Human Dynamics and its effect on sustainability of the Bengal tiger (*Panthera tigris*) population: Evidence from the Bangladesh Sundarbans

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Abstract

This paper studies the dynamics of the Bengal tiger population in the Sundarbans Reserve Forest (SRF) in Bangladesh. It starts with a review of the existing literature on SRF, and more specifically on the tiger population and the dynamics affecting the sustainability of the species. Making extensive use of secondary data, a computer-based simulation model is developed using system dynamics (SD) and used to simulate the tiger population from 2009 to 2020. The results will enable practitioners to obtain a holistic perspective on the dynamics involved and will benefit policy-makers studying trends in order to identify the policy levers for ensuring continuity of the species.

Keywords: *Panthera tigris*; *Axis axis*; Sustainability; Sundarbans; Bangladesh; System dynamics

1. Introduction

Contemporary articles have identified the dynamics and the conflicts associated with wildlife and people in preserving the biodiversity of the protected areas on the Indian subcontinent (Bhattarai and Kindlmann, 2013; Rastogi et al., 2012). There have been several studies relating to human disturbance and decline in the tiger population around the region (Bhattarai and Kindlmann, 2013; Rastogi et al., 2012; Arjunan et al., 2006; Mohsanin et al., 2013). Of all the tiger reserves on the subcontinent, the Sundarbans garners a lot of attention, as it is one of the largest remaining areas of mangrove in the world and because of the presence of an exceptional level of biodiversity in both the terrestrial and marine environments of this UNESCO world heritage site[1].

According to Seidensticker and Hai (1983), "In the Sundarbans, tigers, deer, forest, and men are linked inseparably and so must be their management. Any attempt to separate the tiger from its prey, the deer from the forest, or people from their needs will surely fail." (p. 9). This approach forms the core of this article, which studies the effect of the complex dynamic interactions of three ecosystems: the tiger (*Panthera tigris tigris*) (Linnaeus, 1758), the spotted deer, also known as the chital (*Axis axis*), and the human inhabitants around the Sundarbans Reserve Forest (SRF). It starts with an introduction to the Sundarbans delta in Bangladesh and the interaction dynamics of the abovementioned ecosystems. An extensive literature survey is carried out, and relevant secondary data are collected. Computer-based modeling and simulation using SD methodology is performed for the period 2009–2020, and the trends of the tiger and prey populations are studied. The results are further discussed, identifying the points of leverage that can ensure the sustainability of the species. The novelty of this study lies in its integration of the different ecosystems by using a computer-based simulation method to study and analyze the underlying dynamics of the system.

The Bengal tiger was once found in all the forests of Bangladesh and even in some village groves (Mitra, 1957). The government used to treat them as pests (Prater, 1940) and pay rewards for killing them. Over time, numbers have dwindled rapidly, and now the tiger is categorized as endangered globally (IUCN, 2003) and as critically endangered nationally (IUCN-Bangladesh, 2000). The decline can be attributed to several causes;

[1] https://whc.unesco.org/en/list/798

however, the most prominent of these are depletion of prey (Smith et al., 1987; Karanth et al., 2004; Khan, 2004) and increased human intervention in the SRF (Khan, 2004).

Researchers have studied the three dimensions of the ecosystem in silos (Curtis, 1933; Biswas et al., 2008; Canonizado and Hossain, 1998; Iftekhar and Islam, 2004; Iftekhar and Saenger, 2008; Chundawat et al., 2001; Khan, 2004). However, there has been no study that provides deeper insight by taking a holistic view of the interactions of the three ecosystems. We therefore make an incremental contribution by studying the problem from a systems perspective. The system dynamics (SD) methodology (Sterman, 2000) will be used in this study to examine how the interactions between the ecosystems affect the tiger population. The SD model makes use of the secondary data available in the literature. It is simulated for the period 2009–2020 to project trends in the tiger population.

2. Literature review

Tigers are often considered as a symbol of the healthy ecosystems upon which biodiversity and mankind depend. As tigers need large areas of land to live, saving them entails securing the future of biodiversity and regulating the distribution of the flora and fauna in a region (Ale and Whelan 2008; Wegge et al., 2009). Karanth (2001) aptly summarized the nature of human dependency on tigers:

> Wild tigers are the warning lamps that indicate how healthy natural landscapes continue to remain in the face of our onslaught; their survival is as useful to us as the oil-pressure lamp on the dashboard of a car or the battery live indicator on a laptop computer. (p. iii, in Islam, 2008).

The Bengal tiger (*Panthera tigris tigris*) is the national animal of both Bangladesh and India. It has been an intimate part of the history and culture of both countries (Karanth, 2001). The Bengal tiger is a subspecies found mainly in the tropical forests of

India, Bangladesh, Nepal, and Bhutan. It is the most numerous of all the subspecies, with more than 2,500 individuals remaining[2].

The Sundarbans, a mangrove habitat that borders the two countries of India and Bangladesh, is well known for harboring one of the two biggest unfragmented tiger populations in the world (WWF, 1999; Khan, 2002). It covers about 10,000 km² of southwest Bangladesh (where it is known as the SRF) and West Bengal in India (where it is known as the Sundarbans National Park). The SRF covers an area of 6,017 km² and accounts for 4.07% of the total area of Bangladesh (BBS, 2014).

The SRF is surrounded by eight upazilas or administrative divisions (Fig. 1). The human population has been growing steadily at a rate of 1.1% since 2009 from about 1.7 million[3]. Most people in these upazilas are directly or indirectly dependent on the SRF for their livelihoods (Islam, 2008). Tigers are sensitive to disturbance by human activity, and large areas of habitat need to be protected for their conservation (Rastogi et al., 2012). Several articles have noted that the proximity of the villages around the reserves has created anthropogenic disturbances, leading to a decline in the tiger population (Bhattarai and Kindlmann, 2013; Rastogi et al., 2012; Arjunan et al., 2006).

