THE SUNDARBANS TIGER

ADAPTATION, POPULATION STATUS, AND CONFLICT MANAGEMENT

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ABSTRACT

The Sundarbans of India and Bangladesh is the only mangrove in the world where tigers still live. The Sundarbans is of relatively recent origin and has gone through substantial changes over time, driven by sea level changes, sedimentation, neotectonics, climate change, and human use. The area is of great economic value, provides essential ecosystem services, and is deeply embedded in the culture of the region. The Sundarbans has been under various forms of management for about 2,000 years, and is classified as a Tiger Conservation Landscape of Global Priority. Little is known about the Sundarbans tigers, which are threatened by habitat destruction, prey depletion, and direct tiger loss. This goal of this study was to increase understanding of tiger evolution, population status, and human-tiger conflict. Skulls and body weights of Sundarbans tigers were found to be distinct from other subspecies, indicating that they may have adapted to the unique conditions of the mangrove habitat. Female home ranges, recorded using Global Positioning System collars, were some of the smallest recorded for tigers, indicating that the Bangladesh Sundarbans could have one of the highest densities and largest populations of tigers anywhere in the world. A survey based on tiger track frequency along creek banks in the Bangladesh Sundarbans showed that tigers are still present throughout the landscape, but that abundance is variable. A monitoring program based on this technique has a reasonable power to detect future change in tiger abundance. A review of human-tiger conflict data showed that the number of tiger and human deaths has declined in recent decades. A management framework was developed to support activity selection for the mitigation of human-carnivore conflict, and was applied to human-tiger conflict in the Bangladesh Sundarbans. Collaring problem tigers and creating teams to respond to tiger attacks were identified as the most cost-effective means to reducing the conflict. The monitoring program allows managers to evaluate the effectiveness of conservation strategies. The activity selection framework supports decision-making for the mitigation of human-carnivore conflict. This study highlights the Sundarbans as a high priority area for tiger conservation, and the information collected has been used to help create a national tiger action plan.

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CHAPTER 1

BACKGROUND

INTRODUCTION

Tigers were once widespread across the Bengal region, including much of what is now Bangladesh (Mitra 1957; Khan 1987). However, tiger habitat has been greatly depleted as the human population has increased and forests have been converted to farms and human settlements. Hunting and general forest degradation of the remaining habitat patches has led to further tiger losses (Husain 1981; Khan 1987). As a result of these processes, tigers in Bangladesh are now relegated to the forests of the Sundarbans and the Chittagong hill tracts (Khan 2004). The Chittagong forest is contiguous with tiger habitat in India and Myanmar, but the tiger population is of unknown status (Sanderson et al. 2006). The Sundarbans tigers were selected for research, as this population can contribute most to the persistence of tigers in the region.

The term Sundarbans is most likely derived from the Bengali for beautiful forest ("*sundar bon*"), or from the Bengali name for the main hardwood tree of commercial value ("*sundri*"). The Sundarbans is made up of mangroves, but in earlier periods it would have been contiguous with tracts of other forest types. At approximately 10,000 km^2, the Sundarbans of Bangladesh and India is currently the largest and most bio-diverse mangrove swamp in the world (Iftekhar and Islam 2004a; Giri et al. 2008; Iftekhar 2008).

The Sundarbans gives direct economic benefit to the region, and the tiger is deeply embedded in the Bangladesh culture (Rahman 2000; Miah et al. 2003; Chowdhury et al. in press). Most importantly, the Sundarbans provides essential ecological services such as (1) land maturation, (2) protection of human habitation from cyclones, (3) oxygen production, (4) waste recycling, (5) food supply, and (6) carbon cycling (Iftekhar and Islam 2004b; Biswas et al. 2008).

This section describes the current status of the Sundarbans, outlines its formation, and describes the change over time with respect to coverage, biodiversity, and management. Some aspects of the Indian and Bangladesh portions are described, but emphasis is placed on the Bangladesh side. An overview is also given on previous research on tigers, threats to tigers, conservation activities and the objectives of this study.

The Sundarbans

Formation and current status

The Sundarbans is south of the Tropic of Cancer, and located between N’ 21°30′ - 22°40′, and E’ 88°05′- 89°55′ in the Ganges-Brahmaputra delta (Fig. 1) (Iftekhar and Islam 2004a). The Sundarbans is composed of vegetated low lying islands with elevations ranging from 0.9-2.1 m above mean sea level, interspersed with a maze of tidal waterways (Katebi and Habib 1989; Iftekhar and Islam 2004b).

Although the geographic development of the Sundarbans is poorly understood, it is known to be of relatively recent origin, and the extent of its coverage has changed considerably since its formation (Curtis 1933; Allison 1998a; Stanley and Hait 2000; Allison et al. 2003; Iftekhar and Islam 2004b). Changes in coverage have been driven by a complex interaction of sea level changes, sedimentation rates, and neotectonic subsidence (Islam and Tooley 1999; Stanley and Hait 2000).

The Bengal Basin region, of which the Sundarbans is a part, was formed after the collision of the Indian and Asian continents, about 50 million years before present (BP). This collision resulted in the rising of the Himalayas in the north, and the formation of a subsiding region to the south-west. The subsiding foredeep region then became the collection area for large volumes of sediment, washed down by rivers from the developing mountains (Curray et al. 1982; Allison 1998a). In the east, a hinge zone was formed where a stable shelf to the west and northwest met the subsiding foredeep region. This hinge is located below the current Ganges-Brahmaputra delta at the junction of the Indian, Eurasian, and Burmese plates (Allison et al. 2003; Mukherjee et al. 2008).

The current distribution and thickness of soil types is the result of both deposition and neotectonic activities during the Holocene (Stanley and Hait 2000; Allison et al. 2003; Mukherjee et al. 2008). The sediment composition of the Sundarbans originates from alluvial sand from the Gangetic plain and silt from the Bay of Bengal deposited through prevailing ocean currents (Mukherjee 1975; Allison and Kepple 2001; Allison et al. 2003). The soil has an average pH of 8.0, and is made up of sand, silt, marine silt, and clay (Christensen 1984; Karim 1995; Allison 1998a; Iftekhar and Islam 2004a). The clay tends to cover the surface, while sand tends to form islands ("*chars*") and banks at river mouths (Seidensticker and Hai 1983; Kuehl et al. 1997; Gopal and Chauhan 2006).

Mean sedimentation and subsidence during the Holocene were estimated at 1-7 mm/year and 0.5 cm/year respectively (Stanley and Hait 2000). In recent times, sedimentation rate has been estimated as 0.1-1 mm/year (Allison and Kepple 2001). However, because of the underlying tectonics, subsidence is not evenly distributed, which results in the Sundarbans tilting gradually to the east (Allison 1998b).

Sea level was probably at a maximum height of 1-4 m above its current level during the middle Holocene period (3,000-6,000 years BP) (Nunn and Kumar 2006). Around 6,500 years BP, the Bay of Bengal shoreline may have been up to 300 km inland, with the Sundarbans boundary stretching 120 km north of its current position (Allison 1998b; Islam and Tooley 1999; Stanley and Hait 2000; Allison et al. 2003). There is evidence of mangroves in that area from 6,050-7,000 years BP. As sea levels decreased and sedimentation increased, the mangroves moved towards the south (Stanley and Hait 2000), with the lower deltaic plain evolving in an easterly direction (Allison 1998b; Allison et al. 2003). Forest cover then built up over 3000-4000 years to its current extent, which was established 1,800 years BP (Allison et al. 2003; Mukherjee et al. 2008).

The main rivers that bring alluvium down to the Sundarbans have changed in volume and course over time, due to tectonic activity and human management (Allison et al. 2003). Previously, the Sundarbans main fresh water source was the Ganges, but a major earthquake in the 1800s diverted its course further east, where it joined up with the Brahmaputra (Allison et al. 2003). The Brahmaputra also switched course as a result of an earthquake in 1782 and major flooding in 1787. Its current position has been maintained since 1830 (Brammer 1996).

This general moving of water channels to the east has led to many of the rivers that feed into the Sundarbans losing connection with the Ganges (Allison et al. 2003). The Hooghly in the west and the Meghna in the east are now the only perennial sources of freshwater feeding into the Sundarbans (Ellison et al. 2000). The Raimongol (called Harinbhanga in India) forms the international border that dissects the Sundarbans.

There has been further loss of freshwater due to increasing upstream water use driven by a burgeoning human population and the construction of barrages and dams (Sarkar and Bhattacharya 2003; Wahid et al. 2007).

In the past 200 years, conversion to agricultural land has reduced previous forest cover by half (Curtis 1933; Richards and Flint 1990; Brammer 1996; Allison and Kepple 2001; Biswas et al. 2008). The last major deforestation of 1,500 km^2 occurred from 1873 to 1933 (Curtis 1933; Eaton 1990), after which the Sundarbans boundary has remained relatively stable (Iftekhar and Islam 2004b; Giri et al. 2007). Remote sensing analysis suggests that the net forest area of the Sundarbans increased by 1.4% from the 1970s to 1990, and then decreased by 2.5% between 1990 and 2000 (Giri et al. 2007).

The northern limit of the Sundarbans is now 50-60 km from the sea face (Stanley and Hait 2000), and encompasses a total area of 10,263 km^2 (Giri et al. 2007). The area is split between Bangladesh (6,017 km^2) and India (4,246 km^2), of which 1,750 km^2 and 1,781 km^2 respectively is underwater (Chaudhuri and Choudhury 1994; Iftekhar and Islam 2004b).

Climate

The Sundarbans climate can be classified as maritime, humid, and tropical, with marked seasonality in weather patterns (Iftekhar and Islam 2004b). The seasons are described as dry (December-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-November) (Iftekhar and Islam 2004b). Average annual rainfall ranges from about 1,800 mm in Khulna near the north of the Sundarbans to 2,790 mm on the coast, with the majority of the rainfall (70-80%) occurring during the monsoon. Daily temperatures range from 2^oC in January to 43^oC in March (Seidensticker and Hai 1983; Gopal and Chauhan 2006).

Cyclones primarily occur in May-June or October-November, and have a major impact on the coastal ecosystem, causing loss of vegetation, property, and human lives (Seidensticker and Hai 1983; Islam and Peterson in press).

Water levels and salinity

Fresh and saline water flow in the Sundarbans has changed with shifts in river courses and human use, and also varies temporally with moon phases, rainfall, atmospheric pressure, and wind speed (Wahid et al. 2007). Tidal oscillations have a large influence on water levels; there are two high and low tides each day with mean amplitude of 3-4 m, and a return period of about 12 hours and 50 minutes (Chaffey 1985; Gopal and Chauhan 2006). Tidal waves move progressively north from the coast into the Sundarbans river system. Incoming tides take 2-2.5 hours to pass through the forest, with the timing of water level rise affected by the distance from the sea face, and the depth and orientations of channels in the water's path (Wahid et al. 2007).

There is variation in amplitude due to the phase of the moon, with spring tides 2.5-3 times higher than the neap tide (Wahid et al. 2007). The tide also varies by 0.7-0.8 m between seasons, with a minimum occurring in January and February, and a maximum in the monsoon months of June and July (Khan et al. 2001; Wahid et al. 2007). In the monsoon, the runoff from the Ganges basin increases freshwater flow, and subsequently increases mean water levels by 0.2-0.3 m near the coast.

Water levels are also affected by large-scale cyclical weather phenomena; mean tide level at the coast is approximately 5 cm higher in El Niño years compared to La Niña years (Khan et al. 2001). Tropical storms and cyclones also produce large water level rises, with tidal waves up to 7.5 m recorded (Seidensticker and Hai 1983). Tides and storm surges result in the low lying islands being regularly inundated (Katebi and Habib 1989; Iftekhar and Islam 2004b).

Salinity generally decreases from west to east, and three saline zones have been delineated: oligohaline (< 2 dsm^{-1}), mesohaline (2-4 dsm^{-1}), and polyhaline (>4 dsm^{-1}) (Siddiqi 2001). Salinity levels vary across the Sundarbans due to daily tidal fluctuations, changing moon phases between spring and neap tides, and variation in freshwater inflow. Saline penetration reaches a maximum 100 km inland during high tidal surges and low freshwater inflow during the dry season (Allison 1998b; Allison et al. 2003).

Salinity increases in an east to west direction with the onset of the dry season and peaks in April-May (Wahid et al. 2007). Salinity in north-central and north-eastern Sundarbans is nearly zero during some of the monsoon period (August-September), when large volumes of freshwater come down through the Baleswar, Passur, and Sibsa rivers (Wahid et al. 2007). In the north-west during this time, there are still traces of saline water, however, because the Kobadok and Betna rivers are no longer connected to the Ganges-Brahmaputra system.

Biodiversity

The term mangrove is generally used to describe the assemblage of trees and shrubs that grow in saline coastal habitats, normally found in the tropics and sub-tropics (Karim 1995). Mangrove plants are not land builders but, once established, play a role in stabilization of newly accreted sediment (Blasco et al. 1996). Mangrove tree species have developed a wide range of features, including specialized stomatal, leaf, seed, and root structures, as adaptations for living in a saline environment with high incidence of inundation (Das and Nandy 1999a; Das and Ghose 2001; Nandy and Ghose 2001; Nandy et al. 2007).

Most mangrove species are viviparous; seeds germinate while still attached to the tree. Buoyant seeds develop into mature propagules, which then drop and disperse by water (Karim 1995). Of note is the diversity in root structures of the mangrove tree species, designed to facilitate anchorage, nutrient uptake, and gaseous exchange. Some species, such as *sundri* (*Heritiera fomes*), *keora* (*Sonneratia apetala*), and *baen* (*Avicennia officinalis*), have pneumataphores; upward projecting root branches that enable the gaseous exchange required for respiratory metabolism. Other species, such as *jhanna garjan* (*Rhizophora mucronata*), have “stilt” or “knee” roots for gaseous exchange, while additional features such as the “tap” roots (buttresses) of *sundri* and the horizontal spread of roots in general, add to overall stability. Some plants also excrete excess salt through leaves (Das and Nandy 1999b).

The total growing stock of the Sundarbans has been estimated as 10.6 x 10^6 m^3, and in general there is little variation in mangrove species representation on either side of the Indian-Bangladesh border (Canonizado and Hossain 1998; Gopal and Chauhan 2006). The plants in the Bangladesh Sundarbans include 123 species, including 22 tree species (Hussain and Acharya 1994). Thirty six true mangrove plant species have so far been identified on the Indian side, as well as a wide range of shrubs, herbs, and creepers (Mukherjee 1975; Seidensticker and Hai 1983; Chaudhuri and Choudhury 1994; Chattopadhyay 1998; Gopal and Chauhan 2006).

Distribution and community composition of plants across the Sundarbans seems to be influenced to a large extent by the west to east saline gradient and associated freshwater availability, and to a lesser extent by historical harvesting activities (Ellison et al. 2000; Joshi and Ghose 2003; Gopal and Chauhan 2006; Hoque et al. 2006). The Bangladesh Sundarbans is dominated by *gewa* (*Excoecaria agallocha*) and *sundri*, whereas the Indian side is dominated by *gewa* and *goran* (*Ceriops decandra)* (Khan 1977; Chaudhuri and Choudhury 1994; Gopal and Chauhan 2006; Iftekhar 2008). Other common tree species include *keora, baen, kankra* (*Bruguiera gymnorrhiza*), *jhanna garjan, dhandul (Xylocarpus granatum),* and *passur (Xylocarpus mekongensis)*. Dense patches of thorny *hental* (*Phoenix paludosa*) are scattered throughout the Sundarbans, and *golpatta* palm (*Nypa fructicans*) and *hargoza* (*Acanthus ilicifolius)* are common along the muddy creek banks, particularly on the Bangladesh side.

The Sundarbans has a high diversity of mammal species (49) compared to other mangrove areas, but low compared to other major forest types on the sub-continent (Hussain and Acharya 1994; Iftekhar and Islam 2004b; Gopal and Chauhan 2006). Apart from the tiger, there are no other large terrestrial carnivores. The small carnivore community includes leopard cat (*Prionailurus bengalensis*), fishing cat (*Prionailurus viverrinus*), jungle cat (*Felis chaus*), and otter (*Lutra sp*.) (Seidensticker and Hai 1983). Jackals (*Canis aureus*) are also present, but have only been observed on the south-east coast (pers. obs.)

The main ungulate species are chital (*Axis axis*), wild boar (*Sus scrofa*), and barking deer (*Muntiacus muntjak*) (Hendrichs 1975). Earlier reports implied a more diverse ungulate assemblage, including swamp deer (*Cervus duvauceli*), hog deer (*Axis porcinus*), and buffalo (*Bubalus bubalis*), but it is unclear how abundant or widespread these species were (Curtis 1933; Sanyal 1983; Seidensticker and Hai 1983; Blower 1985). Rhesus macaque (*Macaca mulatta*) is the only wild primate species present (Hendrichs 1975).

Of note in the Sundarbans rivers and near shore waters is the diverse cetacean community, that includes Ganges river dolphin (*Platanista gangetica*), Irrawady dolphin (*Orcaella brevirostris*), Indo-Pacific hump-backed dolphin (*Sousa chinensis*), and finless porpoise (*Neophocaena phocaenoides*) (Smith et al. 2006; Smith et al. 2008).

There is a considerable diversity of reptiles (59 species) (Hussain and Acharya 1994; Gopal and Chauhan 2006) the most often seen are monitor lizards (*Varanus sp.*) and esturine crocodile (*Crocodylus porosus*). The more commonly encountered snakes include dog-faced water snake (*Cerberus rynchops*), white-lipped pit viper (*Trimeresurus albobrabis*), king cobra (*Ophiophagus hannah*), and Indian spectacled cobra (*Naja naja).* Indian python (*Python molurus*) is also present, but rarely seen. Fourteen turtle species and eight amphibian species have been recorded (Hussain and Acharya, 1994; Das and Nandy 1999b).

A total of 315 species of birds have been recorded so far for the Bangladesh Sundarbans, including 95 species of waterfowl, 38 species of raptor, and nine species of kingfisher (Hendrichs 1975; Seidensticker and Hai 1983; Sarker and Sarker 1986; Chaudhuri and Choudhury 1994; Hussain and Acharya 1994; Naskar and Mandal 1999). The brahminy kite (*Haliastur indus*) is widespread, and a common site along the riverside. The white-bellied sea eagle (*Haliaeetus leucogaster*) is also common near the coast. Among waders and shorebirds, species of egrets, shanks, herons, plovers, curlews, gulls, and terns are abundant. Also of note is the presence of the endangered masked finfoot (*Heliopais personata*) (Neaumann-Denzau et al. 2008).

Between 200 and 300 species of fish have been catalogued, many of them distributed in relation to saline gradients (Chaudhuri and Choudhury 1994; Hussain and Acharya 1994; Sanyal 1999; Islam and Haque 2004). Crustaceans, such as crab, shrimp, prawns, and lobster, contribute a substantial proportion of the overall biomass (Hendrichs 1975; Islam and Haque 2004).

Among a diverse array of invertebrate species, the giant honey bee (*Apis dorsata*) is of particular economic importance, due to its annual production of honey and beeswax (Chakrabarti 1987a; Gopal and Chauhan 2006). More comprehensive species lists can be found in previous studies (Hendrichs 1975; Seidensticker and Hai 1983; Hussain and Acharya 1994; Khan 2004; Gopal and Chauhan 2006).

Management history

Between 321-226 BC the Muryan Empire created a Department of Forest Products headed by an official called a "*kupyadhyaksta*" (Farooque 1997). This department supervised the use of eight forest divisions called "*gaja-vanas*" or "elephant forests", classified with respect to their intended use: (1) religious, (2) supply of general forest produce, (3) grazing for royal elephants, (4) royal hunting ground, and (5) public hunting ground. The Sundarbans was part of the Angireya-vana, which included forests from North and South Bengal (Farooque 1997; Iftekhar and Islam 2004a).

New regulations were enacted during the Gupta dynasty (320-415 AD), after which forest management declined and extensive tracts of land were cleared for agriculture (Farooque 1997). From 1204-1575, the Sundarbans was ruled by the Indo-Turkish sultans. During this period, land reclamation was catalyzed by Islamic holy men called "*pirs*", including Khan Jahan, Mubarra Ghazi, Zindah Gazi, Mehr Ali, and Umar Shar (Eaton 1990).

During the Mughal Empire, which reigned from 1575 to 1765, newly reclaimed land was encompassed into management (Eaton 1990). This land was catalogued as administrative units called "*pargana*", recognized as capable of producing revenue. The first *pargana* in the Sundarbans area (Ambarabad, 175 square miles) was established in

1734. From the 15th to 18th centuries, the administration of the Sundarbans became increasingly complex, with plots of land "*ta'alluq*" owned by "*ta'allug-dar*". The *ta'allug-dar* let out subplots for clearing, and supplied revenue to "*zamindars*", who passed on a portion of their earnings to the government (Eaton 1990).

This land tenure system continued to develop when the East India Company took over administration of the 24 parganas area, and then into the period of formal British colonial rule, which started in 1757 (Rahman 2000). The British conducted the first survey of the Sundarbans from 1769 to 1773, took over rights to the area in 1828, and started leasing out land for further clearance in 1830 (Chowdhury and Ahmed 1994). The rate of forest clearance then increased until the formulation of the Forest Act in 1855 (Richards and Flint 1990; Iftekhar and Islam 2004a). At one stage, reclamation grants were suspended and the forest was leased to the Port Canning Company, but this decision was later revoked because the company treated the traditional forest users badly (Bhattacharya 1990).

The first management plan for the Sundarbans, formulated in 1871, was designed to regulate harvesting of *sundri*. Under the earlier recommendation of a Conservator of Forests in Burma, and in line with the Forest Act of 1855, some parts of the Sundarbans were declared as reserved forest in 1878 (Bhattacharya 1990). The boundary of the protected area has been subsequently re-plotted several times in response to an ever-shrinking forest (Bhattacharya 1990). The most comprehensive plan, in the early 1900s, delineated the Sundarbans into management units called compartments, to be periodically harvested and monitored by a complex system that relied upon estimation of tree composition and standing crop in each area (Curtis 1933).

South Asia gained independence from British rule in 1947, and administration of the Sundarbans was split between India and East Pakistan. Bangladesh was created in 1971 after a war of independence with Pakistan. A series of management plans subsequently evolved to update the harvesting strategies of an increasing number of forest products (Heinig 1892; Lloyd 1904; Trafford 1911; Farrington 1960; Choudhury 1968; Chaffey 1985; Government of Bangladesh 1993; Canonizado and Hossain 1998).

In addition to the forest management plans, there were a number of legislative initiatives and formal agreements with relevance to the Bangladesh Sundarbans on both a national and international scale. The Forest Act 1927 prohibits or otherwise restricts the carrying of guns, cattle grazing, tree cutting, removal of forest produce, or land clearance. The Forest Act was later revised in 1989, when cutting of *sundri* was suspended.

Until 1973, tiger hunting in Bangladesh was legal, and bounties were offered as an encouragement to hunters. The tiger eventually gained legal protection under the 3rd Schedule of the Bangladesh Wildlife (Preservation) Order 1973. The order was refined and enacted as the Bangladesh Wildlife (Preservation) (Amendment) Act 1974, under which tigers cannot be killed apart from extreme situations where a tiger becomes a threat to human life. In such a case, a tiger can be officially notified by the Chief Conservator of Forests (CCF) for trapping or killing. Under Clause 21 of the act, it is not an offence if any person kills a tiger in defense of his own life or that of any other person. Under the 2nd Schedule of this act, possession or transport of live tigers or their skin and meat requires a certificate from the CCF.

The Bangladesh Sundarbans is currently classified as a reserve forest, and some areas have been delineated for higher protective status. Under the Wildlife act, three areas in the Bangladesh Sundarbans were designated as wildlife sanctuaries; Sundarbans West (715 km^2), Sundarbans South (370 km^2) and Sundarbans East (312 km^2) (Sarkar and Bhattacharya 2003; Iftekhar and Islam 2004a) (Fig. 2). With respect to these sanctuaries, Clause 23 prohibits the entry of people, cultivation of land, damage or destruction of vegetation, hunting or capturing of wild animals, introduction of exotic species, straying of domestic animals, causing of fires, and pollution of water.

Administration of activities in the Bangladesh Sundarbans is overseen by three Divisional Forest Officers (DFO East, DFO West, and DFO Wildlife), under a Conservator of Forests posted in Khulna. Within the forest there are approximately 60 active guard posts, manned by foresters, forest guards, boatmen, and hired laborers (Fig. 2).

Other important legislation and agreements that effect management of the Bangladesh Sundarbans include the CITES (acceded to in 1983), the Convention on Biological Diversity (signed in 1992), the Ramsar Convention (ratified in 1992), and the Kyoto Protocol (ratified in 1994). In 1997, the three wildlife sanctuaries in the Bangladesh Sundarbans were declared a UNESCO World Heritage Site, and in 1999 it was declared as an Ecologically Critical Area under the 1995 Bangladesh Environment Conservation Act. A more comprehensive review of legislation and agreements concerning the Bangladesh and Indian Sundarbans can be found in previous work (Iftekhar and Islam 2004a; Dey et al. 2006).

All tiger habitat across Asia and the Russian Far East has been delineated into Tiger Conservation, Restoration, or Survey Landscapes (Sanderson et al. 2006) (Figs 3 and 4). The Sundarbans of India and Bangladesh has previously been identified as a Class I (highest priority) Tiger Conservation Unit (TCU) (Wikramanayake et al. 1998). More recently, however, its classification has been revised to a Class III (low priority) Tiger Conservation Landscape (TCL), because of presumed high threat levels and low tiger population levels relative to other areas (Sanderson et al. 2006). The Sundarbans is, however, considered a TCL of Global Priority, because it is the only representation of a mangrove tiger habitat (Sanderson et al. 2006). The Sundarbans is isolated from the nearest tiger landscape by 200-300 km of agricultural and urban land (Fig. 5).

In terms of conservation initiatives in Bangladesh, tigers were the focus of an ecosystem-level plan (Seidensticker and Hai 1983), which was not subsequently implemented. Tigers were also one of the key species targeted for protection under the Sundarbans Biodiversity Conservation Project (an Asian Development Bank initiative), which failed to make any long-term impact. Currently there are a number of national NGOs working in the village areas bordering the Sundarbans, and there are also research and other conservation activities being carried out by the Forest Department in partnership with organizations including the University of Minnesota, the Zoological Society of London, and the Wildlife Trust of Bangladesh.

Human use

For centuries, local people have entered the Sundarbans to collect a wide range of forest produce, and extraction of resources is fundamental to the current economic wellbeing of local communities (Blair 1990; Tamang 1993; Rahman 2000; Miah et al. 2003; Islam and Wahab 2005). There is evidence of previous settlement in the Sundarbans in the Shaker Tek temple, south of Adachai guard post, which dates back to the 1700s (Ahmed 1989). The remains of clay pots, once used for collecting salt, are scattered throughout many sites in the Sundarbans, and are the only remains of a once thriving local industry that came to an end last century.

A 20 km buffer zone on the northern border of the Sundarbans has been delineated to encompass the majority of people directly reliant on forest resource extraction (Iftekhar and Islam 2004a). Approximately 350,000 local people are directly involved in collecting forest products (Tamang 1993), and several million people benefit from these activities (Islam and Wahab 2005). Previous extraction of the valuable *sundri* trees has been suspended due to concerns over sustainability, as has the extraction of *gewa* trees, which were used in the paper manufacturing industry. *Goran* trees, used for fuel in brick-making are collected into a number of barges that form a "*coup*". During the winter months, *coups* are also used to collect palm (*Nypa fructicans*) and grass (*Imperata sp.*), used for thatching and matting (Blower 1985; Tamang 1993). *Goran coups* normally work in the west during the dry season.

Honey collection season starts on April 1st every year, when 8-9 man teams set off in hand-paddled boats to search for bee hives. The honey is economically important for local communities, particularly in the west, where most of the collection takes place (Chakrabarti 1987a). Fishing is a mainstay for the local communities as well as large business interests that deal in fish, crab, shrimp, and prawns (Seidensticker and Hai 1983; Chakrabarti 1987b; Siddiqi 1995; Islam and Haque 2004). Shells are used to make lime for consumption with *pan*, and for shrimp pond maintenance (Blower 1985). Fishing is generally carried out using small (1-4 man) craft within the forest or on larger vessels along the coast. Net and line fishing are carried out throughout the forest, with peaks of activity coinciding with moon phases. There are several areas within the forest with semi-permanent fishing communities, including Dubla, Chaprakhali, and Shapla.

The shrimp fry collection is a huge export driven industry that dominates the economy in many border villages (Islam and Haque 2004). Of particular value is the giant tiger shrimp (*Penaeus monodon*), the larvae of which is collected by local people using fine mesh nylon nets (Sarkar and Bhattacharya 2003; Islam and Haque 2004). Shrimp fry collection is concentrated along the forest-village interface along the northern border of the Sundarbans.

In some areas, people also enter the forest for firewood, timber, grazing livestock, and poaching of animals (Jagrata Juba Shangha 2003). All forest users, including Forest Department staff, face dangers from tigers, crocodiles, local pirates called "*dacoits*", and cyclones (Curtis 1933; Hendrichs 1975; Jagrata Juba Shangha 2003; Islam and Peterson, in press).

The culture of the local communities has been shaped by Islam, Hinduism, and local beliefs about the relationship of communities and the forest; people still use a variety of religious and other spiritual approaches to increase their safety in the jungle (Eaton 1990; Jalais 2008). Before entering the forest, blessings are sought from local spiritual/religious leaders and offerings are made to forest deities such as *Banbibi, Dakshin Rai*, and *Badi Ghazi Khan* (Eaton 1990). Local shaman called "*gunin*", as well as other local spiritual leaders, supply blessed pieces of red cloth and other charms to keep villagers safe during their trip to the forest. *Gunins* accompany some user groups, particularly honey collectors, for the duration of their trip. In these cases, the *gunin* will ensure that the group adheres to a range of practices that show respect to the forest spirits, and will also use various incantations to make an area safe (Eaton 1990; Khan 2004).

The first organized tours to the Sundarbans were developed in the 1980s. Tourist numbers have increased since that time, with most trips occurring between November and February. An overwhelming proportion of tourists are Bangladesh nationals, who visit the Forest Department's small wildlife sanctuary, situated at Karamjal guard post in the north of the Sundarbans. Up to 100,000 people visit Karamjal every year (M. A. Rob pers. comm.).

PREVIOUS RESEARCH ON SUNDARBANS TIGERS

Very little is known about the ecology of tigers in the Sundarbans or what measures need to be taken to ensure their continued survival. The distribution of tigers throughout the Sundarbans has been established but not quantified (Hendrichs 1975; Tamang 1993). It is known that tiger diet in the Sundarbans is primarily made up of chital and wild boar (Reza et al. 2001; Khan 2004). Two studies in the Sundarbans East Wildlife sanctuary documented habitat-use patterns of tigers, and abundances of tiger prey (Khan 2007; Khan and Chivers 2007), and another study investigated tiger parasite load (Mandal and Chowdhury 1985). Some threats to tigers have been identified (Jagrata Juba Shangha 2003; Khan 2004).

A majority of studies focused on human-killing, but no work has lead to management activities that have reduced the scale of this problem (Blanford 1891; Curtis 1933; Chaudhuri and Chakrabarti 1972; Chaudhuri and Chakrabati 1974; Hendrichs 1975; Chakrabarti 1980; Chakrabarti 1984; Blower 1985; Chowdhury and Sanyal 1985a, b; Khan 1987; Sanyal 1987a; Siddiqi and Choudhury 1987; Saha 1988; Chakrabarti 1992; Sanyal 1995; Helalsiddiqui 1998; Gani 2002; Reza et al. 2002; Jagrata Juba Shangha 2003; Khan 2004; Azad et al. 2005; Islam et al. 2007).

Information is lacking on many aspects of Sundarbans tiger ecology, including relative abundance, population status, spatial dynamics, habitat selection, life history characteristics, taxonomy, genetics, and disease. There is also no monitoring program in place to track changes in the tiger population over time, and therefore no way of measuring the response of the population to conservation activities or threats.

THREATS TO SUNDARBANS TIGERS

Habitat Loss and Degradation

The Sundarbans shares many threats to habitat in common with other tiger areas, but also has a variety of factors unique to the socio-political landscape in which it is embedded, and to the particular dynamics of a mangrove ecosystem (Seidensticker and Hai 1983; Seidensticker 1987b).

Habitat loss and degradation imperil tigers by reducing the area in which they can live. The most easily observable threat to tiger habitat in the Sundarbans is unsustainable wood-cutting for local needs and commercial demand. This has led to tree loss and overall decrease in habitat quality (Salam and Noguchi 1998; Blasco and Aizpura 2002; Iftekhar and Islam 2004a). Unsustainable cutting, particularly of *gewa* and *sundri*, has been cited as a cause of habitat degradation since detailed forest inventories began (Curtis 1933; Chaffey 1985; Salam and Noguchi 1998; Iftekhar and Islam 2004a). It is estimated that *gewa* has been depleted by 40% through over-harvesting, and *sundri* reduced by 45% due to a combination of cutting and disease (Chaffey 1985; Iftekhar and Islam 2004a). There is also an unquantified amount of illegal tree-harvesting (Herring 1990; Iftekhar and Islam 2004a).

A condition known as top dying disease has been observed in *sundri* trees, but its impact and causes are not clearly understood (Blower 1985; Hartung et al. 1998; Blasco and Aizpura 2002; Iftekhar and Islam 2004b). The type and distribution of invasive species has been investigated; a total of 23 types of invasive plants were identified, and the rate of invasion was notably higher near river banks and in some areas close to human habitation (Biswas et al. 2007).

Degradation of the Sundarbans marine environment, through continued overexploitation of the fisheries, may also have a negative effect on the overall ecosystem (Hoq et al. 2001; Miah et al. 2003; Thornton et al. 2003; Islam and Haque 2004). Large-scale fossil fuel extraction and transport has not been carried out so far, but the potential for such activities remains a serious threat (Blower 1985; Roy et al. 2002; Mukhopadhyay 2004).

Other threats are more difficult to quantify or even identify because they originate outside the tiger's area, or their effects are measurable only over the long-term. Upstream pollution of rivers from pesticides and industrial effluent may also damage the terrestrial habitat, but little work has been done on this topic, except for preliminary identification of toxins, or the presence of micro-organisms associated with a particular pollutant type (Hussain and Acharya 1994; Roy et al. 2002; Bhattacharya et al. 2003).

Another water-related issue that affects the habitat is the availability and distribution of freshwater supply. Decreased freshwater supply is particularly apparent to the west, where rivers have been cut off from the Ganges (Allison 1998a). In the last 50 years, the increase in water use, mainly for irrigation purposes, and the construction of barrages and dams along the rivers further to the north of the Sundarbans, have lessened the flow even more (Potkin 2004; Mukherjee et al. 2008). The Farakka Barrage built in India in the 1970s, for example, coincided with a substantial decrease in freshwater flow into the Sundarbans (about a 60% decline in the Sibsa), and led to increased siltation and disconnection of several southern distributaries (Karim 1994; Wahid et al. 2007).

The overall decrease in freshwater flow changes the salinity and tidal regimes (Wahid et al. 2007). This in turn has an effect on both the marine and terrestrial components of the habitat by changing the conditions of competition, resource distribution, and niche availability (Wescoat 1990). The reduction in growing stock and the change in relative abundances of tree species in the Bangladesh Sundarbans are thought to be partially explained by the increase in salinity over time (Chaudhury and Ahmed 1994; Naskar and Mandal 1999; Hoque et al. 2006).

Possibly the biggest threat to the Sundarbans is climate change and the associated predictions of sea level rise (Agrawala et al. 2003; Sarwar and Khan 2007). The potential effects of climate change on the Sundarbans are starting to be quantified; a growing number of studies suggest that rising sea levels will reduce the available tiger habitat over the next 50 years, and frequency of damaging cyclones is likely to increase (Stanley and Hait 2000; Agrawala et al. 2003; Allison et al. 2003; Sarwar and Khan 2007; Shamsuddoha and Chowdhury 2007; Day et al. 2008; Pender 2008; Islam and Peterson, in press). The possibility of subsequent landward colonization by the mangroves may be inhibited by current distribution of human habitation. Current predictions are imprecise, however, because they do not take into account other processes such as sedimentation patterns, tectonic shifts of the Bengal basin, and adaptability of the biota (Blasco et al. 1996; Islam and Tooley 1999; Nichols and Goodbred 2004; Woodroffe et al. 2006).

Prey Depletion

The number of tigers that an area can support is largely reliant on the abundance of suitable prey (Smith et al. 1987; Karanth et al. 2004b). Prey depletion is a serious threat to any tiger population and there are signs that it is occurring in the Sundarbans; prey poaching has been detected, with snaring a common practice (Jagrata Juba Shangha 2003). Snares can also be damaging to non-target species including tigers. The market for wild meat consumption is thought to be largely local, but the overall scale of the problem is unknown (Khan 2004).

Prey could also be depleted through disease introduced by domestic animals; in some northern parts of the forest, deer share habitat with cows, goats, and dogs (Rahman unpublished data). There have been no signs of disease in the deer or wild boar populations, but this issue has not been investigated.

A system of monitoring prey using pellet counts has been in development over the last four years. This survey was piloted throughout the Chandpai and Sharankhola ranges of the Sundarbans in early 2008 (Ahmed unpublished data), and is planned to run every two years to monitor changes in prey abundance. Camera-trapping has also been carried out to estimate prey density at some sites (Khan unpublished data).

