Game Theoretic Approach for Tiger Behavioral Pattern Prediction: A Telemetry Data Approach

A Thesis submitted to the

UPES

For the Award of

Doctor of Philosophy

in

Computer Science & Engineering

By

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April 2024

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I certify that the thesis entitled ***"Game Theoretic Approach for Tiger Behavioral Pattern Prediction: A Telemetry Data Approach "*** by **Richa Choudhary (SAP ID: 500064217),** research scholar at UPES, Dehradun, submitted thesis in partial completion of the requirements for the award of the Degree of Doctor of Philosophy in School of Computer Science is an original work carried out by her under my supervision and guidance. It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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ABSTRACT

The tiger reigns supreme as the top predator in the food chain, but its population has dwindled to dangerously low levels over the past few decades, leading to its classification as an endangered species. The primary culprits behind this decline are habitat loss and poaching. However, by analyzing their movement patterns through telemetry data, we can gain valuable insights into their behavior such as home ranges and response to human activities. With advancements in data analysis techniques, we can recognize these patterns more easily and develop conservation strategies that combat poaching and habitat loss. Telemetry data is essential for deciphering tiger movements, which is precisely what our study aimed to do for the Sundarbans region. We analyzed telemetry data from four tigers that provided nearly 4000 GPS locations alongside prey distribution information obtained from the Wildlife Institute of India in Dehradun. This study has investigated the relationship between tiger migration and the distribution of prey and topological features in this region. The community analysis of the tigers that live in the Sundarbans is performed by looking at the distribution of their prey and mapping the vegetation in the area. We have been provided with datasets that comprise information on the distribution of prey, GPS locations of tigers, and vegetation mapping across the Sundarbans region by the Wildlife Institute of India (WII). The results of the research indicate that prey distribution, the kind of vegetation, and the time of day all play a significant role in determining the movements of tigers as a collective community component and suggests that Statistical analysis meticulously quantifies how specific environmental features influence tiger movements within Sundarbans reserve. Next, the model is trained to forecast the immediate next location of the tiger in context of prey distribution of the region using various machine learning algorithms such as Ridge regression, MLP, KNN, Decision tree, SVM we predicted each tiger's next location based on mean prey location before comparing results to determine which algorithm performed best for

this dataset. Machine learning algorithms forecast potential future locations for tigers by utilizing current data on the distribution of their prey. Among these algorithms, the CART Decision Tree algorithm demonstrated superior performance by accurately handling multivariate data across three distinct scenarios or prediction cases. To efficiently decipher these patterns, it is necessary to employ advanced modeling techniques that incorporate principles from game theory and computational frameworks such as finite automata. To forecast tiger movement patterns, a game theory model is constructed employing Stackelberg security games and incorporating geographical characteristics including vegetation density, waterways, and alluvial land. For this, the area is divided into grids in which a predator-prey game is played, this strategy pits players against one another as opposed to encouraging cooperation. The CART Decision algorithm was utilized to compute the payoff matrix for the game theory, as it demonstrated superior performance over the acquired datasets for the previously trained model when predicting the tiger's imminent next location using prey distribution data. Finite automata make a valuable contribution by providing a means to simulate sequential behaviors, such as the gradual progression of a tiger through its environment in response to different stimuli encountered during its journey. By implementing each of these strategies, it is possible to guarantee the majestic felines of the Sundarbans' long-term survival in the face of encroaching human pressures, all the while maintaining ecological balance throughout this fragile biosphere reserve.

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RICHA CHOUDHARY

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ALGORITHMS

LIST OF ABBREVIATIONS

Acronym	Meaning of Abbreviation
BFD	Bengal Forest Department
CART	Classification and Regression Trees
DT	Decision Tree
DNA	Deoxyribonucleic acid
ERDAS	Earth Resource Data Analysis System
FA	Finite Automata
FK	Fixed Kernel
GEE	Generalized Estimating Equations
GPS	Global Positioning System
KNN	K-Nearest Neighbors
LDA	Linear Discriminant Analysis
MCP	Minimum Convex Polygon
ML	Machine Learning
MLP	Multi-Layer perceptron
MPFD	Madhya Pradesh Forest Department
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental Organization
NTCA	National Tiger Conservation Authority
PAWS	Protection Assistant Wildlife Security
QDA	Quadratic Discriminant Analysis
SSG	Stackelberg Security Games
SVM	Support Vector Machine
USGS	United States Geological Survey
VHF	Very High Frequency
WII	Wildlife Institute of India

CHAPTER-1

INTRODUCTION

Tigers are vital apex predators that play a crucial role in maintaining the delicate balance of their ecosystems. Unfortunately, they have been facing numerous threats to their survival for decades, primarily due to human activities such as deforestation, poaching, and illegal trade in tiger parts [1, 2]. Other factors contributing towards the decline of tigers include Human-Tiger conflict leading to retaliatory killing due attacks on livestock or humans by Tigers; Climate change affecting prey availability resulting into starvation among Tigers; Inbreeding depression caused by small, fragmented subpopulations leading towards genetic issues etc. [3, 4]. By occupying an essential position in food chains within their ecosystems as apex predators, tigers play a crucial role in maintaining ecological balance and preserving wildlife diversity. They help keep populations of prey species such as deer, wild boar, and antelopes under control while also acting as indicators for habitat quality since they require large areas with diverse vegetation types to thrive. Protecting tigers ensures that other species dependent on similar habitats are also safeguarded [2, 3]. India is home to approximately 3,000 wild tigers, representing around 70% of the global population, making it a crucial country for tiger conservation [1, 5]. The National Tiger Conservation Authority (NTCA) oversees tiger conservation efforts in India, including monitoring population levels and enforcing wildlife protection laws [1, 2]. The Indian government has launched several initiatives over the years to safeguard tigers and their habitats, such as Project Tiger which began in 1973 [1, 2, 5]. Project Tiger, which creates protected areas known as tiger reserves covering over 50,000 square kilometers across different states in India [2, 4]. Strategies being employed by the NTCA, and other organizations include establishing protected areas for tigers and their prey, involving local communities in conservation efforts, utilizing innovative technologies like camera traps and DNA analysis to monitor populations, implementing non-lethal deterrents along with compensation programs for farmers who suffer losses due to conflict [6]. Anti-poaching measures include increased patrolling within protected areas and intelligence networks established to prevent illegal trade while community-led programs educate people about wildlife protection measures providing alternative livelihoods such as eco-tourism or sustainable agriculture practices that do not harm natural habitats, various studies to understand the ecology of tigers to improve the conservation strategies are incorporated [7]. These collective actions have resulted in an increase in the number of wild tigers living within Indian reserves from less than 1k during mid-2000s up till now when there are more than 2k recorded individuals according to the report [1, 2, 7]. Spread across various states, the country boasts 50 tiger reserves dedicated to conserving and protecting these majestic animals. Aside from their ecological significance, tiger reserves generate significant economic benefits through tourism activities like safari rides and guided tours. Tiger reserves in India support local communities and promote conservation efforts. The establishment of these reserves has led to an increase in tiger populations, with the latest census estimating 2967 tigers across the country compared to only 1411 recorded in 2006 [1, 2, 7]. This increase is attributed to better management practices such as habitat restoration programs, anti-poaching measures, and community participation initiatives. Tiger conservation initiatives include protecting habitats from further degradation, improving law enforcement against poaching, raising awareness about illegal trade, promoting ecotourism and sustainable livelihoods, reducing conflicts between humans and tigers, translocating/reintroducing breeding adults between sub-populations implementing effective monitoring systems using modern technology like camera traps and radio collaring [7,8]. Telemetry data received from radio collars attached to animals provides insights into behavioral patterns that could provide knowledge over biotic & abiotic exchange of species on various behavioral actions [8].

To improve conservation efforts for tigers there is a need to use technological advances across tiger reserves in India. Some of the major tiger reserves in India are [9]:

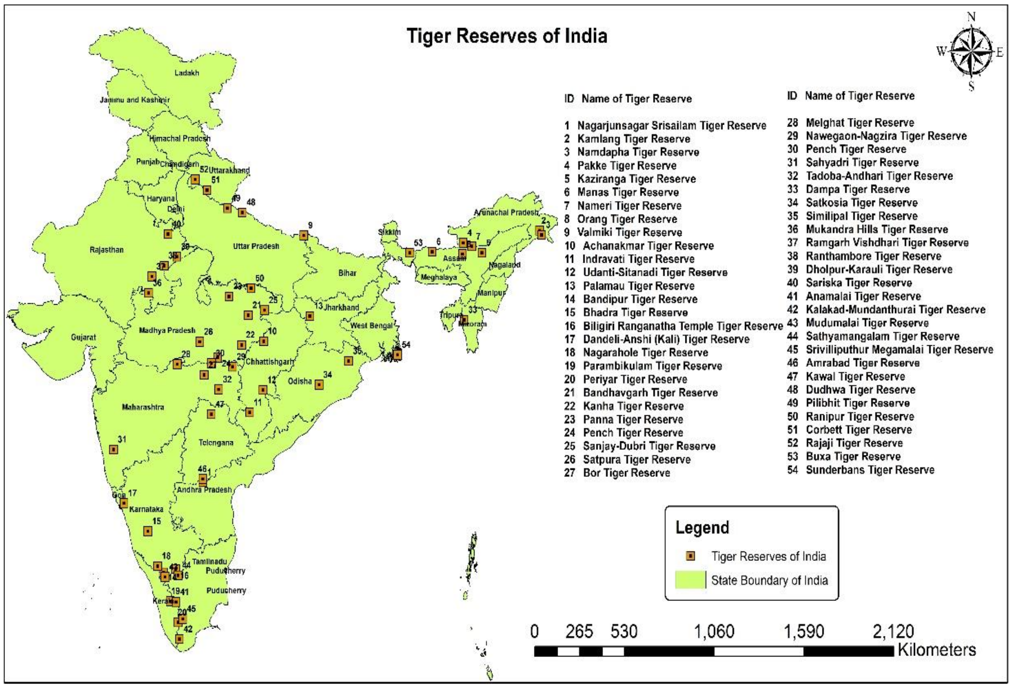


Figure 1.1. Tiger Reserves of India

Bandhavgarh National Park - Located in Madhya Pradesh, it is known for its high density of tigers and is considered one of the best places to spot tigers in the wild.

Kanha National Park - Also located in Madhya Pradesh, it is one of the largest national parks in India and is home to a significant population of Bengal tigers.

Ranthambore National Park - Located in Rajasthan, it is known for its picturesque landscape and is one of the best places to see tigers in their natural habitat.

Sundarbans National Park - Located in West Bengal, it is the largest estuarine mangrove forest in the world and is home to the Royal Bengal Tiger.

Sariska Tiger Reserve - Located in Rajasthan, it was one of the first tiger reserves established in India and is known for its dense forests and hilly terrain.

Periyar Tiger Reserve - Located in Kerala, it is known for its picturesque landscape and is home to a significant population of Bengal tigers.

Tadoba Andhari Tiger Reserve - Located in Maharashtra, it is known for its high density of tigers and is one of the best places to see them in the wild.

The Bandhavgarh, Ranthambore, and Sundarbans National Parks are important for tiger conservation in India due to their high density of tigers [10]. The Sundarbans region is chosen as a study area for the tiger due to its diverse flora and fauna, including the Royal Bengal Tiger. Telemetry is an effective tool for studying wildlife behavior and ecology by using electronic devices such as radio or GPS collars, camera traps, and acoustic monitoring to track animals in their natural habitats [8,11]. This information can be used to design better conservation strategies aimed at protecting fragile ecosystems from human activities that may disrupt them. Through the analysis of tiger movements, we can gain valuable insights into our ecosystem. By studying their habitat selection, group behavior, and population dynamics, among other factors, we can take steps to maintain their habitats and ensure their safety in order to prevent extinction [4]. To collect data on tiger movement patterns, various methods such as camera traps, mark capture-recapture techniques, and telemetry can be employed [6,12]. Tigers are typically solitary animals that reside in core forest areas; therefore, telemetry is a useful tool for collecting movement data. With the development of GPS technology since the 1990s and advancements in remote sensing techniques for acquiring geographical and meteorological data over recent decades, electronic tags have become increasingly popular for recording animal data [11,12,13]. The telemetry data that has been acquired can then be processed using a variety of technical tools, like as game theory and machine learning approaches, in order to categorize animal movements and the behavioral patterns that are associated with them, while also offering insight into environmental characteristics that are linked with these movements [14].

1.1 Motivation

The motivation behind research on tiger conservation is to protect and preserve one of the world's most iconic species from extinction. Tigers are facing numerous threats, including habitat loss, poaching for their body parts, and human-wildlife conflict, which have led to a significant decline in their population over the past century. Research on tiger conservation aims to understand the ecology and behavior of these magnificent animals so that effective strategies can be developed to conserve them [11]. This includes studying their habitat requirements, migration patterns, feeding habits, social behaviors, and reproductive biology as well as identifying key factors contributing to their decline [15]. Through scientific research efforts such as camera trapping studies and genetic analysis techniques researchers have been able to identify important tiger habitats and corridors connecting them across landscapes [16]. Such information has helped guide policy decisions for conserving tigers by identifying priority areas for protection. Another aspect of research on tiger conservation is understanding human-tiger conflicts such as when tigers come into contact with humans in villages or farms. Understanding how these incidents occur helps develop appropriate measures that can minimize conflicts while protecting both people and wildlife. Moreover, tiger conservation also benefits other species sharing ecosystems with tigers. This means that conserving tigers would lead towards overall ecosystem health through preservation of forests, rivers, different plant & animal species etc. Overall, the motivation behind researching tiger conservation comes down not only to preserving this majestic apex predator but also its impact towards maintaining healthy ecosystems. It requires active involvement from governments, private sector, civil society groups, funding agencies, and local communities working together toward sustainable solutions for long term survival of this endangered big cat species- The Tiger.

1.2 Problem Description

With the advancement in telemetry technologies many researchers have achieved good prediction accuracy for their models to suggest insights into animal movements. But despite the great efforts there is not much done towards building a model for predicting the behavioral traits of the tigers.

1.3 Objective

To develop an effective and efficient mathematical model to perform a deterministic prediction analysis for tiger's behavioral pattern recognition.

Sub-Objectives

1. Telemetry Data Acquisition with activities of the species (Tiger).
2. Evaluation of Tiger specific dependence of parameters from the acquired parameters.
3. Correlation & Community analysis of topography and activities.
4. To drive a grammar which would in response, provide a set of rules for predictive analysis of behavioral pattern of species.

1.4 Thesis Contribution

The several noteworthy contributions of the proposed research are summarized below.

1. The review of all existing studies done on tiger's using telemetry data in India

(a) Systematic review is done to show how telemetry data can be helpful to understand the behavior of the tigers.

(b) The findings revealed that telemetry data can be used to understand the movement patterns of the tigers, where they go? Why they go? And how they interact with their surroundings.

(c) The findings revealed that, most of the work is done towards basic understanding of acquired data, no mathematical model is developed to predict the movement of the tigers.

2. The proposed machine learning model is to leverage many data sets, such as the GPS coordinates of tigers, temporal information, and the location of their prey, to forecast the next possible location of a tiger. The ability to forecast future outcomes can be of great significance in the context of animal conservation, specifically in the proactive monitoring and management of tiger populations by researchers and authorities.

3. Community analysis of the tigers of Sundarbans is performed to understand the interaction of tigers to their surroundings which includes vegetation mapping, water bodies, and prey distribution of the region.

a) We have utilized descriptive statistics to establish meaningful correlations between tiger behavior and environmental variables determined through community analysis, such as kind of vegetation or proximity to water. Descriptive statistics comprise the process of summarizing data through the utilization of metrics such as means, medians, and standard deviations. This has enabled us to investigate potential correlations or links between variables.

b) Statistical analysis conducted has indicated that places with dense vegetation exhibit a greater occurrence of tiger sightings, or that tigers display increased activity levels in areas abounding in water resources. These results possess the potential to yield significant insights on the ecological preferences and requirements of tigers, thereby providing conservationists with the necessary knowledge to formulate focused strategies aimed at safeguarding their habitat.

4. The proposed model to predict the behavior of the tiger using a game theory approach is an unprecedented approach to make intelligent prediction about the next cell location of the tiger for a given region. Using this method, researchers can correctly predict where a tiger will be in the next cell. They can then combine these individual predictions to make a trajectory that shows how tigers move in that area. This predicted path is a useful tool for conservationists and wildlife managers who want to protect important areas or reduce conflicts between people and animals. Finally, a finite automaton is constructed to show the different states of the tiger and how the transition occurs from one state to another.

1.5 Thesis Outline

The structure of the remaining thesis is organized as: In the second chapter, an in-depth investigation into the telemetry studies conducted on tigers in India is carried out. In addition to that, the chapter discusses the difficulties that arise when collecting and analyzing telemetry data. Chapter 3 provides additional information regarding the dataset that was utilized, the area of study, feature engineering, and the numerous machine learning techniques that were utilized in order to forecast the subsequent location of tigers in their movement. Using a game theory approach, Chapter 4 introduces a novel method for forecasting Tiger behavioral patterns. This method comes from the field of game theory. A comprehensive look at the results of the model is offered in Chapter 5, which is the fifth chapter. Furthermore, in order to demonstrate the superiority of the suggested model, its performance is tested and compared to that of any current approaches. In the final chapter, which is chapter 6, a summary of the thesis is presented, conclusions are found, and potential future research areas are investigated.

CHAPTER -2

LITERATURE STUDY

The field of wildlife conservation involves a diverse range of interconnected issues that present significant obstacles for researchers. To gain a comprehensive understanding of and effectively tackle these difficulties, an analysis has been conducted on the efficacy of game theory methodologies. A range of methodologies, including conventional approaches, evolutionary strategies, and machine learning algorithms, are utilized to acquire a deeper understanding of the complex dynamics involved in conservation. The choice of these methodologies is contingent upon the study inquiry and its relevance to hypothesis testing, behavior prediction, occupancy models, or species distribution analyses. The field of species conservation has been greatly influenced by game theory for almost half a century, a notable factor that deserves careful attention. The field of game theory gained prominence during the 1950s as it was initially introduced as a methodology for examining the dynamics of interactions between predators and prey [14]. Furthermore, the utilization of machine learning algorithms has become increasingly prevalent in the realm of conservation endeavors. These algorithms possess the capability to effectively process extensive volumes of data, hence empowering researchers to unveil underlying patterns or forecast future behavior by utilizing past observations. In contrast to conventional statistical approaches, which encounter difficulties when dealing with complicated systems containing several variables, machine learning methods demonstrate exceptional performance in such domains [17]. This work introduces a predator-prey model that incorporates the activities of individual predators, aiming to elucidate their interaction dynamics. This is achieved through the utilization of Stackelberg security games and machine learning techniques, which are applied to telemetry data.

By conducting a comprehensive analysis of the available scholarly works, we acquire significant knowledge regarding the significance of game theory and machine learning models that employ telemetry data in the accurate prediction of species behavior.

2.1 Wildlife Conservation using telemetry data.

Many studies have been conducted on tigers over the past century; one of the studies which presented remarkable improvement in studying habitat selection, movement patterns & ecology to understand Tiger's behavior is Radio telemetry [2, 4, 12]. Telemetry is the science of measuring and transmitting data from remote sources such as satellites or radio waves. Wildlife biologists rely on two types of technology, Radiotelemetry and GPS (Global Positioning System), to observe and monitor wildlife. VHF Radio-telemetry, which operates on very high frequency, has been in use since the 1960s and predates GPS [18]. This method involves a transmitter and receiver system that requires researchers to be present in the field to gather data. The study subject is outfitted with a "transmitter," which can be attached through various means, Radio collar is fitted around the neck for animals such as tigers, wild dogs, bears, etc., and to the ankle for animals like Rhinoceros, Elephants [19]. Satellites are used by the GPS system, a relatively new technology that provides geo-spatial positioning. This allows small electronic receivers to determine locations with high precision, including longitude, latitude, and altitude/elevation [18, 19]. Unlike mobile phone GPS systems, tracking wildlife requires transmitting location data back to a satellite for real-time tracking in remote areas. To track wildlife using this technology, they are fitted with a GPS system such as a collar which documents their movements and location. The collected data can then be downloaded onto a computer and mapped out. One advantage of GPS systems is that it can collect points for 24 hours without needing constant supervision from biologists in the field. However, the costs associated with implementing and maintaining this technology exceed those of radio-telemetry systems [12, 19]. Regarding GPS technology, conservationists use radio collars equipped with VHF capabilities along with GPS system. These collars collect GPS data but cannot be accessed remotely; instead, they are programmed to automatically release on a specific date and time. Until then, the animal can still be tracked using radiotelemetry [8,11, 12]. It is according to the research question and region to decide which technology to be used for tracking the animal. Telemetry studies involves attaching devices such as GPS collars or radio transmitters on animals that allow researchers to track their movements and behavior remotely. To prevent radio collars from affecting animals, it is recommended that the collar's weight should not exceed 5 percent of their body weight [18, 19, 20]. One such collar in use is shown in Figure 2.

Figure 2.1 Tiger wearing Radio Collar [12]

However, with technological advancements in hardware and sensors, there are now collars available that weigh only around 1 percent of an animal's body weight [19, 20, 21]. These collars come equipped with a variety of sensors capable of recording the animal's movement activity, body temperature and mortality rates [21, 22]. Three different types of radio telemetry that use Radio-collars to transmit the data.

1. VHF (Very High Frequency) Radio Collars: it is the standard method of collecting telemetry data of the animals by using VHF-based Radio collars. An animal wearing a VHF transmitter transmits the signals which can be received by using antenna and techniques like triangulation and Homing- in [12, 18, 21].
2. GPS (Global Positioning System) Radio Collar: It tracks the animal from a remote location. GPS collars store the data & transmit it at preset intervals. They store the locational data which can be downloaded in many ways [18]. GPS radio collars use the mobile network to transmit the data. These types of collars also come with attached VHF capabilities [12, 17,18]
3. Satellite Radio collar: tracks the animal from a remote location. It uses a satellite to transmit the data to the receiver.

Table 2.1 shows the comparison of different radio telemetry collars used in wildlife.

Table 2.1 Comparison of Radio-tracking/ Radio collars for Tigers

Features	VHF	Satellite Tracking	GPS Tracking
Accuracy	Mostly accurate	Less accurate than VHF (depends on the problem to study)	Highly accurate
Cost	Low cost	High Initial Cost	High Initial Cost
Distance	Used for short distances tracking	Used for monitoring long distances	Used for short-lived applications
On-field Personnel Requirement	Requires personnel on the ground for tracking.	Requires no personnel on the ground	Requires no personnel on the ground
Information provided	Provides more information other than locational data. Such as behavioral activities	Provides only locational data of the species.	Provides only locational data of the species.

Battery Life	Good battery life (average 3 years)	Consumes more battery than VHF (average 2 years)	Consumes more battery than VHF (average 2 years)
Weight	Lighter in weight	Total weight is more than VHF	Total weight is more than VHF (it is usually equipped with VHF capabilities so more weight)
Mortality Information	Provides data on Mortality (transmitter changes the pulse rate of radio signal in case of no movement for hours)	No such feature is available	No such feature is available

Telemetry data provides valuable information about animal ecology, including habitat use, migration patterns, home range size, activity levels, and social interactions [22].