Iftekhar and Islam (2004) identified extraction of resources by the inhabitants as the primary reason for the degradation of the Sundarbans tiger habitat. Other significant conditions include “top dying” in Sundri trees (Canonizado and Hossain, 1998; Iftekhar and Islam, 2004), invasive species (Biswas et al., 2008), river pollution from various sources including industry, shipping, tourism, urbanization, agricultural activity, and aquaculture (Hussain and Acharya, 1994), rising sea levels (Agrawala et al., 2003),

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[2] www.panda.org/downloads/species/tigeraccount01.doc

[3] http://www.bbs.gov.bd/PageWebMenuContent.aspx?MenuKey=141

tropical cyclones (Islam and Peterson, 2008), freshwater inflow due to climatic clauses (Agrawala et al., 2003; MoEF, 2008), and embankment and diversion of water for irrigation purposes within Bangladesh (Iftekhar and Islam, 2004).

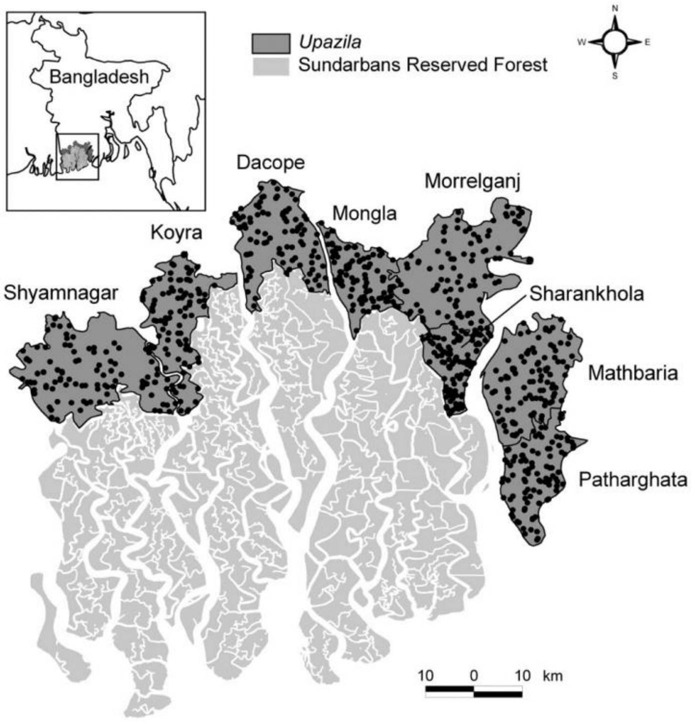

Fig. 1. Map of the Sundarbans Delta (Source: Mohsanin et al., 2013).

The combined impact of these causes is ecological imbalance, not least in vegetation patterns (Agrawala et al., 2003), which affects the distribution of tigers and prey.

In all its habitat ranges across the globe, the tiger is associated with large mammalian herbivorous prey species. These include wild buffalo (*Bubalus bubalis*), gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), swamp deer (*Cervus duvaucelii*), sambar (*Rusa unicolor*), barking deer (*Muntiacus muntjak*), spotted deer (*Axis axis*), and wild boar (*Sus scrofa*) (Schaller, 1967; Johnsingh, 1983, 1992; Sunquist, 1981; Karanth, 1995) and occasionally other carnivores such as leopards (*Panthera pardus*), sloth bears (*Melursus ursinus*), civet cats, and small vertebrate species including frogs (Schaller, 1967). The tiger is reported to have failed to survive in areas where these key prey species have been exterminated (Seidensticker et al., 1999).

Mukherjee and Sarkar (2013) reconstructed the tiger diet through scat analysis and found that spotted deer (70% of the prey biomass) and wild boar (23% of the prey biomass) constituted over 90% of tiger prey in the SRF. Further, Mohsanin et al. (2013) studied the human consumption pattern of spotted deer around the eight upazilas surrounding the SRF. Hence, in the current research, we restrict the focus of the present study to the population of the spotted deer, for two reasons:

(a) wild boar is a prey item of lesser importance for the tigers in the SRF (Reza et al., 2002);

(b) wild boar consumption by local people is largely excluded by the predominance of the Islamic faith in Bangladesh (Mohsanin et al., 2013).

Since the independence of Bangladesh in 1971, several studies have been carried out to estimate its population of tigers (Table 1). Several studies have reported a declining trend between 2004 and 2015 in the number of tigers in the SRF. However, the latest Bangladesh–India Joint Tiger Census Project revealed that the numbers reduced drastically, from about 440 to a mere 106 during this period [4],[5]. Hence, our research question is based on the studies of Mohsanin et al. (2013), Bhattarai and Kindlmann (2013), and Rastogi et al. (2012): does the increase of human activity around the SRF have a substantial effect on the tiger and prey populations within the SRF?

[4] https://www.dhakatribune.com/bangladesh/environment/2017/07/28/sundarbans-tiger-population-2019/

[5] http://www.bbc.com/news/world-asia-33672602

Table 1

Tiger population trends since Bangladesh independence, 1971.

Year	Population	Source
1971	350	Tilson & Seal (1987)
1979	430–450	Gittins & Akonda (1982)
1987	About 350	Tilson & Seal (1987)
1996	300–460	Jackson (1996)
2004	440–500	World Bank (2011)
2015	106	Bangladesh–India Joint Tiger Census Project (2015)[6]

3. Methodology

This research uses SD (Sterman, 2000) to perform a simulation. Stock and flow diagrams are developed using the Vensim® application by Ventana Systems. The data used to define the dynamic interactions of the variables emerge from the contemporary literature. Where relevant data is unavailable, assumptions are made on the basis of consultation with domain experts. The entire model is divided into four submodules: the tiger population submodule, the spotted deer population submodule, the interaction submodule, and the human settlement submodule.

3.1 The tiger population submodule

The total tiger population in the Sundarbans is categorized into tiger cubs, young adult tigers, and old tigers. (Fig. 2 provides a stock and flow diagram for the tiger population.) The simulation assumes the initial value of 440 tigers, which was recorded in 2004 (World Bank, 2011). As there were no data on the demographic distribution of the population, the following assumptions were made based on consultation with experts:

[6] https://www.dhakatribune.com/uncategorized/2015/07/27/census-only-106-tigers-in-sundarbans

150 cubs (34% of the total population), 220 young adults (50%), and 70 old tigers (16%). The gender ratio in the SRF was 2.18 females to 1 male (Aziz et al., 2017; Barlow, 2009).

