Population dynamic modeling to further improve the understanding of the impact of the level of the Proportion of Illegally Killed Elephants (PIKE) on elephant populations at a Monitoring of Illegal Killing of Elephants (MIKE) site in Kenya.

(source: S. Frigyik)

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Abstract

African Elephant populations have declined by 60% over the past 50 years. The causes of increased mortality, aside from natural deaths, are increased illegal killings arising from poaching for ivory as well as human elephant conflict. CITES is the international convention concerned with protecting endangered species and has MIKE, the Monitoring of Illegal Killing of Elephants programme, specifically focused on determining the pressures on elephant populations. PIKE, the proportion of illegally killed elephants, is a poaching pressure measure used by MIKE to report to CITES and is calculated by dividing the number of illegally killed elephants by total dead elephants on a yearly basis. At the 18th CITES Convention of Parties in 2019, it was noted that in previous reports a PIKE level higher than 0.5 was of concern, as it was considered a threshold level at which elephant populations are likely to be in net decline. It was also noted that a process had been initiated to use population dynamics modeling to further improve the understanding of the level of PIKE on MIKE sites across Africa. Using 20 years of data for model validation from an actual MIKE site in Kenya, a system dynamics model was developed to test the hypothesis that when PIKE is above a 0.5 threshold the elephant population will be in net decline in a naturally increasing population, and conversely, when PIKE is less than a 0.5 threshold the elephant population will be in net increase. Simulations run in the model demonstrated that as the PIKE measure does not factor in population growth due to a range of birth rates, the measure alone was not a reliable indicator of whether a population will be in net decline. The hypothesis was therefore disconfirmed by the scenarios generated from the system dynamics model.

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Definitions

Population – the number of elephants within a designated geographic range.

Age Structure – age specific categories or cohorts of pre-weans, juveniles, young adults, adults, mature adults.

Fecundity - Number of calves produced per female adult by cohort per year.

Natural Death – deaths that happen naturally through age, predation or disease.

Illegal Killing – deaths through poaching and human-elephant conflict.

Legal Killing - authorized killing through animal management and culling or trophy hunting.

Introduction - why elephants?

"The elephant and keeper have vanished completely. They will never be coming back."(Murakami, 1994)

Weighing up to 8 tons, elephants are Earth's largest living land mammals. Elephants are naturally found in Africa and Asia, with two species occurring in Africa: the savannah elephant and the forest elephant. As matriarchal animals they have complex social structures of females and calves, with the males usually leaving the groups as they reach puberty to live alone or in smaller groups of bachelors (*Elephant | Species | WWF*, 2021). A notable characteristic of elephants are their large tusks: extended teeth which serve different purposes including digging for water during dry seasons. Tusks are also a desirable commodity in some cultures and this leads to elephants being killed for their tusks through poaching (Schlossberg et al., 2020). Human elephant conflict also results in elephants being killed, and this arises because of changing land use pushing elephants, which require large areas to graze and roam, and humans together (Nyumba et al., 2020). Poaching and killing arising from human elephant conflict are categorized as the illegal killing of elephants. In certain countries, there is also the managed killing of elephants through culling, and in other's trophy hunting of elephants is also permitted (Cruise, 2016). Natural deaths also lead to declines in elephant populations, and this has been associated with drought, declining water availability and reduced grazing lands (Schlossberg et al., n.d.).

There are a host of reasons why the illegal killing of elephants is a cause for concern. These iconic creatures are an important generator of tourist revenue in the countries that they naturally live in, and so too are they complex animals displaying strong emotions with a complex consciousness (Jabr, 2014). Elephants are considered sentient creatures, aware of feelings (Henley, 2019) and they are also keystone species that have an important role in maintaining the biodiversity of the ecosystems in which they live (*Why Are Elephants Important?*, 2021). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has noted that the decline in nature worldwide is unprecedented and accelerating, and there is a need to act as this is also eroding the very systems we as humans rely on (Martin, 2019) (Madding, 2019).

As elephants play an important role in ecosystem function and help maintain suitable habitats for many other species, their future also plays an important role for the future of biodiversity in Africa (Stephenson, 2004).

However, the population of African savanna elephants has decreased by at least 60% over the past 50 years. It is important that the survival of this species is not endangered particularly through illegal killing (*African Elephant Species Now Endangered and Critically Endangered - IUCN Red List*, 2021).

This thesis is concerned with modeling the population dynamics of an African savanna elephant group and investigates in particular how deaths through illegal killing and the measures used to assess this pressure, may impact these population dynamics.

The Illegal Killing of Elephants.

Thousands of years ago humans coexisted with elephants in Africa, hunting the animals for their meat, hides and ivory. There are ivory carvings that are more than 27,000 years old. The human populations across Africa up to about 2000 years ago were small and therefore caused little appreciable impact on the growth and survival of natural elephant populations, but with European colonialization of Africa also came the decline of elephant populations as the demand for ivory soared drastically reducing their numbers. In the 1980's it was estimated that 100,000 elephants were being killed per year, with most of the ivory demand coming from the Far East. After Japan the USA was the largest single importer with an ivory trade worth US$100 million per year. In 1989 the African elephant was placed in Appendix I of CITES, preventing the trade in ivory and elephant products (Stephenson, 2004).

CITES & MIKE

CITES is the Convention on International Trade in Endangered Species of Wild Fauna and Flora, an international agreement between governments whose aim is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species. CITES also includes the interests of trophy hunters (Scanlon, 2011). Currently all African elephants are in Appendix I apart from the populations of Botswana, Namibia, South Africa and Zimbabwe that are included in Appendix II as they have large populations of elephants. Appendix II allows for legal hunting and quotas are set by CITES to permit the limited exports of hunted ivory tusks. However, ivory is still protected under Appendix I although some countries are trying to change the classifications to permit the trade in live elephants and elephant products. These changes, if passed, could lead to the further reduction of elephant populations (*Elephants | CITES*, n.d.-a).

A specific programme under CITES is concerned with monitoring trends in the illegal killing of elephants, the Monitoring the Illegal Killing of Elephants Programme (MIKE).

The stated objective of the MIKE programme is:

"...to provide information needed for elephant range States and the Parties to CITES to make appropriate management and enforcement decisions... to help range States improve their ability to monitor elephant populations, detect changes in levels of illegal killing, and use this information to provide more effective law enforcement and strengthen any regulatory measures required to support such enforcement."

The MIKE programme utilizes personnel in the field to determine the cause of death of elephant carcasses that are found. The information is recorded in a standard format and then consolidated and submitted to the MIKE programme for further analysis. The MIKE programme is then able to further identify trends and changes in poaching pressures and report back to CITES on these. Information and analysis is also presented to annual CITES Standing Committee meetings and at the meeting of the Conference of Parties that happens every 3 years (*Monitoring the Illegal Killing of Elephants (MIKE) | CITES*, n.d.).

There is also a MIKE-ETIS Technical Advisory Group (TAG) that provide technical oversight to MIKE and ETIS. The TAG also assists the MIKE Secretariat in establishing relevant databases and standard reporting protocols for reporting in illegal hunting (*MIKE-ETIS Technical Advisory Group (TAG) | CITES*, n.d.).

PIKE – the Proportion of Illegally Killed Elephants.

PIKE stands for the proportion of illegally killed elephants divided by the total of all dead elephant carcasses. It is a measure used by CITES as a relative indicator of poaching pressures usually reported on an annual basis. While it is a useful measure of relative poaching pressures, it has also been noted that PIKE is subject to various measurement biases (Jachmann, 2012).

PIKE = Number of illegally Killed Elephants / Total number of Elephant carcasses

Or

PIKE = No. of illegally Killed Elephants / (No. of Illegally Killed Elephants + No. Naturally Dead Elephants)

At the 11th Technical Advisory Group Meeting held in Nairobi Kenya from 6-10 December 2011, as well as the Standing Committee 62nd meeting held on July 2012, it was noted that:

> *"…poaching levels are now clearly increasing in all African subregions. While Central Africa continues to display the highest levels of elephant poaching in any subregion, PIKE levels were above 0.5 in all four subregions in 2011. This level is believed by the TAG to be the threshold above which elephant populations are very likely to be in net decline."(MIKE, 2012) (CITES, 2012)*

Furthermore, at the Sixteenth meeting of the Conference of Parties (March 2013) it was also noted that:

> *"…poaching levels in 2011 were clearly increasing in all four African subregions. While central Africa continued to display the highest levels of elephant poaching in any subregion, PIKE levels were above 0.5 in all four subregions in 2011, meaning that more than half of elephants found dead were deemed to have been illegally killed. This level translates to an illegal annual offtake likely to be higher than the number of elephants born annually in a naturally increasing population. In other words, a PIKE level of 0.5 or higher means that the elephant population is very likely to be in net decline."*(*Elephants | CITES*, n.d.-b)

In the following year at the Twelfth Technical Advisory Group meeting held in April 2014, it was also commented that:

> "…*While PIKE appears to have declined to 2010 levels in 2013, the level remained above the sustainability limit of 0.5.*"

However, at the same TAG12 meeting, the minutes also recorded the following concerns:

> *"Colin Craig questioned the justification for the 'red line of sustainability', or the PIKE level of 0.5, above which elephant populations are assumed to be in decline. The Coordinator clarified that, based on a number of explicit assumptions, George Wittemyer at Colorado State University had estimated the PIKE level above which net population declines would result was slightly over 0.5, and that Ken Burnham had proposed 0.5 as a rule of thumb — when half of elephants found dead were illegally killed there is cause for concern. Colin Craig and Iain Douglas-Hamilton agreed that it would be worthwhile to interrogate those assumptions more closely. The Coordinator indicated that this issue would be discussed further under Validation of PIKE inference, but also agreed to tone down the language in the analysis about the 'limit of*

> *sustainability' and rather indicate that a PIKE value of 0.5 indicates that there is likely a problem"* (Tchamba et al., n.d.)

Finally, at the Eighteenth meeting of the Conference of the Parties Colombo (Sri Lanka), 23 May – 3 June 2019 (CoP18 Doc. 69.2) in the report on monitoring the illegal killing of elephants, the following was noted:

> *"16. In previous reports, the Secretariat indicated that PIKE levels above 0.5 are of concern and that it is a threshold above which elephant populations are very likely to be in net decline [document SC62 Doc. 46.1 (Rev. 1)]. This was based on the assumption that, at a PIKE level above 0.5, the illegal annual offtake is likely to be higher than the number of elephants born annually in a naturally increasing population (document CoP16 Doc. 53.1).*
>
> *"18. The Secretariat, in collaboration with the MIKE-ETIS TAG, has initiated a process to investigate the use of population dynamic modelling to further improve the understanding of the impact of the level of PIKE on elephant populations at the MIKE sites across Africa, as well as a broader investigation to determine whether there are alternative means to reflect poaching pressure on affected populations. In the meantime, the use of the 0.5 PIKE 'threshold' should be treated with some caution"*(*E-CoP18-069-02.Pdf*, n.d.)

While on secondment to the Wildlife Unit Ecosystems Division in UNEP and working on a human wildlife conflict project focused on elephants, it was agreed with UNEP and the MIKE Secretariat that the author would develop a system dynamics population model to explore the issue posed by CITES as stated in CoP18 Doc. 69.2 (UIB, 2020). The author's primary client is the MIKE Secretariat.

Research Objectives

The issue to investigate is whether a PIKE of above 0.5 is an indicator that an elephant population is in decline, and by association, whether a PIKE of less than 0.5 is an indicator that a population is increasing. The objective of this thesis is to develop an appropriate elephant population model to test the following research hypothesis: *(1) When PIKE is above a 0.5 threshold the elephant population will be in net decline in a naturally increasing population, and (2) when PIKE is less than a 0.5 threshold the elephant population will be in net increase.*

Based on this hypothesis, the specific research objectives are:

1. Investigate the use of population dynamic modelling to further improve the understanding of the impact of the level of PIKE on an elephant population at a MIKE site in Kenya;
2. Assess whether the use of the 0.5 PIKE 'threshold' should be treated with some caution;
3. Investigate whether there are alternative means to reflect poaching pressure on affected populations.

The language used to form the first part of the research hypothesis is derived from the CoP18 Doc. 69.2 para.16. The interpretation of what is meant by a naturally increasing population is the range of births rates and natural death rates that could be expected in a given elephant population. For the hypothesis to be supported both conditions must be true: a PIKE greater than 0.5 will result in a population decline and below 0.5 a population increase. For the hypothesis to be disconfirmed either can be shown to be incorrect: for a PIKE greater than 0.5 a population can be increasing or below 0.5, decreasing. The intended approach to address the hypothesis is outlined in the process flow in Figure 1.

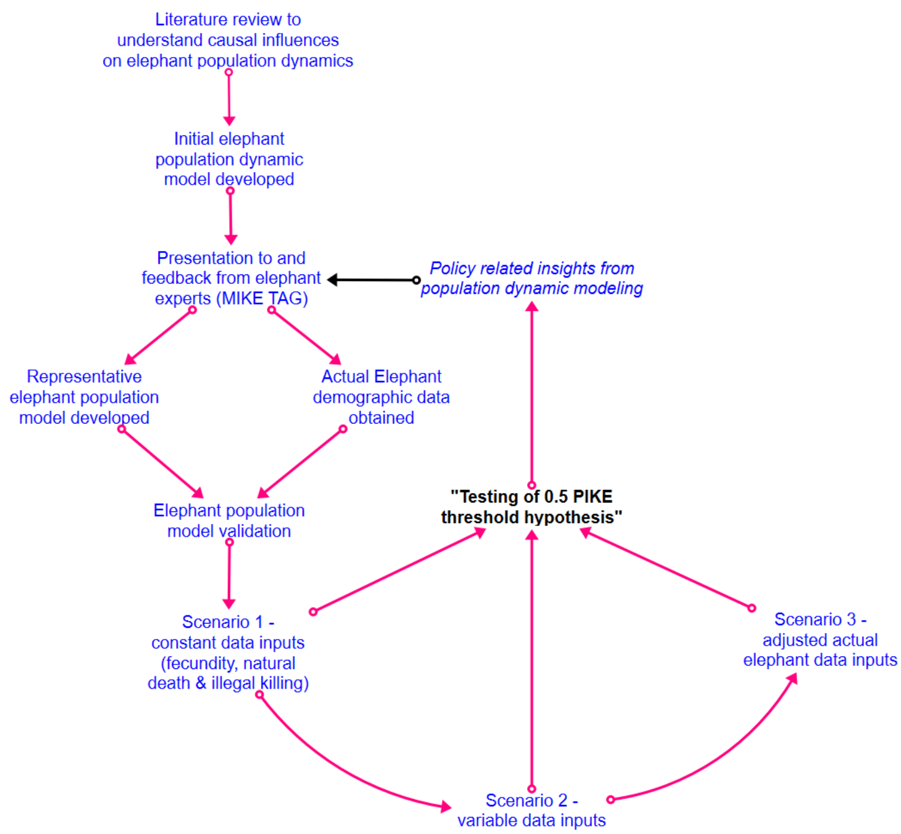

Figure 1 - Process flow for investigating the 0.5 PIKE threshold hypothesis

An Elephant Population Model

The population model was developed using the system-dynamics modeling approach. System dynamics was developed by Jay Forrester at MIT in the 1950s and his early work has defined the modeling principles used today (Forrester, 2013). Although various modeling methodologies exist that each take different approaches, system dynamics was considered suitable for this study as it is well suited to studying broad trends such as growth, decline, fluctuations, equilibrium and simulating complex non-linear social systems with multiple feedbacks and time delays. Rather than focusing on generating precise numerical data, or making accurate predictions and forecasts, a system dynamics model is good for simulating scenarios and is well suited for this research (Bossel, 2007). A key assumption in the system dynamics approach is that the persistent dynamic behavior of any complex system is endogenous and generated from its causal physical structures and information flows. The information and physical flows in the causal structures can be captured through stocks, flows, feedback, delays and various exogenous variables (D. Meadows, 1976).

A simple population model for elephants in a defined area will have a stock of population that increases through inputs of births and decreases though outputs of deaths (natural or through killing). In a simple model, PIKE is calculated from the annual stocks of illegally killed elephants divided by the sum of all dead elephants (Figure 3). In a more complex model, there may also be provision for individual elephants and groups to also pass through, join or leave the populations under study. When the sum of the inflows exceeds the sum of the outflows, the population of elephants will grow, and similarly, when outflows exceed the inflows, the elephant population will decline. Both births and deaths are also directly influenced by the size of the elephant population the inflow of births being determined by the fertility of the population and mortalities determining the outflow through deaths (Bossel, 2007).

Figure 2 - Adult female elephant caring for two juvenile elephants (source S. Frigyik)

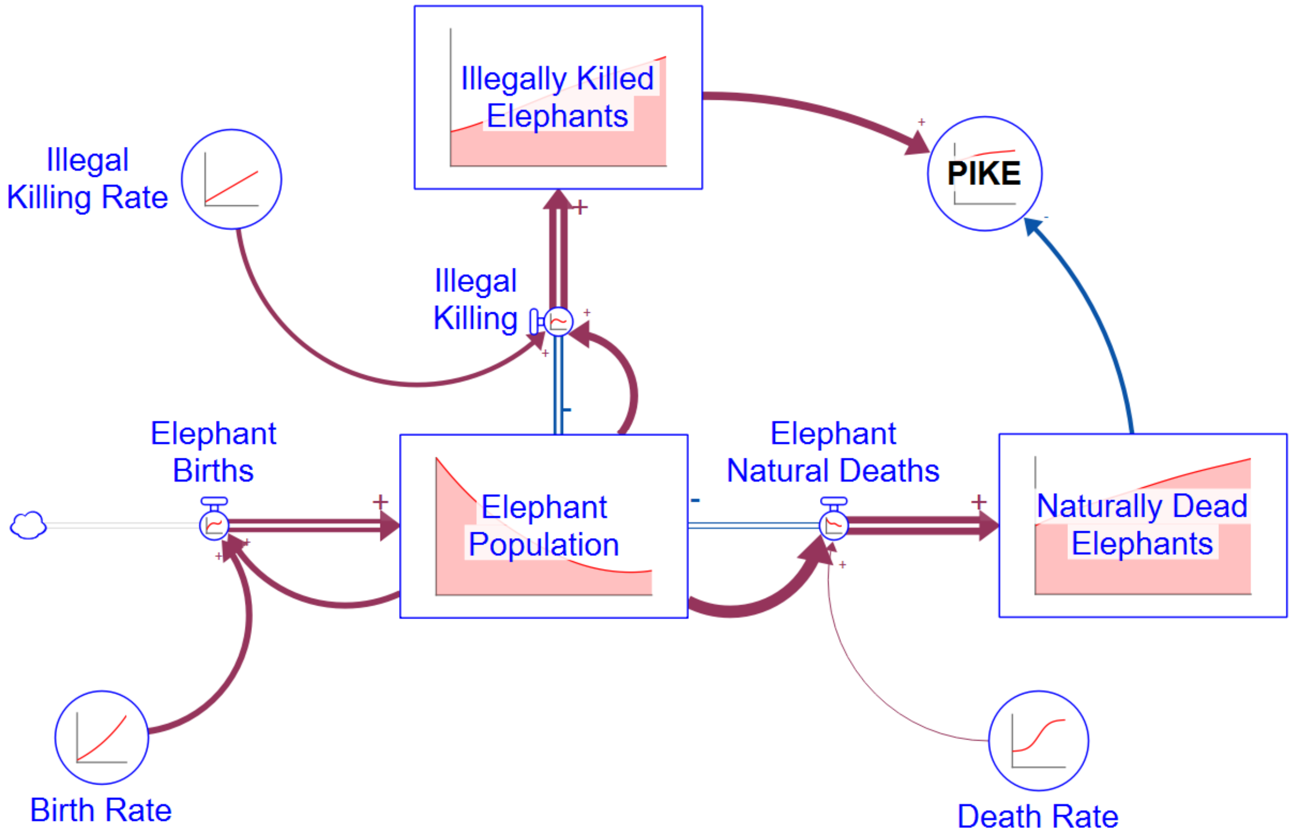

Figure 3 - Simple population stock and flow diagram with one elephant stock filled through births and drained by deaths through natural deaths and illegal killing.

Population size will also be determined by the carrying capacity of its environment – the ability to provide food for the population to grow and thrive and roam as needed. If the population exceeds the carrying capacity of the environment, it will decline through increased mortality and reduced fertility until balance is again achieved (Sterman, 2000). For the purposes of this model, it is assumed that changes in carrying capacity are already implicitly captured in the varying fertility and mortality measurements of the population.