Direct Tiger Loss

Though little is known about tiger poaching and trade of tiger parts in Bangladesh, a previous report noted that trade was active in the country (Nowell 2000). Monitoring this issue has decreased since that time, with poaching cases mainly documented from opportunistic arrests or seizures by the authorities. At present, low numbers of poaching incidents are reported from the Sundarbans, with 0-2 incidents each year (FD records). Given the high regional demand for tiger parts, and the well-established international trade (Nowell 2000; Nowell and Ling 2007), it is unlikely that Bangladesh will be overlooked by poachers and traders as a source of tiger parts. The location of Bangladesh between India and Myanmar (countries which both experience high poaching levels), may also increase the tiger's vulnerability (Nowell and Ling 2007). Illegal poaching and trade, therefore, require high levels of attention, particularly given the potential of this threat to decimate a population over a short period of time (Kenney et al. 1995; Chapron et al. 2008).

There is always the potential of tigers dying from disease, but such cases have yet to be documented. Tigers have been in contact with humans and domestic livestock for hundreds of years, but there is no sign that dangerous pathogens have been transferred to the tiger population. However, disease could be a very real problem for the future; captive tigers have died from avian influenza and distemper (Appel and Summers 1995; Myers et al. 1997; Keawcharoen et al. 2004), and feline immunodeficiency virus is widespread amongst wild felids and has been found in tigers (Olmsted et al. 1992). Other diseases that could affect tigers include feline chlamydophila, dirofilaria, feline calicivirus, feline coronavirus, feline leukaemia virus, feline herpes virus, feline parvovirus, tuberculosis, pseudo-rabies, rabies, and sarcoptic mange (J. Lewis pers. comm.). Another potential threat to an isolated population such as the Sundarbans is inbreeding depression (Smith and McDougal 1991).

Some tigers are killed in retribution as a result of general human-tiger conflict (Gani 2002), which is also manifested in loss of humans and livestock. Loss of a family member causes unnecessary misery and is a huge economic loss to an already impoverished household. Tiger conservation in the Sundarbans, therefore, also includes a moral obligation to help the people that suffer due to the tiger's presence. Livestock depredation occurs in many villages along the forest boundary, particularly those communities situated in the east. Results from preliminary surveys for one village suggest that approximately 80 livestock are killed every year. Animals targeted by tigers include cows, buffaloes, goats, and dogs (Rahman unpublished data; Khan unpublished data). Finding solutions to these issues will be essential for securing the support of villagers, who have a large impact on forest management.

STUDY OBJECTIVES AND CONSERVATION ACTIVITIES

Considering the geographical, ecological, and social context of the Sundarbans, this study's goal was to increase understanding of the Sundarbans tiger to help formulate a long-term conservation program. The main objectives of this research were to:

1. Investigate morphological adaptations of Sundarbans tigers
2. Estimate density, population size, and movement of tigers in the Bangladesh Sundarbans
3. Investigate variation in relative tiger abundance across the Bangladesh Sundarbans, and formulate a monitoring program to track changes in abundance over time
4. Investigate the scale and historical trend of human- and tiger-killing in the Indian and Bangladesh Sundarbans
5. Estimate the number of human-killing tigers in the Bangladesh Sundarbans
6. Formulate and test an activity selection framework for human-carnivore conflict, using human-tiger conflict in the Bangladesh Sundarbans as a case study.

The research activities were part of a larger conservation project, called the Sundarbans Tiger Project, which has also developed capacity building, increased conservation awareness, and introduced structured project management workstreams. Achievements and ongoing activities of this program include:

Capacity building

1. Two wildlife technicians, recruited from local communities, trained to assist with all aspects of research and conservation activities

2. Twenty one Forest Department field staff trained in various aspects of tiger capture, immobilization, and monitoring
3. Three Forest Department officers trained in large mammal immobilization
4. Development of a field handbook entitled "The Forest Department's Sundarbans Handbook", to improve motivation and knowledge regarding tiger ecology and conservation in government staff
5. Distribution of the field handbook to all Forest Department staff in the Sundarbans
6. Recruitment of a Bangladesh student to improve national research and conservation capacity
7. Creation of a Tiger Hotline, to improve communication between the community and Forest Department with respect to tiger issues such as human-killing, livestock depredation, and poaching
8. Creation of Tiger Response Teams to deal with human-killing in the west of the Sundarbans, and stray tigers and livestock depredation in the village areas.

Conservation awareness

1. Presentations given on tiger conservation to school children, local villagers, government officials, university students, media personnel, tourists, and the general public
2. Creation of a project website (www.sundarbanstigerproject.info) to disseminate information on Sundarbans tiger conservation issues
3. Generation of newspaper, TV, radio, and web-based news stories on tiger conservation
4. The project has been featured in two BBC programs "The Ganges" and "The Man-eating Tigers of the Sundarbans"
5. Collection of footage for a short film on tiger conservation for eventual release on Bangladesh television.

The research, capacity building, and conservation awareness activities have been coordinated by the project management workstream. The project management aspect builds funding and implementation partnerships between stakeholders, and formulates short, medium, and longer term strategy. The information gathered by the project has been used, together with input from other sources, to help formulate the draft Tiger Action Plan for Bangladesh (2009-2017) (Bangladesh Forest Department 2008).

FIGURES

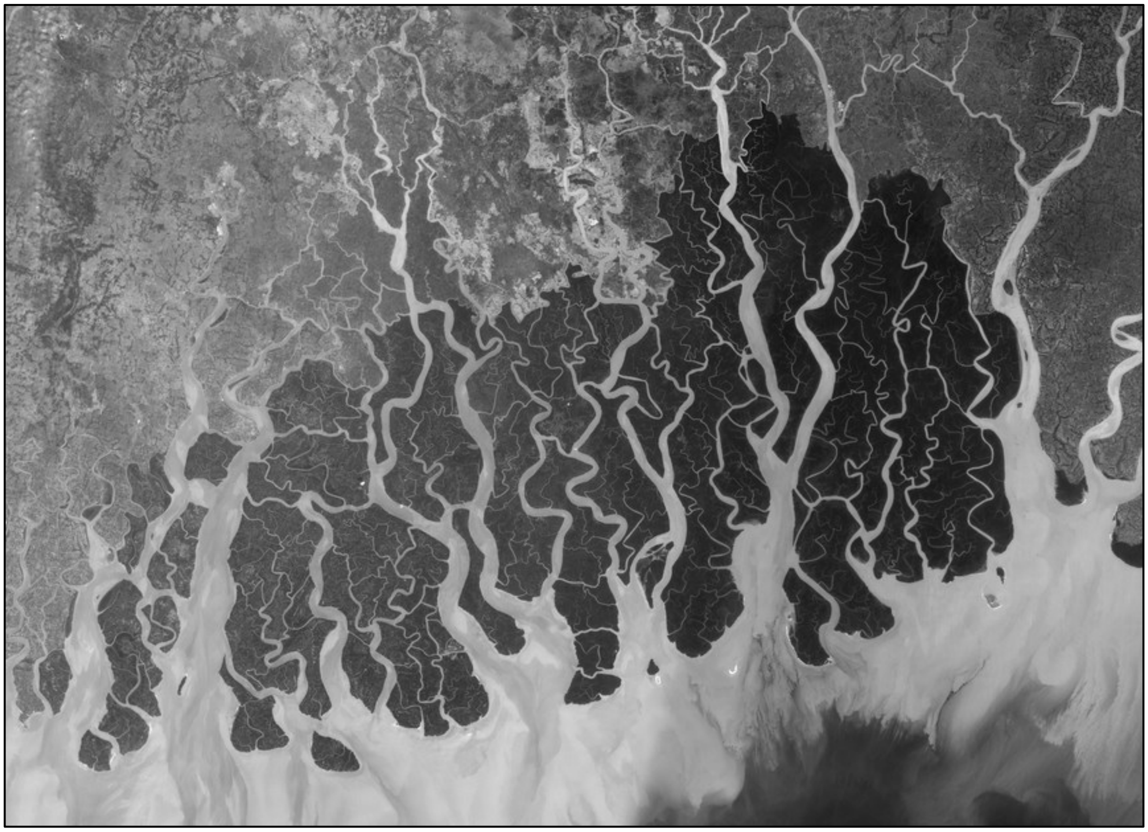

Figure 1. Satellite image of the Indian and Bangladesh Sundarbans.

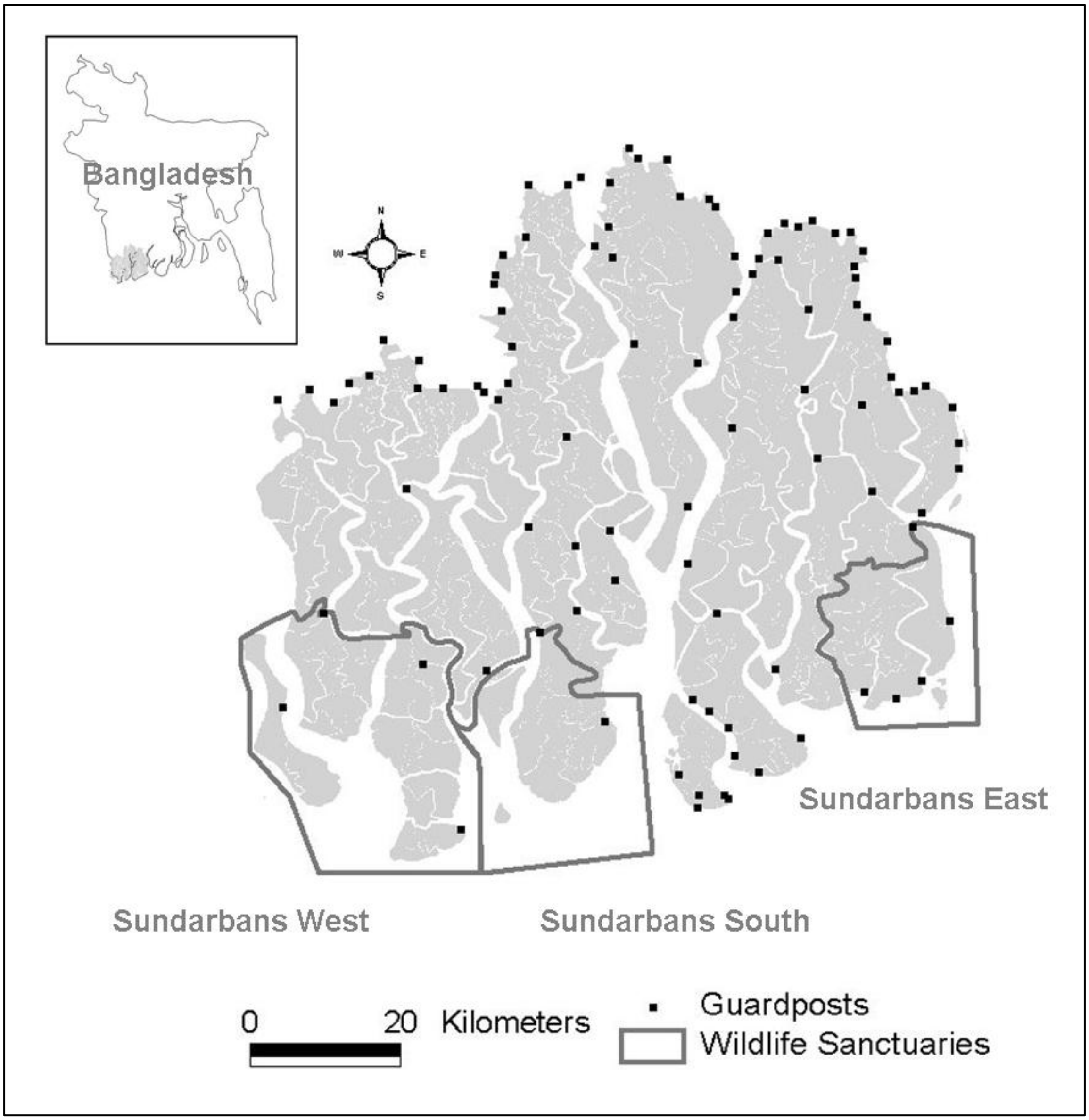

Figure 2. Map of Bangladesh Sundarbans showing distribution of Wildlife Sanctuaries and Forest Department guard posts.

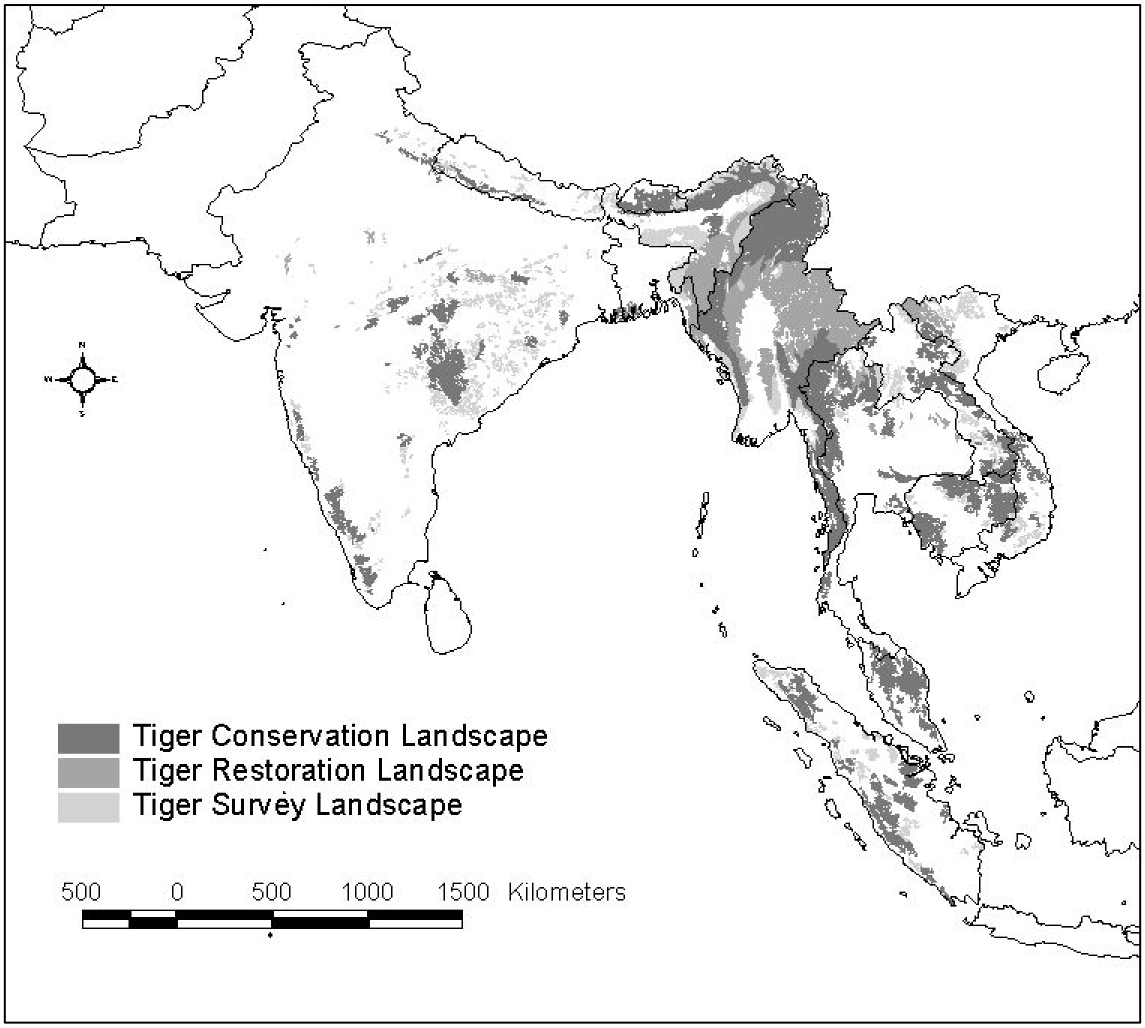

Figure 3. Tiger Conservation, Restoration, and Survey Landscapes in South and South-East Asia (Sanderson et al. 2006).

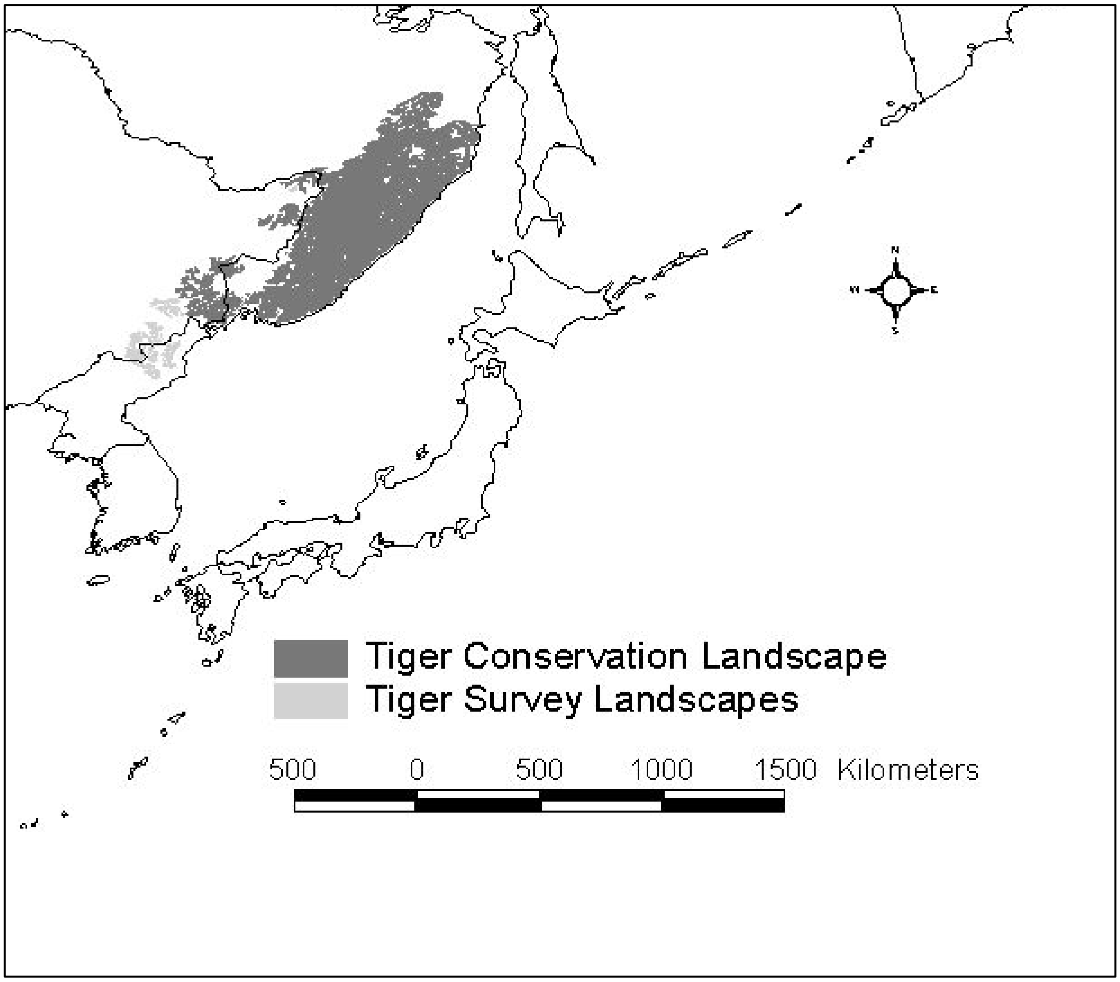

Figure 4. Tiger Conservation and Survey Landscapes in the Russian Far East (Sanderson et al. 2006).

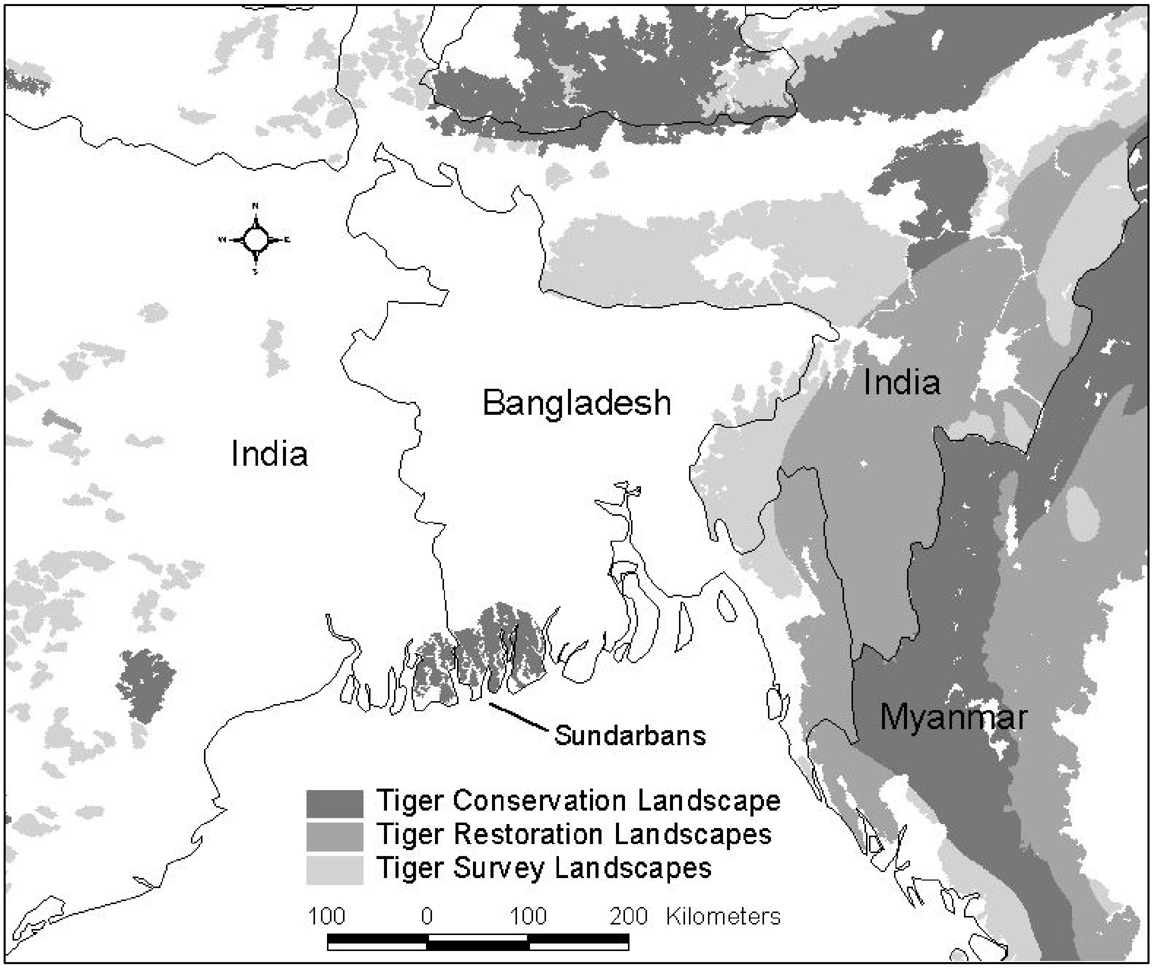

Figure 5. Tiger Conservation, Restoration, and Survey Landscapes in the Sundarbans region (Sanderson et al. 2006).

CHAPTER 2

A PRELIMINARY INVESTIGATION OF EVOLUTIONARY ADAPTATION IN THE SUNDARBANS TIGER

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ABSTRACT

The Sundarbans is classified as a globally important Tiger Conservation Landscape because it is the only mangrove habitat occupied by tigers. However, no study has investigated if these tigers have characteristics that distinguish them from other populations. The objective of this study was to investigate if Sundarbans tigers are morphologically distinct from the recognized subspecies. Five skulls and three body weights of wild Sundarbans tigers were analyzed in comparison to specimens from other groups. Male tiger skulls were found to be significantly different from other subspecies. Female tiger skulls were also different from other subspecies, and particularly distinct from other mainland groups. Mean weight of adult female tigers was smaller than any other group, and significantly different from two mainland subspecies. It is possible that Sundarbans tigers have developed a smaller size in response to small prey. The small sample size of Sundarbans specimens and lack of supporting genetic data makes it premature to classify them as a new subspecies. However, pending further research, the Sundarbans tigers should be tentatively recognized as distinct from other groups as a precautionary measure to ensure preservation of distinct tiger traits.

INTRODUCTION

The tiger (*Panthera tigris*) probably originated in east Asia, and was already well established throughout its historical range by about two million years ago (Hemmer 1987; Kitchener 1999). During the tiger's evolutionary history, it has adapted to a wide range of ecological conditions, from temperate forests to mangroves (Mazák 1979, 1981; Sunquist 1981; Hemmer 1987; Kitchener 1999).

The area available for wild tigers is now quickly diminishing, but conservationists are trying to reverse this situation using a landscape level planning approach (Smith et al. 1998; Wikramanayake et al. 1998; Sanderson et al. 2006). The current range of tigers has been delineated into 76 Tiger Conservation Landscapes (TCL), each evaluated in terms of its contribution to the species' persistence and the representation of evolutionary adaptations to local environmental conditions in its tiger population (Sanderson et al. 2006). Under this rational, TCLs with larger populations and higher probability of long-term viability are classified as higher priority than TCLs with smaller populations. Additionally, a TCL is given a higher priority than another TCL of similar population size, if it represents some rare behavioral, genetic, or morphological trait (Sanderson et al. 2006). Identifying distinguishing traits in a population can, therefore, increase its conservation importance (Cracraft et al. 1998; Kitchener 1999; Kitchener and Dugmore 2000; Luo et al. 2004; Mazák and Groves 2006; Sanderson 2006; Mazák 2008).

Intraspecific genetic and morphological variation of tigers can be categorized using the phylogenetic species concept, or in terms of evolutionary significant units (Cracraft et a 1998, Groves et al. 2002). However, although tiger taxonomy has been studied since at least the latter half of the 18th century, a consensus has yet to be reached on the degree of genetic or morphological variation across the tiger's range. Since the first formal description of tigers as *Felis tigris* in 1758 by Linnaeus, eight subspecies have been established (Pocock 1929; Mazák 1979, 1981; Nowell and Jackson 1996): Bengal (*P.t. tigris*, Linnaeus 1758), Caspian (*P.t. virgata*, Illiger 1815), Amur (*P.t. altaica*, Temminck 1844), South-China (*P.t. amoyensis*, Hilzheimer 1905), Indochinese (*P.t. corbetti*, Mazák 1968), Sumatran (*P.t. sumatrae*, Pocock 1929), Javan (*P.t. sondaica*, Temminck 1844), and Bali (*P.t. balica*, Schwarz 1912). Most of these classifications were determined using a small number of morphological traits from a limited number of skull and skin specimens (Mazák 1967; Kitchener 1999; Mazák 2008).

These classifications have since been disputed on morphological, genetic, and biogeographical grounds (Cracraft et al. 1998; Kitchener 1999; Wentzel et al. 1999; Kitchener and Dugmore 2000), but recent molecular analysis has confirmed significant genetic distinction between three of the eight subspecies (Hendrickson et al. 2000), and Luo et al. (2004, 2008) suggested the addition of a ninth, *P. t. jacksoni*.

Investigation of skull morphology has been used to guide taxonomic classification for a wide range of felid species (Gay and Best 1996; Larson 1997; Leyhausen and Pfleiderer 1999; Meijaard 2004; Kitchener et al. 2005; Mukherjee and Groves 2007; Christiansen 2008a). Studies on tiger skulls have found considerable differences in skull shape and size between some of the sub-species, some clinal variation in craniodental characteristics of mainland tigers, and large differences between mainland tigers and Javan/Bali tigers, with Sumatran tigers intermediary between these two groups (Herrington 1987; Mazák 2004; Mazák and Groves 2006; Mazák 2008).

Analysis of skull characteristics has also called into question classification of an important fossil specimen that was previously listed as a tiger ancestor (Hemmer 1987; Christiansen 2008b). Furthermore, recently identified fossil evidence of tigers in Borneo (Piper et al. 2007), the Philippines (Piper et al. 2008), and Sri Lanka (Manamendra-Arachchi et al. 2005) is adding to our understanding of their former geographical range, dispersal capabilities, and adaptation.

Considering the small sample sizes that current classification is based upon and the lack of agreement amongst studies, there seems considerable scope to improve understanding of tiger evolution and taxonomy. Totally lacking in previous work has been genetic or morphological representation of tigers from the Sundarbans of Bangladesh and India.

The Sundarbans has been classified as a TCL of global priority, but only because it is the only mangrove habitat supporting tigers, rather than the supposed size of the tiger population it supports (Sanderson et al. 2006). Although never examined in detail, these tigers are traditionally assigned to *P. t. tigris,* but they may have been isolated long enough to become morphologically distinct.

Prey assemblage and interspecific competition are both important evolutionary forces for carnivores (Cohen et al. 1993; Abrams and Ginzburg 2000; Linnell and Strand 2000; Emmerson and Raffaelli 2004; Arim and Jaksic 2005; Donadio and Buskirk 2006), and both of these factors are different in the Sundarbans than in other tiger habitats. Throughout all of the tiger's range, with the exception of the Sundarbans, tigers have a prey assemblage that includes a large ungulate species > 200 kg (Sunquist 1981; Seidensticker 1986; Seidensticker 1987a; Rabinowitz 1993; Miquelle et al. 1996; Sunquist et al. 1999; Kawanishi and Sunquist 2004; Karanth et al. 2004b; Johnson et al. 2006). The largest natural prey available for Sundarbans tigers, however, is chital (Reza et al. 2001), which have an average body weight of 55 kg (Karanth and Sunquist 1995).

Apart from the northern part of the Amur tigers range and Sumatra, the Sundarbans is also the only place where tigers do not share their habitat with leopards (*Panther pardus*). Leopards and tigers compete to some degree for prey items, and can effect each other's survival, reproduction, distribution and behavior (Seidensticker 1976; McDougal 1977; Karanth and Sunquist 1995; Karanth and Sunquist 2000; Johnsingh and Negi 2003). It is not clear how the absence of leopards might influence tiger morphology, but I expected that Sundarbans tigers may be relatively small, due to previous observations of track size and the small size of available prey.

The objectives of this study were to determine if skull morphometrics could distinguish Sundarbans tigers from other groups, and to investigate if the weight of Sundarbans tigers is significantly different from that recorded in the literature for other subspecies. This information will help assess the conservation value of the Sundarbans tiger, and builds on earlier investigations of geographic variation in tiger skull morphology and body size (Mazák 1981; Kitchener 1999; Mazák 2004; Slaght et al. 2005; Mazák and Groves 2006; Mazák 2008).

METHODS

Specimens

Apart from natural causes of mortality, tigers are killed in the Bangladesh Sundarbans by (1) the authorities when they have been declared a man-eater, (2) local people when tigers stray into village areas, and (3) poachers (Gani 2002; Jagrata Juba Shangha 2003). If a dead tiger's body is retrieved, the skin is tanned and put into government storage. The remains are generally buried in unmarked plots within Forest Department grounds stations inside the Sundarbans or on its periphery. After decomposition, some skulls are retrieved and put into Forest Department storage or display.

All skull collection was carried out on the Bangladesh side of the Sundarbans. A total of 10 tiger skulls were collected; seven from guard posts, two from Forest Department storage, and one from a display (Table 1, Figs 1, 2 and 3). Of 10 skulls collected, five (three male and two females) were used for analysis, and five were discounted because they were only partial specimens. All skulls are now in Forest Department storage (n = 7), or used for display purposes at the tourist centre of Koromjol post (n = 3).

The Sundarbans skulls were compared to a sample collection of 175 complete skulls (88 males and 87 females) representing nine tiger subspecies, measured by the late V. Mazák (V. M.) and donated by C. P. Groves to J. H. Mazák (Mazák 2004, 2008) (Table 2).

Examining skull variation

Following Mazák (2008), 18 craniodental measurements were taken from each skull (Fig. 4, Table 3). To test for observer bias, ideally variables with a mean CV > 2% should be excluded, but this requires multiple measurements of each parameter (Lynch et al. 1996). Measurements were taken only once for V.M's original data set, so to test measurement errors between observers, a paired *t* test was performed on six, randomly selected male skulls (three Sundarbans and three Sumatra) (Yamaguchi et al. 2004). Errors between observers in all measurements were insignificant ($p > 0.05$).

I used size-adjusted data in order to determine whether any differences between groups were size- or shape-related (Mazák 2008). For size-adjusted data, indices of morphological parameters were created by dividing all 18 log transformed raw measurements by a geometric mean of log condobasal length (Mazák 2008). Since there is considerable sexual dimorphism in tiger body size, male and female skulls were analyzed separately.

One-way analysis of variance (ANOVA) and post-hoc Tukey's honestly significant difference (THSD) tests were carried out to compare the differences between groups on size-adjusted data (Mazák 2008). A principal component analysis (PCA) based on a covariance matrix was used to describe the overall variation pattern in skull morphology between groups, with only those components of eigenvalue > 1 extracted.

The differences between groups were investigated using stepwise discriminant function analysis (DFA), which maximizes between-group variation, while minimizing within group variation. This provided a proportional phenetic distance between groups, and is commonly used in studies of systematics (Shea and Coolidge 1988; Stumpf et al. 2003). Group centroids were then used to construct a Mahalanobis D^2 distance matrix to quantify the differences between groups.

Investigating variance in tiger weights

No verifiable Sundarbans tiger weights were available in the literature. Some weights were listed in Forest Department records, but they were probably mostly guesses, considering the reports of corresponding body lengths (some listed as over 12 feet). Tiger weights were taken in the field from two radio-collared tigers and one tiger killed by local people in a village adjacent to the Sundarbans. The two collared tigers were weighed using 150 kg scales, and the tiger killed by villagers was weighed using a balance scale and weights. All tigers were adult female. Judging by teeth wear, both of the collared animals were relatively old (12-14 years). The female killed by villagers was a young adult (3-4 years old), and probably a pre-territorial transient.

Sundarbans tiger weights were compared to data from other subspecies, compiled by Slaght et al. (2005). Differences between subspecies and Sundarbans tigers was investigated using ANOVA and Tukey's HSD test.

RESULTS

Male skulls

For males, a one-way ANOVA, using size-adjusted data, indicated that means of 13/18 skull parameters differed significantly ($F = 17.28$, $p < 0.01$) among the ten groups. The post-hoc Tukey's HSD test showed that Sundarbans males differed significantly ($p < 0.01$) from mainland subspecies (*P. t. altaica, P. t. virgatta, P. t amoyensis, P. t. jacksoni, P. t. corbetti* and *P. t. tigris*). Sundarbans male tiger skulls were smaller overall (length, width, and jaw size), and had proportionally narrower muzzles and mastoid regions. The Sundarbans male skulls also differed significantly from two Sunda Island subspecies (*P. t. sondaica, P. t. balica*), primarily by having a relatively broad occiput.

Principal Component Analysis (PCA) of male skulls identified two components with an eigenvalue > 1, which accounted for 76% of the variance (Table 4, Fig. 5). PC1 represented the overall skull morphology (skull length and breadth, mandible size, shape of the muzzle, mastoid region, and length of nasal), and was strongly positively related to most size-adjusted data, but weakly to postorbital constriction and supraoccipital breadth (Fig. 5). PC2 was related to shape of occiput, inter-orbital regions, postorbital regions, and tooth row. The Sundarbans males were separated clearly from the mainland and Sunda Island groups with PC1. However, two samples of *P. t. amoyensis* were also separated from the mainland group. Using PC2, Sundarbans males were separated from all other groups (Fig. 5).

A stepwise DFA grouped all samples in two major clusters: a Sunda Island cluster and a mainland cluster, with the Sundarbans group clearly within the range of *P. t. tigris* (Tables 5 and 6, Fig. 6). Mahalanobis D^2 distance analysis shows that the Sundarbans group differs significantly from all other groups, but differs most from *P. t. sondaica*, *P.*

t. altaica and *P. t. sumatrae* (Table 7). A jackknife analysis correctly identified Sundarbans samples with 100% accuracy.

Female skulls

Results of ANOVA and post-hoc Tukey‘s HSD of females are roughly similar to that of males, but the PCA differences between Sundarbans females and other groups were not as marked (Table 8, Fig. 7).

Stepwise DFA, however, clearly separated Sundarbans tigers from all mainland groups (Tables 9 and 10, Fig. 8). Mahalanobis D^2 distance showed that Sundarbans females differed significantly from *P. t. altaica*, *P. t. jacksoni*, *P. t. tigris*, *P. t. balica* and most markedly from *P. t. sondaica* (Table 11). A jackknife classification correctly classified all Sundarbans females with 100% accuracy.

Weight comparisons

The female tigers from the Sundarbans had a mean weight of 76.7 kg (SD = 2.89, range 75-80) (Table 12). One of the two older female's weight (75 kg) was slightly less than normal due to her relatively poor condition at the time of capture.

After combining the Sundarbans female weights with Slaght et al.'s (2005) data from other groups, one-way ANOVA analysis (p = 0.05) indicated a significant difference between groups (df = 7, F = 17.26, p = <0.001). A post-hoc Tukey's HSD test showed that Sundarbans females were significantly different in mean weight from *P. t. tigris* and *P. t. altaica*, as were *P. t. amoyensis*, *P. t. corbetti,* and *P. t. sumatrae*. The *P. t. tigris* group was also significantly different from *P. t. altaica*. With only two and one samples respectively, weights of female *P. t. virgatta* and *P. t. sondaica* were not significantly different from any other group (Table 13).