Tigers mate year-round but most frequently from the end of November to early April (Mazak, 1981). The mean litter size is 3.0 (Smith and McDougal, 1991), but observations of females with cubs indicate that the most common size is 2–3 cubs (Sankhala, 1978). However, in the SRF, Khan (2004) reported a mean litter size of 1.4 (range = 1–3, n = 56, SD = 0.6). This value is used in the simulation.

Tigresses normally give birth to a new litter once every two years (Smith and McDougal, 1991). The interbirth interval is shorter when the tigress loses cubs or after she has raised a single cub (Smith and McDougal, 1991; Kerley et al., 2003).

Smith and McDougal (1991) found first-year cub mortality to be 34% (n = 144 cubs), of which 73% was accounted for by whole-litter loss due to causes such as infanticide, fire, and flood. As the environment in the SRF is relatively harsh, for our simulation we assume a mortality rate of 50%.

The male becomes sexually mature at three to four years of age, whereas the female becomes sexually mature at about three years (Sankhala, 1967; Smith, 1984; Smith and McDougal, 1991; Christie and Walter, 2000; Sunquist and Sunquist, 2002; Kerley et al., 2003). Hence, in this simulation we took 3.5 years as the average age for attaining sexual maturity.

Although captive tigers have lived for up to 26 years (Jones, 1977), in the wild it is assumed that the Bengal tiger lives for an average of eight to 10 years[7]. Hence, we used the value of 10 years in the simulation. This relatively short life span can be attributed to a variety of factors, including territorial fights after dispersion from the mother at a young

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[7] https://www.nationalgeographic.com/animals/mammals/b/bengal-tiger/

age (Smith, 1984, 1993) and poaching (Martin and De Meulenaer, 1988; Kenny et al., 1995).

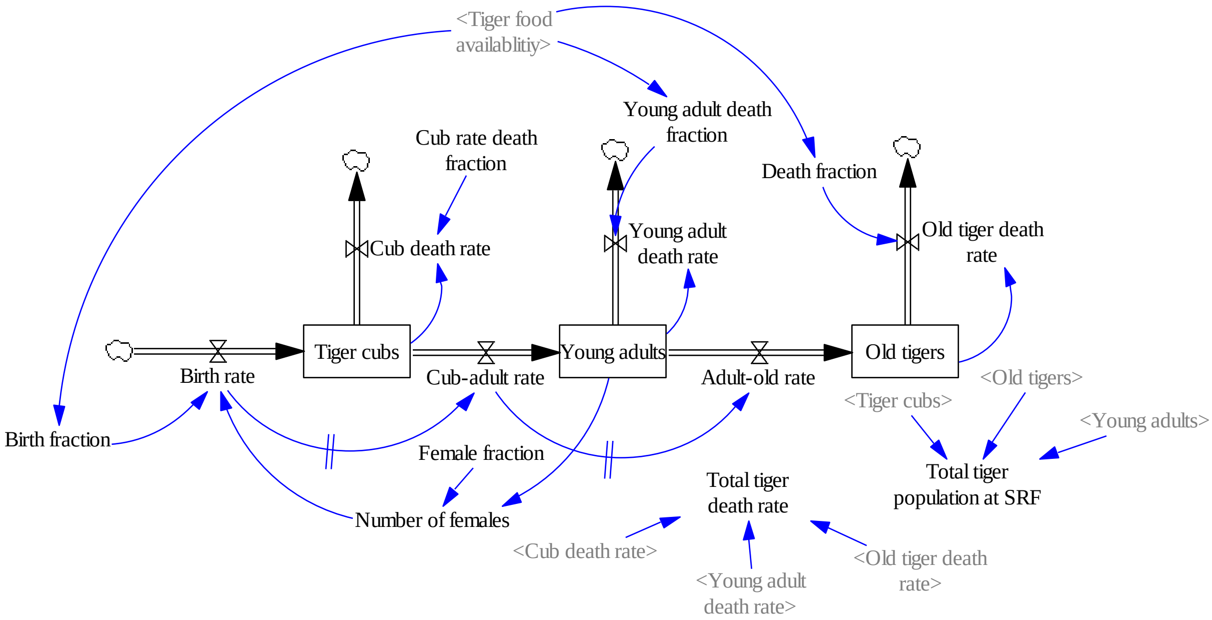

Fig. 2. Tiger population stock and flow.

3.2 The spotted deer population submodule

Spotted deer or chital (*Axis axis*) form approximately 70% of tiger prey consumption (Reza et al., 2001). The population of spotted deer has reduced drastically, with an average extinction rate of 45% over the last 50 years (Karanth et al., 2010). In addition to their role as prey, these animals are hunted by humans for food, sport, and other purposes. (Fig. 3 provides a stock and flow diagram for the spotted deer population.)

Deer breed throughout the year (Sankar and Acharya, 2004). A high fawn mortality rate (up to 48%) during the early weeks has been reported (Schaller, 1967). Chitals are considered prolific breeders; the major threats to the population are predation, diseases, accidents, and poaching (Sankar and Acharya, 2004). The mating season of females last about three weeks, and the female will give birth to a single fawn approximately 225 days after mating. The average life span of chitals is 22 years in captivity but only five to 10 years in the wild (Geist, 1998; Schaller, 1984).