A simple three stock population model was initially developed and for descriptive simplicity the causal influences of this model as depicted in Figure 4 are explained below.

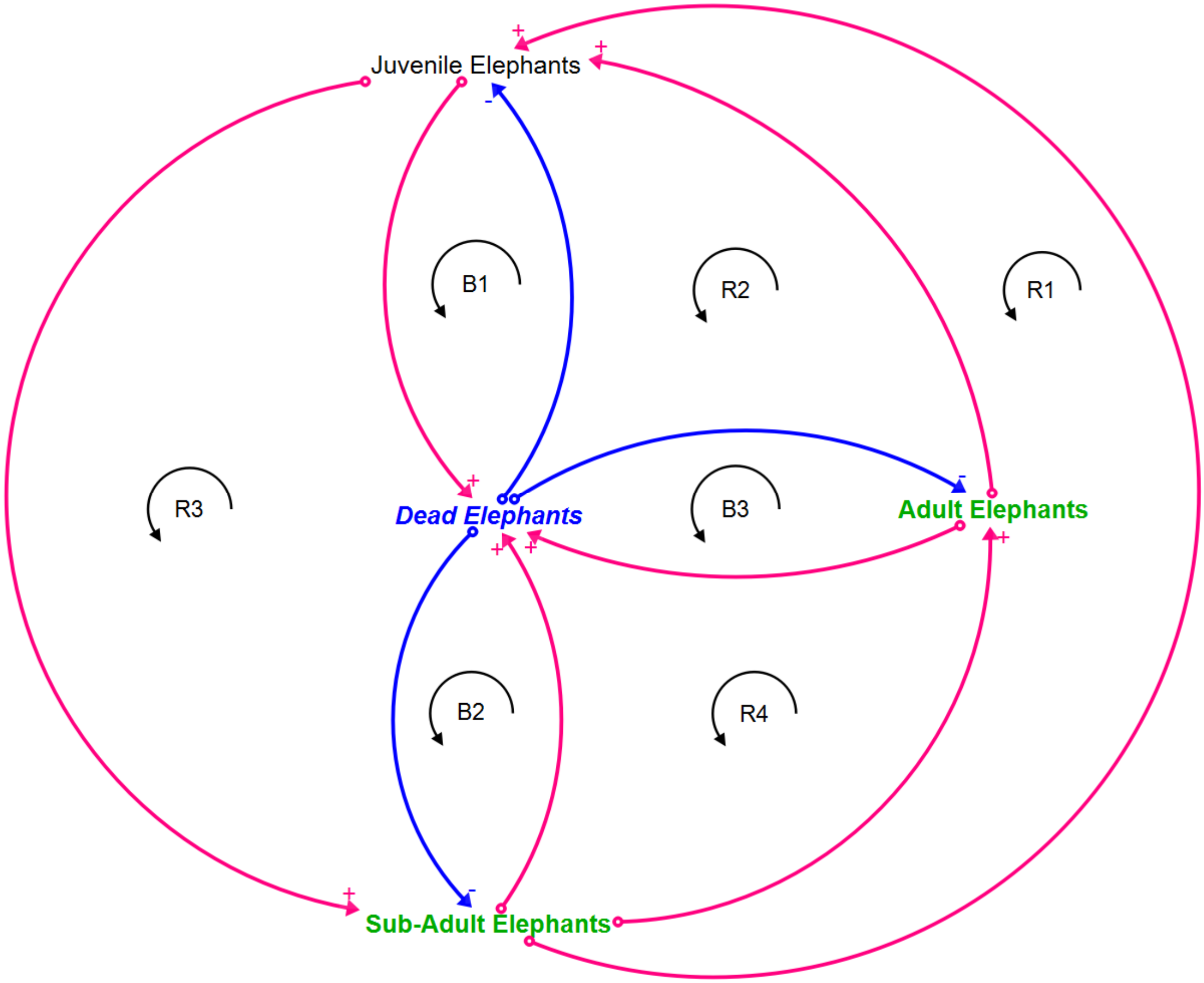

Figure 4 - Causal loop diagram demonstrating key causal influences in a simple 3 age cohort elephant population of Juveniles (0-9 years) Sub-Adults (10-18) and Adults (19+). Red arrows indicate reinforcing feedback loops and blue arrows, balancing feedback loops. Green text refers to fertile live adults and blue text dead stocks of elephants.

The 3-stock model categorizes age cohorts of combined sexes into stocks of Juvenile Elephants (no reproductive ability), Sub-Adults Elephants (reproductive ability), and mature Adults Elephants (higher reproductive ability) (Figure 2). The stock of Juvenile Elephants increases through births arising from Sub-Adult Elephants and Adult Elephants through the reinforcing loops R1 and R2. Increasing Juvenile Elephants in turn causes the stock of Sub-Adults Elephants to increase through reinforcing loop R3 and similarly, the increase in stock of Sub-Adult Elephants causes Adult Elephants to increase through reinforcing loop R4.

The three stocks of elephants are in turn each depleted through the stock of increased deaths (natural deaths and illegal killing are combined in this instance) which acts as three balancing loops: B1, B2 and B3. With more Sub-Adult Elephants and Adult Elephants there are more births and the Juvenile Elephants eventually grow into Sub-Adult Elephants and then Adult Elephants unless removed through deaths.

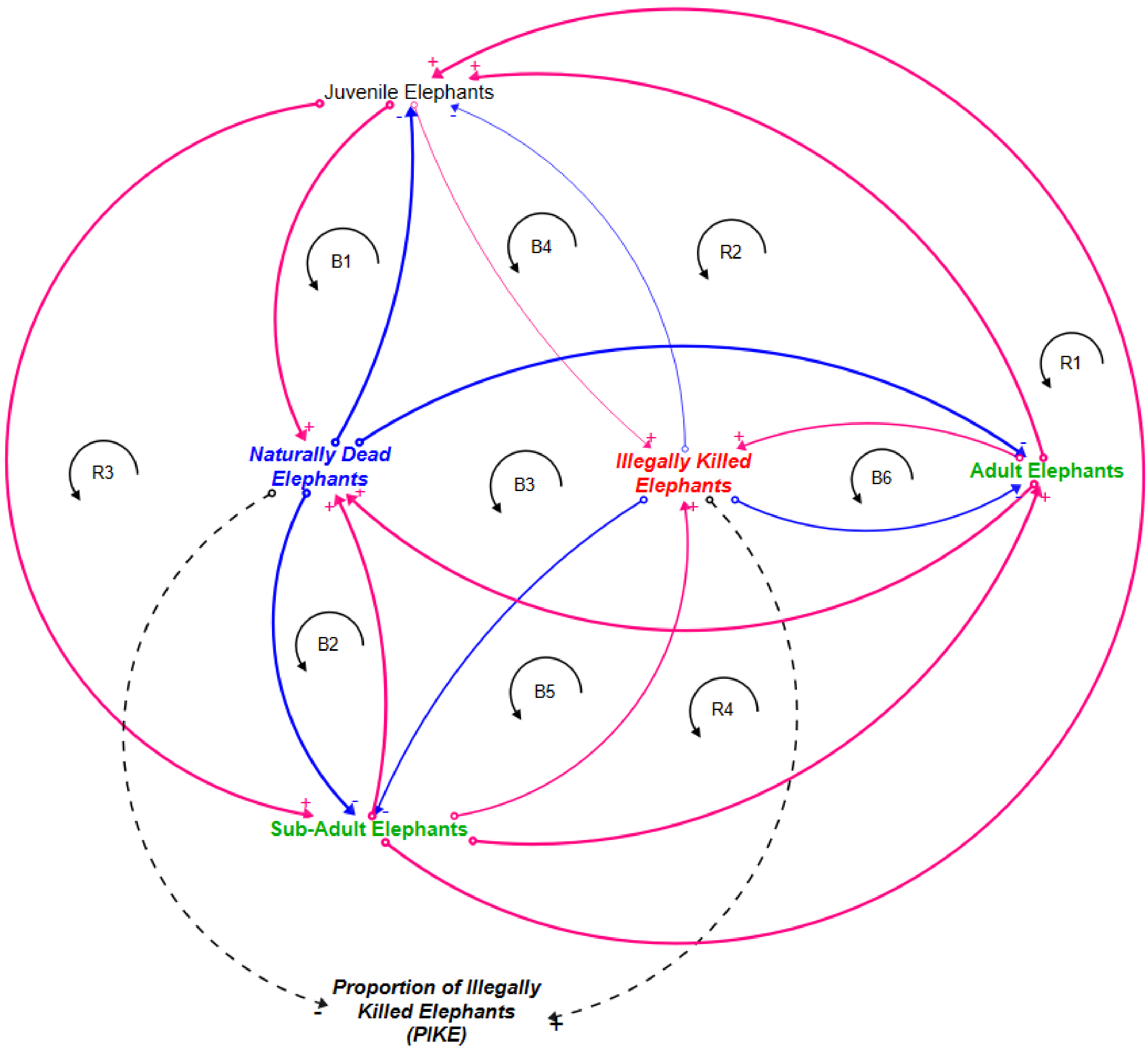

Figure 5 - Causal loop diagram of 3 age cohort elephant population of Juveniles (0-9 years) Sub-Adults (10-18) and Adults (19+) with deaths separated into natural deaths and illegally killed elephants and with PIKE indicator. Variations in thickness of arrows is an indicator of how strong or weak feedback is.

If deaths are then separated into Naturally Dead Elephants and Illegally Killed Elephants as indicated in Figure 5, a further 3 balancing loops are added (B4, B5 and B6) which further reduces the population of Juvenile, Sub-Adult and Adult elephants. Also included is PIKE: the measure of the proportion of illegally killed elephants in relation to the total number of dead elephants. As the stock of Illegally Killed Elephants increases relative to Naturally Dead Elephants, PIKE will increase, and conversely when the stock of Naturally Dead Elephants increases relative to Illegally Killed Elephants, then PIKE will decrease.

As each of the 3 population age cohorts experience differing rates of natural deaths and illegal killing, the PIKE measure will be impacted in different ways over time. Evident from the causal loop diagram is that PIKE is focused on changes in the stocks of dead elephants (natural and illegally killed) and it does not directly factor in changes in the stocks of live elephants due to births. This is an early insight into a potential limitation of PIKE as a standalone indicator of whether a population is in net decline.

Model Development

The author presented an initial conceptual eight age cohort group elephant population dynamics model to the MIKE TAG at meeting held on 17th September 2019, parameterized with summary published data available for an elephant population in Samburu in northern Kenya over a 14 year period from 1997 to 2011 (Wittemyer et al., 2013). The TAG members expressed support for the development of the elephant population model, and it was agreed at that meeting that the population dynamics model should:

- take into consideration the challenges relating to natural mortality rates and clarify why a specific rate is used / ensure the model can include varying natural mortality rates;
- consider the fact that some populations are shared (transboundary populations);
- carefully consider the parameters used in the model although demographic data (age and sex specific data) are available and could be used to calibrate a model, expert input should also be obtained to refine it);
- include a sensitivity analysis; and
- consider issues of scale (site level as well as a sub-regional and regional level).

TAG members also expressed a willingness to provide guidance to the author in the development of the model. The MIKE Coordinator Ms. Thea Carroll, through the TAG board member and Director of

Research at Save the Elephants Dr. Chris Thoulass, put the author in contact with the elephant researcher Dr. George Wittemyer at Colorado State University. The author liaised with Dr. Wittemyer on specific data required for testing and validating the model.

For model validation purposes, it was proposed that a specific elephant population in the Samburu and Buffalo Springs national reserves (Samburu) in northern Kenya be used, as detailed population data over an extensive 20-year period from 1998 to 2017 had been collected for this MIKE site (Figure 6). As data associated with elephant populations is sensitive information, a further summarized and analyzed version of the raw data was used for the actual calibration of the model. The detailed summary data is not published in this thesis.

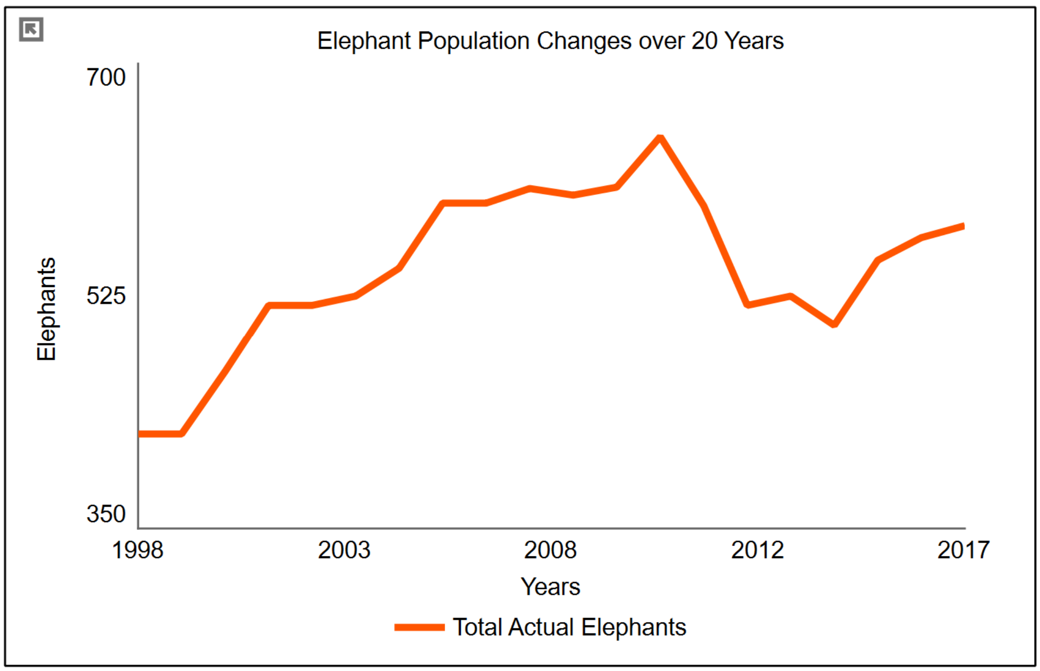

Figure 6 - Actual changes in total elephant population in the Samburu & Buffalo Springs National Reserves from 1998 to 2017 (Wittemyer, G 2021)

A number of iterations of models were developed, following the recommendations from the MIKE TAG, with the final model consisting of separate male and female stocks, each with 5 age cohort groups and with conveyor stocks (total of 10 population stocks). Each stock has outflows for natural deaths and illegal killing, inflows and outflows for migration (unused in model) and added at the request of the client, outflows for managed killing (see Appendix C for full model details). For each population stock, a conveyor stock was used to more evenly distribute the flow of elephants though the stock. The conveyor stocks varied in transit times from 2 years for the 1-2 year-old elephant cohort, to a transit time of 25 years for the 36+ year old elephant cohort. The starting populations of elephants were evenly distributed in the stocks (there was no noticeable changes in behavior of the model with differing distributions of starting populations in the conveyors in the stocks). Although not applicable in Kenya, in various other countries culling is also a possible legal method of killing elephants and, in some countries, controlled trophy hunting is also legal (Dube, 2021). Although provision for legal killing was made in the model, no scenarios were explored as there is no culling or trophy hunting permitted in Kenya.

The data requested for model validation included yearly elephant population data by sex, age cohorts, birth rates, natural death rates, illegal killing rates, migration of elephants in and out of the population being studied, and any other relevant data that could affect the elephant population. Data was provided over a 20-year period from 1998 to 2017 for measured populations on fecundity by reproductive female cohort for producing female calves, and total deaths per cohort per sex per year (Wittemyer et al., 2020). No data was provided on illegal killing and the author was advised that it could not be empirically determined what the cause of death was in this study. Illegal deaths were instead included in the total death data provided. In the absence of corresponding illegal killing data a specific detailed PIKE analysis could not be conducted on the Samburu and Buffalo Springs population, however the data provided was adequate to proceed with testing and initially validating the population model. For more realistic scenario testing, estimates were then made of possible illegal killing rates for the Samburu population using published research from an earlier study (Wittemyer et al., 2013). Various scenarios were then explored using measured summary fecundity, as well as natural mortality and illegal killing data available from CITES, and these results were used to test the research hypothesis.

The model was parameterized with starting populations in 1998 using male and female data provided for each of the 5 age cohort stocks (Figure 8). Using imported data, fecundity rates were applied for each of the 20-year period for females in the age cohorts 9-18, 19-35 and 36+. As fecundity data was only provided for female calves, the average ratio of male calves to female calves born was calculated at 0.839, and this factor was then applied to the fecundity data to approximate the fecundity levels for male calves. Deaths rates per cohort per sex were also imported and applied to the model. Although these death rates included illegal killing, in the absence of this separate detail being provided, they were all applied to the natural death flows for the purposes of initial model validation. Switch A was included in the model to switch between applying actual fecundity/adjusted natural death/estimated illegal killing data or simulating these using other graphical selected inputs or constant inputs using a second Switch B (Figure 7). A model interface with explanation of different settings was also included in the model for users to further explore scenarios of interest (Figure 27).

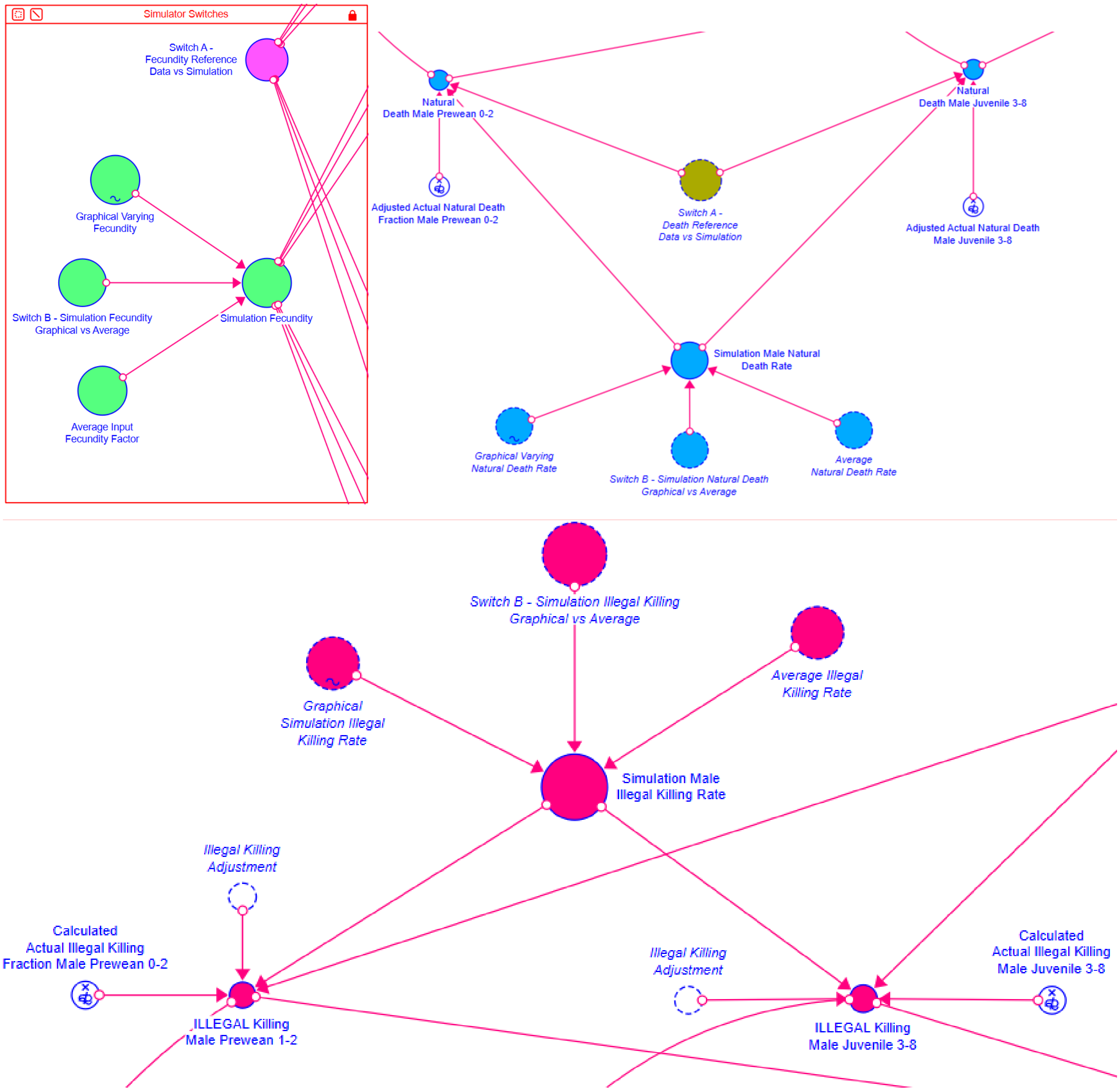

Figure 7 – Switch A in model to move between simulating scenarios using actual fecundity, adjusted actual natural deaths and estimated illegal killing and other user simulations using Switch B, graphical or constant.