As presented by Slaght et al. (2005), the mainland groups had the largest mean weights compared to the island groups. This was true except for the Sundarbans, which had the smallest mean weights of any group (Fig. 9).

DISCUSSION

Sundarbans tiger morphology

Skulls of Sundarbans tigers are significantly different craniometrically from all other currently defined subspecies, both in terms of size and shape. This distinction was most notable for male tigers, which tend to have more variable morphology than females (Mazák 2004, Mazák 2008). This findings add to previous work on tiger craniometrics that found substantial differences between the mainland and Sunda island subspecies (Mazák and Groves 2006; Mazák 2008).

Although there were no male weights available, the female weights so far recorded suggest that Sundarbans tigers are the smallest in size throughout the tiger's range, despite the closest subspecies geographically (*P. t. tigris* and *P. t. corbetti*) having relatively large body sizes. Historically, the Sundarbans tigers would have been contiguous with these groups, but it seems that conditions in the mangrove forest selected for smaller tigers.

Explanations for geographic variation

Geographic variation in skull dimensions and body mass could potentially be explained by island/insular dwarfism, latitude, prey size, or some unidentified variable (Bergmann 1847; Foster 1964; Guthrie 1984; Kitchener 1999; Yom-Tov and Geffen 2006; Mazák 2008). The mechanism for island/insular dwarfism is difficult to define, but is probably a combination of resource availability, competitive environment and restrictions of gene flow (Heaney 1978; Dayan and Simberloff 1998; Kitchener 1999; Meiri et al. 2004). Island/insular dwarfism may have influenced the size of Sunda island tigers, but it is difficult to test the hypothesis, and would probably not apply to the species as a whole, given its distribution and the historical connectivity between populations (Kitchener 1999; Sunquist et al. 1999; Kitchener and Dugmore 2000).

Both Kitchener (1999) and Mazák (2008) concluded that, although there was some clinal variation in skull dimensions related to latitude, this factor did not satisfactorily explain all differences. The Sundarbans tigers are smaller than all other groups to the north and south, and occur at the same latitude as the largest subspecies, *P. t. tigris* (Slaght et al. 2005). *P. t. tigris* is the largest subspecies, despite occurring south of *P.t. altaica* (Slaght et al. 2005), which suggests that a factor other than latitude may select for size differences among groups.

Kitchener (1999) also suggested that prey size could be an important influence of tiger morphology. The results of this study concur with this, and I suspect that the small skull and body size of Sundarbans tigers may be a consequence of having no sambar (*Cervus unicolor*) sized or larger prey available. Sundarbans tigers mainly prey on chital and wild boar (*Sus scrofa*) (Reza et al. 2001; Khan 2004). Elsewhere tiger prey always includes a large ungulate species, such as sambar, swamp deer (*Cervus duvauceli*), sika deer (*Cervus Nippon*) or banteng (*Bos javanicus*), that contribute a substantial component to tiger diets (Schaller 1967; McDougal 1977; Karanth and Sunquist 1995; Miquelle et al. 1996; Biswas and Sankar 2002). There have been records that the Sundarbans once harbored swamp deer, hog deer (*Axis porcinus*), wild buffalo (*Bubalus bubalis*), and a species of rhinoceros (possibly *Rhiniceros sondaicus*), but not in sufficient numbers or distribution likely to have a strong influence on tiger adaptation (Curtis 1933; Hendrichs 1975; Khan 2004).

There is probably a combination of factors that explain geographic variation in tiger morphology, but carnivores must have a minimal mass and body size to overcome prey (Earle 1987; Hemmer et al. 2004) above a certain size, additional body mass will be a disadvantage as net energy gain diminishes (Caraco and Wolf 1975; Gittleman 1985; Iriarte et al. 1990, Hoogesteijn and Mondolfi 1996; Owen-Smith and Mills 2008). Additional data on prey selection and tiger morphology is needed to improve understanding of the relationship between tiger and prey size. Although there is a considerable database of skull specimens (Mazák 2008), and a growing database of body weights (Slaght et al. 2005), there are no published prey selection studies for most of the tiger's range. Nearly all such data comes from the Indian sub-continent (Schaller 1967; McDougal 1977; Sunquist 1981; Johnsingh 1992; Karanth and Sunquist 1995; Stoen and Wegge 1996; Biswas and Sankar 2002; Sankar and Johnsingh 2002; Reddy et al. 2004), with only one study from Russia (Miquelle et al. 1996) and Thailand (Rabinowitz 1989), and none from any TCL in the Sunda Islands area.

Leopard absence

Leopards had the opportunity to colonize the Sundarbans since they were previously found in neighboring (non-mangrove) forests (Curtis 1933). Furthermore, there is ample suitably sized prey in the Sundarbans upon which they could subsist (Curtis 1933). Leopards were either unable to establish themselves in the mangrove habitat, or have since been extirpated.

Although the absence of leopards may not have contributed directly to the small size of Sundarbans tigers, it is interesting to speculate why they are not found in this mangrove habitat, and how this relates to tiger ecology in the area. The absence of leopards in the Sundarbans may potentially be explained by overall prey diversity; in all other habitat types, leopards are able to coexist with tigers, because competition between the two species is limited to some degree by prey partitioning (Karanth and Sunquist 2000). It seems unlikely that these two large felids would be able to coexist on the same two species of medium sized prey available in the Sundarbans. Tigers sometimes kill leopards, and possibly force them into peripheral areas (Seidensticker 1976; McDougal 1988). However, leopards are considered more adaptable to sub-optimum conditions, and generally more suited to subsisting on the prey types available in the Sundarbans (Karanth and Sunquist 2000), so it is not altogether clear why tigers are present instead of leopards. Whatever the case, tigers seem to have had some competitive advantage that excluded leopards from the Sundarbans, and perhaps over time the tiger evolved a smaller body size more suitable for the energy requirements of subsisting on smaller prey types.

Recommendations

The Sundarbans tiger inhabits a unique mangrove habitat type, isolated from neighboring tiger populations by hundreds of kilometers of agricultural and urban land. Given evidence that they are morphologically distinct in terms of skull morphometrics and body size, I recommend that the Sundarbans tiger population be evaluated further to determine if it is an evolutionary significant unit. Although there is some disagreement over the definition and application of this term (Crandall et al. 2000), I use it in the sense that the Sundarbans tiger population may represent significant adaptive variation based on concordance between sets of data derived by different techniques (Ryder 1986). From a conservation perspective, recognizing the Sundarbans tigers as a potential evolutionary significant unit is a precautionary measure, to highlight the population's importance in preserving distinct tiger traits. Considering the morphological differences and a lack of gene flow from other populations, it seems that the Sundarbans tigers may be in the early stages of allopatric speciation.

There may also be other tiger populations, like the Sundarbans, that are considered one of the current sub-species, but may have developed unique morphological or genetic traits over time (Hemmer 1987). Sampling from less studied populations would help determine if these populations are phylogenetically distinct.

Furthermore, the current disparity in agreement regarding tiger classification, based on limited and conflicting evidence, creates unnecessary confusion that may hinder conservation planning. I suggest that current classification is in need of an extensive review, based on all available genetic and morphological evidence. Classification should be formulated to guide in-situ and ex-situ efforts to secure the full range of tiger attributes. Guidelines on the process to update subspecific classification of tigers are also required. A profile of genetic and morphological traits is needed for populations in each TCL, collated in a central, open access database.

Importantly, no exchange of individuals or re-introduction should be allowed that mixes tigers from distinguishable populations, or when the characteristics of a population in question have not been ascertained (Moritz 1999). This could lead to outbreeding depression that imperils the population receiving translocated animals, as seen in the case of the Tatra mountain ibex (*Capra ibex ibex*) (Templeton et al. 1986). Exceptions to this rule would be in cases of inbreeding depression, as observed in the Florida panther

(*Puma concolor coryi*) (Pimm et al. 2006), or when tigers have been extirpated from an area and there are no tigers of a suitable type available for re-introduction.

TABLES

Table 1. Sex and age class of Sundarbans tiger skull specimens.

ID	Sex	Age class	Collection point	Notes on cause of death
ST01	Male	Adult	Dhangmari post	Man-eater killed by villagers
ST02	Male	Adult	Karamjal post	Found dead next to water hole
ST03	Unknown	Adult	Bagerhat office	Killed by villagers
ST04	Female	Adult	Bagerhat office	Old female with bad teeth condition, displaced from territory by another tiger
ST05	Unknown	Unknown	Talimpur post	Unknown
ST06	Male	Adult	Burigoalini post	Strayed into village and shot by authorities
ST07	Male	Adult	Khulna office	Unknown
ST08	Male	Adult	Karamjal post	Killed in cyclone
ST09	Female	Adult	Nalian post	Killed by villagers
ST10	Female	Adult	Nalian post	Unknown

Notes: Sex and age class were determined by Forest Department Records (ST06, ST07, ST08, ST10) or physical examination (ST01, ST02, ST03, ST04, ST09).

Table 2. Sample sizes for each group used in craniometric analysis of tiger skulls.

	Specimens	
Group	**Males**	**Females**
P. t. altaica	11	12
P. t. virgatta	5	5
P. t. amoyensis	6	4
P. t. jacksoni	3	3
P. t. corbetti	10	16
P. t. tigris	30	21
P. t. sumatrae	7	13
P. t. sondaica	14	11
P. t. balica	2	2
Sundarbans	3	2
Total	91	89

Table 3. Description and abbreviations of tiger skull measurements.

Measurement	Abbreviation	Name	Description
1	GLS	Greatest Skull length	Distance between prosthion and opisthocranion
2	CBL	Condylobasal length	Distance between prosthion to condylion
3	BL	Basal length	Distance between prosthion to basion
4	RB	Rostral breadth	Breadth across maxillae above canines
5	IFB	Infraorbital breadth	Distance between inner edges of infraorbital foramiua
6	IOB	Interorbital breadth	Distance between inner edges of orbits
7	POB	Postorbital constriction	Breadth of postorbital bar
8	BZB	Bizygomatic breadth	Distance between zygion-zygion
9	MB	Mastoidal breadth	Breadth across occipital crests above mastoidal processes
10	SOB	Supraoccipital breadth	Distance between notches of lateral margins of the occiput
11	OH	Occipital height	Distance between basion and the occiput tip
12	GLN	Greatest nasal length	Length of nasal bones
13	ML	Mandible length	Distance between most oral point of the lower jaw and condylion medial
14	MH	Mandible height	Distance between inferior point of processes angularis and tip of processes musеularis
15	P4L	Upper carnassial length and breadth (PM4	Length and greatest breadth of the crown of upper carnassial
16	CP4L	C-P4 length	Distance between anterior edge of canine alveolus and posterior edge of pm4 alveolus
17	M1L	Lower carnassial length and breadth (M1):	Length and breadth of the lower carnassial crown
18	CM1L	C-M1 length	Distance between anterior edge of canine alveolus and posterior edge of m1 alveolus

Note: Measurement number corresponds to the measurements outlined in Fig 4.

Table 4. Factor loadings for PCA of male tiger skulls.

Measurement	PC 1	PC 2
GLS	0.827	0.513
CBL	0.796	0.526
BL	0.813	0.504
RB	0.69	0.517
IFB	0.58	0.596
IOB	0.542	0.658
POB	0.277	0.645
BZB	0.798	0.466
MB	0.782	0.546
SOB	0.222	0.948
OH	0.722	0.557
GLN	0.792	0.286
ML	0.82	0.49
MH	0.882	0.185
P4L	0.543	0.281
CP4L	0.523	0.675
M1L	0.526	0.255
CM1L	0.664	0.621

Note: Abbreviations correspond to measurement names listed in Table 2.

Table 5. Standardized canonical DFA coefficients for male tiger skulls.

	Function								
Measurement	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
GLS	-2.195	-0.084	-0.527	-0.677	1.858	0.471	-0.33	-2.208	0.427
CBL	-0.418	1.676	0.289	-3.945	-1.698	1.82	-0.668	1.042	1.312
BL	1.559	-2.791	0.348	4.728	0.655	-1.987	-0.885	0.244	-1.22
RB	-0.843	0.117	0.774	-0.182	-0.272	0.051	0.679	0.691	-0.934
IFB	-0.038	-1.032	-0.246	0.643	-0.832	0.371	0.46	-0.361	0.707
IOB	-0.449	0.734	-0.055	-0.665	-0.087	-0.512	-0.184	-0.149	0.88
POB	0.583	-0.045	-0.391	0.681	0.788	0.499	0.143	0.136	-0.344
SOB	1.115	-0.135	-0.448	0.024	-0.18	-0.146	-0.261	0.116	-0.114
OH	1.039	0.661	0.346	-0.018	-0.576	-0.639	0.909	0.046	-0.641
GLN	0.101	1.372	0.141	0.313	-0.263	0.417	-0.023	0.09	-0.12
P4L	0.013	0.009	0.3	0.353	0.259	-0.575	0.289	0.513	0.513
CP4L	0.618	-0.277	0.27	-0.759	0.521	0.311	0.322	-0.139	0.007

Note: Abbreviations correspond to measurement names listed in Table 2.

Table 6. Step-wise DFA classification results for male tiger skulls.

Group	P. t. altaica	P. t. virgatta	P. t. amoyensis	P. t. jacksoni	P. t. corbetti	P. t. tigris	P. t. sumatrae	P. t. sondaica	P. t. balica	Sundarbans	Total	% correction
P. t. altaica	8	2	0	0	1	1	0	0	0	1	13	61.5
P. t. virgatta	1	2	1	0	0	1	1	0	0	0	6	33.3
P. t. amoyensis	0	1	2	0	2	0	1	0	0	0	6	33.3
P. t. jacksoni	0	0	0	1	1	1	0	0	0	0	3	33.3
P. t. corbetti	0	1	2	0	6	4	0	0	0	0	13	46.2
P. t. tigris	0	2	0	10	4	25	1	0	0	0	42	59.5
P. t. sumatrae	1	0	0	0	0	0	7	0	0	0	8	87.5
P. t. sondaica	0	0	0	0	0	0	1	14	0	0	15	93.3
P. t. balica	0	0	0	0	0	0	0	0	2	0	2	100
Sundarbans	0	0	0	0	0	0	0	0	0	0	3	100

Table 7. Mahalanobis D^2 values for male tiger skull dimensions.

Group	P. t. altaica	P. t. virgatta	P. t. amoyensis	P. t. jacksoni	P. t. corbetti	P. t. tigris	P. t. sumatrae	P. t. sondaica	P. t. balica	Sundarbans
P. t. altaica	-									
P. t. virgatta	2.22	-								
P. t. amoyensis	**4.44**	1.60	-							
P. t. jacksoni	**4.25**	1.74	1.89	-						
P. t. corbetti	**7.70**	**2.70**	**3.19**	1.20	-					
P. t. tigris	**10.57**	**3.58**	**4.99**	1.26	**2.99**	-				
P. t. sumatrae	**8.90**	**4.35**	**4.19**	**5.14**	**10.59**	**14.98**	-			
P. t. sondaica	**26.90**	**14.49**	**15.17**	**6.60**	**18.49**	**29.59**	**15.75**	-		
P. t. balica	**8.97**	**5.90**	**5.07**	**3.66**	**6.15**	**7.51**	**4.09**	1.59	-	
Sundarbans	**10.14**	**7.18**	**5.90**	**3.80**	**5.22**	**7.48**	**9.82**	**13.06**	**5.78**	-

Note: Significant results are in bold.

Table 8. Factor loadings for PCA of female tiger skulls.

Measurement	PC 1	PC 2
GLS	0.889	0.355
CBL	0.864	0.343
BL	0.859	0.35
RB	0.802	0.315
IOB	0.735	0.303
POB	0.462	0.427
BZB	0.853	0.296
MB	0.704	0.443
SOB	0.266	0.963
OH	0.761	0.445
GLN	0.778	0.253
P4L	0.659	0.205
CP4L	0.692	0.398

Note: Abbreviations correspond to measurement names listed in Table 2.

Table 9. Standardized canonical DFA coefficients for female tiger skulls.

	Function								
Measurement	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
GLS	-1.728	-0.667	1.731	-0.937	1.652	0.828	-1.315	-0.859	-2.358
CBL	0.776	4.125	-1.239	2.108	-2.952	-1.624	-0.961	-1.265	0.517
BL	0.853	-3.42	-0.355	-0.217	1.443	0.443	1.256	2.077	0.27
RB	-0.817	-0.451	-0.328	1.047	0.485	0.197	0.116	0.737	-0.219
IOB	0.161	0.57	0.384	-0.546	-0.236	-0.312	-0.627	0.721	0.587
BZB	-0.178	0.601	0.222	-1.07	-0.082	-0.16	1.515	-0.706	-0.411
MB	-0.679	0.073	0.394	0.526	0.829	-0.249	0.087	-0.245	1.132
SOB	1.074	-0.476	0.17	-0.018	-0.015	-0.339	0.013	-0.156	-0.238
OH	0.795	-0.104	0.167	-0.055	-1.231	1.034	0.319	0.362	0.613
CP4L	0.697	0.307	-0.7	-0.686	0.575	0.4	-0.205	-0.201	0.306

Note: Abbreviations correspond to measurement names listed in Table 2.

Table 10. Step-wise DFA classification results for female tiger skulls.

Group	P. t. altaica	P. t. virgatta	P. t. amoyensis	P. t. jacksoni	P. t. corbetti	P. t. tigris	P. t. sumatrae	P. t. sondaica	P. t. balica	Sundarbans	Total	% correction
P. t. altaica	7	1	3	0	0	1	0	0	0	0	12	58.3
P. t. virgatta	0	4	0	0	0	2	0	0	0	0	6	66.7
P. t. amoyensis	1	0	1	0	2	0	0	0	0	0	4	25
P. t. jacksoni	0	0	0	1	0	0	1	0	1	0	3	33.3
P. t. corbetti	0	2	1	1	7	3	1	0	0	1	16	43.8
P. t. tigris	4	2	2	2	0	9	4	0	0	0	23	39.1
P. t. sumatrae	0	1	0	1	0	1	12	0	0	0	15	80
P. t. sondaica	0	0	0	0	0	0	0	11	0	0	11	100
P. t. balica	0	0	0	0	0	0	0	0	2	0	2	100
Sundarbans	0	0	0	0	0	0	0	0	0	2	2	100

Table 11. Mahalanobis D^2 values for female tiger skull dimensions.

Group	P. t. altaica	P. t. virgatta	P. t. amoyensis	P. t. jacksoni	P. t. corbetti	P. t. tigris	P. t. sumatrae	P. t. sondaica	P. t. balica	Sundarbans
P. t. altaica	-									
P. t. virgatta	**2.70**	-								
P. t. amoyensis	1.57	**3.19**	-							
P. t. jacksoni	**3.45**	**2.81**	**4.39**	-						
P. t. corbetti	**4.21**	**2.85**	**3.08**	1.64	-					
P. t. tigris	**3.23**	**2.44**	**4.31**	1.83	**3.04**	-				
P. t. sumatrae	**10.99**	**6.32**	**7.24**	2.21	**6.46**	**7.19**	-			
P. t. sondaica	**22.73**	**15.93**	**13.85**	**5.63**	**15.86**	**18.09**	**10.83**	-		
P. t. balica	**6.38**	**4.86**	**5.25**	2.46	**3.20**	**4.62**	**3.54**	2.38	-	
Sundarbans	**2.93**	1.90	2.12	**3.14**	2.53	**2.73**	2.16	**8.31**	**4.00**	-

Note: Significant results are in bold.

Table 12. Male and female tiger weights.

	Males			Females		
Group	n	Mean (kg)	SD	n	Mean (kg)	SD
P. t. tigris	3	212	13.75	16	138.16	20.53
P. t. altaica	44	173.72	28.01	62	122.9	18.85
P. t. virgatta	2	156.5	34.65	2	116	28.87
P. t. amoyensis	15	134.89	19.47	11	103.41	18.01
P. t. corbetti	6	120.6	8.86	7	98.52	8.73
P. t. sumatrae	22	110.82	15.48	21	86.73	12.71
P. t. sondaica	1	110	0	1	95	0
Sundarbans	-	-	-	3	76.67	2.89

Notes: All weights taken from Slaght et al. (2005), plus the Sundarbans weights from this study. n = sample size, and SD = standard deviation.

Table 13. Tukey's HSD results of female tiger weight comparisons between groups.

Group	P. t. tigris	P. t. altaica	P. t. virgatta	P. t. amoyensis	P. t. corbetti	P. t. sumatrae	P. t. sondaica	Sundarbans
P. t. tigris	-							
P. t. altaica	0.10	-						
P. t. virgatta	-18.71	-32.21	-					
P. t. amoyensis	13.41	1.77	-29.30	-				
P. t. corbetti	14.94	2.73	-26.22	-21.47	-			
P. t. sondaica	-13.02	-27.00	-45.75	-48.52	-54.74	-		
P. t. sumatrae	33.35	22.54	-11.06	-3.61	-11.99	-47.51	-	
Sundarbans	27.21	14.07	-10.42	-8.76	-15.75	-44.60	-23.58	-

FIGURES

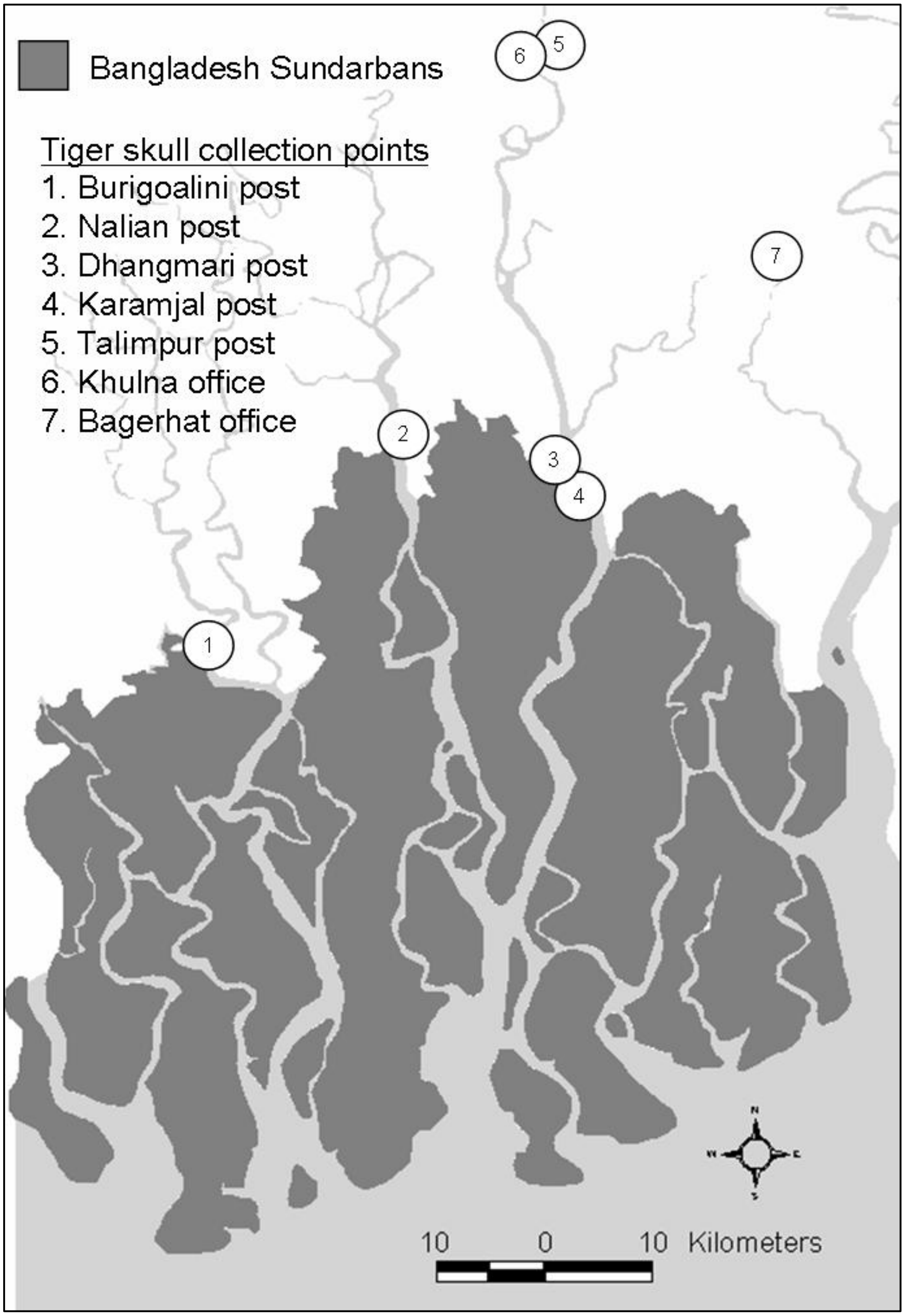
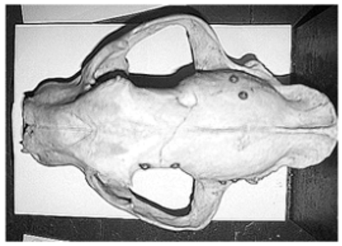
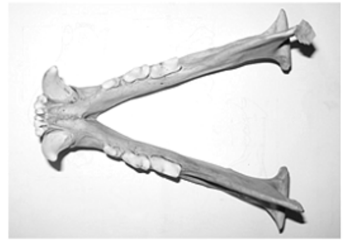
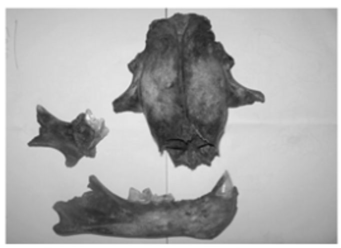
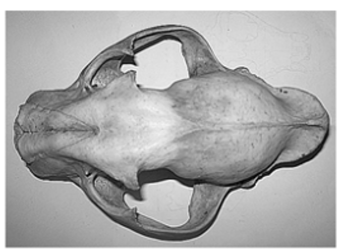
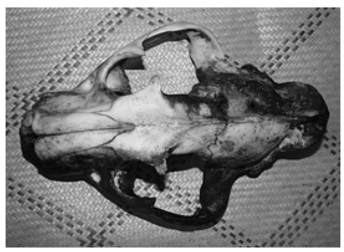
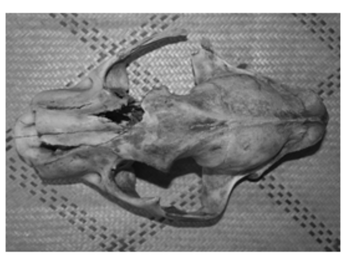


Figure 1. Tiger skull collection points in the Bangladesh Sundarbans area.

Skull	*Views*	
ST01		
ST02		
ST03		
ST04		
ST05		

Note: views not to scale

Figure 2. Photos of Sundarbans tiger skull specimens (skulls 1-5).

Skull	*Views*	
ST06		
ST07		
ST08		
ST09		
ST10		

Note: views not to scale

Figure 3. Photos of Sundarbans tiger skull specimens (skulls 6-10).

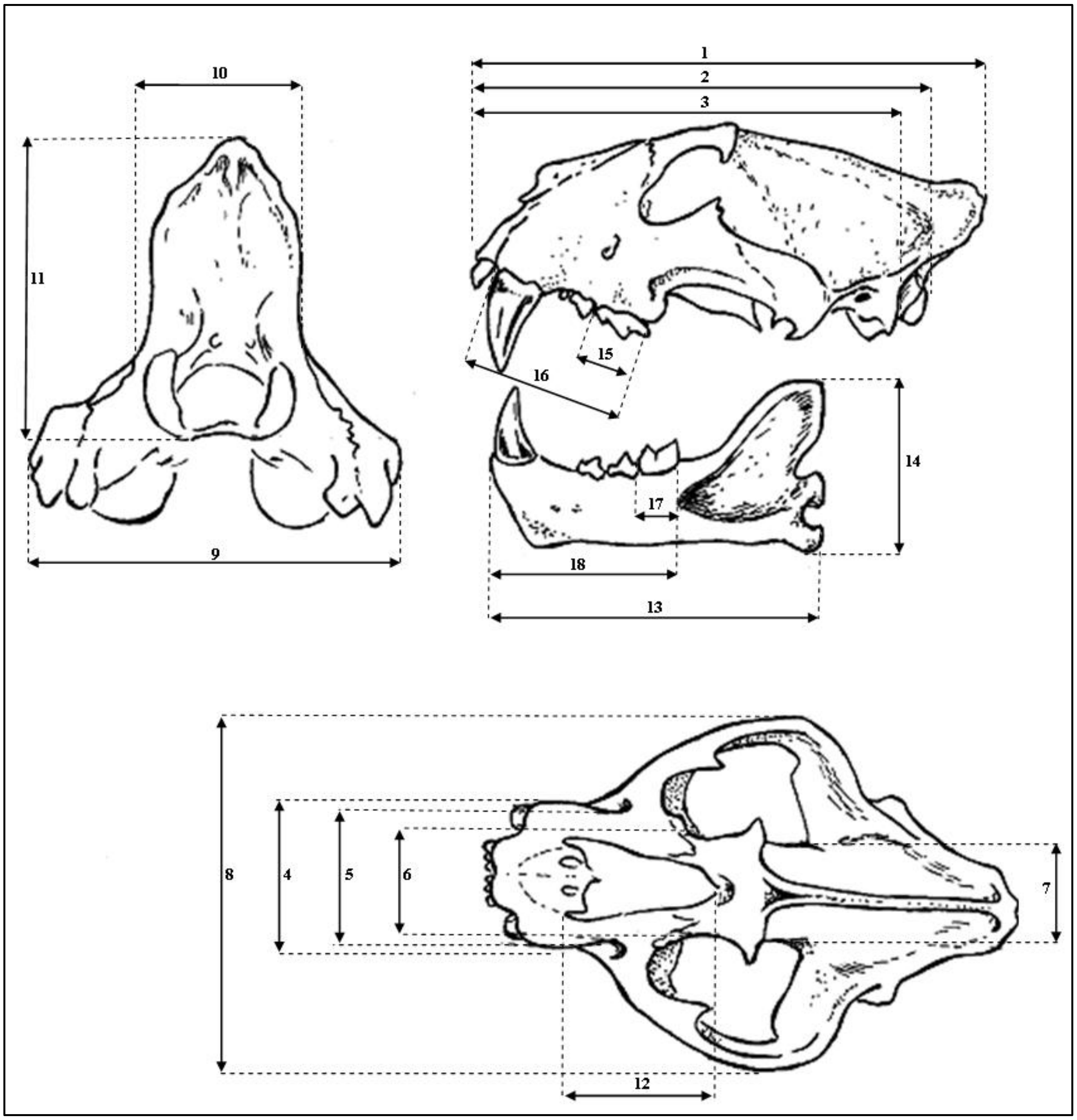


Figure 4. Measurements taken on tiger skulls. Numbers correspond to the measurement labels listed in Table 3.

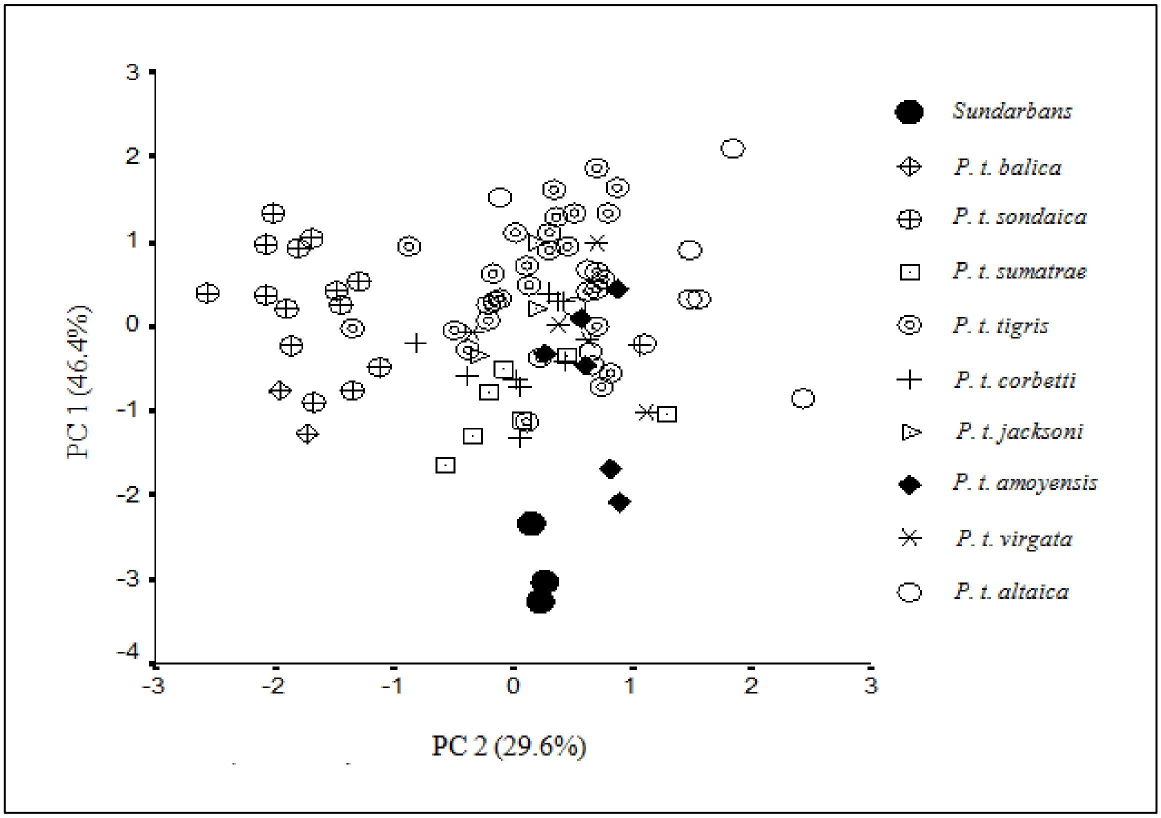


Figure 5. Principle component analysis results of male tiger skull measurements.

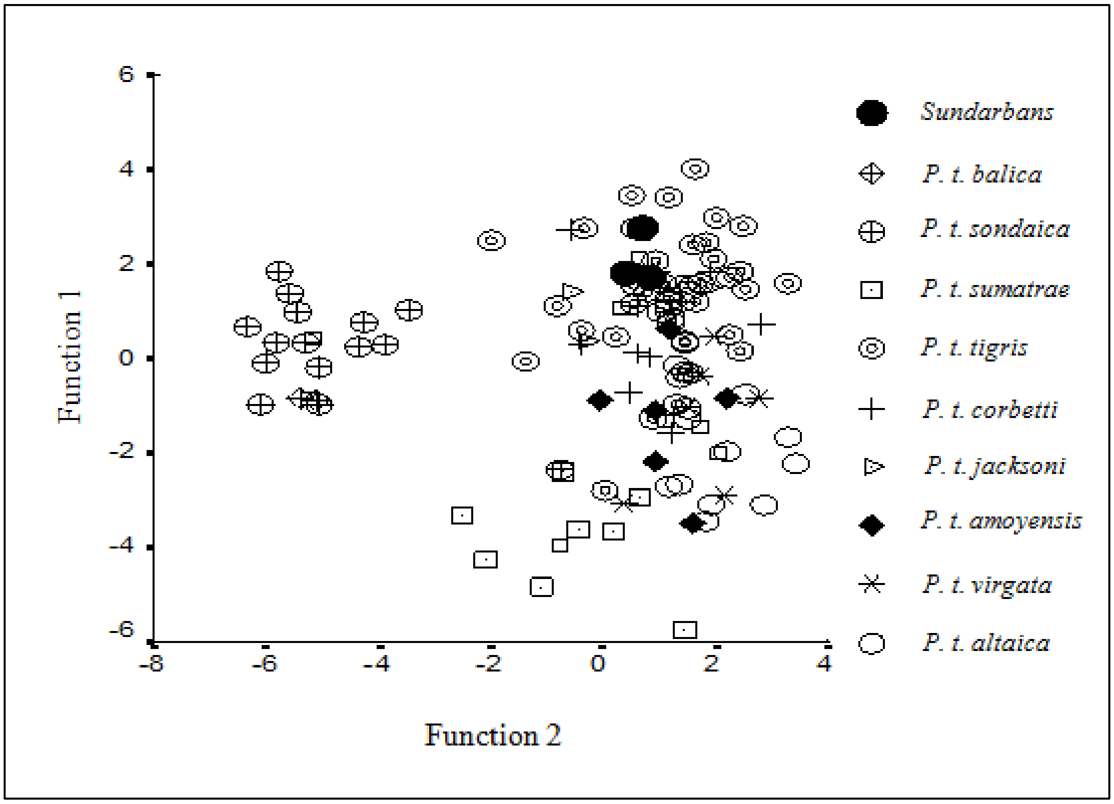


Figure 6. Results of Discriminant Function Analysis of male tiger skull measurements.