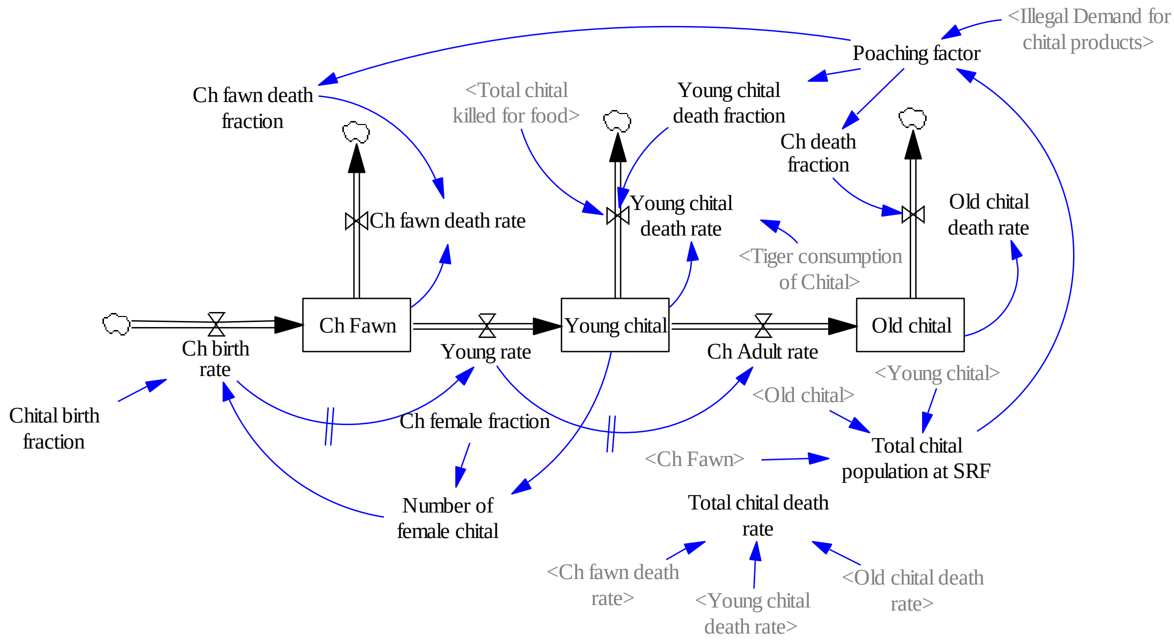

Fig. 3. Spotted deer population stock and flow.

3.3 The interaction submodule

Previous studies have indicated that a decrease in the abundance of prey increases the risk of tiger populations becoming extinct, as it reduces the carrying capacity of breeding female tigers and reduces cub survival (Smith et al., 1987; Karanth and Stith, 1999; Karanth et al., 2004; Linkie et al., 2006; Datta et al., 2008; Harihar et al., 2008). A DPSIR (drivers, pressures, state, impact, and response) analysis of the challenges facing tiger conservation conducted by Rastogi et al. (2012) highlighted the impact of the dependence of local communities on livestock. The same authors also pointed out that ecological models estimate that an average tiger needs about 50 ungulates per year. Hence, they concluded that prey densities are a key determinant of the tiger population and that loss of prey can worsen vulnerability to poaching, thus reducing the tiger population. According to the predator–prey model of Wilensky (2005), there is an inverse relation between the dynamics of predator and prey: as the population of the predator increases, the population of the prey decreases, and vice versa. Hence, it is interesting to study the complex dynamics of the predator and prey in this research. (Fig. 4 provides a causal loop diagram.)

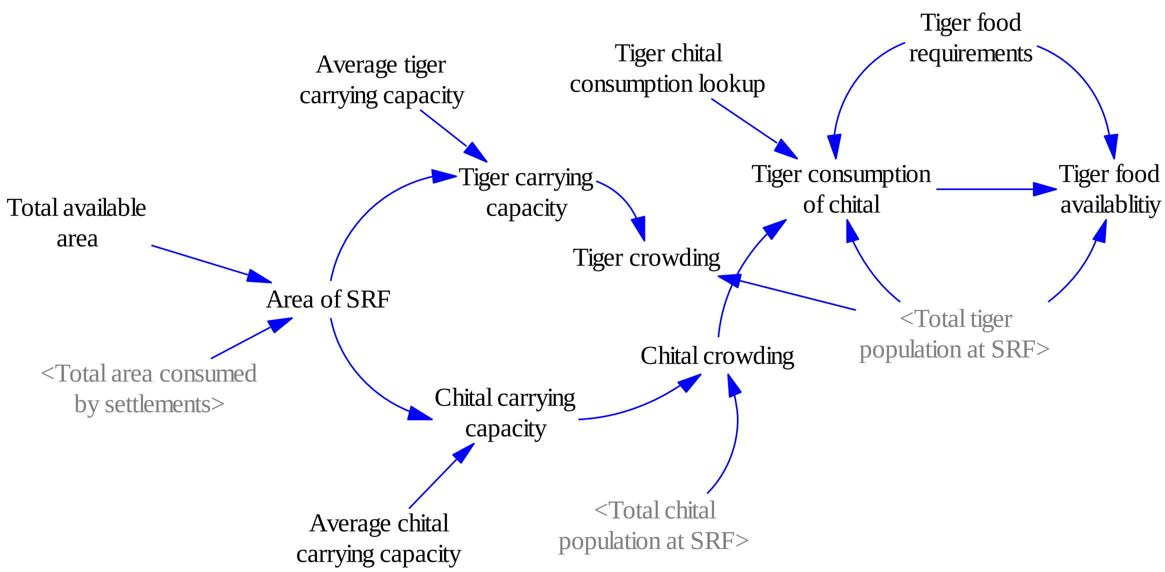

Fig. 4. Interaction dynamics.

3.4 The human settlement submodule

Adjacent to the SRF, there are eight densely populated upazilas (administrative divisions) (Mohsanin et al., 2013). Because of their proximity to the jungle, the deer consumption in these areas is relatively high. (Fig. 5 provides a stock and flow diagram for human settlement.) The area of the upazilas spans up to 8,155 km^2, and it houses around 346,950 households with a population of 1,702,026 people[8].

Studies have been conducted in this area to understand the consumption of deer meat by locals. Mohsanin et al. (2013) reported that around 48.5% of households consume deer meat (mean consumption = 1.13 kg/household/year) and that, given that a deer

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[8] http://www.bbs.gov.bd/PageWebMenuContent.aspx?MenuKey=141

provides 35 kg of consumable meat, the number of deer killed for meat in a year in the SRF is around 11,195.

It has been reported that, although the locals know that deer consumption is illegal, they ignore this restriction. While they mainly consume deer for the taste, a substantial proportion reported killing deer in order to use their antlers and hide (Mohsanin, 2013).