In India, radio telemetry was first performed for Gharials (Gavialis gangeticus) at the Crocodile Research Centre of the Wildlife Institute of India, Hyderabad in the year 1983. It was conducted on 12 Gharials and has marked the beginning of Radio telemetry in India [8]. The first radio telemetry study done on tigers in India, and it took place at Nagarhole National Park along with the leopards, elephants, Asiatic Lions, and their prey such as- Sambar, wild Pig, Chital and Nilgai [8, 12]. Telemetry provides the spatial & temporal data of the species; it gives the locational coordinates of the species to the receiver at the survey site [23]. This information can be used to find their exact location from the survey site. Telemetry data has been utilized in numerous studies to predict the movements of tigers across various landscapes in India [17]. One such study [24] examined GPS collar locations of six tigers from 2012-2016 within the Sundarbans mangrove forest on India's eastern coast. The researchers discovered that Vegetation Cover Density was a significant predictor variable for tiger movement within this landscape type, while elevation gradient had no impact on their movements. Another study conducted by Athreya et al., 2013 analyzed GPS collar data from four tigers located in the Western Ghats region of India and found that Distance from water source and prey availability index were significant predictors for tiger movement, with tigers moving closer to water sources during dry seasons and areas with higher prey availability. In addition, Suryawanshi et al. (2010) carried out a study that utilized telemetry data and analyzed radio-telemetry information from five tigers that were located in the Sariska Tiger Reserve, which is located in the state of Rajasthan in India. They came to the conclusion that the presence of prey was a major predictor variable for the movements of tigers within this particular type of environment, whereas the density of vegetation cover had no impact on the individuals' movements. The primary research projects that were carried out in India with the help of telemetry data are detailed in Table 2.2. An overview of major studies conducted in India for tiger conservation using telemetry data is presented in Table 2.2. These studies have played a crucial role in understanding the behavior and movement patterns of tigers, leading to more effective conservation measures. For instance, a study [34] utilized radio-telemetry data to track tiger movements within Nagarahole National Park, revealing their territorial nature and tendency to stay within certain areas. This information helped park authorities develop management strategies that were tailored to each gender's territory size. Another study [35] monitored tiger populations across multiple protected areas through GPS collars, finding significant variations in population densities between different habitats and regions. Thus, targeted conservation efforts based on local conditions are necessary for successful preservation of these majestic animals. Telemetry data has been used in numerous studies to gain a better understanding of ecological issues such as home range usage, migration patterns, and landscape utilization [36].

Table 2.2 Major telemetry studies conducted on Tigers in India from 2010 to 2021

Ref.	Monitoring Duration	Study Objective	Number of tigers in the area in 2021	Tiger collared for the study	Location/ Tiger Reserve	Type of collar used	Stakeholders
[24]	2008- 2014	Ranging patterns and Habitat preference	Estimated no is 96	6	Sundarbans National Park, west Bengal, India	GPS satellite & VHF Collars	WII, Dehradun, India
[25]	2008-2009	Home Range, Population Density Estimation	Approximately 500	6	Kanha Tiger Reserve. Madhya Pradesh, Central India	VHF/ GPS	Project Tiger Directorate (Government of India) and WII, Kanha Tiger Reserve.
[26]	2008- 2011	Ranging and Dispersal Pattern	Estimated no. is 44	3	Pench Tiger Reserve, Madhya Pradesh, India	Satellite & VHF	Madhya Pradesh Forest Department (MPFD), NTCA and WII, Dehradun
[27]	2011 to 2014	Mapping of corridors over entire India Tiger Reserves	Estimated Tiger Population (2967)		All Tiger Conservation Landscapes of India	Unknown	NTCA and WII, Dehradun
[28]	2006 - 2013	The population dynamics,dispersal,survival rate	Estimated no. is 44	4	Pench Tiger Reserve, Madhya Pradesh, India	VHF radio collar	Madhya Pradesh Forest Department (MPFD), WII, Dehradun

[29]	2009 - 2014	Behavioral response of reintroduced Tiger Population	Estimated no is 70	9	Panna Tiger Reserve, Central India, Madhya Pradesh, India	VHF/ GPS/UHF collars	Madhya Pradesh Forest Department (MPFD), NTCA and WII, Dehradun
[30]	2009- 2014	habitat selection by the reintroduced tiger population	Estimated no. is 70	9	Panna Tiger Reserve, Central India, Madhya Pradesh, India	VHF/ GPS/UHF/Satellite collar	Madhya Pradesh Forest Department (MPFD), NTCA and WII, Dehradun.
[31]	2020-2023(expected)	Human-Tiger Interactions	Estimated no. is 96	1	Sundarbans National Park, west Bengal, India	Unknown	Bengal Forest Department(BFD)
[32]	2015 – 2020	Patterns of Tiger migration	Estimated no. is 312	15	Eastern Vidarbha Landscape, Nagpur, Maharash Ctra, India	Iridium, VHF/ Activity	Maharashtra Forest Department(MFD) & WII, Dehradun
[33]	2014 - 2019	Understanding Movements patterns in Human dominated Landscapes	Estimated no is 312	14	Eastern Vidarbha Landscape, Nagpur,Districts of Pune and Solapur, Maharashtra, India	GPS Collars	Maharashtra Forest Department(MFD) & WII, Dehradun.

However, most investigations only provide basic statistical information about the data. Few studies have explored the relationship between abiotic factors and animal movement or provided density estimates of different species in various landscapes. Computational approaches are now playing an increasingly important role in ecological research and wildlife conservation efforts. These models have proven highly efficient at predicting animal behavior based on acquired telemetry data through the use of game theory and machine learning algorithms [14, 37]. When it comes to the study of wildlife dynamics, telemetry data is one of the most important inputs. This information is utilized for the purpose of conducting predictive analysis for the purpose of managing wildlife habitat, which includes the construction of green corridors, the management of core regions of habitat, and the development of policies for the conservation of wildlife [38].

2.2 Investigation into locomotion patterns of tigers using telemetry data.

This section discusses various studies and research conducted to understand the movement patterns of tigers using telemetry data.

Tigers require vast amounts of space to fulfill their needs, including hunting, mating, and territorial defense. They are solitary creatures known for their large home ranges and wide-ranging movements [13, 39]. To study the movement patterns of tigers, researchers employ various techniques such as radio telemetry, GPS collars, camera traps and satellite imagery [40]. These methods allow scientists to track individual tigers over time and gain insight into how they utilize different habitats within their range. One significant discovery from these studies is that tigers tend to follow specific paths or corridors through their habitat. This behavior helps them conserve energy while navigating dense vegetation or challenging terrain [41]. Additionally, researchers have observed that tigers avoid areas with high human activity or disturbance like roads and settlements. Another crucial aspect of tiger movement patterns is seasonal migration between different habitats in search of food resources [42]. For instance, male Tigers in India's Kanha National Park migrate up to 100 km during monsoon season when prey densities decrease in core areas. Understanding tiger movement patterns is essential for conservation efforts aimed at protecting this endangered species [43, 44]. By identifying key corridors used by tigers between protected areas we can prioritize conservation actions like habitat protection along those routes which will help maintain genetic diversity among populations separated by barriers like highways etc. Table 2 provides a summary of studies aimed at understanding the movement patterns of tigers specifically. One example is a study conducted which analyzed satellite collar data from six female Bengal tigers living around Kanha Tiger Reserve in central India. The researchers found that these females had relatively small home ranges compared to male counterparts studied elsewhere – likely due to differences in prey availability or competition with other predators like leopards or dholes (wild dogs) [45]. Furthermore, they noted that some individuals would occasionally venture into neighboring reserves outside their usual range – possibly indicating dispersal events or seeking new hunting grounds during times when resources are scarce.

Table 2.3. Major Studies conducted to understand the movement patterns of tiger

Study Aim	**Dataset**	**Methods**	**Findings**	**Ref.**
Multi Scale habitat modelling and predicting change in distribution of tiger and leopard using random forest algorithm	Species Occurrence data of tigers and leopards	Random Forest Algorithm	Proposed a framework for multi species to model multiscale habitat and impact of climate change on their distribution	[17]
Ranging, Activity and Habitat Use by Tigers in the Mangrove Forests of the Sundarbans	Telemetry data of 6 tigers	Minimum Convex Polygon (MCP) Fixed Kernel (FK)	Home ranges Daily Distance travelled. Water channels which are crossed and not crossed by tigers	[24]

Insights into movement of large carnivores in human dominated landscapes in India	Telemetry data of 26 large carnivores	Brownian Bridge Movement Model	Movement of large carnivores inside and outside the protected areas of Reserve. Impact of human population density, land use, highways inside the home ranges on large carnivores is analyzed.	[33]
Animal Movement prediction based on Predictive Recurrent Neural Network	Telemetry data of Long- Billed Curlew migration from Idaho	Recurrent Neural Network, Random Forest	Proposed an approach for animal movement prediction using RNN and Random Forest techniques.	[47]
Habitat suitability does not capture the essence of animal – defined corridors	GPS locations of 25 black bears,7 bob cats, 21 coyotes, 7 wolves	Various R language packages	No direct linkage between corridors and habitat suitability movement data can help to identify corridors	[48]
Long-distance dispersal by a male sub-adult tiger in a human-dominated landscape	GPS telemetry data of one adult Tiger	dynamic Brownian Bridge Movement	GPS telemetry allows to observe dispersal at fine temporal scale.	[49]

		Model (DBBMM)		
Crossing structure use in a tiger landscape and implications for multi-species mitigation	Used multiple Camera trap which gave n = 22,267 images of mammals	-	temporal use of Crossing structure is impacted for all wild species. use of crossing structure is different for different species	[50]
Temporal scale of habitat selection for large carnivores: Balancing energetics, risk and finding prey	Telemetry data of 14 African lions and 20 Pumas	Logistic Regression and generalized estimating equations (GEE)	shown the importance of temporal grain with movement of large Carnivores	[51]
Prey selection and food habits of the Tiger Panthera tigris (Mammalia: Carnivora: Felidae) in Kalakkad-Mundanthurai Tiger Reserve, southern Western Ghats, India	Density of different prey is analyzed using line transect(n=21)	program 'DISTANCE' version 7.2	Major prey of tigers is classified. Density of major prey species is provided for the region	[52]
Using Machine Learning for Remote Behavior Classification—Verifying Acceleration Data to Infer Feeding Events	Telemetry data of 5 Cheetahs	KNN, SVM, CART, Random Forest, linear discriminant analysis (LDA), quadratic	Proposed a method to remotely detect the feeding event of free ranging cheetahs	[53]

in Free-Ranging Cheetahs		discriminant analysis (QDA)		

Table 2.3 suggests that the use of technology, particularly machine learning, has been proposed as a potential solution to aid conservation efforts. Machine learning involves the development of algorithms that enable computers to learn from data and improve their performance over time without being explicitly programmed. Machine learning has enormous potential in aiding wildlife conservation efforts through data analysis, predictive modeling capabilities, and real-time monitoring among others; Machine learning techniques are of paramount importance in the analysis of large amounts of data and the extraction of significant patterns from them [54]. In the domain of exploring species behavior prediction through the utilization of machine learning algorithms, researchers make use of diverse methodologies, including supervised learning (such as classification), unsupervised learning (such as clustering), and reinforcement learning (such as Markov decision processes) [54, 55]. It is possible to train predictive models using supervised learning algorithms based on labeled data sets containing information about observed behaviors of distinct species under specific conditions. Given new input data, these models can then be used to predict future behavior patterns. When working with unlabeled datasets with no prior knowledge of behavioral categories, unsupervised learning techniques are advantageous. Researchers can detect unique behavioral groups within populations by using clustering techniques like k-means or hierarchical clustering on variables taken from raw data (such as movement trajectories or physiological measurements) [54, 55]. However, there are several limitations that need to be addressed [56]. Developers of these tools must ensure

they are transparent, unbiased, and accessible to all stakeholders involved in conservation efforts [57, 58]. By doing so, machine learning can become a critical tool for wildlife conservationists worldwide.

2.3 Game theory and telemetry data in wildlife conservation

The application of game theory in the prediction of tiger behavior represents a pioneering methodology with significant implications for learning and effectively controlling their patterns of movement and behavioral approach. Through the implementation of this methodology, researchers can acquire significant knowledge regarding the way tigers traverse their surroundings, therefore enabling them to make accurate inferences referring to their possible locations. However, predicting the behavioral patterns of wild tigers accurately has always been a challenge due to their complex social structures and individual personalities [14]. Although applying game theory is not necessary for anticipating tiger movement, it can provide a distinct viewpoint and valuable insights. Tigers, although they prefer to be alone, make decisions by evaluating the perceived hazards and rewards in their surroundings. Thus, their movements might be perceived as a "game" in which they engage with prey, obstacles, and even humans. Game theory can explain their moves by analyzing strategic decision-making [59]. It can consider environmental factors such as the availability of prey and human activities. It can be beneficial for comprehending conflict situations that arise between tigers and humans. Game theory requires a substantial amount of data about the specific behavior of each tiger, a task that is frequently challenging to accomplish. Creating a model of the "game" might be intricate and need a significant amount of processing resources [60]. Game theory is beneficial in situations where, forecasting the migration of tigers in a landscape is characterized by sparse data. Gaining insight into distinct tiger behaviors, such as territorial tendencies or hunting tactics [61]. Developing conservation techniques that take into account the ecological dynamics and behaviors of tigers in their natural habitat. The optimal strategy ultimately hinges on the particular objectives of the forecast and the data that is accessible. Game theory can provide important insights when combined with other methodologies, whenever feasible. But an inherent benefit of employing game theory in the prediction of tiger behavior is in its capacity to consider multiple elements that impact the movement patterns of these species. Game theory incorporates various factors that influence the behavior of tigers, including their innate instincts, natural tendency, and external variables such as the availability of prey, suitability of habitat, presence of humans, and territorial boundaries [59]. Game theory provides a mathematical framework that scientists can use to analyze strategic decision-making among individuals or groups [14, 59, 60]. By applying principles from game theory, researchers can forecast how tigers may behave in various scenarios, providing valuable insight into these majestic creatures' needs and preferences that could aid conservation efforts [61].

It has been widely applied in various fields such as economics, political science, psychology, biology, and computer science. The basic elements of game theory include players, strategies, payoffs, and information. Games can be classified based on the number of players involved (two-player or multi-player games), whether they are cooperative or non-cooperative games and whether they are zero-sum or non-zero-sum games [59, 60, 61]. Game theory has been used to analyze markets behavior such as oligopoly competition; auctions; bargaining negotiations between labor unions & employers over wages & working conditions etcetera [62]. It has also been applied in political science to study voting behavior, international relations, and conflict resolution; biology to explain animal behavior such as the evolution of cooperation among animals; mating strategies of different species; predator-prey interactions etcetera.; psychology to understand human decision-making processes by studying how people make choices under uncertainty or risk [63]. Table 2.4 outlines the major studies conducted for wildlife conservation utilizing the game theory. Game theory can be applied to wildlife conservation efforts to understand the complex interactions between stakeholders, including governments, local communities, poachers, and conservationists [14].

Table 2.4 Major studies conducted in wildlife conservation using Game Theory

Reference No.	Proposed Work	Dataset Used	Key Findings	Future Work/ Shortcomings
[14]	Game theory in biology: 50 years and onwards	Reviewed articles on game theory in biology from past 50 years	Success and challenges of game theory of cooperation is presented with different scenarios.	More Realistic mechanisms can be incorporated which are derived from the species psychology in Game theory in biology
[61]	Balancing Large-scale wildlife protection and forest management goals with a game - theoretic approach	Case study area: Churchill caribou range, Ontario, Canada	Game theory-based approaches are shown for: -Woodland Caribou Habitat protection -Maximizing the harvest revenue for locals	The proposed can be extended to incorporate data for multiple species as the current model is focusing over single species.
[62]	Game theory as a tool to address conservation conflicts	Various studies are used to present different approaches of game theory	Real life examples are discussed with the presented approaches of game theory to address conservation conflicts	Game theory can be explored to check how they might fit in different context
[64]	To present the new technical advances in Stackelberg Security Games	Presented different approaches of SSG with	SSG is deployed successfully in wildlife conservation	SSG is quite successful in handling security

	(SSG) and resenting new potential applications in SSG	deployed applications in real world	along with many new potential application areas	problems in many domains.
[65]	Game theory-based Pixel Approximation for remote sensing imagery	Landsat 5 TM data of five cities Delhi, Jodhpur, Kolkata, Odisha, western ghats region	Game theory is utilized to address the mixed pixel - percentage of approximation.	The proposed game theory-based method for addressing class of mixed pixel can be tested with supervised classification technique.
[66]	Deploying PAWS: Field optimization of the Protection Assistant for Wildlife Security	Case study area: Uganda and Malaysia	PAWS is first model of ‘green security games’ application to combat poaching	The future work will continue to test the PAWS at different locations under ARMORWAY
[67]	PAWS: Game Theory Based Protection Assistant for wildlife Security	Input data on Terrain information, Patrol Track, Observation data of species	PAWS focuses on one module of wildlife conservation – how to optimize foot patrols	Future work can focus on other modules of wildlife conservation.
[68]	A Predator-prey model with predator using hawk and dove tactics	Data and size of predator and prey are assumed to create a mathematical model	There is strong relationship between the prey density and the strategies adopted by predators.	Proved results can be tested with the real predator prey at a particular landscape.

The paper titled “Game theory: basic concepts” [63] discussed about the fundamental concept of game theory, which refers to the examination of decision-making processes undertaken by individuals or entities in situations where their results are dependent upon the decisions made by others. This underscores the significance of strategic thinking and intelligent decision-making in such circumstances. Game theory is a mathematical framework that allows for the analysis and evaluation of the outcomes resulting from various combinations of strategies employed by players, with a focus on measuring the value of payoffs. Payoffs denote the measure of utility, benefit, or satisfaction that is obtained by each participant, contingent upon the methods they select, and the strategies used by other participants [69, 70, 71]. This paper [64] elucidates the two primary representations employed in game theory, namely normal form, and extensive form, for the purpose of understanding and analyzing games. Normal form games involve the representation of strategies and payoffs in a matrix format, whereas extensive form games employ a tree-like structure to illustrate the sequential nature of decisions and their corresponding consequences. Zero-sum games represent a distinct category of games in which the aggregate payout for all participants remains constant, as any gains made by one player are precisely offset by the losses incurred by the other player. The notion of a zero-sum game and the minimax theorem are presented. The concept of Nash equilibrium holds significant importance within the field of game theory. Game theory encompasses a collection of strategic approaches wherein no participant possesses a motivating factor to unilaterally alter their chosen course of action [62, 63]. This study examines the notion of Nash equilibrium and its implications in several game scenarios. The Prisoner's Dilemma, a well-known scenario, is commonly cited as a paradigmatic illustration of a non-cooperative game. This exemplifies the phenomenon wherein individuals who act rationally may not consistently make choices that are collectively optimal. This study [70] presents a distinction between cooperative and non-cooperative games. Cooperative games are characterized by the presence of participants who could establish binding agreements, whereas non-cooperative games are predicated on the assumption that individuals behave autonomously and do not engage in explicit agreements. This work [90] examines the empirical validation of game theory predictions, with a particular focus on the extent to which theoretical models have been validated by experimental studies. The publication titled "Game Theory in Biology: 50 Years and Onwards" [14] acknowledges the significant influence that game theory had on the examination of evolution, social interactions, and behavioral ecology within the realm of biological sciences.

This statement underscores the historical importance of this methodology, while also anticipating future progress and integration possibilities in the forthcoming years. The paper titled "PAWS: Game Theory-Based Protection Assistant for Wildlife Security" [67] employs game theory and predictive analytics to aid wildlife security organizations in their endeavors to safeguard endangered animals from the threat of poaching. The proposed methodology provides a strategic framework for the implementation of patrolling activities and allocation of resources, with the aim of mitigating risks to wildlife and maximizing the efficient utilization of limited resources. The literature survey provides a comprehensive overview of distinct game models employed within the framework of evolutionary game theory. These models may encompass well-known games such as the Prisoner's Dilemma, Hawk-Dove, and diverse forms of coordination games. Another paper [66] discusses the diverse applications of evolutionary game theory, including its utilization in the analysis of animal behavior, economics, sociology, and evolutionary biology. Additionally, it may explore the utilization of game theory in the context of practical issues and obstacles. These scholarly articles enhance our comprehension of the evolutionary processes behind the development of strategies and behaviors across diverse contextual frameworks. Stackelberg security games are a type of sequence security game used to help people make decisions and decide how to use resources to better protect and secure important assets or resources [64]. These games simulate how a defender (leader) and a possible attacker (follower) would talk about strategy. The leader acts first, and the attacker watches what the leader does before choosing what to do. Stackelberg security games offer a systematic framework for maximizing security measures and resource allocation. This technique enables the defender to adopt a proactive position and carefully plan their actions, while considering probable replies from attackers. This paradigm enhances the efficacy of security techniques and provides improved safeguarding of precious assets [68, 69, 71]. By modeling human-wildlife conflicts and predicting poacher behavior, effective strategies for minimizing harm while maximizing benefits for all parties involved can be developed. Game theory also helps with allocating funds based on expected outcomes and overall impact on biodiversity preservation despite budget constraints. Involving local communities in conservation fosters shared ownership over natural resources among stakeholders who may have conflicting interests. International cooperation is often necessary for effective wildlife protection, and game-theoretic concepts such as Nash equilibria or cooperative games can identify optimal agreements that benefit all participating nations while minimizing negative impacts on global biodiversity levels. Understanding stakeholder motivations and strategic choices through game theory provides valuable insights into developing efficient strategies for preserving ecosystems and protecting endangered species for future generations. Overall, the study highlights the potential utility of game theory in shaping wildlife conservation policies and identifying effective approaches for safeguarding endangered species and their habitats.

Finite Automata in game theory

Finite automata (FA) are a concept in computer science to represent processes with states that vary based on the input symbols. The significance of machines in game theory lies in their capacity to subtly introduce irrational behavior through the implementation of various constraints on the automata's computational power [71, 72]. The tactics employed by these competitors can be conceptualized as finite automata, in which distinct states for each participant symbolize potential courses of action or strategies that are accessible at any given moment, contingent upon prior occurrences or information. An instance of this could be the utilization of finite-state machines to simulate the efforts of park rangers to prevent poaching while balancing limited resources [73]. Specifically, these machines would navigate between different zones within a reserve in accordance with rules derived from game theoretic analysis that identify the most probable locations and times for poaching activities. Adaptive management techniques that integrate learning algorithms resembling finite-state machines and are modified over time via feedback loops are well-suited to conservation objectives because ecosystems are dynamic and frequently unpredictable environments [74]. These techniques ensure resilience to both natural and anthropogenic factors that cause change. It is possible to forecast prospective outcomes of various policy decisions and enforcement strategies by simulating diverse scenarios involving combinations of state transitions under varying conditions; this facilitates the development of more effective evidence-based conservation plans [75, 76].