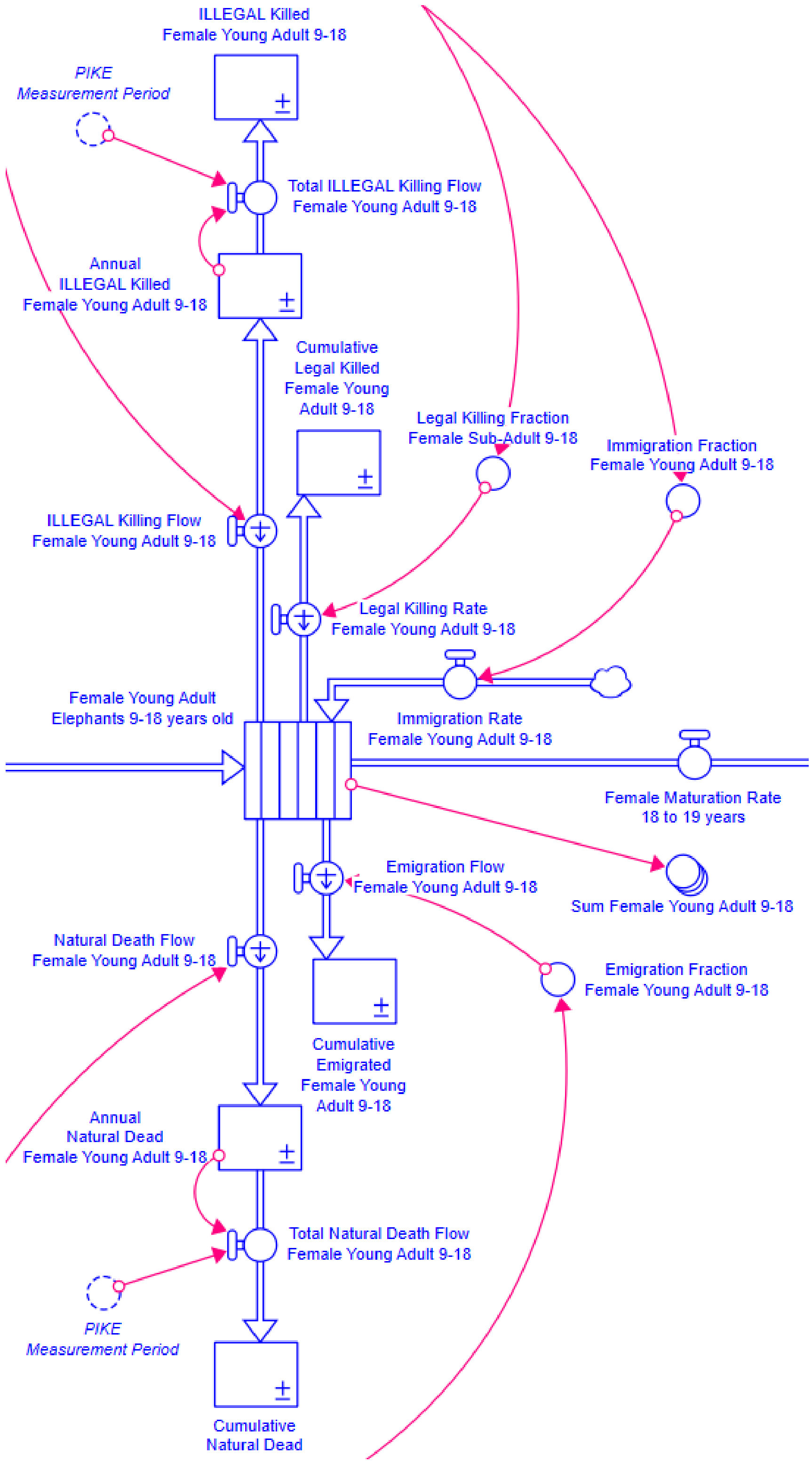

Figure 8 - Basic recurring stock and flow element, conveyor age cohort stock with inflow from preceding age cohort stock and outflow to next age cohort. Outflows for illegal killing, natural deaths (and other elements immigration, emigration and legal killing not used here for simulations).

PIKE is measured in the model by dividing the sum all the stocks of the annual illegally killed male and female elephants by the sum of the total of annually illegally killed and naturally dead male and female elephants as in Figure 9. These stocks are located above and below each population conveyor stock as noted in Figure 8.

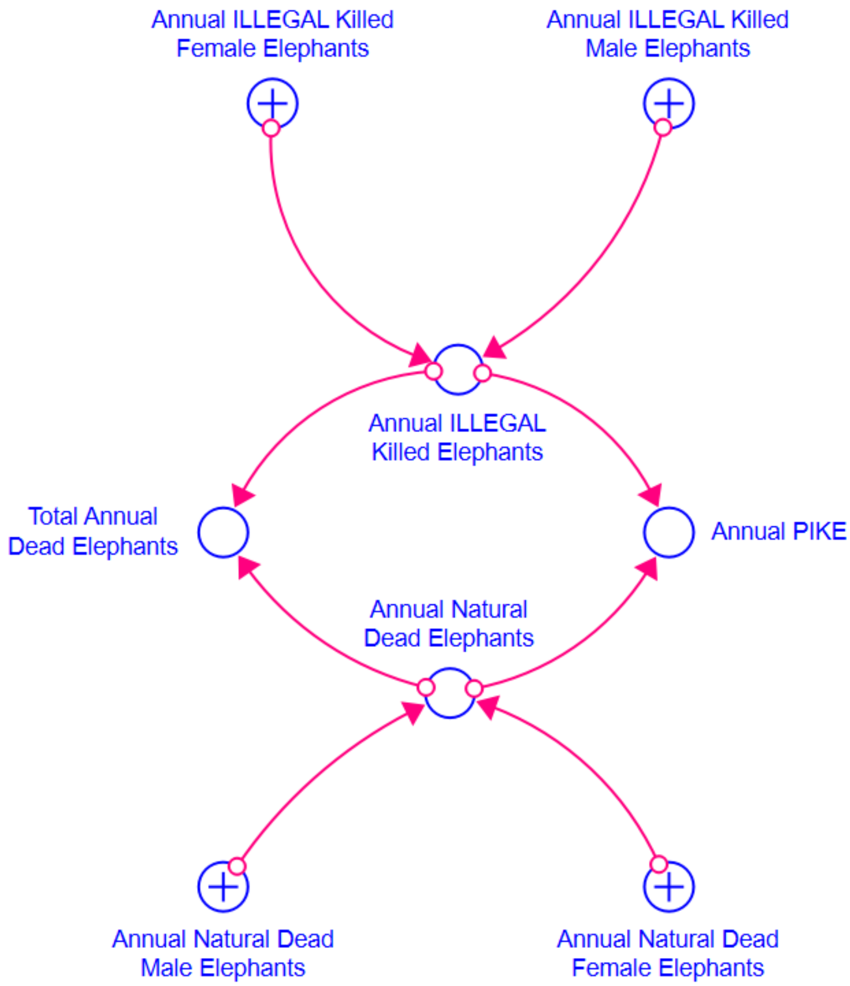

Figure 9 - Calculation of PIKE using stocks of annual illegally killed elephants and naturally dead elephants

Extensive testing was conducted as the model was continually developed through various iterations (Barlas, 1996). The final model generated behavior in Figure 10 over the 20-year period represented by the solid line in comparison to the actual total elephant population change represented by the dashed line. The model's generated behavior trends closely resemble the actual observed data trend. As mentioned earlier, the importance of system dynamics models is in correctly capturing trends (increasing, decreasing, fluctuations or equilibrium) and not necessarily the exact detailed replication of data. The model demonstrates that the population increases rapidly initially, and then levels out somewhat before again increasing rapidly, again leveling out and then peaking before declining and eventually increasing slightly again, then dropping and in the last few years of the 20-year study increasing sharply. The behavior generated by the model increases and decreases as is it should when compared with actual elephant population data. Although the model's dynamics are driven by exogenous inputs, causing the model to "dance to a particular beat" the feedback through the development of the population stocks over time is endogenous (Sterman, 2000). Earlier models with combined male and female stocks generated behavior with various systematic errors such as parameter bias and phase shifts. This was addressed by creating separate male and female stocks. Considering that the model is relatively simple with just 5 population conveyor stocks for each of the male and female elephants representing a period of 59 years, the behavior generated tracks actual data with similar trends very well and with an apparent unsystematic error (Sterman, 2000).

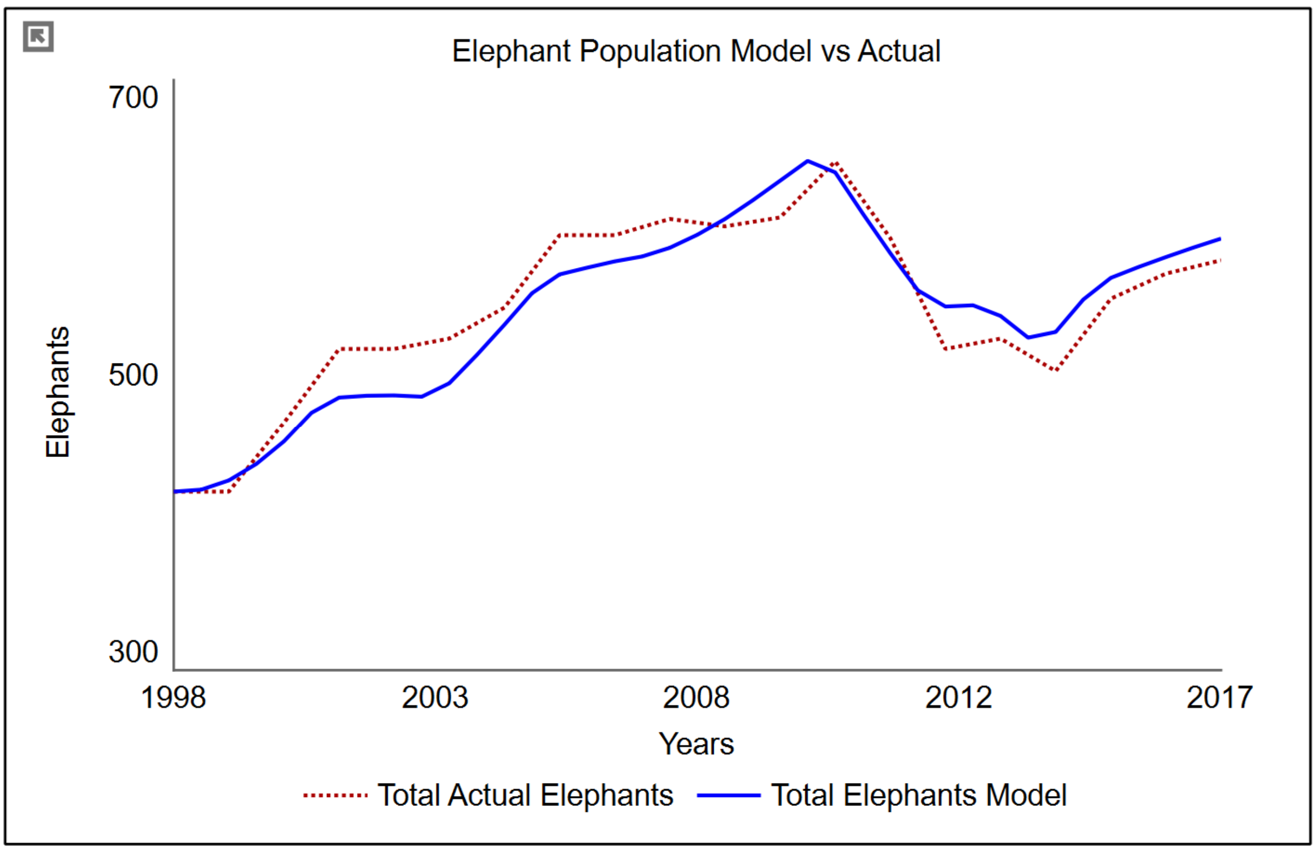

Figure 10 - Model generated population behavior (solid line) versus actual population data (dashed line) over a 20-year period.

Model Validation

A full range of sensitivity tests were conducted for each of the input variables, fecundity, natural death and illegal killing using constant inputs for both expected ranges of high and low values, as well as extreme values (0 to 1). As not all requested data was available, the author improvised with what there was, when it was received, and what interpretations could be made from the raw data, and in the absence of requested actual data, what other closely related published data was available.

Table 1 indicates the values used for testing and their sources. Fecundity data was provided although the original plan was to use natality data in the model which is what is commonly referred to in the literature. Fecundity data however turned out to be better as it provides greater detail on age-specific fecundity allowing for greater fine tuning of the model. The fecundity values in Table 1 are taken from the actual data averages analyzed from the Samburu population as this information was not available from the CITES literature (Wittemyer et al., 2020). Ideally, the fecundity data for the East African region would be used corresponding to the natural death and mortality reported by CITES, but this data was not reported by CITES. Similarly, for the sensitivity testing, actual death data was not used for the Samburu population as there was no distinction between natural deaths and illegal killing.

Table 1 - Measured averages and upper and lower limits of fecundity, natural mortality and illegal killing (CITES) used for sensitivity testing and then exploring scenarios.

Variable	***Range***	***Average***	***Source***
Fecundity Rate **(per year)**	0.001 to 0.190 Minimum and Maximum Average Fecundity across 3 female elephant cohorts	0.101	Wittemyer G. 2021. (Raw data provided over 20 years. Analyzed & summarized by author)
Natural Mortality Rate **(per year)**	0.015 to 0.045 Or 1.5% to 4.5%	0.03 Or 3%	CoP18 Doc. 69.2 paragraph 39
Illegal Killing Rate **(per year)**	0.014 to 0.103 Or 1.4% to 10.3%	0.05 Or 5%	CoP18 Doc. 69.2 paragraph 40

Note on units - decimal values are used for all rate variables Fecundity, Natural Deaths and Illegal Killing as this is how the data was applied in the model. However, in literature fecundity is often presented as a decimal value and death rates are often expressed as percentages.

Fecundity - the number of calves produced by female adults by cohort per year.

In the first set of sensitivity tests fecundity was varied uniformly over 10 runs between 0.001 and 0.190 and natural death held constant at 0.03 and illegal killing 0.032 (initial equilibrium state). The range of population development is as expected in Figure 11 (Graph left) and will decline at the lower fecundity and increase at the higher fecundity levels. The extreme test with fecundity ranging from 0 to 1, although perhaps unrealistic on the high side, generates a wide range of population development in Figure 11 (Graph right). This does provide an insight into the high sensitivity that the elephants' growth has to fecundity rates.

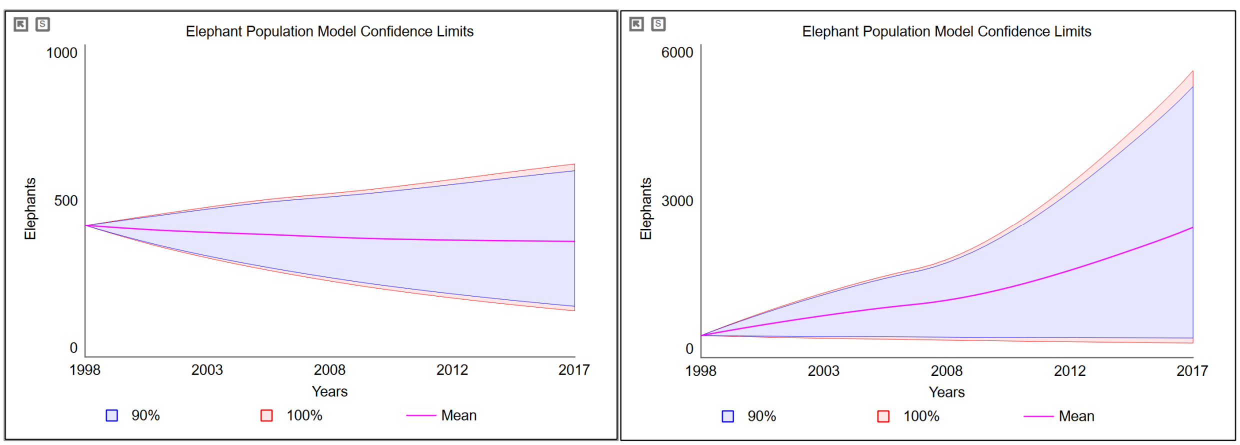

Figure 11 - (Graph left) Fecundity sensitivity test with 10 uniform runs between 0.001 and 0.190 and resulting 90% and 100% confidence limits and mean. (Graph right) Similar extreme sensitivity test for fecundity between 0 and 1.

Sensitivity analysis on natural deaths and illegal killing both demonstrated similar results (Figures 12 & 13). The range of sensitivity for natural deaths was 0.015 to 0.045, narrower than illegal killing (0.014 to 0.103), which explains the wider population variation for illegal killing. The extreme test with natural death and illegal killing ranging from 0 to 1 both generated similar results. The extreme tests also provided an insight into the high sensitivity that the elephants' decline has to deaths.

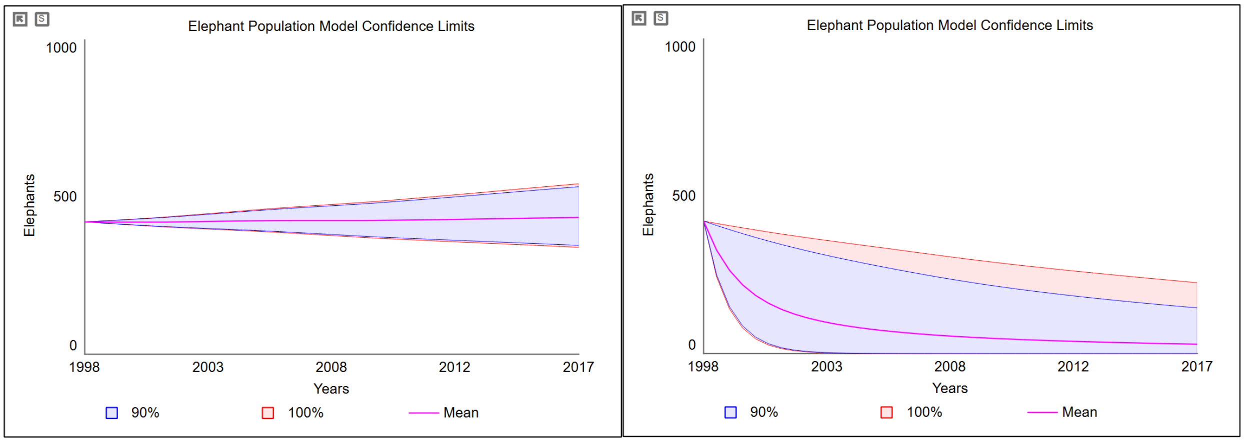

Figure 12 - (Graph left) Natural deaths sensitivity test with 10 uniform runs between 0.015 and 0.045 and resulting 90% and 100% confidence limits and mean. (Graph right) Similar extreme sensitivity test for natural deaths between 0 and 1.