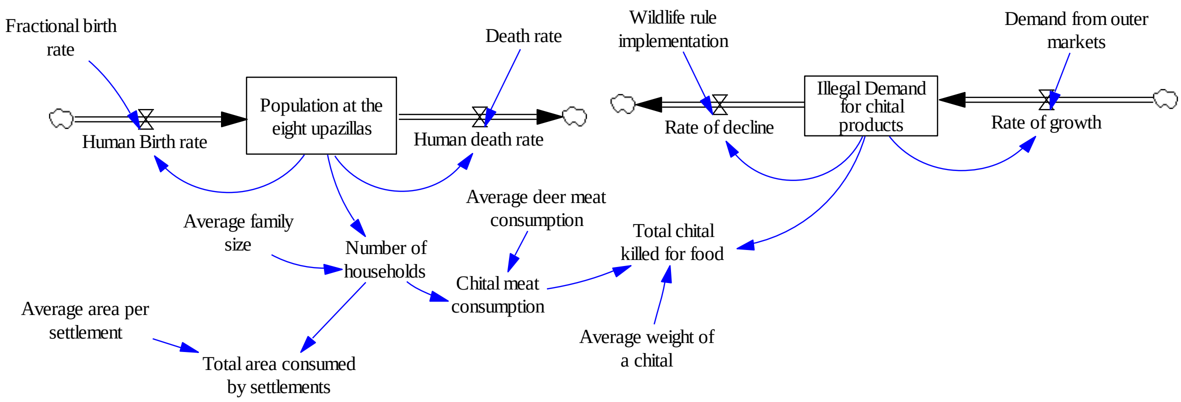

Fig. 5. Human settlement stock and flow.

4. Results

The stock and flow model is simulated for the period 2009–2020. The initial population in the year 2009 is set as 1.7 million, taking the eight upazilas together (Mohsanin et al., 2013). The population has been growing at approximately 1.1% per year, and the human death fraction was assumed to be 20% per year[9]. The population in the region is expected to increase steadily and to reach a figure of 1.82 million by the year 2020 (Fig. 6). In this study, the population of the SRF is the primary exogenous variable that ultimately determines the size of the tiger population.

[9] http://www.bbs.gov.bd/PageWebMenuContent.aspx?MenuKey=141

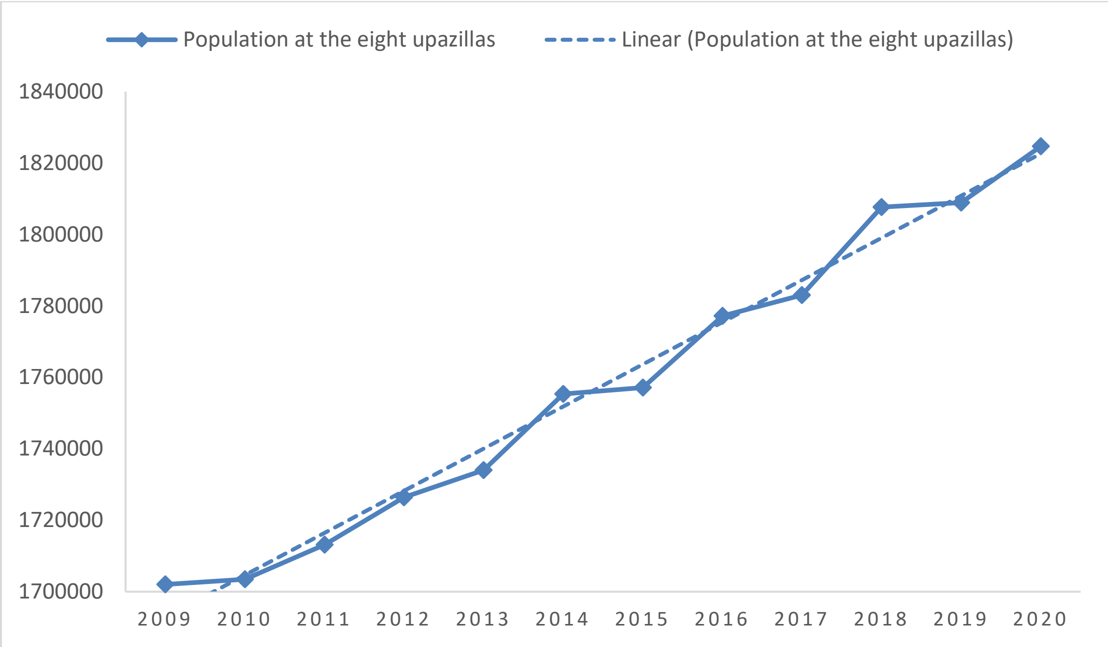

Fig. 6. Human population growth around the SRF.

Fig. 7 indicates the simulation output for the area of SRF during the period 2009–2020. This graph shows a declining trend over a period of ten years. As the population of the region increases, the number of households in the region increases. This generates a requirement for new human settlements to be built to accommodate the growing population and results in human encroachment to the forest area surrounding the eight upazilas. The simulation reveals that the area of the SRF will decline drastically, from around 6,300 km^2 in the year 2009 to 5,700 km^2 by the year 2020.

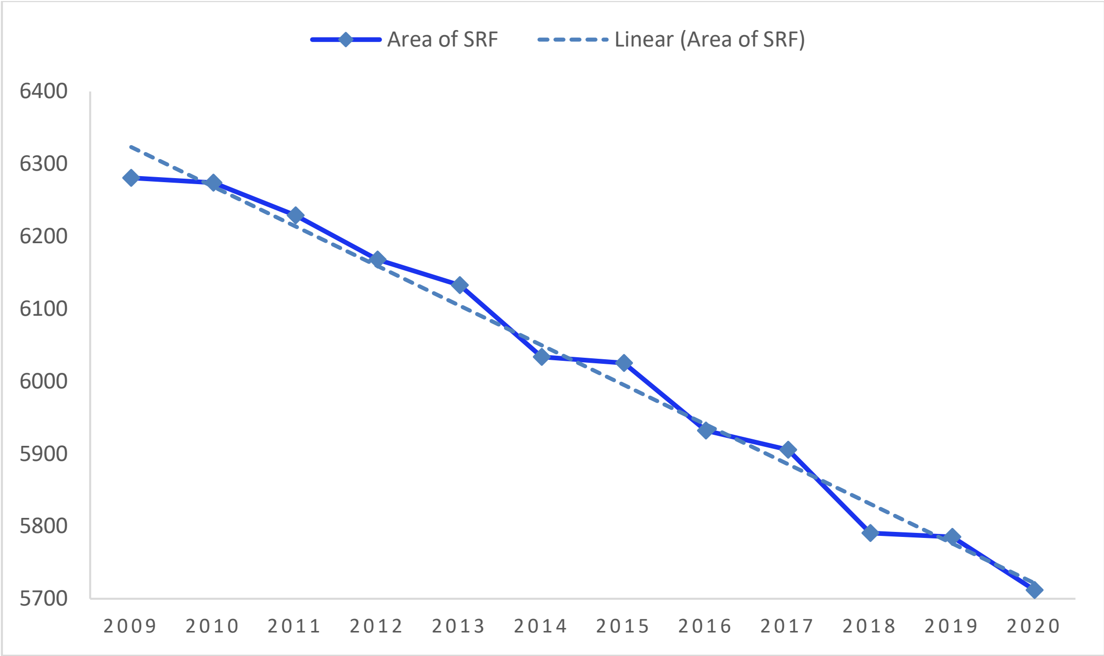

Fig. 7. Area of SRF.

