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A SURVEY TO DETERMINE THE CONSERVATION STATUS OF SIAMESE CROCODILES IN KAENG KRACHAN NATIONAL PARK, THAILAND

CHUTION KANWATANAKID-SAVINI[1], MANOON PLIOSUNGNOEN[1], ANAK PATTANAVIBOOL[1], JOHN B. THORBJARNARSON[2], CHAIWAT LIMLIKHITAKSORN [3], AND STEVEN G. PLATT[4]

[1]*Wildlife Conservation Society, P.O. Box 170 Laksi, Bangkok, 10210, Thailand, e-mail: csavini@wcs.org*
[2]*Wildlife Conservation Society, Species Program, 2300 Southern Blvd., Bronx, New York 10460, USA (deceased)*
[3]*Kaeng Krachan National Park, Kaeng Krachan, Petchaburi, 76170, Thailand*
[4]*Wildlife Conservation Society, P.O. Box 1199, Savannakhet, Lao PDR*

***Abstract.*—The Siamese Crocodile (*Crocodylus siamensis*) is one of the most endangered crocodilians in the world, and wild populations throughout Southeast Asia have precipitously declined over the last 50 years. Although initially feared extinct in Thailand, surveys in 2001 located a remnant population of *C. siamensis* in Kaeng Krachan National Park (KKNP), an extensive (2,915 km^2) protected area along the Thai-Myanmar border. Our objectives were to assess the conservation status of *C. siamensis* populations within the park, determine if reproduction is occurring, and develop conservation recommendations based on these findings. We used a combination of nocturnal spotlight counts, track and sign surveys, and village interviews to census crocodile populations in KKNP from 2009–2011. Interview data suggest crocodiles occasionally enter Kaeng Krachan Reservoir, although we observed none during spotlight counts. No evidence of crocodiles was found on the Mae Pradone River. We recorded 10 detections of crocodile sign (tracks and scat) along the Petchburi River, although overall detection rates were low (< 0.30/km). We found three nests along the Petchburi River from 2009–2011. Differences in mean egg width among clutches suggest one to three females nested. Clutches were considerably larger than those reported from other wild populations, but contained only non-viable eggs, possibly due to an insufficient number (or complete absence) of males in the Petchburi River. Collectively our survey data suggest at least four, and perhaps as many as six non-hatchling *C. siamensis* inhabit KKNP. The viability of this small population is doubtful and without direct conservation action, extinction appears inevitable. To avoid this fate, the existing population should be augmented using crocodiles obtained from commercial farms in Thailand.**

Key Words.—conservation; *Crocodylus siamensis*; Kaeng Krachan National Park; population survey; Siamese Crocodile; Thailand

INTRODUCTION

The Siamese Crocodile (*Crocodylus siamensis*) is considered one of the least studied and most endangered crocodilians in the world (Thorbjarnarson 1992; Simpson and Bezuijen 2010). Although formerly widespread and abundant throughout much of Southeast Asia (Tirant 1885; Smith 1919, 1931; Mouhot 2000), *C. siamensis* is currently recognized as Critically Endangered on the IUCN Red List (IUCN Red List of Threatened Species. 2009. Available from http://www.iucnredlist.org [Accessed 25 May 2011]) and included in Appendix I of the Convention on International Trade in Endangered Species of Fauna and Flora (Simpson and Bezuijen 2010). The recovery of wild populations has been accorded high priority by the IUCN/SSC Crocodile Specialist Group (Ross 1998; Simpson and Bezuijen 2010).

Siamese Crocodile populations have precipitously declined during the past 50 years, largely as a result of widespread habitat destruction, over-collecting to stock crocodile farms, and illegal hunting for skins and meat (Thorbjarnarson 1992; Simpson and Bezuijen 2010). Remnant populations of questionable long-term viability remain in parts of Cambodia (Daltry and Chheang 2000; Platt et al. 2004b; Simpson and Han 2004; Platt et al. 2006; Simpson et al. 2006) and Laos (Stuart and Platt 2000; Thorbjarnarson et al. 2004). Extant wild populations apparently no longer exist in Vietnam (Platt and Tri 2000; Stuart et al. 2002), and reintroduction efforts (Fitzsimmons et al. 2002; Polet 2002) have as yet proved unsuccessful in establishing a self-sustaining group of breeding crocodiles (Simpson and Bezuijen 2010). Little information is available from Malaysia and Indonesia; *C. siamensis* appears to be extinct in Peninsular Malaysia and Java, although a small, genetically distinct population persists in a single river system of Kalimantan (Simpson and Bezuijen 2010).

