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Abstract

Species extinctions have been a significant part in disturbing the biodiversity. This creates an importance in trying to simulate the populations of the species of interest to get an idea when its population looks threateningly low. We will try to get an idea regarding the mathematics working behind the prediction of the extinction time of a creature. We will briefly overview the associated ideas and how the predictions work mathematically. We will also take a real-life example to understand the idea better. A detailed statistical assay is being carried out using deterministic and non-deterministic approaches to study the Northern White Rhinoceros population curve. Probability heuristics is used along with its terminologies to analyze the extinction of Northern White Rhinoceros.

1 Introduction

Extinctions have always been an inevitable part of evolution[1]. Of the 400 billion species which had evolved on earth, 99% are now gone. In the last 5 decades, more than 900 species have gone extinct. In spite of this huge time scale, humans have also played significant roles in the extinctions of a large number of species including which has even resulted in imbalances in nature[2][3]. For the same, it has become extremely important for us to prevent more creatures getting wiped out of the planet and in order to fulfill our goal; we need to make some predictions and work strategically. Here is where mathematics helps us.

Roughly five billion species or over 99 percent[4] of all the species that have ever existed on Earth—are thought to have perished[5]. According to estimates, there are presently 8.7 million species of eukaryotes in the world, and if bacteria and other microbes are included, there could be many times more[6][7]. Non-avian dinosaurs, saber-toothed cats, mammoths, ground sloths, trilobites, golden toads, etc., are a few noteworthy extinct animal species. Throughout the process of speciation, new variants of organisms emerge and flourish when they are able to track down and exploit an evolutionary path. Species go extinct when they are unable to survive under shifting environmental conditions or against stronger competition. Animals and their respective ecological processes have a well-established link[8]. A normal species become extinct 10 million years after it first appears, but certain species, known as living fossils, can persist for millennia with little to no morphological change[9].

While localized strandings are rather frequent, mass extinctions are comparatively uncommon. Recently, extinction rates have been noted, and scientists are concerned about the current high rate of extinctions. The majority of extinct species are never recorded officially[10][11]. Before 2150, up to half of the currently known plant and animal species could go extinct, according to some scientists. According to a 2018 study, it will take 5–7 million years for the 300 mammal species whose morphological diversity has been lost due to human activity ever since Late Pleistocene[12].

2019 Global Assessment Report on Biodiversity and Ecosystem Services(2019) by IPBES says a million species are in danger, natural ecosystems have shed approximately half of their territory, and the biomass
of wild mammals has decreased by 82 percent[13]. 20–25 percent of plant and animal species are in danger of being extinct[14]. One 1,000,000 flora and fauna were in danger of going extinct as of June 2019. Since 1750, at least 571 species have perished, but there are probably many more. Natural ecosystems are being destroyed by human actions like clearing forests and turning land into farmland, which is the main cause of extinctions[15]. A species' extermination can happen suddenly, wiping out the otherwise better and healthier species completely, as when contamination makes its entire habitat uninhabitable, or it can happen gradually over thousands or millions of years, as when a species gradually loses out to competitors who are specifically tailored in the competition for food. Extinction debt is a phenomenon where extinction may take place many years after the trigger events. In this paper, we are going to study different theoretical methods to approximate the population curve of extinct animals. We are going to discuss about deterministic and non-deterministic models to study the extinction curve of different animals. Specifically, we will do a statistical assay on the population and extinction curve of Northern White Rhinoceros found in East and Central Africa[16][17].

2 Estimation For The Time Of Extinction

2.1 The Deterministic Model

We will begin with the simplest deterministic model. Let's assume that we are studying the growth of a species of birds in a particular region[18]. We will begin with, we have 2 birds (We are now considering the fact that no bird dies) and we get the following table.

<table>
<thead>
<tr>
<th>Time after the 1st day</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 year</td>
<td>6</td>
</tr>
<tr>
<td>2 years</td>
<td>12</td>
</tr>
<tr>
<td>3 years</td>
<td>22</td>
</tr>
<tr>
<td>4 years</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 1
Population dynamics, starting with two birds.