Another effect of the increase in the number of households in the region is rising demand for food. Chitals are a potential target food for people living in this region, primarily because of ease of access. In 2009, the number of chitals killed for food consumption was around 20,000 (Mohsanin et al., 2013), and demand for chital meat is expected to increase with the size of the population. The simulation results indicate that by the year 2020 the number of chitals killed for food by humans will be close to 30,000, a substantial increase of 10,000 (Fig. 8). However, it should be noted that this is just one factor that affects the chital population, and various other factors are discussed in subsequent paragraphs.

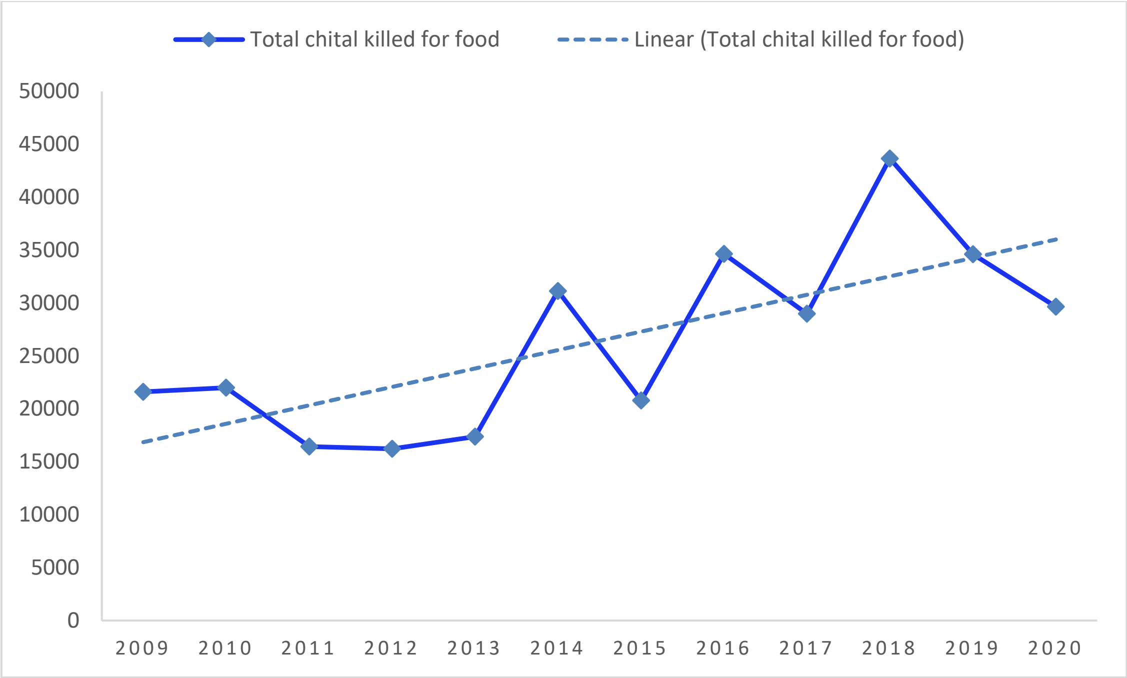

Fig. 8. Chital killings.

Our projection indicates the population dynamics of chital population in SRF over the simulation period 2009–2020 (see Fig. 9). The initial chital population in the region is taken as 220,000 in the year 2009 (Mohsanin et al., 2013). Until 2011, the chital population showed a declining trend. The population of chitals then increased to 400,000 by 2015. However, this trend then reversed, with just 150,000 chitals by 2017. A further spike in population is observed in 2018, but this growth is not sustainable and, by 2020, the figure is 50,000. Over the entire simulation period, there is clearly a declining trend in the chital population. The main reasons for this decline are an increase in chital killing by humans for food and for chital products and preying on chitals by tigers. A further reason for the decline in the number of chitals is a reduction in the area of the SRF, caused by an increase in human settlement.

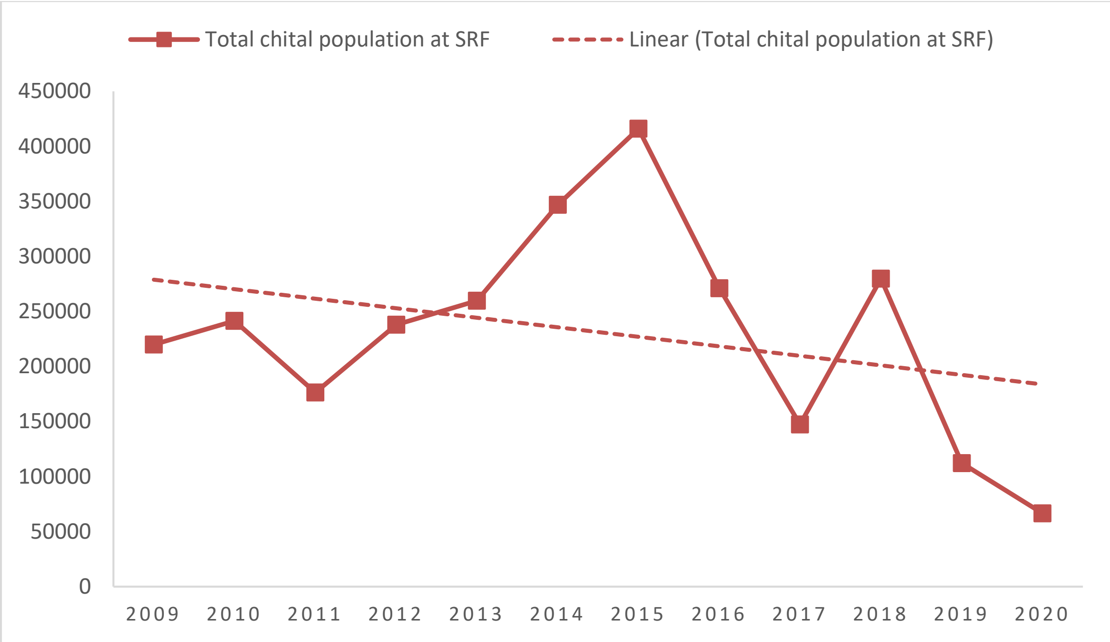

Fig. 9. Chital population.