Historically, *C. siamensis* was abundant in wetlands of central and southern Thailand (Smith 1916; Bock 1985; Mouhot 2000; Platt et al. 2002a), but population declines were noted in the early 1900s due to widespread indiscriminate shooting (Smith 1919, 1931). By the 1970s, the only population known to remain in Thailand consisted of about 200 crocodiles near Bung Boraphet (Groombridge 1982). This population was subsequently decimated by illegal collecting to supply crocodile farms with brood stock, deliberate destruction of nests and

eggs, and accidental drowning in fishing nets (Pendleton and Kingsbury 1962; Ross 1998), leading Suvanakorn and Youngprapakorn (1987) to conclude *C. siamensis* was approaching extinction in Thailand. However, a spate of reports in the 1990s suggested such conclusions were premature and indicated a small number of crocodiles continued to survive in the wild. One crocodile was observed during a spotlight survey of Pang Sida National Park (Ratanakorn et al. 1994), and according to Kreetiyutanont (1993), another was photographed at Khao Ang Ru Nai Wildlife Sanctuary, a carcass was found in Yot Dom Wildlife Sanctuary, and tracks and drag marks were encountered in Phu Khieo Wildlife Sanctuary and Kaeng Krachan National Park (KKNP).

Additional evidence for the continued survival of *C. siamensis* in KKNP was forthcoming when an adult crocodile (total length [TL] *ca.* 200 cm) was photographed with a remotely triggered camera during a large mammal survey along the Petchburi River in 2001 (Platt et al. 2002a). Subsequent surveys found tracks and drag marks at several points along the river, leading Platt et al. (2002a) to conclude that a small population of *C. siamensis* was present in KKNP. Shortly thereafter, Kekule (2004) provided further photo-documentation of *C. siamensis* in the Petchburi River. Owing to the critically endangered status of *C. siamensis*, this population was deemed of global conservation significance, and a more intensive survey of the Petchburi River and its watershed was recommended (Platt et al. 2002a; Pauwels and Chan-ard 2006). In accordance with these recommendations, we conducted a population survey of *C. siamensis* in KKNP and herein report the results. Our objectives were to assess the population status of *C. siamensis* populations within the park, determine if reproduction is occurring, and develop conservation recommendations based on these findings.

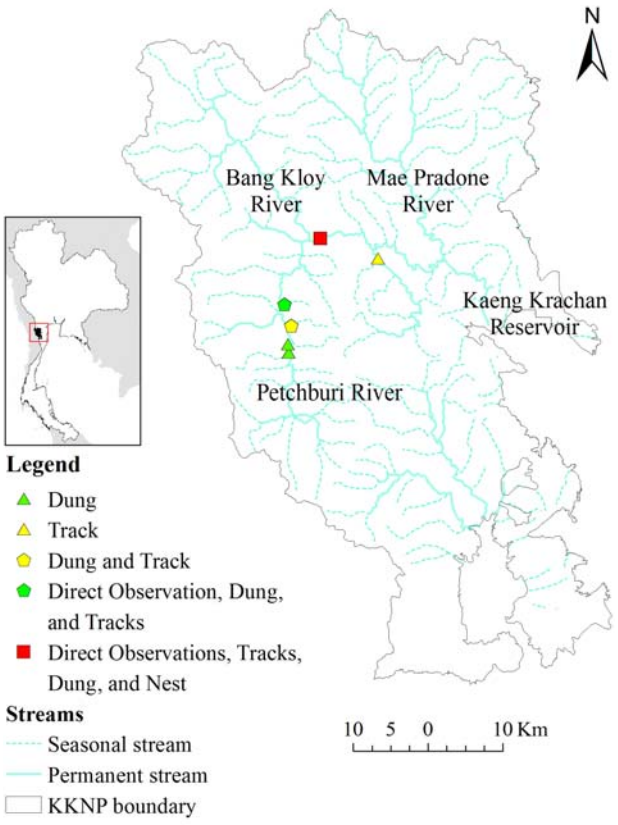

FIGURE 1. Map of Kaeng Krachan National Park showing major river systems and Kaeng Krachan Reservoir. Inset shows location of the national park in Thailand. Symbols denote locations where crocodiles were observed and tracks, scat, and nests found along the Petchburi River (2010–2011).