It's easy to understand that more the number birds, more is the difference between the populations in two successive time stamps. Similarly, if we consider deaths, it's easy to see that the difference between populations of successive time stamps is again directly proportional to the population size. (More individuals imply more deaths/births)[19]. So if we write this mathematically, then we will have the following equation.

\[
\frac{dP}{dt} = rP
\]
Where \( P(t) \) is the population at time stamp \( t \). Here \( r \) is the constant of proportionality, also can be considered as the rate of change of the population. But we need to add one modification that we need to add to this equation. A population can't go on indefinitely owing to the limited resources and other factors. Therefore we need to put an upper bound to it as the following.

\[
\frac{dP}{dt} = \begin{cases} \ rP; & 1 < P < K \\ 0; & P = K \end{cases}
\]

Here \( K \) is the upper-bound for the population. (Here \( r > 0 \). The growth of the population stops after reaching the threshold). We are now interested in knowing the expected time of extinction. We will call the time at the beginning \( T_0 \) and the time when the population is extinct \( T_n \). We note that the population is \( N \) at \( T_0 \) and a single individual at time \( T_n \). (A single individual can't reproduce, therefore, we can say that that is the point of no return for the species.) Mathematically, we can write it as

\[
P(T_0) = N, \ P(T_n) = 1
\]

Now we have

\[
\frac{dP}{dt} = rP \Rightarrow dP = rP dt \Rightarrow \frac{dp}{p} = r dt
\]

Now if we integrate both sides keeping the respective limits

\[
\int_{N}^{1} \frac{dp}{p} = \int_{T_0}^{T_n} r dt \Rightarrow \ln \left( \frac{1}{N} \right) = r (T_n - T_0)
\]

\[
\Rightarrow T_n = T_0 + \frac{1}{r} \ln \left( \frac{1}{N} \right)
\]

The above expression hence is the approximate time for extinction. We can clearly understand from here that if the value of \( r \) is greater than 0, or if the population is increasing, it is impossible for the species to get extinct.

### 2.2 The Non-Deterministic Model

From the deterministic approach, we get to see only the partial picture. In the book *The Theory of Island Biogeography* by Robert MacArthur and Edward O. Wilson, we get to see an amazing formula for estimating the approximate time of extinction of a species[20].

Here we will define “birth” and “death” probabilities (\( \lambda \) and \( \mu \) respectively). We will call them per capita birth and death rates in unit time of a certain population. Therefore, over a time period of \( h \), the probability that a birth will take place is \( h\lambda \) and similarly for death we have \( h\mu \). Therefore we can say that the probability for any change in the population is \( (\lambda + \mu) h \). Therefore, the fraction of changes that are
increments in the population is \( \frac{\lambda}{\lambda + \mu} \). Similarly, the fraction of changes that are decrement is \( \frac{\mu}{\lambda + \mu} \). Next, we note that, the time that will take for a single change to occur is \( \frac{1}{\lambda + \mu} \). (Note: \( \lambda + \mu \) is the total change per unit time).

Keeping these factors in mind, we will now try to create a model for estimating the time for a population to survive. It is worth noting that since the size of a population has an upper bound and keeping the fact in mind that all creatures must die, a population of any size is bound to get extinct given enough time. As mentioned in the book *The Theory of Island Biogeography*[21][22] soon after colonizing the island while its size is still small, the population has a short life expectancy. However, if it survives and grows to a large size, it will have a higher life expectancy. The final expression that we get for the estimated extinction time of a population of size \( x \), is the following.

\[
T(x) = \frac{1}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} T(x + 1) + \frac{\mu}{\lambda + \mu} T(x - 1)
\]

The expression \( \frac{1}{\lambda + \mu} \) essentially gives us the time when the first change occurs (birth or death). After that time, the population can either be \( x + 1 \) or \( x - 1 \). Now the probability that a change is birth is given by \( \frac{\lambda}{\lambda + \mu} \) and for death we have \( \frac{\mu}{\lambda + \mu} \). Now if the first change is an increment, its extinction time would be \( T(x + 1) \). Similarly for the case of death, we will have \( T(x - 1) \). Now we multiply the times with the respective probabilities and by the additive rule of probability, we will get the above expression. Now on solving the above recurrence relation we get \( T_1 \) in terms of \( K \) i.e., “The Carrying Capacity”.