Chitals being one of the primary prey for tigers, it is important to analyze how the decline in the chital population has affected the overall food availability for tigers.

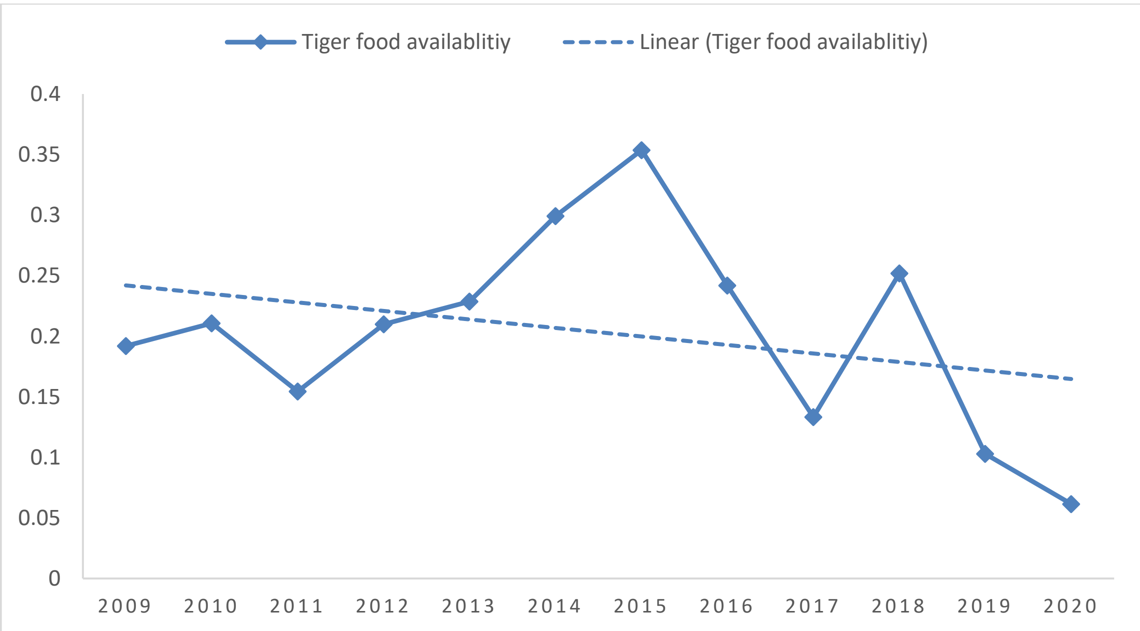

Fig. 10. Tiger food availability.

Food availability follows a similar trend to that of the chital population simulation (compare Figs. 9 and 10), as chitals constitute around 70% of the tiger's diet. If the availability of food was 0.2 in 2009, it reduces to almost 0.1 in 2020. Overall food availability is also affected by the reduction in forest area caused by human encroachment.

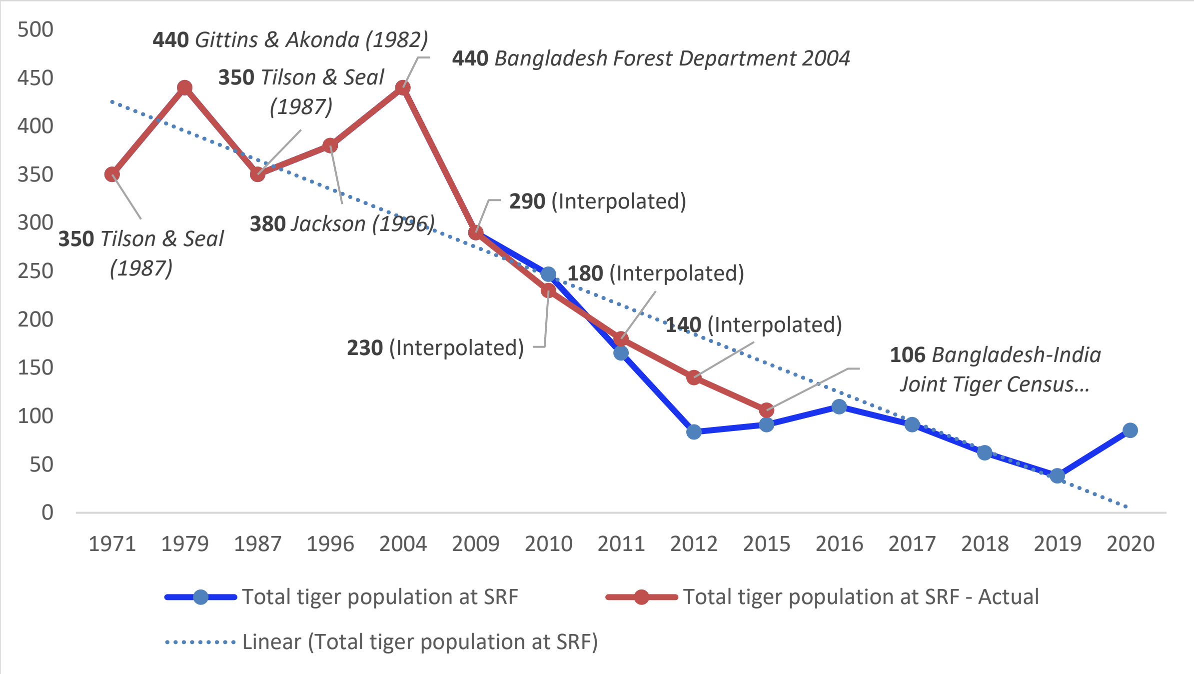

Fig. 11. Tiger population simulation.