2.4 Summary of the chapter

The current chapter describes that by examining the utilization of game theory and machine learning in conjunction with telemetry data for the purpose of predicting species behavior patterns, conducting such a survey can yield valuable insights into current research, employed methodologies, and potential applications. Game theory is a valuable tool for understanding the behaviors of individuals within a population or across various species. Through the analysis of tactics utilized by these people, game theory allows for the identification and examination of the fundamental dynamics that influence their actions. Researchers often employ game-theoretic models to investigate various aspects of animal behavior, such as predator-prey dynamics or the competition for limited resources. Machine learning methodologies are of paramount importance in the analysis of extensive datasets since they facilitate the extraction of significant patterns from such data. In the field of studying the prediction of species behavior through the application of machine learning algorithms, researchers make use of a variety of methodologies. These methodologies include supervised learning (such as classification), unsupervised learning (such as clustering), and reinforcement learning (such as Markov decision processes). To train predictive models, supervised learning techniques are frequently utilized. These techniques involve the utilization of labeled data sets that contain information regarding the observed behavior of various species within specific environments. Following that, these models can be utilized to make predictions regarding forthcoming behavioral patterns by utilizing unique input data. Unsupervised learning techniques are useful in cases when the datasets in question do not contain any labels and where there is no prior knowledge of behavioral categories. Researchers can discover unique behavioral groups within populations by employing clustering algorithms, such as k-means or hierarchical clustering, on variables derived from raw data, such as movement trajectories or physiological measurements. To better understand these ideas, let us consider the possibility of conducting a hypothetical inquiry on the prediction of the foraging activities of predators. Game theory has been utilized by researchers to create models that are able to represent the strategic decision-making processes of predators when they are presented with a multitude of possibilities for getting food, as evidenced by a complete evaluation of the existing literature in this field. Game-theoretic models can forecast the prey preferences of a predator by considering a variety of criteria, including the quantity of prey available, the closeness of the individual to the food supply, and the presence of other predators that are in competition with the individual. Machine learning methodologies have the potential to enhance these predictions by integrating further variables such as environmental circumstances (e.g., weather conditions) or individual attributes (e.g., age or prior experience). For example, the employment of supervised learning algorithms, which are trained on labeled data sets that comprise observed foraging activities, has the potential to facilitate the prediction of the behavioral patterns. Unsupervised learning algorithms have the potential to reveal behavioral patterns that were not previously detected among predator populations when they are applied to data that does not contain any labels. Following that, this information might be applied to enhance and perfect the game-theoretic models that are now being utilized, hence boosting the accuracy of their respective forecasts. In summary, the undertaking of a comprehensive review of existing literature pertaining to the utilization of game theory and machine learning in the prediction of species behavior patterns yields significant contributions to the understanding of research methodology and potential practical implementations. Through the integration of mathematical frameworks such as game theory with sophisticated machine learning techniques and finite automata researchers can enhance their comprehension of animal interactions and improve the precision of their predictions regarding future behaviors within diverse ecological contexts. The following chapter will discuss the region of the study and the process of dataset acquisition and preparation.

CHAPTER -3

STUDY AREA & DATASET PREPARATION

In this chapter, we delineate the strategies used to select the study region and required datasets, including the sources we consulted. In the context of performing a study on tiger conservation, it is imperative to employ utmost care in the process of selecting the study region and preparing the dataset to ascertain results that are both precise and significant. This chapter also provides insight into the meticulous preprocessing steps carried out to enhance the utilized datasets.

3.1 Study Area

The research site under consideration is the Sundarbans region. The Sundarbans, an expansive mangrove forest, is located at the confluence of the Ganges, Brahmaputra, and Meghna rivers, where they converge with the Bay of Bengal [77]. The ecosystem under question encompasses regions within India and Bangladesh, with a total area of around 10,000 square kilometers. The geographical features of the area exhibit a wide range of diversity, including densely populated mangrove forests, meandering tidal streams, expansive mudflats, sandy beaches, and several small islands scattered across the terrain [77, 78]. The forest floor is covered in thick layers of mud that are regularly replenished by tides. Additionally, the forest floor contains a network of streams that serve as a suitable home for various aquatic flora and fauna, including fish, crabs, and shrimps. The ecosystem not only offers a suitable habitat for many wildlife species, such as tigers, but also functions as a protective barrier against coastal erosion and storm surges [1,12, 77]. This dual role contributes to safeguarding the local communities residing in this area and preserving the surrounding environment, mitigating possible harm caused by natural calamities. Over the passage of time, the accumulation of sediment through the action of river currents has led to the emergence of several small islands, popularly known as "char," so contributing to the distinctive attributes of the area [77]. The Sundarbans is characterized by its natural abundance and serves as a crucial habitat for the preservation of Bengal tigers, boasting the greatest population of this species globally [79]. The linked waterways inside this deep mangrove forest create an optimal hunting environment for these magnificent creatures, allowing them to navigate effortlessly. The Sundarbans Tiger Reserve, which was formed in 1973, is a designated protected area located in the state of West Bengal in India. Its primary objective is to safeguard the critically endangered Bengal tiger species [77, 80]. The reserve encompasses an estimated area of 2,585 square kilometers and serves as the habitat for roughly 100 Royal Bengal tigers, known for their adept swimming abilities and predation on aquatic organisms [80]. The tigers in question have successfully undergone adaptations in response to the constraints presented by their environment, which include dense forest, tidal creeks, and mudflats. One of the most prominent characteristics of these creatures is their exceptional capability to go great distances in water and capture aquatic prey such as fish, crabs, and small crocodiles [77, 80, 81]. They have also been seen climbing trees when the water level rises during high tide. Even though conservation efforts protect these tigers, they still face many dangers in their natural environment. Poaching for body parts, like bones or skin, that are used in traditional Chinese medicine and are very valuable, is the main danger. Other dangers include the loss of habitat due to deforestation or land conversion for farmland, conflicts between humans and wild animals caused by people moving into tiger habitats, rising sea levels caused by climate change, and so on [80]. The area is also home to a wide range of plants and animals, but poaching and the destruction of habitats caused by cutting down trees for timber or farming are major problems. The unique scenery of the Sundarbans is a key part of the area's rich biodiversity. It also helps millions of people make a living through fishing, collecting honey, and other activities [82]. But the rise in sea level caused by climate change, along with things like deforestation and pollution, are big problems for this fragile environment. Government agencies have implemented various conservation measures, such as intensifying patrols to combat poaching, promoting eco-tourism, establishing community-based conservation programs that engage local communities in safeguarding natural resources, offering alternative livelihood options, and undertaking reforestation initiatives [80, 82]. To address these challenges, governmental entities in conjunction with non-governmental organizations (NGOs) specializing in the preservation of wildlife have undertaken a range of conservation initiatives throughout the course of history.

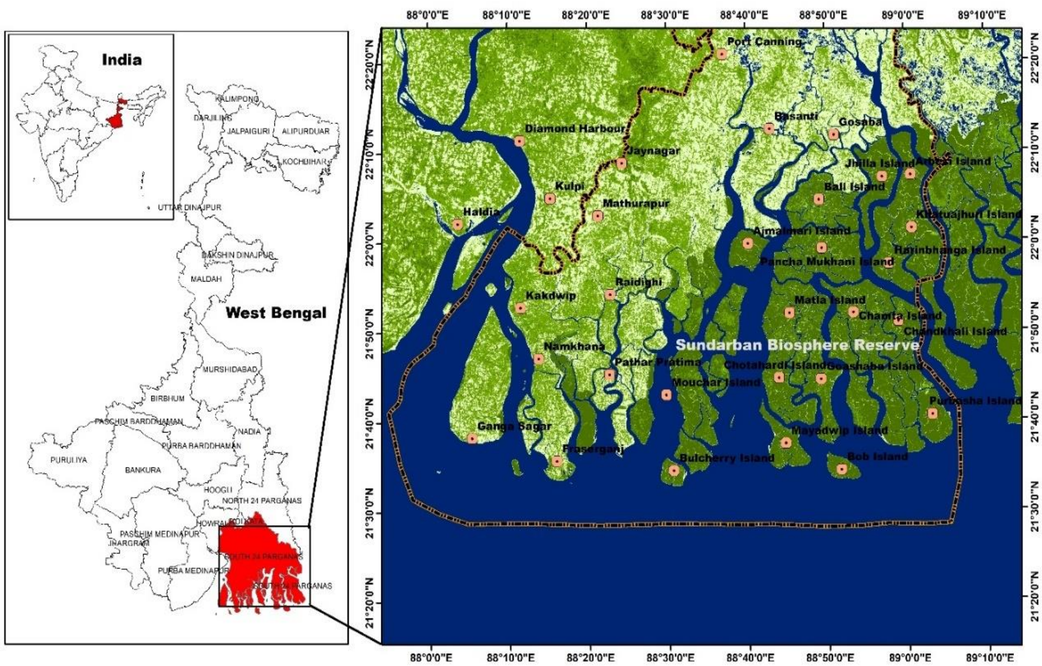


Figure 3.1. Study area - Sundarbans Region

Figure 3.1 depicts the exact geographical positioning of the Sundarbans inside the boundaries of India, as indicated on a map. The visual representation provided in Figure offers a means to visually comprehend the strategic geographical positioning of the famed Sundarbans inside the territorial boundaries of India. The presence of different flora and fauna not only makes a substantial contribution to the biodiversity of the region, but also serves as a vital mechanism for protecting coastal areas and sustaining the livelihoods of local residents.

3.2 Dataset Used

The dataset used contains telemetry data of tigers which is collected by WII (Wildlife Institute of India), Dehradun for the Sundarbans region. This data is collected by the WII for the tigers in Sundarbans area in India and Bangladesh by using telemetry collars on the tigers. Telemetry data of tigers contains the geo locations of the 4 tigers for the below mentioned period.

Table 3.1 Tiger's Dataset Description

Tiger ID	Number of records	Duration
7825	2092	Feb 2010 – Aug 2010
7224	415	March 2010 – June 2010
7831	1949	May 2010 – Nov 2010
Tigress_Priyadarshini	38	June 2010 – Dec 2010

The dataset comprises tuples that consist of a set of attributes, including TigerId, UTC_Date, UTC_Time, Latitude, and Longitude. The data was obtained through the capture of tigers and subsequent attachment of Telonix VHF MOD 400, GPS PLUS IRIDIUM radio collars. The Radio collars were outfitted with a configurable GPS schedule capable of recording fixes at intervals ranging from 1 to 3 hours. The dataset comprises a total of 4494 GPS locations, with no instances of outliers. The movements of tigers have a strong correlation with the distribution of prey within the given territory [83]. The prediction is based on prey distribution data of the Sundarbans, which was obtained from the Wildlife Institute of India (WII). The Wildlife Institute of India (WII) has acquired a supplementary dataset comprising data pertaining to the distribution of prey species. The dataset pertaining to the distribution of prey was collected and supplied by the Wildlife Institute of India (WII). A comprehensive examination revealed the presence of eleven discrete prey species, namely the Chital, Egret, Estuarine Crocodile, Human, King Cobra, Lesser Adjutant Stork, Otter, Red Jungle Fowl, Rhesus Macaque, Water Monitor Lizard, and Wild Pig. The data regarding prey distribution includes the geographic coordinates (latitude, longitude, or GPS) of 11 different prey species in the specified area, documented on a yearly basis. Figure 3 depicts the dispersal patterns of tigers, specifically those identified by collar IDs 7825, 7224, 7831, and Priyadarshini. This study examines the arithmetic mean of each prey, specifically focusing on the average value of prey p1. This value is then correlated with the various GPS positions of tiger t1. The inclusion of data on the average location of prey will enhance the model's understanding of tiger movements. The presence of many prey places may introduce bias, as it becomes uncertain which prey is being tracked by each individual tiger. The availability of telemetry data for each individual prey at frequent intervals would introduce greater variability into the model. If telemetry data is available for every single prey for very small intervals, it will increase the randomness in the model. Thus, an average of their multiple locations makes more value for forecasting the tiger's movement. Prey will go around the habitat and tiger will look around in the home range only, as tigers roam in their home range only [83]. The home range is a geographic area that encompasses all the necessary resources for the species' survival. It is expected that the tiger's home range would encompass regions characterized by abundant prey distribution [84, 85]. An additional dataset has been obtained from the World Imagery Index (WII) pertaining to vegetation mapping inside the Sundarbans region. The dataset comprises the Normalized Difference Vegetation Index (NDVI) values of the landscape. The dataset obtained from the Wildlife Institute of India (WII) regarding vegetation mapping in the Sundarbans region holds significant value in understanding and investigating the vegetation changes within this distinctive environment. The dataset primarily centers its attention on furnishing information pertaining to the Normalized Difference Vegetation Index (NDVI) values throughout the landscape. The Normalized Difference Vegetation Index (NDVI) is a commonly employed metric obtained through the analysis of remote sensing data. Its primary purpose is to evaluate and track the condition and abundance of vegetation. The method measures the disparity between near-infrared light, which is reflected by plant chlorophyll, and red light, which is absorbed by plants, in order to estimate the quantity of green biomass inside a given region [86]. Through the utilization of ratio calculations, valuable insights can be obtained pertaining to diverse facets encompassing plant growth, photosynthetic activity, leaf area coverage, and the general state of vegetation [86, 87]. The proposed model functions by utilizing telemetry data obtained from tigers as its input. The temporal dimension of this data, particularly the year of collection, is irrelevant to the training process of the model, as it primarily emphasizes GPS locations along with other datasets. It is essential that the data on the distribution of prey, mapping of vegetation or NDVI values of the region are collected for the same duration and time period. This is necessary to maintain consistency and accuracy in the analysis conducted by the model.

3.3 Dataset Preprocessing & Feature Engineering

The present study employs three datasets acquired from the Wildlife Institute of India (WII) to construct a predictive model for tiger behavioral patterns. The analysis of movement patterns is of utmost importance in understanding tiger behavior, as movements are intricately linked to behavioral features [47, 88]. Telemetry data was acquired from the Sundarbans region, in conjunction with prey distribution information, to obtain a comprehensive understanding of the movement patterns of the subjects. Furthermore, it is crucial to examine the landscape characteristics and vegetation mapping data of this area to have a comprehensive understanding of tiger ecology, as these elements significantly influence their patterns of dispersal [89, 90]. The dataset details have been previously addressed in the dataset section. After acquiring data, data preparation is the subsequent appropriate procedure. In this particular investigation, the data that was utilized was of an exceptionally high quality and was gathered by the WII; hence, there were no instances of outliers. This dataset is temporally organized, therefore qualifying as time series data, as it captures the movement of tigers across different locations, influenced by their assessment of prey abundance in each respective area. To construct mathematical models, this data is manipulated to extract the necessary features for predictive model building using Feature Engineering.

Feature Engineering

The process of feature engineering for timestamp data entails converting raw time-related information into significant features that can be effectively utilized in predictive models [17]. Below are few commonly used strategies for feature engineering with timestamp data [91, 92]:

1. Time Component Extraction: Decompose the timestamp into its constituent elements, encompassing the year, month, day, hour, minute, and second. These components have the potential to offer useful insights on patterns and trends across various time spans.
2. Lag Feature creation: The process of generating lag features entails utilizing past values of a variable to forecast its present value. One method for generating lag features involves collecting values from the same variable at earlier timestamps, such as the temperature from the preceding hour. This methodology facilitates the identification and analysis of temporal dependencies and sequential patterns within the dataset.
3. Time Calculation for Event Occurrences: In cases where there are designated events or incidents linked to timestamps, such as the date of customer registration, it is possible to compute the time length between each timestamp and the occurrence of the event as a feature.
4. Statistics Aggregation: The process of aggregating statistics involves calculating statistical measures such as the mean, median, and standard deviation over various time periods, such as hourly averages. This allows for the summarization of patterns within these specific intervals.

5. Periodicity Analysis: Employ Fourier transforms or autocorrelation analysis to detect cyclic patterns within the dataset, focusing on periodic variables such as time of day or day of the week.
6. Rolling Window Statistics: Compute rolling window statistics, such as moving average or cumulative total, for a designated time prior to each timestamp to capture transient patterns within the dataset.
7. Temporal Analysis of Event Occurrence and Change Point identification: Employ change point identification methods to ascertain the temporal duration between specific events or identify sudden shifts within your dataset.

These techniques are dependent on the specific problem domain and dataset characteristics. Feature engineering plays a pivotal function in augmenting the accuracy of predictions. For instance, temporal characteristics encompass diurnal cycles or seasonal fluctuations, which influence the availability of prey species in distinct geographic areas throughout the year. Furthermore, it is worth noting that tiger migration patterns may also be influenced by environmental factors such as forest cover and closeness to water sources [93]. In this work, the techniques employed from the above-mentioned techniques are periodicity analysis and rolling window statistics.

Rolling window statistics is applied to the acquired dataset to rectify any omissions or discrepancies, any rows without data were eliminated from the start or end of the dataset. To address the issue of missing values in the dataset, a technique known as a 5-period moving average was employed to replace the missing values in the latitude and longitude columns. Additionally, for the missing timestamp values, an incremental approach was adopted to fill in the gaps.

Periodicity Analysis is applied to detect the cyclic patterns in the dataset. There exist certain variables that cannot be directly fed into the model. The dataset provided in this context comprises time-series data, wherein it is customary for the index of the data frame to adhere to a date-time format (YYYY-MM-DD HH:MM: SS). Nevertheless, this structure fails to offer substantial and valuable insights beyond the mere arrangement of data points. However, it is possible that the dataset contains concealed patterns that are not shown by conventional characteristics. The patterns under consideration include cyclical phenomena, such as the progression of hours within a day, the succession of days within a week, the sequence of months within a year, or the rotation of seasons. The challenge lies in transforming this information into an understandable feature. In the context of constructing a behavior prediction model for tigers, it is crucial to understand the movement patterns of the tigers. In the case of analyzing their movement patterns, time of day greatly influences their behavior. To represent time within the range of 00:00 to 23:59, a conversion can be made to express it in minutes, spanning from 0 to 1439. Nevertheless, a challenge arises when turning it exclusively into minutes as the model interprets the time difference between 23:58 and 00:02 as 1336 minutes instead of a mere four minutes [94]. The issue at hand can be effectively addressed by employing a sine cosine transformation on the timestamp, so converting it into a pattern that fluctuates between the range of -1 to 1. To make this data more meaningful and usable, two steps were taken: first, converting date time into seconds; secondly, applying a sin cos transformation to create a repetitive pattern that can be exploited by models. Figure 3.2 illustrates the transformation of timestamp values into a feature that is appropriate for the model.

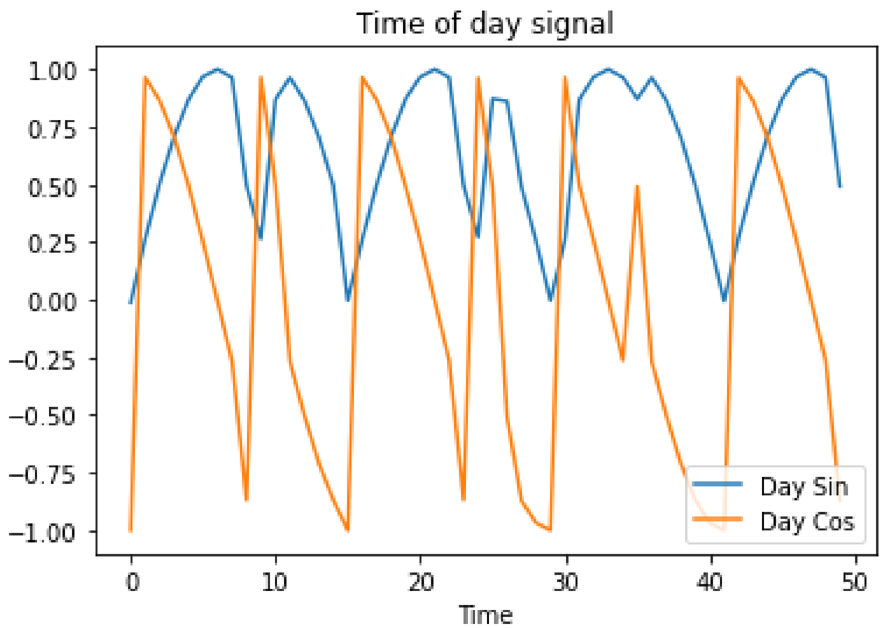


Figure 3.2. Sine cosine transformation of timestamp column

The timestamp column is not very useful because its sole purpose is to organize the data into periodic intervals; it does not provide any information that stands out as particularly significant. By utilizing this adjustment, the model has the potential to gain access to the most crucial frequency information. The model may access the most essential frequency information via this modification. The resultant data, following the application of the sine cosine transformation, is depicted in Figure 3.3. The datasheet includes the geographic coordinates (latitude and longitude) of tigers, as well as additional columns that have been modified to represent timestamp values. Additionally, it includes GPS coordinates for several prey species. The fundamental steps involved in the application of the sine cosine transformation to timestamped data are outlined in Algorithm 1. The date and time of the tiger's position can be found in the telemetry data obtained from the Wildlife Institute of India (WII). This data is afterwards encoded into a cyclical pattern to facilitate the identification of any concealed patterns.

1	Day sin	Day cos	Year sin	Year cos	tiger_lat	tiger_long	lat_prey_chittal	long_prey_chittal	lat_prey_Egret	long_prey_Egret	lat_prey_Esturine_crocodile	long_prey_Esturine_crocodile
2	-0.012362434	-0.999923582	0.632674745	-0.774417631	21.919451	88.746845	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
3	0.264714685	0.964326779	0.638774169	-0.769394282	21.919478	88.747082	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
4	0.504527624	0.863395551	0.638224356	-0.769850422	21.919533	88.747031	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
5	0.709570737	0.70463421	0.637676058	-0.770304645	21.919433	88.747048	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
6	0.868307051	0.49602708	0.637121451	-0.770763424	21.919508	88.747047	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
7	0.96854698	0.248830759	0.636556687	-0.771229917	21.918656	88.745903	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
8	0.999981342	-0.006108614	0.636012631	-0.771678646	21.918794	88.746027	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
9	0.964114713	-0.265486006	0.635457651	-0.772135722	21.918849	88.748863	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
10	0.496405903	-0.868090536	0.633801676	-0.773495595	21.919495	88.750822	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
11	0.26352231	0.964653302	0.638776773	-0.76939212	21.919618	88.751748	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
12	0.869027575	0.494763655	0.637118382	-0.770765961	21.919574	88.751729	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
13	0.963494289	-0.267728882	0.635452731	-0.772139771	21.919567	88.751399	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
14	0.864055236	-0.50339701	0.634910341	-0.772585826	21.919569	88.751758	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
15	0.705923081	-0.708288503	0.634361174	-0.773036804	21.919618	88.751761	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717
16	0.497037065	-0.86772931	0.633803216	-0.773494333	21.919634	88.751702	21.77494295	88.77987452	21.83535185	88.7570679	21.76190384	88.77973717

Figure 3.3. Datasheet containing entries after sine- cosine transformation.

The algorithm receives as input the date and time of the tiger's location and produces as output the sine and cosine values of each date and time value, which range from -1 to 1. These feature engineering techniques are combined and used in different ways in our work to improve the performance of the model.

Algorithm- 1 Algorithm for Conversion of Date Time using sine-cosine conversion

1. Input: Date Time of tiger location fetched from telemetry/GPS collar.
   $DT = \{YY - MM - TT\ HH - MM - SS\}_{i=1}^{n}$
2. Output: Range bound repeating sine – cosine waves $W = \{w_i, w_j\}$ where i represents the value of sine component & j represents the value of cosine component.
3. Function: time_convert(x)
   Where $x = \{t_1, t_2, \ldots \ldots, t_n\}$
   3.1 Repeat $for\ all\ \{t_i\} \in R^{+}$ do
      a. day ←24*60*60
      b. year ← (365.2425) *day
   end
   3.2 for i in x
      a. $day_{sin} \leftarrow sin(\frac{2\pi i}{day})$
      b. $day_{cos} \leftarrow cos\left(\frac{2\pi i}{day}\right)$
      c. $year_{sin} \leftarrow sin\left(\frac{2\pi i}{year}\right)$
      d. $year_{cos} \leftarrow cos\left(\frac{2\pi i}{year}\right)$
   end
4. *return {(day_{sin} , day_{cos}) , ($year_{sin}$, $year_{cos}$)}*
5. EXIT

3.4 Summary of the Chapter

In conclusion, the dataset preparation chapter is a thorough walkthrough of the complex process of converting raw data into a well-organized, high-quality dataset. It demonstrates the commitment to transparency and rigor in determining the dataset's suitability for answering the research questions and serves as a crucial preface to the next analytical chapters, establishing the foundation for insightful deductions and significant discoveries. At the beginning of the procedure, there are steps that involve rigorous cleaning and preparation. Within this context, the techniques of feature engineering come into play as strong tools for boosting the prediction capacity of our dataset. This is accomplished by extracting more relevant properties from the raw data features. In addition, missing values present yet another substantial barrier, as was discussed previously in Chapter 2. These values can be the result of a variety of collection problems, such as malfunctioning sensors or gaps in reporting systems. Imputation methods, in which missing items are filled in based on observed patterns among other variables within the dataset, are one example of the sophisticated ways that are required to manage this challenge in a resilient manner without introducing bias or losing vital information. Feature Engineering techniques are applied to address the challenges posed by timestamped columns within datasets and instances where certain values were missing due to the issues faced while collecting the data as mentioned above in chapter 2. Three standard datasets are used to create the proposed system discussed in the next chapter. Throughout this chapter, we have gone over the comprehensive overview of the proposed model that utilizes game theory to make predictions about the behavioral patterns of tigers by making use of telemetry data.