MATERIALS AND METHODS

Study area.—Kaeng Krachan National Park (Fig. 1), established in 1981, encompasses 2,915 km^2 in Petchburi and Prachuab Khirikhan provinces (*ca.* 12°26′–13°19′N; 99°4′–99°39′E) of southwestern Thailand (Dobias 1982; Platt et al. 2002a). As such, KKNP is the largest national park in Thailand (Dobias 1982). Located in the Tenasserim Mountains adjacent to the Thai-Myanmar border, KKNP is characterized by steep ridges (to 1,513 m) with swift-flowing rivers within restricted valleys. The region experiences a tropical monsoonal climate with a pronounced wet season beginning in late May and continuing through late October. Peak monthly rainfall (*ca.* 500 mm) occurs in September and October (Ngoprasert 2004). Sporadic precipitation may fall during the dry season, which extends from early November through late May (Ngoprasert 2004). Mean monthly temperatures are high, with the hottest months being March and April (Thailand Institute of Scientific and Technological Research 1994). A diversity of vegetation types occur within the park, including various secondary associations, bamboo, mixed deciduous forest, dry dipterocarp forest, and evergreen hill forest (Pauwels and Chan-ard 2006; Phillip Round, unpubl. report). Lands surrounding KKNP are largely deforested and dominated by secondary vegetation. Kaeng Krachan National Park protects watersheds of the Petchburi, Bang Kloy, and Mae Pradone rivers; these are swift-flowing, high gradient rivers with deep pools interspersed between numerous rapids (Fig. 2; Dobias 1982; Platt et al. 2002a) that supply Kaeng Krachan Reservoir (46.5 km^2), formed when the lower Petchburi River was dammed in the mid-1960s (Thailand Institute of Scientific and Technological Research 1994). Small groups of ethnic Karen settled along the lower Petchburi River in the early 1960s (Thailand Institute of Scientific and Technological Research 1994). Currently, about 750 Karen villagers live in settlements within the boundaries of KKNP (World Wildlife Fund 2008). Expansion of these settlements, swidden agriculture,

FIGURE 2. The Petchburi River is characterized by swift-flowing rapids (a) interspersed between deeper pools with minimal current (b). (Photographs by Manoon Pliosungnoen)

and illegal activities such as poaching pose some threat to wildlands and wildlife within the park (Wildlife Conservation Society Thailand Program, unpubl. report).

Survey methods.—We investigated the conservation status of *C. siamensis* in KKNP from July 2009 through August 2011 using a combination of nocturnal spotlight counts, track and sign surveys, and village interviews. To census crocodiles on Kaeng Krachan Reservoir during May, June, and August 2011, we used nocturnal spotlight counts (Bayliss 1987; King et al. 1990). We conducted nocturnal counts from a 4-m, wooden fishing boat equipped with a long-shaft outboard motor, and we used a 100,000 candlepower, handheld spotlight to search for crocodile eyeshines. Survey routes closely followed the shoreline because crocodiles are generally concentrated in shallow, lacustrine habitats (King et al. 1990). We calculated encounter rates during spotlight counts as the number of crocodiles observed per kilometer of survey route (Platt and Thorbjarnarson 2000a).

Safety concerns precluded the use of nocturnal spotlight counts to census crocodile populations on swift-flowing rivers within the park. Instead, we relied on track and sign surveys (Simpson 2006) to confirm the presence of crocodiles in these habitats. We conducted surveys monthly (excepting February 2011) during the dry season (November 2010 through June 2011), when low river levels exposed suitable tracking substrates on sandbars and mudflats. Survey teams of six to 10 persons traveled downstream by rubber raft and searched for crocodile tracks, drag marks, trails, and scat at likely sites along the Petchburi and Mae Pradone rivers. We recorded GPS coordinates of tracks and signs with a Garmin GPSMAP® 60CSx (Garmin International, Inc., Olathe, Kansas, USA) Global Positioning System (GPS), which we later entered into ArcView, Version 3.2a (Environmental Systems Research Institute Inc., Redlands, California, USA). Because we often detected multiple tracks or clumps of scats at a single location, we considered each location as a separate detection in our analysis. We defined locations as sites separated by ≥ 0.5 km of river distance. We independently calculated detection rates for tracks (including drag marks) and scats, as signs encountered per 10 km of survey route. Overall detection rates were calculated as total number of detections divided by total km of survey route. We measured rear-foot tracks (RFT) from the base of the heel to the tip of the longest toe (Platt et al. 1990; Simpson 2006). We estimated the TL of crocodiles associated with measurable-quality tracks using the formula $TL = 11.7 \times RFT - 7.4$ ($r^2 = 0.96$; Platt et al. 2009). We measured the diameter of intact scats at the widest point of the bolus (Simpson 2006). To allow future replication of our survey, we used GPS to record beginning and endpoints of both nocturnal spotlight counts and track and sign surveys. We determined the distance traveled during nocturnal spotlight and track and sign surveys with ArcView, Version 3.2a.

During August-September 2010 and June-July 2011, we conducted open-ended interviews (*sensu* Martin 1995) of local villagers regarding crocodile sightings, nesting activity, and past and present exploitation. Such individuals are typically an excellent source of information regarding the local occurrence of wildlife, especially culturally or economically important species (Thirakhupt and van Dijk 1994; Fogerty 2001; Platt et al. 2004b). In accordance with the format of an open-ended interview, we asked each informant a series of questions that included standard questions prepared in advance and others that arose during the course of conversation (Martin 1995).