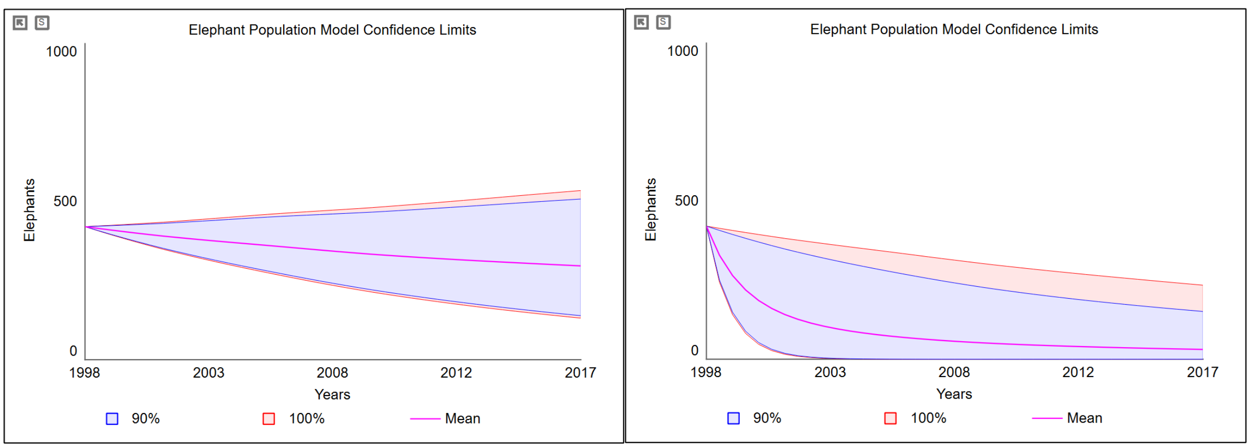

Figure 13 - (Graph left) Illegal killing sensitivity tests with 10 uniform runs between 0.014 and 0.103 resulting 90% and 100% confidence limits and mean. (Graph right) Similar extreme sensitivity test for illegal killing between 0 and 1.

The sensitivity tests also demonstrated that under the extreme tests, the decline of the population will be more sensitive to deaths, and the increase in the population will be more sensitive to births.

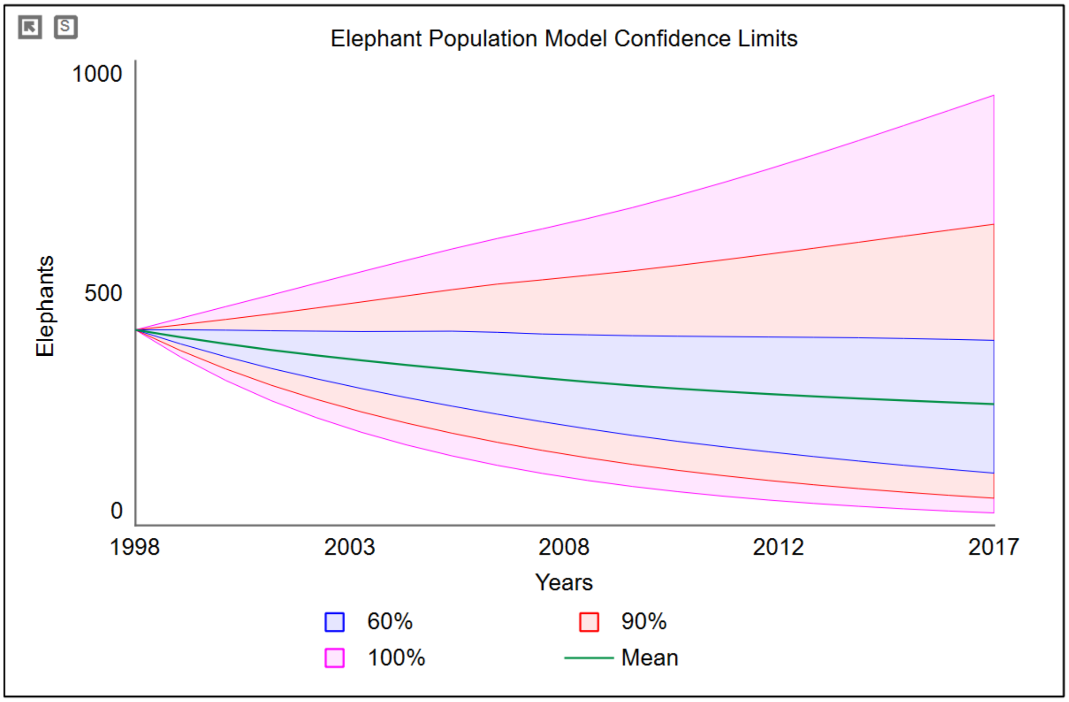

Figure 14 - Sensitivity test 100 runs of all variables, fecundity, natural deaths and illegal killing within expected ranges. Average population declines and even at upper limit of 60% confidence interval.

Extensive further sensitivity testing was also completed, and an interesting insight was gained from Figure 14 which indicates that when all variables are tested over 100-runs, there is an average decline in the elephant population, even at the upper limit of the 60% confidence interval. A similar average decline was generated over 1000 runs.

The model was also tested over a 60-year period and remained in the initial equilibrium test state. Varying integration methods were also used to test for integration error, as well as delta times varied. Under all extreme test conditions, the model was stable and performed well (refer to Appendix A for summary of tests conducted) (Barlas, 1996). The model was therefore considered to reliably generate realistic trend behavior, and in view of this, is a good basis to test the hypothesis that when PIKE is above a 0.5 threshold, the elephant population will be in net decline and below 0.5 a population will be in net increase. Full model documentation is provided in Appendix C (Rahmandad & Sterman, 2012).

Simulation scenarios to test the Hypothesis.

The hypothesis to test is that when PIKE is above a 0.5 threshold, the elephant population will be in net decline or below 0.5 a population will be in net increase. A series of scenarios is investigated starting with linear inputs of individual variables, then changing individual inputs, and then finally inputs that are more complex and closely resemble the fluctuations observed in the Samburu population. Note that in all the graphs PIKE starts off initially at zero as in the validation data no dead elephants were reported at the initial time interval in 1998 and so the starting death stocks (see Figure 8) are initially set to zero.

Scenario 1 – Constant Inputs for Fecundity, Natural Death and Illegal Killing

The initial scenario was to undertake visually simple tests, a more focused form of sensitivity testing, using constant inputs, varying one while keeping others constant to see what the influence would be on the population development and PIKE. Under each of these initial scenarios, the initial action was to place the model into an equilibrium state (population doesn't reduce or grow) using the variable that is being varied with others kept constant at the averages in Table 1.

Once in equilibrium the different variables could be varied between the upper and lower limits to see what the impact on PIKE would be and what the corresponding population development trend is. Other scenarios also explore changing variables over time (Scenario 2) as well as actual data changes (Scenario 3). The average fecundity of 0.101 female calf births per female per year was calculated from the raw data provided for the Samburu population. This fecundity rate was used as a starting point, along with a natural death rate of 0.03 per year and an illegal killing rate of 0.05 per year, the average rates referred to by CITES.

Scenario 1.1 – Varying Illegal Killing

In order to determine the effect of varying illegal killing, the average fecundity was set at 0.101 and average natural death at 0.03 with illegal killing varied between a lower limit of 0.014 and upper limit of 0.103. The model was in equilibrium at an illegal killing of 0.032 with a corresponding PIKE of 0.52 as shown in Figure 15. Under Scenario 1.1 the hypothesis is not convincingly disconfirmed as the turning point at which population starts to decline is at an illegal killing rate that increases from 0.032 with a PIKE of 0.52. For illegal killing below 0.032 the PIKE values are below 0.52 and the population increases. The range of scenario 1.1's with varying fecundity are summarized in Table 2. In all the graphs PIKE starts at zero as there are no stocks of dead elephants recorded initially.

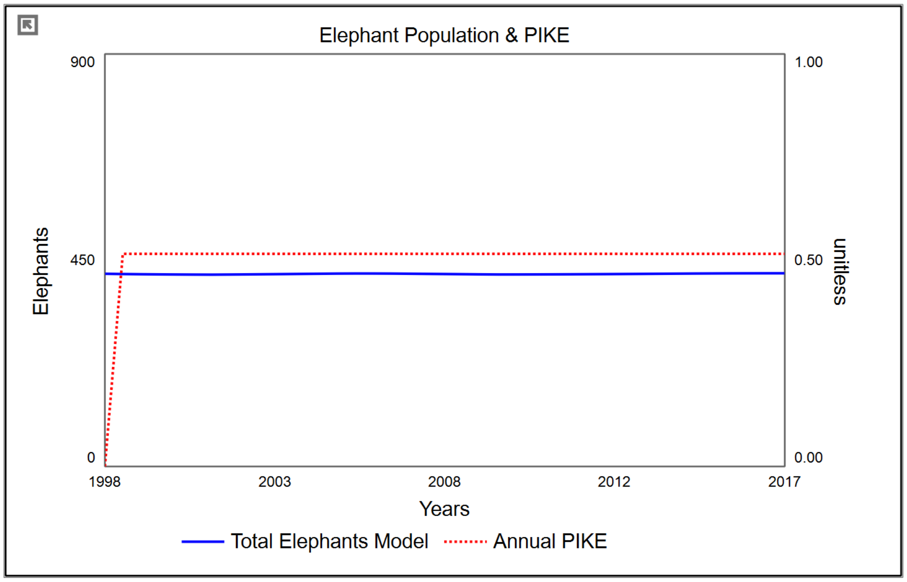

Figure 15 - Scenario 1.1.1 Model in equilibrium state with Fecundity 0.101, Natural Death 0.03 and Illegal Killing 0.032 producing a PIKE of 0.052 (PIKE starts at zero as there are no initial stocks of dead elephants).

Table 2 - Constant Average Fecundity and Natural Death with varying Illegal Killing rates

Scenarios (Switches A&B set to 1)	**Average Fecundity (rate /year)**	**Average Natural Death (rate /year)**	**Average Illegal Killing (rate /year)**	**Population change over 20 years**	**PIKE**	**Population Trend**
Scenario 1.1 – Average Fecundity 0.101 Average Natural Death 0.03 Illegal Killing varying 0.014 to 0.103						
1.1.1 Equilibrium Illegal Killing	0.101	0.03	0.032	1	0.52	Equilibrium
1.1.2 Lower Limit Illegal Killing	0.101	0.03	0.014	174	0.32	Increasing
1.1.3 Higher Limit Illegal Killing	0.101	0.03	0.103	(315)	0.77	Rapid Decline
1.1.4 **PIKE 0.50**	0.101	0.03	0.03	18	0.50	**Slowly increasing**
Comment: Under this theoretical scenario the hypothesis is not convincingly supported. All changes in illegal killing resulting in a PIKE > 0.52 results in a declining population. For PIKE < 0.52 population will be increasing.						

Scenario 1.2 – Varying Natural Death

To determine the effect of varying natural death, the average fecundity was again set at 0.101 and the average natural death varied between a lower limit of 0.015 to an upper limit of 0.045 with illegal killing kept constant at an average of 0.05. Under these conditions the equilibrium point is at a natural death rate of 0.012 (lower than the observed lower limit of 0.015) and with a PIKE value of 0.81. Figure 16 demonstrates that at a PIKE value of 0.53 the population will be rapidly decreasing. As PIKE is a fractional measure with natural deaths only occurring in the denominator, any increases in natural deaths relative to a fixed illegal killing will bring PIKE down, although total deaths will be increasing. This also demonstrates that PIKE alone is not a strong indicator of whether the population will be increasing or decreasing without understanding how births are changing. The range of scenarios under 1.2 with varying natural deaths are summarized in Table 3.

Table 3 - Constant Average Fecundity and Illegal Killing with varying Natural Death rates

Scenarios (Switches A&B set to 1)	**Average Fecundity (rate /year)**	**Average Natural Death (rate /year)**	**Average Illegal Killing (rate /year)**	**Population change over 20 years**	**PIKE**	**Population Trend**
Scenario 1.2 – Average Fecundity 0.101 Average Natural Death 0.015 to 0.045 Illegal Killing 0.05						
1.2.1 Equilibrium Natural Death	0.101	0.012	0.05	1	**0.81**	**Equilibrium**
1.2.2 Lower Limit Natural Death	0.101	0.015	0.05	(23)	**0.77**	**Slowly Decreasing**
1.2.3 Higher Limit Natural Death	0.101	0.045	0.05	(198)	**0.53**	**Very Rapid Decline**
1.2.4 PIKE **0.50**	0.101	0.05	0.05	(219)	0.50	**Very Rapid Decline**
Comment: Under this theoretical scenario the hypothesis is not supported. The equilibrium state is below the lower natural death rate limit and so all rates higher than this will result in a declining population up to a rapid decline as the upper natural death rate limit is reached or 0.045. At the equilibrium state PIKE is 0.81.						

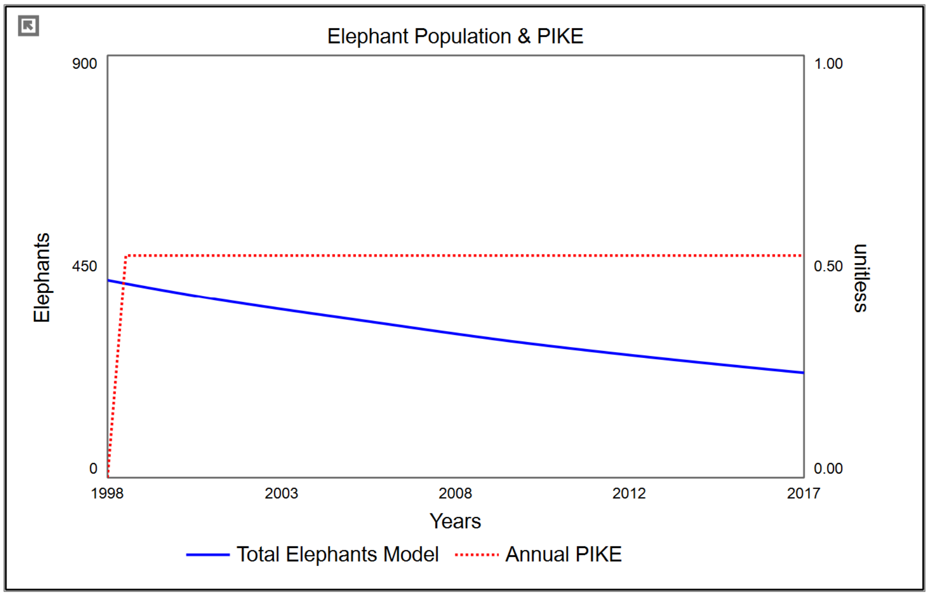

Figure 16 - Scenario 1.2.3 Fecundity 0.101, Natural Death 0.045 and Illegal Killing 0.05 producing a PIKE of 0.53. At this threshold PIKE value there is a rapid decrease in population by 198 elephants.

Scenario 1.3 – Varying Fecundity

Under this scenario, fecundity is varied between the actual data lower average of 0.009 to an upper limit of 0.191 with an average natural death of 0.03 and an average illegal killing rate of 0.05. Under these conditions, PIKE remains constant at 0.63 as both death and killing rates are constant. The equilibrium point is at a fecundity of 0.160 where population is stable. If the average values in Table 1 are input to the model, the population declines by 123 elephants as indicated in Scenario 1.3.2 in Figure 17. Figure 17 demonstrates that even as PIKE remains constant, population can decline slowly or rapidly as fecundity varies. In Figure 18 there is a higher fecundity resulting in population growth in the left graph, but as fecundity drops PIKE remains the same and population declines as in the graph on the right. These scenarios demonstrate that PIKE can remain constant and the elephant population can be rapidly increasing or decreasing depending on how the fecundity value changes.

Table - 4 Varying Fecundity with constant Average Natural Death and Illegal Killing Rates.

Scenarios (Switches A&B set to 1)	**Average Fecundity (rate /year)**	**Average Natural Death (rate /year)**	**Average Illegal Killing (rate /year)**	**Population change over 20 years**	**PIKE**	**Population Trend**
Scenario 1.3 – Average Fecundity 0.009 to 0.191 Average Natural Death 0.03 Illegal Killing 0.05						
1.3.1 Equilibrium Fecundity	0.160	0.03	0.05	1	0.63	Equilibrium
1.3.2 Averages	0.101	0.03	0.05	(123)	0.63	Decline
1.3.3 Lower Limit Fecundity	0.009	0.03	0.05	(323)	0.63	Rapid Decline
1.3.4 Higher Limit Fecundity	0.191	0.03	0.05	133	0.63	Steady Increase
1.3.5 PIKE 0.50	0.191	0.03	0.03	392	0.50	Rapid Increase
1.3.6 PIKE 0.50	0.191	0.05	0.05	(44)	0.50	Slight decline
1.3.7 PIKE 0.50	0.101	0.045	0.045	(179)	0.50	Decline
Comment: Under this theoretical scenario the hypothesis is not supported. With both natural deaths and illegal killing kept constant at their average values constant PIKE will also remain constant. However, as fecundity is varied population increases and decreases, whereas PIKE remains constant.						

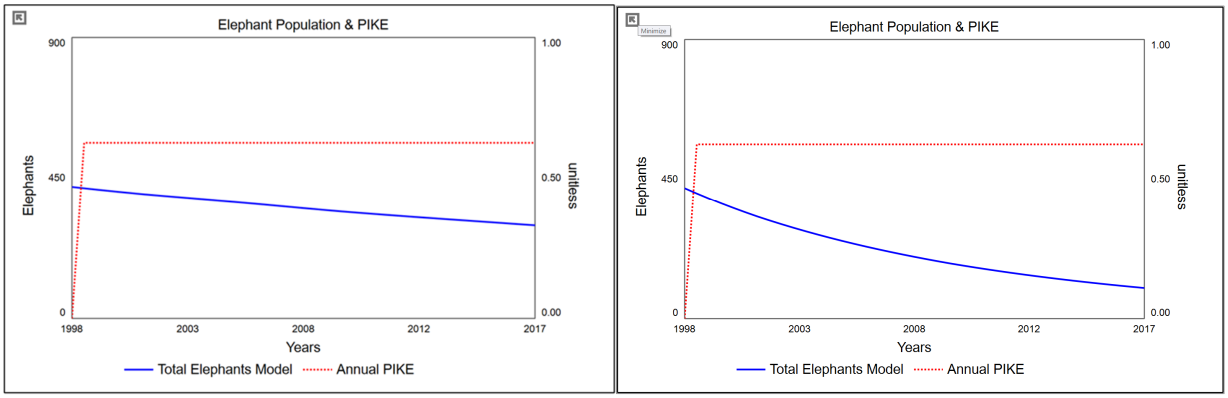

Figure 17 - (Graph L) Scenario 1.3.2 Fecundity 0.101 with PIKE of 0.63 resulting in population decrease by 123 elephants. (Graph R) Scenario 1.3.3 Fecundity decreased to 0.009, PIKE remains the same at 0.63 yet there is a rapid population decrease by 323 elephants.

Scenarios 1.3.5 and 1.3.6 in Figure 18, where both illegal killing and natural deaths are the same resulting in a PIKE of 0.50, also clearly demonstrates that PIKE, as a measure only focused on illegal killing and natural deaths, is not on its own a reliable measure of whether an elephant population is declining or increasing without also knowing how fecundity and more broadly, birth rates are changing.

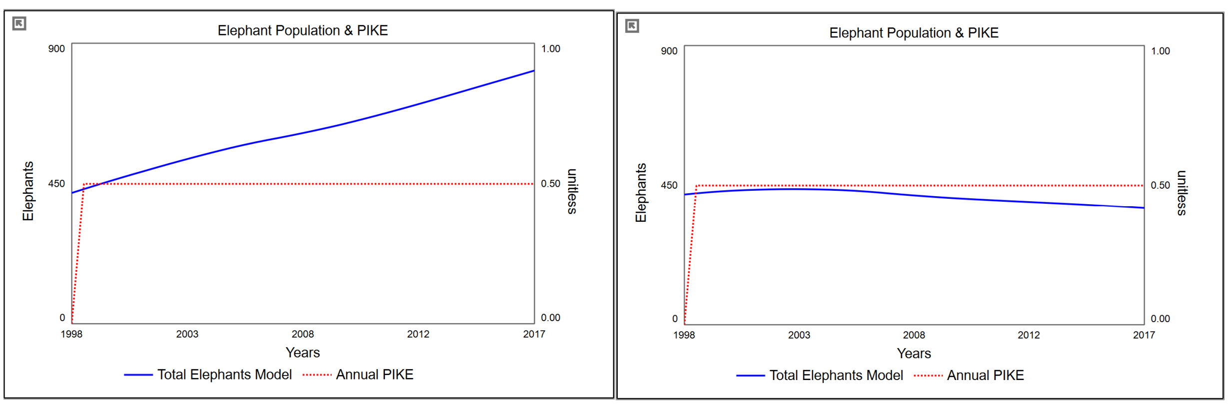

Figure 18 - (Graph L) Scenario 1.3.5 Fecundity is increased to 0.191, Natural Death 0.03 and Illegal Killing 0.03 producing a PIKE of 0.50 with a rapid population increase by 392 elephants. (*Graph R) Scenario 1.3.6 Fecundity is the same at 0.191, Natural Death increased to 0.05 and Illegal Killing increased to 0.05 producing a PIKE of 0.50 resulting in a decline in population by 44 elephants.*

The final scenario 1.3.7 in Figure 19 that includes the average fecundity of 0.101 and the upper limit of natural deaths at 0.45 with illegal killing also at 0.45 with a PIKE of 0.50, results in a steadily declining population. This scenario did not support the hypothesis.

