitor movements of radio-collared individuals. Attempts to immobilize *R. unicornis* were confined to the dry period between late October and late May. Abundant standing water and swollen rivers during the rainy season (June–early October) precluded capture at that time for fear of an animal drowning. During the hot season (February–May; mean maximum temp = 35 C) we attempted to complete field operations before 0800 h to avoid subjecting immobilized animals to heat stress.

Adult male *R. unicornis* may exceed 2,000 kg whereas adult females are slightly smaller. Calves <1 year old weigh <200 kg. Adults and subadults were immobilized with dosages of 2.0–2.5 mg of etorphine (M99, Lemmon Co., Sellersville, PA 18960) mixed with 1 cc acepromazine (Tech America, Fermenta Animal Health Co., Kansas City, MO 64190). Calves were immobilized with a mixture of 0.5–1.0 mg etorphine and 0.5 cc acepromazine. Syringes (Palmer Chemical & Equipment Co., Inc., Palmer Village, Box 867, Douglasville, GA 30133), equipped with 5-cm and 2.5-cm needles for adults and calves, respectively, were powered by medium-speed charges (Palmer Chemical & Equipment Co., Inc., Palmer Village, Box 867, Douglasville, GA 30133). One individual, an adult female, was immobilized with 0.7 mg carfentanil citrate (Wildlife Laboratories, Fort Collins, CO 80524) reversed with diphmorphine (M50/50, Lemmon Co., Sellersville, PA 18960).

Normally, each capture attempt included 10–15 elephants. The large number of elephants proved useful in surrounding a single *R. unicornis* or mother and calf in a ring and forcing the target within 10 m of the elephant for darting. Once darted, the ring of elephants enabled us to keep the animal within view and prevented the individual from entering open water. By the middle of our study, some *R. unicornis* had become habituated to the close presence of elephants and on 5 occasions when more elephants were unavailable, we immobilized *R. unicornis* with only 5 of them.

The animals were darted either in the shoulder or rump. We measured induction time as the period elapsed between injection and sternal recumbency. We tested for complete immobilization by kicks to the rump. Once the animals were anesthetized, we began measuring pulse, respiration, and temperature. We covered the eyes of sedated *R. unicornis* and plugged the ears with cotton.

We attached radio collars to 21 individuals. One breeding male was recollared twice and 4 breeding males, 3 nonbreeding males, and 1 breeding female were recollared once. Radio transmitters were attached to fiberglass-reinforced machine belting by epoxy, secured with 2 screw clamps, and wrapped with duct tape. Neck girth and consequent collar size varied considerably between adult males depending upon age and breeding status (Dinerstein and Price, unpubl. data). Collars were fastened with pop rivets. The antagonist (diphmorphine) was administered either intramuscularly or by intravenous injection in an ear vein.

RESULTS AND DISCUSSION

Capture

In all but 5 of the 51 darting episodes, the dart penetrated the hind quarters or shoulder. In the other episodes the dart entered the flesh around the tail or the upper leg because the animal moved just before the gun was fired. These animals were immobilized without any complications. Dominant males proved easiest to immobilize because they rarely ran from an approaching elephant. Subadults were less cooperative. On 10 occasions (3 for which immobilization data are lacking), subadults had to be chased over short distances (<0.5 km) and encircled several times before being darted. We failed to capture subadults on 3 attempts when they outran the elephants. Capturing young calves ($n = 7$) was easiest if the mother was immobilized first. Calves remained standing next to the sleeping cow. On one occasion where the calf was darted first, the mother nearly trampled her immobilized calf during induction. Therefore, we recommend that cows be immobilized before their calves. An additional danger if the calf is immobilized first is that the cow will remain in the vicinity and try to reunite with the calf, posing mortal danger to the field crew on the ground. A sufficient number of elephants can drive off the mother and keep her away from the calf. However, in tall grass habitats, this may not always be feasible.

Three animals had to be chased for several kilometers, 1 after it had been darted and the other 2 prior to darting. Despite the apparent stress associated with the chase, these animals eventually were immobilized with no obvious complications. On 2 occasions during a relocation operation, *R. unicornis* were herded to a loading site >2 km from where first located. By quietly surrounding each *R. unicornis* with 15 elephants kept close together, we slowly ushered it to the darting/loading site without problems.