CHAPTER-4

A NOVEL METHOD FOR TIGER BEHAVIORAL PATTERN PREDICTION USING GAME THEORY UTILIZING TELEMETRY DATA

In this chapter, we have discussed the detailed overview of the proposed model to predict the tiger behavioral pattern prediction using game theory by utilizing telemetry data.

4.1 The proposed model for Tiger behavioral pattern prediction using game theory utilizing telemetry data.

This section proposed a game theoretic approach for tiger behavioral pattern prediction utilizing telemetry data. The aim is to gain insights into tiger behaviors and then develop educated strategies for their conservation efforts. The graphical representation of the game theoretic approach for predicting tiger behavioral patterns is depicted in Figure 4.1. This approach includes the first step of telemetry data acquisition, which entails the collection of telemetry data. This is something that can be done by professionals working in the field of wildlife conservation. In this particular work, telemetry data is obtained from WII. After that comes the process of visually representing this enormous amount of spatial-temporal data in a manner that is simple to comprehend, so that researchers can quickly recognize trends. Following that comes the community analysis for feature extraction, which extracts the meaningful features from the datasets that have been acquired. Following that comes the step of model building using machine learning, along with grid generation for the region, final step is model building for payoff scores and game theory based behavioral prediction.

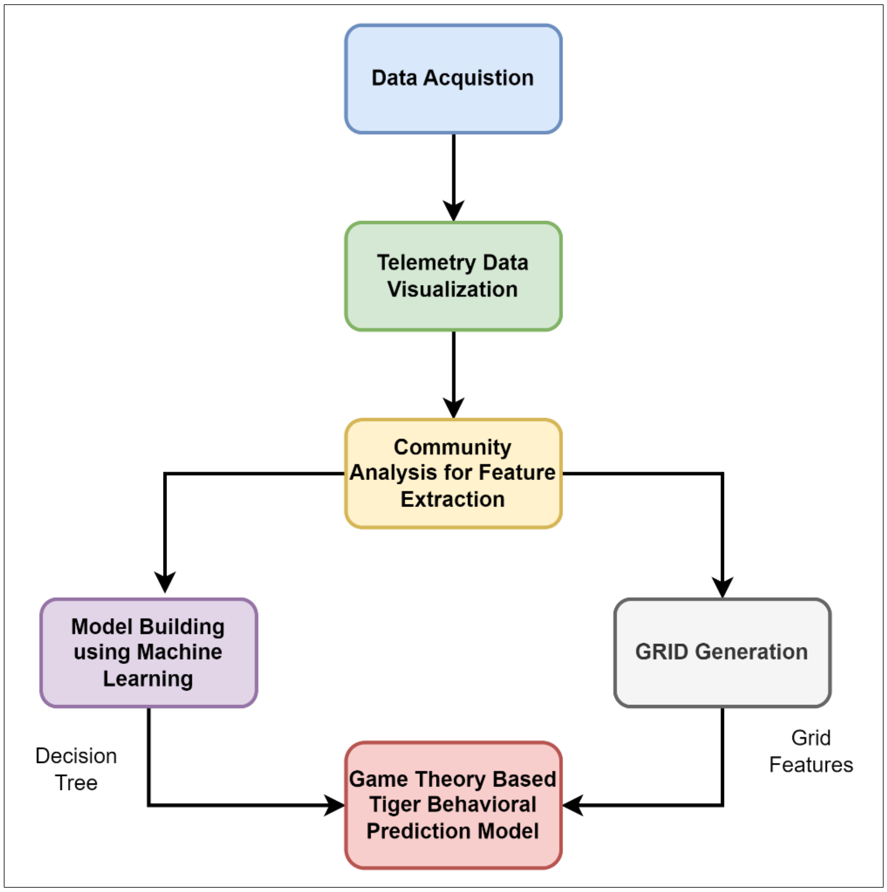


Figure 4.1 The schematic flow of the proposed Game theoretic tiger behavioral pattern prediction model.

4.1.1 Data Acquisition

The acquisition of data holds immense significance when it comes to studying ecological processes to devise more effective conservation strategies. Gathering data on wildlife species is an arduous and challenging endeavor, and obtaining this valuable information often entails jeopardizing the safety of these species. Therefore, the initial stride towards constructing a predictive model for wildlife preservation revolves around procuring the necessary data. Typically, only ecologists accompanied by their teams have the capacity to collect such data. This study utilizes three datasets obtained from the Wildlife Institute of India (WII) to make predictions about tiger behavioral patterns. The analysis of movement patterns is crucial in understanding tiger behavior because of the significant correlation between motions and behavioral features. To enhance understanding of the movement patterns exhibited by the individuals under study, telemetry data was collected from the Sundarbans region, in conjunction with data pertaining to the distribution of prey. Furthermore, the examination of landscape characteristics and the analysis of vegetation mapping data of this region is of utmost importance to comprehend the ecological dynamics of tigers, since these elements significantly impact their patterns of migration.

4.1.2 Telemetry Data Visualization to understand features of the landscape

Telemetry data visualization serves the purpose of facilitating data interpretation. Telemetry systems are designed to gather extensive and intricate data from several sources, including GPS collars, satellite tags, and sensor networks. The utilization of visual aids such as charts, graphs, maps facilitate the enhanced interpretation of data by researchers and scientists. The utilization of visual representations of telemetry data facilitates the identification of patterns and trends that may not be readily evident when solely examining the raw numerical values.

To fully interpret the telemetry data, it is crucial to possess a comprehensive grasp of the specific geographical context in which it was collected. Upon the conclusion of data collecting for a certain species, the subsequent step involves the initiation of analysis and study of the designated area. The study area pertains to the geographic locations where GPS data were collected for the species, enabling the creation of a map to delineate the bounds of their travels. After the selection of this place, the acquisition of parameters becomes significant importance. Various elements, including weather patterns, prey availability, geographical features, and topography, must all be carefully considered and accounted for. These features are discussed in this section.

Normalized Difference Vegetation Index (NDVI): The Normalized Difference Vegetation statistic (NDVI) is a widely used remote sensing statistic that serves to assess and quantify the presence of healthy green vegetation within a given geographical region [86, 87, 95]. The calculation of this metric is derived from satellite data and is extensively applied across several disciplines, including wildlife conservation research. The Normalized Difference Vegetation Index (NDVI) holds significant importance in the field of animal conservation research due to multiple factors. Through the examination of NDVI values in various regions or ecological systems, researchers can make estimations regarding levels of biodiversity [96]. High NDVI values are indicative of substantial vegetation coverage, a characteristic that frequently corresponds with the presence of various plant communities that provide sustenance for a wide array of animal species [86, 87, 95, 96].

The study has utilized a Landsat TM satellite image, specifically focusing on the Indian sector of the Sundarbans region. The resolution of this image, which was acquired from the Earth Explorer website of the United States Geological Survey (USGS), is 30 meters. The Earth Resource Data Analysis System (ERDAS) Imagine program was utilized to employ the vegetation delineation function to account for atmospheric variables [87]. Furthermore, the haze reduction capabilities available in ERDAS software were employed to effectively reduce small regions affected by various forms of haze present in the photos. Near – infrared (NIR) and red bands are utilized to find the normalized difference vegetation index (NDVI) maps of the region. The reclassification of these maps was conducted by employing a range of NDVI values spanning from -1 to +1, which corresponds to vegetation levels determined through analysis of spectral reflections.

$$NDVI = (NIR - RED) / (NIR + RED) \qquad (4.1)$$

The above-mentioned formula is used for the NDVI analysis, resulting in the identification of four separate categories: water body (-0.29 to 0.00), land/alluvium (0.01 to 0.1), sparse vegetation (0.11 to 0.2), and thick vegetation (0.21 to 0.51) [87]. To achieve the aims of the study, the researchers employed digital image processing, and ArcGIS software, for the purposes of picture alteration, categorization, analysis, and the production of the NDVI map. The utilization of ArcGIS played a crucial role in the generation of a fake color composite through the amalgamation of near-infrared (NIR), red, and green spectral bands extracted from Landsat TM 2010 satellite images. The utilization of this composite enabled the discernment of vegetation because of the higher reflectance of chlorophyll in the near-infrared spectrum in contrast to wavelengths within the visible range. Table 4.1 shows the vegetation mapping of Sundarbans region.

Table 4.1. Vegetation Mapping /NDVI for Sundarbans region

NDVI Class	NDVI Value Range
Water Body	-0.29 – 0.00
Land/Alluvium	0.01 – 0.1
Sparse Vegetation	0.11 – 0.2
Dense Vegetation	0.21 – 0.51

Among the many applications of telemetry is the monitoring and recording of animal movement across huge geographical regions. Through the use of this visualization, useful information regarding migration routes, vegetation, and the evaluation of home ranges for both individual animals and populations can be obtained. These discoveries help to a more comprehensive understanding of animal behavior and ecology, as well as to the development of techniques for more effective management of wildlife conservation.

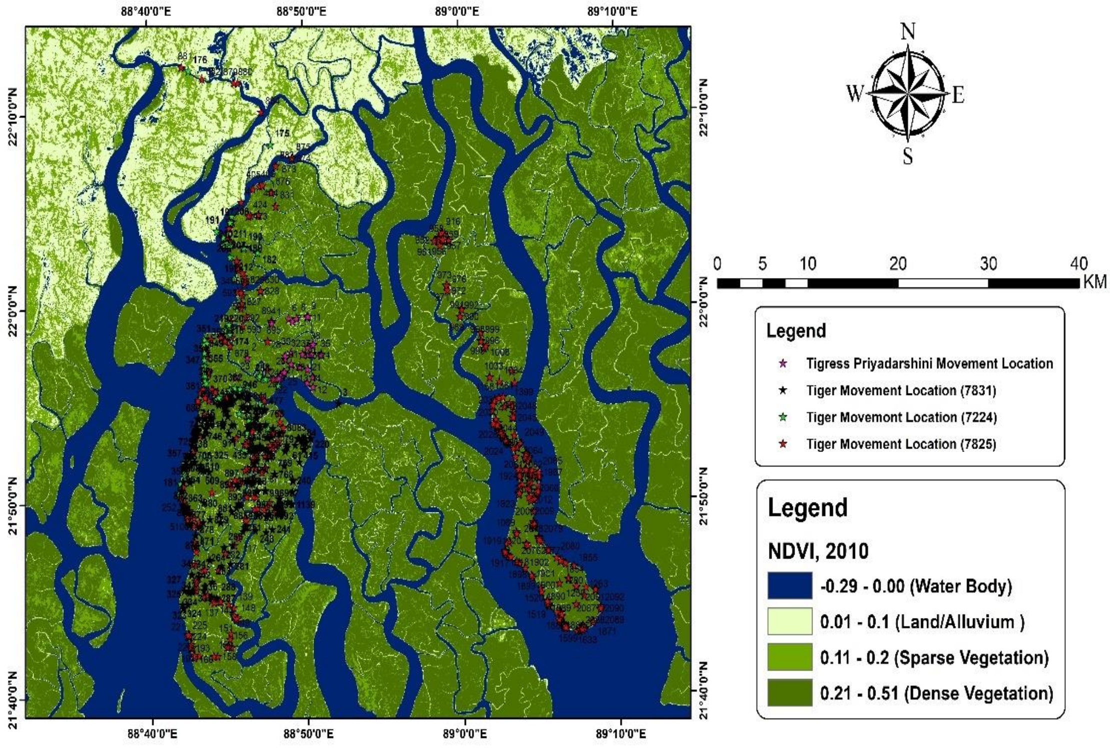


Figure 4.2 Map of Sundarbans region with movements of 4 tiger/tigress shown in different colors

Figure 4.2 shows the location of all 4 tigers across the Sundarbans region, The numerical identifiers accompanying the tiger locations shown in Figure 4.2 serve as distinct labels assigned to each individual place. These identifiers are exclusively used to precisely differentiate and locate each location on the map. It can be seen clearly from the figure that the few locations of the tigers are also found to be inside the water channels as well. Tiger_7825 has crossed the water channels. Another Tiger_7831 can also be seen having few locations inside the water channels. Tigress_priyadarshini has also crossed the water channels and can be seen with locations in water channels as well. All four tigers have their location across the water channels, which clearly suggests that these channels were crossed by all the tigers without any hindrance. It can be seen from Figure 4.2 that tigers can cross water channels with ease and at times their location is seen inside the water channel.

This validated those tigers can cross water channels. In future work, it can be analyzed which type of channels they cross easily and others occasionally. The data obtained through the utilization of the ARCGIS tool presents NDVI values (as shown in table 4) for the Sundarbans area, as well as details regarding certain locations situated within water channels, which provide crucial information.

4.1.3 Community Analysis for Feature selection

To understand how tigers interact with their surroundings including vegetation, water sources, and other species is known as community analysis [97]. To understand the behavioral aspect of tigers in their ecological niche, it is important to analyze their movements & their interactions with the geographical elements [98]. The Sundarbans serve as a habitat for one of nature's most iconic and endangered creatures—the Bengal tiger (Panthera tigris tigris) [78]. Within this unique ecosystem, an intricate relationship exists between vegetation, prey availability, and water sources that significantly shape the behavior and survival of these majestic felines. The dense mangrove forests offer vital cover for hunting activities as well as periods of rest [99]. With its tall grasses, thickets, and interwoven roots acting as effective camouflage during stalking pursuits while providing sanctuary from potential dangers. By comprehending how different types of vegetation impact tiger movement patterns, conservationists can develop strategies to safeguard critical habitats while ensuring optimal conditions for successful hunts [24, 99]. Prey availability stands out as another pivotal factor influencing tiger populations in the Sundarbans [24]. The distribution and availability of prey species have a direct impact on the migrations and population dynamics of tigers [100]. To understand how tigers adapt their hunting behaviors, it is important to assess variations in prey densities across different regions within the Sundarbans. By identifying areas with higher concentrations or seasonal fluctuations in prey populations, conservation efforts can focus on protecting these crucial feeding grounds [98, 100]. The presence of water sources is essential to the functioning of this one-of-a-kind ecosystem because these water sources both give tigers the opportunity to drink and act as pathways that connect various sections of their territory [24]. Access to freshwater rivers, creeks, or tidal channels can influence the migrations of tigers. Natural water resources are becoming scarce due to tidal oscillations & changes in the salinity levels [24]. Community analysis is performed to acquire better understanding of their social structure, daily activity cycles, individual behavior and their interaction with other species. This can help in providing the features to train the model that can help to address important issues impacting the overall population trends. To comprehend the behavior of tigers in their natural habitat, it is essential to examine their movements and how they interact with geographical features. To achieve this, statistical analysis is conducted using GPS data on tiger locations, prey distribution, and the topographical features of the Sundarbans region.

Steps to perform community analysis.

The examination of the ecological communities in which tigers reside and their relationships with other species within those communities is known as community analysis for tigers.

- When analyzing tiger communities, a crucial factor to consider is the examination of the prey species that tigers depend on as their source of sustenance.
- Another important aspect is studying the habitat structure or landscape characteristics including vegetation cover, water resources etc.
- Analyzing the daily Movements of tigers in community can assist in identifying possible clashes between humans and tigers when they coexist

in the same environment or utilize similar resources, such as grazing areas or water sources.

4.1.3.1 Community Analysis of Vegetation cover and water resources

The movement of tigers is greatly affected by vegetation, playing a vital role in their behavior, hunting patterns, and overall survival [101]. Here are some important factors to consider: Vegetation provides crucial habitat for tigers as it offers cover for resting, hiding, and stalking prey. Dense vegetation such as tall grasses, thickets, or forests allows tigers to effectively blend in while patiently waiting to ambush their prey [102]. Tigers primarily hunt alone and rely on stealthy approaches to catch their prey. Vegetation helps them remain hidden from potential victims until they can get close enough for a successful attack. The presence of dense vegetation increases the success rate of tiger hunts by providing effective concealment during the stalk. Vegetation acts as natural pathways connecting different habitats within a landscape. Dense vegetation often supports higher populations of herbivores like deer or wild boar – which serve as primary prey for tigers [103, 104]. Suitable vegetative cover encourages these herbivores to thrive due to the availability of food sources and protection from predators. Vegetation plays an important part in the community formation of any species [105].

To perform this analysis the following features are utilized:

a) Four classes are created ‘Land’, ‘Sparse Vegetation’, ‘Dense vegetation’, ‘Water Body.’
b) Time is divided into 4 classes ‘morning: {5:00 , 12:00}’, ‘Afternoon : {12:00 , 17:00} ‘, ‘Evening : {17:00 , 20:00}’, ‘Night: {20:00 , 5:00}’
c) The data on the location of tigers, along with timestamps, is compared to determine how many times a tiger has been found in a particular vegetation type. This is done by increasing the corresponding vegetation counter based on pre-defined time classes.

4.1.3.2 Community Analysis of Prey Species

To conduct an analysis on the geographical locations of tigers and their proximity to the average value of prey, the latitude-longitude or GPS coordinates are transformed into a kilometer-based scale. The following formula is used to calculate the distance between data points in kilometers approximately [106].

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2) \tag{4.2}$$

$$c = 2 \cdot \mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)}) \tag{4.3}$$

$$d = R \cdot c \tag{4.4}$$

Where,

$\Delta\varphi$ is representing difference between latitudes of tiger/ prey i.e. latitude1 – latitude2 for given GPS coordinates.

$\Delta\lambda$ is representing difference between longitudes of tiger/ prey i.e. longitude1 – longitude2 for given GPS coordinates.

R is Radius of earth in Km = 6371

d is the distance between two GPS locations in Km.

To analyze the impact of prey distribution on Tigers, we have taken the location of different preys and checked how many times it was within the range of 1 sigma, 2 sigma, 3 sigma deviation of tiger location.

4.1.3.3 Community Analysis of Daily Movements of Tigers

The locational data of sampled tigers is analyzed, and descriptive statistics is performed to understand the basic patterns in the data. The data is analyzed to find the average movement in 1-hour, total area explored by the tiger, percentage of Sundarbans area covered by the tiger. Table 4.2 shows data of these 4 tigers. The average distance moved in a time span of 1 hour by Tiger 7831 is 0.3606 km. Tiger

7825 exhibited a mean displacement of 0.2985 kilometers for one hour. The tiger with identification number 7224 exhibited an average displacement of 0.9443 kilometers, whilst Tigress_ Priyadarshini traveled an average distance of 1.5721 kilometers within a one-hour time. After calculating the comparative movement of all the four subjects individually with respect to all of them together, in the areas of Sundarbans Forest, it is concluded that tiger 7831 moved 11.37%. Tiger 7825 moved 9.41% in comparison to the whole. Tiger 7224 moved 29.72% more while Tigress_Priyadarshini moved and covered 49.49% of the area.

Table 4.2 The average hourly displacement of radio collared tigers in the Sundarbans region.

Tigers	**Movement Track (1-Hour Average) (in KMs)**	**Comparative Movement (in %)**	**Male-Female Movement Ratio (Male: Female)**	**Area Explored (in sq. km)**	**Area of tiger/ Area of Sundarbans (%)**
7831	0.3606	11.37 %	0.5344:1.5721	11	0.18
7825	0.2985	9.41 %		70	1.17
7224	0.9443	29.72 %		70	1.17
Tigress_Priyadarshini	1.5721	49.49 %		15	0.25

Upon calculating the Male-Female Movement Ratio for the given four subjects, the ratio came up to be 0.5344:1.5721. Tiger Displacement was another parameter taken under consideration for the data wherein statistical analysis is performed to find out how much the tiger displaces in an hour’s time interval. Tiger 7831 dispersed a total of 11 sq. km, tiger 7825 and tiger 7224 displaced 70 sq. km. in an hour, individually. Tigress_Priyadarshini covered an area of 15 sq. km. (on an average) in an hour.

4.1.4 Model Building using Machine Learning

In this section, we will delve into the model that is used to forecast the immediate whereabouts of tigers in relation to the distribution of their prey within the Sundarbans region. As we have established in previous sections, data acquisition serves as an essential initial step for any ecology-based study; however, it can be a laborious process to obtain data from those who have collected it. Once the data has been acquired, the subsequent logical step involves examining and analysing the specific area from which the data was gathered. It is important to gather pertinent details about the study area such as landscape features, vegetation mapping, and terrain characteristics [107]. This step is explained in data visualization section, where the features of the Sundarbans are extracted, after obtaining these features, we established the correlations between the selected features and tigers' activities to comprehend their influence on daily activities. The objective of this section is centred around constructing a model that can anticipate future locations based on prey distribution within Sundarbans. For carnivore animals, prey search is a major cause of movements [107, 108]. As per their capacity, such animals make movements from one place to another and hunt for prey. Tigers roam in the area where potential prey could be found. Most of the tiger's movements are done for hunting or searching for prey [109]. Their movement can be short term or long-term depending upon the availability of the prey [109, 110]. Tiger's activities roughly coincide with their preferred prey. The literature suggests that tigers while hunting are highly organized and move in a specified direction, which increases the probability of finding prey [111]. Tigers are very flexible, and their way of hunting also varies with the age and their experience, this makes tigers have a wide variety of prey types and sizes [101]. This work's primary achievement is in creating a precise correlation between the movements of tigers and the presence of prey in the region. When the tiger moves slowly or fast or changes the line of movement depends a lot on the ecology of the potential prey [112]. As a result, it was essential to measure the movement of the tiger in relation to the movement of the prey in order to determine the most crucial aspects of the tiger's movement. As a result of this, the four tigers who were intended to serve as a sample for this research project were observed for their movements in accordance with the selection of prey.

Model Building

In this section, we describe how the prediction model is built to understand the movement of tigers with respect to the prey distribution of the region Sundarbans by analyzing telemetry data, in one of the crucial tiger conservation landscapes using the machine learning algorithms. The overall flow of the experiment to build the model is shown in figure 4.3.