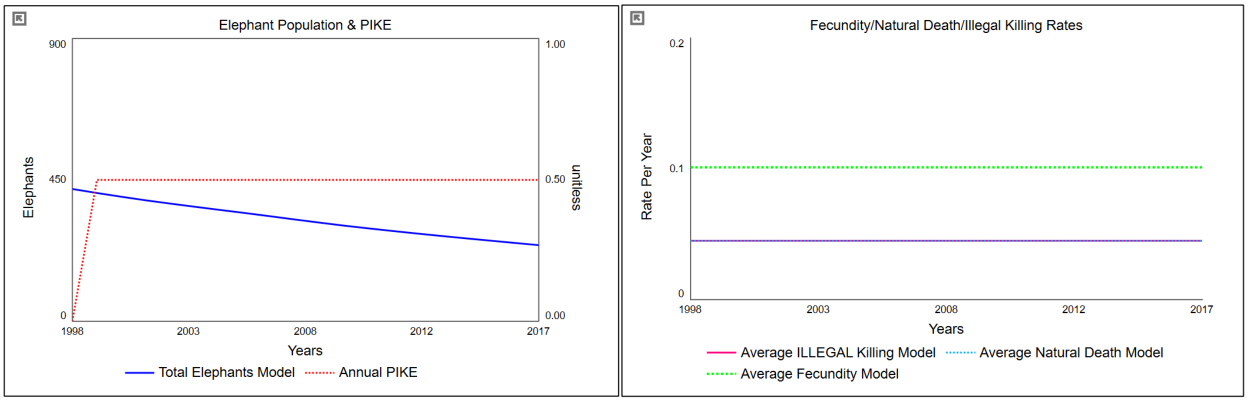

Figure 19 – Scenario 1.3.7 Fecundity is at the average of 0.101 and Natural Death at upper limit of 0.045 and Illegal Killing also 0.045 producing a PIKE of 0.50 with a decline in elephants of 179.

Scenario 2 – Continuously changing Fecundity, Natural Death and Illegal Killing

The previous Scenario 1 used simple constant linear variables of fecundity, natural death and illegal killing to demonstrate visually how population trends vary in relation to differing PIKE values. In reality these variables are not constant, and will all vary over time. Under Scenario 2 other population development scenarios are investigated that have a mix of varying variables over time.

Scenario 2.1 – Decreasing Fecundity, constant Natural Deaths and Illegal Killing

A relatively simple scenario in Figure 20 is where fecundity is declining and both natural deaths and illegal killing are held constant results in a population that first increases and then decreases although PIKE remains constant at 0.50. The reinforcing feedback of births and the balancing feedback of deaths described in Figures 4 & 5, and changing dominance between these feedbacks, results in the observed population behavior. In Scenario 2.1 an initial higher fecundity results in a strong reinforcing feedback loops that results in population growth. As this fecundity declines and the reinforcing feedback loops weaken, the combined natural deaths and illegal killing results in balancing feedback loops that causes population growth to level out. The fecundity reinforcing feedback loops are eventually so weak that the death balancing loops cause the population to decline. If there are no other changes the equilibrium point reached in this scenario is when all the elephants are dead. The first Scenario 2.1, although apparently simple, results in population changes that cannot be explained by only observing PIKE.

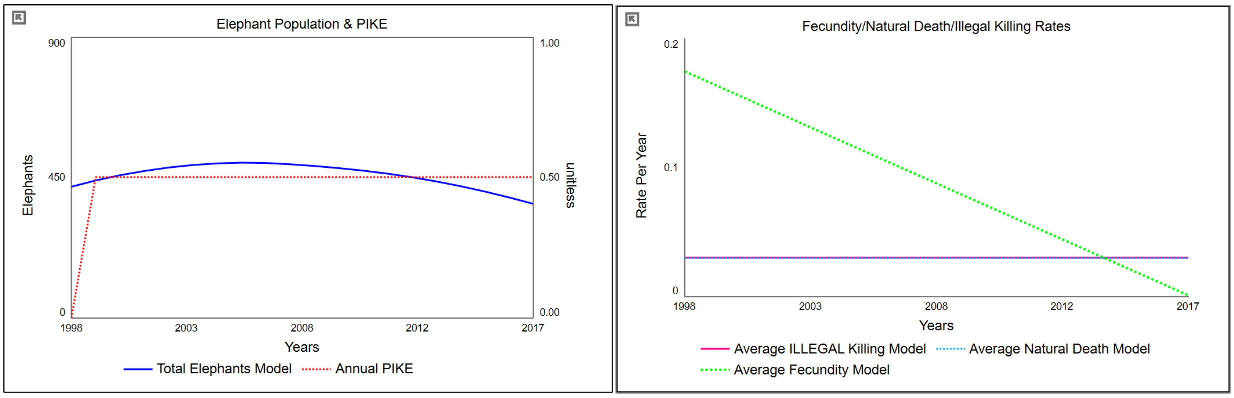

Figure 20 – Scenario 2.1 Fecundity decreasing with PIKE at 0.50 and population increasing and then decreasing.

Scenario 2.2 – Increasing Fecundity and decreasing Natural Deaths, constant Illegal Killing

In the more realistic scenario represented in Figure 21, fecundity is increasing at first rapidly and then gradually, with natural death decreasing steadily - perhaps the desirable situation envisioned for a naturally growing population, although illegal killing is also steadily increasing. Population declines sharply at first as the fecundity reinforcing feedback loops are initially weak and the natural death balancing feedback loops stronger, but then population dips, rises and then levels out as the fecundity reinforcing feedback become stronger causing more births. As the fecundity starts to level out, the illegal killing balancing feedback loop strengthens causing population to peak and then decline. Although population is decreasing, increasing, and decreasing again, PIKE is increasing steadily throughout and is initially low, well below 0.50, although population is initially declining. Even as PIKE rises above 0.50 the population is still increasing and then eventually starts to decline. The population change is due to changing loop dominance between reinforcing fecundity feedback loops and the varying balancing death feedback loops: at first a stronger natural death and then later a stronger illegal killing. The PIKE 0.5 threshold hypothesis is disconfirmed by the changing population behavior demonstrated in this scenario with a population that has increasing births and reducing natural deaths.

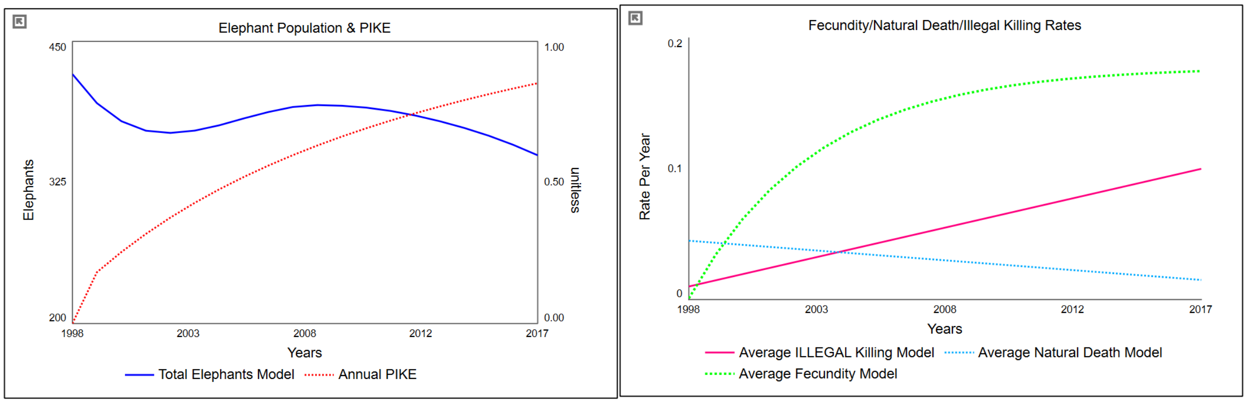

Figure 21 – Scenario 2.2 Fecundity increasing, Natural Death decreasing, Illegal Killing increasing – population first declines then recovers and increases before declining again. PIKE is increasing all the time.

Scenario 2.3 - Decreasing Fecundity, increasing Natural Death and Illegal Killing

Another more realistic scenario is in Figure 22 where fecundity is decreasing and natural deaths are increasing in an opposite situation to Scenario 2.2, and illegal killing also increasing. The population first increases, peaks and then decreases sharply. PIKE initially rises rapidly to move past 0.50 and becomes level above 0.50 and then starts to increase again. Fecundity reinforcing feedback loops are strong initially causing the population to grow, but as they weaken and the death balancing feedback loops become stronger and more dominant, the population starts to decline.

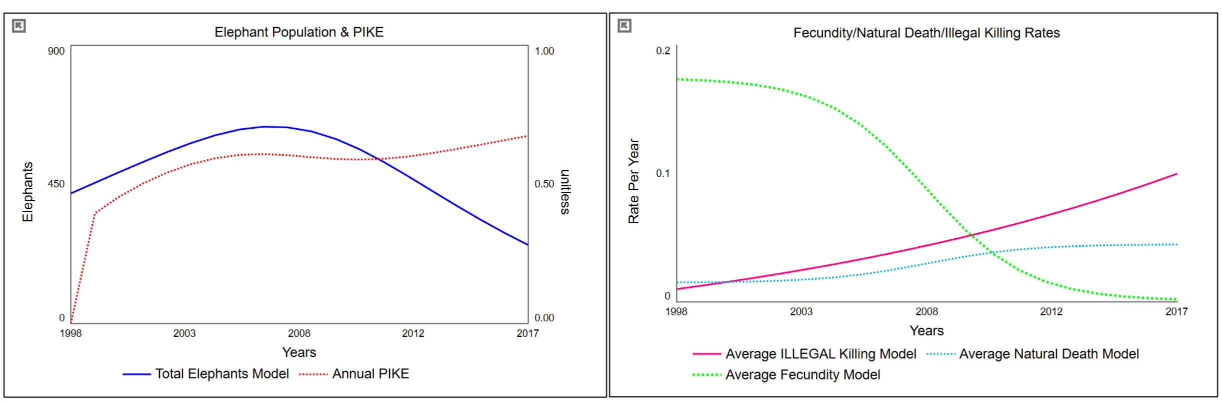

Figure 22 – Scenario 2.3 Fecundity is decreasing, Natural Death increasing, Illegal Killing is increasing – population first increases, peaks and then declines. PIKE is above and remains above 0.5 as population changes.

The three previous scenarios demonstrate that by including variables that are steadily increasing or decreasing over time, the population trend becomes more complex and displays non-linear behavior that is often difficult to anticipate. In these scenarios there is no clear threshold association of how PIKE can help indicate whether the population will be declining or increasing, even in a situation where births are increasing and natural deaths declining. In all cases there are periods where PIKE is above 0.50 and yet the population is either increasing or decreasing. Scenario 2.2 disconfirms the hypothesis that when PIKE is above a 0.5 threshold the elephant population will be in net decline in a naturally increasing population, and when PIKE is less than a 0.5 threshold the elephant population will be in net increase.

Scenario 3 – Actual data (adjusted and calculated)

The final scenarios take a further step towards simulating the level of complexity that might be expected in real life. The 20-year fecundity and mortality data for the Samburu population was used for this analysis (Wittemyer et al., 2020). As the naturally dead and illegally killed data provided was combined, adjustments were done on the data using natural death and illegal killing approximations from published research on the Samburu area. The summary published PIKE data covered the period of 14 years from 1998 to 2011 - at least 65% of the 20-year period from 1998 to 2017 (Wittemyer et al., 2013). The population development over the first 14 years in the 2013 study was however not exactly the same as the new data that was provided, so the populations measured in the two datasets may have been slightly different, or the new data may have been adjusted. The intention was not to try and replicate the exact illegal killing situation in the 20-year period, but rather to provide a scenario of varying natural deaths and illegal killing that would be as realistic as possible in order to run a simulation to see how population would vary in relation to PIKE. Further details of this adjustment are provided in Appendix B.

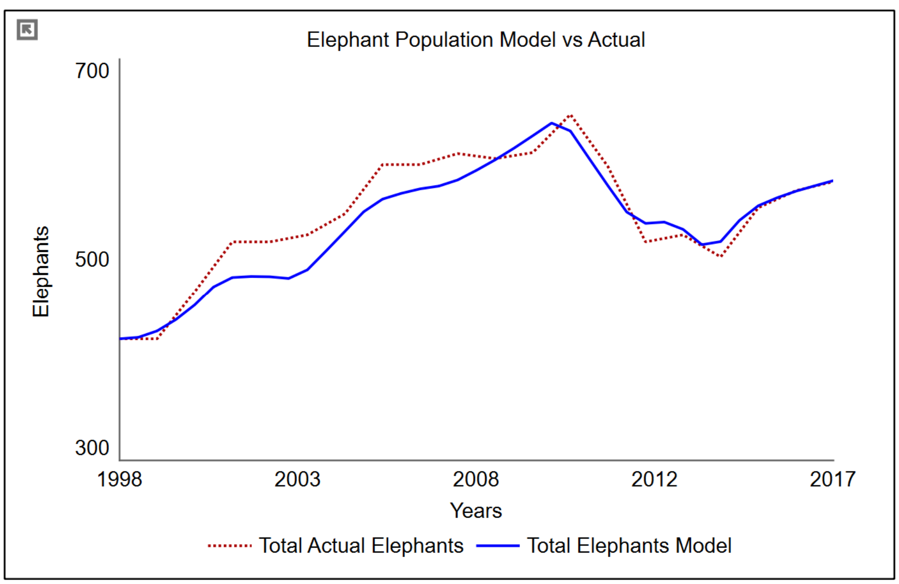

Figure 23 - Model generated population behavior (solid line) but with adjusted actual natural death and estimated illegal killing compared with actual population data over a 20-year period (similar to Figure 10).

With the adjustments made to natural death and estimates included for illegal killing, the model again generated good representative population behavior (solid line) versus actual population data (dashed line) over a 20-year period in Figure 23 and compared well with the earlier validation in Figure 10.

Scenario 3.1 - Actual Fecundity, Adjusted Natural Death, Estimated Illegal Killing.

Running the model with the amended data produced the results in Figure 24. The overall population trend is close to what was measured. However, it should be noted that the PIKE generated by the model differed to what was published in the 1998-2011 study. As there is no detailed illegal killing data available to investigate these differences further, the illegal killing in this Scenario 3.1 must be considered hypothetical. Once actual illegal killing data is available, it would be possible to investigate these differences further. Additionally, the age cohorts used in the two studies were close but not the same (see Appendix B).

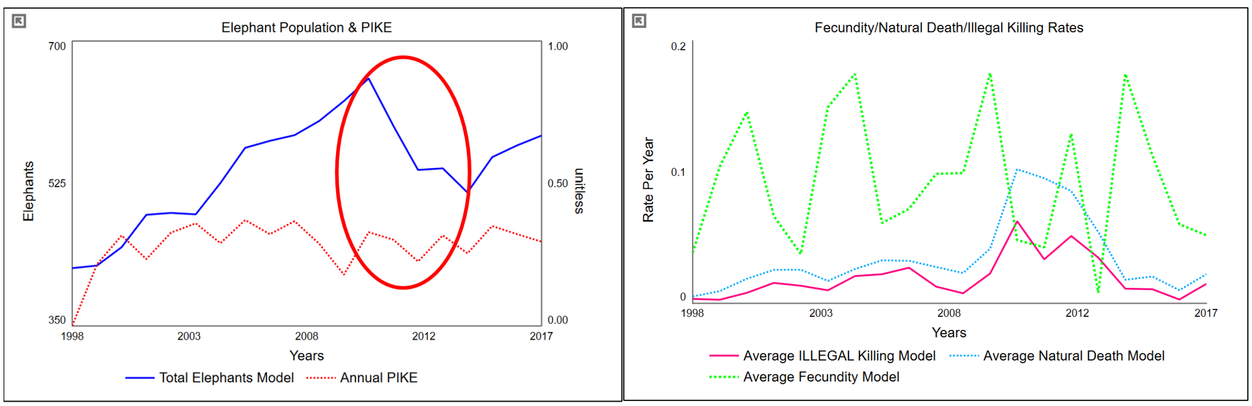

Figure 24 – Samburu Actual Fecundity over 20-years, Adjusted Natural Death and Estimated Illegal Killing (theoretical)

Figure 24 demonstrates that with widely varying fecundity and deaths the resulting population trend is more complex but underlying this is a similar interaction of birth reinforcing feedback loops and death balancing feedback loops, with feedback loop dominance changing over time. In the simulation there is a period between 2010 and 2014 indicated by the red circle in Figure 24 where the population declines significantly by 22% over this period whereas PIKE remains below the 0.5 threshold.

Scenario 3.2 - Actual Fecundity, Adjusted Natural Death, constant Illegal Killing

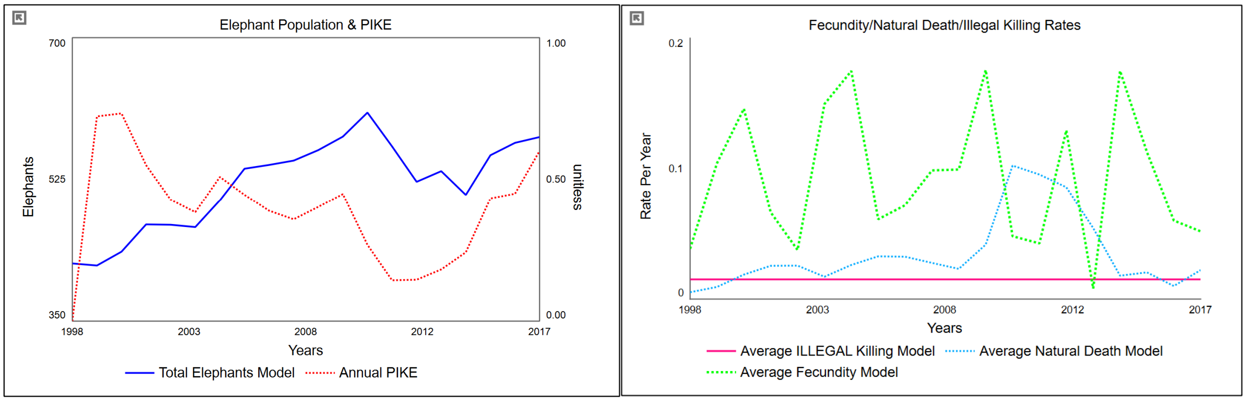

Figure 25 - Actual Fecundity, Adjusted Natural Death, constant Illegal Killing 0.0151

Earlier scenarios demonstrated the benefit in understanding the population development of changing one constant variable. In Scenario 3.2 illegal killing is kept constant at an input of 0.0151, which results in a broad population change in Figure 26 similar to what was observed in the more realistic simulation demonstrated in Figure 23. The population for the period from 1998 to 2009 is naturally increasing as in Figure 25. However, under this scenario, PIKE varies in a completely different way to what's observed in Figure 24 and yet the population development is similar. What this scenario demonstrates, although theoretical, is that similar population development can be generated with completely different variations in PIKE and this casts further doubt on it being a good indicator of whether population is declining or increasing.

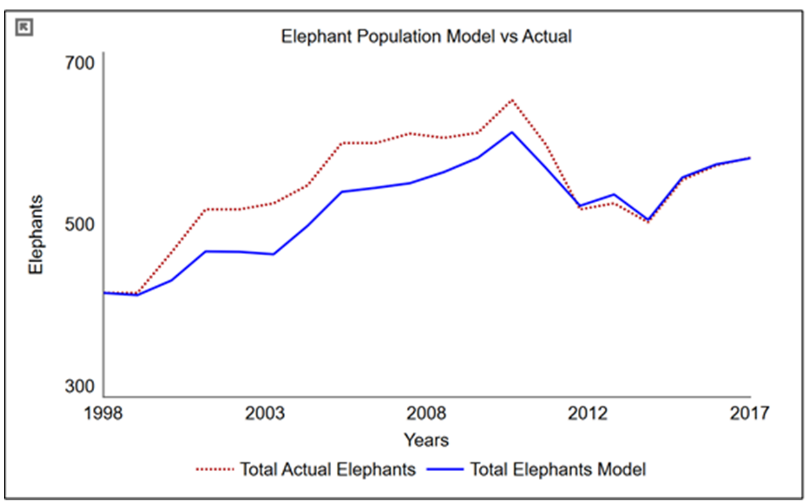

Figure 26 – Actual Fecundity and Adjusted Natural Death with Illegal Killing 0.0151 model generated population behavior (solid line) compared to actual (also compare with Figure 23).