We searched potentially suitable habitat for crocodile nests during July 2009, June-July 2010, and April-July 2011. We carefully opened each nest, determined the clutch size, and measured (length and width determined

to nearest 0.1 mm) and weighed (± 0.5 g) every intact egg. Prior to removal from the nest, we marked the top of each egg with a pencil to ensure proper orientation during handling. We determined egg viability by the presence of opaque bands on the eggshell (Ferguson 1985). To estimate the number of reproductive female crocodiles nesting in KKNP, we compared mean egg width among clutches deposited in different years. Intraclutch egg width is highly conserved in oviparous reptiles due to constraints imposed by pelvic aperture diameter (Congdon and Gibbons 1985; Thorbjarnarson 1994), and differences in mean egg width among clutches have been used to distinguish individual nesting females (Platt and Thorbjarnarson 2000b; Platt et al. 2004a). Because our data violated the assumptions of normality and homogeneity of variances required by parametric statistics (Zar 1996), we used a non-parametric Kruskal-Wallis test to compare mean egg width among years (Neave and Worthington 1988). We used a Multiple Behrens-Fisher Test (Munzel and Hothorn 2001) to make post hoc pairwise comparisons of mean egg width between years.

Because crocodilian nests often suffer high rates of predation and risk flood-related mortality (Fleming et al. 1976; Platt et al. 2009), National Park authorities decided to transfer eggs to an artificial incubator in hopes of rearing hatchlings for eventual release back into the wild. Therefore, we returned to each nest approximately midway through the incubation period, placed eggs in a Styrofoam box filled with nesting material, and transported the clutch to an incubation chamber at KKNP headquarters. Despite doubts concerning viability (see below), eggs were incubated in natural nesting material under ambient conditions for the duration of the expected incubation period. At the conclusion of the incubation period, we opened unhatched eggs to determine if vascular development or embryos were present. We present mean values throughout as ± 1 SD and results were considered significant at $P \leq 0.05$. We performed statistical analyses using R statistical software Version 2.13.2 (R Development Core Team, Vienna, Austria).

RESULTS

We conducted three nocturnal spotlight counts in Kaeng Krachan Reservoir, but encountered no crocodiles (Table 1). Lack of access points, manpower constraints, and logistic difficulties limited us to a single track and sign survey of the Mae Pradone (24–29 November 2010; begin = 12º48.86´N, 99º22.11E´; end = 12º50.65´N, 99º19.48E´; distance surveyed = 48.4 km), and we found no evidence of crocodiles along this river. We recorded 10 detections of crocodile sign (tracks and scat) during seven surveys of the Petchburi River (Table 2); however, overall detection rates for both tracks and scat were low (< 0.30/km). Detections of crocodile sign were clustered along the upper reaches of this river (Fig. 1). A single measurable-quality track (RFT = 10.5 cm) was found and the estimated TL of this crocodile was 115.4 cm. The diameter of three intact scats ranged from 20–34 mm. We are unaware of any equations relating scat diameter to body size in crocodilians; however, our experience with other crocodilians suggests these scats were produced by large juveniles or subadults.

TABLE 1. Nocturnal spotlight counts of crocodiles conducted in Kaeng Krachan Reservoir, Thailand during May-June 2011. Geographic coordinates (latitude and longitude) presented for beginning and endpoints of each survey (WGS84 Datum).

Date	km surveyed	Begin (N, E)	End (N, E)	Crocodiles
30–31 May	2.3	12º53.55´, 99º37.81´	12º53.56´, 99º37.83´	0
28 June	39.8	12º53.55´, 99º37.83´	12º54.05´, 99º37.75´	0
29 June	38.5	12º53.56´, 99º37.86´	12º53.56´, 99º37.85´	0

We interviewed 37 persons regarding the occurrence of crocodiles within KKNP and Kaeng Krachan Reservoir. Most respondents were lifelong residents ranging in age from 23 to 80 years (mean age = 48 ± 15 years) with extensive experience in the area, who reported observations of crocodiles at scattered localities in Kaeng Krachan Reservoir, and along the Petchburi and Mae Pradone rivers (Fig. 3). Observations date to the early 1970s, and slightly less than half (43.2%) occurred before 2000. Local place names provided by respondents allowed us to establish the approximate location of crocodile observations along the Petchburi River. Because crocodiles were last encountered in the Mae Pradone River many years ago, respondents were unable to recall specific locations of sightings. Respondents reported several incidents of past illegal exploitation of crocodiles in KKNP; at least one adult was captured and sold to a crocodile farm (1980), and another adult was shot (1984). During the 1980s, several smaller crocodiles were reportedly captured by villagers while electro-fishing and sold to crocodile farms. Respondents provided no evidence of recent crocodile poaching in the area.