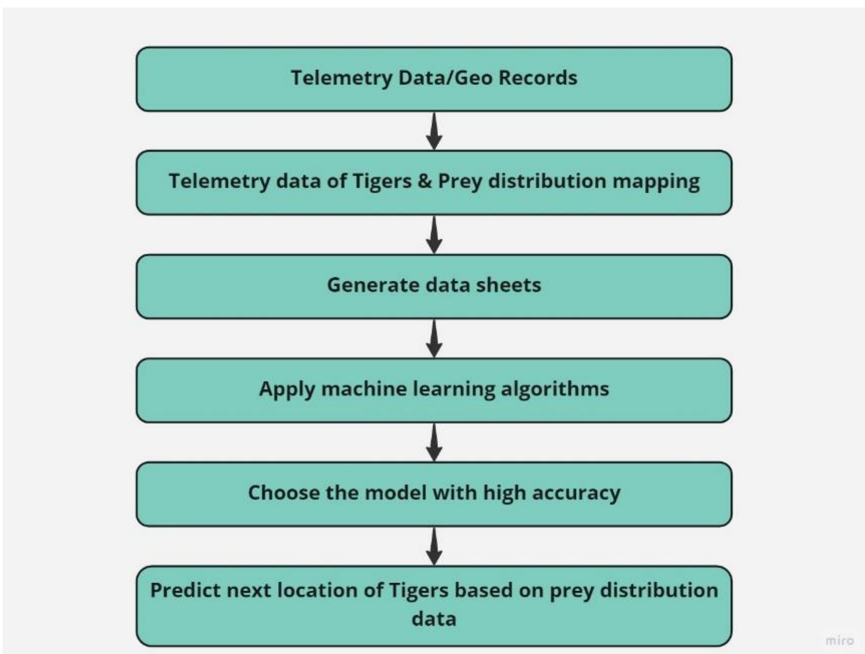


Figure 4.3 Overall Flow of Tiger Movement Prediction using ML in context of Prey Distribution in the region

In figure 4.3 the first step is to collect the telemetry data or geo records for the study. To understand the movement patterns of tigers, firstly we explored tiger movement patterns according to prey context using data from GPS-collared individuals within the Sundarbans region. The GPS location data is obtained from collars fitted onto three adult male and 1 female Bengal Tigers/Tigress. The prey distribution dataset which was also collected and supplied by the WII. There were eleven different preys namely, 'Chital', 'Egret', 'Estuarine Crocodile', 'Human', 'King Cobra', 'Lesser Adjutant Stork', 'Otter', 'Red Jungle Fowl', 'Rhesus Macaque', 'Water Monitor Lizard' 'Wild Pig'. Multiple GPS locations are there for the prey in the dataset. In this work we are considering Arithmetic mean of each prey for example, the average value of prey P1 is taken and mapped with all GPS locations of tiger T1. It will help the model to understand the movements of tiger w.r.t average location of prey. Multiple locations of prey can cause bias as it is not certain which prey is tracked by which tiger. If telemetry data is available for every single prey for very small intervals, it will increase the randomness in the model. Thus, an average of their multiple locations makes more value for forecasting the tiger's movement. Prey will go around the habitat and tiger will look around in the home range only, as tigers roam in their home range only. Home range is a region which provides all the resources required for the survival of the species. Naturally, a region with high prey distribution would be the part of tiger's home range [113]. By analyzing these data sets we will be able to understand how prey availability or scarcity influence tiger movements which can provide insights into how best we can manage this population [111, 112, 113]. Predicting the movement of any animal with time is possible by generating the sequences from the obtained geo records [114]. All the movements of the tigers were studied separately and thus four different records were maintained before a collective study could be done. The data was a first-hand record obtained from the institute and thus it was mainly high-quality data. Daily movements of the tigers, their wandering for prey is observed, which is a major factor in understanding their ecology [113, 115].

Figure 4.4 shows the prediction cases considered for the study. The figure shows the different cases used for predicting the next location of tiger w.r.t prey location. The different cases are shown and explained below:

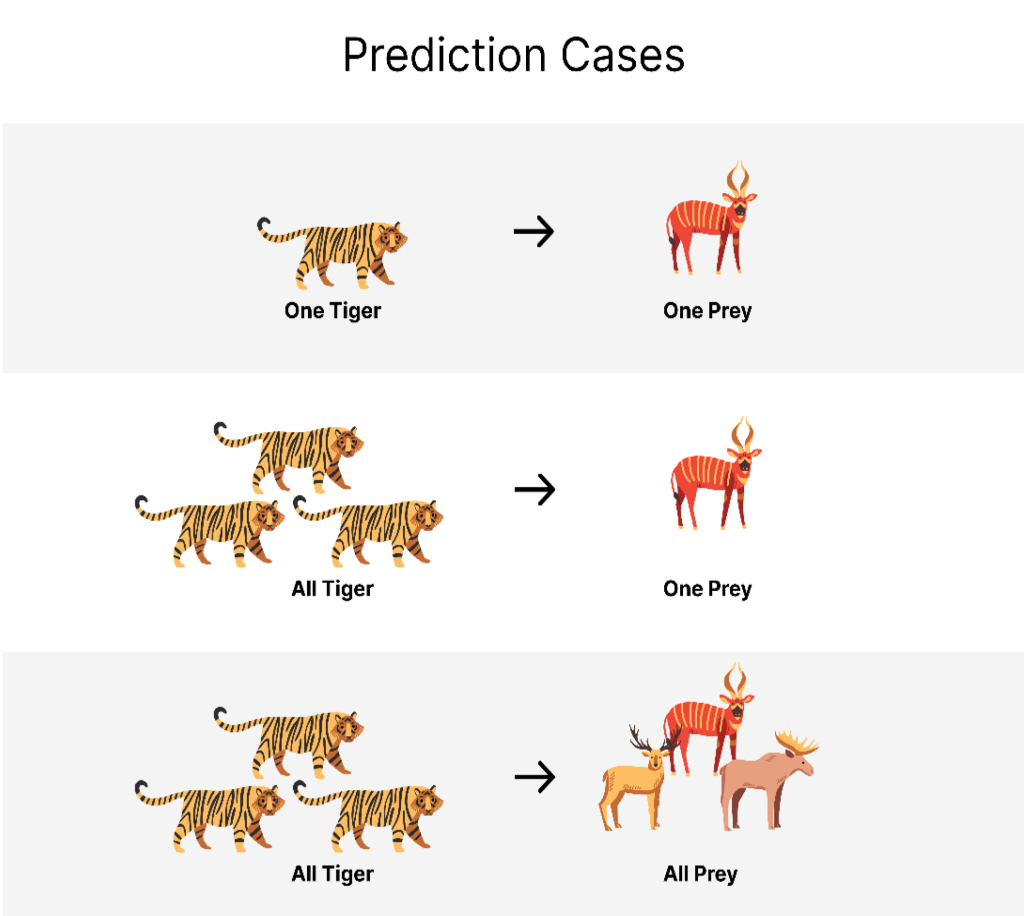


Figure 4.4. Prediction Cases used in Model Building

a) One Tiger: One Prey

   Data of one tiger is mapped with the average value of one single prey. For example, data of Tiger_7825 is mapped with the average value of chital.

b) All Tiger: One Prey

   Data of all four tigers is mapped with the average value of one single prey. For example, data of Tiger_7825, Tiger_7224, Tiger_7831 and Tigress_Priyadarshini is mapped to the average value of prey chital.

c) All Tiger: All Prey

Data of all four tigers is mapped with the average value of all prey. For example, data of Tiger_7825, Tiger_7224, Tiger_7831 and Tigress_Priyadarshini is mapped to the average value of prey Chital, Egret, Estuarine Crocodile, Human, King Cobra, Lesser Adjutant Stork, Otter, Red Jungle Fowl, Rhesus Macaque, Water Monitor Lizard, Wild Pig.

As mentioned in figure 4.3, the third step is to generate datasheets, these are generated using the above-mentioned prediction cases. To train the model 3 different cases of prey distribution data has been created along with the telemetry data of tigers as shown in table 4.3 and figure 4.4. Figure 4.4 provides an explanation of how the tiger and prey mapping process is carried out according to the collected dataset. Table 4.3 presents the three distinct scenarios, each of which demonstrates how the mapping is carried out. For the purpose of understanding the movement patterns of tigers in connection to the distribution of prey in the Sundarbans region, it also displays the total number of records that were generated for each example of a forecast.

Table 4.3 Prediction Cases for Model Building

Prediction Case	Mapping of Tiger & Prey Distribution Data in single sheet	No of data points generated
Case1	Each tiger is mapped with Expected value of location of prey, in a one-to-one mapping	49434
Case 2	Tiger location is mapped to expected value of prey in a many to one mapping	4494
Case 3	Each tiger is mapped with Expected value of location of prey, in many-to-many mapping	4494

In this study, we have used machine learning techniques such as Ridge regression, MLP, KNN, Decision tree, SVM to predict the next location of tigers with respect to location of prey in Sundarbans. Traditional Approaches such as occupancy models and linear models need are dependent on the statistical expertise in ecological domain to achieve unbiased outcome [116]. Machine learning algorithms such as support vector machines, MLP, random forest, decision tree etc. have been applied to telemetry data. Machine learning algorithms have gained popularity in ecological studies to understand movement patterns and behavioral state changes [116, 117, 118]. Support vector Machines perform excellent in classification and pattern recognition [117], the algorithm utilized is designed to locate the hyperplane with the most significant separation between classes, also known as the maximum-margin hyperplane. The support vectors are determined by identifying instances that fall closest to this hyperplane. This hyperplane is exclusively defined by its set of support vectors, which are located at the outermost edge of each class distribution within the border region separating them [117]. K-Nearest Neighbor (KNN) is using n=3 for the model, other algorithms such as decision tree is based on the condition, if the condition is true then another condition is tested and so on. MLP is also used to predict the next location of the tiger. Random forest algorithm is also implemented for the dataset. Currently, it is outperforming many traditional approaches for detecting the patterns and underlying behaviors in ecology [116, 117, 118]. In MLP there are 30 input nodes, and a hidden layer has 30 nodes and only 1 output node. Comparative analysis is done on the results of these machine learning models to get the best performing machine learning model for the data. The dataset is divided into training and testing data, 80% of the complete dataset is used to train the model and 20% of the complete dataset is used to test the model. Supervised machine learning algorithms are performing excellent over the movement data to detect the patterns in ecological studies [118, 119]. The accuracy of the model is dependent on the GPS locations sampling frequency and the temporal grain. To perform the experiment, we are assuming that the territorial behavior of tigers results in preference for prey animal which they find in their area. Thus, the assumption that different tigers have different prey preferences sounds legitimate. Also, figure 4.2 indicates that water channels are not a point of concern for the tigers as they can be found inside the water channel and at time cross the channels with ease. Thus, for model building we need not provide any special treatment to the water channel and can be explored in future studies. Thus, we make the following assumptions about the data.

Assumption 1: Tigers are always equidistant from their prey.
Assumption 2: Water channels are not a hindrance in movement.

The hypothesis tested for statistical analysis are as follows:

Test1:

$$H_0 : \forall prey(d_{avg}(prey_{mean}, tiger_{day-to-day}))is\ constant\ for\ all\ tigers$$

$$H_a : \forall prey\left(d_{avg}(prey_{mean}, tiger_{day-to-day})\right)is\ different\ for\ all\ tiger$$

To test the hypothesis, the distance of the tiger from their prey is calculated. For these calculations equations 4.2 to 4.4 are used. The geo locations of the tiger and prey are converted into Kms. To find the distance of tigers from their prey. Figure 4.5 shows the distance of each tiger from their prey, the distance that was there on a day-to-day basis between tiger and mean location of the prey. The analysis demonstrates the movement of four sampled tigers throughout the areas where the possibility of catching prey could be the most. It involves the distance of tigers from other animals and is portrayed through graphical representation. It can be seen through figure 4.5 that tigers are not equidistance from their prey. Again, there seems to be a preference in prey they like to consume. Also, as observed from figure 4.5, estuarine crocodiles and otters are also prey for tigers. Both are water-based animals. This dietary habit points in the direction that tigers have food habits for water-based animals. It is evident that the null hypothesis, H_o is rejected, and our alternate hypothesis is validated.

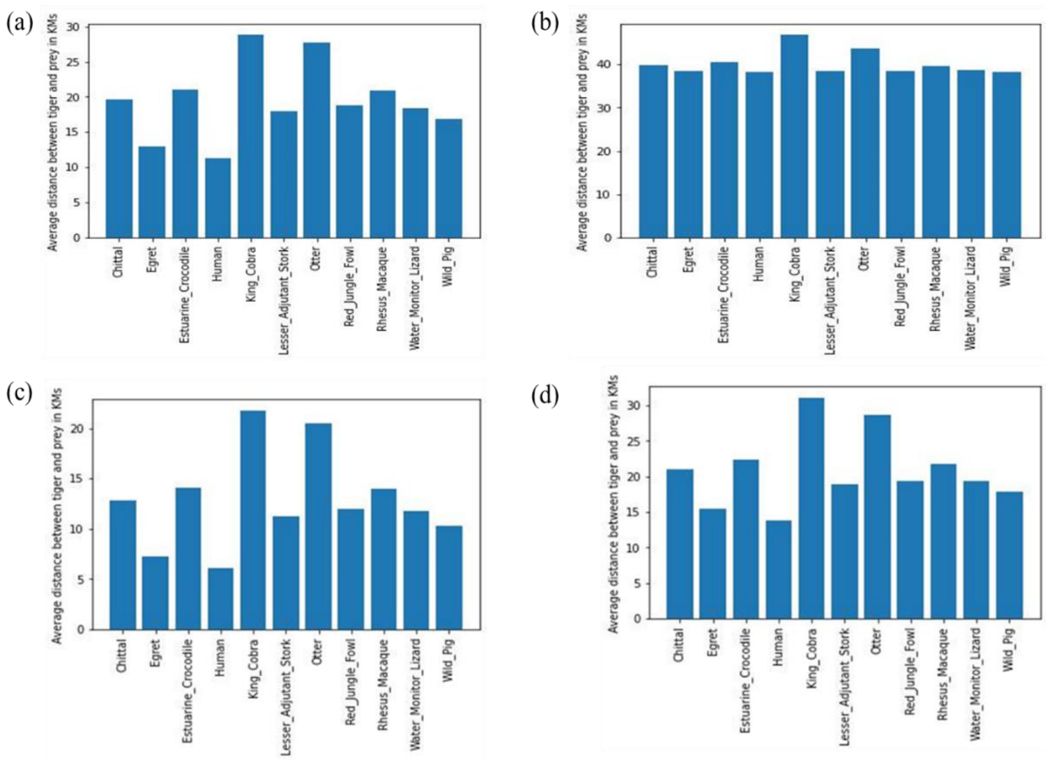


Figure 4.5. Distance of each Tiger from its each prey a) Tiger_7224 b) Tiger_7825 c) Tiger_7831 d) Tigress_Priyadarshini

Again, it can be said that prey distance varies from prey to prey. It leads to construction of models that could help to study the movement and ecology of tigers. This is helpful in creating an individual level model for tiger movement as per the prey distribution in the area. Using these hypotheses as the base for model construction, model will predict the immediate next location of the tiger w.r.t prey. Telemetry data is time series data which contains (x, y) as coordinates of the location of the tiger as well as prey at a given time t. The coordinates of the new location at time t+1 will be given by the model. The coordinates of tiger & prey at time t will be given to the model as input, the trained model will provide new coordinates at time t+1 for tiger.

$$f_t(\varphi_T, \lambda_T, \varphi_P, \lambda_P) \rightarrow f_{t+1}(\varphi_T, \lambda_T) \tag{4.5}$$

Where:

φ_T *represents the latitude of tiger.*

λ_T *represents the longitude of tiger.*

φ_P *represents the latitude of prey.*

λ_P *represents the longitude of prey.*

At a given time t.

Algorithm 2 shows the steps of model building for predicting the next location of tiger based on GPS location of tigers, prey distribution and time of day for each GPS location provided for the region Sundarbans. Input for the algorithm is telemetry data of tigers and prey which contains GPS location with time. In the output the next location of the tiger is given by Machine learning algorithm. Here, the best performing algorithm result is shown, the details for the same are discussed in the result section.

Algorithm- 2 Prediction based on prey latitude/longitude, tiger latitude/longitude and time of day using machine learning algorithms

1. Input: Tiger location is captured using telemetry collar/radio collar, $L_{tiger} = \{lat_i, long_i\}_{i=1}^{z}$
   Coupled with datetime $T = \{yy - mm - dd\ hh{:}mm{:}ss\}$ and $L_{prey} = \{lat_{prey}, long_{prey}\}$
2. Output: Next Latitude, Longitude position of the Tiger
   $L_{tiger+1} = \{lat_{i+1}, long_{i+1}\}$
3. Function: $Predict\_1(L_{tiger}, T, L_{Prey})$
   $L_{tiger} \leftarrow \{\{lat_1, long_1\}, \{lat_2, long_2\} \ldots \ldots, \{lat_n, long_n\}\}$
   $T \leftarrow \{(yy - mm - dd\ \ hh{:}mm{:}ss)_1, \ldots \ldots \ldots\ (yy - mm - dd\ \ hh{:}mm{:}ss)_{n,}\ \}$
   $Lprey\ \leftarrow \{(lat_{prey}, long_{prey})\}$
   $Repeat$ for all $\{L_{tiger}, T, L_{Prey}\}$ do
      $t \leftarrow time\_convert(T)$
      $Lprey \leftarrow mean(Lprey)$
      $predict\ \leftarrow decision\ \_tree(\text{Ltiger}, \text{T}, \text{Lprey})$
   end
4. Return $(predict)$
5. EXIT

4.1.5 The GRID Generation

To apply a game theory-based approach for forecasting the next location of a tiger, we need to split the area in a grid where the game will be played. Figure 4.6 shows the grid over the Sundarbans region. To generate the grid, the same image is used which is used to generate the NDVI values of the Sundarbans region as explained in the above sections. The process of generating the grid is explained below.

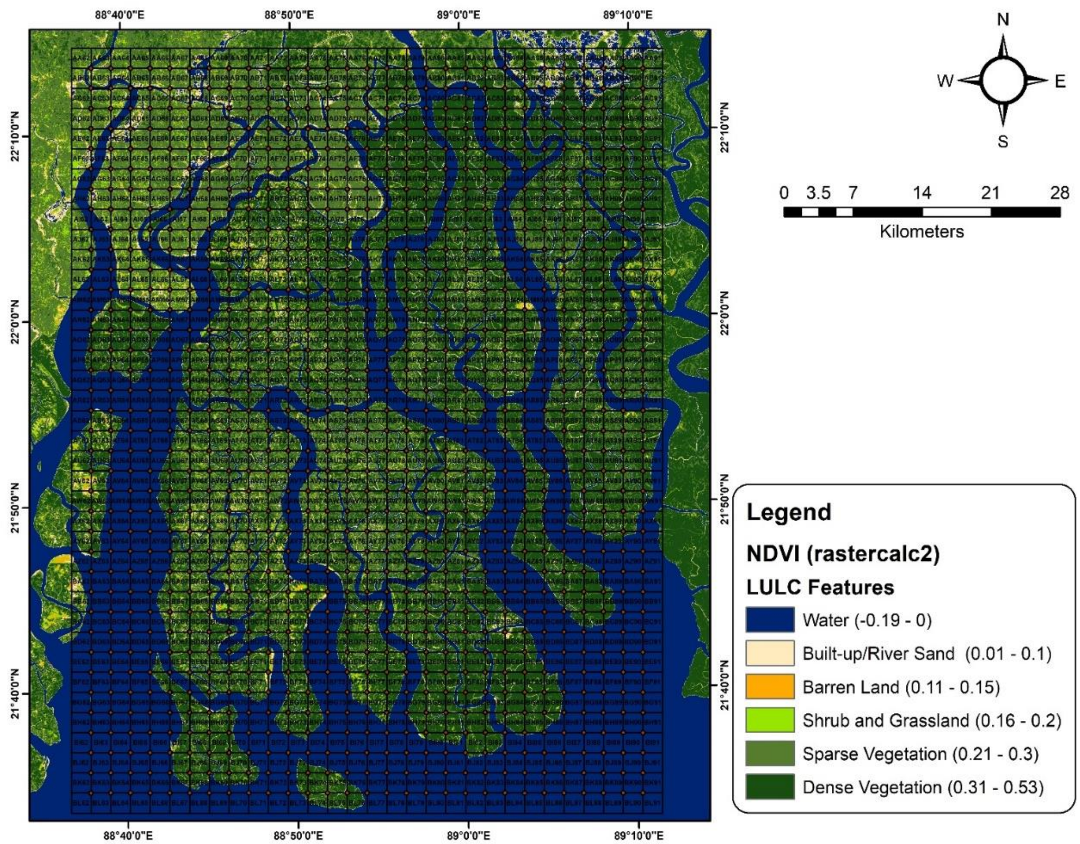


Figure 4.6. Sundarbans region divided into grids each of 2 x 2 km.

Data used

In the present study, a Landsat multispectral cloud-free satellite image was collected, downloaded from the free available United State Geological Survey

(USGS: https://earthexplorer.usgs.gov/). Landsat-8 OLI image was used for analysis for Normalized difference vegetation index (NDVI) in the study area.

Coordinate Referencing system

There is a standardized approach of depicting places that is provided by the coordinate referencing system. There is a great deal of different kinds of references [122]. Choosing a referencing system is contingent upon the data that has been gathered, the scope of the geographic data, the purpose of the data, and other related parts of the needs that are currently being met. [123]. A coordinate reference system depends on the following aspects:

1. Projection,
2. Datum and
3. Ellipsoid

1. Projection: A projection is a two-dimensional representation of the three-dimensional Earth that uses easting and northing coordinates. [124].
2. Datum: A datum defines the origin and orientation of the coordinate axes. It provides the information needed to anchor the abstract coordinates to the earth. The datum defines the origin point of the coordinate axes and defines the direction of the axes [123, 124].
3. Ellipsoid: To begin the process of building a CRS, the first step is to determine the shape of the earth. The basic shape of the Earth can be represented using a straightforward model known as an ellipse. In every single mapping and coordinate system, this shape serves as the foundation. The Earth is almost spherical, however there is a tiny bulge at the equator that makes it ~0.33% larger than at the poles [124,125]. The ellipsoid is an approximation and does not fit the Earth perfectly [124,125]. There are different ellipsoids in use, some are designed to fit the whole Earth (WGS84, GRS80) and some are designed to fit a local region (NAD27) [122, 123, 125]. Local ellipses can be more accurate

for the area they were designed for but are not useful in other parts of the world. The modern trend is to use a global ellipsoid for compatibility, such as WGS84 [124]. There are a great number of maps that are based on the local-best fitting ellipsoid, even though this notion is today considered to be quite outdated.

Table 4.4 Some Common Ellipsoids [124]

Name	Equatorial axis (m)	Polar axis (m)	Inverse Flattening (1/f)
Airy 1830	6377563.4	6356256.9	299.3249753
Clarke 1866	6378206.4	6356583.8	294.9786982
Bessel 1841	6377397.155	6356078.965	299.1528434
International 1924	6378388	6356911.9	297
Krasovsky 1940	6378245	6356863	298.2997381
GRS 1980	6378137	6356752.3141	298.257222101
WGS 1984	6378137	6356752.3142	298.257223563
Sphere (6371 km)	6371000	6371000	∞

Data Processing

The Landsat image was made by ArcGIS platform. The radiometric and atmospheric correction method was used to reduce the influence of inconsistencies of remotely sensed data. Google Earth was used for geo-referencing of satellite images [87, 96]. Universal Transverse Mercator (UTM) projection and datum (WGS84) have been projected during the processing of Landsat 8/9 OLI dataset [124]. Normalized difference vegetation index (NDVI) is used most comprehensively for the distribution characteristics of mangrove forests [96]. The values of NDVI lower than 0.15 indicate the presence of barren areas, sandy or build-up surfaces. Moderate values (0.16 – 0.2) of NDVI indicate the presence of the shrub and grassland of the study area. The Higher value (0.21-0.3 and 0.31 – 0.53) indicates the presence of Sparse and dense vegetation cover of the study area. The values nearest to 0 indicate the presence of water bodies [86, 87]. Details of

NDVI values are already discussed in the section of data visualization. The Grid index features have been created to define 2×2 sq.km each grid of the study area. These grids have been defining the spatial extent, reference, and NDVI values of the entire study area. These grids created using Grid Index Features in geo-processing tools (Cartography Tools) of the study area. After that, to create the intersections points of each grid using Intersect tool in ArcGIS that are must be a clear point at which the lines intersect other lines or the boundary of a polygon. After that, intersections points have been extracted as point features. Geographical locations of all intersection points have been extracted using the multi-point extraction method [124, 125] of the study area. Finally, NDVI Value has been extracted based on the intersection points using multi-points to value extractions tools in ArcGIS.