The previous different modeling scenarios have demonstrated that the hypothesis under investigation - for PIKE above a 0.5 threshold, the elephant population will be in net decrease and below 0.5 a population will be in net increase – is not supported, and in the more realistic Scenario 2.2 is also disconfirmed. This statement does not accurately cover the scenarios investigated.

Policy Considerations.

The author was tasked to develop an elephant population dynamics model to help address the issue posed by CITES at CoP16 in paragraph 18 of Doc.53.1. The elephant population model developed incorporated guidance from the MIKE TAG at the initial meeting held on 17th September 2019 (refer to Paragraph on Model Development). An updated model was presented at a more recent meeting with the MIKE TAG held on 29th June 2021, and it was agreed that a final model will be presented by October 2021. Consultations continue with elephant experts on refining the model further, with advice and other relevant data, as well as developing a suitable user interface that is focused on researchers' interests (Figure 27). In the recent MIKE TAG meeting it was also noted that the model incorporates true PIKE rather than reported PIKE in the field. Furthermore, there was a question on whether the data used in this model would be applicable to other MIKE sites. These are important considerations: the question on data will be addressed through ongoing consultations with researchers interested in fine tuning the model to sites they are investigating. The model will continue to be developed and refined further.

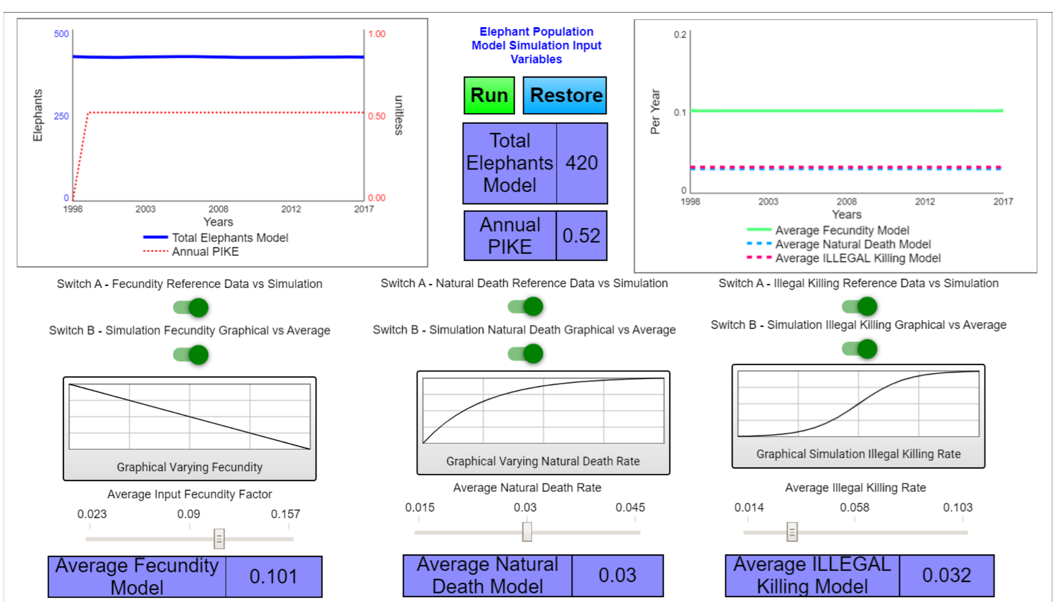

Figure 27 - Elephant population model user interface.

From the various scenarios explored, it is evident that in order to understand how an elephant population is changing, information on the inflow to the stock of births of elephants is also required. Focusing only on the natural death and illegal killing outflows of the stock of an elephant population cannot alone provide an indicator of whether the population is growing or decreasing. As the simple stock and flow diagram in Figure 2 demonstrated, if there is concern about whether the elephant population stock is increasing or decreasing, the inflows through births are as important as knowing the respective outflows from deaths.

Simple indicators are useful and in the case of PIKE there has been extensive analysis associated with the indicator to provide insights into poaching pressures on elephants. A section in MIKEs reporting to CITES is devoted to the statistical analysis of PIKE. Although a relatively simple indictor, PIKE is prone to various errors including the difficulty of recording this information correctly in the field, which is also partly referenced in the TAG comment about actual PIKE being different to true PIKE measured in the model. Including a further measure, such as births, may bring in a whole new level of complexity. MIKE is also primarily focused on reporting deaths, requiring a different type of field training (often security focused), than would be required to be assessing births. However, there are institutions and NGOs that monitoring elephant demographics and births, so opportunities would exist for good collaboration in this area.

The author also experimented with the model to ascertain whether different combinations of outflows (deaths), inflows (births), as well as stocks could provide insights into a simple but meaningful indicator of the population dynamic trends. There was no simple ratio measurement that was apparent that could determine whether a population was increasing or decreasing. It is possible that such a measure could be developed, but noting the non-linear behavior observed in the model, it is unlikely that a simple to calculate and understandable ratio can also adequately capture the complexity. If, however there is an alternative measure that is developed in the future, it could be tested using the model.

The MIKE programme is specifically concerned with monitoring trends in the illegal killing of elephants and is also concerned about the impact of illegal killing on elephant populations. The mandate does provide for access to elephant populations databased under Conf. 10.10 (Rev. CoP18) Paragraph 27 (h) "*data on elephant populations will be maintained in databases established by the IUCN/SSC African and Asian Elephant Specialist Groups, to which MIKE will have direct access; access by, and release to third parties will be subject to the relevant data access and release policies of IUCN" (E-Res-10-10-R18.Pdf, n.d.).* A clear way forward would be to adapt the elephant population model to incorporate data available, as well as expert opinions, to understand population trends in the various MIKE sites and to use this model as a complementary tool to the PIKE measure. This approach would provide useful insights into how elephant populations are changing.

Engagement with the MIKE programme on the elephant population model will continue after the submission of this thesis and through an ongoing iterative process of presentation to the TAG and feedback and discussions, new options will be explored to make the model and interface a more fine-tuned tool that is useful for researchers and that can be used to provide insights into elephant population dynamics. The model can also be calibrated for other elephant populations and the author has had discussions on adapting the model for a researcher focused on a smaller 50 elephant population based in a wildlife conservancy in Laikipia County (S. Oduor, August 2021).

The model interface in Figure 28, that will be adapted through on-going discussions with researchers, will also be accessible on UNEP's World Environment Situation Room website, as a data analysis model, where a holding page has already been created under the URL: https://wesr.unep.org/foresight/projects (*Draft Ministerial Declaration Fifth Draft as of 14.03.2019.Pdf*, n.d.).

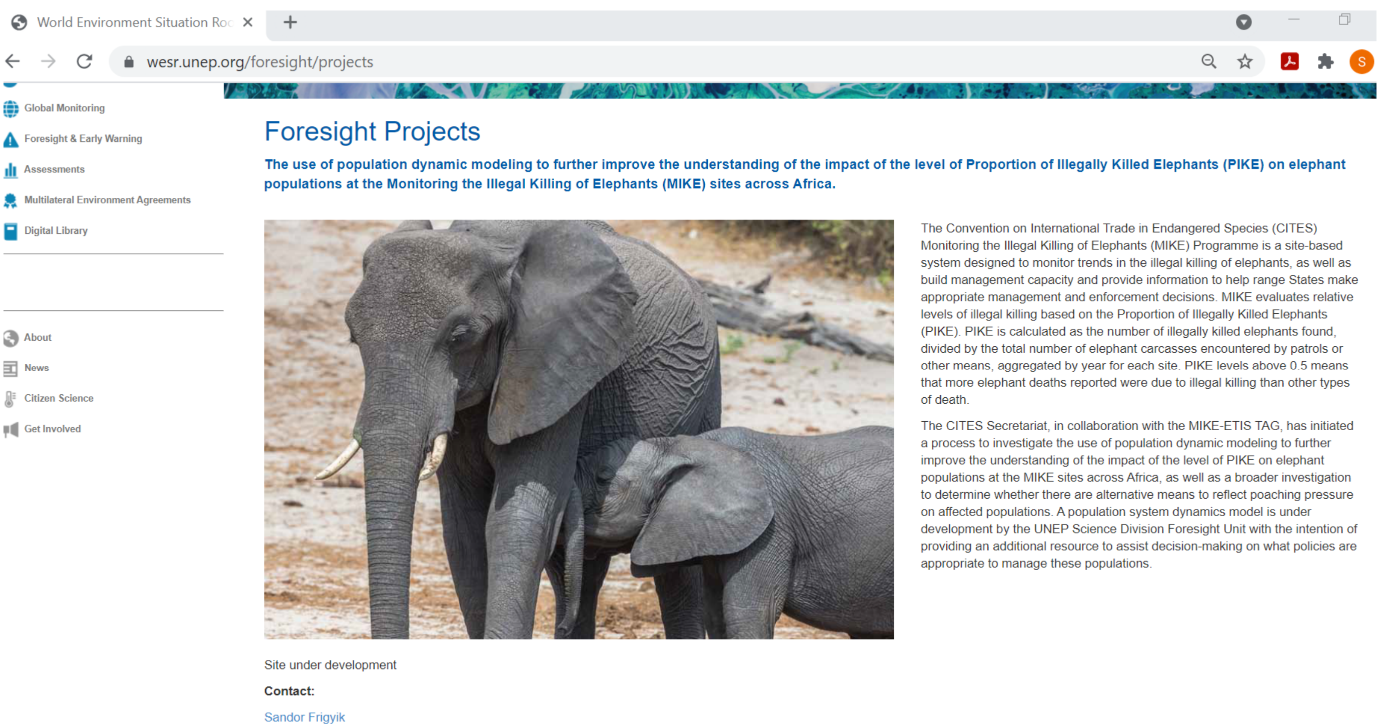

Figure 28 - The UNEP World Environment Situation Room Foresight Project website where the elephant model interface will be made accessible for researchers (https://wesr.unep.org/foresight/projects).

Discussion

The objective of this thesis was to develop an appropriate elephant population model to test the following research hypothesis: *(1) When PIKE is above a 0.5 threshold the elephant population will be in net decline in a naturally increasing population, and (2) when PIKE is less than a 0.5 threshold the elephant population will be in net increase.*

Various scenarios investigated disconfirmed the hypothesis. Based on the hypothesis the research objectives of this thesis were:

1. Investigate the use of population dynamic modelling to further improve the understanding of the impact of the level of PIKE on an elephant population at a MIKE site in Kenya;
   This could not be fully explored as intended as detailed illegal killing data was not available. However, the theoretical scenarios did provide insights into how the population would change based on changing variables, and the corresponding PIKE values.

2. Assess whether the use of the 0.5 PIKE ‘threshold’ should be treated with some caution;
   Based on the modeling scenarios investigated, it is confirmed that the 0.5 PIKE threshold should be treated with caution.

3. Investigate whether there are alternative means to reflect poaching pressure on affected populations.
   As noted in the policy discussion, there is no simple solution that was found, and so this remains an ongoing investigation.

The issue of the 0.5 PIKE threshold appeared to arise in relation to questions about the sustainability of elephant populations experiencing illegal killing. An expression commonly used in these references is: ”a *PIKE level of 0.5 or higher means that the elephant population is very likely to be in net decline.”* Does very likely mean that 90% to 100% of the time a PIKE of 0.5 or higher will lead to elephant decline? It is also unclear what is meant by a naturally increasing population - what percentage increase is considered acceptable? With clarification on what these mean numerically the model can then be used to test the validity of these assumptions. For example, if sustainability is the concern related to the 0.5 PIKE threshold, a sensitivity test could be incorporated into the model to measure what percentage of instances there are where PIKE is below 0.5 and the population is declining. This type of more robust analysis would be best undertaken in close consultation with the MIKE Secretariat.

On the broader issue of sustainability, the sensitivity analysis in Figure 14 conducted using the range of variables noted in Table 1 demonstrates that over the 20-year period, there would on average be a decline in population, if experiencing the range of illegal killing noted by CITES. More specific illegal killing data could be applied to the model to provide more meaningful insights.

However, it is also important to remember that this system dynamics model is intended to explore broad trends, such as whether the population is increasing or decreasing, and as such it is not suitable for accurate forecasting or prediction of population numbers.

The limitations of PIKE have been explored in various research papers, and sophisticated statistical analysis has also been conducted by fitting statistical models to the data to undertake PIKE predictions. In one study, it was correctly acknowledged that a potential bias in PIKE was that natural mortality could be high possibly due to drought. The response to addressing this bias was *"In principle, these variations in background mortality could be allowed in the statistical analysis by a Bayesian hierarchical model in which the number of carcasses encountered by a patrol (the binomial "n" in our models) is also considered as a random variable, with, say, a Poisson distribution, and modelled on covariates"* (Burn et al., 2011).

In focusing on causal influences in systems with dynamic behavior, and considering feedback, time delays and non-linearities, the system dynamics modeling approach introduces another type of useful as well as complementary analysis tool to the discussion. As Donella Meadows once noted *"Systems modelers say that we change paradigms by building a model of the system, which takes us outside the system and forces us to see it whole"* (D. H. Meadows & Wright, 2008). Through ongoing discussions and dialogue, initiatives using different modeling approaches whether causal-descriptive or correlational, should introduce new insights that improve understanding (Barlas, 1996).

How are the elephant populations best managed? The elephant population model provides some perhaps common-sense insights. Sensitivity tests indicate the elephant population's growth in the model is sensitive to fecundity levels, and decline is sensitive to deaths, both natural and through illegal killing. Fecundity, however, is a much more difficult variable to manage, as are natural deaths. Illegal killing is a variable that can be managed with the right policy focus and implementation. Factors that cause decreased fecundity or natality, and increased natural death, are likely to arise from increased drought and reduced food availability. Environmental degradation is an aspect that can be expected to increase as climate change worsens. This will lead to greater pressures on the growth of elephant populations as the carrying capacity of their environments are reduced (Mpakairi et al., 2019). The impact of climate change will also be experienced by humans, and poorer opportunities to grow food and an increased likelihood of drought will further exacerbate the risk of human elephant conflict. This increased conflict further raises the likelihood of elephants being killed.

Figure 29 – Inter-calving intervals for female elephants will vary with environmental stresses encountered (Source S. Frigyik)

A logical next step would be to increase the elephant population model boundaries to include other environmental and social causal influences as well as changes that influence carrying capacity (Figure 30). For example, as inter-calving intervals of female elephants vary with droughts, a drought factor could be incorporated and related fecundity variables endogenized in the model (Figure 29). The expanded causal linkages can be added to the model based on expert and local knowledge, and data if available. These would provide further insights on what leverage points there may be elsewhere in the system, and what policy actions can be taken to anticipate worsening times (D. H. Meadows & Wright, 2008). A project is also underway in UNEP, in collaboration with the University of Bergen, on African Coexistence Landscapes, specifically focused on elephants and the issue of human-wildlife conflict. Insights gained from that initiative, which also includes group model building with stakeholders, could feed into this elephant population model that could be useful for elephant researchers seeking solutions elsewhere in the system.

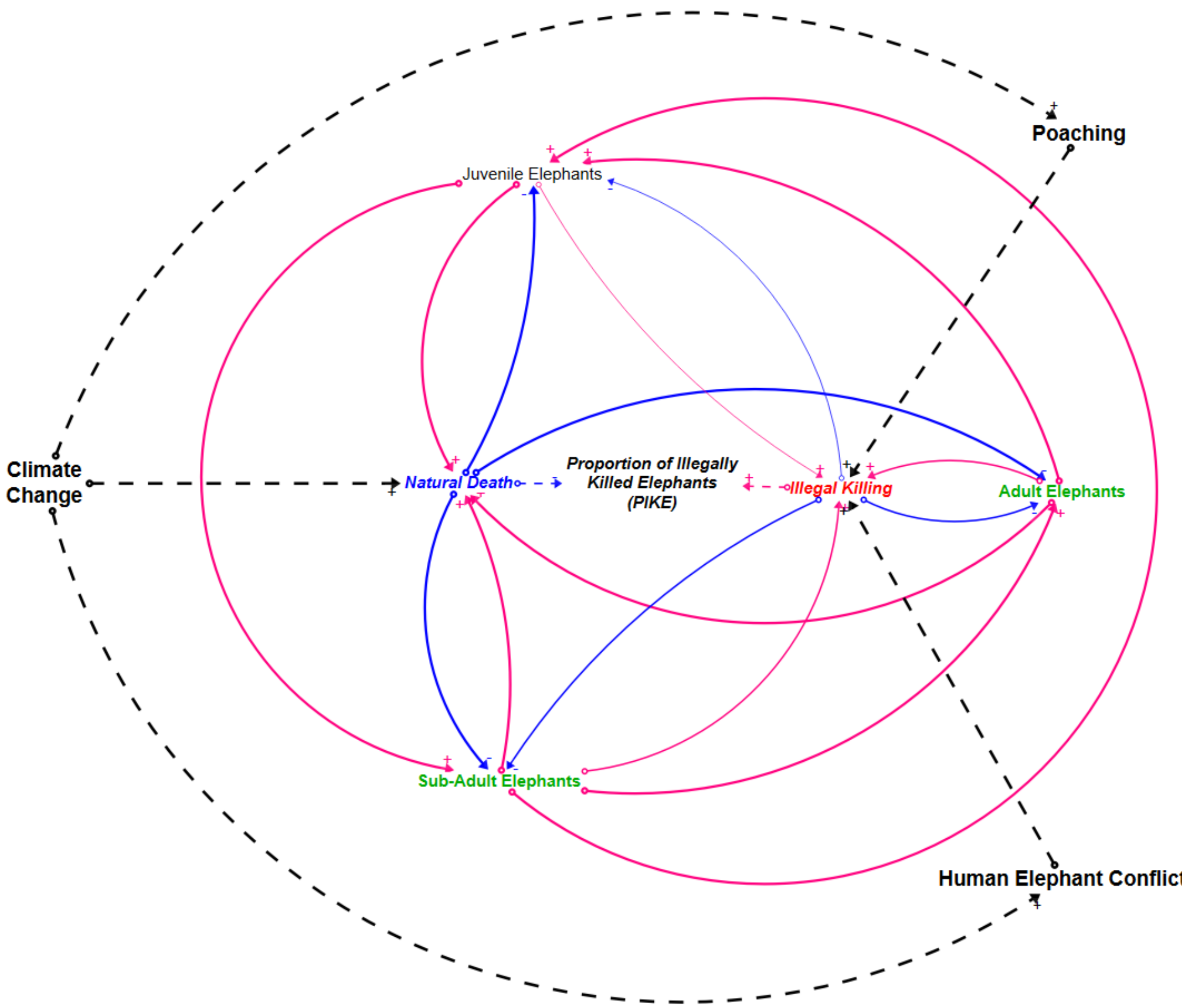

Figure 30 - Expanding model boundaries to include the impact of climate change as well as other causes of human elephant conflict and poaching can provide new insights into leverage points located elsewhere in the system.

PIKE as a simple ratio is a useful indicator for measuring relative poaching pressures. Under certain conditions it may also provide insights beyond what it was intended to be used for. As conditions change, these insights can become less useful, and perhaps even misleading without additional analysis. The MIKE Secretariat and TAG realized this and took the action to investigate the PIKE 0.5 threshold further. This system dynamics population model has adequately replicated through its causal structure the complex population trends of the Samburu elephant population. The model does this because it captures the most important feedback loops that are dominating in the time period studied. However, the model may not always generate representative trends in the future if the dominant feed-back loops change. As with all paradigms, relevancy under changing conditions should always be questioned, so that users do not fall into a false sense of assurance. There may be new unknown factors that adversely affect fecundity, or natural death, such as the new unknown pathogens experienced in Botswana in 2020 and Zimbabwe in 2021 that resulted in elephant deaths (Karombo, 2021). The model therefore provides useful insights for this population under current conditions. Variable limits could also change based on changing environmental conditions and human influences. The model could also be adapted for other populations, such as the African forest elephants.