We found a single crocodile nest in July 2009, June 2010, and August 2011 at a site along the Petchburi River (12º58.55´N, 99º20.26E´). These nests were constructed on elevated embankments beside landlocked pools adjacent to the main river channel. Although elevated above normal dry season water levels, the nest sites were subject to flooding during the wet season. Nests were constructed among dense stands of Giant Reed (*Arundo donax*) with little overhead canopy cover, and consisted of large mounds (*ca*. 1.5 m wide × 0.75 m

TABLE 2. Results of track and sign surveys of the Petchburi River in KKNP, Thailand (2010–2011). Geographic coordinates (latitude and longitude) presented for beginning and end points of each survey (WGS84 Datum). Overall detection rate for tracks and scat calculated as total detections (tracks or scat) divided by total km surveyed.

Date	km surveyed	Begin (N, E)	End (N, E)	Detections (detections/10 km) Tracks	Scat
09–12 November 2010	18.8	12º48.88′, 99º22.11′	12º50.65′, 99º19.46′	0	2
15–20 December 2010	35.1	12º50.65′, 99º19.46′	12º58.71′, 99º22.35′	1	2
18–22 January 2011	48.5	12º50.91′, 99º19.45′	12º56.33′, 99º27.21′	0	2
20–24 March 2011	31.6	12º50.65′, 99º19.46′	12º58.75′, 99º22.31′	1	0
27–30 April 2011	37.1	12º50.65′, 99º19.46′	12º58.78′, 99º22.32′	1	1
25–29 May 2011	37.8	12º50.65′, 99º19.46′	12º58.76′, 99º22.33′	0	0
14–15 June 2011	32.9	12º50.65′, 99º19.46′	12º58.76′, 99º22.33′	0	0
Total	241.8			3 (0.12)	7 (0.28)

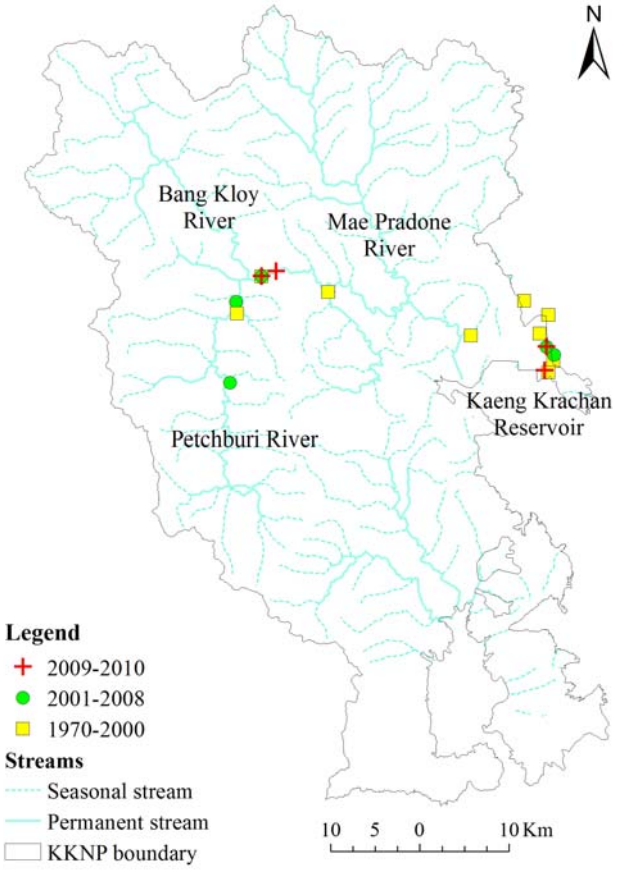

FIGURE 3. Map of Kaeng Krachan National Park showing approximate location of crocodiles observed by villagers based on information provided during interviews. Insufficient information was provided by villagers to confidently establish locations of crocodile sightings along Mae Pradone River (1970–2000).

high) of grass, soil, and woody debris. A crocodile (TL *ca*. 210 cm), presumed to be the nesting female was found concealed among dense grass beside a nest during several visits in June 2010.

Clutch size in 2009, 2010, and 2011 was 31, 40, and 32 eggs, respectively. We measured the linear dimensions and mass of 83 crocodile eggs during our survey (Table 3). Based on data pooled from 2009–11, mean egg width and length were 50.4 ± 1.2 mm (range = 47.0–53.0 mm) and 81.4 ± 2.7 mm (range = 77.4–93.8 mm), respectively, and mean egg mass was 121.6 ± 6.7 g (range = 91.0–135.5 g). There was a significant difference in mean egg width among clutches deposited in different years (H = 38.8; df = 2; P < 0.001). Mean egg width was significantly greater in 2010 than in 2009 (P = 0.039) and 2011 (P < 0.001), and significantly greater in 2009 than 2011 (P < 0.001).