- Death is density dependent i.e., \( T_k = T_{k+1} \) we get \( T_1 \) as:

\[
T_1 = \frac{\lambda}{\mu} \cdot \frac{1}{\lambda} + \left( \frac{\lambda}{\mu} \right)^2 \cdot \frac{1}{2\lambda} + \left( \frac{\lambda}{\mu} \right)^3 \cdot \frac{1}{3\lambda} + \cdots + \left( \frac{\lambda}{\mu} \right)^K \cdot \frac{1}{K\lambda}
\]

- Birth is density dependent i.e., \( T_k - T_{k+1} = \frac{1}{\mu(K+1)} \) we get \( T_1 \) as:

\[
T_1 = \frac{\lambda}{\mu} \cdot \frac{1}{\lambda} + \left( \frac{\lambda}{\mu} \right)^2 \cdot \frac{1}{2\lambda} + \left( \frac{\lambda}{\mu} \right)^3 \cdot \frac{1}{3\lambda} + \cdots + \left( \frac{\lambda}{\mu} \right)^K \cdot \frac{1}{K\lambda} + \left( \frac{\lambda}{\mu} \right)^K \cdot \frac{1}{\mu(K+1)}
\]

### 3 Probability Heuristics

Probability distributions are functions which give probabilities of occurrences of different possible outcomes of an experiment. We will get to see how it’s significant in something like predicting extinction times.

#### 3.1.1 A few terminologies in probability
A random variable can be considered as a function which takes random events as inputs and gives a real number as output (let’s stick to real numbers for now). For instance we can assign the occurrence of heads in a coin toss “1” and “-1“ for tails[23]. The random variable which takes infinitely many possible inputs is called continuous random variable. The density function on the other hand for a sample in the sample space (Set of all possible events) provides the likelihood that the value of the random variable will be close to that sample. Finally, we have the cumulative distribution or just distribution function of x which gives the probability that the random variable is less than x[24].

3.1.2 A brief introduction to Weibull distribution

The Weibull distribution is a continuous probability distribution used in statistical hypothesis testing and estimate stochasticity. Although it was initially recognised by Maurice René Fréchet and first used by Rosin & Rammler (1933) to define a particle size distribution, it was named after Swedish mathematician Waloddi Weibull who explained it in depth in 1951.

The density function of a Weibull random variable is given by:

\[
f(x; \lambda, k) = \begin{cases} 
\frac{k}{\lambda} \left( \frac{x}{\lambda} \right)^{k-1} e^{\left( \frac{x}{\lambda} \right)^k}, & x \geq 0 \\
0, & x < 0
\end{cases}
\]

Here we encounter 2 parameters. \( \lambda > 0 \) is the scale parameter and \( k > 0 \) is called the shape parameter. The cumulative distribution function for Weibull distribution is:

\[
F(x; k, \lambda) = 1 - e^{\left( \frac{x}{\lambda} \right)^k}
\]

Here, \( F(x) = 0 \) if \( x < 0 \).

When \( k < 1 \), it means that the failure rate is on the decline. This arises when there is a high rate of "infant mortality," or when malfunctions fail prematurely, with the failure rate gradually declining over time as the defective products are eliminated from the population. This refers to unfavourable phrase in the context of the dissemination of innovations: the danger function is a monotonically decreasing function of the proportion of adopters;

When \( k = 1 \), the failure rate is said to be constant throughout time. This can imply that failure or fatality is being caused by arbitrary external circumstances. An exponential distribution results from reducing the Weibull distribution.

When \( k > 1 \) denotes a rising failure rate over time. If there is a "ageing" process or if there are components which are more prone to failure with time, this occurs. Since the danger function is a monotonically increasing function of the proportion of adopters, this refers to good phrase in the perspective of the
diffusion of innovation theory. \( \frac{1}{e^k} - 1 \), \( k > 1 \), is, where the function inflexion point is located. The function is initially convex and later concave.

The Weibull modulus is the name for the form factor \( k \) of a distribution of strengths in the study of materials. The Weibull distribution is a "pure" imitation/rejection model when it comes to the diffusion of innovation theory[25][26].