Immobilization

We immobilized *R. unicornis* representing all sex and age classes on 51 occasions without mishap. Four breeding males, 3 nonbreeding adult males, and 1 adult female were immobilized on 2 occasions and 1 male was immobilized 3 times. Data on induction time, length of immobilization, and recovery time after administering the antagonist were available for most captures (Table 1). Mean induction time for breeding males was significantly longer than for nonbreeding adult males (13.6 min vs. 10.3 min; Mann-Whitney $U = 118$, $n = 13, 7$, $P < 0.001$). However, breeding males rarely moved far from the point of darting and often continued to walk slowly and squirt-urinate (a dominance behavior) for several minutes after injection. We detected no significant differences in induction time within a sex or age class related to time of immobilization (morning vs. afternoon) or season (cool vs. hot). Induction times varied widely for adult females, breeding males and subadults, and less so for calves and nonbreeding adult males. Variation in induction time is most likely influenced by the location of the needle in relation to the thick skin folds of *R. unicornis* and perhaps body condition and weight.

Immobilized individuals showed the typical sequence of response to etorphine hydrochloride. Animals went down in sternal recumbency. During immobilization, respiration rate, pulse rate, and rectal temperature among free-ranging adults and subadults were 6–10/minute, 55–82/minute, and 35.0–39.8 C, respectively. Normal respiration rates, heart rate, and rectal temperature for captive *R. unicornis* were 14–18/minute, 62–68/minute, and 36–39 C, respectively (S. Shrestha, unpubl. data). Our policy was to abandon other activities and inject the antagonist immediately if respiration fell below 4 breaths per minute during immobilization. This situation never occurred. Individuals selected for relocation were pushed over on their sides only prior to transport on a sledge.

One breeding male was captured twice, and on both occasions a second injection of etorphine was required to immobilize it. In both instances we felt certain that the normal dose had been injected. In the first capture, even after 2 doses of etorphine, this dominant male

Table 1. Induction time (using etorphine), length of immobilization, and recovery (in minutes) after administering antagonist (diphmorphine) for free-ranging *Rhinoceros unicornis* in Royal Chitwan National Park, Nepal, 1986–88. Sample sizes for length of immobilization and recovery time are in some cases smaller than for induction time due to incomplete data.

	Adult females	Adult nonbreeding males	Breeding males	Subadults	Calves	*N*
Induction time						
N	12	7	13	7	5	44
$\bar{x}$	12.5	10.3	13.6	12.1	8.6	
SD	6.47	2.76	4.48	3.09	1.74	
Range	5–25	4–13	8–24	8–16	6–11	
Length of immobilization						
N	11	7	12	7	5	42
$\bar{x}$	61.3	47.1	50.2	65.7	96.0	
SD	23.35	12.79	14.84	6.65	45.64	
Range	28–107	39–71	32–92	53–73	42–173	
Recovery time						
N	10	7	12	6	3	38
$\bar{x}$	13.1	11.4	12.4	16.2	7.7	
SD	3.96	3.29	6.95	5.46	1.89	
Range	8–20	8–18	6–27	9–24	2–9	

stood up suddenly and ran off after remaining unconscious for 27 minutes. Such an incident did not occur during other immobilizations.

Length of Immobilization

We attempted to limit the period an animal was immobilized to 1 hour (Table 1). Calves sent to zoos remained immobilized longer due to the time required to transport them by vehicle from less accessible parts of the park to a loading site. Two subadult females selected for translocation to Dudhwa National Park were sedated for 2 hours and another for nearly 3 hours. All animals survived capture and the subsequent 24-hour ride in a truck prior to release in a holding facility. These data suggest that etorphine mixed with acepromazine allows for safe handling of animals and that *R. unicornis* are able to tolerate long periods of narcosis.

Recovery

Recovery time varied widely following an IM injection of diphmorphine (Table 1). When administered by IV in an ear vein (2 breeding males and 1 calf), reversal occurred in 2 minutes. The difficulty of locating an ear vein and the presence of a large field crew on the ground usually led to the decision to inject the antagonist intramuscularly. On >10 occasions animals appeared to remain recumbent several minutes after reversal was complete. After standing up, animals were followed for 1 hour to ensure complete recovery.

Collar Life

Fights between breeding bulls are violent and in at least 3 incidences during our 4-year study resulted in mortalities (Dinerstein and Price, unpubl. data). Radio collars and transmitters worn by breeding males remained operative for a shorter period of time ($\bar{x}$ = 10.2 months, SD = 6.30, n = 8) than those on breeding-age females ($\bar{x}$ = 25.6 months, SD = 2.33, n = 5) (U test = 40, n = 8, 5, P = 0.002) as did collars worn by both breeding and nonbreeding males ($\bar{x}$ = 10.6 months, SD = 5.87, n = 10) vs. breeding-age females (U = 50, n = 10, 5, P = 0.001). In calculating this statistic, we ignored incidences where males slipped out of collars attached too loosely ($n = 2$) and 4 breeding-age females whose collars were still operating at the end of the study.