In Kenya, where poaching is coming under better control, it may be necessary to separate the outflows of deaths due to human elephant conflict, from poaching. Although both are forms of illegal killing, they require different policy actions (S. Oduor, August 2021). Poaching is a criminal activity whereas elephant human conflict could be related to survival of communities and require a different form of intervention. With climate change this type of conflict is likely to increase.

The model can provide interesting insights into the future but should not be used to try and accurately forecast elephant population numbers or for elephant management decisions, as that's not what it has been designed for.

Conclusion

The system dynamics elephant population model provides an interesting and alternative insight into the causal influences effecting an elephant population. A simple measure focused on a ratio of deaths or outflows of a population cannot be a useful indicator of how an elephant population is changing without also knowing the births or inflows to the population. Both deaths and births are also dependent, through feedback, on the sizes of the elephant populations and so the indicator should not be replaced by another simple formulation that includes births. With worsening climate change there is likely to be even greater pressures on elephant populations through human elephant conflict. Expanding the model boundaries to include these other aspects may provide useful insights on points of leverage as well as possible policy actions elsewhere in the larger system. This thesis set out to test the hypothesis that a PIKE above a threshold of 0.5 is an indicator that an elephant population is declining and below 0.5 that the population will be increasing. The investigation concludes, based on the system dynamics elephant population modeling, that the threshold of 0.5 should be treated with caution. As the custodians of life on the planet, we must ensure that elephants survive and thrive. We live in an interconnected world and elephants are a keystone species - if they vanish and never come back, we too as their keepers may suffer the same fate.

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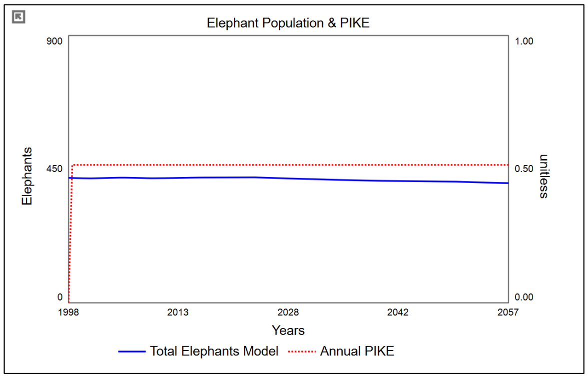
Appendix A – Model Testing

Model purpose: to generate representative population development over a 20-year period for an elephant population in northern Kenya to test the hypothesis: when PIKE is above a 0.5 threshold, the elephant population will be in net decline in a naturally increasing population, and below 0.5 a population will be in net increase.

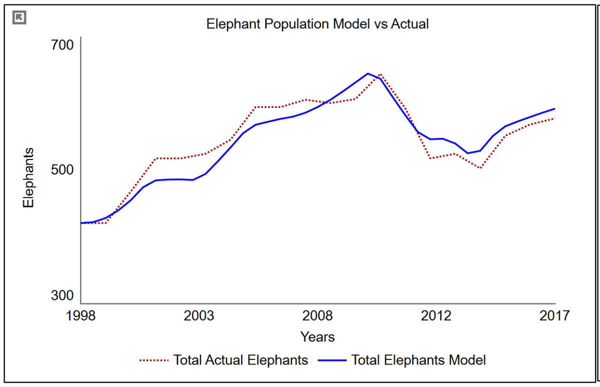
Test Type	**Summary Description**	**Outcome**
Empirical Tests		
Direct -Structure Tests Structure-confirmation test	Population model is consistent with structures of elephant populations as well as generic population models in literature.	Confirmed
Direct -Structure Tests Parameter-confirmation test	Parameters used were obtained from elephant researchers and organizations with relevant elephant expertise (CITES & MIKE).	Confirmed
Theoretical Tests		
Structure-confirmation test	On-going while building and refining the model. Led to changes in the model, e.g. separation into male and female population groups. Behavior generated corresponded to actual data. E.g. population growth over time.	Confirmed
Parameter-confirmation test	Elements in real system correspond to model parameters.	Confirmed
Direct extreme-condition test	Extreme value tests completed (e.g. fecundity = 0, natural death = 1, illegal killing = 1, all bulls killed no population growth etc.).	Confirmed
Dimensional consistency test	No dummy variables have been included to make model run as intended.	Confirmed
Structure-oriented behavior tests		
Extreme-condition test	Extreme conditions tested. All variables subjected to extreme sensitivity tests (expected ranges as well as 0-1). Also included running model over long time periods. Over 60 year test the model remained stable but started to drop from steady equilibrium. Model remained in stable equilibrium for 24 years sufficient for intended purpose.	Confirmed
Behavior sensitivity test	Population growth observed to be sensitive to fecundity (births) and population decline sensitive to natural deaths and killing.	Confirmed
Modified-behavior prediction	Not applicable.	
Boundary adequacy test	Carrying capacity limit was not applied as the elephants studied were resident with enough food and space. Carrying capacity limits are also reflected in changes in fecundity and natural death, for example during drought periods.	Confirmed
Qualitative features analysis	The behavior generated is consistent with the model structure, reinforcing feedback when fecundity level is high and balancing feedback when death rates are high.	Confirmed
Turing test	Presentations done to elephant experts and no anomalies in population behavior were noted.	Confirmed
Behavior Pattern Tests	The simulated behavior generated by the model closely resembled the actual data measured over 20-years.	Confirmed

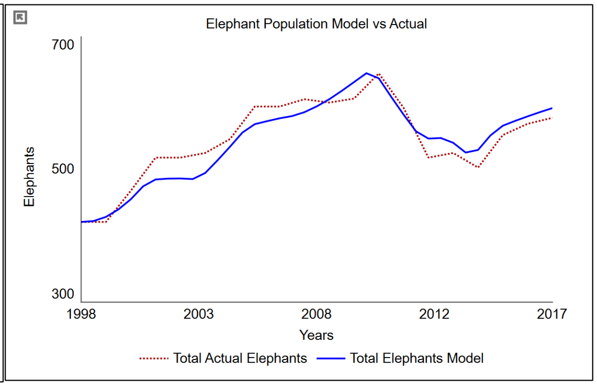
Model over 60 years remains in equilibrium:

Fecundity 0.101 Nat death 0.03 Illegal Killing 0.032



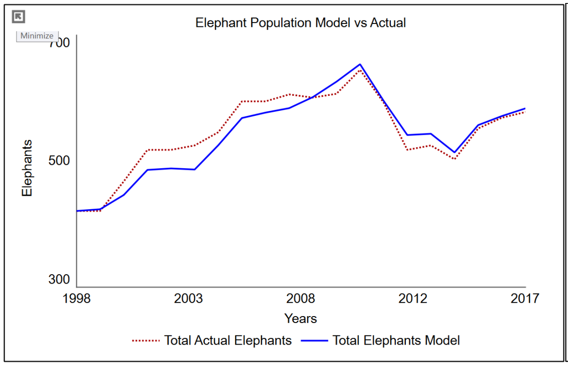
Differentiation method:

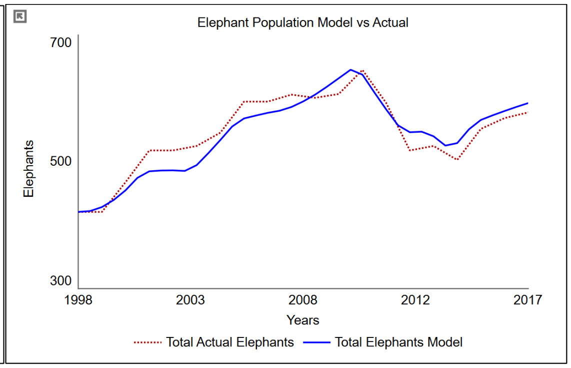




No significant difference between Euler and RK4. Euler selected.

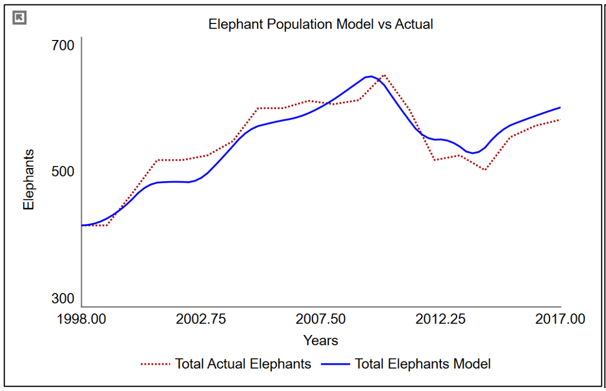
Time Step:

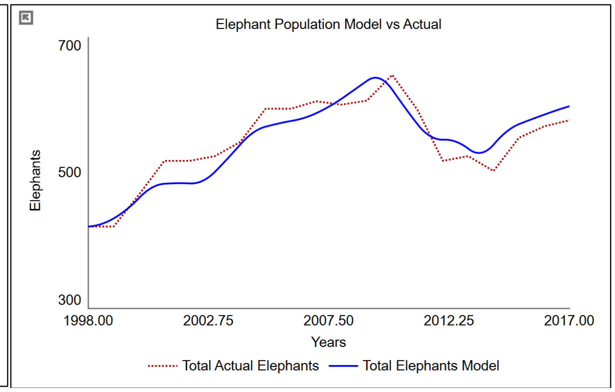




DT=1 DT=1/2 (both time steps were used).

Time Step:





DT=1/4 DT=1/20 (not used)

Differences between model population total and actual:

Year	Total Elephants Model	Total Actual Elephants	Difference Model and Actual
1998	421	421	*0*
1999	429	421	*8*
2000	455	468	*(13)*
2001	485	518	*(33)*
2002	487	518	*(31)*
2003	495	525	*(30)*
2004	534	546	*(12)*
2005	568	595	*(27)*
2006	577	595	*(18)*
2007	586	606	*(20)*
2008	606	601	*5*
2009	632	607	*25*
2010	638	645	*(7)*
2011	583	593	*(10)*
2012	547	518	*29*
2013	540	525	*15*
2014	530	503	*27*
2015	566	552	*14*
2016	580	569	*11*
2017	593	578	*15*

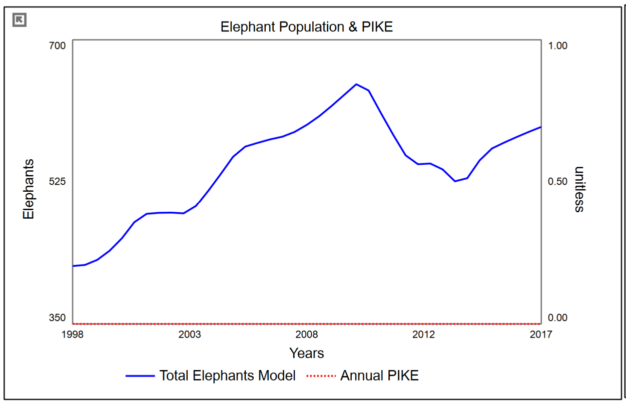
No significant variations in model data versus actual data.

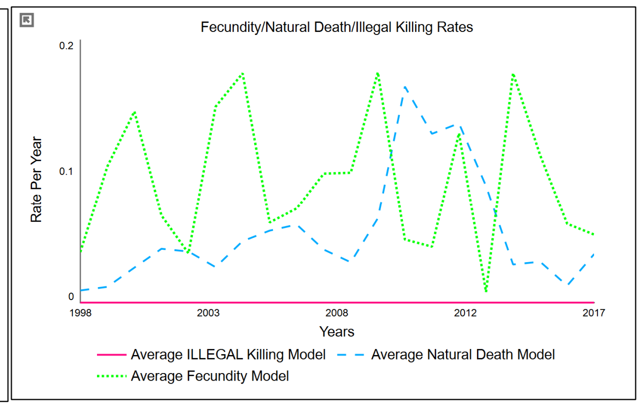
Appendix B – Adjusted Natural Death and Estimated Illegal Killing

November 1997-Deptember 2011

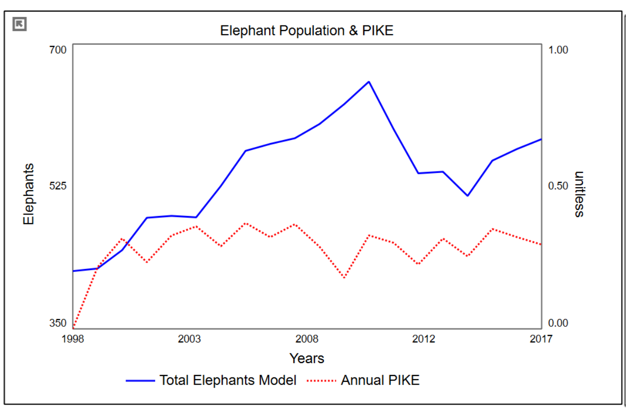
	Sex	Natural		Illegally Killed		Unknown		% illegally killed	% illegally killed	% natural dead	Total	% illegally killed	% natural dead	Total
		Male	Female	Male	Female	Male	Female		Female	Female	Female	Male	Male	Male
Juvenile	**0-2**	15	4	0	0	0	0	0%	0%	100%	100%	0%	100%	100%
Juvenile	**3-9**	17	13	2	2	4	1	10%	13%	88%	100%	9%	91%	100%
Sub-Adult	**10-18**	2	5	1	4	3	4	26%	31%	69%	100%	17%	83%	100%
Adult	**19-30**	6	3	3	10	1	1	54%	71%	29%	100%	30%	70%	100%
Adult	**31-50**	3	5	7	9	1	2	59%	56%	44%	100%	64%	36%	100%
Adult	**50+**	0	2	1	2	0	0	60%	50%	50%	100%	100%	0%	100%
	Total	43	32	14	27	9	8	31%	40%	60%	100%	21%	79%	100%

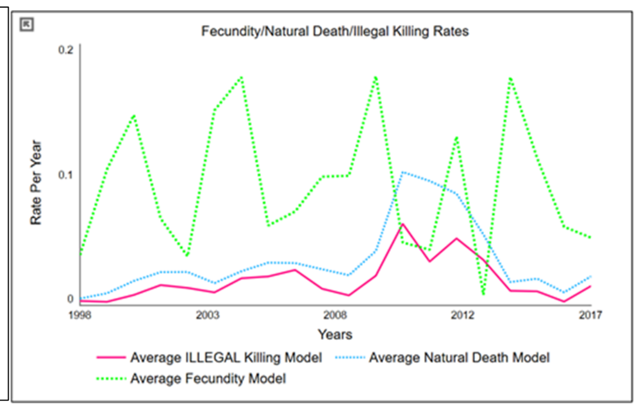
Reproduced and adapted (Wittemyer et al., 2013)





Actual fecundity data and total death data (includes illegal killing) used for initial model validation.





Actual fecundity data with adjusted natural death data and estimated illegal killing based on estimates and analysis from prior research in table above.

Appendix C – Model Documentation

Model file name: Elephant Population Dynamic Model Sandor Frigyik 15082021.stmx

Software: Stella Architect 2.1.3

Hardware: ThinkPad T480s

Imported data: Elephant Population Model CITES 15082021.xlsx

		Equation	Properties	Units	Documentation	Annotation
	Top-Level Model:					
	"Annual_ILLEGAL_Killed_Female_Adult_19-35"(t)	"Annual_ILLEGAL_Killed_Female_Adult_19-35"(t - dt) + ("ILLEGAL_Killing_Flow_Female_Adult_19-35" - "Total_ILLEGAL_Killing_Flow_Female_Adult_19-35") * dt	INIT "Annual_ILLEGAL_Killed_Female_Adult_19-35" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Female_Juvenile_3-8"(t)	"Annual_ILLEGAL_Killed_Female_Juvenile_3-8"(t - dt) + ("ILLEGAL_Killing_Flow_Female_Juvenile_3-8" - "Total_ILLEGAL_Killing_Flow_Female_Juvenile_3-8") * dt	INIT "Annual_ILLEGAL_Killed_Female_Juvenile_3-8" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Female_Mature_Adult_36+"(t)	"Annual_ILLEGAL_Killed_Female_Mature_Adult_36+"(t - dt) + ("ILLEGAL_Killing_Flow_Female_Mature_Adult_36+" - "Total_ILLEGAL_Killing_Flow_Female_Mature_Adult_36+") * dt	INIT "Annual_ILLEGAL_Killed_Female_Mature_Adult_36+" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Female_Prewean_1-2"(t)	"Annual_ILLEGAL_Killed_Female_Prewean_1-2"(t - dt) + ("ILLEGAL_Killing_Flow_Female_Prewean_1-2" - "Total_ILLEGAL_Killing_Flow_Female_Prewean_1-2") * dt	INIT "Annual_ILLEGAL_Killed_Female_Prewean_1-2" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Female_Young_Adult_9-18"(t)	"Annual_ILLEGAL_Killed_Female_Young_Adult_9-18"(t - dt) + ("ILLEGAL_Killing_Flow_Female_Young_Adult_9-18" - "Total_ILLEGAL_Killing_Flow_Female_Young_Adult_9-18") * dt	INIT "Annual_ILLEGAL_Killed_Female_Young_Adult_9-18" = 0	Elephants	Annual amount of illegally killed elephants	

	"Annual_ILLEGAL_Killed_Male_Adult_19-35"(t)	"Annual_ILLEGAL_Killed_Male_Adult_19-35"(t - dt) + ("ILLEGAL_Killing_Flow_Male_Adult_19-35" - "Total_ILLEGAL_Killing_Flow_Male_Adult_19-35") * dt	INIT "Annual_ILLEGAL_Killed_Male_Adult_19-35" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Male_Juvenile_3-8"(t)	"Annual_ILLEGAL_Killed_Male_Juvenile_3-8"(t - dt) + ("ILLEGAL_Killing_Flow_Male_Juvenile_3-8" - "Total_ILLEGAL_Killing_Flow_Male_Juvenile_3-8") * dt	INIT "Annual_ILLEGAL_Killed_Male_Juvenile_3-8" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Male_Mature_Adult_36+"(t)	"Annual_ILLEGAL_Killed_Male_Mature_Adult_36+"(t - dt) + ("ILLEGAL_Killing_Flow_Male_Mature_Adult_36+" - "Total_ILLEGAL_Killing_Flow_Male_Mature_Adult_36+") * dt	INIT "Annual_ILLEGAL_Killed_Male_Mature_Adult_36+" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Male_Prewean_1-2"(t)	"Annual_ILLEGAL_Killed_Male_Prewean_1-2"(t - dt) + ("ILLEGAL_Killing_Flow_Male_Prewean_1-2" - "Total_ILLEGAL_Killing_Flow_Male_Prewean_1-2") * dt	INIT "Annual_ILLEGAL_Killed_Male_Prewean_1-2" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_ILLEGAL_Killed_Male_Young_Adult_9-18"(t)	"Annual_ILLEGAL_Killed_Male_Young_Adult_9-18"(t - dt) + ("ILLEGAL_Killing_Flow_Male_Young_Adult_9-18" - "Total_ILLEGAL_Killing_Flow_Male_Young_Adult_9-18") * dt	INIT "Annual_ILLEGAL_Killed_Male_Young_Adult_9-18" = 0	Elephants	Annual amount of illegally killed elephants	
	"Annual_Natural_Dead_Female_Adult_19-35"(t)	"Annual_Natural_Dead_Female_Adult_19-35"(t - dt) + ("Natural_Death_Flow_Female_Adult_19-35" - "Total_Natural_Death_Flow_Female_Adult_19-35") * dt	INIT "Annual_Natural_Dead_Female_Adult_19-35" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Female_Juvenile_3-8"(t)	"Annual_Natural_Dead_Female_Juvenile_3-8"(t - dt) + ("Natural_Death_Flow_Female_Juvenile_3-8" - "Total_Natural_Death_Flow_Female_Juvenile_3-8") * dt	INIT "Annual_Natural_Dead_Female_Juvenile_3-8" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Female_Mature_Adult_36+"(t)	"Annual_Natural_Dead_Female_Mature_Adult_36+"(t - dt) + ("Natural_Death_Flow_Female_Mature_Adult_36+" - "Total_Natural_Death_Flow_Female_Mature_Adult_36+") * dt	INIT "Annual_Natural_Dead_Female_Mature_Adult_36+" = 0	Elephants	Annual amount of naturally dead elephants	

	"Annual_Natural_Dead_Female_Prewean_1-2"(t)	"Annual_Natural_Dead_Female_Prewean_1-2"(t - dt) + ("Natural_Death_Flow_Female_Prewean_1-2" - "Total_Natural_Death_Flow_Female_Prewean_1-2") * dt	INIT "Annual_Natural_Dead_Female_Prewean_1-2" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Female_Young_Adult_9-18"(t)	"Annual_Natural_Dead_Female_Young_Adult_9-18"(t - dt) + ("Natural_Death_Flow_Female_Young_Adult_9-18" - "Total_Natural_Death_Flow_Female_Young_Adult_9-18") * dt	INIT "Annual_Natural_Dead_Female_Young_Adult_9-18" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Male_Adult_19-35"(t)	"Annual_Natural_Dead_Male_Adult_19-35"(t - dt) + ("Natural_Death_Flow_Male_Adult_19-35" - "Total_Natural_Death_Flow_Male_Adult_19-35") * dt	INIT "Annual_Natural_Dead_Male_Adult_19-35" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Male_Juvenile_3-8"(t)	"Annual_Natural_Dead_Male_Juvenile_3-8"(t - dt) + ("Natural_Death_Flow_Male_Juvenile_3-8" - "Total_Natural_Death_Flow_Male_Juvenile_3-8") * dt	INIT "Annual_Natural_Dead_Male_Juvenile_3-8" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Male_Mature_Adult_36+"(t)	"Annual_Natural_Dead_Male_Mature_Adult_36+"(t - dt) + ("Natural_Death_Flow_Male_Mature_Adult_36+" - "Total_Natural_Death_Flow_Male_Mature_Adult_36+") * dt	INIT "Annual_Natural_Dead_Male_Mature_Adult_36+" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Male_Prewean_1-2"(t)	"Annual_Natural_Dead_Male_Prewean_1-2"(t - dt) + ("Natural_Death_Flow_Male_Prewean_1-2" - "Total_Natural_Death_Flow_Male_Prewean_1-2") * dt	INIT "Annual_Natural_Dead_Male_Prewean_1-2" = 0	Elephants	Annual amount of naturally dead elephants	
	"Annual_Natural_Dead_Male_Young_Adult_9-18"(t)	"Annual_Natural_Dead_Male_Young_Adult_9-18"(t - dt) + ("Natural_Death_Flow_Male_Young_Adult_9-18" - "Total_Natural_Death_Flow_Male_Young_Adult_9-18") * dt	INIT "Annual_Natural_Dead_Male_Young_Adult_9-18" = 0	Elephants	Annual amount of naturally dead elephants	
	"Cumulative_Emigrated_Female_Adult_19-35"(t)	"Cumulative_Emigrated_Female_Adult_19-35"(t - dt) + ("Emigration_Flow_Female_Adult_19-35") * dt	INIT "Cumulative_Emigrated_Female_Adult_19-35" = 0	Elephants	Variable included for future use but not applicable in the current model.	