### 3.2 Causes of Extinction

Species have been going extinct for as long as there have been evolving species. Over 99.9% of all species thought to have ever existed are thought to be extinct. A species' lifespan ranges from 1 to millenia on average, though it varies greatly amongst taxa. A species or group of animals may become extinct due to a number of factors, either directly or indirectly. According to Beverly and Stephen C. Stearns, "each extinction is unique, just as each species is. The causes for each are different—some are varied and nuanced, others are plain and simple."[27] To put it simply, any species that is unable to thrive in its environment, reproduce, or find a new environment in which to do so, dies out and goes extinct. A species' extinction can happen suddenly, obliterating an otherwise healthy species entirely, as when contamination makes its entire habitat uninhabitable, or it can happen gradually over thousands or millions of years, as when a species gradually loses out to competitors who are particularly suited in the competition for resources. Resurrection debt is a phenomenon where extinction may take place many years after the trigger events[28].

#### Genetical and Demographical Phenomenon

A population will become extinct if adaptability increases community fitness more slowly than environmental deterioration and the accumulation of marginally harmful mutations. Smaller populations see fewer advantageous variants per generation, which slows adaptation. Limited populations also make it simpler for mildly harmful mutations to be fixed; the ensuing positive feedback loop between a relatively small population and low viability can end in mutational meltdown[29].

Under ambient rates, geographic range is the primary factor influencing genus extinction, but as mass extinctions occur, this factor becomes less significant.

Small population number and higher vulnerability to regional environmental disasters are both caused by limited geographic range.

#### Genetical Pollutants

When a species that has evolved to live in a particular ecosystem is subjected to genetic pollution, such as unchecked hybridization, introgression, and genetic infesting that culminates in homogenization or out-competition from the introduced (or hybrid) species, it can lead to extinction. Endangered populations may go extinct if new populations are imported, created by human breeding practises, or brought together
through habitat change. When rare species interact with more common ones, they are more likely to become extinct because interbreeding might saturate the rarer gene pool and produce hybrids, which deplete the homogeneous gene pool. Morphological and architectural (non-genetic) observations do not always show such extinctions. A certain amount of gene flow is a typical part of the evolutionary process, but hybridization—with or without introgression—threatens the survival of uncommon species[30].

**Habitat Degradation**

Consequently, the primary anthropogenic driver of species extinctions is habitat deterioration. Agriculture is the primary source of habitat deterioration on the planet, followed by urban growth, logging, mining, and some fishing methods. The functional topography of a species may change due to habitat deterioration to the point that it is no longer able to exist and goes extinct. This can happen either directly, as in a poisonous environment, or indirectly, as in a species’ ability to compete successfully for scarce resources or against novel competitor species[31]. A species can be wiped out quickly by habitat deterioration caused by toxicity by contaminating or sterilising all surviving descendants. It can also happen for longer stretches of time and at lower toxic potential by influencing life expectancy and fertility, capacity, or competition.

**Coextinction and Competition**

Coextinction emphasizes the loss of one species as a result of the extinction of another; for instance, pathogenic insects perish after the demise of their hosts. In a feeding chain, coextinction can also happen when a predator loses their prey or when a species loses its pollinator." The interconnectivity of animals in complex ecosystems is demonstrated by species coextinction. Coextinction is undoubtedly a sneaky cause of species extinction, even though it may not be the most significant one." When a keystone species becomes extinct, coextinction becomes more prevalent. According to models, coextinction is the most prevalent type of biodiversity loss. The abiotic factors may experience a spiral of coextinction[32][33].

Throughout the instinctual course of events, species go extinct for a variety of reasons, such as but not limited to: the extinction of a necessary host, prey, or pollinator; cross and inter-species competition; inability to deal with evolving diseases; and changing environmental conditions that can act to incorporate novel predators or to eliminate prey. Humans have subsequently in geological history become another factor in the extinction of some species, either by acting as an enhanced capacity or by moving plants and animals over the globe. Since ancient times, these introductions have occasionally been done on purpose. Although imports of invasive alien species are typically unsuccessful, when they do succeed in establishing themselves, the results can be disastrous. Native species may experience direct effects of invasive alien species. either directly by consuming them, engaging in competition with them, or transmitting viruses or parasites that make them unwell or kill them.

**Change in Climate**
Research findings on fossils have shown that extinction due to climate change is real. Specifically, the demise of amphibians that occurred 305 million years ago during the Carboniferous Rainforest Collapse. A 2003 analysis of 14 biodiversity research institutions anticipated that 16–38% of terrestrial species will be "marked to oblivion" by 2050 as a result of climate change. The Cape Floristic Region and the Caribbean Basin are among environmentally rich regions that could perhaps sustain the greatest losses. Heatwaves and a potential doubling of carbon dioxide concentrations in these regions could result in the extinction of 3,700 animal and 56,000 plant species. Aquifer depletion and biodiversity loss have both been linked to climate change[34].