All three clutches consisted of non-viable eggs; no egg in any clutch exhibited opaque banding on the eggshell that becomes obvious as embryos develop, and unhatched eggs contained no embryos or evidence of vascular development. We were unable to estimate the laying date for any clutch owing to the lack of opaque bands. Prior to our survey, park rangers found an old nest mound with eggshells (2007), and an active nest containing about 50 eggs (2008) in the same area where we found nests during 2009–11. The nest containing 50 eggs was later opened by a predator (probably *Varanus* spp.), which consumed the clutch.

DISCUSSION

Our survey indicates that a population of *C. siamensis* continues to survive in KKNP, although whether or not crocodiles inhabit Kaeng Krachan Reservoir is less clear. Despite reported observations by several villagers, we failed to detect crocodiles during repeated spotlight surveys of the reservoir, suggesting that if present, densities are extremely low. Local reports of crocodiles in the reservoir most likely represent transient individuals that moved downstream from the park and later returned. While some reservoirs support high-density populations of crocodiles (Espinal and Escobedo-Galván 2011; Somaweera et al. 2011), we consider Kaeng Krachan Reservoir to be suboptimal habitat for several reasons. First, and perhaps most importantly, fishing activity is widespread, and as a result, crocodiles risk not only direct harassment by fishermen, but also entanglement and drowning in

TABLE 3. Attributes of three clutches of *Crocodylus siamensis* eggs found along the Petchburi River in Kaeng Krachan National Park, Thailand. Mean values presented as ± 1 SD with *n* in parentheses.

Attribute	2009	2010	2011
Egg length (mm)	82.4 ± 2.9 (23)	80.9 ± 2.0 (28)	81.2 ± 2.8 (32)
Egg width (mm)	50.6 ± 1.0 (23)	51.0 ± 1.3 (28)	49.8 ± 0.9 (32)
Egg mass (g)	120.7 ± 2.0 (23)	125.9 ± 4.1 (28)	118.7 ± 8.7 (32)

fishing gear (Platt and Thorbjarnarson 2000a; Platt and Tri 2000). Furthermore, aquatic and shoreline vegetation are absent from the reservoir, probably due to extreme fluctuations in water levels between wet and dry seasons. Such vegetation constitutes critical foraging habitat, particularly for smaller crocodiles (Platt et al. 2002b), and provides construction material as well as concealment for nests.

Based on previous reports (Platt et al. 2002a; Kekule 2004), and our recent track and sign surveys, observations of nesting activity, and interview data, it appears that crocodiles in KKNP are largely confined to upper reaches of the Petchburi River. Assuming at least two nesting females are present (but see below), these data indicate a minimum of four, and perhaps as many as six non-hatchling *C. siamensis* inhabit this region. Assessing long-term trends in this population is difficult, but we found nothing to indicate the number of crocodiles has increased since their presence was first documented in the park about 10 years ago (Platt et al. 2002a).

Whether the upper Petchburi River ever supported high densities of *C. siamensis* is open to question. There is no mention of crocodiles in historic faunal surveys of the region now encompassed by KKNP (Gairdner 1915a and b; Smith 1915), suggesting they were never common. Ratanakorn et al. (1994) regarded fast-flowing upland streams such as the Petchburi to be marginal habitat and considered it unlikely these areas ever supported large numbers of crocodiles. Platt et al. (2002a) speculated crocodiles moved into the upper Petchburi River in response to increasing anthropogenic disturbance as downstream reaches of the river were developed. Nonetheless, the crocodiles now inhabiting KKNP are of both national and global conservation significance; not only is this population (the only extant wild population known in Thailand), it is also one of just a handful of such populations remaining within the historic range of *C. siamensis*.

Our observations of nesting along the Petchburi River constitute one of the few reports of reproduction among wild *C. siamensis* (see also Simpson and Han 2004; Thorbjarnarson et al. 2004; Platt et al. 2006; Starr et al. 2010). Field studies of *C. siamensis* reproductive ecology have proven difficult because most known populations consist of < 10 breeding adults, and consequently few nests have been found in the wild (Platt et al. 2011). Crocodiles in KKNP appear to conform to the pattern of mid-dry to early-wet season nesting observed among captive *C. siamensis* (Suvanakorn and Youngprapakorn 1987; Platt et al. 2011). Given an incubation period of 68–80 days (Suvanakorn and Youngprapakorn 1987), hatchlings are expected to emerge from the nest in late July to early September (Platt et al. 2011), a period when elevated water levels allow neonates ready access to food resources and protective cover afforded by flooded vegetation (Platt et al. 2009). Our observation of nest attendance by an adult (presumably the nesting female) crocodile is the first report of this behavior among wild *C. siamensis*, although one of us (SGP) has since observed similar behavior in Lao PDR. Nest attendance is not unexpected in *C. siamensis* as many crocodilians exhibit parental care behaviors that include nest attendance and post-hatching care of neonates (Lang 1987; Brazaitis and Watanabe 2011).