Size of Grid Cell

The Sundarbans region has been divided into 2 x 2 km grids, with each grid cell representing a tiger location. This size was chosen based on the average daily displacement of tigers in the area, which was calculated using telemetry data and found to be approximately 2.39 km. To simplify calculations, we have rounded this down to 2 km as the average daily displacement for tigers in the Sundarbans. Using latitude and longitude data as input for geopy library in Python at a given time t, we computed the average displacement of the tigers. As a result, the entire area under consideration has now been divided into a grid measuring 2 km by 2km.

4.1.6 Game theory Based Tiger Behavioural Prediction Model

As shown in Figure 4.1, this is the last step of the proposed methodology through which we can finally propose the novel mathematical model to predict the tiger behavioural pattern prediction. By gaining an understanding of animal behavior, it is possible to develop management measures that are more effective in the context of wildlife conservation and study. Within the context of this field, this section refers to a novel mathematical model that was developed with the purpose of predicting the behavioural patterns of tigers. It is discussed in detail in section below.

4.2 Game Theory Based Model for Tiger Behavioural Pattern Prediction using Telemetry Data

In this section the novel approach of using game theory to predict the behavioral pattern of tiger utilizing their telemetry data is discussed and shown in figure 4.7.

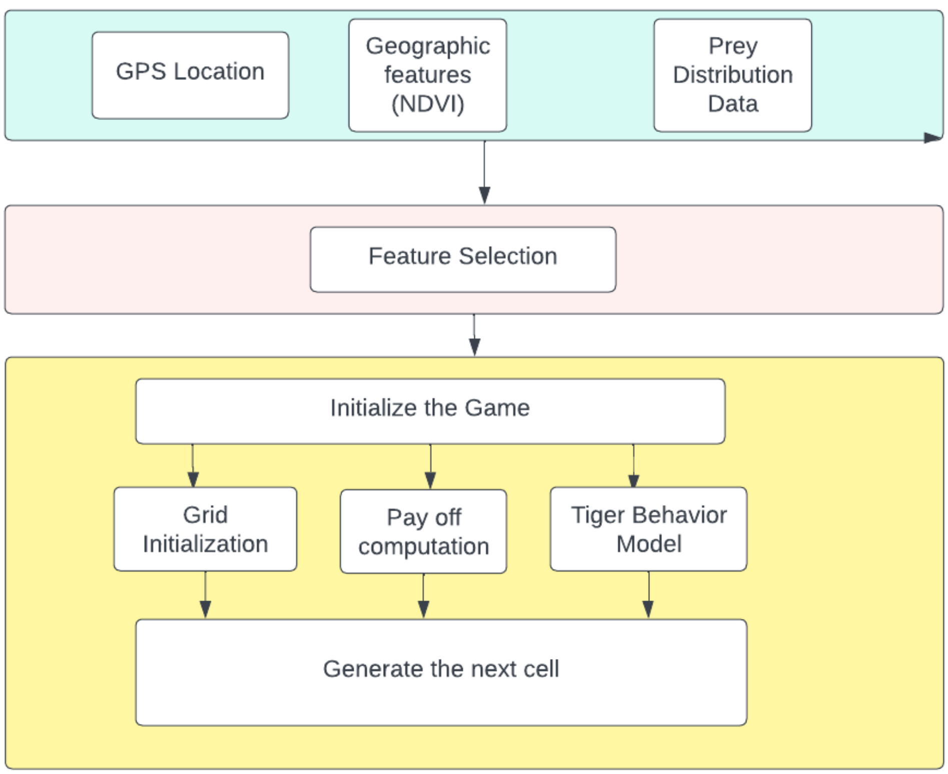


Figure 4.7 Proposed Model to predict Tiger Behavioral pattern prediction using game theory.

Developing a model for predicting the movement of tigers by utilizing game theory is an intriguing and demanding undertaking. Game theory, which concerns itself with decision-making in competitive scenarios, can be employed to examine the strategic interactions between tigers and their prey or other tigers [67]. The prediction of tiger movements involves a strategic interaction between tigers and environmental factors, with two parties having opposing interests: the tiger trying to catch prey, while the prey tries to avoid being caught. This entire interaction is influenced by the environment, with each player striving for an outcome that benefits them the most. To succeed in this game, both sides must play intelligently and consider their opponent's potential actions carefully. For example, if a tiger follows the same route every day, its prey can easily avoid it or vice versa. Therefore, it is advantageous for tigers to adopt an unpredictable approach when hunting. Rather than relying on purely random selection of the areas, tigers should prioritize areas with higher animal densities and key species using what is known as the "tiger strategy." This strategy involves choosing from various potential routes in a randomized manner based on forecasting where tigers are likely to be next considering prey density and other environmental factors. While achieving ideal scenarios may not always be feasible due to enormous environmental factors' various forms of interactions, implementing a game-theory-based approach can still yield positive results. In Stackelberg Security Games, defenders must continuously defend a set of targets using limited resources while attackers observe their strategies and plan attacks accordingly [64]. For defenders, an action or pure strategy involves deploying a specific set of resources (R), whereas for attackers it represents targeting one location. The defender's mixed strategy comprises a probability distribution over various pure strategy. Each target also has associated payoff values that determine utilities for both defender and attacker based on successful or failed attacks. [64, 67] The tiger behavioral prediction model utilizes game theoretic analyses (as shown in figure 4.7) and considers various input data, including the GPS locations of tigers with timestamps, prey distribution information for the region, and geographical features like water channels, barren land, and vegetation type. After conducting feature selection on this input data, we found that all features were valid for building our model. Given the inherent conflict between tigers and their prey, we modeled this recurring behavior as a predator-prey game using Stackelberg security game where participants are in competition rather than collaboration. This approach is particularly useful when simulating competitive environments since it lacks external regulations mandating cooperation. Next, initialize the grid and then calculate a payoff matrix to predict where the tiger will move next on the grid.

GPS Location, Geographic Features, Prey Distribution Data and Feature selection

To build a game theoretic model for Deciphering the movement patterns of tigers which are crucial in comprehending their ecology since movements are intricately linked to behavioral characteristics [47]. Our approach involves integrating geographical features obtained from vegetation mapping, including water channels, dense or sparse vegetation, and alluvial land. These geographic attributes serve as pathways for both tigers and prey to move around. Furthermore, our model incorporates data on prey distribution within the region. Finally, we make use of GPS locations of the tigers to complete our analysis. Through community analysis, it is observed that all the geographic features mentioned here are having an impact on their movements and is already discussed in the section above.

Initialize the Game

a) Grid Initialization

The predator-prey game is a crucial aspect of the natural world, one that serves to maintain balance and promote biodiversity. In this game, predators rely on their hunting skills to capture prey, while prey must use their agility and speed to evade capture. This dynamic creates a delicate dance between predator and prey, where each must constantly adapt in order to survive. The stakes are high for both sides - without predators, herbivores would overgraze and damage ecosystems, while without prey, carnivores would starve. Despite its ruthless nature, the predator-prey game ultimately benefits all species involved by ensuring that only the fittest survive. As such, it remains a fascinating phenomenon worthy of further study and appreciation in our ever-changing world.

To commence the game, it is possible to select any arbitrary cell inside the grid as the initial location for the tiger. The predictive model will determine the subsequent cell inside the grid that the tiger is likely to move to.

b) Payoff Computation

In game theory, a payoff matrix is utilized to illustrate the consequences of various strategies chosen by two players [62, 67]. When examining predator-prey games, we can employ a payoff matrix to demonstrate how each player's strategy will impact their own fitness or reproductive success based on the actions of the other player. To create a payoff matrix for a predator-prey game, it is necessary to consider the potential strategies that each player may adopt and their corresponding payoffs [126]. The following is an example of payoff matrix generated for a particular cell in the grid. The payoff matrix is generated for probability of movement for cell change. This probability generation takes into consideration the distance of different prey from tiger, time of day, time of year and geographical features of the region. Time of day and time of year is used to handle seasonality variations in the behavior of tiger.

As in the preceding section we have seen the model predicting the next location of tiger using machine learning algorithms. This model takes in input- GPS locations with time for tigers and prey data. The results showcased that among all ML algorithms, Decision Tree algorithm produced best results with highest accuracy rate of predicted predator location compared to actual location (the results are discussed in further section).

CART model of Decision tree is used, CART constructs binary trees using the feature and threshold that yield the largest information gain at each node. CART is used for the model building as it yields the largest information gain at each node [127].

In the proposed approach, payoff is the probability of the next cell in the grid. To compute the payoff, we must find the probability of the next cell. The next cell location can be in the north, east, west, south, or same of the current cell/location. In the proposed model, the tiger is assumed to be in any random cell of the grid as initial location then model will simulate the possibilities of generating next cell, which is a payoff in this work. To decide over the direction of predicted location of the tiger from the current location forward Azimuth is used. Stackelberg Security Games was used to finally predict the path of tiger.

Forward Azimuth

Azimuths are the horizontal angles that are measured from the reference meridian in a clockwise direction. The forward direction of a line is called the forward azimuth. In this study, the azimuth is used with clrk66 ellipsoid to depict the relative location of tiger to the present location. The formula used to calculate the forward azimuth is [128, 129]:

$$Foward\ Azimuth = atan2(sin\Delta\lambda) * \cos(\varphi 2), \cos(\varphi 1) * \sin(\varphi 2) - \sin(\varphi 1) * \cos(\varphi 2) * \cos(\Delta\lambda)) \qquad (4.6)$$

Where:

$\Delta\lambda$ is the difference in longitude between the two points.

$\varphi 1$ is the latitude of the starting point.

$\varphi 2$ is the latitude of the destination point.

atan2 is the arctangent function that returns values in the range -π to π (or -180° to 180°).

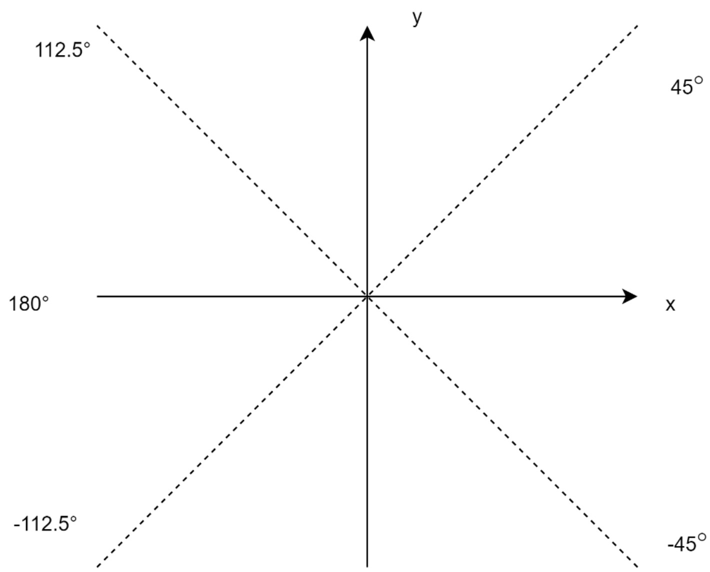


Figure 4.8 Forward Azimuth Values

The directions of movement are in reference to cell. The values are as shown in Table 4.5.

Table 4.5 Forward Azimuth Values for each Direction

Direction	**Angle Range**
North	45 - 112.5
South	-45 - (-112.5)
East	45 - 0, -45 - 0
West	112.5 - 180, -180 - (-112.5)
Centre	0

The Stackelberg game simulated 10000 for each cell while predicting the path by introducing a minor change in the tiger location keeping everything else constant.

The variables for the change were derived from a uniform distribution. To simulate the model, Tiger should stay in the same cell, but variations are required in the latitude longitude of the tiger to train the model for 10000 number of iterations. Thus, the tiger was maintained in the cell it was. This led to a final model output of producing the track. To bring variations in the latitude and longitude, random numbers are introduced in a defined range such as

$$latitude \pm \Delta x, longitude \pm \Delta x \qquad (4.7)$$

Where, x is uniform and, in the range, (0, 0.0007)

Uniform Distribution & Random number generation

A uniform distribution refers to a type of probability distribution in which all possible outcomes have an equal likelihood of occurring [130]. Stated differently, every value inside a specified range possesses an equal probability of being chosen. The process of generating random numbers from a uniform distribution entail producing numbers that adhere to the notion of equal likelihood. There exist multiple techniques for generating random numbers that follow a uniform distribution [130]. A frequently employed approach involves the utilization of pseudorandom number generators (PRNGs). Pseudorandom number generators (PRNGs) are computational techniques designed to generate sequences of numbers that exhibit the characteristics of randomness but being generated by deterministic procedures [131]. In this work, the `uniform()` function from the `random` module of python programming language is used to produce random floating-point values inside a defined range (0 , 0.00007).

c) Tiger Behavioral Model

The decision tree model used to simulate tiger movement patterns is a complex algorithm that considers several parameters [54, 132]. These parameters are crucial in understanding how tigers move and behave in their natural habitat [132]. One of the most important factors considered by the model is the current latitude and longitude of the tiger. This information helps determine which areas of the forest or grassland ecosystem are most likely to be frequented by tigers at different times of day and year. For example, if a tiger is located near a water source during dry season, it may remain close to that area for longer periods than usual. Another critical parameter incorporated into this decision tree model is time. The model considers both time of day and year when predicting tiger movements. Tigers exhibit different behaviors depending on whether it's daytime or nighttime, as well as seasonal changes like monsoons or droughts. In addition to these variables, prey availability also plays an essential role in determining where tigers will go next. The location data for potential prey species like chital (Axis axis) based on their latitude and longitude coordinates provide insights into where herbivores can be found more frequently. Finally, NDVI values for each cell are also considered to accurately replicate tiger behavior. The final model of Game theory-based tiger behavior prediction model is shown below with steps:

To model predator prey games using Stackelberg security games & simulate movement patterns for predators, various approaches could be used such as rule-based systems, finite state machines or even machine learning algorithms [59]. In this model we have used machine learning algorithm – decision tree:

1. **Setup a 2-D grid or coordinate system where the predator & prey can move**.
2. **Initialize the predator (T) & prey (P):**
    1. Place the predator T & prey P on the grid with random initial positions.
3. **Define the rules for predator movement:**

    Determine the movement patterns of the predator based on certain conditions. The Decision tree model is used to simulate the movement pattern of tiger over the grid.

4. **Implement the Decision Tree**

   The decision tree is simulated 10000 times over each cell. The final values are used to generate the payoff matrix.

5. **End of the Simulation:**

   Once we meet the final state where tiger and prey are in same cell or the maximum number of iterations is reached, we stop the simulation.

Algorithm 3 provides a thorough overview of the predator-prey simulation process, including a high-level view of the main phases and methods involved in the simulation. The text describes the basic actions and relationships that govern the behavior of predators and prey, summarizing the key elements and their sequential implementation inside the simulation framework.

Algorithm- 3 Game Theory for Prediction of Predator Location

1. Input(S_G, Loc_{Pd}, Loc_{Pr}, Itr)
   where S_G= Grid_size, Loc_{Pd} = Location of Predator, Loc_{Pr} = Location of Prey, and ITR_{Ti} = Iteration at time T_i
2. Output: Loc_{Pd_Final} = ($Loc_{Pd} \approx Loc_{Pr}$) || ($Loc_{Pd}$!= Loc_{Pr})
   Loc_{Pd_Final} is the list of positions of the predator to reach the location of a prey
3. $Loc_{Pd} \in RAND(a_{Pd}, b_{Pd})$ and $Loc_{Pr} \in RAND(a_{Pr}, b_{Pr})$
   Where (a_{Pd}, b_{Pd}) and $(a_{Pr}, b_{Pr}) \in (X, Y)$ //Initialize the predator and prey positions randomly.
4. While ($ITR_{Ti} \neq MAX$)
   a. $\Delta\ Loc_{pd} = max(U_{pd}(C_i, p))$
      where i∈ {1,2,3,4,5},C_i is the i^{th}cell, p is probability, and $U_{pd}(C_i, p)$is Stackelberg Security Game function
   b. $Loc_{Pd} = Loc_{Pd} + \Delta\ Loc_{Pd}$
   c. Update Loc_{Pd} in (X, Y) grid
   d. If ($Loc_{Pd} \approx Loc_{Pr}$)
      Loc_{Pd_Final} = ($Loc_{Pd} \approx Loc_{Pr}$) *(Collision occurs between Predator and Prey)*
      Where $((a_{Pd}, b_{Pd}) = (a_{Pr}, b_{Pr})) \in (X, Y)$
   e. ELSE
      i. $ITR_{Ti} = ITR_{Ti+1}$
      ii. Goto STEP 4
5. Repeat STEP 2 till ITR_{Ti} = MAX *(Collision does not happen)*
   a. If (ITR_{Ti} = MAX)
      i. Loc_{Pd_Final} = (Loc_{Pd})
         Where $((a_{Pd}, b_{Pd}) != (a_{Pr}, b_{Pr})) \in (X, Y)$
6. Get and print LocPd_Final and LocPr
7. EXIT

Algorithm 3 provides a high-level overview of the predator-prey simulation process. For clear understandability of the above algorithm, let us consider a 2D grid and a point/cell representing a pair of coordinates (a, b) ∈ (X, Y), where 'a' and ‘b’ is the value on the X-axis and Y-axis respectively. In context with the algorithm, point (a, b) denotes the free movement of the predator & prey in the grid. To perform Algorithm, the expected inputs are the size of a grid, initial locations of predator & prey, a maximum number of iterations, and the desired output is the location of the predator nearby equal to the prey location. Initialize the predator and prey on the grid with random initial positions. DT technique applied to the initial location of a predator, the author simulated this predator’s location 10000 times by using the Uniform Distribution to generate the optimal location of predator in a particular cell (C_i), owing to other real-life factors being considerable. For each iteration, determine the next movement of the predator based on the Decision Tree model. The 10,000 times movement of predator i.e., in an adjacent cell/ being stationary will give the probability of inter-cell movement (p). To apply the concept of game theory in the proposed work, the probability (p) used in the Utility Matrix of Stackelberg Security Games and find out the maximum probability value of a cell i.e. $max\left(U_{pd}(C_i, p)\right)$.This will help to find out the next considerable position of predator and update this position on the grid. Check if the predator and prey are in the same cell (i.e., a collision occurs). If yes, stop the simulation and the algorithm terminates. If not, continue to the next time step. Repeat these steps for the maximum number of iterations. The end of the simulation will be the finding of the final positions of the predator and prey after the simulation ends or the maximum time steps reached. Additionally, to understand the behavior of tigers, the predator’s movement prediction is based on above-mentioned parameters such as prey distribution and vegetation mapping for Sundarbans region. Based on the movement of tigers, it is easier to find the different behavioral patterns.

Finite Automata to generate rules:

Tigers, being apex predators, demonstrate intricate behaviors that are impacted by a range of circumstances, such as hunting, territoriality, and social relationships. Game theory, which models strategic interactions and decision-making, enables the prediction and comprehension of these behaviors [67, 70]. Finite automata, in their capacity as mathematical representations of computing and decision-making processes, can be incorporated into this predictive framework [71, 135].

Automata

Automata is a mathematical concept that enables the examination of systems that undergo state changes over time. It serves as a theoretical framework for analyzing the operations of machines, computers, and other intricate systems [71, 72, 73, 74]. In computer science, automata theory plays a crucial role in exploring various types of abstract models like finite automata, pushdown automata, Turing machines etc., which are instrumental in solving problems related to computation, language recognition and parsing algorithms in compilers [75]. Abstract models of machines known as automatons use a series of states or configurations to perform computations on an input [71, 135]. During each stage of the computation, a transition function analyzes a finite portion of the current configuration and determines the subsequent configuration. Such machines possess certain traits, including:

Inputs: considered to be sequences of symbols chosen from a limited collection I of input signals. Specifically, set I is comprised of $\{x_1, x_2, x_3 ... x_k\}$, where k represents the quantity of inputs [71].

Outputs: sequences of symbols picked from a finite assortment Z. To clarify, set Z consists of $\{y_1, y_2, y_3 ... y_m\}$, with m denoting the number of outputs [71].

States: a finite group Q whose meaning hinges on the specific type of automaton being discussed.

State-transition diagrams or tables can be used to represent automata. These diagrams depict each potential state as a node (or circle) connected by arrows representing transitions between states based on specific inputs [71, 72, 135]. By tracing these transitions from one state to another according to input values provided at each step it's possible to determine what output will be produced by the system. Overall, understanding how complex systems operate and optimizing them through careful modeling and analysis techniques requires an essential foundation in automata theory [135]. Finite automata can depict several behavioral tactics exhibited by tigers, including hunting, patrolling their territory, and engaging in interactions with other tigers. Every strategy is associated with a state in the automaton [75]. In this system we are modeling the movement of tiger and prey with input states as

$$Input \rightarrow \{Change(C), No\ Change\ (NC), Hunt\ (H)\} \quad (4.8)$$

Change(C) suggest that tiger is moving from one cell to another cell in the grid of Sundarbans landscape. The strategy shows the movement which could be influenced by the environmental parameters or prey sightings. No change (NC) suggests that tiger is in the same cell which is another strategy in the game. Hunt (H) is a strategy which shows the tiger and prey were in the same cell and model is assuming it as Hunt.

$$States \rightarrow \{Initial\ State\ (s_0), Intermediate\ State(s_i), Final\ State(s_h)\} \quad (4.9)$$

Finite automaton is defined using 5-tuple definition, the 5-tuple definition for this model is shown in table 4.6 using the input and states defined in eq 4.8 – 4.9.

Table 4.6 Description of 5-Tuples FA

S.no.	Tuples used	Description
1	$Q = \{S_0, S_i, S_h\}$	Finite set of states
2	$\sum = \{C, NC, H\}$	Finite set of inputs symbols
3	S_0	Initial state
4	S_h	Final state
5	$\delta(\{S_0, S_i\}, \sum) \rightarrow Q$	Transition Function

The alphabet, denoted as Σ, refers to the collection of input symbols or cues that tigers can see or respond to. Within the realm of tiger behavior, several aspects come into play, such as environmental conditions, the availability of prey or the presence of other tigers, as well as a range of triggers. This is represented in the form of change(C), No change (NC), Hunt (H) which could be influenced by above mentioned aspects.

States (Q): States refer to the discrete behavioral states or strategies that a tiger can display. In relation to tiger behavior, the states encompass activities such as "Hunting," "Patrolling," and "Resting". Each stage is associated with a certain behavioral pattern.

The transition function δ determines the possible state transitions of the tiger in response to detected stimuli or inputs. This study delineates the reaction of a tiger to various stimuli. As an illustration, when a tiger detects the existence of potential prey (input symbol), it may undergo a transition from the "Patrolling" state to the "Hunting" state.

The initial state, denoted as S_0, is the starting point of a system or process. The variable S_0 symbolizes the initial state or behavioral template from which a tiger initiates its observations or interactions. It could potentially align with the tiger's state of repose or a state of neutrality within a specific situation.

Final states denoted as S_h, pertain to the realm of forecasting tiger behavioral patterns and are indicative of states that denote outcomes or situations of significance. For example, a "Final State" may refer to a state that signifies a successful hunting endeavor or the acquisition of a specific territory. These states offer valuable insights on the behavioral habits of tigers.