**Sexual Selection and Male Dominance**

Research findings of fossil records that track genera from the period of their evolution to their extinction reveal that species with elevated sexual dimorphism, particularly traits in males used to start competing for coitus, are at a higher threat of extinction and die out quicker than less sexually dimorphic species, with the most sexually dimorphic species dying out within just a few thousand years. Prior research based on comparing the number of pre-existing species in modern taxa revealed a greater range of animals in more sexually dimorphic taxa, which was interpreted as higher survival in taxa with more sexual selection. However, such research of modern species only measures the indirect effects of extinction and is susceptible to bias[35].

Even during habitat recession of species that are close to extinction, error sources include dying and doomed taxa speciating more as a result of breaking habitat ranges into more small isolated groupings. Expensive sexually selected ornaments that have a negative impact on the ability to survive natural selection and genetic drift expelling a distinctiveness of genes that under prevailing ecological conditions are unbiased for selective breeding but some of which may be pertinent for surviving climate change are possible causes of the higher extinction risk in species with more sexual selection, as shown by the thorough fossil studies that rule out such possible errors[36].

**4 Statistics Of Extinction**

**4.1 When did Dodos go extinct?**

The dodo (Raphus cucullatus), a Pleistocene flightless bird, was confined to Mauritius, an archipelago in the Indian Ocean to the east of Madagascar. The Rodrigues solitaire, which went extinct as well, was the dodo's closest genetic relative. The two were members of the extinct clade of flightless birds known as the Raphinae, which also included the pigeon and the dove. The Nicobar pigeon seems to be the dodo's closest surviving relative. It has always been believed that a white dodo lived on the nearby island of Réunion, however it is now recognised that this belief was erroneous because of the likewise extinct Réunion ibis and white dodo artworks[37].

David L Roberts and Andrew R. Solow used the Weibull distribution method to bring up a function, which could predict the extinction time of a species based on its most recent sightings. The 10 most recent
confirmed sightings of Dodo are 1662, 1638, 1631, 1628, 1611, 1607, 1602, 1601 and 1598. The estimated time of extinction was predicted to be 1690. Considering the controversial sighting in 1674, the estimated time would then go to 1700.

4.2 Northern White Rhinoceros Population Statistical Analysis

One amongst two genera of the white rhinoceros is the northern white rhinoceros (Ceratotherium simum cottoni), often known as the northern Square-Lipped Rhinoceros. These subspecies, which was formerly present in various nations in East and Central Africa south of the Sahara, grazes in grasslands and savanna woods. Since 19 March 2018, there have only been two female northern white rhinos left in existence, Najin and Fatu. This effectively declares the subspecies extinct, excepting the discovery of any male northern white rhinos that have been misidentified in other parts of Africa. The two female rhinos are guarded by security personnel and are property of the Dvůr Králové Zoo in the Czech Republic, despite the fact that they reside in the Ol Pejeta Conservancy in Kenya.

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Year</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1960</td>
<td>2225</td>
</tr>
<tr>
<td>2</td>
<td>1965</td>
<td>1773</td>
</tr>
<tr>
<td>3</td>
<td>1970</td>
<td>665</td>
</tr>
<tr>
<td>4</td>
<td>1975</td>
<td>500</td>
</tr>
<tr>
<td>5</td>
<td>1980</td>
<td>410</td>
</tr>
<tr>
<td>6</td>
<td>1985</td>
<td>7</td>
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<td>7</td>
<td>1990</td>
<td>15</td>
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<td>15</td>
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<td>10</td>
<td>2005</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>2010</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>2015</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>2018</td>
<td>2</td>
</tr>
</tbody>
</table>
The former territory of the northern white rhino included portions of North-Eastern Democratic Republic of the Congo, eastern the Central African Republic, Southern Sudan, and North-West Uganda. Their distribution may have stretched throughout Chad and Cameroon and as well as as far west as Lake Chad. Throughout the 1970s and 1980s, poachers reduced their population from 500 to 15. The population recovered to more than 32 animals between the early 1990s and the middle of 2003. Poaching has increased and then further decreased the wild population since mid-2003. The dramatic reduction of white rhinos in the past was primarily brought on by unrestrained hunting during the colonial era. Today, the major danger is poaching because of their horn. Due to its low level of aggression and tendency to reside in herds, the white rhino is especially susceptible to poaching.