The clutches we found in KKNP were larger than those recently reported from other wild populations of *C. siamensis* (Simpson and Han 2004; Starr et al. 2010). Because a strong positive correlation exists between female body size and clutch size in crocodilians (Thorbjarnarson 1996), the reduced clutch size found in other wild populations probably reflects the small body size of the few remaining females (Platt et al. 2011). Clutches consisting of as many as 60 eggs were reported from Thailand (Siah 1957) before *C. siamensis* populations were decimated by over-harvesting that removed most large adults (reviewed by Platt et al. 2011).

The linear dimensions and mass of *C. siamensis* eggs we found in KKNP are within the range of values reported for a large sample of eggs obtained from commercial crocodile farms in Cambodia (Platt et al. 2011). Similar to our findings, Smith (1931) stated eggs measured "about 75–80 mm long by 50 broad". Other data sets are unavailable for comparison. Significant differences in mean egg width among years suggest three different females deposited these clutches. However, we urge caution when interpreting these results because differences in mean egg width, although statistically significant, were minor and could reflect annual variation in the size of eggs produced by one female. We therefore cannot rule out the possibility that all three clutches represent the reproductive effort of a single female crocodile. In that case, the "breeding population" of *C. siamensis* in KKNP may consist of only one individual.

Causes underlying the repeated production of non-viable clutches by females in KKNP remain speculative, although several possibilities exist. We consider it most likely that the few adult females remaining along the Petchburi River are depositing clutches of unfertilized eggs because males are lacking from this small

population. Clutch failure could also be the result of suboptimal or lethal environmental conditions within the nest mound, in particular extremely high or low incubation temperatures; however, the complete absence of vascular development in every egg yet examined suggests otherwise. Had viable eggs been exposed to suboptimal or lethal incubation conditions, at least some would be expected to contain partially developed embryos.

Another possibility, albeit unlikely is that environmental pollutants are involved in clutch failure. Exposure to organochlorine contaminants has been demonstrated to reduce clutch viability in the American Alligator, *Alligator mississippiensis*, under field (Woodward et al. 1993, 2011) and laboratory (Rauschenberger et al. 2007) conditions. However, no obvious source of environmental pollutants exists in this near-pristine watershed, and while the aerial deposition of contaminants from distant areas (Daly et al. 2007; Shen et al. 2005) is possible, there is currently nothing to indicate that crocodiles in KKNP are being exposed to contaminants.

The apparently small number of breeding adults and their continued failure to reproduce, coupled with the extinction risks inherent in any small population (Gilpin and Soulé 1986), call into question the long-term viability of this population. Without direct, aggressive conservation intervention by park authorities, the eventual extinction of *C. siamensis* within KKNP is inevitable. Indeed, the crocodiles inhabiting KKNP are what Rosenzweig (2003) has described as a "zombie species", i.e., a population composed of a few, often long-lived individuals ("the living dead") that is ultimately doomed to extinction because of the continued lack of reproductive success.

Management recommendations.—To avoid the near-certain extinction of *C. siamensis* in KKNP, we recommend the existing population be augmented using crocodiles obtained from commercial farms in Thailand. Because hybridization of *C. siamensis* with *C. porosus* and to a lesser extent *C. rhombifer* is widespread on crocodile farms, and hybrids often cannot be distinguished solely on the basis of morphology (Fitzsimmons et al. 2002; Starr et al. 2009), it is essential to genetically ascertain individuals used for population augmentation are indeed pure *C. siamensis*. We recommend multiple strategies be implemented to augment the existing population of *C. siamensis* in KKNP. First, several adult males should be released into the upper Petchburi River. If viable eggs are not forthcoming from resident females, alternate hypotheses to explain clutch failure should be investigated. If nests containing viable eggs are found, we recommend collecting each clutch for artificial incubation, rearing hatchlings to a TL of about 1.0 m, and then following Temsiripong et al. (2006), repatriating them as a group into the maternal home range. Additionally, small groups of male and female subadult crocodiles (TL *ca*. 1.0–1.5 m) should be released in consecutive years along the Petchburi River. Subadult crocodiles are invulnerable to most predators and when released, typically experience high growth and survival rates, and are less likely to disperse great distances (Child 1987; Elsey et al. 1992, 1998, 2000). Regardless of size class, crocodiles should be penned on-site for three to six months to engender site fidelity prior to release (Temsiripong 2007).