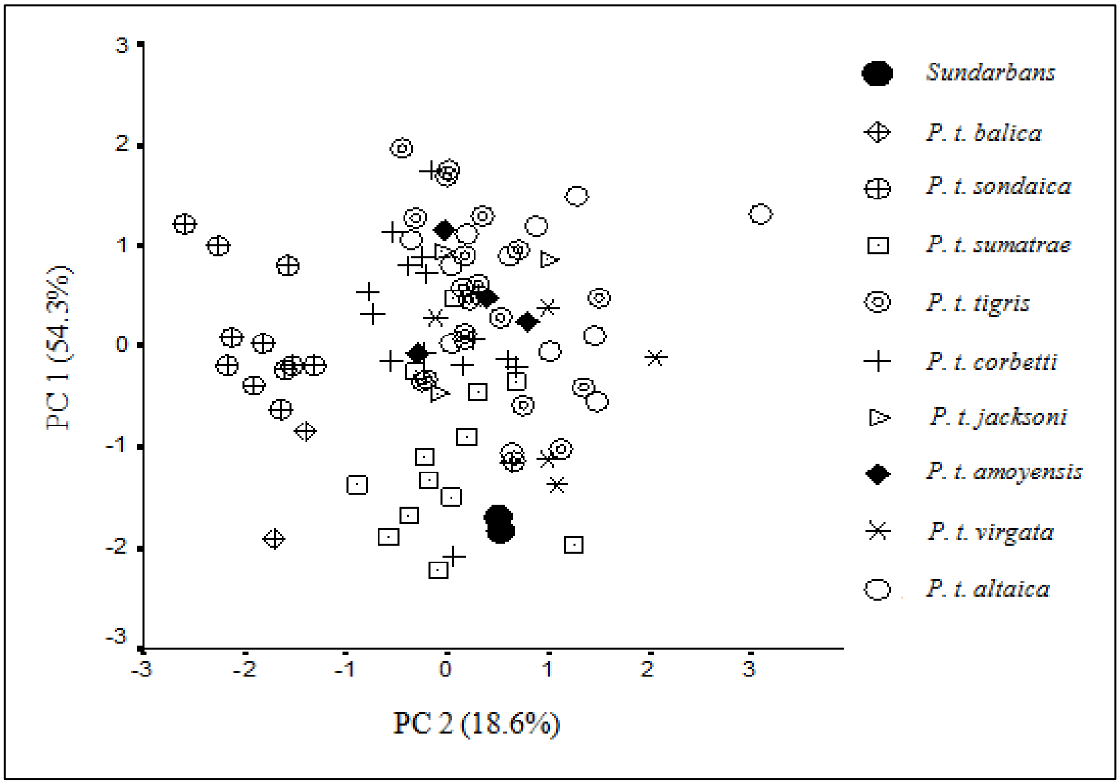


Figure 7. Principle component analysis results of female tiger skull measurements.

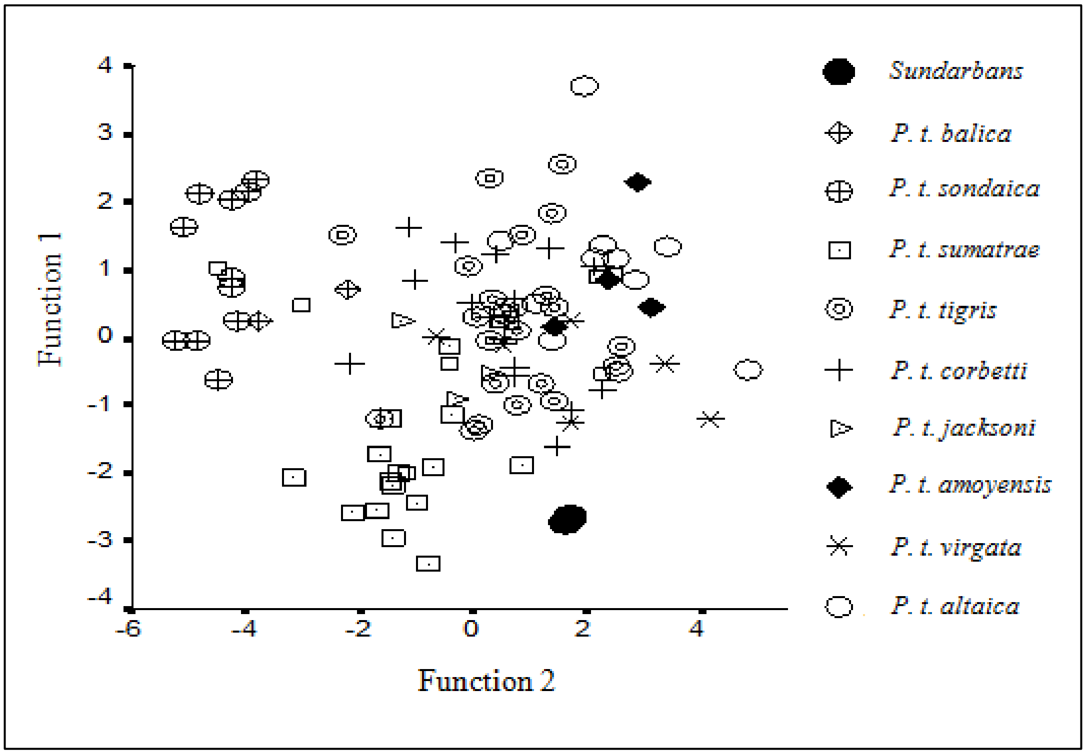


Figure 8. Results of discriminant function analysis of female tiger skull measurements.

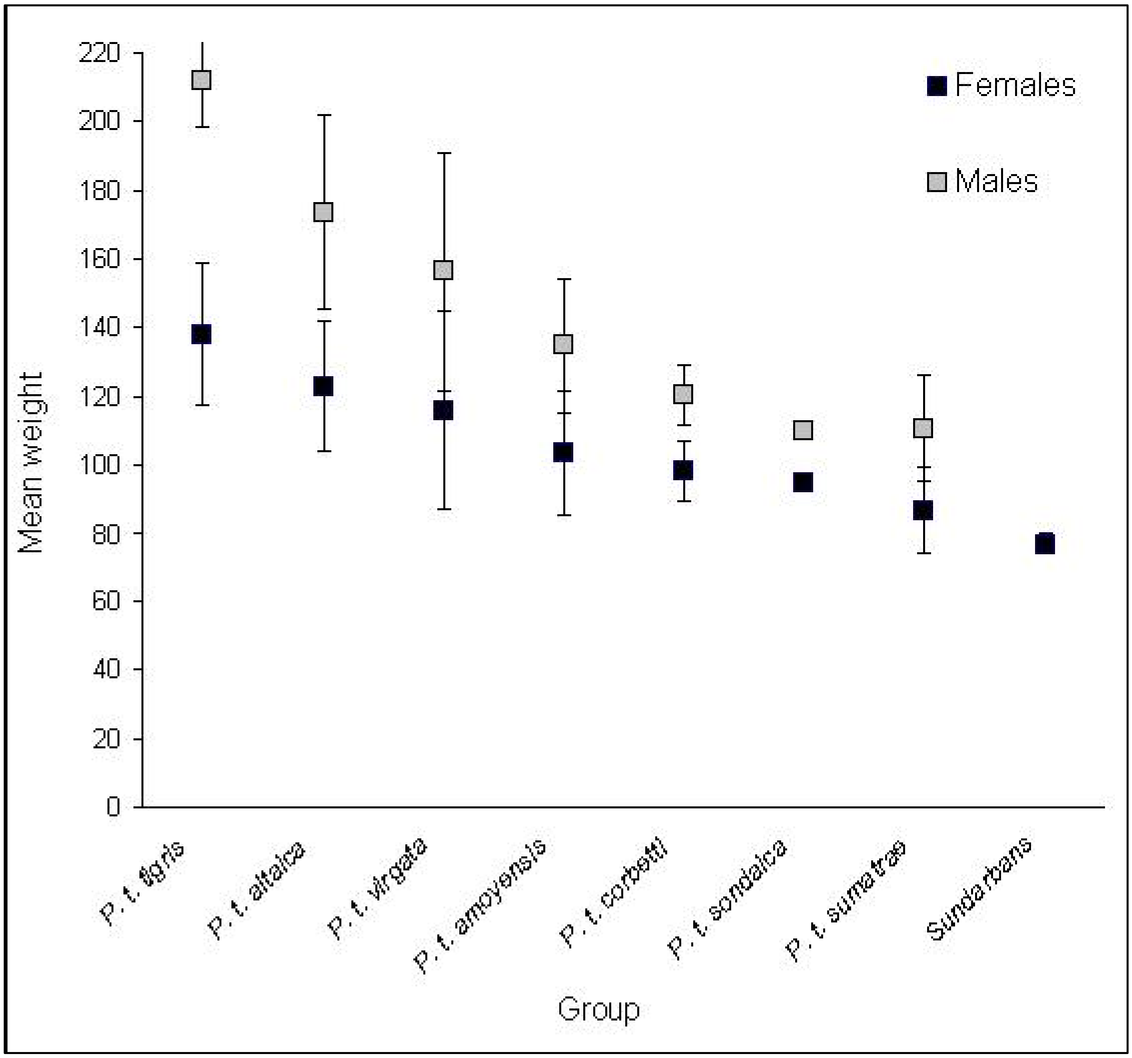


Figure 9. Variation in tiger weights for each group. Tiger weights were taken from this study for the Sundarbans, and Slaght et al. (2005) for all other groups.

CHAPTER 3

DENSITY, POPULATION SIZE, AND MOVEMENT OF SUNDARBANS TIGERS

TO BE SUMITTED FOR PUBLICATION AS: BARLOW, A. C. D, J. L. D. SMITH, I. U. AHMED, A. N. M. HOSSAIN, M. RAHMAN, AND A. HOWLADER. DENSITY, POPULATION SIZE AND MOVEMENT OF SUNDARBANS TIGERS.

ABSTRACT

Basic information required to conserve wild tigers is lacking for the Sundarbans of Bangladesh. The objectives of this study were to estimate, density, population size, and movement of tigers in this mangrove habitat. Two adult female tigers were captured with snares, and fitted with Global Positioning System collars. Density estimates were calculated using the female home range sizes, and the ratios of females to other demographic groups. Population size was estimated under different scenarios that reflected the uncertainty in the variation of home range size across the landscape. For an area in the south-east of the Sundarbans, mean fixed kernel home range size for adult female tigers was 14.2 km^2 (range 12-16.2 km^2), and estimated density was 23.5 tigers/100 km^2. The population size for the Bangladesh Sundarbans was estimated as 100-150 adult females or 335-500 tigers overall. Mean distance moved was 3.57 km/day, with a maximum of 11.3 km/day. Tigers crossed water bodies at a mean rate of one crossing every 2-3 days, and water bodies up to 1.5 km wide were crossed. These preliminary results indicate that the Sundarbans of Bangladesh has one of the highest tiger densities in the tiger's range. Considering the large land area, the Sundarbans also has one of the largest remaining tiger populations, highlighting the area's importance for the conservation of the species. The movement data suggests that a survey of tiger track set frequency along creek banks, is likely to detect tiger presence.

INTRODUCTION

Basic information needed to conserve tigers is lacking for the Bangladesh Sundarbans. Among a wide range of data requirements, estimation of tiger density, population size, and movement is needed to help formulate management plans.

Tiger density is one measure of habitat quality, and can be used to assess a forest type's capacity to hold tigers (Karanth et al. 2004b). Estimating density helps managers to predict the change in tiger population that could result from changes in habitat availability, or decide where best to allocate resources between different habitat types. Information on tiger density can also be used to select appropriately sized sampling units for monitoring programs (Hayward et al. 2002; Barlow et al. 2008; Barlow et al. in press). The Sundarbans is thought to have a low density of tigers (0.8 tigers/100 km^2), but this has been inferred from a single camera-trapping study on the Indian side (Karanth and Nichols 2000). Estimating tiger density with camera-trapping relies on maximizing the probability of capture by placing cameras along tiger travel routes (Karanth and Nichols 1998). However, there are few recognizable paths in the Sundarbans due to repeated inundation of much of the forest floor by the tide, so camera traps were placed near water holes (Karanth and Nichols 2000). This resulted in a low capture rate that did not necessarily reflect a correspondingly low tiger density (Karanth and Nichols 2000).

Information on tiger population size is necessary to model the likelihood of extinction under different threat or management scenarios (Kenney et al. 1995; Karanth and Stith 1999; Chapron et al. 2008). The Indian pug-mark method has been used in the Sundarbans to estimate tiger population size (Singh 1999; Bangladesh Forest Department 2004), but this technique is flawed due to problems associated with data collection and analysis (Karanth et al. 2003).

Understanding movement is needed to assess the rate at which tigers cross waterways, and the connectivity between habitat patches (Smith et al. 1998). Estimating how frequently tigers cross waterways is needed to quantify the relationship between track abundance and tiger density, for a recently developed monitoring approach (Barlow et al. 2008). Investigating connectivity of habitat patches is required, because future sea level rise from climate change threatens to fragment the Sundarbans forest (Agrawala et al. 2003). No such data exists for the Sundarbans, except for one unverified report (Garga 1947).

Radio or Global Positioning System (GPS) collars on tigers can be used to estimate density, population, and movement, as has been done in other parts of the tiger's range (Sunquist 1981; Smith et al. 1987; Smith 1993; Smith et al. 1998). Estimating home range size of female tigers can infer density and population size, because it is directly related to prey biomass, and tigers defend territories from conspecifics of the same sex, creating a natural spacing of individuals (Sunquist 1981; Smith et al. 1987). Essentially, female home ranges can be considered to be roughly equally sized pieces of a puzzle, that fit together with little overlap or gaps between them. In other areas, home ranges size has been used to estimate adult female density for tigers (Sunquist 1981) and leopards (Simcharoen et al. 2008). The number of tigers from other demographic groups can then be calculated as a function of the number of adult females (Kenney et al. 1995; Karanth and Stith 1999). Tracking individual tigers can also help to understand tiger movement, and their likelihood to cross certain habitat features (Smith 1993; Smith et al. 1998).

The objectives of this study were to estimate density, population size, and movement of Sundarbans tigers using GPS collars. This study is the first of its kind on tigers living in a mangrove habitat, and it provides information needed to help guide tiger conservation efforts in the area.

METHODS

Catching tigers

Between 2004 and 2006, attempts were made to capture tigers in three areas: Katka-Kochikali, Nilkamol-Hiron Point, and Chaprakhali (Fig. 1). Following protocols developed in other studies, three different methods were used to capture tigers: cages, snares, and darting over bait (Sunquist 1981; Smith 1983; Goodrich et al. 2001; Frank et al. 2003).

The snares were either Aldrich design, or a new spring-activated model currently undergoing application for patent. The trailing cables of the snares were attached to logs that acted as shock absorbers to any struggling animal, and the ends of the cables were bolted to nearby trees. Snares were setup at the entrances to rudimentary corrals set around bait, or next to trees where tiger spray was detected (Goodrich et al. 2001; Frank et al. 2003). All trap sites were monitored at least twice daily to minimize the length of time a captured tiger would be in a snare. In another approach, a researcher waited in a camouflaged cage to dart a tiger if it approached bait placed 10-15 m away.

Tigers were immobilized with 6-8 mg/kg of Telazol (tiletamine hydrochloride and zolazepam hydrochloride), administered using 5 cc darts and a Cap-Chur model dart gun (Palmer Cap-Chur Inc., Douglasville, Ga.). Telazol was considered a safe drug because it has been used on tigers captured in Nepal, Thailand, and Russia (Seidensticker 1976; Sunquist 1981; Smith 1983; J. Goodrich pers. comm.; S. Simcharoen pers. comm.), and a variety of other felid species (Crawshaw and Quigley 1989; Anderson and Lindzey 2003; Grassman et al. 2004; Marker and Dickman 2005; Manfredi et al. 2006; De Azevedo and Murray 2007). Age of tigers was approximated by examining condition of their teeth. Tigers were fitted with GPS collars (Advanced Telemetry Systems, Minnesota), and recovering animals were kept in sight until they walked away from the capture site. All procedures for trapping, immobilizing and collaring tigers followed established guidelines (Gannon and Sikes 2007).

Estimating home range size

GPS locations from collared tigers were analyzed with ArcView v3.3 software (ESRI, Redlands, California) and Animal Movement extension v1.1 (Hooge and Eichenlaub 1997), to construct Minimum Convex Polygon (MCP) (Mohr and Stumpf 1966) and Fixed Kernel (FK) (Worton 1989) home ranges. Both the MCP and FK methods have some theoretical weaknesses, arbitrary parameter settings, and inherent assumptions (Harris et al. 1990; Gitzen and Millspaugh 2003; Hemson et al. 2005), but MCP estimation allows comparisons to other tiger studies dating back over 30 years

(Seidensticker 1976; Sunquist 1981; Smith et al. 1987; Chundawat et al. 1999; Miquelle et al. 1999; Karanth and Sunquist 2000), and the FK method is growing in application for tigers (Karanth and Sunquist 2000; Goodrich et al. 2005).

The smoothing factor for FK isopleths was determined by least squares cross validation, as recommended by Seaman et al. (1999). I used 95% MCP and FK areas to estimate home ranges, and 50% areas to estimate areas of core activity. The locations were not reduced or filtered, because both MCP and FK estimates are unlikely to be impaired by auto-correlated data collected at regular time intervals (De Solla et al. 1999; Blundell et al. 2001).

Water bodies that were never crossed by the study animals, or land that lay across from those water bodies, were discounted from the home range estimates. These areas were considered non-habitat (e.g. the Bay of Bengal), or likely to be used by a different tiger. The high frequency of location acquisition by the GPS collars (one location/four hours or one location/30 minutes) made it unlikely that the tigers could have crossed these waterways and returned without recording a location.

Location-area curves were made using BIOTAS software v1.03 (Ecological Software Solutions, Florida) to calculate when the 95% home range size had been reached. The temporal utilization of area was calculated as the percentage of total 95% home range used each month.

Estimating density

Adult female tiger density (female tigers/100 km^2) was calculated using the FK home range sizes, because this technique is not affected by grid dimension or orientation, and can estimate home ranges of any shape (Seaman and Powell 1996).

There is no information on demographic ratios for Sundarbans tigers, so overall tiger density was calculated using the mean ratios of adult females to other demographic groups recorded in Nepal: 3 adult females: 1 adult male, 1 adult female: 1.67 young, and 1 adult female: 0.33 transients (Barlow et al. 2009).

Estimating population size

Population size was estimated using the total landmass of the Bangladesh Sundarbans (4,267 km^2), mean female home range, and the demographic ratios of tigers recorded in Nepal. There is no information on how tiger home range varies across the Bangladesh Sundarbans, so the mean female home range size was estimated under three scenarios of uncertainty classified as naïve, reasonable, and conservative. The naïve scenario assumes that the recorded home range sizes are representative of all tigers across the Sundarbans. This is almost certainly not the case, considering that the collared tigers were living in areas of relatively high track frequency, relative to other areas (Barlow et al. 2008). The reasonable scenario takes into account the likely variation in density across the landscape, and uses twice the mean estimated female home range size to make a population estimate. The conservative scenario uses three times the mean home range size to acknowledge the high uncertainty in variation of home range size.

These scenarios are dependent on arbitrary assumptions concerning the variation of home range size, but seem appropriate considering the variation in home range sizes recorded from other tiger habitats; the largest female home range sizes derived from telemetry in Nepal were approximately three times the smallest (Sunquist 1981; Smith et al. 1987), and the largest in Russian Far East were four times the smallest (Goodrich et al. 2005). Overall the mean female home ranges of these two studies varied by 44% and 39% for Nepal and Russia respectively (Smith et al. 1987; Goodrich et al. 2005).

Using female home range size to estimate overall population size also assumes home range was recorded accurately, no overlap between home ranges, and no vacant territories. These assumptions seem reasonable considering that (1) home range size is likely to be recorded accurately due to the high number of locations acquired by GPS collars, (2) other studies have detected little or no overlap between adult female home ranges (McDougal 1977; Smith 1993; Sunquist 1981), (3) tiger sign has been recorded across the entire study area (Barlow et al. 2008), and (4) vacant tiger territories are generally filled in 1-2 months (McDougal 1977; Sunquist 1981; Smith et al. 1987).

Investigating tiger movement

Tiger movement was assessed by the distance moved/day and the likelihood of tigers to cross water bodies. Location data of the study animals were analyzed using BIOTAS to determine mean and maximum distance moved/day, using one location/day, one location/four hours, and one location/30 minutes. Location data were used to identify crossing points, and the mean frequency of waterway crossing/month was calculated for each tiger. The maximum width of waterway crossed was investigated using the movement data from the collared tigers, ancillary information collected in the course of general field work, and during an abundance survey based on tiger track frequency (Barlow et al. 2008).

RESULTS

Tiger capture

Over four years a total of eight months was spent trying to capture tigers. Trap effort was not recorded for the first two years, and for the last two years effort totaled 332 and 174 trap nights respectively (one trap night = one bait or cage set out for one night).

Two adult female tigers were caught by snares placed near baits; the first female (F1) at Katka-Kochikali, and the second female (F2) at Chaprakhali. Both tigers were caught by their fore paw: F1 had a minor abrasion where she had been held by the snare, and F2 had minor swelling that subsided soon after the snare was taken off.

Based on general teeth condition, F1 was judged to be 12-14 years old; teeth were generally discolored and worn, one lower pre-molar was broken, and two lower incisors and a right lower canine were missing. The age of F2 was estimated at 10-14 years old; teeth were discolored, and one upper canine was broken, as were some upper incisors. There was no evidence to suggest that either female had any dependent offspring.

The two tigers were released at their capture sites. Both tigers were recorded eating from kills within 1-4 days of capture. F1's collar was set to record locations every four hours, and F2's collar was set for every 30 minutes. F1 was tracked for about six months until she died. F2 was tracked for 2.5 months until the GPS collar batteries expired. F2 was then re-captured and released after taking the collar off.

Home range size

The GPS collars recorded 679 locations for F1 (one location/four hours) between April and October, 2004, and 1,528 for F2 (one location/30 minutes) between March and May, 2006. Overall mean success rate of location acquisition/month for F1 and F2 was 31% (range 26-34%) and 37% (range 19-48%) respectively (Table 1).

After four months of monitoring, F1 made a foray to the east of her normal home range, returning after three days. She moved to the same area six weeks later, and died approximately 9 km from her normal home range (Fig. 2). Tracks of a new female were observed in F1's home range within days of F1 moving out. Female tracks together with large cub tracks were observed in the same area a year later. The poor condition of F1's teeth, her movement pattern, and the appearance of a new female suggest that F1 may have been unable to defend her territory from a rival and was subsequently pushed out. Therefore, the forays to the east were discounted from the calculation of home range size, as it was not representative of F1's normal movement pattern.

Data area curves generated with BIOTAS suggested that 95% MCP home ranges were acquired after approximately 275 and 910 locations (about two months) for F1 and F2 respectively (Fig. 3). The 95% and 50% MCP home ranges were 10.6-14.1 km^2 (mean = 12.3 km^2) and 2.5-3.9 km^2 (mean = 3.3 km^2) respectively. The mean 95% and 50% FK home ranges sizes were 12.2-16.2 (mean = 14.2 km^2) and 4.2-5.3 km^2 (mean = 4.6 km^2) respectively (Fig. 4, Table 2). Mean monthly utilization of MCP and FK home ranges was 70% (SD = 18.9, range = 56.6-83.3%) and 66.2% (SD = 23.78, range = 49.4-83%) respectively (Table 2).

Density and population size

A mean female home range size of 14.2 km^2 would indicate a density for the south-east Sundarbans of seven adult females/100 km^2, or a total of 23.5 tigers/100 km^2 based on similar population structure as Nepal. Using mean home ranges of 14.2 km^2 (naïve), 28.4 km^2 (reasonable), and 42.6 km^2 (conservative), the 4,267 km^2 landmass of the

Bangladesh Sundarbans may contain 300, 150, or 100 adult female tigers or approximately 1,000, 500, or 335 total tigers under the respective scenarios. These may be slight underestimates because the recorded home ranges included some waterways, whereas the total landmass area used to calculate population size did not.

Tiger movement

Using one location/day, estimated mean straight line distance moved for female tigers was 1.65-1.72 km/day (mean = 1.69 km/day). Using one location/four hours increased the estimates of mean daily movement to 2.16-2.34 km/day (mean = 2.52 km/day). Using one location/30 minutes, mean daily travel was estimated as 0.02-10 km/day (mean = 3.57 km/day. Maximum distance moved/day was 11.3 km for F1 and 10 km for F2 (Table 3). All distances moved included traversing both terrestrial habitat and waterways.

F1 crossed waterways at a frequency of 14/month (SD = 1.8, range = 12-16), or one crossing every two days (Fig. 5). F2 crossed at a frequency of 20/month (SD = 1.5, range = 18-21), or one crossing every two days (Fig. 6).

In terms of widest water bodies crossed, F1 crossed a 0.6 km wide river on three occasions when she dispersed outside of her normal home range, and F2 had a 0.2 km wide river within her home range that she crossed regularly (Fig. 6). During a tiger track survey, tiger sign was recorded on an island 0.7 km from the shore, but not on another island 3.9 km from shore. During the course of general fieldwork, a 3-4 year old transient was recorded to have crossed a 1.5 km wide river near Nalian guard post (Fig. 7).

DISCUSSION

Home range size

The high frequency of location acquisition together with the results of the data area curves, suggests that home range sizes were effectively estimated, but it is possible that the full home ranges were not ascertained. The relatively old age of the study tigers (10-14 years old), should not have influenced their home range sizes; other studies suggest that female tiger territory size does not change with age, and that tigers are displaced when no longer capable of defending their territory (McDougal 1977; Sunquist 1981; Smith 1984; Smith 1993).

The two 95% MCP home ranges of the female tigers (14.1 km^2 and 10.6 km^2) are some of the smallest in the world (Table 4). They are much smaller than the 181-761 km^2 home ranges in the temperate forests of Sikhote Alin, Russia, and slightly smaller than the 27 km^2 recorded in tropical dry forests of Panna, India (Chundawat et al. 1999; Goodrich et al. 2005). The Sundarbans home ranges are similar to the 16.5 km^2 recorded in tropical deciduous forests of Nagarahole, India, and within the range of the 16-21 km^2 recorded in the alluvial floodplain habitat of Chitwan, Nepal (Sunquist 1981; Smith et al. 1987; Karanth and Sunquist 2000). One other radio telemetry study in Kanha, India, reported that female tigers utilized areas of 4.9-9.8 km^2, but these estimates were based on a limited number of locations (8-12), and determined using an unstated methodology (Kotwal and Gopal 1995).

Tiger density and population size

The estimated density of seven adult females/100 km^2, or 23.5 total tigers/ 100 km^2 for an area in the south-east of the Sundarbans is the highest recorded anywhere in the tiger's range (Table 5), indicating that the study area represents good quality tiger habitat. The Sundarbans density could be an overestimate if the ratio of females to other demographic groups is lower in the Sundarbans than it is in Nepal. This may be the case, as indicated from studies in Russia where there are less females to males (Smirnov et al. 1999) and mortality rates are generally higher relative to Nepal (Chapron et al. 2008; Goodrich et al. 2008). However, the Sundarbans home range sizes indicate that adult female density is certainly high. A comparison of densities between sites suggests that, in general, regeneration of tiger habitat on the Indian subcontinent could increase tiger numbers more than regenerating the same amount of area in South-East Asia or the Russian Far-East (Table 5).

High tiger density in the Sundarbans most likely to be related to high prey biomass (Smith et al. 1987; Karanth et al. 2004b), but estimates of prey numbers has yet to be ascertained. Additionally, Sundarbans tigers are small compared to other tigers (Chapter 2), so they will have lower metabolic requirements and could therefore live at higher densities.

Even considering that the home range sizes could be underestimates and the demographic ratios may be smaller in the Sundarbans compared to Nepal, the results of this study still suggest that the Sundarbans may have one of the largest remaining tiger populations in the world. Using the reasonable and conservative scenario home range estimates, would mean that the Bangladesh Sundarbans alone may hold 100-150 adult females or 335-500 tigers in total. Only the Western Forest Complex of South-East Asia and the Russian Far East may have comparable populations (Matyushkin et al. 1999; Simcharoen et al. 2007; Sanderson et al. 2006). This result contradicts previous findings that indicate that the Sundarbans has relatively low tiger numbers (Karanth and Nichols 2000; Sanderson et al. 2006).

The naïve scenario estimate of 300 females or 1,000 total tigers is not reflective of current conditions (Barlow et al. 2008), but it may represent an optimistic carrying capacity, assuming that the lower relative abundances of tigers in other parts of the Bangladesh Sundarbans are due to anthropogenic pressures that can be reversed through improved management intervention (Barlow et al. 2008). This means that there may be potential to substantially increase the Sundarbans tiger population from its current level.

Although the Sundarbans population estimates required arbitrary doubling and tripling of the recorded home ranges, this seems reasonable considering the variance in home range sizes recorded in other studies (Smith et al. 1987; Goodrich et al. 2005), and that the female tiger home range on the Indian side, recorded by telemetry, is approximately 40 km^2 (R. Sharma pers. comm.). However, the population estimates should be considered as preliminary, considering the small sample size of home ranges used, and the use of demographic ratios from a different site.

Tiger movement

Using one location/day, the mean distance moved for Sundarbans females (1.69 km/day) was greater than that recorded by the same means in Panna (1.4 km/day), similar to Nagarahole (1.7-2 km/day), and less than Chitwan (2.4 km/day) (Sunquist 1981; Chundawat et al. 1999; K. U. Karanth pers. comm.). However, using all locations the mean movement was 3.6 km/day, and the maximum distance moved was 11.3 km/day. These are the longest recorded movement estimates for a female tiger within her home range, but this is because they were calculated using more than one location/day (Sunquist 1981; Chundawat et al. 1999; K. U. Karanth pers. comm.).

The mean rate of water way crossing (one crossing every 2-3 days) suggests that a monitoring survey, based on track counts along creek banks, would have a high chance of detecting tiger presence. The widest river crossed by a tiger (1.5 km) recorded in this study is likely to be an underestimate of tiger swimming capabilities. An unverified report, citing records from 1900 to 1922, suggested that tigers swum across 29 km of the Hooghly river, and that one tiger may have crossed 10-56 km of open water, depending on where it started (Garga 1947).

The daily movement and likelihood of tigers to cross water bodies, can be used to model connectivity in a metapopulation scenario resulting from climate change induced habitat fragmentation.

Recommendations

Management of all TCLs requires information on tiger density, population size, and movement (Sanderson et al. 2006). For certain habitat types, telemetry offers insight into these aspects of tiger ecology that other methodologies, such as secondary sign surveys and camera-trapping, cannot always provide (Sunquist 1981; Smith 1993; Chundawat et al. 1999; Miquelle et al. 1999; Karanth and Sunquist 2000; Kerley et al. 2003; Goodrich et al. 2005). However, despite its benefits, telemetry studies have only been published from six (8%) of the 76 TCLs, with work from Nepal and Russia contributing the majority of information (Seidensticker 1976; Sunquist 1981; Smith et al. 1987; Smith

1993; Kotwal and Gopal 1995; Chundawat et al. 1999; Miquelle et al. 1999; Karanth and Sunquist 2000; Kerley et al. 2003; Goodrich et al. 2005; Goodrich et al. 2008). More telemetry studies across the tiger's range would add information that could improve the long-term prospects for the survival of this species.

In terms of the Sundarbans, data collected from different areas would improve understanding of variation in home range size, density, and population estimates. Additional collaring of tigers is also required to investigate tiger survival, reproduction and habitat selection.

TABLES

Table 1. Number of locations for collared tigers.

			Locations	
Tiger	**Month**	**Attempted**	**Acquired**	**Success rate (%)**
FI	April	72	21	29%
	May	372	125	34%
	June	360	116	32%
	July	372	128	34%
	August	372	92	25%
	September	360	122	34%
	October	168	44	26%
	Total	2076	648	31%
F2	March	1316	578	44%
	April	1410	679	48%
	May	1457	271	19%
	Total	4183	1528	37%

Note: F1's and F2's collar was set to attempt location acquisition every four hours and 30 minutes respectively.

Table 2. Estimated size (km^2) and % monthly utilization of female tiger home ranges.

		MCP (km^2)		FK (km^2)	
Tiger	**Month**	**95%**	**% used**	**95%**	**% of total**
FI	May	6.7	48%	5.3	33%
	June	10.4	74%	10.6	65%
	July	9.1	65%	10.3	64%
	August	7.7	55%	9.1	56%
	September	5.9	42%	4.7	29%
	All	14.1	-	16.2	-
F2	March	10.4	98%	13.6	112%
	April	7.9	74%	9.3	76%
	May	8.3	78%	7.4	61%
	All	10.6	-	12.2	-
ALL	Mean	12.3	-	14.2	-

Note: % used = 95% home range area as a % of overall 95% home range.

Table 3. Daily distances moved by female tigers.

	Distance moved (km)											
	1 location/24 hours				1 location/4 hours				1 location/30 minutes			
TGR	Total	Mean	SD	Range	Total	Mean	SD	Range	Total	Mean	SD	Range
F1	239	1.72	1.69	0-8.97	442	2.68	2.34	0.01-11.30				
F2	121	1.65	1.4	0.01-6.12	164	2.35	2.16	0.02-9.44	264	3.57	2.56	0.02-10.02
Mean	180	1.69	0.05		303	2.52	0.23					

Note: Distances calculated from 139 consecutive days for F1 and 73 consecutive days for F2.

Table 4. Tiger adult female home range sizes across the species range.

				Home range size		
Country	Site	Method	n	Mean (km^2)	Range (km^2)	Reference
Nepal	Chitwan	RT (adjusted MCP)	3	16	15.3-16.5	Sunquist 1981
	Chitwan	RT (100% MCP)	7	20.7	10-51	Smith et al. 1987
Bangladesh	Sundarbans	GPS (95% MCP)	2	12.3	10.6-14.1	This study
India	Panna	RT (MCP)	1	27		Chundawat et al. 1999
	Nagarahole	RT (95% MCP)	1	16.5		Karanth and Sunquist 2000
Russia	Sikote-Alin	RT (95% MCP)	14	402	181-761	Goodrich et al. 2005
Total			28			

Notes: RT = Radio Telemetry, n = sample size.

Table 5. Recorded tiger density throughout its range.

Country	Site	Density (Tigers/100 km^2)	Study method	Source
Bangladesh	Sundarbans	23.5	RT	This study
Nepal	Chitwan	18.0	CT/TR	Barlow et al. 2009
India	Kaziranga	16.8	CT	Karanth et al. 2004
India	Bandhavgarh	14.3	CT	Carbone et al. 2001
India	Nagarahole	14.3	CT	Royle et al. 2008
India	Bandipur	12.0	CT	Karanth et al. 2004
India	Kanha	11.7	CT	Karanth et al. 2004
India	Ranthambore	11.5	CT	Karanth et al. 2004
India	Pench-MR	7.3	CT	Karanth et al. 2004
India	Panna	6.9	CT	Karanth et al. 2004
India	Melghat	6.7	CT	Karanth et al. 2004
India	Rajaji	5.1	CT	Harihar et al. 2008
India	Pench-MP	4.9	CT	Karanth et al. 2004
India	Bhadra	3.4	CT	Karanth et al. 2004
Indonesia	Way Kambas	3.3	CT	Franklin 2002
India	Tadoba	3.3	CT	Karanth et al. 2004
Indonesia	Kerinci Seblat	2.4	CT	Linkie et al. 2006
Malaysia	Temenggor	2.3	CT	Carbone et al. 2001
Myanmar	Hukaung	2.2	CT	Lynam et al. 2008
Thailand	Huai Kha Khaeng	2.0	CT	Simcharoen et al. 2006
Malaysia	Temanggor	2.0	CT	Lynam et al. 2007
Malaysia	Ulu Temiang	2.0	CT	Lynam et al. 2007
Thailand	Queen Sirikit	1.8	CT	Carbone et al. 2001
Malaysia	Taman Negara	1.7	CT	Kawanishi and Sunquist 2004
Indonesia	Gunung Leuser	1.7	CT	Griffiths 1993
Indonesia	Bukit Barisan Selatan	1.6	CT	O'Brien et al. 2003
Thailand	Halabala	1.2	CT	Carbone et al. 2001
Thailand	Khao Yai	1.2	CT	Carbone et al. 2001
Thailand	Phu Keio	1.2	CT	Lynam 2001
Malaysia	Bintang Hijau	1.0	CT	Carbone et al. 2001
Malaysia	Ulu Temaing	1.0	CT	Carbone et al. 2001
Malaysia	Bintang Hijau	0.7	CT	Lynam et al. 2007
Russia	Sikote-Alin	0.6	TR	Smirnov and Miquelle 1999
Malaysia	Gunung Tebu	0.5	CT	Carbone et al. 2001
Malaysia	Gunong Tebu	0.5	CT	Lynam et al. 2007
Malaysia	Ayer Ngah	0.5	CT	Lynam et al. 2007
Malaysia	Lepar	0.5	CT	Lynam et al. 2007
Lao	Nam Et-Phou Louey	0.5	CT	Johnson et al. 2006

Notes: RT = Radio Telemetry, TR = Tracking, CT = Camera-Trapping. Density estimates for O'Brien et al. 2003, Karanth et al. 2004; Kawanishi and Sunquist, 2004, Karanth et al. 2006, Linkie et al. 2006; Simcharoen et al. 2006 , Harihar et al. 2008 and Lynam et al. 2007, 2008 are for adult tigers or those over one year of age.