4.3 Summary of the Chapter

This study centers on the implementation of a model for Tiger behavioral pattern prediction using game theory utilizing telemetry data. This model comprises data acquisition, telemetry data visualization, community analysis for feature extraction, ML model building, GRID generation and the development of game theory-based tiger behavioral prediction model. This proposed system holds diverse applications, including prediction of the next location of tiger, developing trajectory from the predicted locations, these can help in combating tiger poaching as well. The movement patterns of tigers were predicted in this study using three datasets obtained from WII. Since movements are closely linked to behavioral traits, analyzing these patterns is crucial for understanding tiger behavior. To gain insight into their movement patterns, telemetry data was collected from the Sundarbans region along with information on prey distribution. It is also important to study landscape features and vegetation mapping data of this region as they play a significant role in tiger ecology and their movements. Understanding the location where telemetry data was obtained is imperative to comprehend it fully. Once the collection of data for a particular species has been completed, analysis and examination of the area can commence by generating a map that establishes boundaries for their movements based on GPS coordinates recorded within the study area. Parameter acquisition becomes crucial at this stage; factors such as weather patterns, prey availability, geographical features and topography must all be considered when identifying regions where tigers move most frequently. To fully understand tiger behavior in their natural habitat, it's crucial to analyze how they move around and interact with the environment. Therefore, statistical analysis is conducted using GPS data on tiger locations, prey distribution, and terrain features of the Sundarbans region. To understand tiger movement patterns according to prey context within the Sundarbans region, we explored GPS-collared individuals' data first. The main accomplishment of this analysis lies in establishing a precise connection between the movements of tigers and the presence of prey in their habitat. To achieve this, various machine learning techniques such as Decision Tree, SVM, KNN, Ridge Regression, Random Forest and MLP have been employed to predict the next location of tigers. The model considers GPS coordinates for four tigers and an estimated value for each prey's location as input. To train the model to forecast the tiger's immediate next move accurately, three prediction cases are utilized. The first case involves pairing each tiger data point (GPS location) with every prey location before dividing it into training and testing sets to evaluate accuracy across all algorithms mentioned above. In the second case, all tiger data points are combined and mapped against each prey coordinate before being tested again using all algorithms. Finally in the third case both tiger and prey data points are merged into one sheet before being fed through the same process**.** The three cases vary depending on which predator-prey combinations are being considered. Out of all the methods that were tested, including SVM, KNN, Decision Tree, MLP and Ridge Regression, it was found that Decision Tree was the most effective approach under these specific circumstances. Our method has been successful in generating movement paths for tigers when provided with information about expected prey locations. We have also identified preferred prey for each of our four tigers. It is important to note that this analysis assumes easy water channel crossings by tigers and does not take vegetation parameters into account. Unfortunately, mapping an adequate sample of all potential prey in Sundarbans region proved difficult and limited our research scope; therefore, increasing randomness within our model. This model relies on various factors, such as how tigers hunt and consume their prey. Time is also an important factor in determining tiger movement patterns. Stackelberg Security games are utilized to better understand predator-prey interaction along with environmental factors. Finally, a game theory-based model is proposed to predict the next location/cell of tiger to decode their behavioral traits. The automata that display the movements of tigers with different inputs is a fascinating concept in game theory. In essence, it is a simulation that aims to predict and display how the tigers would interact with the environment and other species based on their individual behaviors and strategies. Game theory provides us with a framework for understanding strategic decision-making between rational agents. The automata take this idea further by creating an interactive model where we can observe the outcomes of different decisions made by these agents. By modeling the interactions between predators like tigers and their prey, scientists can gain insights into how these animals behave under certain conditions. In creating an automaton that displays tiger movements with different inputs, researchers might consider various factors such as habitat size or availability of prey. They could also explore how changes in one agent's strategy affect the outcome of the interaction – for instance, if one tiger decides to hunt more aggressively than usual. In this study, we are simulating the locomotion patterns of tigers and their prey, utilizing input states represented using the finite automata. The change in state suggests that the tiger is transitioning between cells within the Sundarbans landscape grid. The technique demonstrates the potential impact of environmental conditions or prey sightings on movement patterns. The concept of "No Change" (NC) entails the placement of the tiger in the same cell, which serves as an alternative tactic inside the game. The strategy denoted as "Hunt" (H) indicates that both the tiger and the prey were in the same cell. The model assumes this configuration to be a hunting scenario. The following chapter of the thesis examines the suggested system and discusses the outcomes of the simulations conducted.

CHAPTER-5

EXPERIMENTAL RESULTS AND DISCUSSION

5.1 Experimental Setup and Evaluation Parameters

When it comes to performing simulations in scientific research or engineering projects, explaining the experimental details is of utmost importance. Information such as CPU models, RAM capacity, and GPU configurations can significantly impact simulation performance. The proposed model is simulated on the below mentioned environment.

Table 5.1 The experimental details used to perform the simulations work for the proposed methodology.

S.no.	Parameters Used	Values/Remark
1	Dataset Size	4000
2	Platform	Anaconda-clean **1.1.0**
3	Environment	Jupyter Notebook
4	Language used	Python 3.9.16
5	Operating System	Windows 11
6	Hardware used	x86 64-bit CPU (Intel / AMD architecture), 4 GB RAM, and 5 GB free disk space.

We have considered three evaluation parameters for the assessment of Model predicting next location of tiger using ML algorithms: When evaluating the accuracy of predictions, R^2 and Mean Absolute Error (MAE) are commonly used metrics [137]. The Coefficient of determination, or R^2, is utilized to assess how well a model fits a given dataset. Meanwhile, MAE measures the discrepancy between predicted and actual values. A higher R^2 score indicates better results for the model, with scores ranging from -1 to 1; as for MAE, closer values to 0 indicate superior performance [137]. The formulae to estimate the values of R^2 and Mean Absolute Error (MAE) are given in Eq 5.1 - 5.2.

$$R^2 = 1 - \frac{SSR}{SST} \qquad (5.1)$$

Where:

R^2 is the R-squared value.

The SSR, or sum of squared residuals, refers to the summation of the squared discrepancies between the observed values and the anticipated values generated by the model [137, 138, 139].

The SST, or total sum of squares, is the cumulative sum of the squared deviations between the observed values and the mean of the predicted value [137, 138, 139].

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |y_i - \hat{y}_i| \qquad (5.2)$$

Where:

MAE is Mean Absolute Error

n is the no of datapoints within dataset.

y_i is the observed value for i^{th} data point.

$\hat{y}_i$ is the predicted value for i^{th} data point.

The evaluation metrics typically employed in machine learning, particularly in decision tree-based algorithms such as Classification and Regression Trees (CART), comprise precision, recall, and F1 score [138, 139]. These metrics can be utilized to evaluate the efficacy of a Classification and Regression Tree (CART) model in the context of a classification task.

Precision is a metric that quantifies the degree of accuracy in the positive predictions generated by a given model. The accuracy metric is defined as the proportion of accurately predicted positive cases (true positives) to the total number of instances predicted as positive. In the context of Classification and Regression Trees (CART), precision refers to the measure of the model's accuracy in correctly detecting positive examples within a certain class [137, 138, 139].

$$Precision = \frac{TP}{TP + FP} \tag{5.3}$$

Where:

TP is True Positives and FP is False Positives

Recall, alternatively referred to as sensitivity or true positive rate, assesses the model's capacity to accurately detect all relevant instances belonging to a particular class. The metric being referred to is the ratio between the number of instances correctly identified as positive (true positives) and the total number of instances that are positive [137, 138, 139].

$$Recall = \frac{TP}{TP + FN} \tag{5.4}$$

Where:

TP is True Positives and FP is False Negatives

A high recall value suggests that the model has proficiency in identifying a significant proportion of positive examples [137, 138, 139].

The F1 score can be defined as the mathematical average of precision and recall, specifically calculated using the harmonic mean. The metric offers a well-rounded evaluation of a model's efficacy, particularly in scenarios when there exists a disparity between precision and recall. The F1 score is a composite metric that integrates precision and recall [137, 138, 139].

$$F1 = \frac{2(Precision * Recall)}{Precision + Recall} \quad (5.5)$$

In the context of CART and other decision tree-based algorithms, the utilization of these metrics enables the assessment of the model's success in data classification [138, 139]. Prediction accuracy, commonly known as classification accuracy, is a quantitative measure employed to evaluate the overall effectiveness of a model. The metric denotes the ratio of accurately categorized instances within a given dataset [137, 138, 139]. The formula for calculating prediction accuracy is as follows:

$$Accuracy = \frac{Number\ of\ Correctly\ Predicted\ Instances}{Total\ Number\ of\ Instances} \quad (5.6)$$

The term "Number of Correctly Predicted Instances" denotes the quantity of data points for which the model accurately predicted their respective class labels. The term "Total Number of Instances" refers to the whole count of data points included inside a given dataset. The accuracy number is commonly represented as a percentage by multiplying it by 100. For instance, a precision of 0.85 signifies that the model accurately categorized 85% of the cases within the dataset. Table 5.2 shows the performance metrices used for the CART Decision Tree algorithm to predict the next cell direction in the Grid for Tiger Movement. Table 5.2 presents a detailed overview of the performance parameters used to assess the accuracy of the CART Decision Tree algorithm in predicting the direction of tiger movement within a grid. The table presents a collection of important measurements intended to evaluate the algorithm's ability to make predictions, providing insights into its accuracy, precision, recall, and other pertinent indicators. The performance indicators are essential for evaluating the model's overall predictive abilities and its capacity to anticipate the movement of tigers inside the specified grid. By incorporating these metrics into Table 5.2, we improve our comprehension of the algorithm's effectiveness and its appropriateness for modeling and predicting tiger behavior in the specified situation.

Table 5.2 Performance Metrices for CART in Next Cell Prediction

Class	Precision	Recall	F1-score
-1 (Center)	0.84	0.86	0.85
1(North)	0.12	0.07	0.09
2(South)	0.03	0.20	0.27
3(West)	0.26	0.30	0.28
4 (East)	0.26	0.23	0.24

5.2 Results and discussion on various modules of the proposed Game Theoretic approach for Tiger Behavioral pattern prediction utilizing Telemetry data.

The various modules of the proposed work are shown in figure 4.1 and figure 4.7. the results for the same are discussed in the sections below:

5.2.1 Community Analysis & Feature Extraction

The main objective of this module was to enhance knowledge of tiger’s community structure. To achieve this aim, the study has examined factors such as the movement data of tigers, prey distribution and vegetation of the region. Statistical analysis is performed to understand the correlations that may exist between tiger behavior/prey availability/vegetation characteristics. Detailed assessments of vegetation preferences are conducted by analyzing movement data over the period. The analysis of movement data in context to prey is performed to provide a holistic understanding of the community structure of tigers. The findings from this research informed us about the impact of each acquired dataset and all these features are used in training the game theory-based model.

5.2.1.1 Statistical Analysis of Movement Data of tigers in Sundarbans Landscape

The plots in figure 5.1 explain the fact that movement is subject to a normal distribution and tigers were mostly confined within 3 sigma deviation from the mean. It can be further seen from the graphs that there can be huge difference in the movement dynamics of the tigers and 1 sigma deviation can be as little as around 5 kms for female tigers and go up to 40 kms for individual male tigers. This can extend up to 120 in case of 3 sigma deviations from the mean. It is also observed from the following charts that there is difference between the movement of male and female tigers. In the wild, there exists a notable distinction in the conduct displayed by males and females. Both genders are required to engage in hunting activities for their sustenance. Initially it is assumed that there is no noteworthy contrast in the movement patterns exhibited by male and female tigers during their hunt for food. So, the null hypothesis is constructed as

$$H0 = Male\ and\ female\ tigers\ show\ equal\ amount\ of\ displacement$$

A statistical analysis using a T test was performed on the movement data of the four tigers, resulting in a p-value of 0.148120. Given that the p-value surpasses the threshold of 0.05, it is appropriate to infer that the observed outcome lacks statistical significance, and the hypothesis is rejected. Figure 3 illustrates deviation plots from the average latitude and longitude coordinates. There are following observations from the plots as in figure 5.1:

1. Female displacement is minimum as compared to male counterparts.
2. Tiger 7825 shows the maximum displacement as compared to other tigers, indicating that some tigers can have extreme displacements from their mean.

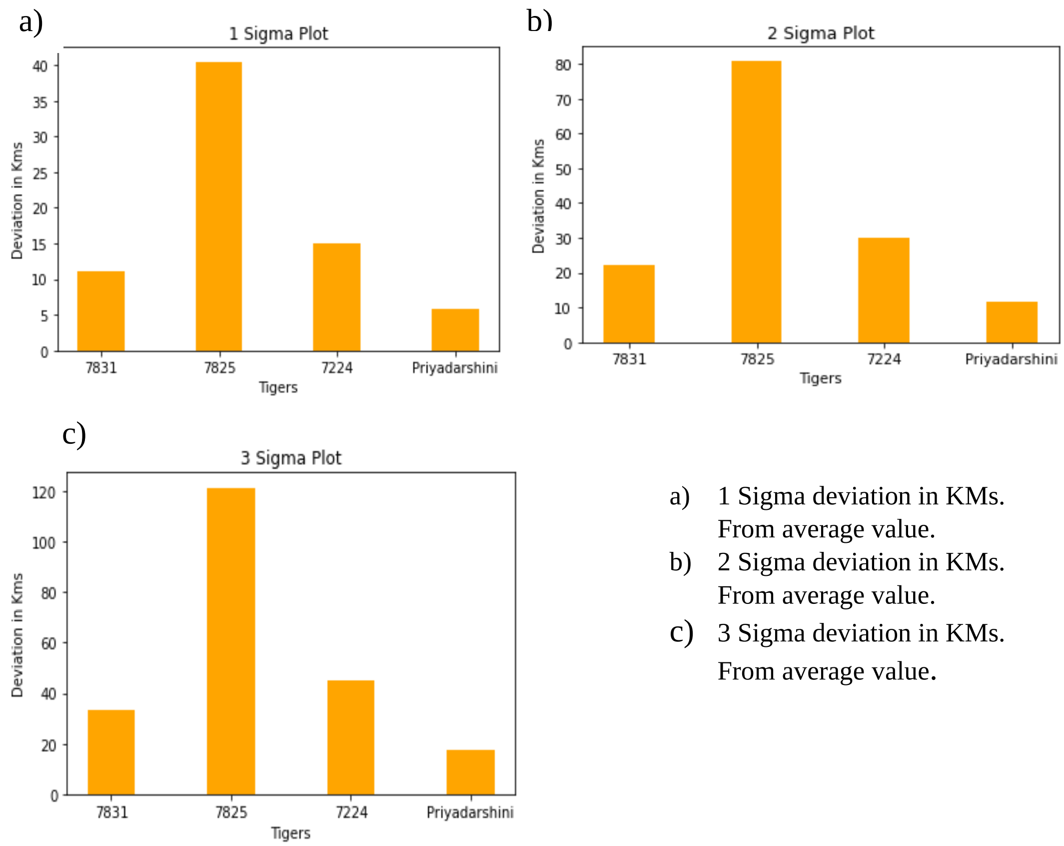


Figure 5.1 Statistical Analysis of Movement data of Tigers

5.2.1.2 The Influence of Vegetation on the Temporal Displacement of Tigers

In this section to understand the impact of Vegetation in Sundarbans for tigers, following hypothesis is assumed:

$$H0 : Time\ of\ day\ has\ no\ impact\ on\ tiger\ movement$$

To validate the hypothesis, the NDVI average of the grid in which the tiger was present was taken and count was generated. This was further segregated upon the time of day as shown in figure 5.2. Contrary to the notion that the time of day has no impact on tiger movement, it is worth noting that tigers are crepuscular creatures, meaning they are most active during dawn and dusk.

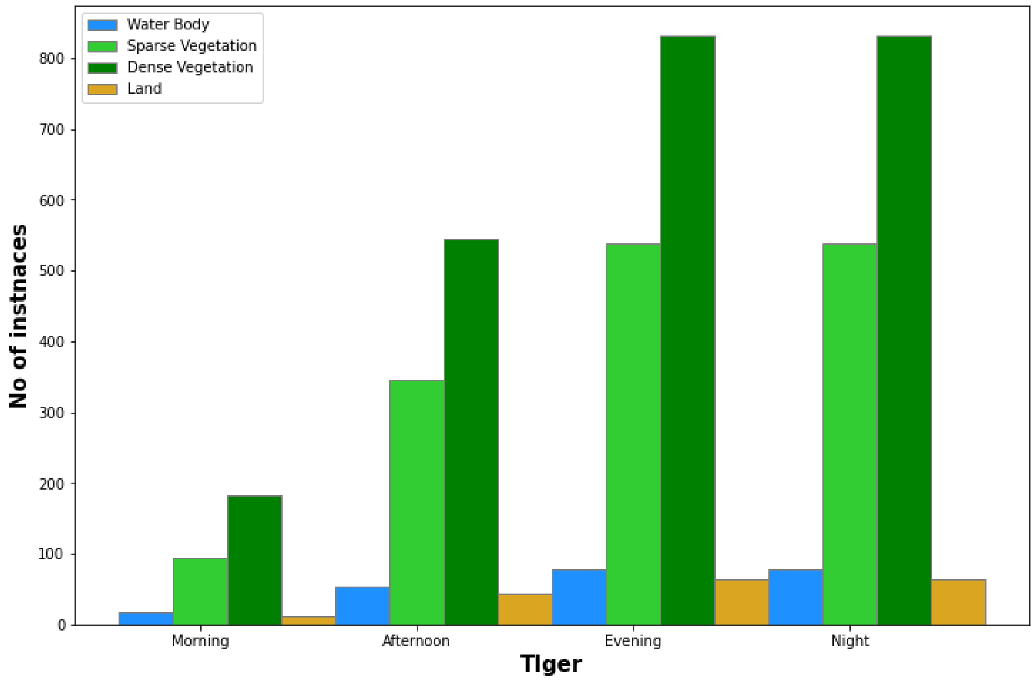


Figure 5.2 Bar Chart showing temporal presence of tigers in different types of vegetation.

Although tigers can be active at any hour, their hunting behavior and movement tendencies are more pronounced during these periods of low light. The time-of-day influences tiger movement for a variety of reasons: Tigers have adapted to primarily hunt during twilight hours when visibility is diminished. Their exceptional night vision combined with the concealment provided by darkness enables them to approach prey without being detected [13, 17, 52]. Tigers frequently exhibit a behavioral pattern of seeking shade and engaging in periods of rest during the most intense periods of daylight, to conserve energy and mitigate the risk of overheating. Consequently, they may display less activity during midday hours when temperatures reach their peak. Many herbivores (such as deer), which constitute a significant portion of a tiger's diet [13, 52], also exhibit heightened activity levels during early morning or late afternoon when temperatures are cooler, and vegetation is more accessible for grazing purposes. Tigers adjust their movements accordingly to capitalize on these predictable patterns among their prey.

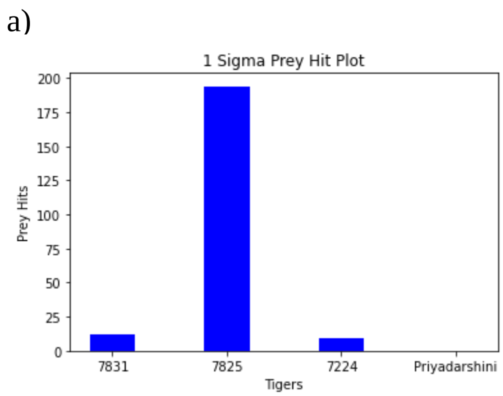
As evident from the movement plots Vs time of day the following observations can be made:

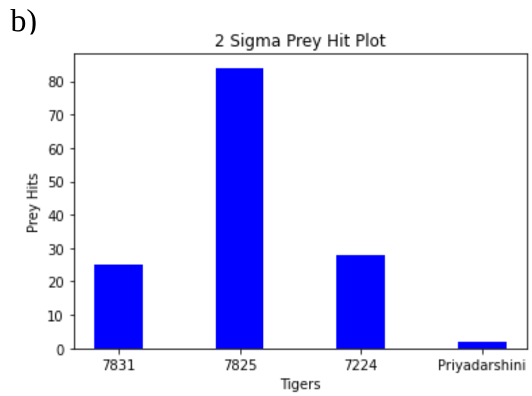
1. Tigers have preference of moving during the nighttime,
2. Tigers prefer vegetation over land and water bodies,
3. Dense vegetation being the most favored among all these.

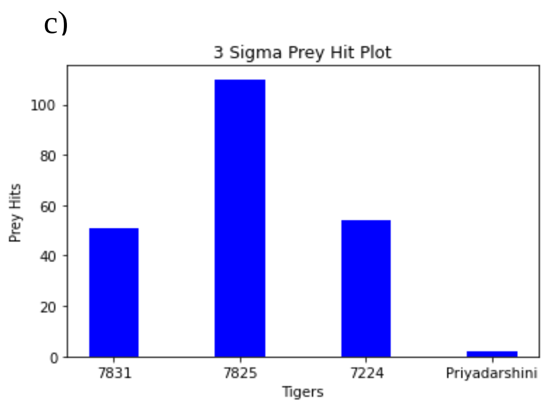
5.2.1.3 Impact of prey distribution in region

The way prey is distributed in a particular area has a significant impact on how tigers move and behave. Figure 5.3 explains the hunting for tigers. It can be observed that there is difference between prey hunts of male and female tigers. The male tigers were able to hunt much more than the female tigers. Female tiger/tigress can successfully hunt in the 3-sigma deviation range. Also, the number of successful hunts seems to be dependent upon the movement from the mean deviation. Tigers adapt their movements accordingly by following herds or concentrating around areas where certain types of prey become more abundant during different times of the year. Prey distribution also plays a role in determining which natural corridors tigers use as they travel between different habitats or territories while searching for food sources. The following observations can be made from the figures 5.3:

1. Female tigers have least prey hunts,
2. Tiger 7825, shows the maximum success while hunting depicting that higher movement is positively correlated with movement of tigers,
3. All Tigers can hunt in 2- sigma deviation.







a) Number of prey hits in 1 sigma deviation
b) Number of prey hits in 2 sigma deviation
c) Number of prey hits in 3 sigma deviation

Figure 5.4 Hunt Patterns based on Prey Distribution of Sundarbans region.

5.2.2 ML Model Building for Identifying best performing algorithm in predicting next location of tiger in context to prey.

The model building was done using three types of mapping as elaborated on the experimentation design part. It was observed from the results that the models performed differently for different mappings. Different algorithms performed differently for all three cases (Table 4.3 & Figure 4.4) considered in the model building for this study. Table 5.3 shows the performance of various ML algorithms for the acquired dataset of Sundarbans region utilizing the eq 5.1 – 5.2 for evaluating the performance of algorithms.

Table 5.3 Machine learning algorithm performance for Case 3 of prediction cases

Model	**Mean Absolute Error**	**R^2**
Kernal Ridge Regression	0.585949517	0.751881
Kernal Ridge Regression with Grid search for optimization	2.969172307	-0.24159
Support Vectors Machines	2.34093992	0.000875
Stochastic Gradient Descent	1.05828E+31	-1.3E+31
Nearest Neighbor	0.776938997	0.671036
Voting Regressor - Gradient Boosting, Random Forest, Linear regression	0.223155495	0.901644
Decision Tree	0.0083	0.754

Table 5.3 presents the R2 score and MAE for the algorithm that performed best (CART Decision Tree). In Case 1(Table 4.3 & Figure 4.4) where we had all tigers mapped to a specific prey, the total number of models generated was 46641. Out of all these scenarios, the best results obtained for Case 1 are presented here which shows MLP provided on an average R2 score of 0.81 and mean absolute error of 0.36 and the best result was obtained for 2-layer architecture of (10,13). In the same scenario, the use of decision trees provided the best results with an r2 score of 0.997837 and mean absolute error of 0.007872. In Case 2, where we had all the all tigers mapped to all prey and the total number of models trained was 9327. Out of these the best results were optioned in Machine learning and deep learning are reported. MLP provided an R2 score of 0.715178 and mean absolute error of 0.82577 on a layer combination of (29,12) whereas decision trees outlasted deep learning-based architecture with an R2 score of 0.997826 and mean absolute error of 0.007882. In scenario 3, 849 models were tested for accuracy in with all tigers and multiple prey mapping and the best results are reported here. MLP provided an R2 score of less than 0.52 and mean absolute error stood above 0.008 in all the cases. As in the above two cases, traditional machine learning model Decision tree

outperformed the deep learning-based architecture MLP and provided R2 score of 0.754 and mean absolute error of 0.0083. The results for the other algorithms can be checked at the link provided in Annexure 1. Only the first two best performing models are discussed in this section.