Post-release monitoring is a critical although often neglected aspect of wildlife reintroduction programs, and essential for evaluating the success of recovery efforts and designing corrective actions if deemed necessary (Dodd and Seigel 1991). To this end, we recommend using radiotelemetry to monitor the movements of each crocodile for at least one year after release. Vigorous attempts should be made to retrieve any crocodile that wanders beyond KKNP boundaries. Retrieval of wandering crocodiles might curb the initial flight response and foster site fidelity in the same manner suggested for translocated tortoises (Tuberville et al. 2005). Each crocodile should also be permanently marked prior to release by clipping a unique series of caudal scutes (Jennings et al. 1991) to enable future identification. Augmentation programs similar to the one we outline here have proven successful in arresting declines and increasing populations of endangered crocodilians in a number of countries (Elsey et al. 2000).

Finally, it is important to involve local communities in crocodile conservation efforts at KKNP. We therefore recommend a village warden system be established, whereby designated villagers dwelling along the Petchburi River will be enlisted to record crocodile sightings, monitor released crocodiles and nesting activity, assist park authorities with safeguarding crocodiles, and perhaps guide tourists wishing to observe crocodiles. Because of the likelihood that crocodiles will enter Kaeng Krachan Reservoir and conflicts with fishers could arise, we also recommend an education campaign be conducted in communities surrounding the reservoir prior to the release of any crocodiles. Such a campaign should foster an awareness of the role played by crocodiles in maintaining healthy fisheries elsewhere, and emphasize the minimal risk to humans posed by *C. siamensis*. Given the popularity of nature-based tourism in Thailand, we expect the opportunity to view crocodiles will prove a significant attraction for ecotourists visiting KKNP (e.g., Tisdell and Wilson 2002). In that event, every effort should be made to ensure that significant economic benefits from increased tourism accrue to local villagers.

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CHUTION KANWATANAKID-SAVINI is a Conservation Project Manager working with Wildlife Conservation Society Thailand. She received her B.S. in Biology from Prince of Songkhla University (1995), and her M.S. (2000) and Ph.D. (2007) in Wildlife Ecology from Mahidol University. Chution serves as a technical advisor to Kaeng Krachan National Park on relevant wildlife issues. In addition to conducting crocodile surveys, she is currently involved in resolving human-elephant conflicts in communities surrounding the park, and reducing threats to wildlife in the park by enhancing the law enforcement and patrolling skills of park staff. (Photographed by Mattana Srikrachang)

MANOON PLIOSUNGNOEN is a Research Scientist working with Wildlife Conservation Society Thailand. Manoon received his B.S. in Environmental Science from Khon Kaen University (2002) and his M.S. in Conservation Ecology from King Mongkut's University (2009). He is currently involved with various projects in Kaeng Krachan National Park, including crocodile surveys, resolving human-elephant conflicts, and coordinating wildlife and law enforcement patrols with park rangers. (Photographed by Nikom Boriboonrananakom)

ANAK PATTANAVIBOOL has been Director of the Wildlife Conservation Society Thailand Program since 2004. He received his B.S. in Wildlife Management from Kasetsart University (1985), his M.S. in Wildlife Science from Oregon State University (1993), and his Ph.D. in Biogeography from University of Victoria (1999). Anak works in close collaboration with various government agencies, academic institutions, and non-governmental organizations to build and strengthen science-based conservation initiatives throughout Thailand. (Photographed by Manat Inchum)

JOHN B. THORBJARNARSON was Senior Conservation Zoologist with the Wildlife Conservation Society and Courtesy Professor at the University of Florida. John received his B.S. from Cornell University (1978), and his M.S. (1984) and Ph.D. (1991) from the University of Florida. John devoted his life to the study and conservation of crocodilians throughout the world. He died in 2010 after contracting malaria while researching Nile Crocodiles (*Crocodylus niloticus*) in Uganda. His book on the Chinese Alligator (*The Chinese Alligator: Ecology, Behavior, Conservation, and Culture* co-authored with Xiaoming Wang; Columbia University Press) was posthumously published in early 2010. (Photographed by Kent Vliet)

CHAIWAT LIMLIKHITAKSORN has been the Superintendent of Kaeng Krachan National Park since 2009. He received his B.S. in Forest Resource Management (1990) and M.S. in Forest Resource Administration (2007) from Kasetsart University. Chaiwat is responsible for all aspects of park administration ranging from wildlife research to law enforcement and management of ecotourism. (Photographed by Suriyon Photibandit)

STEVEN G. PLATT is the Regional Herpetologist for Wildlife Conservation Society in Southeast Asia. He received his B.S. in Forestry and Wildlife Management from Louisiana State University (1985), M.S. in Biology from Southeastern Louisiana University (1990), and Ph.D. in Zoology from Clemson University (1996). His current focus is the study and conservation of turtles and crocodilians in Southeast Asia, with an emphasis on Myanmar, Thailand, and Laos. (Photographed by Lewis Medlock)