FIGURES

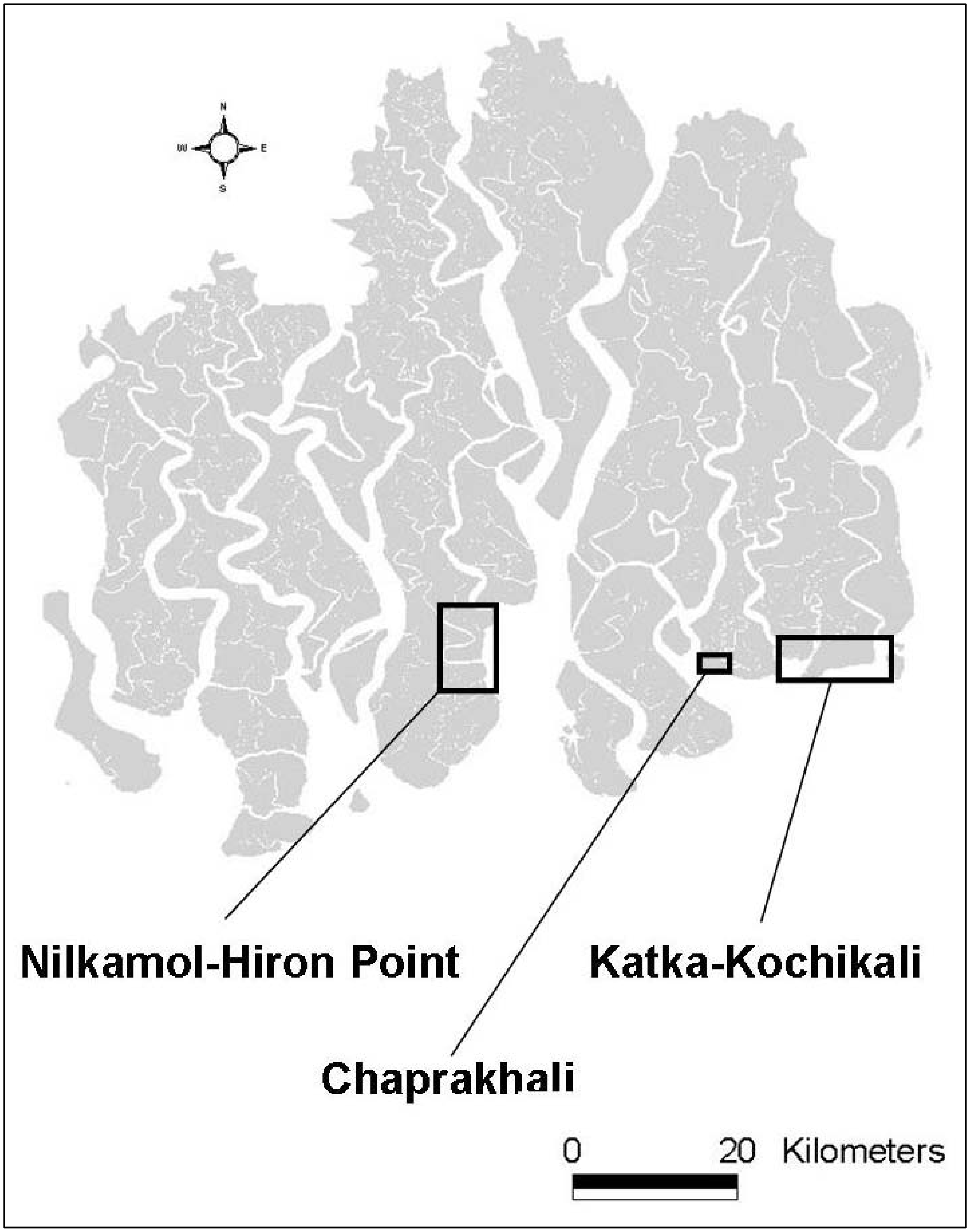


Figure 1. Tiger trapping locations.

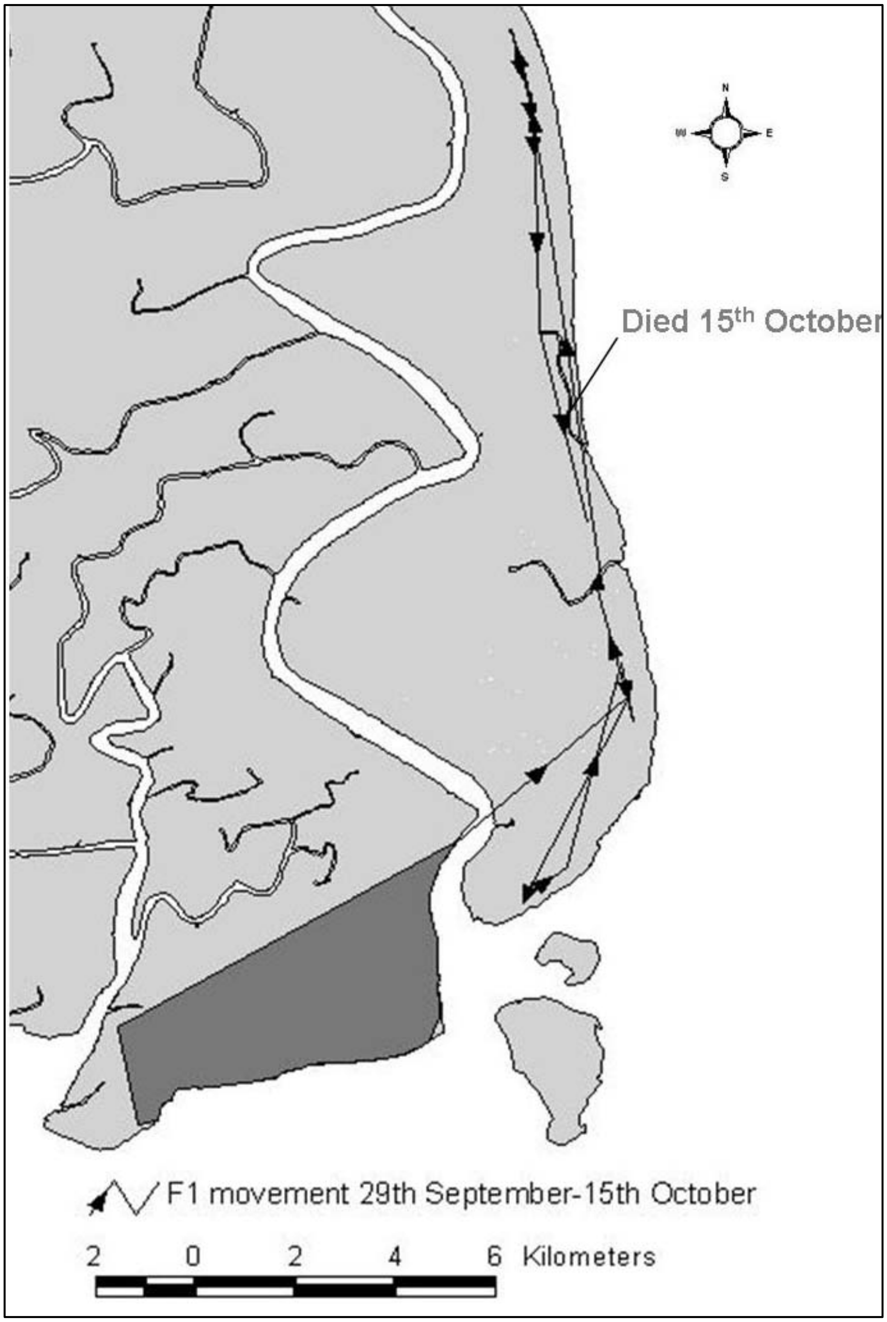


Figure 2. Movement of female tiger F1 after leaving her territory.

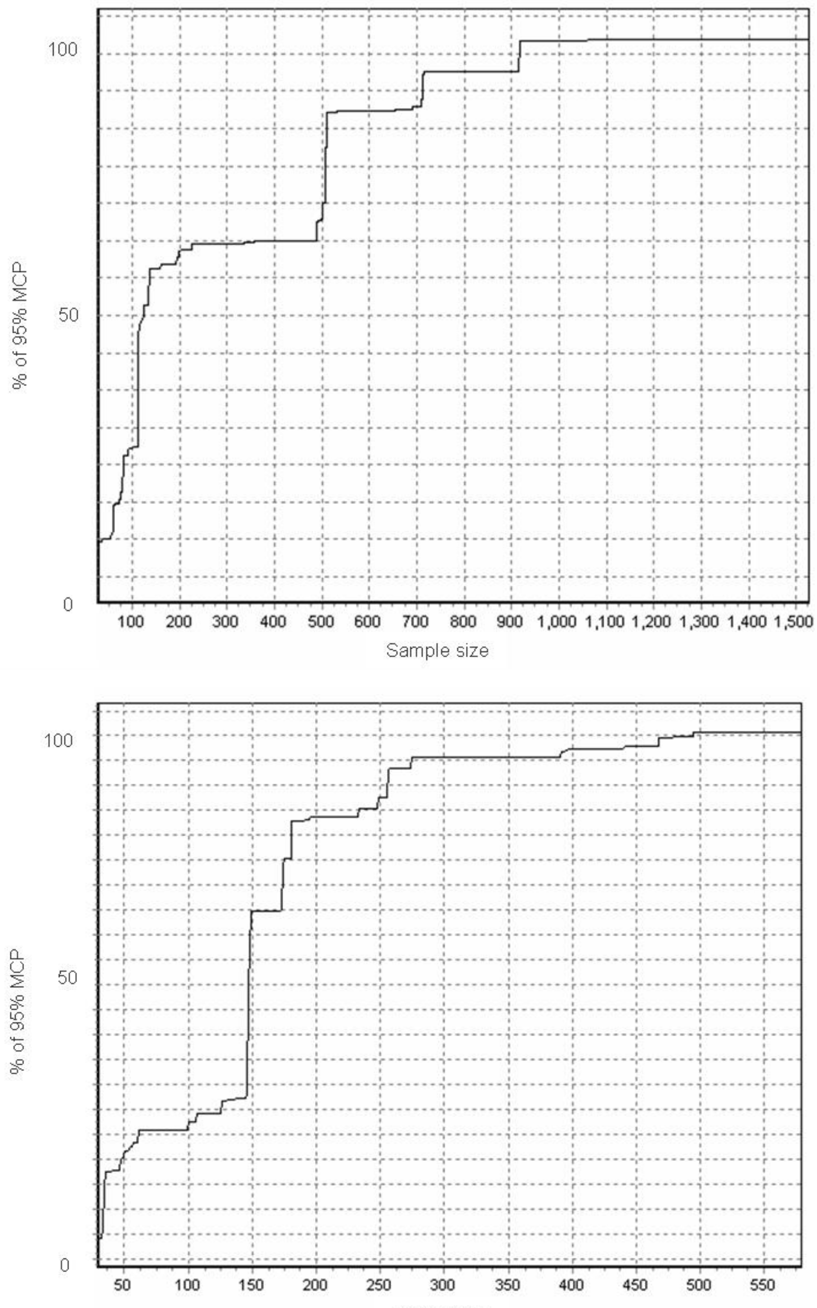


Figure 3. Data area curves for minimum convex polygon home ranges of female tigers.

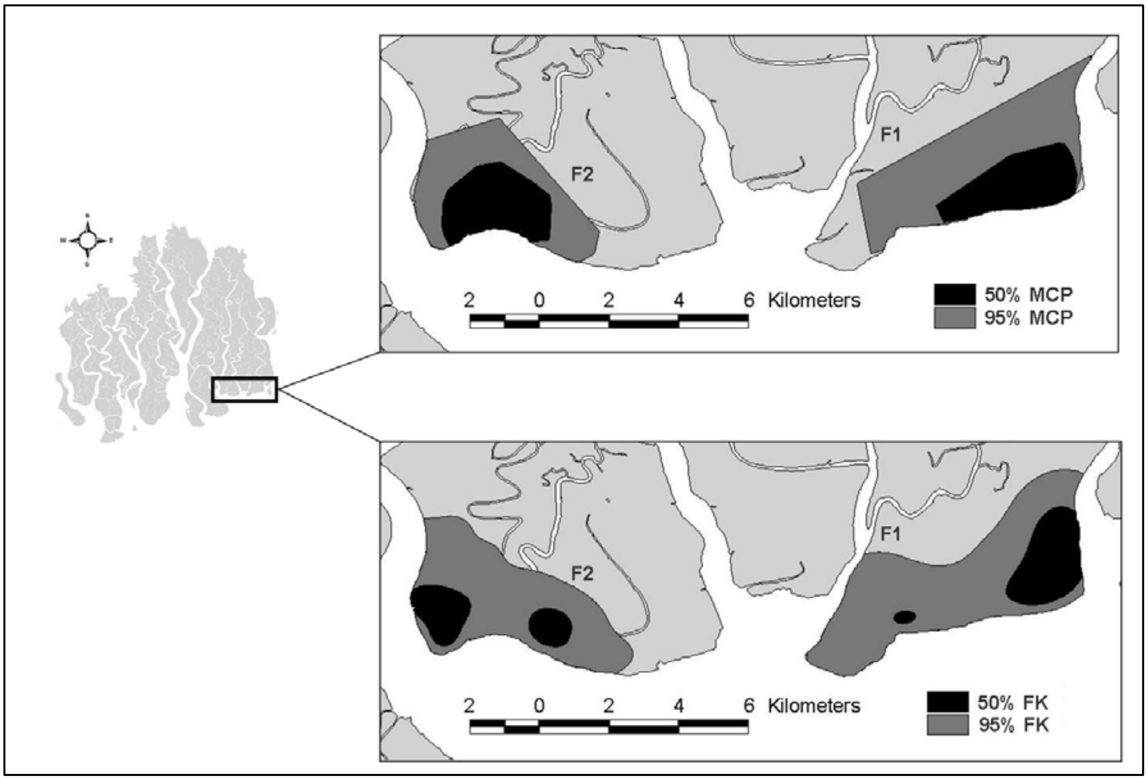


Figure 4. Minimum convex polygon and fixed kernel home ranges of female tigers.

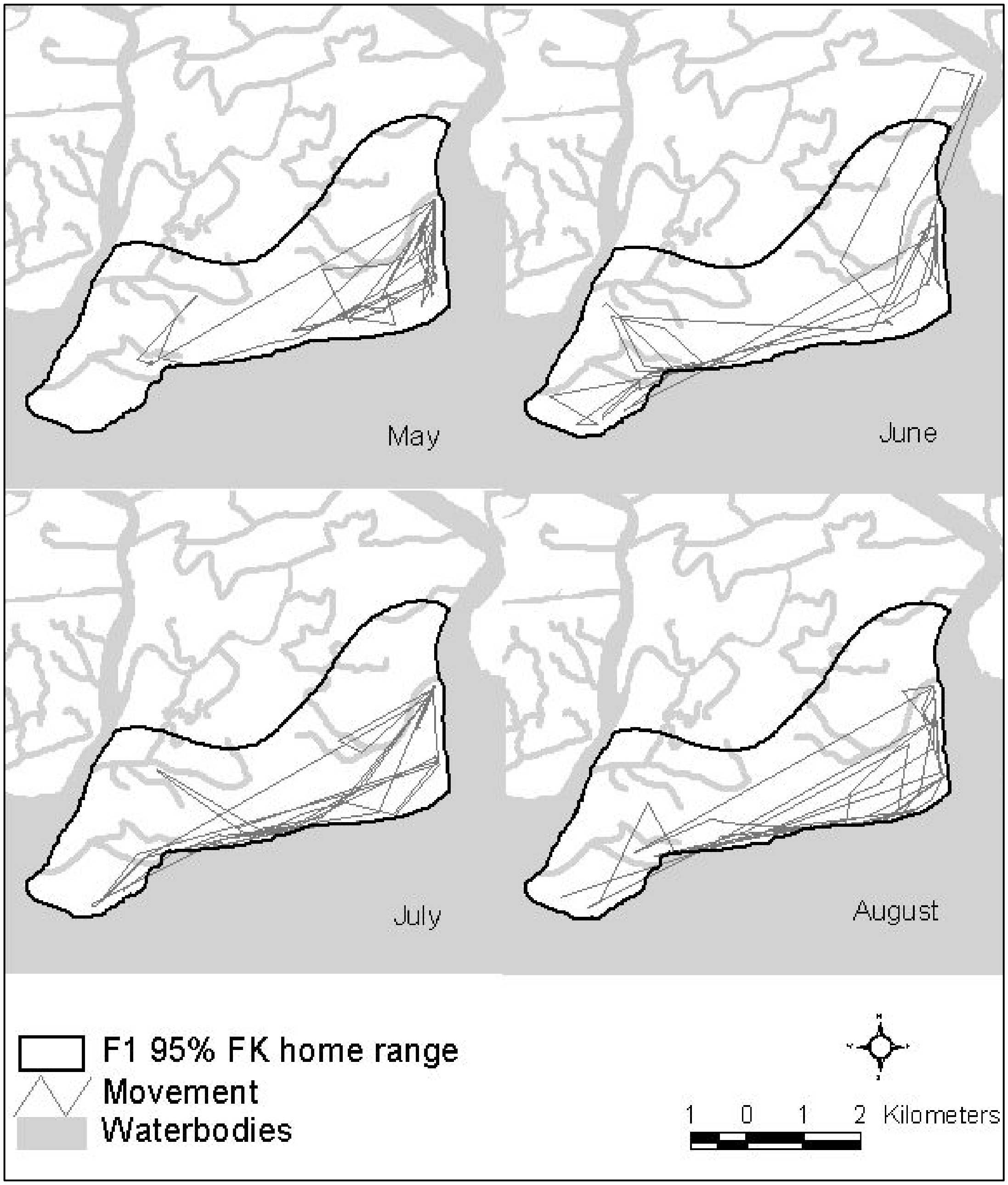


Figure 5. Movement pattern and waterway crossings of F1 within her home range.

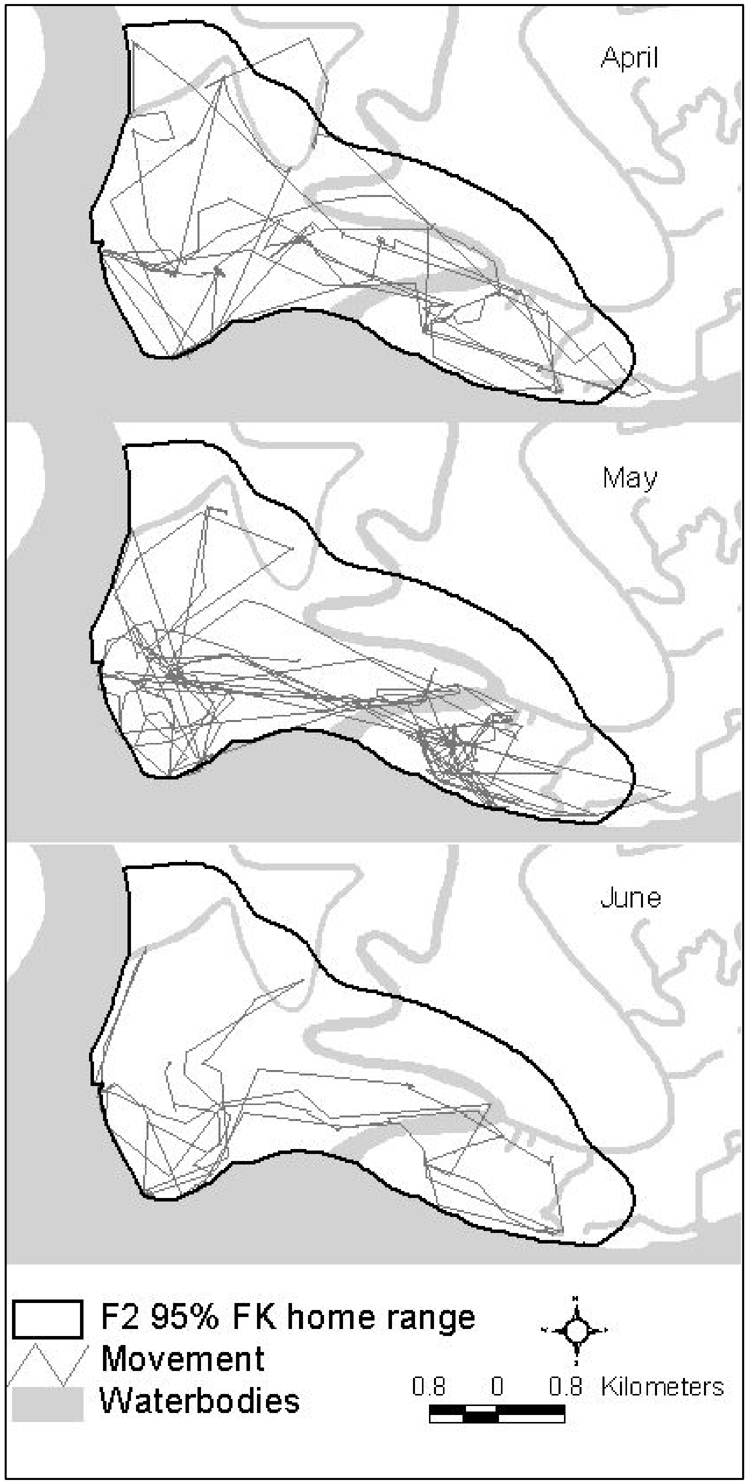


Figure 6. Movement pattern and waterway crossings of F2. June movement is only for 14 days.

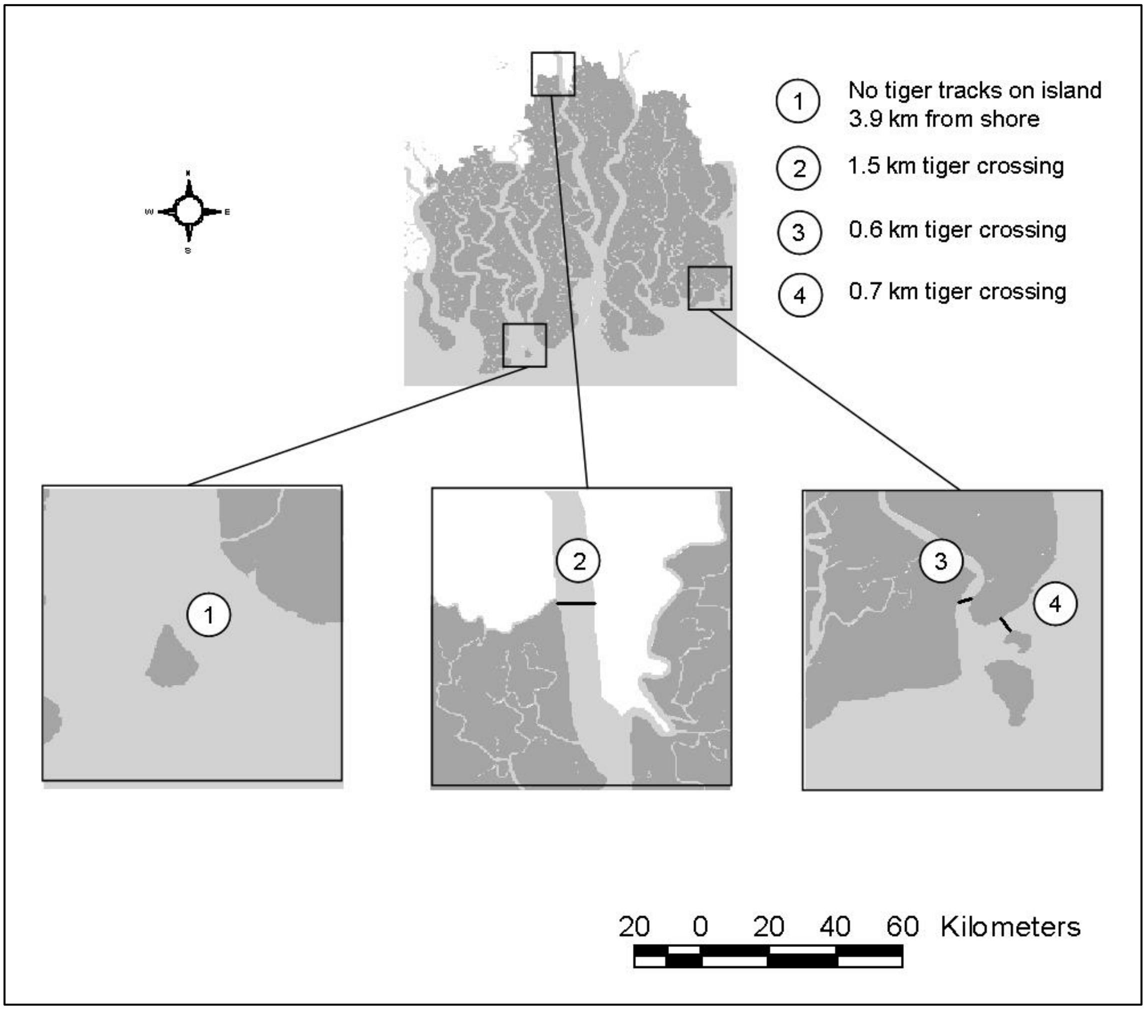


Figure 7. Water body crossings by tigers recorded in the Bangladesh Sundarbans.

CHAPTER 4

RELATIVE TIGER ABUNDANCE ACROSS THE BANGLADESH SUNDARBANS

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ABSTRACT

Baseline data on distribution and abundance of tigers in the Sundarbans is required to identify problem areas and evaluate management strategies. This paper outlines a *khal* (creek) bank survey of track set frequency throughout the Bangladesh Sundarbans to aid formulation of a management-driven monitoring program. Three teams of two observers surveyed a total of 1,201 km of waterways throughout the Sundarbans, recording 1,338 tiger track sets. These sets became unrecognizable as tiger sign after a mean 10 days (range 6-14). Proportion of detectable sign recorded was 0.91. Mean (± standard error) sample unit track frequency was 1.12 ± 0.86 track sets/km of *khal*. The mean coefficient of variance in sample unit track rate, estimated by multiple counts of six sample units, was 0.21 (range 0.06-0.34). Track frequency generally increased from northeast to southwest. Four sample units (6%) had signs of reproduction, with a mean litter size of 1.75 ± 0.5. Monte Carlo simulation suggest a monitoring program of one complete survey every two years will have power of 0.8 ($\alpha = 0.2$), to detect track frequency declines of ≥ 19% and increases of ≥ 17% . I recommend this monitoring scheme be implemented on the Indian side of the Sundarbans to provide a standard assessment of the tiger population and to form the basis for setting management objectives and evaluating transboundary conservation initiatives.

INTRODUCTION

Despite over 30 years of listing on the International Union for the Conservation of Nature's endangered list, wild tigers (*Panthera tigris*) continue to be threatened from poaching, habitat destruction, and prey depletion (Dinerstein et al. 2007). The remaining forest patches throughout the tiger's range have been prioritized by their potential contribution to long term survival of the species, with the 10,000 km^2 Sundarbans of India and Bangladesh listed as one of 20 Tiger Conservation Landscapes classified as global priorities for tiger conservation (Sanderson et al.. 2006).

Although there have been previous studies on various aspects of tiger ecology in the Sundarbans (Hendrichs 1975; Khan and Chivers 2007), no scientifically sound monitoring scheme has been implemented. Without reliable monitoring data, authorities are forced to make management decisions without means to evaluate their impact (Ringold et al. 1996). This paper addresses this issue for the Sundarbans, where an initial phase of surveillance monitoring is required to understand system state and generate future targeted hypotheses that can guide decisions within an adaptive management framework (Nichols and Williams 2006).

Karanth et al. (2006) obtained a trend estimate for tigers living in a part of Nagarahole reserve, India using 10 years of camera trap data. However, the high cost and time requirements of camera-trapping, together with the generally large confidence intervals of resulting density estimates, may limit its use in some scenarios for monitoring population change and guiding management practices, particularly in large study areas such as the Sundarbans (Karanth and Nichols 2000).

Frequency, or presence of secondary sign, has also been used to assess tiger populations (Hayward et al. 2002; Johnsingh and Negi 2003; Linkie et al. 2006), and to design robust monitoring schemes for other low density carnivore species (Kendall et al. 1992; Smallwood 1994; Johnson 2008). In the Sundarbans, tiger tracks are often observed on the muddy banks of creeks ("*khal*s") and appear to be the best available source of information on tiger distribution and abundance: they have high frequency of occurrence, are highly visible, cannot be mistaken for other animal's sign, and the substrate on which they are found is consistent over the entire study area.

Critical to long-term monitoring for conservation management is estimation of power (Taylor and Gerrodette 1993; Taylor et al. 1996; Gibbs et al. 1999), which in this case can be considered the probability of detecting a change should one occur (Gerrodette 1987; Cohen 1988). Power (1- β) is affected by *n* (sample size), σ^2 (variance), *r (*effect size), α (risk of incorrectly accepting the null hypothesis; a Type I error) and β (not rejecting null hypothesis when it was false; a Type II error) (Cohen 1988). Setting *r*, α and β levels must be defined *a priori* by the investigators and will dictate what kind of sampling strategy is needed in terms of sample size, number of surveys and time between surveys (Cohen 1988). For the purpose of population monitoring, effect size can be set considering the minimum required detectable change in abundance from one time interval to another. Setting effect size is a management decision based on the costs associated with not detecting important changes and reacting to perceived changes when none in fact occurred. Traditional wildlife literature sets α at 0.05 and β at 0.2 (Mapstone 1995; Stephano 2003), but there is no reason not to relax α so that power to detect a trend is higher if the cost not to detect a trend is high, and the manager is willing to occasionally spend resources in response to an incorrectly identified problem (Kendall et al. 1992; Taylor and Gerrodette 1993; Mapstone 1995; Buhl-Mortensen 1996; Zelinski and Stauffer 1996; Gibbs et al. 1998).

Together with setting management objectives, a well-designed monitoring program must also incorporate considerations of sampling strategy, variance, trend analysis, coverage, bias and detection probability (Hatch 2003; Conn et al. 2004; Seavya and Reynolds 2007), and these elements are addressed in this paper. The overall objectives of this study were to conduct a tiger track survey in the Bangladesh Sundarbans to (1) collect baseline data on relative abundance of tigers, (2) identify areas requiring additional management intervention, and (3) design a long-term monitoring program with adequate sensitivity to detect population trends in line with management needs.

METHODS

Sample design and data collection

Tigers make deep, distinctive tracks in the soft mud bank of *khals*. A track set is a group of tracks either going up or down a creek bank where a tiger has crossed. In general tigers do not walk parallel to a *khal* along the sloping bank, which is difficult to traverse. The number of tiger track sets/km of *khal* surveyed was used as an index of abundance.

All field work to record track set frequency and collect data on its variance were carried out in the winter season, the period with lowest rainfall. Initial training and finalization of survey protocol was carried out in December 2006. All sample units were surveyed from January-February, 2007. Repeat counts of a sub-set of the total sample units and data collection on track degradation rate was carried out between December 2006 and March, 2007. Three teams (composed of two observers, two forest guards and a boat driver) carried out the survey, each led by someone with at least two years field experience studying tigers and their sign. To decrease observer bias, observer pairs were changed each day and the same six observers were used in all activities.

To improve spatial definition, the Sundarbans was delineated into sample units. To allow for detection of changes in abundance (rather than presence/absence), sample units need to be large enough so that they can be occupied by several tigers (Hayward et al. 2002). There is no information on the current distribution of tiger home ranges in the Sundarbans, but preliminary results from a telemetry study documented home range sizes for two adult females of between 12 and 15 km^2 (Chapter 3). Acknowledging the possibility of larger home ranges of tigers in other parts of the Sundarbans, 40 km^2 was set as a minimum sample unit size; an area that could potentially encompass two resident females. The current framework of 55 management compartments was then used to delineate sample units. Compartments < 40 km^2 were joined to adjacent units and those > 100 km^2 were split along watercourses. A total of 65 sample units was created with a mean area of 63.3 ± 14.1 km^2 (range = 40-100 km^2). To obtain a complete geographic assessment of tiger distribution all sample units were surveyed, and track set frequencies between sample units were assumed to be independent. A 1.7 km width buffer, calculated from the mean daily straight line distance moved by the two satellite collared resident female tigers (Chapter 2), was made around all surveyed *khal*. The percentage of each sample unit contained by the buffer was used as a measure of survey coverage.

It was neither practical nor possible to randomly select *khals* up to a predefined set or minimum accumulated length; many *khals* on existing GIS coverages have changed course, silted up or ceased to exist altogether. Furthermore, because the survey was dependant on tides it was not possible to predict length of an existing *khal* that could be surveyed before the survey vessel would ground. *Khals* surveyed for tiger tracks were selected within each sample unit so that any residing tiger had some probability of being detected; the aim was to have no contiguous area of > 20 km^2 in any sample unit not surveyed, as judged by the area not included by the *khal* buffers.

Although not necessarily a barrier to movement, width of waterway may at some stage present a large enough obstacle to tiger movement that some streams become a natural territorial boundary. Tigers are capable swimmers, but *khals* > 50 m wide were judged to be probable deterrents to normal (within home range) movements, so only *khals* of < 50 m wide were surveyed. If this assumption is invalid it will decrease the number of *khals* available for survey but will not affect the sample unit track frequency recorded as long as coverage is sufficient.

Khals were checked approximately three hours either side of low tide when tiger tracks below the high water mark could be detected in the soft mud of the *khal* banks. To ensure high track detection rate, the boat was kept between 1-3 m from the *khal* bank with a speed of 4-6 km/hr, and all obscure signs were checked by inspecting the suspected track on foot. Only one side of each *khal* was surveyed.

Presence of cub tracks was recorded as evidence of reproduction in that sample unit and in each case cub numbers were estimated by the number of cub track sets accompanying the mother. All locations of tiger sign and the route of surveyed *khals* were recorded using GPS.

Estimating variance

Within survey time variance includes variance due to track degradation, track detection, animal behavior and observer bias. Although tracks are left in the same medium and degraded by the same tidal inundations, there will be a range of values for degradation rate resulting from such factors as water level at time of crossing and steepness of bank. These factors may potentially influence the number, depth and definition of accumulated tracks. Degradation rate was estimated by marking 28 tracks (based on appearance to be ≤ 24 hours old), and checking them every two days until they became unrecognizable.

To estimate detection rate (the proportion of detectable sign recorded), *khal* were surveyed using the normal procedure and marked all places where sign was recorded. The same *khal* were then immediately re-surveyed, recording any sign that was not detected the first time. To minimize potential observer bias, observer pairs were switched daily, and the authors worked with all teams to ensure that survey protocol and data collection procedure were strictly maintained.

Overall within-sample variance was estimated by re-counting six sample units three times each, with time between each re-sample long enough (> 10 days) to allow accumulation of new sign, but short enough (< 60 days) to reasonably assume that the local population was closed during the re-sampling period.

Detectability of track sets was assumed not to vary between sample units; the high concentration and relatively even distribution of *khal* means that all tigers have to cross *khal* during normal movements within their home ranges.

Setting management requirements

For management purposes, an effect size *r* of 30% over two years was considered the minimum degree of change (either positive or negative) in tiger track frequency needed to be detected, assuming that the relationship of track frequency and tiger abundance is linear. This threshold in change detection acts as an 'early-warning' system that triggers further action (Atkinson et al. 2006). A larger threshold could allow for potentially dangerous declines in tiger numbers that could threaten the overall population.

For setting α and β levels I used the theoretical framework described by Mapstone (1995) where costs of risk levels, in terms of achieving management objectives, are explicitly considered. The framework establishes the relative importance of Type I and II errors, considering economic, political, environmental and social costs. Because there is an absence of sufficient data for the Sundarbans tiger population, I followed Mapstone's (1995) recommendation of using $\alpha = \beta$. Researchers and Forest Department officials set α and β at 0.2, which will result in a 20% chance of rejecting H_o when it is true and a maximum threshold of a 20% chance of not identifying a trend when it has occurred (incorrectly accepting H_o). An α and β level of 0.2 has also been used in Russian Far East for detecting trends in tiger abundance through sign surveys (Hayward et al. 2002).

Power analysis

Program MONITOR v10.0 (Gibbs and Ramirez de Arello 2006) was used to conduct Monte Carlo simulations to estimate the power of the *khal* survey to detect trends in the tiger population over time. MONITOR constructs deterministic trends starting from the initial mean estimate and variance and then projecting to the next survey occasion. It then takes sample measures from random values at each survey time, taken from a distribution (i.e. it presumes a Poisson distribution) with a mean generated from the trend projection and variance in proportion to that mean. These steps are repeated multiple times, with power estimated as the proportion of iterations where there was a significant difference between the two survey times (determined in this case by a paired t-test) (Gibbs and Ramirez de Arello 2006).

Using the recorded sample unit track frequency and the mean within-sample variance estimated during the survey, I investigated the power to detect a trend (with $\alpha = 0.2$) by surveying all sample units every two years. I followed Thompson et al. (1998) and Hayward et al. (2002) by using exponential response and lognormal measurements to best model natural changes in a tiger population. From other options available in the software, the paired plots, coefficient of variation in proportion to mean and pooled variance were selected. The paired plots option generally increases estimated power, and tests the hypothesis that the difference in first and second surveys of each sample unit averaged across all sample units is greater or less then zero. The test takes into account both the variation among plots and the variance in values/plot (Gibbs and Ramirez de Arello 2006). Power was estimated using a two-tailed test because, although a one-tailed test would increase power to detect a negative trend, it is also necessary to evaluate positive responses due to management intervention. The simulation was run with 10,000 iterations.

RESULTS

Survey effort and track frequency

A total of 1,201 km of *khal* was surveyed. Mean length of total *khal* surveyed/sample unit was 18.5 ± 8.16 km. The mean length of *khal* surveyed/area of sample unit was 0.3 ± 0.11 km of *khal*/km^2. The area contained within the 1.7 km buffer of surveyed *khal* covered 81.1% of the total study area and a mean 81.4 ± 12.3% of each sample unit. One sample unit had a contiguous area of > 20 km^2, where a resident female tiger could potentially reside without any probability of being detected (Fig. 1).