Now, we have previously explained about Weibull’s distribution and its importance in studying population graph of extinct animals. We will now plot Weibull’s Distribution for suitable value of $k$ and $\lambda$. Fitting a single Weibull function to the age-at-death data of this strain yields an estimate of $\lambda = 20.7$ and $k = 1.9$.

Hierarchical (tree-structured) data is shown in treemaps as a collection of layered rectangles. The branches of the tree are represented by smaller rectangles that are tiled onto the larger rectangle assigned to each branch of the tree. The area of the rectangle on a leaf node corresponds to a certain data dimension. Leaf nodes are frequently coloured to display a different dimension of the data.

One can frequently easily see patterns that would be challenging to identify in other measures, like whether a specific colour is particularly relevant, when the colour and size parameters are associated in some manner with the tree structure. Another benefit of treemaps is that they make effective use of available space due to their design. They are able to legibly display thousands of objects on the screen as a consequence.

So, we will now draw the treemap to represent the hierarchical population data of the Northern White Rhinoceros.

The density function of a Weibull random variable is given by

$$f(x: \lambda, k) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

After running some necessary fitting tests, we can fit the Weibull curve for the observed population of the Northern White Rhinoceros. The fitting constant of the Weibull curve would be approximately $c = 2.5 \times 10^{80}$.

As we can observe from the above graph that after fitting also there are quite some differences between the observed and the theoretical graphs. Hence, we can say that Weibull Distribution is not an accurate distribution to study Extinction population graphs.
5 Conclusion

Precision of predictive tools plays a significant role in the precision of the estimations of extinction times. The deterministic approach, though simple, fails to give us a reliable output as it ignores the presence of randomness. The non-deterministic approach considers the probability of the occurrence of a death or a birth considering the mortality and natality rates, which finally gives us a recursive relation for the extinction time. This appears more reliable as it allows the occurrences of different behaviours. The Weibull distribution can be considered one significant estimation methods. For the prediction of the extinction time of Dodo, this distribution proved to be pretty accurate. Even for the case of Northern White Rhinoceros, we get to see that the graph is pretty accurate for the starting few years. However, the estimation did not suit well for the following few years. One of the possible reasons can be the number of unnatural deaths, which includes poaching. Unfortunately, we have known too less about the creatures on our planet. An estimate suggests that about 7% of the planet's invertebrates may have already gone extinct and 98% of the extinctions on earth are going undetected. Regardless of the different conservations and protocols, we need to have predictive models which can warn us before it's too late.

Declarations

Compliance with Ethical Standards

This study isn't funded by any organization or company. Both author 1 and author 2 declares that they have no conflict of interest. This article does not contain any studies with human participants or animals performed by any of the authors. The data of animal population is collected from authentic sources and any of the authors were not involved in the primary collection of the data.

References


Figures
Figure 1

Picture of Male Northern Rhinoceros from International Rhino Foundation. The International Rhino Foundation began intensive involvement with northern white rhino conservation in 1995, investing millions of dollars in an attempt to save the subspecies.
Figure 2

$T_1$ is the total extinction time for a population beginning with a single propagule. Here propagule represents the minimal number of individuals capable of reproducing. $\lambda$ is taken to be 2 for both figures.
$T_1$ is the total extinction time for a population beginning with a single propagule. Here propagule represents the minimal number of individuals capable of reproducing. $\lambda$ is taken to be 2 for both figures.
Figure 4

Dodo was a flightless bird from Mauritius and associated islands. The last confirmed sighting was in 1662. although it was claimed that the bird was seen in 1674 as well.
Figure 5

Observed population graph of Northern White Rhinoceros.
Figure 6

Treemap of the observed hierarchical population data of Northern White Rhinoceros from 1960 to 2018.
Figure 7

Weibull Distribution for $\lambda = 20.7$ and $k = 1.9$. (A suitable trendline is added to the graph for better representation)
Figure 8

Weibull Distribution graph for population density of Northern White Rhinoceros after fitting tests being applied.