On 2 occasions males lost their collars during clashes with other males. Bulls frequently slash each other around the neck folds with the outer lower incisors. These tusks measure up to 9 cm long in dominant males (E. Dinerstein, unpubl. data) and cause slashes in the belting. More common was early transmitter failure ($n = 11$), most likely the result of the impact of 1 bull crashing into another during a fight for dominance. Wallowing behavior of *R. unicornis* did not result in sudden collar failure. During August and September, the peak period of relative humidity, *R. unicornis* may wallow up to 8 hours/day and for at least a few minutes in every month (E. Dinerstein, unpubl. data).

Chemical Immobilization and the Future of Translocation Programs of Asian Rhinoceroses

One of the major impediments in initiating translocation programs for the 3 species of Asian rhinoceroses is the reluctance of wildlife officials to subject these highly endangered mammals to the potential risks of chemical immobilization. It is not clear that Sumatran rhinoceros (*Dicerorhinus sumatrensis*) and Javan rhinoceros (*Rhinoceros sondaicus*) will prove to be as tractable as *R. unicornis*. However, the safe manner with which *R. unicornis* responded to immobilization with etorphine suggests that fears of mortality during anesthesia may be unwarranted. Without doubt, the potential for mortality exists, but our experience illustrates that *R. unicornis* can be immobilized, revived, and transported over long distances without mishap.

Successful immobilizations in Chitwan depended heavily on the skills of trained elephants and their drivers. Trained elephants can also be used in anti-poaching patrols and for wildlife tourism. The close association between *R. unicornis* and elephants allows humans mounted on elephants to approach *R. unicornis* closely for capture operations and to monitor the movements, condition, and behavior of radio-collared animals. We encourage the use of domesticated elephants in all reserves containing Asian rhinoceroses and in parks under consideration as sites for relocation.

SUMMARY

We immobilized greater one-horned rhinoceros (*R. unicornis*) on 51 occasions (representing 39 individuals) between 1985 and 1988 in Royal Chitwan National Park, Nepal, to facilitate radio-telemetry research, a translocation program, and for shipment of calves to zoological parks. *Rhinoceros unicornis* were located and then surrounded by trained elephants and immobilized by firing a projectile dart. Etorphine was used in all but 1 immobilization and reversed with diphmorphine, the exception being an adult female immobilized with carfentanil citrate. Dosages for adults and subadults were 2.0–2.5 mg etorphine mixed with 1 cc acepromazine; calves were immobilized with a mixture of 0.5–1.0 mg etorphine and 0.5 cc acepromazine. Animals immobilized with etorphine showed little variation in response, although mean induction time for breeding males was longer than for nonbreeding adult males ($P < 0.001$). Twenty-one animals were radiocollared. Collars and transmitters remained functional for nearly twice as long on adult females as on adult males ($P = 0.002$). Fights among all 7 breeding males radiocollared on 11 separate occasions resulted in damage to transmitters and collars and reduced signal life. No fatalities occurred during capture, immobilization, or release in Chitwan, demonstrating the effectiveness and safety of etorphine for use on *R. unicornis*.

Acknowledgments.—The King Mahendra Trust for Nature Conservation, the Department of National Parks and Wildlife Conservation (DNPWC), His Majesty's Government of Nepal (HMG), the Conservation and Research Center, World Wildlife Fund, and the United States Agency for International Development provided logistical and financial support. B. N. Upreti, U. R. Sharma and R. P. Yadav of DNPWC made possible the chemical immobilization of *R. unicornis* in Chitwan. We deeply acknowledge the help of the Smithsonian/Nepal Terai Ecology Project staff and Ram Lotan, the director of the elephant drivers from the HMG haatisaar for their skill and patience in all aspects of the field work. M. Bush, D. Edge, M. Sunquist, and C. Wemmer improved the manuscript with their comments.

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Received 23 May 1989.
Accepted 16 August 1989.

***Wildl. Soc. Bull.* 18:41–48, 1990**

EVALUATION OF THREE MINIATURE RADIO TRANSMITTER ATTACHMENT METHODS FOR SMALL PASSERINES

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Biologists have used radio telemetry to study wildlife since the 1960's (Lord et al. 1962, Cochran et al. 1967, Amlaner and MacDonald 1980, Cochran 1980, Kenward 1987), but most work has been with mammals and medium- to large-sized birds (>20 g) using radio transmitters weighing >2 g. Numerous harness ar-

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