A total of 1,338 tiger track sets was recorded, with tiger sign detected in all 65 sample units (Fig. 2). Mean sample unit track rate was 1.12 ± 0.86 track sets/ km of *khal* surveyed. Track frequency generally increased from northeast to southeast (Fig. 3). Cub tracks, from animals of unknown age, were recorded in four (6%) of the sample units, with a mean litter size of 1.75 ± 0.5.

Estimated variance

From 10 *khal* double surveyed to estimate detection rate of track sets, 50 track sets were detected on the initial survey and five additional sets on the second; an overall detection rate of 0.91. Fresh tracks (n = 28, considered by appearance to be more than one day old) degraded to the point where they could not be confidently identified as tiger sign in a mean of 10 days (range 6-14) (Fig. 4).

From six sample units surveyed three times each (within 60 days), mean sample variance (including variance due to tiger movement and sample error), had a mean coefficient of variation (CV) of 0.21 (range 0.06-0.34).

Power analysis

A monitoring strategy of conducting a survey every two years had an estimated power of 0.99 ($\alpha = 0.2$) to detect a track frequency net decline over two years of 30% and power of 0.97 to detect an increase of 30%. At the minimum power threshold of 0.2, this survey design could detect estimated net decreases of ≥ 19% and increases of ≥ 17% (Fig. 5).

DISCUSSION

Relative tiger abundance

Tigers occur throughout the Bangladesh side of the Sundarbans, but their relative abundance, as indicated by track set frequency, varies considerably.

There was a conspicuously low relative track frequency in the north relative to areas further south and west. While possibly a response to natural variation in some ecological variable, the low relative track frequency in the north-west may also be due to low tiger abundance attributable to human activities. Further research is needed in the Sundarbans to study the relationship between relative tiger track set frequency and various ecological factors to better understand underlying driving forces and improve future threat mitigation.

Litter size recorded in the Sundarbans (1.75) is less than that reported from Nepal (2.98) and Russia (2.4) (Smith and McDougal 1991; Kerley et al. 2003). However, the sample size for the Sundarbans is small (n = 4) and the cub track sets were made by animals of unknown age, so these results are not conclusive. Likewise, the small percentage of sample units with detected cub tracks (6%) is not cause for immediate concern; cubs are less mobile than other age classes so will have naturally lower detection probabilities in this type of survey. However, this preliminary litter data does highlight the importance of future efforts to quantify age class specific survival and reproduction rates for the Sundarbans tiger population, as these parameters will influence threat assessment and predictions of long-term population viability.

Management targets

How evaluation and response activities might integrate in a cyclical manner has been outlined by Gibbs et al. (1999) and Nichols and Williams (2006) the magnitude and causal factors of change at the start of each period drive forward prevention, mitigation, and restoration activities up until the next evaluation. Working within this framework, clearly outlined management objectives will be the benchmark for assessing the effectiveness of response efforts (Ringold et al. 1996; Gibbs et al. 1999).

The initial management goal for the Sundarbans tiger population will be to maintain or increase tiger numbers. To improve understanding of threats, it is necessary to establish prey and habitat monitoring activities to run concurrently with future *khal* surveys, together with an assessment of deer and tiger poaching levels. This information base will enable management to identify threats, formulate appropriate responses and react to changing conditions.

During the interim period in which this data is being collected, it is still necessary to mitigate possible anthropogenic-based threats. I recommend increased patrolling efforts over the next two years, with priority areas selected using the track set frequency recorded in this study.

Monitoring strategy

The validity of this monitoring program rests on the assumption that track frequency is directly related to abundance. This appears reasonable (Johnson 2008), but the nature of the relationship is unknown. I have assumed a linear, directly proportional relationship but this may not be true. Track frequency may also be affected by the mixture of individuals from different demographic groups within a sample unit, local environmental factors that affect movement patterns and spatial variation in track set detectability. The uniform tracking medium and the high sample unit coverage (81 ± 12.3%) suggests that the variation in track set frequency recorded is not likely to be greatly influenced by sample unit dependent detection probability. Other studies of carnivores have corroborated the connection between frequency of sign and actual animal numbers through validation by radio telemetry (Servin et al. 1987; Stander 1998). Further investigation using satellite collared tigers is needed to address this issue for the monitoring program in the Sundarbans.

The threshold of detecting a net decreases of ≥ 30% over two years as a management goal accepts the risk of unnecessary resource expenditure, offset by reducing the greater risk of losing the Sundarbans tiger population from lack of intervention. In addition, the intensive surveying employed increases professional skills and has the secondary function of patrolling for illegal activities. Results of this survey suggest that a monitoring scheme that conducts a full *khal* survey in all 65 sample units once every two years has sufficient power (> 0.8, $\alpha = 0.2$) to detect ≥ 19% decreases and ≥ 17% increases in track frequency, which is more than adequate for the *a priori* set of management requirements.

It is important to note that I used within-sample variance to compute power but this will be an underestimate of the true variance because it does not include between-sample or interannual variance (Gibbs et al. 1999; Hatch 2003). However, reacting to a perceived change at pre-set thresholds, whether it is due to natural or anthropogenic factors, is a necessary precautionary measure for endangered species management.

The survey will be improved by better coverage of the one sample unit where buffers around surveyed *khal* revealed an area where a resident female tiger could potentially reside without any reasonable probability of detection. For future surveys, it will be also essential to retain experienced staff and repeat the training period before commencing the next survey. Observer teams should ideally be composed of one Forest Department and one independent observer. This will enable capacity building and ensure the acceptability of the results to the scientific community, government officials and general public.

Broader implications

The outlined survey methodology and sampling strategy is applicable for use on the Indian side of the Sundarbans, and a coordinated monitoring program between the two countries would improve long-term prospects for tiger management in this vast area.

The first scientifically sound monitoring program for tigers utilizing track set counts was developed in Russia (Hayward et al. 2002) I have used and modified this in developing the Sundarbans survey design. If sample variance due to sign detection, sign degradation, and observer bias can be accounted for, there may well be other habitat types where track frequency surveys could be used to achieve management-based monitoring objectives. Furthermore, where site specific conditions are favorable with respect to detectability, secondary sign surveys may be more appropriate than camera-trapping where cost, coverage and power to detect trends are important considerations.

This paper is a real world example linking sound monitoring to goal orientated management intervention. The process of experimental design, baseline data collection, objective setting, power analysis and explicit intervention response provides a framework for adaptive management applicable to any species recovery program.

FIGURES

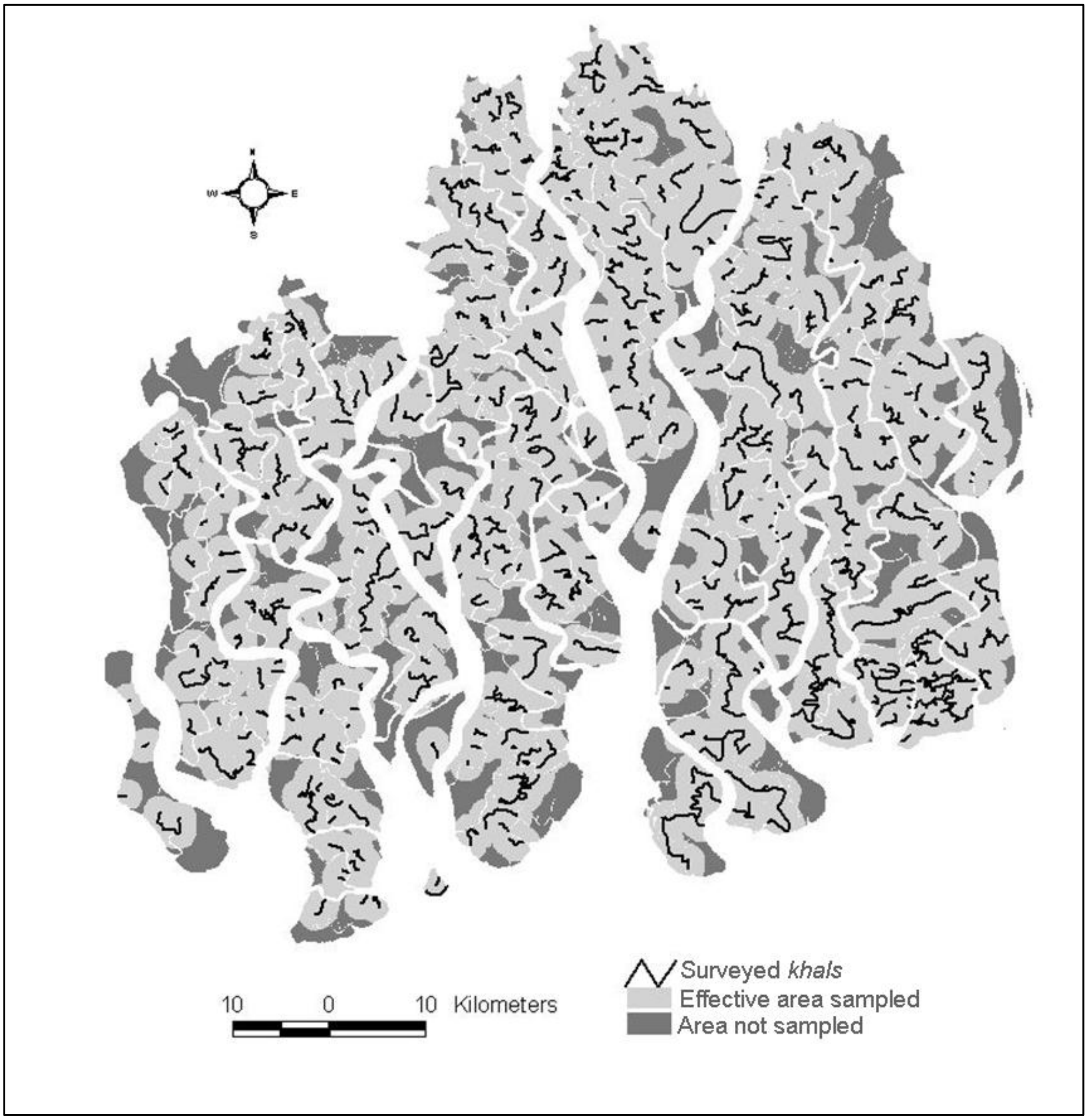

Figure 1. Surveyed khal with 1.7 km buffer width to represent the effective area sampled. The buffer width is determined by the mean daily straight line movement of two resident female radio-collared tigers.

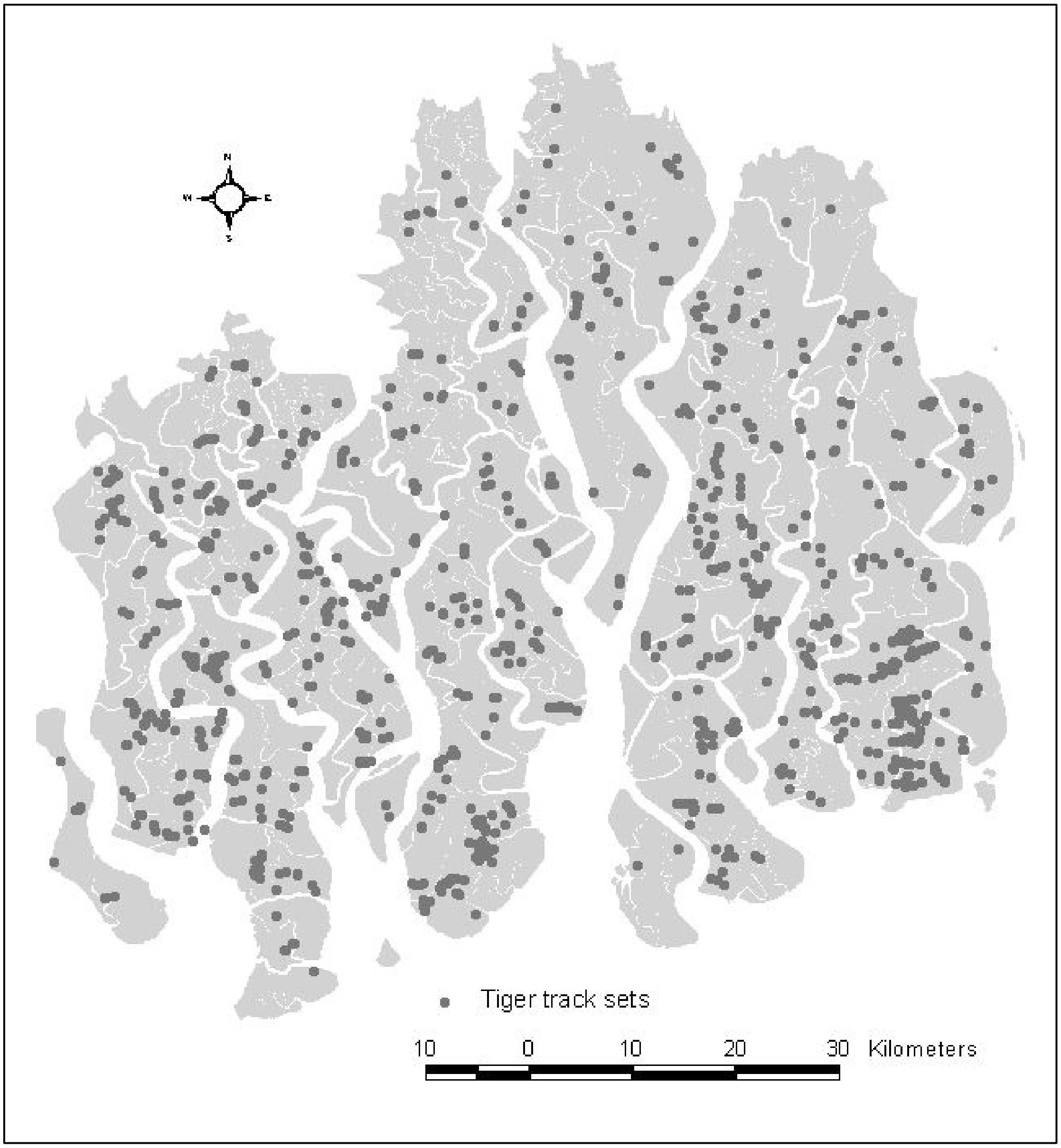

Figure 2. Distribution of tiger track sets detected during survey of Bangladesh Sundarbans.

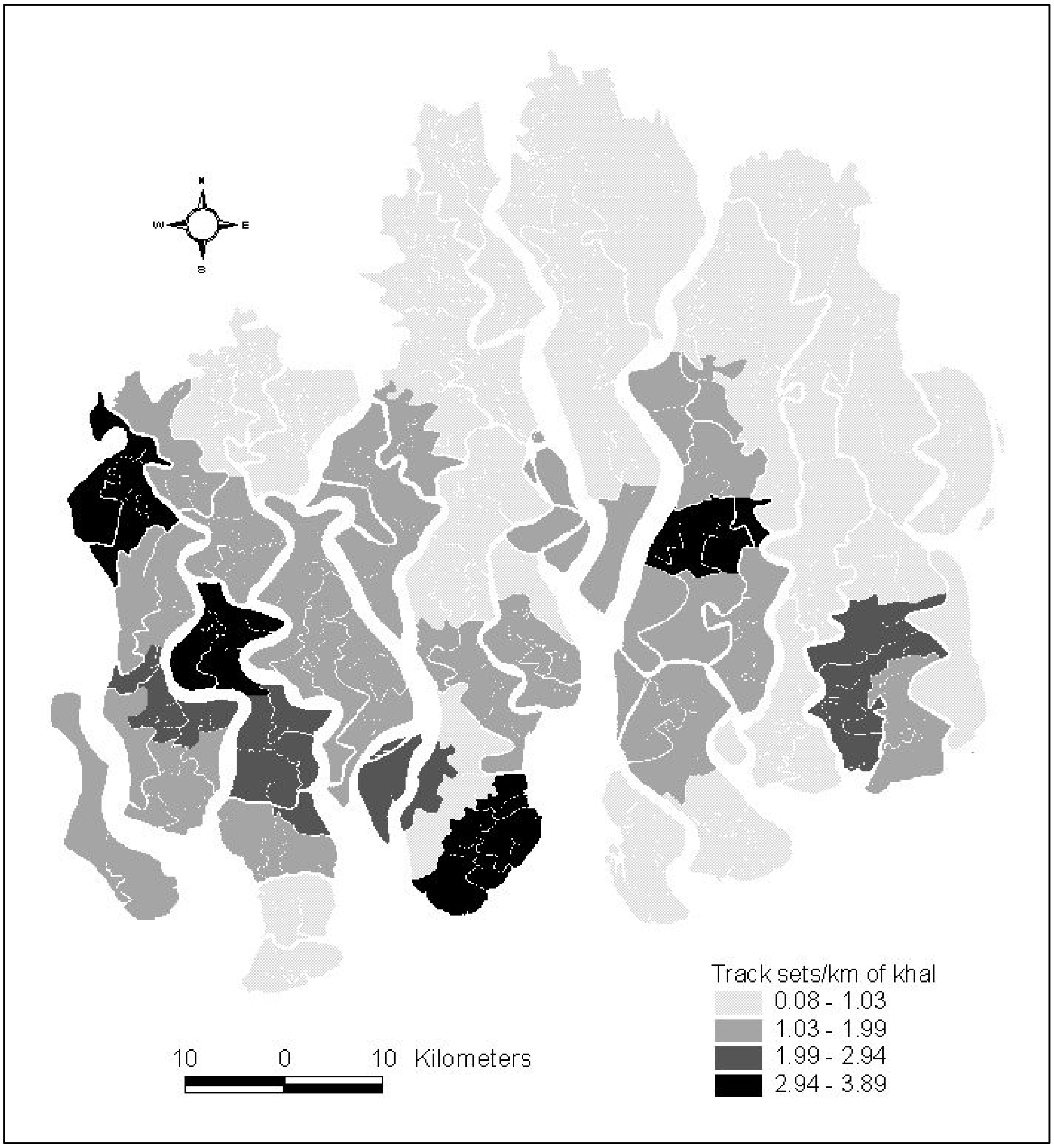

Figure 3. Sample-wise track rate (track sets/km of khal surveyed) for 65 sample units across the Bangladesh Sundarbans.

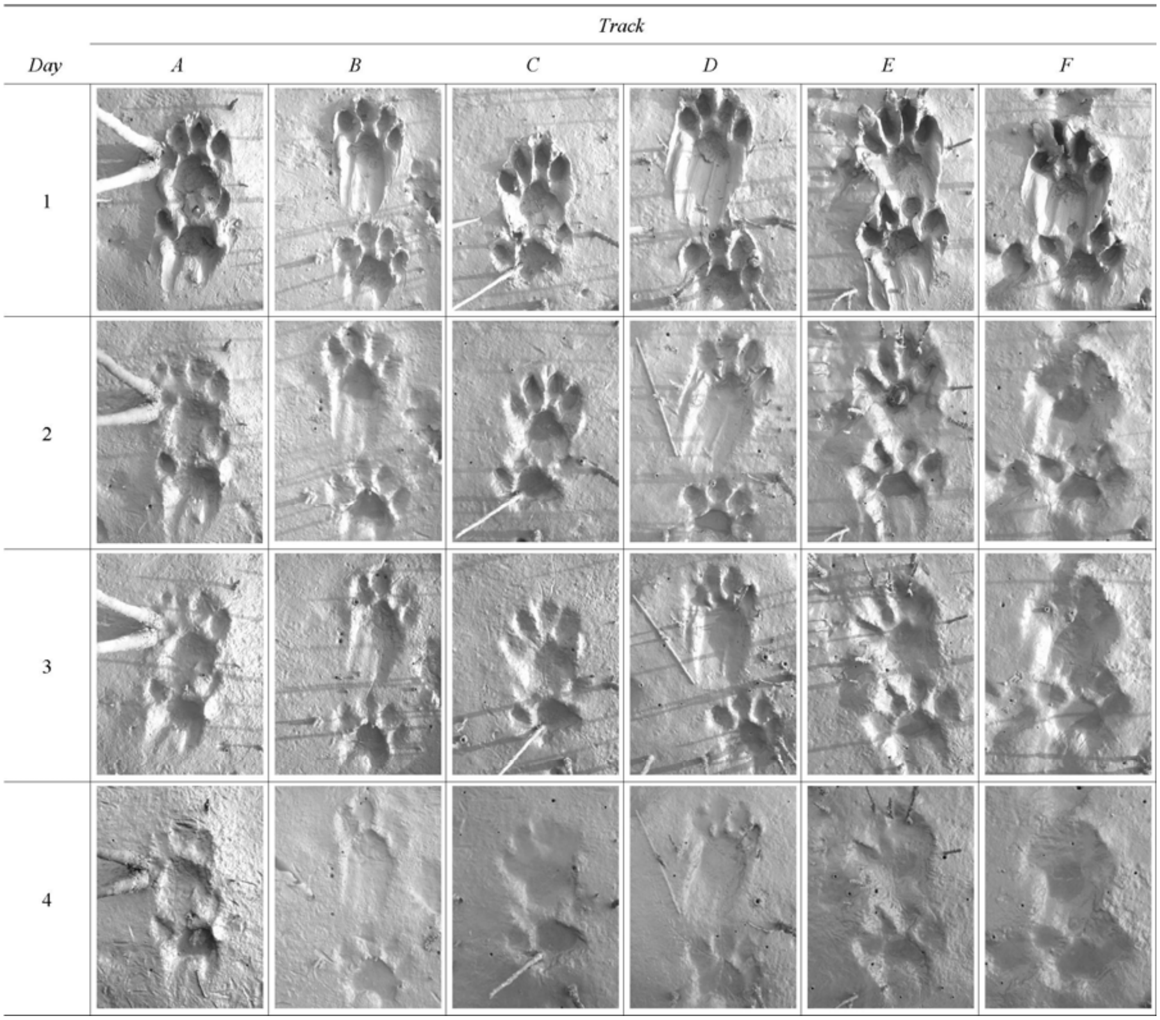

Figure 4. Example of tiger track degradation for one tiger track set over four days.

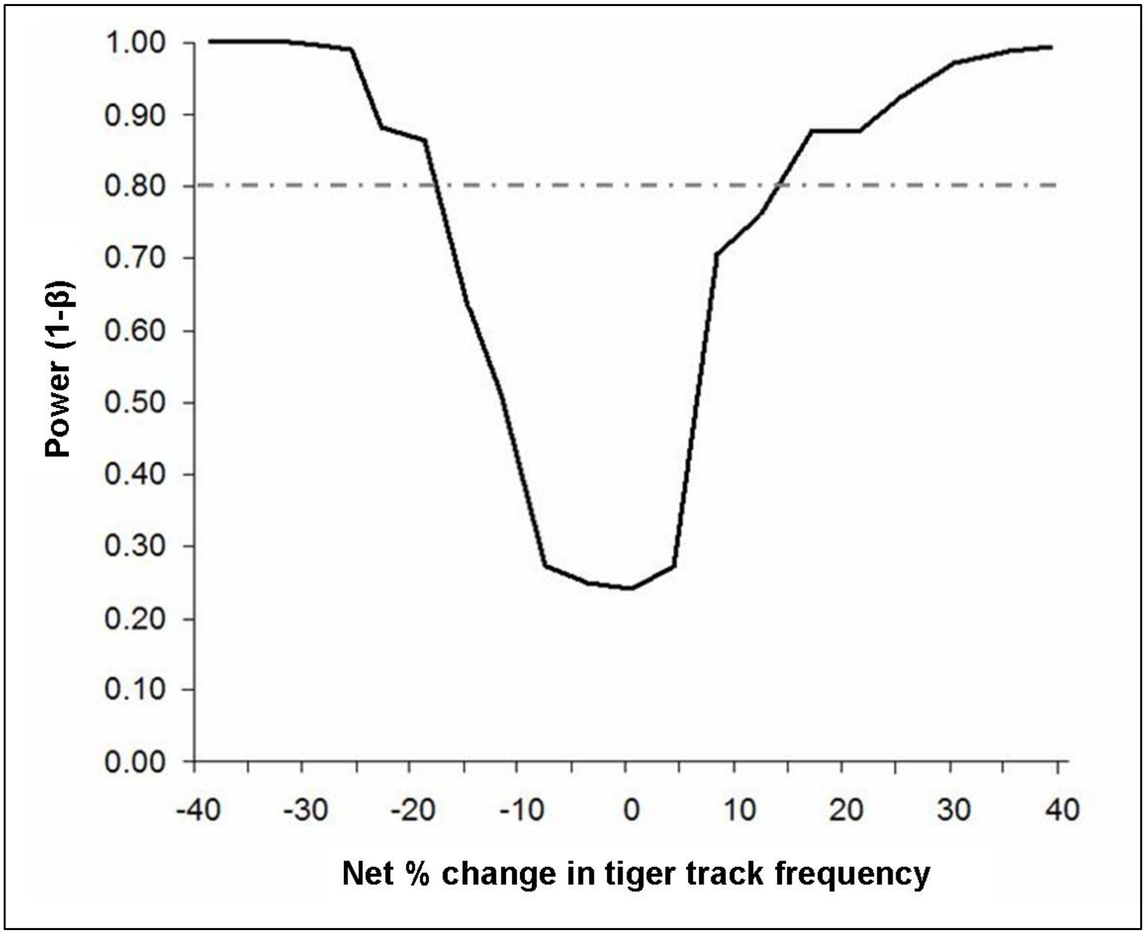

Figure 5. Graph of power to detect net change in tiger track frequency for a khal survey conducted every two years. Power is calculated by program MONITOR with α = 0.2, r = ± 30%, paired plots, exponential response, lognormal measurements, coefficient of variation in proportion to mean, pooled variance, a two-tailed test and 10,000 iterations. The dashed line indicates the minimum power threshold required by management (β = 0.2).

CHAPTER 5

THE SCALE AND HISTORICAL TREND OF HUMAN-AND TIGER-KILLING IN THE SUNDARBANS

TO BE SUBMITTED FOR PUBLICATION AS; BARLOW, A. C. D., M. I. U. AHMED, AND J. L. D. SMITH. THE SCALE AND HISTORICAL TREND OF HUMAN-AND TIGER-KILLING IN THE SUNDARBANS.

ABSTRACT

Human-tiger conflict is an ancient problem that has contributed to the loss of tiger subspecies and populations. Human-killing by tigers and tiger-killing by humans in the Sundarbans is an example of human-tiger conflict at its most extreme. Creating an information base is necessary dealing with the problem, but current understanding of the scale and historical trends in human and tiger deaths is scattered among numerous sources. The objective of this study was to review the number of human and tiger deaths in the Sundarbans, using data collected from published documents and Forest Department records. A total of 3,615 human deaths were recorded, with data available from 84 years over a period of 126 years (1881-2006). Using only years where data was available for both the Indian and Bangladesh Sundarbans gave an average of 51 human deaths/year (range 0-168). Taking into account missing data and a 33% error in recording efficiency, the estimated total number of people killed was 9,540, or 76 human deaths/year. A total of 1,259 tiger deaths were recorded from 81 years from 1881 to 2006, but some years had data for only the India or Bangladesh side. The mean number of tiger deaths was 6/year for Bangladesh and 1/year for India. The numbers of humans and tigers killed each year have dropped in recent decades, but current levels of conflict severely impacts local communities and may be a serious impediment to tiger conservation.

INTRODUCTION

The area where wild tigers can still survive is diminishing at an alarming rate, with tiger habitat now 7% of its historical extent (Sanderson et al. 2006). The remaining tiger habitat continues to be depleted through land conversion and the increasing demand for forest products from a burgeoning human population (Linkie et al. 2003; O'Brien and Kinnaird 2007; Dinerstein et al. 2007). Where tiger habitat still occurs, grazing pressure, unsustainable resource use, and direct hunting of tigers and their prey are threatening the tiger's survival (Damania et al. 2003; Tilson et al. 2004; Lynam et al. 2006; Steinmetz et al. 2006; Dinerstein et al. 2007; Goodrich et al. 2008; Ranganathan et al. 2008). In many areas, the tiger's future is further imperiled through human-tiger conflict, manifested in livestock depredation and human-killing (Miquelle et al. 1996; Qui et al. 1997; Nagothu 1998; Madhusudan 2000; Nyhus et al. 2004; Johnson et al. 2006; Wang and Macdonald 2006; Yu et al. 2006; Gurung et al. 2008; Sangay and Vernes 2008; Tamang and Baral 2008).

Loss of people and livestock leads to negative attitudes towards tigers, and in some cases retribution killings by local communities (Jagrata Juba Shangha 2003; Jalais 2007; Gurung et al. 2008). This additional source of mortality for tigers may have a substantial impact on the long-term viability of the tiger population in question (Kenney et al. 1995; Kerley et al. 2002; Chapron et al. 2008; Goodrich et al. 2008; Barlow et al. 2009). Human-tiger conflict has already contributed to the extinction of the Bali (*P. t. balica*) and Javan (*P. t. sondaica*) subspecies (Hoogerwerf 1970; Seidensticker 1987a), and threatens many of the remaining populations (Nyhus and Tilson 2004; Dinerstein et al. 2006).

Human-killing and retaliatory tiger-killing in the Sundarbans of India and Bangladesh is an example of human-tiger conflict at its most extreme. Human-killing by tigers produces unnecessary human misery and economic stress, while tigers that enter villages are often killed in return (Gani 2002; Chowdhury et al. in press). Management aimed at reducing this conflict will require building a solid information base (Löe and Röskaft 2004). Information on human and tiger-killing in the Sundarbans, however, is scattered across reports and papers not readily accessible by the authorities. The objective of this paper is to assess the scale and historical trend of human and tiger deaths in the Indian and Bangladesh Sundarbans.

METHODS

Data source and analysis

Data on the number of human and tiger deaths for the Indian and Bangladesh Sundarbans were collected from the literature and Forest Department records. The records included people attacked both inside the forest and in the villages along its border. Literature with overlapping data sets, or those with data not recorded by official government sources, were not included. It was assumed that there were no temporal or spatial variations in recording efficiency of tiger attacks.

The number of human deaths reported in official records is, however, an underestimate of the total number of fatalities; people attacked while working illegally in the forest or those that later die due to injuries, tend either not be reported by their companions, or not catalogued by the authorities (Helalsiddiqui 1998; Jagrata Juba Shangha 2003; Khan 2004). It is not known how many human-caused tiger deaths went unrecorded.

The average number of recorded humans killed/year was used to estimate the number of deaths for years when data were missing. The mean number of human casualties missed by official records has been estimated to be between 33% (Jagrata Juba Shangha 2003) and 820% (Khan 2004). The Jagrata Juba Shangha (2003) estimate was used to calculate the total number of human deaths, because it was obtained over a longer study period (three years) than Khan (2004) (18 months). To investigate trend over time, the mean and variance of human and tiger deaths were calculated for each decade.

RESULTS

Data sources

The number of humans killed by tigers in the Sundarbans was catalogued in 22 documents (Blanford 1891; Curtis 1933; Chaudhuri and Chakraborti 1972; Chaudhuri and Chakrabati 1974; Hendrichs 1975; Chakrabarti 1980; Chakrabarti 1984; Blower 1985; Chowdhury 1985; Chowdhury and Sanyal 1985a; Siddiqi and Choudhury 1987; Khan 1987; Sanyal 1987a; Chakrabarti 1992; Sanyal 1995; Helalsiddiqui 1998; Gani 2002; Reza et al. 2002; Jagrata Juba Shangha 2003; Khan 2004; Azad et al. 2005; Islam et al. 2007) and Forest Department records from Bangladesh (1984-2006) and India (1985-2000).

The number of tigers killed by man was collated from nine sources (Curtis 1933; Chaudhuri and Chakraborti 1972; Hendrichs 1975; Jalil 1998; Mukherjee and Tanti 2001; Gani 2002; Reza et al. 2002; Khan 2004; Halder 2005; Bangladesh Forest Department records 2000-2006).

Some records were listed as consecutive years (e.g. 1915/1916), in which case they were assigned to the first mentioned year. Data for groups of years were used to estimate the total number of deaths, and the mean number of deaths/decade, but not for the yearly averages, variance or range.

Number of humans killed by tigers

A total of 7,833 human deaths from tiger attacks were recorded in the Sundarbans, between 1860 and 2006. A majority of these (4,218 deaths, or 54% of total) were recorded from a six year period (1860-1866), giving an average of 703 human deaths/year for that period (Blanford 1891). These records were not included for further analysis, because the data were not year specific, and it was not clear how the information was collected (Blanford 1891).

The remaining cases were recorded from 1881 to 2006 (Curtis 1933; Chaudhuri and Chakrabarti 1972; Hendrichs 1975; Chakrabarti 1980; Siddiqi and Choudhury 1987; Sanyal 1995, Indian Forest Department records 1985-2000; Bangladesh Forest Department records 1984-2006). Records were available for 84 of the 126 years, but some of the years had data for only the Indian or Bangladesh side. A total of 3,615 human deaths were recorded; 1,396 in Bangladesh, 1,231 in India, and 988 not specified to a particular country (Fig. 1). For those years for which data were available for all of the Sundarbans (3,199 human deaths, 63 years), the average number of human deaths was 51/year (SD = 37.3, range 0-168). The Indian side had a greater mean number of human deaths/year (mean = 30, SD = 15.2, range 4-64) compared to Bangladesh (mean = 22, SD = 16.6, range 0-96) (Fig. 2).

Using the mean number of human deaths/year (51) for years with no records, gives an estimate of 6,398 human deaths for the whole Sundarbans. The overall mean recorded number of people killed/decade in the Sundarbans has decreased from 1881-1890 (mean = 165, SD = 4.95) to 1991-2000 (mean = 35.6, SD = 25.1). Over the last 50 years in India, the recorded human deaths has decreased steadily from 38 human deaths/year from 1951 to 1960, to 17.5/year (SD = 16.2) from 1991 to 2000, whereas the numbers for the Bangladesh side have remained more constant, averaging about 24 human deaths/year, only dropping slightly in the last decade to 18.1 human deaths/year (SD = 12.4) (Fig. 3).

Considering approximately 33% of incidents may go unrecorded (Jagrata Juba Shangha 2003), gives a total estimate of 9,550 human deaths between 1881 and 2006, or an average of 76 human deaths/year.

Number of tigers killed by humans

A total of 1,259 tiger deaths were recorded from 1881-2006; 233 tiger deaths in Bangladesh over 42 years, 6 tiger deaths in India over 6 years, and 1,020 tiger deaths over 33 years for the whole Sundarbans, where the country was not specified. (Curtis 1933; Chaudhuri and Chakraborti 1972; Hendrichs 1975; Jalil 1998; Mukherjee and Tanti 2001; Reza et al. 2002; Bangladesh Forest Department records 2000-2006).

The mean for Bangladesh was six tiger deaths /year (SD = 10.1, range 0-57), for India was one tiger death/year (SD = 1.1, range 0-3), and for the whole Sundarbans was 16 tiger deaths/year (SD = 21.3, range = 2-79) (Figs 4 and 5).

Recorded tiger deaths peaked in the decade 1911-1910, with a mean 43 tiger deaths/year (SD = 14.4, range = 31-79), and decreased thereafter to four tiger deaths/year (SD = 2.3, range = 1-8) for 1991-2000 (Fig. 6). The number of recorded tiger deaths on the Bangladesh side peaked at 57 in 1955 and then decreased to 10 tiger deaths/year or below since then (Fig. 6). For the most recent decade 1991-2000 in Bangladesh, a mean of 3 tiger deaths /year (SD = 2.3, range = 1-8) was recorded (Fig. 6).

DISCUSSION

Human and tiger deaths

The estimation of 9,550 human deaths in the last 126 years is probably conservative; Khan (2004) recorded 41 tiger attacks in an 18 month period when official records only listed five, which suggests that underreporting of attacks may be higher than the 33% estimate I used (Jagrata Juba Shangha 2003).

With a mean 76 human deaths/year over the last 126 years, the Sundarbans probably has the highest level of human-killing anywhere in the tiger's current range. Tiger attacks on humans exerted a heavy toll in many places in the Indian subcontinent and parts of South-East Asia a century ago (McDougal 1987). Since then, tiger numbers and the forests in which they once lived have been reduced at alarming rates (Dinerstein et al. 2007). This has led to a reduction in human-killing cases and the number of places where tiger attacks occur (McDougal 1987; Sanderson et al. 2006). However, human-killing still remains a problem in other areas. From 1978 to 1997, a total of 146 people were killed by tigers on the island of Sumatra, at an average of 7.1 human deaths/year (Nyhus and Tilson 2004). Human-tiger conflict is also a serious conservation issue in Nepal; 88 people were killed in Chitwan from 1976-2006, and the rate of human killing has increased from 1.2 human deaths/year (1976-1997) to 7.2 human deaths/year from 1998-2006 (Gurung et al. 2008).

The Sundarbans may also have the highest number of human deaths caused by carnivore attacks. The second highest is probably Tanzania, where >563 human deaths from lion attacks were recorded from 1990 to 2004 (Packer et al. 2005).

Conservation implications

Current levels of human and tiger deaths in the Sundarbans are relatively low compared to mean levels recorded in the last 126 years. Considering that there is no data on temporal changes in human use patterns, prey levels, and reporting efficiency, a precautionary approach would be to assume the decrease in recorded human deaths may be related to a reduction in tiger numbers.

Killing tigers in the Sundarbans may have reduced tiger attacks on human in the past; Curtis (1933) attributed the sharp decline in human deaths in the early 1900s to the high levels of tiger hunting (43 tiger deaths/year) during that time. Hunting problem animals, however, is not currently politically acceptable or in line with conservation objectives to preserve the tiger population. Furthermore, the 2-3 tigers killed each year in the Sundarbans, plus an unknown number poached, could threaten the long-term viability of the tiger population, which is estimated at about 150 adult females (Kenney et al. 1995; Chapron et al. 2008; Chapter 3). Further research is needed to estimate the level of tiger poaching to assess the scale of that threat.