Table 5.4 Best Performing Machine Learning algorithms to predict the next location of Tiger as per the expected location of Prey in Sundarbans region.

Prediction Case	Mapping of Tiger and Prey Distribution Data	Best Performing Algorithm	R^2 Score	Mean Absolute error
Case 1	1 Tiger – 1 Prey	Decision Tree	0.997837	0.007872
Case 2	All Tigers – 1 Prey	Decision Tree	0.997826	0.007882
Case 3	All Tigers – All Prey	Decision Tree	0.754	0.0083

Owing to the results obtained in Case 3 of prediction cases (Table 4.3 & Figure 4.4), It can be said that the best model was obtained with all tigers mapped to all prey as the model generated was more vivid. The model encompasses all the prey in the area and was still able to provide extremely high accuracy. Thus, in predicting movement of tigers based on the prey alone we can conclude that decision trees outperform all the other types of models. The proposed method employs a range of machine learning techniques, including Decision Tree, SVM, KNN, Ridge Regression, Random Forest and MLP to predict the next location of tigers. The model takes in GPS coordinates for four tigers and an anticipated value for each prey's location as input. These three cases differ depending on which specific predator-prey combinations they consider. Of all methods tested SVM, KNN, Decision Tree, MLP, Ridge Regression (refer to result sheet link for results of all these methods), Decision Tree proved most effective under these circumstances. Our approach can successfully generate movement paths for tigers when given information about expected prey locations**.** We depicted the preferred prey as well for each of the 4 tigers. In this section of work, it is assumed that the tigers can cross the water channels easily and vegetation parameters are not included.

5.2.3 Game Theory based model for predicting the next cell in the grid for tiger movement.

Understanding tiger behavior in their natural habitat requires analyzing their movements and interactions with the environment. As in the preceding section CART Decision tree provided the best result for predicting the next location of tiger when provided with the expected location of prey. But the said model does not include topographic features. To include these features and utilize game theory approach, A game theory model is designed by utilizing Stackelberg security games to predict the movements patterns of tigers by incorporating geographical features such as waterways, vegetation density, and alluvial land. This approach involves dividing the area into grids where a predator-prey game is played, pitting participants against each other rather than promoting cooperation. The payoff matrix illustrates how different strategies chosen by two players will impact their outcomes and fitness based on the actions of their opponent.

Final State

In the proposed model, the ultimate state is defined as the state in which both the tiger and the prey occupy the identical cell inside the grid. This stage also serves as the termination point. If the end state is unattainable, the simulation will cease upon reaching the maximum iteration limit. The predetermined number of iterations during which the simulated model will forecast the subsequent cell is set as a constant value and maintained at a significantly high magnitude. Upon the completion of these iterations, there is a significant probability of achieving the end state. Alternatively, the iterations will cease.

Next Cell Prediction based on Payoffs.

The utilization of a payoff matrix is employed to simulate and examine the interactions between the two participants involved in the game. The primary objective of the predator is to optimize its strategic decisions by taking into consideration the anticipated response of the prey. Conversely, the prey strategically responds to the leader's actions in a manner that maximizes its own utility. The primary objective of the predator is to optimize its anticipated outcome, taking into consideration the prey location alongside environmental factors.

Table 5.5 Payoff Matrix for predicting probability of next cell in the grid.

Cell Position	Center	North	South	West	East
Center	0.0671	0.4627	0	0.4018	0.0683
Center	0.0214	0.1049	0	0.76	0.1136
Center	0.0123	0.0629	0.0095	0.85	0.0652
Center	0	0	0	0.9351	0.0648
Center	0.0077	0	0	0.8283	0.1639

Table 5.5 shows potential outcomes resulting from different choices made by tigers when deciding their inter-cell movement. Each choice has associated probabilities, which denotes how likely a particular inter-cell movement is for a given choice made by a tiger. The current location or cell of tiger is considered as center, now there are five possible choices available for a tiger: moving left towards West with probability P(W), moving right towards East with probability P(E), moving up towards North with probability P(N), moving down towards South with probability P(S), or staying in the current cell with probability P(C). These probabilities are calculated based on factors such as available resources, prey availability, vegetation mapping of the region. The probabilities P(W), P(E), P(N), P(S), P(C) represent the payoffs or rewards associated with inter-cell movement. These payoffs can vary

depending on various factors like resource availability in the destination cell, risk involved in moving to a particular cell (e.g., proximity to potential predators), or potential benefits gained from exploring new areas. The model will predict the next cell by using the cell with highest probability value. The model will keep on predicting the next cell for tiger movement to form a trajectory. This process of prediction will stop when the final state is achieved, or maximum limit of iterations is reached.

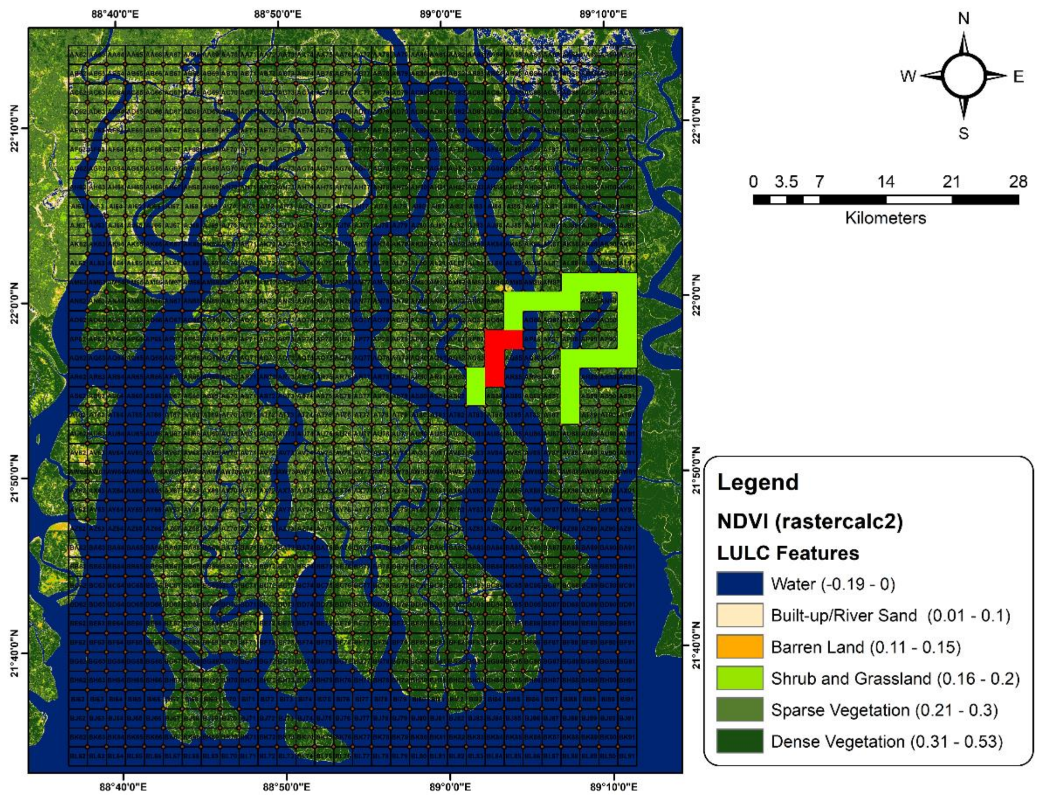


Figure 5.5 Predicted trajectories of tiger movement using Game Theoretic model.

Figure 5.5 shows the predicted movement path for the tiger simulated by the proposed model. The accuracy of the predicted path is computed using eq 5.6 and found to be 85.71%, the accuracy percentage indicating how many times our proposed model successfully predicted where the tiger would move next based on its features. To calculate this accuracy, data from previous movements of tigers can be used to train and test the model. The training data includes information about past movements and their corresponding outcomes, while the testing data consists of new instances where we know what happened but want to see if our model can accurately predict it. For example, let's say we have historical data on 100 instances of tiger movement. We use 80% (80 instances) for training and 20% (20 instances) for testing. After training the model with these 80 instances, we then use it to make predictions on those remaining 20 instances to evaluate its performance.

5.2.4 Finite automaton to generate rules for behavioral patterns utilizing game theory result.

The goal is to present a more general tool to present the state change which ultimately presents a behavioral phenomenon. The finite automata seem appropriate in defining different states and transition from those states. Automata is compact and describes actions of players in game in few states. We can create a simple finite automaton to model this system. The different states for different input are listed in table 5.6:

Table 5.6 Transition Table for Finite Automata

Input / States	**C**	**NC**	**H**
S_0	S_i	S_0	S_h
S_i	S_0	S_i	S_h
S_h	-	-	-

Finite automata provide a convenient framework for describing different states and the transitions between them. These automata offer a concise depiction, accurately defining the behaviors of participants in a game using a restricted set of states. By utilizing the capabilities of finite automata, we may create a streamlined representation to encompass the behavior of the system, as described in the accompanying table. This technique allows for a more easily understood and intuitive depiction of changes in state, making it easier to comprehend the complex behaviors inherent in the system being studied. Figure 5.6 visually represents the state transition diagram that captures the complex behavioral patterns displayed by tigers. This figure provides a visual depiction of the several states that a tiger can experience and the changes that occur between these states. Every unique state depicted in the diagram represents a particular behavioral pattern, encompassing details of how tigers react to various stimuli or environmental circumstances. The arrows linking the states represent the transitions, demonstrating the movement of the tiger from one behavioral state to another. This visual representation facilitates the understanding of the dynamic aspect of tiger behavior, highlighting the flexibility and capacity of their replies. The state transition diagram, depicted in Figure 4.8, facilitates a better understanding of their interactions with their surroundings.

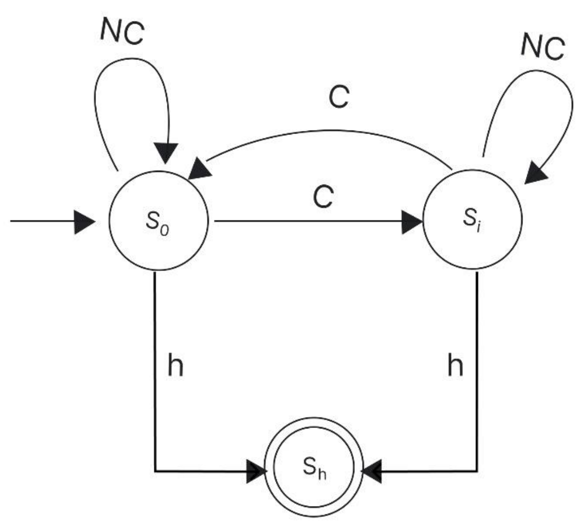


Figure 5.6 State Transition Diagram for Tiger Behavioral patterns.

This finite automaton has three states represented by circles labeled as "S_0", "S_i" and "S_h". The start state is indicated by an arrow pointing to it. The final state(s) is shown with double circle. The transitions between these states are represented by directed arrows labeled with the input symbol or condition that triggers the transition. For example, there is an arrow going from S_0 to S_i labeled with 'C' indicating that if the input received at current stage is 'change', i.e.

$$C= max\left(U_{pd}(C_i, p)\right) \qquad (5.9)$$

indicates that it will move from State zero(S_0) to State i (S_i), otherwise ‘NC’ where NC is no change in its current state; indicates that it will be at same initial state S_0. Another arrow going from S_0 to S_h labeled with ‘H’ indicating that if input received at current stage is ‘Hunt’ then it will move from State zero (S_0) to State h (S_h). Similarly, there’s another arrow going from S_i to S_0 labeled with ‘C’ indicating ‘Change’ then it will move from Si to S_0. Similarly, another arrow going from S_i to S_i labeled with ‘NC’ indicating that if input received at current stage is ‘No change’ then it will move from State i (S_i) to State i (S_i). Finally, an arrow going from S_i to S_h labeled with ‘H’ indicating that if input received at current stage is ‘Hunt’ then it will move from State zero (S_i) to State h (S_h), which leads us into final accepting stage of our Automata i.e., Stage h (S_h), thus recognizing our desired pattern. This type of finite automaton can be used for recognizing movement patterns of tigers as different behavioral states.

5.3 Summary of the Chapter

In this chapter, an outline of the experimental setup and design for the Game theory-based tiger behavioral prediction model is presented. The results indicate that the vegetation is a significant factor that plays a role in determining the patterns of movement of these tigers. During times when they are on the prowl for prey, tigers can make excellent use of the mangroves' thick undergrowth to conceal themselves. Tigers are known to favor regions that have a lot of flora because it helps them blend in with their environment and improves their chances of effectively ambushing their victim. In addition, research that was carried out on this group of tigers revealed that most of the time, they are nocturnal animals. They tend to be more active during the nocturnal hours. In terms of movement patterns, the analysis that was carried out as part of this research project revealed fascinating data linked to the distance that tigers travel from their typical site, also known as their home range. It was found that every individual was able to hunt within a mobility range that was no more than three standard deviations (sigma's) away from their typical location. This was one of the observations that was made. This points to a bell-shaped or Gaussian distribution pattern for the tiger's movements being the most likely explanation. These findings provide important new information about the ways in which royal Bengal tigers adapt and survive in the ecosystem of the Sundarbans delta. The fact that they like to spend the night in heavily wooded areas is evidence that they can effectively exploit available resources. Through these findings it is established that all these features are crucial while building a model for tiger behavioral patterns prediction.

This study analyzed data on prey distribution and tiger movements for the Sundarbans region. Using this data set as input for various machine learning algorithms such as SVM (Support Vector Machines), KNN (K-Nearest Neighbors), Ridge Regression, Random Forest, Decision Tree and MLP (Multilayer Perceptron) models were trained to predict where each tiger would move next based on its current location relative to nearby prey concentrations. The results showed that some algorithms performed better than others in predicting future locations of tigers. For instance, decision tree performed best among all the ML algorithms for the acquired dataset. Overall though all models could accurately predict tiger movements based solely on their proximity to prey. However, it should be noted that initially the model is trained considering two parameters: the location of tigers along with time and expected locations of different prey in the region. It is assumed that water channels or vegetation did not affect tiger movement while hunting for prey which may not always be accurate since these features can play significant roles in determining predator-prey interactions as discussed already. The utilization of the Stackelberg security games (SSG) idea is employed to represent the predator-prey interactions within the Sundarbans environment. In this study, it was observed that the decision tree algorithm exhibited superior performance compared to the machine learning algorithm. The decision tree algorithm was employed to construct a payoff matrix, which provided the probability of the next cell based on various factors such as the GPS locations of tigers over time, estimated prey locations, and the NDVI value of each cell to account for vegetation and water channels. The model that was proposed demonstrated a high level of accuracy, accurately generating the following cell with an accuracy rate of 85.71%. Modeling predator-prey games with finite automata is done. The tiger and the prey are two agents in this model, and they have different tactics. The tigers' possible states and how they change between them based on their plans and the results of their interactions would be shown by the finite automata. This model helps us understand how the game works, like which strategies work best, what actions lead to better results, and how the movement of one agent changes the strategies of the other. By looking at these, we can guess how they will behave, where the balance points are where neither agent can get better by changing their strategy on their own, and how different starting conditions or changes in strategies might affect how the predator-prey interaction turns out in the end. Understanding these precise facts of tiger behavior can improve conservation efforts overall by assisting researchers in locating crucial habitats and developing management measures that are specifically customized for the one-of-a-kind population that can only be found in the Sundarbans delta region. The following chapter will summarize the findings obtained from this research project and outline possible directions for future investigation in this developing field.

CHAPTER -6

CONCLUSIONS AND FUTURE DIRECTION

It is vital for the conservation of tigers to comprehend their movement patterns. Tigers, being apex predators, necessitate expansive territories for their survival. These territories frequently encompass diverse landscapes characterized by unique features that can exert an impact on tiger behavior and overall survival. There is a distinct population of royal Bengal tigers that can only be found in the Sundarbans delta, which is situated in the Bay of Bengal. This region's environment is one of a kind and extremely diversified. This population has differentiated themselves into their own distinct community because of their adaptation to the presence of mangrove trees inside the delta basin.

6.1 Summary of the Thesis and Objective Attenuation

In this thesis, a game theoretic model to predict the location of tigers in the Sundarbans region is developed which is a significant step towards wildlife conservation. The model considers various factors such as telemetry data of tigers, prey distribution, and vegetation mapping to compute the probability of the next cell for tiger movement. This information is then used to create a payoff matrix that helps in predicting the location of tigers. To generate an automata machine that displays the movements of tigers with different inputs, finite automata is used. The output from game theory approach provides three finite states- Resting, Moving and Hunting which are taken as rules for Finite Automata. With this information, an automata machine can be created that accurately predicts tiger movements. The accuracy rate achieved by this model is 85.71%, making it highly reliable in forecasting tiger trajectories in Sundarbans region. The proposed model's specificity in predicting tiger movements indicates that it may have limits when used to forecast the movements of other species. Tigers have unique behavioral patterns, movement dynamics, and habitat preferences in comparison to other species. The parameters and variables utilized in the model can be adjusted to accurately represent these features, hence reducing its applicability to other species exhibiting distinct behaviors. Tigers exhibit distinct habitat preferences and prey selections that influence their movement patterns. The model may take into account variables such as forest cover, water sources, and prey availability, which may not be applicable to other species with distinct habitat and food preferences. Tiger movements are shaped by spatial and temporal elements specific to their ecosystem. These parameters may not be relevant to other species, resulting in mistakes when using the model to forecast their movements. Although the model can be adjusted for different species, it may still need substantial alterations and validation to guarantee its precision and applicability. Although the proposed model is successful in forecasting tiger movements, its species-specific characteristics restrict its usefulness to other species. When developing predictive models for other species, it is important to consider their distinct ecological characteristics, the availability of data, and their interactions within their ecosystems. Wildlife conservationists can use this model effectively to plan their conservation strategies better for tigers and save these beautiful creatures from extinction. Another potential challenge when working with dynamic inputs predicted by game theory is ensuring accuracy. Predictive models that have been trained using past data may encounter difficulties in applying their predictions to unfamiliar or unobserved situations or settings. Modifications in environmental circumstances, human actions, or tiger conduct over a period of time might impact the accuracy of model forecasts, particularly in ever-changing environments. Evaluating the precision and dependability of predictive models for tiger movements necessitates thorough verification against empirical data. Validating intricate models that integrate game theory and machine learning methods presents hurdles due to the requirement for inclusive and varied datasets. Predicting human behavior alone can be difficult enough; predicting animal behavior adds another layer of complexity since we cannot directly communicate with them about their intentions or thought processes. Nonetheless, this kind of research holds great promise for advancing our understanding of complex systems – whether they involve humans or wildlife - and providing new insights into decision-making processes across various domains. The creation of an automata that displays tiger movements using game theory predictions offers an exciting opportunity to better understand predator-prey interactions among animals and other strategic scenarios involving rational agents. This innovative approach has immense potential not only for tiger conservation but also for other endangered species worldwide. It showcases how technology can be leveraged to address critical environmental challenges and protect our planet's biodiversity for future generations. To sum up, utilizing the predator-prey game in conjunction with geographical features can serve as a valuable technique for anticipating the next whereabouts of tigers in their natural habitats. By simulating how predators and prey interact within a specific environment, we can gain insight into the movements and behaviors of these animals over time. An example of this approach is the finite automata model, which could be utilized to forecast tiger movements based on various inputs such as change or no change in their movement, or other inputs such as sightings of other predators or changes in terrain. This type of model has potential applications for conservationists and wildlife researchers seeking to comprehend tiger behavior patterns and devise strategies for safeguarding them from threats like poaching or habitat loss. In conclusion, although more research is necessary to refine the models further, it holds promise for enhancing our understanding of intricate ecological systems and assisting us in safeguarding endangered species like tigers in their natural habitats.

6.2 Research Future Directions

Survival of the tigers is influenced by various factors, some of the crucial factors are studied in this research and their impact is shown on their behavior and overall survival of the tigers. For future studies, terrain elevation that significantly influences habitat suitability and connectivity for tigers is an important factor. Density and width of water channels are additional topographical elements that are vital to tiger habitats. Although tigers are renowned for their swimming skills, broad waterways may function as obstructions. In regions such as the Sundarbans mangrove forest in India and Bangladesh, where tigers have adapted to a highly variable tidal environment, it is crucial to comprehend how they maneuver through these ever-changing conditions. The integration of tidal wave data into research endeavors may unveil the manner in which coastal tigers coordinate their movements with the phases of the tides—possibly impacting their hunting tactics or territorial behaviors as a result of altered habitat accessibility. Prey density is an additional critical factor that has a direct influence on tiger populations, as it determines the size of territories required to support healthy individuals. In addition, the integration of data on human settlements unveils prospective zones of conflict between humans and wildlife—a significant issue considering that the growth of human populations frequently results in increased frequency of encounters with these sizable carnivores. Further investigation is required to examine these supplementary parameters longitudinally, or over extended time periods, in order to identify temporal changes that may indicate pressures from environmental factors or anthropogenic activities. In future studies therefore additional parameters such as landscape features like terrain elevation, water channel density, width of water channels, tidal waves data, prey density etc. could be included together with human settlements data to gain a more comprehensive understanding about how these factors affect Tiger's movement patterns over time. Also, the accuracy of game-theoretic models for predicting tiger movement can be enhanced by integrating several data sources, such as telemetry data from GPS-collared tigers, remote sensing data, prey abundance studies, and socio-economic data. Subsequent studies may focus on the advancement of data fusion techniques to combine diverse data sources and enhance the accuracy of model predictions.

Thorough validation and evaluation of game-theoretic models using empirical data are crucial for determining their predicted accuracy and reliability. Future research endeavors may prioritize the development of validation frameworks and criteria to assess the concordance between model predictions and actual tiger movement patterns. Additionally, these investigations should examine the efficacy of the models across various environmental circumstances. This will enable conservationists to make informed decisions about how best they can protect these majestic animals from extinction by creating effective management plans for protecting wildlife habitats while minimizing human-wildlife conflicts. Through an in-depth examination of every determinant influencing tiger ecology—ranging from minute details like the availability of individual prey to significant occurrences like the consequences of climate change—conservationists will acquire a comprehensive understanding that will enable them to not only develop focused strategies for safeguarding tiger populations but also effectively involve local communities by demonstrating how the preservation of this pivotal species upholds the integrity of ecosystems as a whole, thus promoting sustainable livelihoods.

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LIST OF PUBLICATIONS

1. Choudhary, R., Dahiya, S. & Choudhury, T. (2023). A review of tiger conservation studies using nonlinear trajectory: A telemetry data approach. Nonlinear Engineering, 12(1), 20220235. https://doi.org/10.1515/nleng-2022-0235

2. Choudhary, R., Choudhury, T., & Dahiya, S. (2023). Exploring tiger movement pattern according to prey context: A case study in Sundarbans region of India. Spatial Information Research. https://doi.org/10.1007/s41324-023-00525-1

3. Richa Choudhary, Tanupriya Choudhury, Susheela Dahiya. *"Tiger Community Analysis in the Sundarbans,"* International Conference on Micro- Electronics & Telecommunication Engineering (ICMETE), Ghaziabad, India, 2023.

ANNEXURE 1

Link to access result sheets
https://github.com/RichaChoudhary86/Tiger_Location_prediction-

Richa Final Thesis

ORIGINALITY REPORT

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