The final part of the simulation predicts the tiger population in the coming years, taking into account the interaction of all the dynamic variables, including human population, habitat, and chital population. In Fig. 11, the red line shows the population of tigers in SRF from 1971 to 2015. These numbers are obtained from the literature as indicated. In 1971, the number of tigers in the SRF was close to 350. A study in 2004 gave a figure of 440. The next available secondary data on tiger population in the SRF indicated a reduction to 106 by 2015. Owing to a lack of available published data, we interpolated the tiger population for the four years 2009–2012, obtaining the values 290, 230, 180, and 140, respectively. Hence, overall a declining trend in population is observed from 1971 to 2015. The blue line indicates the running of the simulation, starting in 2009, where the initial tiger population was taken as 290. The simulation from 2009 to 2015 can be seen to closely follow the actual population trend in the SRF over the same period (compare the blue and red lines). This validates the SD model and shows its closeness to reality. This behavior reproduction (Sterman, 2000) is an important test for the validation of an SD model. Our simulation predicts that the tiger population in SRF follows a declining trend. It is expected that by the year 2020 the number of tigers remaining in the reserve will be significantly below 100 (specifically, 85). These figures are alarming and call for prompt action from the authorities.

5. Policy scenarios and conclusions

We simulated three scenarios to identify the policy levers for protecting the tigers of the Sundarbans. Our focus was on how the trends would develop in the coming years if certain actions were taken in 2017.

The first scenario involved enforcement of existing regulations so that human consumption of deer meat would be reduced. We varied the factor from 0.1 to 0.25, based on consultation with academicians. A value of 0.25 was deemed appropriate, as the experts believed that the inaccessibility of the Sundarbans makes it difficult to monitor compliance with the policy. They thought it likely that this situation would lead to continuing consumption of deer meat and would defeat the sole purpose of the policy. The results in Fig. 12 suggest that in this scenario there would be around 91 tigers instead of 85.

The second scenario involved a reduction in the tiger cub mortality rate. In this study, tiger cub mortality is assumed to be 50%. However, under a policy of breeding pairs in safe locations and later returning them to the wild, the mortality rate could be reduced to half of its current value (i.e., to 25%). The simulations demonstrate that, in such a scenario, the total number of tigers in the SRF would be around 101. However, the complexities of implementing this breeding policy are manifold, and the experts believed it to be unfeasible.

The third scenario involved a combination of the earlier scenarios; here the emphasis was not only on regulating the consumption of deer meat but also on reducing tiger cub mortality. This combined scenario produced a stronger effect, with the overall tiger population of the SRF projected to be around 119 by 2020.

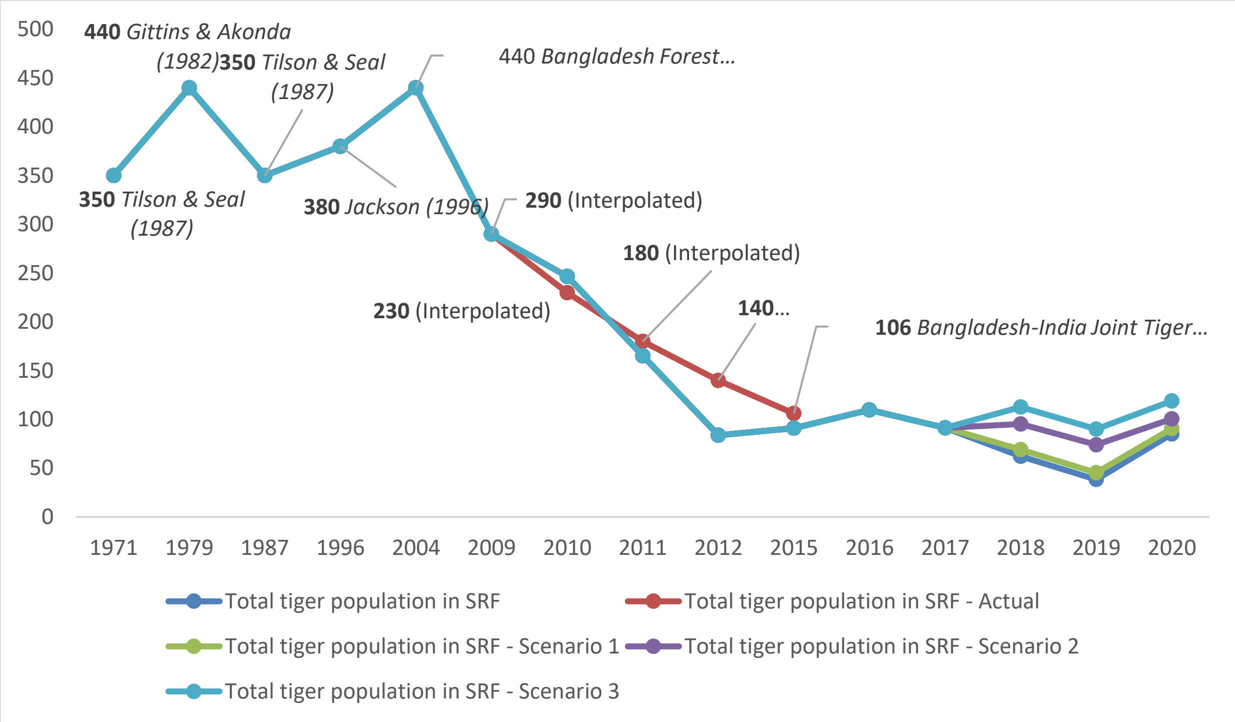

Fig. 12. Simulation of policy scenarios.

Hence, it is important to note that the decline in the tiger population is not impacted solely by human consumption of the deer population. To ensure the survival of the species, adequate emphasis must also be laid on reducing the cub mortality rate. This calls for other strategies that may involve artificial breeding of tigers or their reintroduction into the wild (Rastogi et al., 2012; Gratwicke et al., 2008; Kirkpatrick and Emerton, 2010; Lynam, 2010; Mitra, 2006).

In conclusion, this study adds to the body of knowledge by providing a new method for forecasting the tiger population given certain identified variables. There is considerable scope for future research that identifies the complex dynamic interactions among other variables, thereby enabling the development of a more robust model.

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