Considering the large number of people that work in the Sundarbans, the probability of anyone being killed by a tiger is very small (Seidensticker and Hai 1983). However, tiger conservation, must take into account the local socio-economic conditions of which human-tiger conflict is an important feature (Jalais 2007; Chowdhury et al. in press). Even though human-killing seems to have decreased in recent decades, it still exerts considerable stress to local communities that rely of the forest for their livelihoods; working in the jungle is the only potential source of income for many people living along the forest border, and those killed are normally the main providers of income for a family (Azad et al. 2005; Gurung et al. 2008; Chowdhury et al. in press).

Human-tiger conflict also strains relationships between local communities and the authorities, and may impede development of co-management strategies. If future conservation efforts increase tiger numbers, then human-tiger conflict can be also be expected to increase, as has happened recently in Nepal (Gurung et al. 2008).

Reducing both tiger and human deaths is therefore needed to improve conservation prospects for tigers in the Sundarbans. An obvious initial management activity is to improve data collection on human and tiger deaths, to help evaluate the impact of management intervention (Löe and Röskaft 2004). The next step is to formulate a management response to reduce the conflict. The authorities on both sides of the Sundarbans have tried a wide range of solutions to reduce tiger attacks on humans (Seidensticker et al. 1976; Chowdhury 1985; Saha 1988, Sanyal 1987a, b; Rishi 1988, 1993; Mukherjee and Tanti 2001; Mukherjee 2003), but none have so far proven successful. A more structured approach is required to assist with and formalize the process of mitigation activity selection.

FIGURES

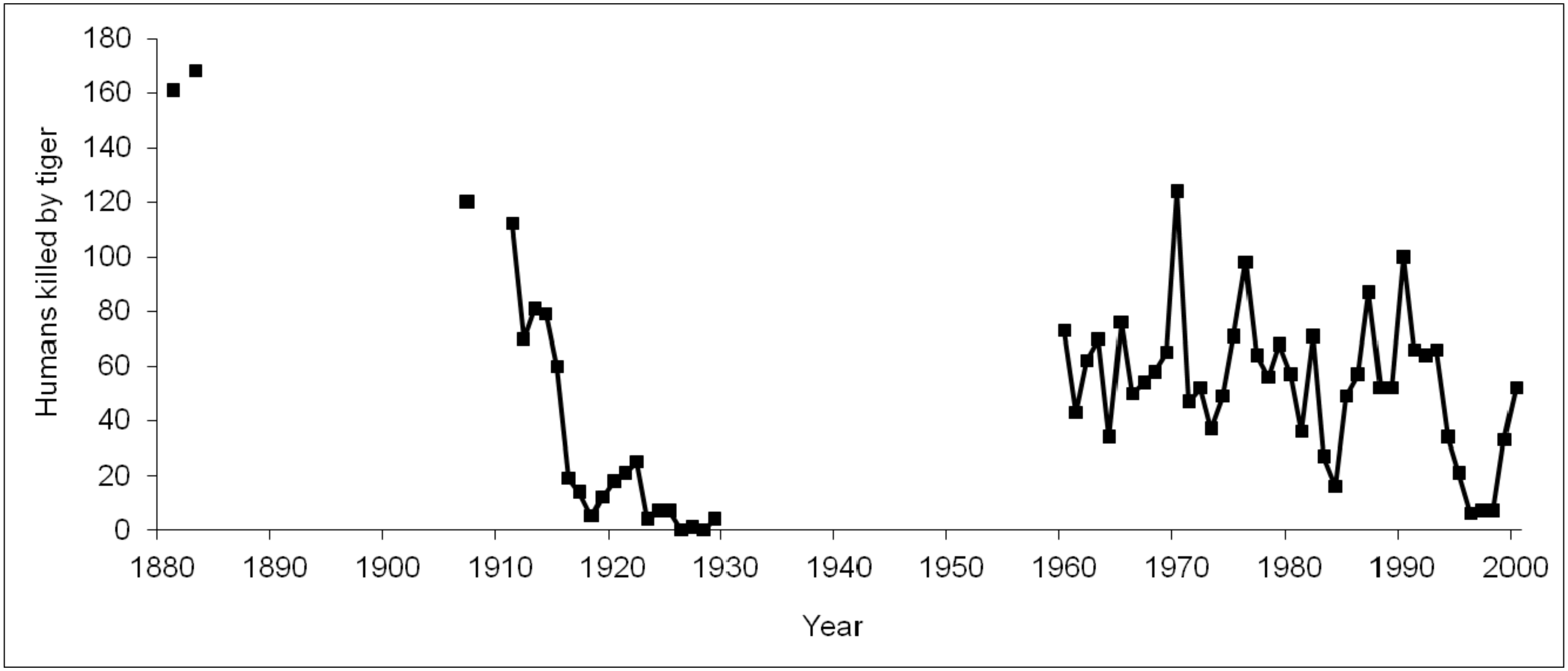

Figure 1. Number of human deaths/year from tiger attacks, recorded for the entire Sundarbans.

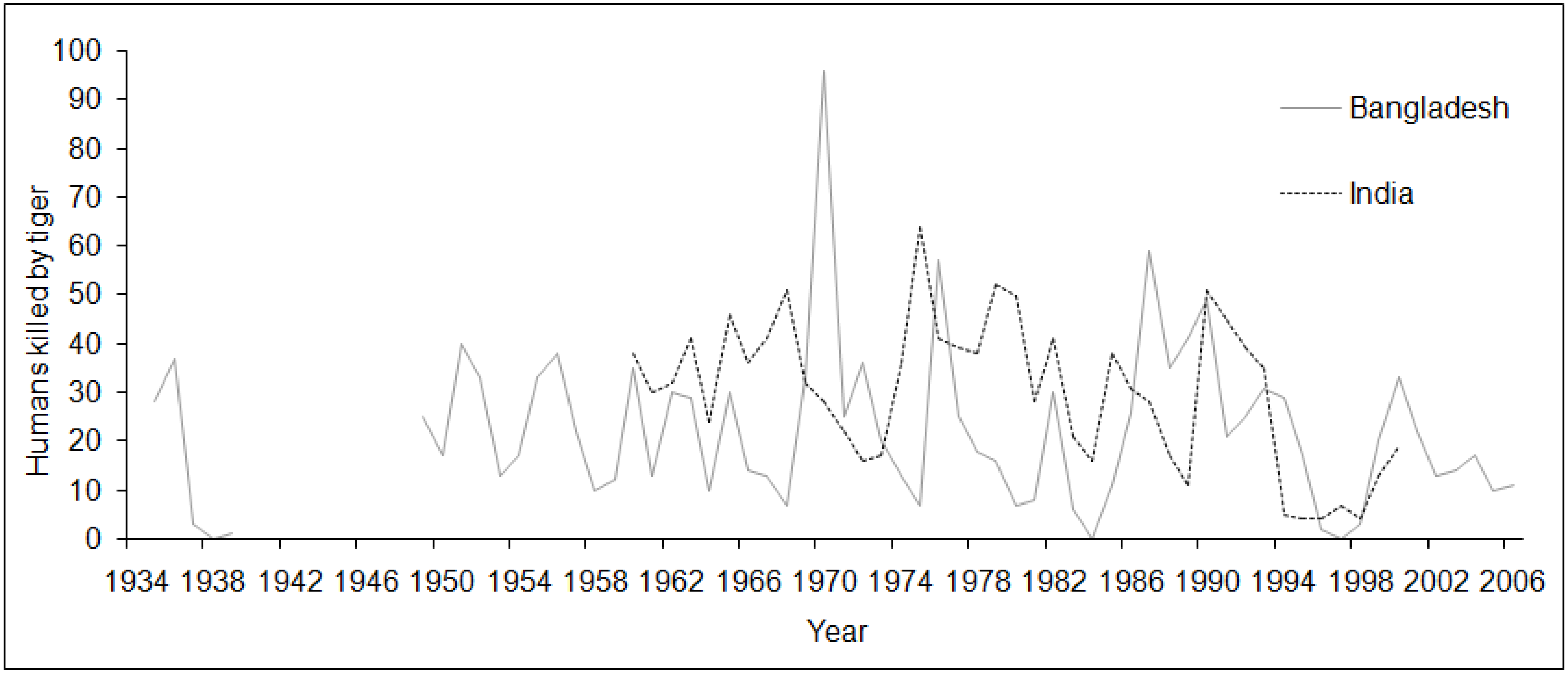

Figure 2. Number of human deaths/year from tiger attacks, recorded for the Bangladesh and the Indian Sundarbans.

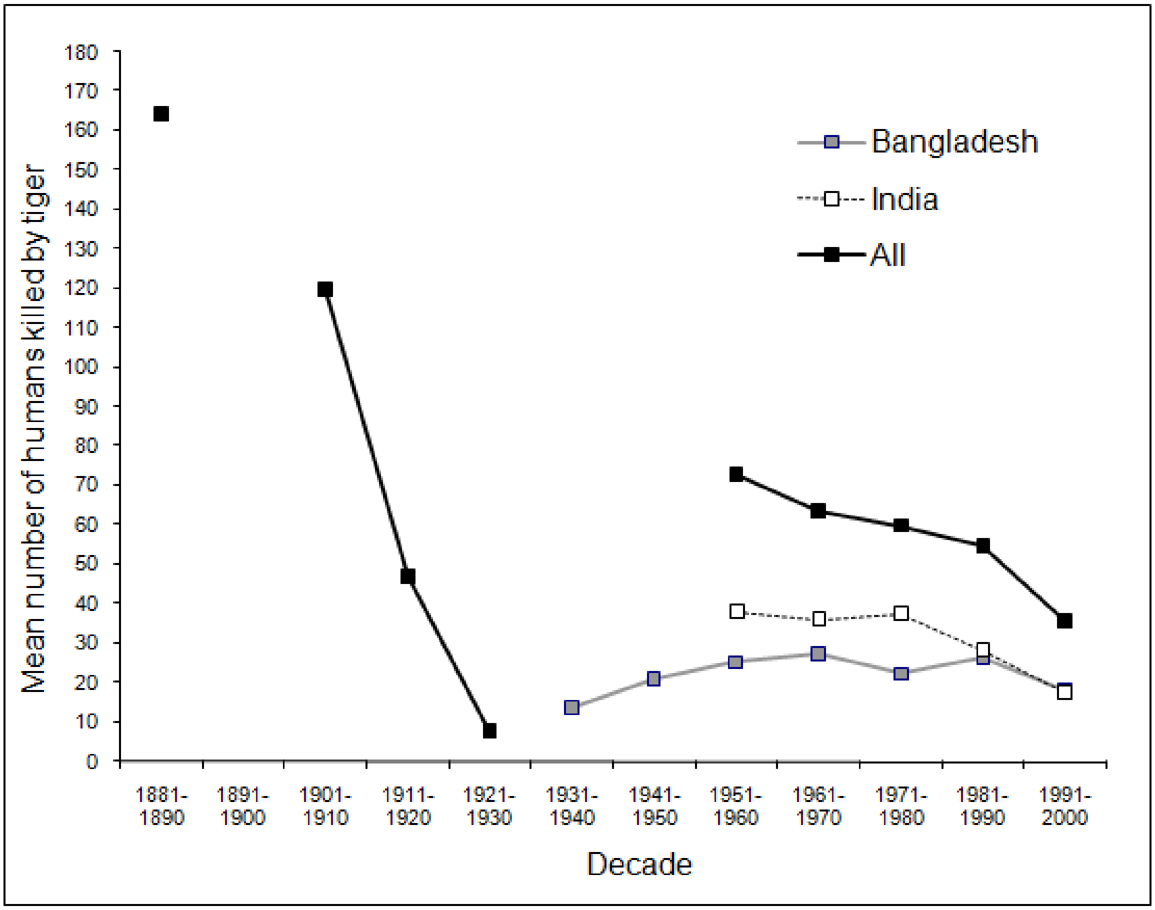

Figure 3. Trend in the number of human deaths/year from tiger attacks, recorded for the Bangladesh and the Indian Sundarbans.

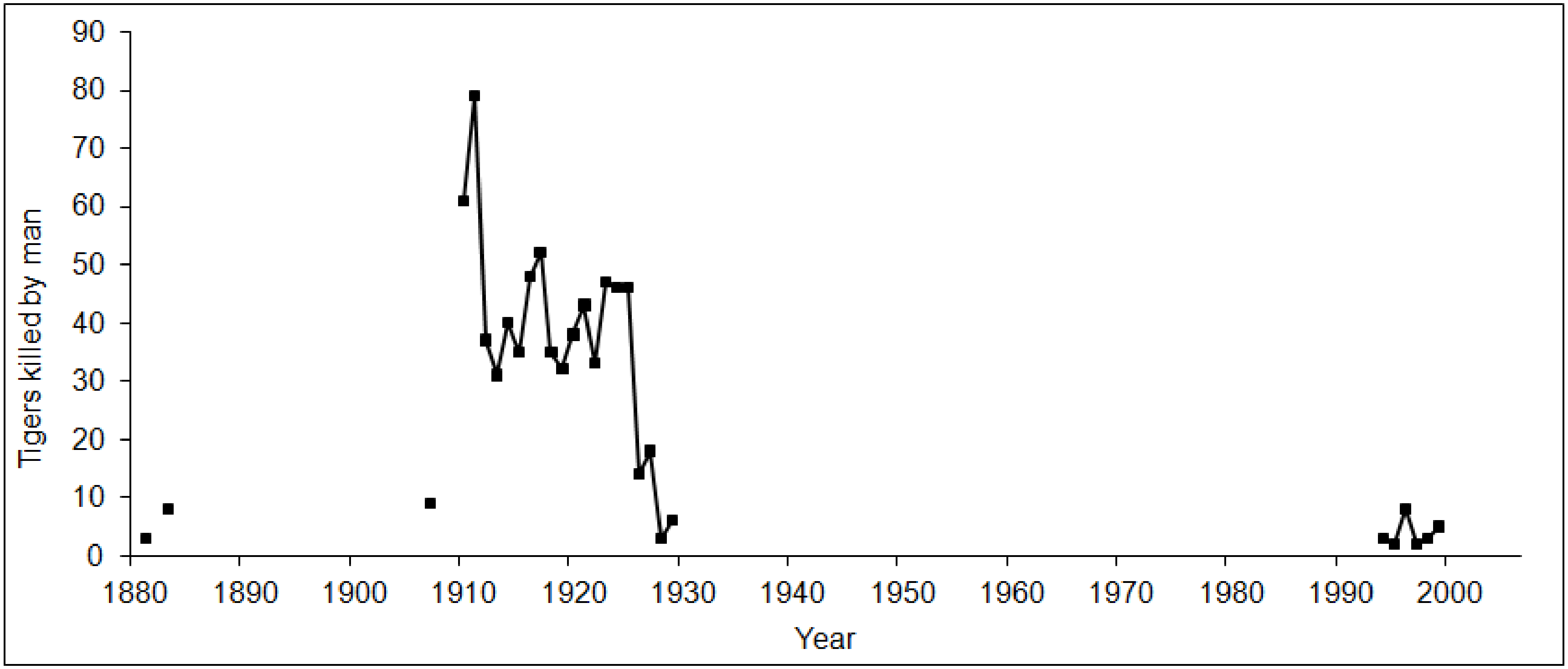

Figure 4. Number of tigers killed/year, recorded for the entire Sundarbans.

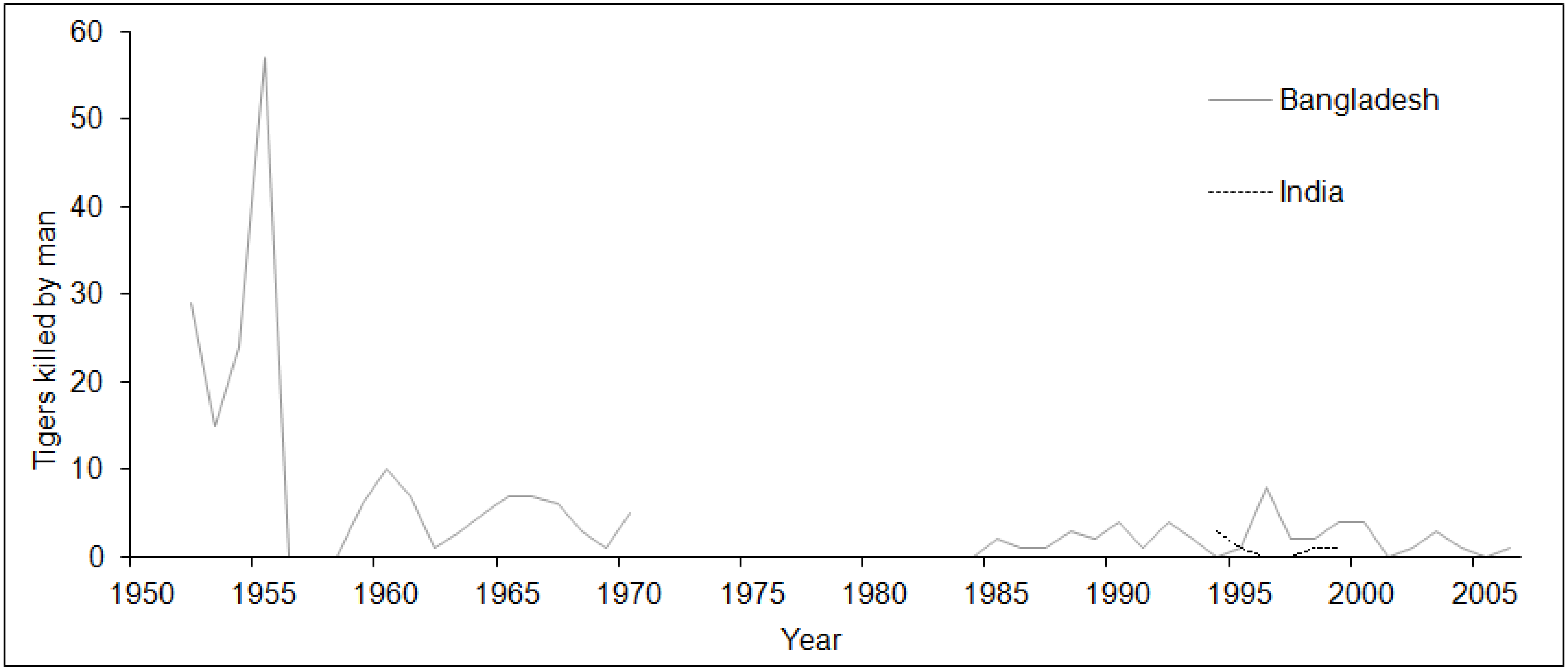

Figure 5. Number of tigers killed/year, recorded for the Bangladesh and the Indian Sundarbans.

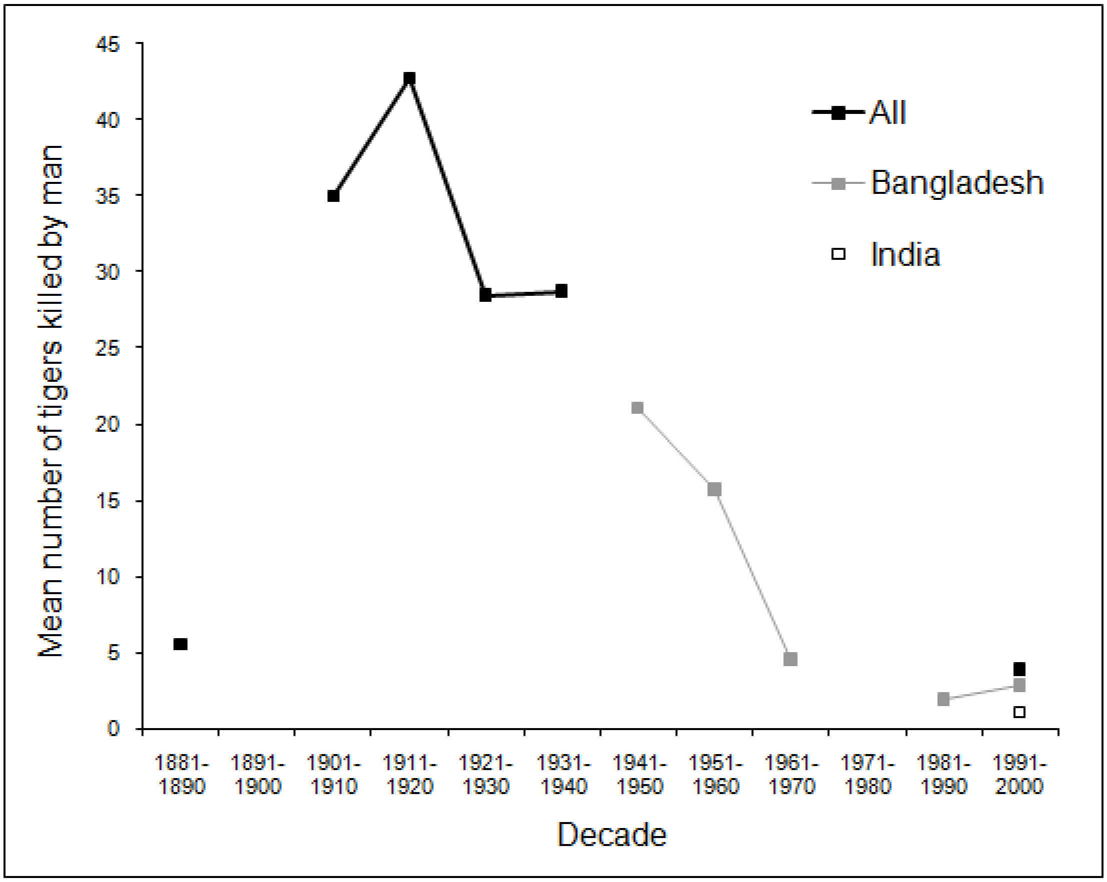

Figure 6. Trend in the number of tigers killed/year, recorded for the Bangladesh and the Indian Sundarbans.

CHAPTER 6

ESTIMATING THE NUMBER OF HUMAN-KILLING TIGERS IN THE BANGLADESH SUNDARBANS

TO BE SUBMITTED FOR PUBLICATION AS; BARLOW, A. C. D., M. I. U. AHMED, AND J. L. D. SMITH. ESTIMATING THE NUMBER OF HUMAN-KILLING TIGERS IN THE BANGLADESH SUNDARBANS.

ABSTRACT

Human-killing by tigers has a negative impact on tiger conservation in the Sundarbans of Bangladesh. Improved understanding of the human-killing tigers is needed to develop appropriate mitigating activities. This study used government records to investigate the number of human-killing tigers, the number of victims/tiger, the length of time each tiger was active, and the spatial distribution of human-killing tigers. The time between consecutive human deaths within a management compartment was used to estimate the number of human-killing tigers over a 23 year period. The estimated total number of human-killers was 110, with an average 8 human-killers active/year. There were an estimated mean 5 victims/tiger, and 50% of human-killers were responsible for 81% of human deaths. Human-killers were active for an average of 8.2 months, and the longest time a human-killer was active was 68 months. Human-killers were distributed unevenly across the Sundarbans, with clusters in the west, south and north. High level of uncertainty in the estimates meant that they should be considered in the context of identifying management solutions, rather than adding insight into tiger behavior. The results will be used to help select management activities to deal with human-tiger conflict in the Sundarbans.

INTRODUCTION

Human-killing in the Sundarbans of Bangladesh is an important issue for tiger conservation, because it creates negative attitudes towards tigers and drives retribution killings. Information is lacking, however, on the tigers involved in the attacks.

A study by Hendrichs (1975) used the timing and location of attacks to investigate the number of tigers involved in three outbreaks of human-killing. In the first case, a male and female tiger known as “the Chapra pair” were thought to be responsible for a spate of human-killing in the south-east of the Sundarbans. In the second instance, a male tiger, “the Mara-Passur man-eater”, was identified as killing up to 32 people. In the third case, a male tiger, “the Arpangasia/Jafa man-eater”, was reported as killing people either side of the Arpangasia River in the north-west of the Sundarbans (Hendrichs 1975). However, no study has provided information on human-killing tigers in the Sundarbans in sufficient detail to help formulate management responses to human killing.

An estimation of the number of active human-killing tigers/year is needed to scale any management response that targets the problem animals. Understanding the number of victims/tiger and the number of months a tiger is active, is required to decide when to start managing a problem animal and for how long management actions should be continued. Information on the distribution of human-killers is also needed to determine where to focus mitigating activities.

This chapter uses government records on human-killing in the Bangladesh Sundarbans to investigate (1) the number of human-killing tigers, (2) the number of victims/tiger, (3) number of months human-killers were active, and (4) the spatial distribution of human-killers.

Although records of human deaths go back to 1881 (Chaudhuri and Chakraborti 1972), the analysis was restricted to 1984-2006, as this should be more reflective of current environmental conditions and human use levels. Only one previous study has estimated the number of human-killing tigers operating in an area over a specified period of time (Gurung et al. 2008).

METHODS

Estimating the number of human-killers

Using Bangladesh Forest Department records (1984-2006), the number of active human-killers/year was estimated as the number of compartments with human deaths.

The total number of human-killers was calculated using the time between consecutive human deaths within each compartment. It was assumed that if a tiger, having killed someone previously, did not kill again within time t then it had ceased to operate in that area, either having moved away or died. Time t was set at 12 months to take into account the variation in environmental conditions and availability of victims over the course of a year.

Using time t, victims were assigned to a particular tiger, from which the number of human deaths/tiger and the number of months a tiger was active was also calculated. The number of human-killers/compartment was used to investigate the spatial distribution of the conflict.

There were four sources of error in this approach. Firstly, the analysis assumed that compartment-wise attacks were independent, i.e. one tiger did not kill people in more than one compartment. This assumption is supported by female tiger home range size for Sundarbans tigers (mean = 14.2 km^2, range 12.2-16.2 km^2) being smaller than compartment sizes (mean = 91 km^2 range = 28-194 km^2) (Chapter 3). However, male tigers are likely to have larger territories, possibly three to seven times the size of females (McDougal 1977; Sunquist 1981; Smith et al. 1987) and transients can move over relatively large distances (Smith 1993). This suggests that the calculated number of human-killing tigers may be a slight over estimate in this respect.

Secondly, the approach assumes that no more than one human-killer/compartment was active at any time. This is supported to some degree by the natural spacing of tigers; adult tigers aggressively defend their territories from intrusion by conspecifics of the same sex (Smith et al. 1987; Smith et al. 1998). However, more than one tiger may be operational in the same area at any given time, because (1) mean female home ranges were smaller than mean compartment size, (2) male and female territories overlap (Smith et al. 1987),

(3) adult females may have dependent offspring that take part in attacking humans (Gurung et al. 2008), and (4) transient animals move through other tiger's territories (Smith 1993). A study in Nepal indicated that multiple tigers were killing people in the same area in approximately 6 (17%) of 36 cases (Gurung et al. 2008).

Thirdly, government records do not record all human deaths because people without official permits to work in the forest are generally under reported (Jagrata Juba Shangha 2003; Khan 2004). Although there are estimates of this degree of error (Jagrata Juba Shangha 2003; Khan 2004), they were not incorporated into the analysis as this would have required additional assumptions regarding the temporal and spatial distribution of missing records.

Finally, the selection of a t = 12 months is arbitrary, and may not reflect a reasonable cut off point, after which subsequent kills are attributed to a new tiger. For sensitivity analysis, more stringent (8 months) and relaxed (16 months) values of t were used.

Overall, the high level of uncertainty in the estimates means that they should only be considered in the context of identifying management solutions, rather than adding insight into tiger behavior.

RESULTS

Between 1984 and 2006, 490 human deaths from tiger attacks were recorded. The estimated mean number of active human-killers/year was 8 (SD = 5, range = 0-16).

Using t = 12 months, an estimated total of 110 human-killers were active over 23 years, with a mean five victims/tiger (SD = 7.1 range 1-39). Approximately 50% of tigers only killed one person (Fig. 1), and tigers that killed more than one person accounted for 81% of total human fatalities. The mean time a human-killer was active was 8.2 months (SD = 13.4, range 1-68) (Table 1).

The mean proportion of compartments with human deaths was 14%/year (SD = 8%, range = 2-29%). The number of human-killers was not distributed evenly across the area; most human-killers were clustered in the west, but there were patches of human-killers in the south and north (Fig. 2).

The sensitivity analysis (using t = 8 months or 16 months) showed that variation in t did not have a large effect on the number of estimated human-killers, the number of victims/tiger, or the length of time each tiger was active (Table 1).

DISCUSSION

Due to multiple sources of potential error, it is not possible to know how many tigers were involved in killing people in the Sundarbans. However, using the location and time between deaths, it was possible to obtain a coarse estimate that is useful for management purposes. Results suggest that approximately 110 tigers have been responsible for human-killing with an estimated 8 human-killers active each year in the Bangladesh Sundarbans over a 23 year period. If this is representative of future conditions, then the cost and impact of potential management response directed at killing/translocating/monitoring the problem tigers can be estimated and compared to other available solutions.

Half of the human-killers killed one person, and the other half accounted for 81% of victims. Furthermore, the mean time a human-killer was active (8 months), indicates that there is a high turnover of human-killers. This means that managers should consider the number of victims/tiger when considering intervention, as this will have a large effect on the number of human-killers to be dealt with and the total number of intervention activities.

The longest estimated time a tiger was active (68 months) is possible, considering that the mean land tenure for resident female tigers is approximately 72 months (Smith and McDougal 1991), and that two tigers in Chitwan held territories for > 156 months (McDougal pers. comm.). Furthermore, the high proportion of estimated tigers that only killed one victim (50% of total), is similar to findings in Nepal, where 17 (47%) out of 36 human-killers, only killed one person (Gurung et al. 2008). In addition, the sensitivity analysis of varying t did not have a large effect on the estimates, indicating that the analysis was not highly dependent on this arbitrary parameter setting.

The clustered distribution of human deaths suggests management response should be primarily focused in the west of the Sundarbans, and that there may be particular ecological factors or human activities that predispose tigers to kill humans. Further research to identify the cause(s) of human-killing by tigers, may help plan future strategies to decrease the conflict.

Tables

Table 1. Estimated number of human-killing tigers in the Bangladesh Sundarbans (1984-2006).

		Months active			Victims/tiger		
t (months)	Human-killers	Mean	SD	Range	Mean	SD	Range
8	142	4.1	6.6	1-35	4	5.60	1-37
12	110	8.2	13.4	1-68	5	7.10	1-39
16	101	10	16.4	1-74	5	7.80	1-39

Notes: The number of human-killing tigers, and the number of victims per tiger was estimated using Forest Department records of tiger human fatalities in each of 55 compartments, over a 24 year period. Time *t* is the time limit between human fatalities in a compartment, after which attacks are attributable to a new tiger.

FIGURES

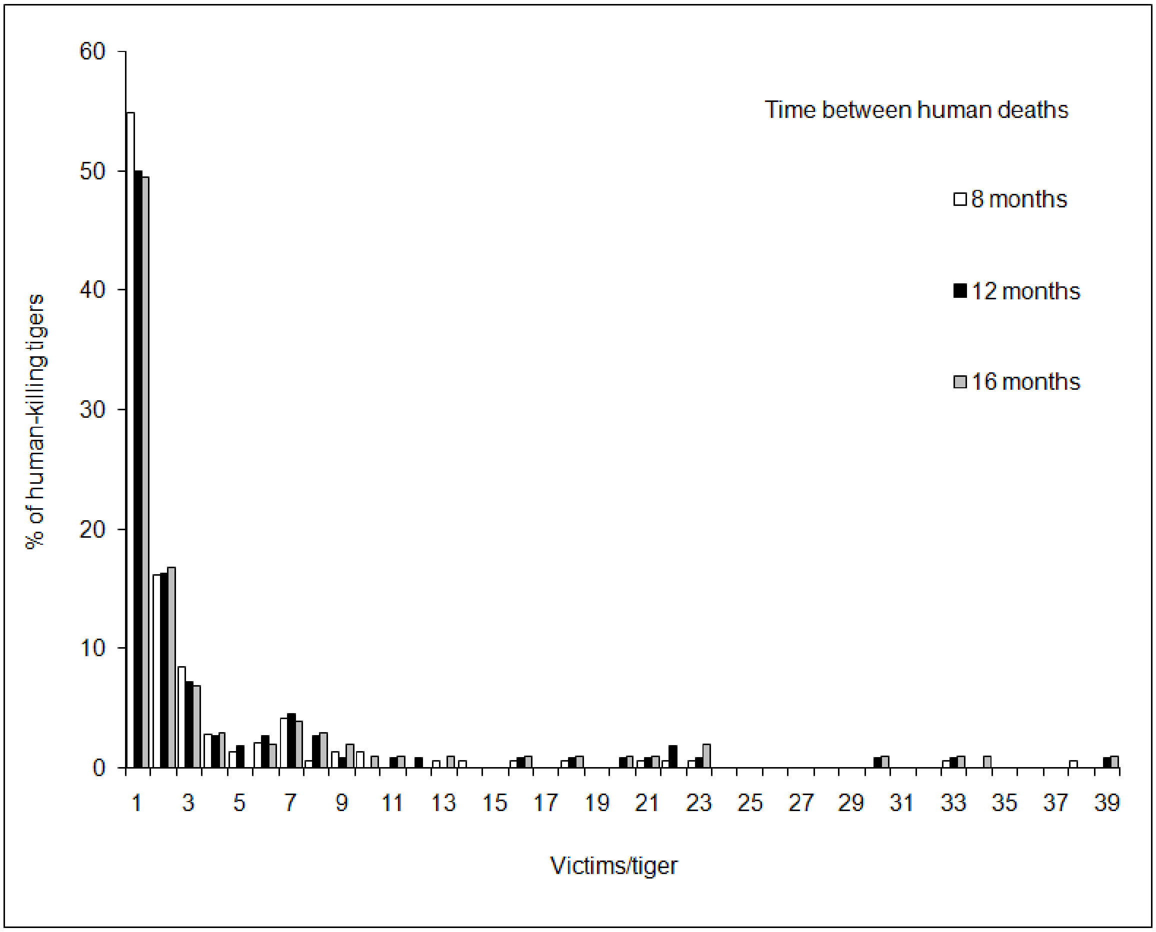

Figure 1. Number of victims/tiger, estimated by the time between human deaths in each compartment.

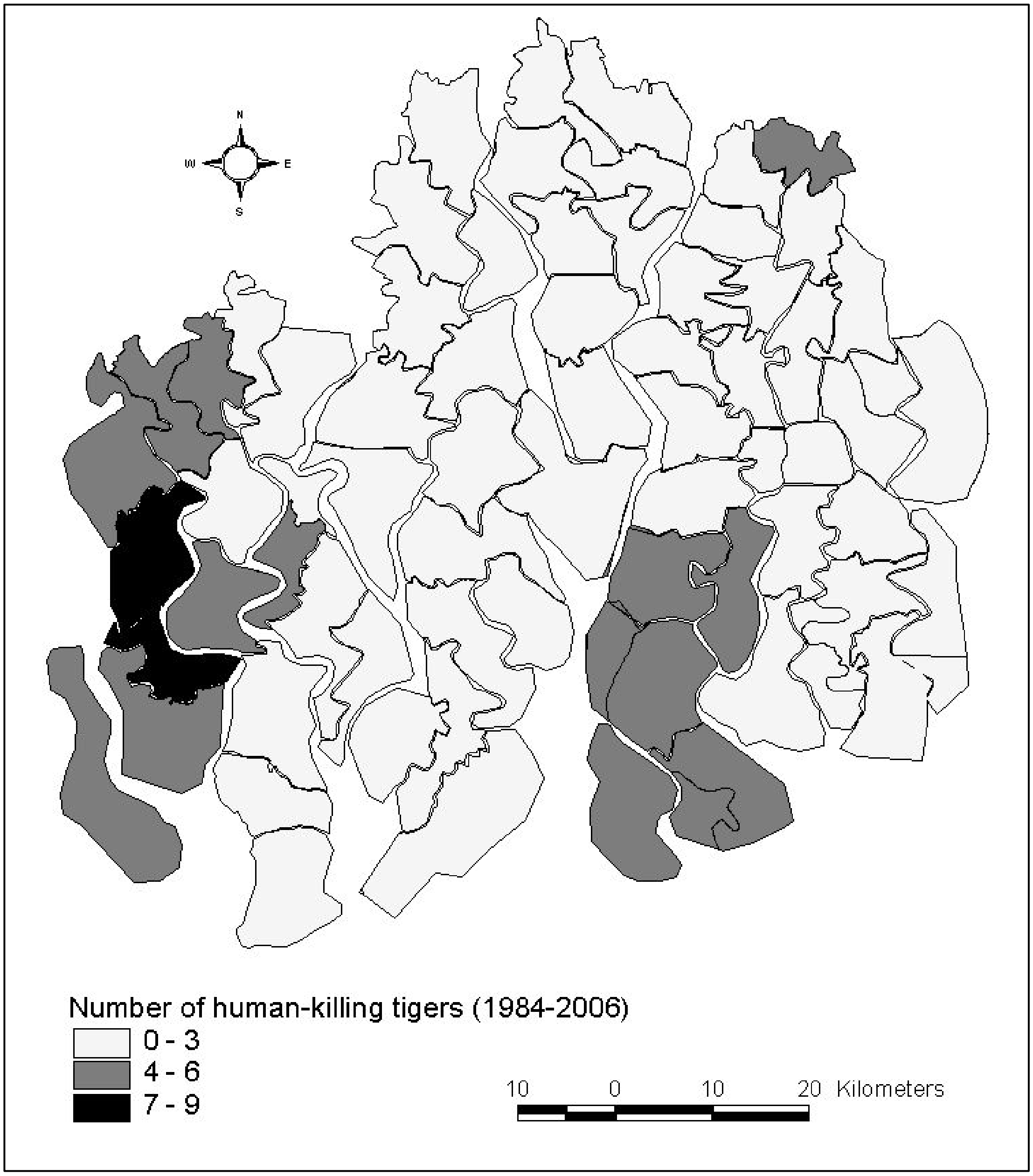

Figure 2. Spatial distribution of human-killing tigers, calculated by the number and time between human deaths recorded in each compartment (1984-2006).

CHAPTER 7

AN ACTIVITY SELECTION FRAMEWORK FOR HUMAN-CARNIVORE CONFLICT: HUMAN-TIGER CONFLICT IN THE BANGLADESH SUNDARBANS AS A CASE STUDY

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ABSTRACT

Human-carnivore conflict is manifested in the death of humans, livestock, and carnivores. The resulting negative local attitudes and retribution killings imperils the future of many endangered carnivores. This study tailors existing management tools to create a framework for selecting activities to alleviate human-carnivore conflict. Dealing with human-tiger conflict in the Bangladesh Sundarbans was used as an example of how the framework can improve existing approaches. The objectives were to minimize human and tiger deaths over eight years. Conflict and causality profiles were created to understand the scale and spatial, temporal and social characteristics of the problem. Potential activities were identified considering previous management efforts, local knowledge, field work experience, and work in other countries. Activities were ranked based on impact and return on investment. Collaring problem animals and tiger response teams were ranked highest across all criteria. The results also highlighted that research into causality is required to improve long-term management strategies. The framework has potential for use in a wide range of human-wildlife conflict scenarios.

INTRODUCTION

Human-carnivore conflict is a key issue for the conservation of many threatened carnivore species (Mishra 1997; Rajpurohit and Krausman 2000; Stahl et al. 2001; Treves et al. 2004; Bauer and De Iongh 2005; Graham et al. 2005; Michalski et al. 2006; De Azevedo and Murray 2007). The conflict is generally manifested in the loss of livestock or human lives, which in turn leads to negative attitudes and retaliatory persecution that can imperil the carnivore species in question (Saberwal et al. 1994; Woodroffe et al. 2005; Treves et al. 2006; Baker et al. 2008; Wydeven et al. in press).

Previous work on human-carnivore conflict has tended to focus on the characterization of site-specific case studies, or broad-scale explanatory factors and solutions (Saberwal et al. 1994; Nowell and Jackson 1996; Primm and Clark 1996; Weber and Rabinowitz 1996; Linnell et al. 1999; Treves and Naughton-Treves 1999; Rajpurohit and Krausman 2000; Woodroffe 2000; Woodroffe and Ginsberg 2000; Peterhans and Gnoske 2001; Treves and Karanth 2003; Nyhus and Tilson 2004; Treves et al. 2004; Packer et al. 2005; Michalski et al. 2006). There is some guidance for overall management of human-wildlife conflict (Clark et al. 1996; Primm and Clark 1996; Treves and Karanth 2003; Graham et al. 2005; Treves et al. 2006; Rondinini and Boitani 2007; World Wildlife Fund 2007; Gurung et al. 2008; Pressey and Bottrill 2008), but it is not clear from the literature how wildlife managers can approach the specific task of selecting alleviation activities.

This paper presents a framework to guide managers through the process of activity selection for the mitigation of human-carnivore conflict. It uses existing conservation management approaches (The Nature Conservancy 2003; Mace et al. 2006; Murdoch et al. 2007; World Wildlife fund 2007; Busch and Cullen 2008), and tailors them specifically for human-carnivore conflict.

The true test of a management framework is its application to a real-world setting, with all the associated uncertainty, lack of information, and judgment that entails. This paper uses a case study of human-tiger conflict in the Sundarbans of Bangladesh to help examine the process and enable conservation managers to visualize how the framework can support existing efforts.

ACTIVITY SELECTION FRAMEWORK

A number of management frameworks have been developed to support conservation programs (Poiani et al. 1998; Margules and Pressey 2000; Groves et al. 2002; TNC 2003; World Wildlife Fund 2007; Pressey and Bottrill 2008). The World Wildlife Fund (2007) example breaks down program management into five components: define, design, implement, adapt, and share. The activity selection framework presented in this paper falls within the design component (Fig. 1), and includes five steps: objective setting, building the conflict profiles, activity identification, activity prioritization, and identifying research needs (Fig. 2).

Objective setting

Setting objectives for human-carnivore conflict can be a difficult undertaking, however, because it will require a combination of ethical, political, socio-economic, and ecological judgments. Useful objectives must be specific, measurable, achievable, realistic, and time bound (SMART) (Tucker et al. 2005). Where humans and carnivores interact in a common landscape, it is not a reasonable or achievable objective to prevent all loss of human, livestock, and carnivore life. Human-carnivore conflict instead represents a damage limitation scenario, so objectives should aim to minimize bad outcomes (e.g. human and carnivore killings). Having the objectives time bound enables comparisons between mitigating activities and evaluation of success.

In addition, it is important that objectives are considered flexible entities that can be updated at any time in response to new information, or a changing socio-political landscape (Johnson 1999; McCarthy and Possingham 2007).

In a conflict scenario involving an endangered species, there will be more than one objective. It will be necessary to reduce loss of human lives and property, to increase local support for carnivore conservation and to fulfill a moral obligation to reduce the human suffering caused by the carnivore (Dorrance 1983). It will also be necessary to improve the situation for the carnivore, by reducing unnecessary mortality and decreasing the population's vulnerability to extinction (Kenney et al. 1995; Treves et al. 2004;

Chapron et al. 2008). An explicit process or rationale may be needed to prioritize between potentially conflicting objectives (Munda et al. 1994; Nute et al. 2000; Murdoch et al. 2007).

Building the conflict profiles

The available information on the conflict should be organized into two sets of profiles: (1) a profile of the conflict itself, and (2) a profile of the underlying causes that drive the conflict. For each profile, information will be needed on scale and spatial, temporal, and social characteristics. These two profiles can be used to outline parameters for activity development, in terms of the where the activity will take place, when the activity will be carried out, and who will take part in or be affected by the activity. The profiles will also highlight information gaps that require further research. Data sources may include government records, scientific papers, NGO reports, local knowledge, and the media.

Activity identification

The information from the conflict and causality profiles can be used to help identify a range of activities designed to alleviate the conflict problem. Care must be taken to ensure activity ideas are in line with objectives; tools such as results chains and log frames can facilitate this process (World Wildlife Fund 2007).

To develop ideas for mitigating activities, managers should use brainstorming sessions, focus group discussions, and literature reviews (Poiani et al. 1998; The Nature Conservancy 2003). Activities previously used in the area, new approaches identified through field work, local solutions, and measures used to reduce human-carnivore conflict in other countries should all be considered. Key stakeholders, such as government staff, NGOs, and local people, must be involved to ensure valid ideas are developed, and to build a sense of joint ownership of the solutions (Pinkerton 1999).

Doing nothing should also be considered as an activity as this may be the best management strategy under certain circumstances. Budget constraints should not be considered at this stage to ensure a comprehensive appraisal of potential solutions.

Activity prioritization

Several ranking approaches should be used to help decision makers select between activities. Activities should first be ranked based on impact, with respect to achieving the objective, to build an understanding of the best possible outcomes. Impact can be measured in ranges or absolute numbers depending on the type, quality, and quantity of the available information. Where possible, impact should be measured in human deaths, economic loss (livestock), and carnivore deaths. The expected year when impact will be first realized must be incorporated into the calculation of total impact over the pre-defined time period.

Decision makers are often forced to make conservation choices in the context of scarce funding, so consideration must be given to which activities provide the best value for money (Hughey et al. 2003; Murdoch et al. 2007; Bottrill et al. 2008). Cost-effectiveness analysis (CEA) (Busch and Cullen 2008), incorporating a structured return on investment (ROI) calculation can be used to determine the most effective use of funds to mitigate the conflict (Murdoch et al. 2007). ROI is calculated by dividing impact by cost. Cost should take into account the implementing organization's capacity and include startup, training, equipment, and maintenance expenditure over the full timeframe (Murdoch et al. 2007). Comparing between impact and cost-effectiveness rankings then allows managers to see what measure of impact is lost if a decision is based on value for money.

Because human-carnivore conflict is generally emotive and highly political, I recommend that objectives are not initially weighted, in order to avoid situations where (1) carnivores are valued above people, which may be inhumane, or (2) consideration of human benefit is always primary, which may lead to species extinction. Instead, the combined impact and ROI ranks of activities against all objectives can be used to identify activities that may lead to win-win scenarios for both humans and carnivores.

If multiple activities are being selected for implementation then managers should try to avoid complementarity. This occurs when impact is summed across different activities, which may result in double counting and an overestimation of impact (Murdoch et al. 2007). If all activities have low or uncertain impact then measuring their chance of success may also help the selection procedure (Mace et al. 2006; Murdoch et al. 2007). If activities are very similar in impact and cost-effectiveness, then they may be differentiated based on leverage, which can be any additional conservation benefit of an activity, unrelated to the threat and objectives in question (The Nature Conservancy 2003, Murdoch et al. 2007). Importantly, the opportunity costs of a strategy must be explicitly stated; if activity A is selected, then managers must be aware of the benefits foregone (e.g. in human or carnivore lives) by not selecting activity B.

Activities for which there is insufficient information to define cost or an impact score, should be classified as either meriting further research, or as disregarded from future consideration.

Identifying research needs

Information gaps highlighted during the build conflict profiles and activity selection steps will provide the basis for a list of research needs. Additional research can be pursued to improve (1) the conflict and causality profiles, to enable a more informed activity identification process; and (2) the impact estimates, to increase confidence in activity prioritization results. If understanding about causality can be improved then management response can progress from being reactive to preventative. More preventative activities may have a greater and longer-lasting impact that compensates for the initial cost of research. Any additional research should run concurrently with the management activities designed to immediately alleviate the human-carnivore conflict problem.

HUMAN-TIGER CONFLICT IN THE BANGLADESH SUNDARBANS

Background

People are attacked when they are working in the forest or when tigers stray into villages. Some tiger attack victims die outright, while others succumb to their injuries on the way to treatment. A common scenario is for a victim with untreated wounds to face a 1-2 day journey to reach medical assistance, through the maze of the Sundarbans waterways, in an open, man-powered craft. Other people are killed or injured as they attempt to save the person originally attacked, or when they attempt to retrieve the victim's body for burial. As a warning to other people, creek entrances where attacks occur are normally marked with a piece of cloth attached to a tree or pole. If seen at all, such markings do not generally dissuade villagers from using nearby creeks that are very likely within the range of the tiger responsible for the original attack.

There have been a variety of approaches employed to reduce human-killing in both the Indian and Bangladesh sides of the Sundarbans, but none have been sufficiently evaluated (Sanyal 1987a; Mukherjee 2003).

Tigers are sometimes killed when they stray into villages; bludgeoned to death by hundreds of local people armed with sticks and farm tools (Gani 2002). People are also injured or killed in the process. Tigers can also be killed by feeding from a carcass poisoned with pesticide. In India there is a specialized team to immobilize and move stray tigers, but no such management tool exists on the Bangladesh side (Mukherjee and Tanti 2001). Overall, there has been little progress in developing any formal management strategy for dealing with human or tiger-killing.

Objective setting

The Forest Department of Bangladesh is currently in the process of developing the first Bangladesh Tiger Action Plan (BTAP) (Bangladesh Forest Department 2008). Human-tiger conflict in the Sundarbans has been identified as a critical component of the plan (Bangladesh Forest Department 2008). The specific objectives for the eight year course of the BTAP are to minimize the number of humans killed by tigers and the number of retribution killings of tigers in the Bangladesh Sundarbans.

Building the conflict profile

Information was gathered from the literature (Curtis 1933; Garga 1947; Hendrichs 1975; Chowdhury 1985; Sanyal 1987a, b; Rishi 1988; Saha 1988; Sanyal 1995; Reza et al. 2002; Jagrata Juba Shangha 2003; Mukherjee 2003; Islam et al. 2007), Forest Department records of tiger and human deaths, local knowledge, and during the course of other field work. This data was used to build the conflict and causality profiles (Tables 1 and 2).

Activity identification

Ideas for potential activities were collected from (1) activities previously used in the Sundarbans, (2) field work experience, (3) discussions with local communities, and (4) activities suggested or used elsewhere. The activities were developed taking into consideration the parameters highlighted by the conflict and causality profiles. Potential activities were grouped into four categories: tiger management, education, construction, attack deterrent, and life-saver (Table 3).

Tiger management activities would involve tiger capture following procedures outlined by previous studies (Goodrich et al. 2001; Frank et al. 2003; Chapter 3), and include killing, translocation, and collaring approaches (Linnell et al. 1997; Goodrich and Miquelle 2005). Government-authorized killing of problem tigers has been carried out previously, and tigers can legally be killed in Bangladesh if they are declared human-killers by the Forest Department. Killing problem tigers in large numbers to reduce human-killing seems to have been effective in the past (Curtis 1933; Hendrichs 1975). However, given the conservation status of the species and the uncertainty in estimates of population and other threats, additional human-caused mortality may imperil the long-term viability of the tiger population (Kenney et al. 1995; Chapron et al. 2008).

Translocation of problem tigers has been carried out with some degree of success in the Russian Far East, where both human use and tiger density are low (Goodrich and Miquelle 2005). In the Sundarbans, however, human use and tiger density are both relatively high (Iftekhar and Islam 2004b; Barlow et al. 2008). Therefore, translocation of tigers in the Sundarbans is likely to move the problem to another area instead of reduce it, because there is human use across all of the forest area. Furthermore, it is expected that some translocated tigers would die due to confrontation with territory holders of the area into which they have been moved, and others may return to their original range (Linnell et al. 1997; Craven et al. 1998; Athreya 2006; Armstrong and Seddon 2008).

Another approach would be for the Bangladesh Forest Department to collar tigers suspected of killing two or more victims. This threshold of two victims/tiger takes into account previous findings that 50% of human-killing tigers kill only one victim, and that those that kill more than one account for about 80% of all victims (Chapter 6). Collaring problem animals has been proposed as an approach to deal with human-killing tigers in Nepal, and has been used in Kenya to reduce livestock deaths and retaliatory killings of lions (Gurung et al. 2008, L. Frank pers. comm.). By monitoring the tigers on a daily basis, the tracking team would be able to warn away forest users if they got too close, or scare away the tiger to avoid a dangerous situation. Including villagers in the monitoring program would also improve relationships between the government and local communities, and build a sense of stewardship over the tigers (Gurung et al. 2008). The mobilization of specialist teams would also improve protection of problem tigers from retribution killings and poaching. An ancillary benefit of monitoring would be gaining insight into why these animals are killing people in the first place (Gurung et al. 2008).

Construction activities included building fences and dredging water channels to form a barrier at the forest-village interface in the north-west of the Sundarbans, which experiences the highest levels of stray tigers (Rishi 1993). Fences and dredging were expected to have a limited effect, because tigers can overcome fencing and traverse large water bodies (Garga 1947; Hendrichs 1975). Another construction activity was to build freshwater ponds, to reduce the intake of saline water by tigers (Saha 1988), which is meant to predispose them to human-killing (Hendrichs 1975). However, there is no evidence for a biological link between water salinity and human-killing behavior in tigers.

Some attack deterrent activities were aimed at high risk user groups such as honey collectors, fishermen, and woodcutters operating in the west. Masks worn on the back of the head were considered as a means to dissuade tiger from attack (Rishi 1988; Saha 1988; Sanyal 1995; Mukherjee 2003). Tigers do in general attack from the rear, and seem less confident in a face-on confrontation (Seidensticker and McDougal 1993; pers. obs.), so it seems plausible that they could reduce human deaths. Masks have been used in India their impact has not been sufficiently assess (Rishi 1988; Mukherjee and Tanti 2001). Another deterrent is firecrackers, sometimes used by forest users to scare away a tiger from an area before starting work. This has some potential to help avoid dangerous confrontations. Electrified dummies designed to condition tigers not to attack people have been previously piloted in India, but at scale too small to evaluate their impact (Chowdhury 1985; Mukherjee 2003).

A life-saving activity was for forest users to wear protective fiberglass headgear, previously used on the Indian side of the Sundarbans (Rishi 1988, 1993). These may save the lives of some users, but current designs are cumbersome and not practical to use by forest users (Rishi 1993). Another life-saving activity was the use of "Tiger Response Teams", strategically stationed in areas of high human and tiger-killing. The role of these teams would be to treat injured persons, transport them to medical assistance, and patrol the area of the attack to prevent further incidents. Another duty would be to respond to situations in which tigers have strayed into a village, in which case teams would reduce violent confrontations by keeping tigers and people separate.

Based on the social and spatial aspects of tiger and human deaths, education activities would be focused on local villagers to reduce the number of stray tigers killed, and on forest users to improve their safety.

Zonation to further separate people from tigers was not considered, because it would increase economic stress to already impoverished local communities.

Activity prioritization

Each activity was ranked according to its potential impact in reducing human deaths, its impact to reduce tiger deaths, and its cost over the eight year period covered by the BTAP, calculated using data if available, and experience based judgment if not (Tables 4 and 5). Based on Forest Department records (1984-2006), the conflict scenario considered was 30 human deaths and 3 tiger deaths each year. All tiger deaths occur when tigers stray into the village areas in the east, 27 human deaths occur in the forest and 3 in the village areas. Impact for each activity is the estimated number of human and tiger deaths that are prevented. The construction activities at the forest-village interface have the potential to prevent only those tiger and human deaths that occur in the village areas. The tiger management activities have the potential to prevent human and tiger deaths. However, because an estimated 50% of tigers only kill one victim, intervention is only initiated on tigers that have killed at least two victims. It is assumed that the problem tigers can be identified by location of victims, tracks associated with the kill site and in some cases camera-trapping. The deterrent, life saver and education of forest users activities have the potential to prevent human deaths in the forest area. The education of villagers activities can prevent tiger deaths only. The life save activity of tiger response teams also can potentially prevent tiger deaths. All activities were compared to the management option of doing nothing. Costs were estimated from start up, equipment, replacement, running, maintenance and training costs considering the current Forest Department resource availability.

Ranking activities on the estimated number of human deaths avoided, identified tiger collaring and tiger-killing as the best options, and dredging and freshwater ponds as the worst. However, taking reduction of tiger deaths into consideration, tiger collaring and tiger response teams were ranked highest, while many activities had no impact, and tiger-killing had a negative impact and was ranked last (Table 6).

Based on cost-effectiveness, killing problem tigers and tiger collaring were the most cost effective solution for reducing human deaths, and dredging water channels and freshwater ponds were the worst solutions. For reducing tiger deaths, natural material fencing and tiger response teams were the most cost effective solutions, and the worst solution was killing tigers (Table 7).

Consideration of the combined impact ranking scores, without weighting objectives for tiger and human death reduction, indicated that tiger collaring and tiger response teams were the best options, while doing nothing was the worst option (Table 8). The combined cost-effectiveness ranking, without weighting objectives, suggested that tiger collaring and tiger response teams were the best activities, while dredging water channels and freshwater ponds were the worst (Table 8).

Identifying research needs

The lack of data in the causality profile indicates the need for further research into causality to develop more preventative solutions. Further research is needed on the socio-economic forces that cause people to enter the forest to harvest resources. Research to understand the behavioral and ecological mechanisms that pre-dispose tiger to killing humans, may also help future development of more preventative activities.

The use of masks merit further research as they are relatively low cost and there is reason to suppose that they may reduce human-killing. Using electric dummies, freshwater ponds, dredging, and electric fencing do not merit further research as they are too costly, or there is little plausible explanation as to how they would impact human-killing.

DISCUSSION

Dealing with human-tiger conflict

Construction activities tended to rank consistently low because they were high cost but low impact. Education and deterrent activities were of medium rank, because even if they had low relative cost, their impact was low or difficult to assess in relation to the objectives. The highest ranked activities were either tiger management or life-saver options, because they either dealt directly with the problem animal or reduced the loss of lives from attacks. These results are not necessarily applicable to human-tiger conflict as a whole, but it makes sense that over a medium-term timeframe (< 10 years), dealing directly with the conflict rather than the causality may be a better general strategy. However, this may not be the case if a longer timeframe is considered.

Tiger collaring and tiger response teams were the best overall activities in terms of both impact and cost effectiveness. Tigers can only be identified for collaring after they have killed two people, so this method will not lead to the total eradication of the conflict; even at its full potential, at least six people would be killed a year. However, this approach has the potential to reduce the number of human deaths by 20/year and tiger deaths by three a year. This would result in 80 humans and zero tigers being killed overall, but this is in contrast to the 240 humans and 24 tigers lost over eight years by choosing to do nothing. Importantly, future evaluation of activities must take into account that activities may appear to fail with improved efficiency of data collection, wherein the number of deaths is recorded more accurately.

At the time of writing, two tiger response teams had already been created. One team based in the west, deals with the high level of tiger attacks in this area. The second team, based in the east, manages both the medium-level of tiger attacks in the south-east and the persistent problem of tigers straying into villages in the north-east. These teams are also conducting medical training for other guard posts and providing basic first aid kits to improve the survival rate of tiger attack victims. General medical and safety training for Forest Department staff has also begun, and an immobilization training programme is being developed.

This approach to managing human-tiger conflict will have further application to the Indian side of the Sundarbans, and many other sites where human-tiger conflict imperils the survival of the species.

Framework application

Decision makers are usually forced to make choices about how to mitigate human-carnivore conflict in the context of scarce funding, fast declining species and habitats, lack of information, and uncertainty of success. This framework is designed to support decision-making by providing a structured approach to activity selection. It also enables managers to explicitly state the reasoning behind their choices.

The underlying structure of the framework does not preclude flexibility. For example, there are other techniques available for ranking activities that might be more appropriate for a different scenario (Cullen et al. 2001; Engeman et al. 2002; McCarthy and Possingham 2008). Weighting of objectives may become useful, only if win-win activities cannot be identified without it. Weighting is itself socially mediated process relying on value trade-offs, which may not be suitable for deciding between the importance of human and endangered carnivore life (Keeney 1977; Mace et al. 2006).

In many cases of human-carnivore conflict, the majority of available information will relate to the conflict itself rather than its underlying causes. This can lead management to a reactive instead of a (potentially more beneficial) preventative approach. The impact of reactive activities maybe more immediate and easier to predict, but if understanding of causality can be improved, then more long-term sustainable solutions may be identified. In any case, because human-carnivore conflict involves the loss of human or carnivore life, it is imperative to start proactive management as soon as possible.

TABLES

Table 1. Human-killing profile.

Category	Conflict	Conflict information source	Causality	Causality information source
Scale	30 human death/year, 8 active human-killers/year, , 50% of human killers take only 1 victim	FD records (1984-2006)	Maybe driven in part by unsafe human behaviour	Field observation
Spatial characteristics	27 human deaths/year in forest, 3 human deaths/year in village	FD records (1984-2006)	Unsafe behaviour concentrated in west	Field observation, FD records (1984-2006)
Temporal characteristics	High human deaths in Dec, Jan and Apr. Low in Jun, Jul, and Aug.	FD records (1984-2006)	Human activity peaks in Dec, Jan. Unsafe behaviour peaks in Apr.	Field observation, FD records (1984-2006)
Social characteristics	Fishermen, woodcutters and honey gatherers most at risk	FD records (1984-2006)	Honey collectors most at risk due to behaviour	Field observation, FD records (1984-2006)

Table 2. Tiger-killing profile.

Category	Conflict	Conflict information source	Causality	Causality information source
Scale	3 tigers killed a year	FD records (1984-2006)	Multiple tigers straying into villages	Field observation, FD records (1984-2006)
Spatial characteristics	2-3 in village areas, 0-1 inside forest	FD records (1984-2006)	Tiger straying mainly in north-east	Field observation, FD records (1984-2006)
Temporal characteristics	No temporal pattern	FD records (1984-2006)	No temporal pattern	FD records (1984-2006)
Social characteristics	Tigers killed by local villagers	FD records (1984-2006)	Retribution killings, or fear of future human loss	Field observation, FD records (1984-2006)

<u>Table 3. List of potential activities.</u>

Activity	Category	Idea source
Do nothing	-	-
Fencing - electric	Construction	Previous activity
Fencing natural	Construction	Local knowledge
Fencing - nylon	Construction	Local knowledge
Freshwater ponds	Construction	Previous activity
Dredging water channels	Construction	Previous activity
Electrified dummies	Deterrent	Local knowledge
Firecrackers	Deterrent	Local knowledge
Masks	Deterrent	Previous activity
Education program - forest users	Education	Field work
Education program - villages	Education	Field work
Tiger response teams	Life saver	Field work
Fiberglass headgear	Life saver	Previous activity
Tiger collaring	Tiger management	Used elsewhere
Killing problem tigers	Tiger management	Previous activity
Tiger translocation	Tiger management	Previous activity

Table 4. Activity impact assumptions and information sources.

Activity	Impact Assumptions	Impact information
Tiger collaring	Tigers collared after 2 victims	Chapter 6
Killing problem tigers	Tigers killed after two victims	Pilot field work
Tiger translocation	Tigers translocated after two victims	Chapter 6
Tiger response teams	Five lives saved by medical treatment, three by patrolling	Pilot field work
Fiberglass headgear	Protection from some attacks	Expert opinion
Education program - forest users	Forest users work more safely in the jungle	Pilot field work
Firecrackers	To scare away a tiger in an area	Local knowledge
Education program - villages	Villagers decrease attacks on stray tigers	Expert opinion
Fencing - electric	Effects village-forest interface	JJS 2003, Rishi 1993
Fencing-natural	Effects village-forest interface	JJS 2003
Fencing - nylon	Effects village-forest interface	JJS 2003
Electrified dummies	Unlikely to effect human-killing	Chaudhuri 1985; Mukherjee 2003
Masks	Tigers dissuaded from attacks	Expert opinion
Do nothing	Maximum human (30) and tiger (3) deaths	Forest Department records (1984-2006)-
Freshwater ponds	No link between human-killing and salinity	JJS 2003
Dredging water channels	Tigers are capable swimmers	Garga 1947; Hendrichs 1975

Table 5. Cost assumptions and information sources.

Activity	Cost Assumptions	Cost information
Killing problem tigers	$20,000 RC	Previous field costs
Tiger collaring	$20,000 RC, $14,000 E, $2,000 T	Previous field costs
Fiberglass headgear	$5 E x 10,000 forest users, 10% R	Local material costs
Tiger response teams	$20,000 RC	Previous field costs
Tiger translocation	$20,000 RC, $14,000 E, $2,000 T	Previous field costs
Education program - forest users	$23,000 RC	Local material and manpower cost
Firecrackers	$3 E x 10,000 forest users, 40% R	Market price
Fencing natural	$300/km x 45 km SU, 50 % M	Local material and manpower cost
Education program - villages	$23,000 RC	Local material and manpower cost
Fencing - nylon	$500/km x 45 km SU, 30 % M	Local material and manpower cost
Fencing - electric	$8000/km x 45 km SU, 20 % M	Equipment description (Rishi 1983)
Electrified dummies	$800 E, $20,000 RC	Equipment description (Chaudhuri 1985)
Masks	$2 E x 10,000 forest users, 10% R	Rishi 1988; Saha 1988; Sanyal 1995; Mukherjee 2003
Do nothing	-	-
Dredging water channels	$3,500/km x 30 km SU, 10% M	Previous dredging costs
Freshwater ponds	$1,000/pond x 30 SU, 5% M	Local material and manpower cost

Notes: RC = running costs, E = equipment, R = replacement, T = training, M = maintenance, and SU = start up costs. U = unknown impact.

Table 6. Estimated impact of activities.

Activity	First year of impact	Humans saved: Impact/ year	Humans saved: Impact over eight years (B1)	Humans saved: Impact rank	Tigers saved: Impact/ year	Tigers saved: Impact over eight years (B2)	Tigers saved: Impact rank
Tiger collaring	1	20	160	1	3	24	1
Killing problem tigers	1	15	120	2	-3	-24	15
Tiger translocation	1	10	80	3	1	8	3
Tiger response teams	1	8	64	4	2	16	2
Fiberglass headgear	1	5	40	5	0	0	8
Education program - forest users	1	5	40	5	0	0	8
Firecrackers	1	3	24	7	0	0	8
Education program - villages	1	2	16	8	1	8	4
Fencing - electric	2	2	14	9	1	7	5
Fencing-natural	2	1	7	10	1	7	5
Fencing - nylon	2	1	7	10	1	7	5
Electrified dummies	1	U	0	12	0	0	8
Masks	1	U	0	12	0	0	8
Do nothing	1	0	0	14	0	0	8
Freshwater ponds	2	0	0	15	0	0	8
Dredging water channels	2	0	0	15	0	0	8

Note: Impact is measured in number of human or tiger lives saved.

Table 7. Estimated cost-effectiveness of activities.

Activity	Set up costs	Running cost/year	Cost over eight years (C)	Humans saved ROI (B1/(C/1000))	Humans saved ROI rank	Tigers saved ROI (B2/(C/1000))	Tigers saved ROI Rank
Killing problem tigers	£20,000	£20,000	£160,000	7.50	**1**	-1.50	**16**
Tiger collaring	£36,000	£36,000	£288,000	5.56	**2**	0.83	**3**
Fiberglass headgear	£50,000	£5,000	£85,000	4.71	**3**	0.00	**9**
Tiger response teams	£20,000	£20,000	£160,000	4.00	**4**	1.00	**2**
Tiger translocation	£36,000	£36,000	£288,000	2.78	**5**	0.28	**6**
Education program - forest users	£23,000	£23,000	£184,000	2.17	**6**	0.00	**9**
Firecrackers	£30,000	£12,000	£114,000	2.11	**7**	0.00	**9**
Fencing natural	£13,500	£4,050	£41,850	1.67	**8**	1.67	**1**
Education program - villages	£23,000	£23,000	£184,000	0.87	**9**	0.43	**5**
Fencing - nylon	£22,500	£11,250	£101,250	0.69	**10**	0.69	**4**
Fencing - electric	£360,000	£36,000	£612,000	0.23	**11**	0.11	**7**
Electrified dummies	£20,800	£20,800	£166,400	U	**12**	0.00	**9**
Masks	£20,000	£2,000	£34,000	U	**12**	0.00	**9**
Do nothing	£0	£0	£0	0	**14**	0	**8**
Dredging water channels	£105,000	£10,500	£178,500	0.00	**15**	0.00	**9**
Freshwater ponds	£30,000	£1,500	£40,500	0.00	**15**	0.00	**9**

Note: ROI is Return on investment.

Table 8. Activities ranked by combined impact and return of investment ranks.

Activity	Combined impact rank	Combined ROI rank	Humans killed	Tigers killed	Leverage
Tiger collaring	**1**	**1**	80	0	Improved understanding of human-killing, increased sense of stewardship in local communities
Tiger response teams	**2**	**2**	176	8	Act as training unit for Forest Department staff and villagers
Tiger translocation	**2**	**4**	160	16	
Education program - villages	**4**	**6**	224	16	Improved general knowledge about tiger conservation in local communities
Education program - forest users	**5**	**9**	200	24	Improved general knowledge about tiger conservation in local communities
Fencing - electric	**5**	**12**	226	17	Reduction in illegal grazing
Fiberglass headgear	**5**	**4**	200	24	
Firecrackers	**7**	**10**	216	24	
Fencing - nylon	**9**	**6**	233	17	Reduction in illegal grazing
Fencing natural	**9**	**3**	233	17	Reduction in illegal grazing
Killing problem tigers	**11**	**11**	120	48	
Electrified dummies	**12**	**13**	240	24	
Masks	**12**	**13**	240	24	
Dredging water channels	**14**	**15**	240	24	Improved waterways for boat transport
Freshwater ponds	**14**	**15**	240	24	Fresh water source for Forest department guard posts
Do nothing	**16**	**8**	240	24	

Note: ROI is Return on investment. Impact is measured in number of human or tiger lives saved.

FIGURES

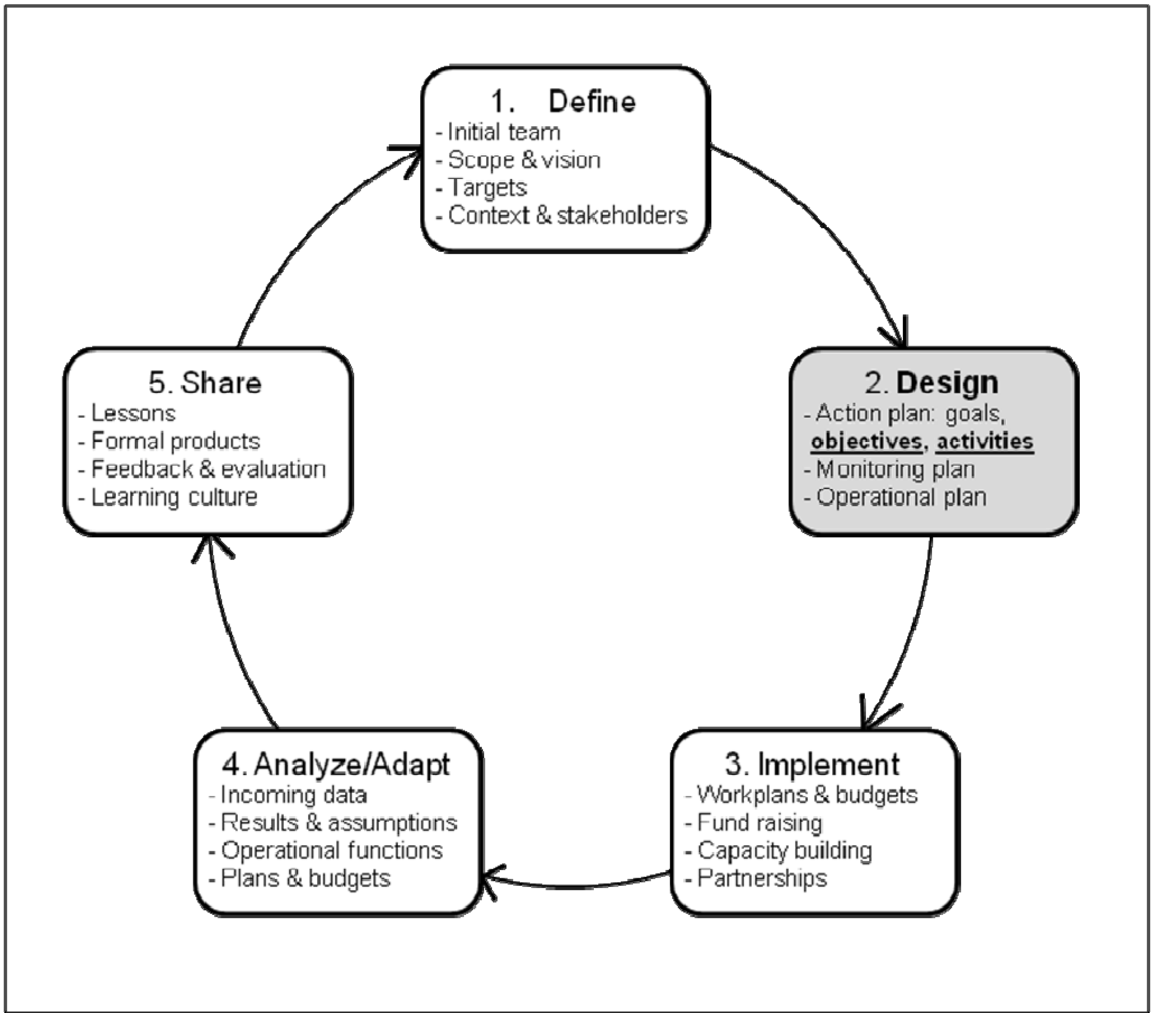

Figure 1. Conservation project/program cycle (World Wildlife Fund 2007).

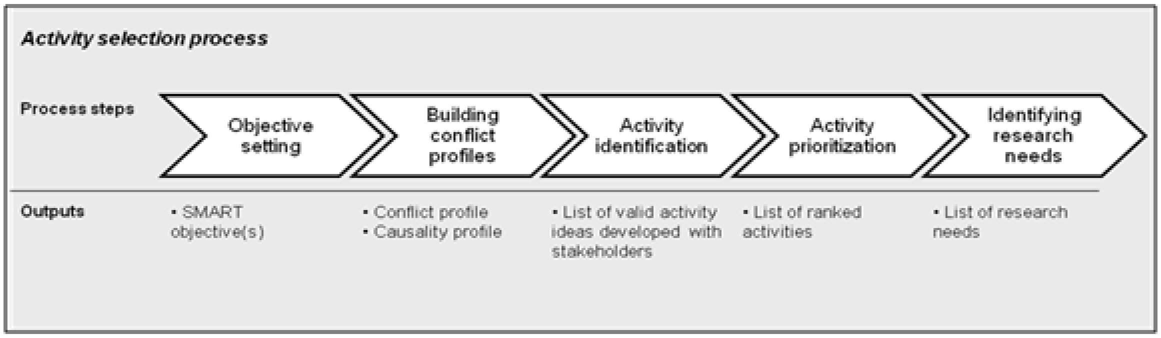

Figure 2. Framework for selecting activities to mitigate human-carnivore conflict.

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