	"Cumulative_Emigrated_Female_Juvenile_3-8"(t)	"Cumulative_Emigrated_Female_Juvenile_3-8"(t - dt) + ("Emigration_Flow_Female_Juvenile_3-8") * dt	INIT "Cumulative_Emigrated_Female_Juvenile_3-8" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Female_Mature_Adult_36+"(t)	"Cumulative_Emigrated_Female_Mature_Adult_36+"(t - dt) + ("Emigration_Flow_Female_Mature_Adult_36+") * dt	INIT "Cumulative_Emigrated_Female_Mature_Adult_36+" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Female_Prewean_1-2"(t)	"Cumulative_Emigrated_Female_Prewean_1-2"(t - dt) + ("Emigration_Rate_Female_Prewean_1-2") * dt	INIT "Cumulative_Emigrated_Female_Prewean_1-2" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Female_Young_Adult_9-18"(t)	"Cumulative_Emigrated_Female_Young_Adult_9-18"(t - dt) + ("Emigration_Flow_Female_Young_Adult_9-18") * dt	INIT "Cumulative_Emigrated_Female_Young_Adult_9-18" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Male_Adult_19-35"(t)	"Cumulative_Emigrated_Male_Adult_19-35"(t - dt) + ("Emigration_Flow_Male_Adult_19-35") * dt	INIT "Cumulative_Emigrated_Male_Adult_19-35" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Male_Juvenile_3-8"(t)	"Cumulative_Emigrated_Male_Juvenile_3-8"(t - dt) + ("Emigration_Flow_Male_Juvenile_3-8") * dt	INIT "Cumulative_Emigrated_Male_Juvenile_3-8" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Male_Mature_Adult_36+"(t)	"Cumulative_Emigrated_Male_Mature_Adult_36+"(t - dt) + ("Emigration_Flow_Male_Mature_Adult_36+") * dt	INIT "Cumulative_Emigrated_Male_Mature_Adult_36+" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Male_Prewean_1-2"(t)	"Cumulative_Emigrated_Male_Prewean_1-2"(t - dt) + ("Emigration_Rate_Male_Prewean_1-2") * dt	INIT "Cumulative_Emigrated_Male_Prewean_1-2" = 0	Elephants	Variable included for future use but not applicable in the current model.	
	"Cumulative_Emigrated_Male_Young_Adult_9-18"(t)	"Cumulative_Emigrated_Male_Young_Adult_9-18"(t - dt) + ("Emigration_Flow_Young_Male_Adult_9-18") * dt	INIT "Cumulative_Emigrated_Male_Young_Adult_9-18" = 0	Elephants	Variable included for future use but not applicable in the current model.	

	"Cumulative_ILLEGAL_Killed_Female_Adult_19-35"(t)	"Cumulative_ILLEGAL_Killed_Female_Adult_19-35"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Female_Adult_19-35") * dt	INIT "Cumulative_ILLEGAL_Killed_Female_Adult_19-35" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Female_Juvenile_3-8"(t)	"Cumulative_ILLEGAL_Killed_Female_Juvenile_3-8"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Female_Juvenile_3-8") * dt	INIT "Cumulative_ILLEGAL_Killed_Female_Juvenile_3-8" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Female_Mature_Adult_36+"(t)	"Cumulative_ILLEGAL_Killed_Female_Mature_Adult_36+"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Female_Mature_Adult_36+") * dt	INIT "Cumulative_ILLEGAL_Killed_Female_Mature_Adult_36+" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Female_Prewean_1-2"(t)	"Cumulative_ILLEGAL_Killed_Female_Prewean_1-2"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Female_Prewean_1-2") * dt	INIT "Cumulative_ILLEGAL_Killed_Female_Prewean_1-2" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Female_Young_Adult_9-18"(t)	"Cumulative_ILLEGAL_Killed_Female_Young_Adult_9-18"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Female_Young_Adult_9-18") * dt	INIT "Cumulative_ILLEGAL_Killed_Female_Young_Adult_9-18" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Male_Adult_19-35"(t)	"Cumulative_ILLEGAL_Killed_Male_Adult_19-35"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Male_Adult_19-35") * dt	INIT "Cumulative_ILLEGAL_Killed_Male_Adult_19-35" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Male_Juvenile_3-8"(t)	"Cumulative_ILLEGAL_Killed_Male_Juvenile_3-8"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Male_Juvenile_3-8") * dt	INIT "Cumulative_ILLEGAL_Killed_Male_Juvenile_3-8" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Male_Mature_Adult_36+"(t)	"Cumulative_ILLEGAL_Killed_Male_Mature_Adult_36+"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Male_Mature_Adult_36+") * dt	INIT "Cumulative_ILLEGAL_Killed_Male_Mature_Adult_36+" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_ILLEGAL_Killed_Male_Prewean_1-2"(t)	"Cumulative_ILLEGAL_Killed_Male_Prewean_1-2"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Male_Prewean_1-2") * dt	INIT "Cumulative_ILLEGAL_Killed_Male_Prewean_1-2" = 0	Elephants	Total amount of illegally killed elephants	

	"Cumulative_ILLEGAL_Killed_Male_Young_Adult_9-18"(t)	"Cumulative_ILLEGAL_Killed_Male_Young_Adult_9-18"(t - dt) + ("Total_ILLEGAL_Killing_Flow_Male_Young_Adult_9-18") * dt	INIT "Cumulative_ILLEGAL_Killed_Male_Young_Adult_9-18" = 0	Elephants	Total amount of illegally killed elephants	
	"Cumulative_Legal_Killed_Female_Adult_19-35"(t)	"Cumulative_Legal_Killed_Female_Adult_19-35"(t - dt) + ("Legal_Killing_Rate_Female_Adult_19-35") * dt	INIT "Cumulative_Legal_Killed_Female_Adult_19-35" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Female_Juvenile_3-8"(t)	"Cumulative_Legal_Killed_Female_Juvenile_3-8"(t - dt) + ("Legal_Killing_Rate_Female_Juvenile_3-8") * dt	INIT "Cumulative_Legal_Killed_Female_Juvenile_3-8" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Female_Mature_Adult_36+"(t)	"Cumulative_Legal_Killed_Female_Mature_Adult_36+"(t - dt) + ("Legal_Killing_Rate_Female_Mature_Adult_36+") * dt	INIT "Cumulative_Legal_Killed_Female_Mature_Adult_36+" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Female_Prewean_1-2"(t)	"Cumulative_Legal_Killed_Female_Prewean_1-2"(t - dt) + ("Legal_Killing_Rate_Female_Prewean_1-2") * dt	INIT "Cumulative_Legal_Killed_Female_Prewean_1-2" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Female_Young_Adult_9-18"(t)	"Cumulative_Legal_Killed_Female_Young_Adult_9-18"(t - dt) + ("Legal_Killing_Rate_Female_Young_Adult_9-18") * dt	INIT "Cumulative_Legal_Killed_Female_Young_Adult_9-18" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Male_Adult_19-35"(t)	"Cumulative_Legal_Killed_Male_Adult_19-35"(t - dt) + ("Legal_Killing_Rate_Male_Adult_19-35") * dt	INIT "Cumulative_Legal_Killed_Male_Adult_19-35" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Male_Juvenile_3-8"(t)	"Cumulative_Legal_Killed_Male_Juvenile_3-8"(t - dt) + ("Legal_Killing_Rate_Male_Juvenile_3-8") * dt	INIT "Cumulative_Legal_Killed_Male_Juvenile_3-8" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Male_Mature_Adult_36+"(t)	"Cumulative_Legal_Killed_Male_Mature_Adult_36+"(t - dt) + ("Legal_Killing_Rate_Male_Mature_Adult_36+") * dt	INIT "Cumulative_Legal_Killed_Male_Mature_Adult_36+" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	

	"Cumulative_Legal_Killed_Male_Prewean_1-2"(t)	"Cumulative_Legal_Killed_Male_Prewean_1-2"(t - dt) + ("Legal_Killing_Rate_Male_Prewean_1-2") * dt	INIT "Cumulative_Legal_Killed_Male_Prewean_1-2" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Legal_Killed_Male_Young_Adult_9-18"(t)	"Cumulative_Legal_Killed_Male_Young_Adult_9-18"(t - dt) + ("Legal_Killing_Rate_Male_Young_Adult_9-18") * dt	INIT "Cumulative_Legal_Killed_Male_Young_Adult_9-18" = 0	Elephants	Total amount of legally killed elephants (variable included at request of MIKE for future use but not used in this model).	
	"Cumulative_Natural_Dead_Female_Adult_19-35"(t)	"Cumulative_Natural_Dead_Female_Adult_19-35"(t - dt) + ("Total_Natural_Death_Flow_Female_Adult_19-35") * dt	INIT "Cumulative_Natural_Dead_Female_Adult_19-35" = 0	Elephants	Total amount of naturally dead elephants	
	"Cumulative_Natural_Dead_Female_Juvenile_3-8"(t)	"Cumulative_Natural_Dead_Female_Juvenile_3-8"(t - dt) + ("Total_Natural_Death_Flow_Female_Juvenile_3-8") * dt	INIT "Cumulative_Natural_Dead_Female_Juvenile_3-8" = 0	Elephants	Total amount of naturally dead elephants	
	"Cumulative_Natural_Dead_Female_Mature_Adult_36+"(t)	"Cumulative_Natural_Dead_Female_Mature_Adult_36+"(t - dt) + ("Total_Natural_Death_Flow_Female_Mature_Adult_36+") * dt	INIT "Cumulative_Natural_Dead_Female_Mature_Adult_36+" = 0	Elephants	Total amount of naturally dead elephants	
	"Cumulative_Natural_Dead_Female_Prewean_1-2"(t)	"Cumulative_Natural_Dead_Female_Prewean_1-2"(t - dt) + ("Total_Natural_Death_Flow_Female_Prewean_1-2") * dt	INIT "Cumulative_Natural_Dead_Female_Prewean_1-2" = 0	Elephants	Total amount of naturally dead elephants	
	"Cumulative_Natural_Dead_Female_Young_Adult_9-18"(t)	"Cumulative_Natural_Dead_Female_Young_Adult_9-18"(t - dt) + ("Total_Natural_Death_Flow_Female_Young_Adult_9-18") * dt	INIT "Cumulative_Natural_Dead_Female_Young_Adult_9-18" = 0	Elephants	Total amount of naturally dead elephants	
	"Cumulative_Natural_Dead_Male_Adult_19-35"(t)	"Cumulative_Natural_Dead_Male_Adult_19-35"(t - dt) + ("Total_Natural_Death_Flow_Male_Adult_19-35") * dt	INIT "Cumulative_Natural_Dead_Male_Adult_19-35" = 0	Elephants		
	"Cumulative_Natural_Dead_Male_Juvenile_3-8"(t)	"Cumulative_Natural_Dead_Male_Juvenile_3-8"(t - dt) + ("Total_Natural_Death_Flow_Male_Juvenile_3-8") * dt	INIT "Cumulative_Natural_Dead_Male_Juvenile_3-8" = 0	Elephants		

	"Cumulative_Natural_Dead_Male_Mature_36+"(t)	"Cumulative_Natural_Dead_Male_Mature_36+"(t - dt) + ("Total_Natural_Death_Flow_Male_Mature_Adult_36+") * dt	INIT "Cumulative_Natural_Dead_Male_Mature_36+" = 0	Elephants	To prevent dividing by zero at time 1998	
	"Cumulative_Natural_Dead_Male_Prewean_1-2"(t)	"Cumulative_Natural_Dead_Male_Prewean_1-2"(t - dt) + ("Total_Natural_Death_Flow_Male_Prewean_1-2") * dt	INIT "Cumulative_Natural_Dead_Male_Prewean_1-2" = 0	Elephants		
	"Cumulative_Natural_Dead_Male_Young_Adult_9-18"(t)	"Cumulative_Natural_Dead_Male_Young_Adult_9-18"(t - dt) + ("Total_Natural_Death_Flow_Male_Young_Adult_9-18") * dt	INIT "Cumulative_Natural_Dead_Male_Young_Adult_9-18" = 0	Elephants		
	"Female_Adult_Elephants_19-35_years_old"(t)	"Female_Adult_Elephants_19-35_years_old"(t - dt) + (Female_Maturation_Rate_18_to_19_years + "Immigration_Rate_Female_Adult_19-35" - Female_Maturation_Rate_35_to_36_years - "Legal_Killing_Rate_Female_Adult_19-35" - "Natural_Death_Flow_Female_Adult_19-35" - "ILLEGAL_Killing_Flow_Female_Adult_19-35" - "Emigration_Flow_Female_Adult_19-35") * dt	INIT "Female_Adult_Elephants_19-35_years_old" = 3, 3, 3, 3, 3, 3, 3, 3, 4, 4, 4, 4, 4, 4, 4, 4, 4 TRANSIT TIME = 17 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for female adults – between the ages of 19 and 35 years Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR
	"Female_Adult_Elephants_60+_years"(t)	"Female_Adult_Elephants_60+_years"(t - dt) + ("Female_Maturation_Rate_60+_years" - Old_Age_Female_Deaths) * dt	INIT "Female_Adult_Elephants_60+_years" = 0	Elephants		
	"Female_Juvenile_Elephants_3-8_years_old"(t)	"Female_Juvenile_Elephants_3-8_years_old"(t - dt) + (Female_Maturation_Rate_2_to_3_years + "Immigration_Rate_Female_Juvenile_3-8" - Female_Maturation_Rate_8_to_9_years - "ILLEGAL_Killing_Flow_Female_Juvenile_3-8" - "Legal_Killing_Rate_Female_Juvenile_3-8" - "Natural_Death_Flow_Female_Juvenile_3-8" - "Emigration_Flow_Female_Juvenile_3-8") * dt	INIT "Female_Juvenile_Elephants_3-8_years_old" = 14, 14, 14, 14, 15, 15 TRANSIT TIME = 6 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for female juveniles – defined as those individuals between the ages of 3 to 8 years old (the lower bound for primiparity in the population) Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR

	"Female_Mature_Female_Adult_Elephants_36+_years"(t)	"Female_Mature_Female_Adult_Elephants_36+_years"(t - dt) + (Female_Maturation_Rate_35_to_36_years + "Immigration_Rate_Female_Mature_Adult_36+" - "Female_Maturation_Rate_60+_years" - "Legal_Killing_Rate_Female_Mature_Adult_36+" - "Natural_Death_Flow_Female_Mature_Adult_36+" - "ILLEGAL_Killing_Flow_Female_Mature_Adult_36+" - "Emigration_Flow_Female_Mature_Adult_36+") * dt	INIT "Female_Mature_Female_Adult_Elephants_36+_years" = 2, 2, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,1 TRANSIT TIME = 25 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for female mature adults over the age of 36 years, being the stage-class during which females lead family units (Wittemyer, Douglas-Hamilton, et al., 2005) and males are in their prime reproductive ages (Rasmussen et al., 2008). Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR
	"Female_Prewean_Elephants_1-2_years_old"(t)	"Female_Prewean_Elephants_1-2_years_old"(t - dt) + ("Immigration_Rate_Female_Prewean_1-2" + Female_Births - Female_Maturation_Rate_2_to_3_years - "ILLEGAL_Killing_Flow_Female_Prewean_1-2" - "Natural_Death_Flow_Female_Prewean_1-2" - "Legal_Killing_Rate_Female_Prewean_1-2" - "Emigration_Rate_Female_Prewean_1-2") * dt	INIT "Female_Prewean_Elephants_1-2_years_old" = 9, 9 TRANSIT TIME = 2 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for female dependent calves – defined as individuals 2 years and under (ages of lactational dependence for survival) Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR
	"Female_Young_Adult_Elephants_9-18_years_old"(t)	"Female_Young_Adult_Elephants_9-18_years_old"(t - dt) + (Female_Maturation_Rate_8_to_9_years + "Immigration_Rate_Female_Young_Adult_9-18" - Female_Maturation_Rate_18_to_19_years - "ILLEGAL_Killing_Flow_Female_Young_Adult_9-18" - "Legal_Killing_Rate_Female_Young_Adult_9-18" - "Natural_Death_Flow_Female_Young_Adult_9-18" - "Emigration_Flow_Female_Young_Adult_9-18") * dt	INIT "Female_Young_Adult_Elephants_9-18_years_old" = 5, 5, 5, 5, 5, 5, 5, 6, 6, 6 TRANSIT TIME = 10 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for female young adults – defined as individuals between the ages of 9 and 18 years (the span of age during which females produce their first calf and males disperse from their natal groups) Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR
	"Male_Adult_Elephants_19-35_years_old"(t)	"Male_Adult_Elephants_19-35_years_old"(t - dt) + (Maturation_Rate_Male_18_to_19_years + "Immigration_Rate_Male_Adult_19-35" - Maturation_Rate_Male_35_to_36_years - "Legal_Killing_Rate_Male_Adul	INIT "Male_Adult_Elephants_19-35_years_old" = 3, 3, 3, 3, 3, 3, 3, 3, 4, 4, 4, 4, 4, 4, 4, 4, 4 TRANSIT TIME = 17	Elephants	Conveyor stock for male adults – between the ages of 19 and 35 years Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low	CONVEYOR

		t_19-35" - "Natural_Death_Flow_Male_Adult_19-35" - "ILLEGAL_Killing_Flow_Male_Adult_19-35" - "Emigration_Flow_Male_Adult_19-35") * dt	CONTINUOUS ACCEPT MULTIPLE BATCHES		human impact on a wild African elephant population. Manuscript in Review.	
	"Male_Adult_Elephants_60+_years"(t)	"Male_Adult_Elephants_60+_years"(t - dt) + ("Maturation_Male_Rate_60+_years" - Old_Age_Male_Deaths) * dt	INIT "Male_Adult_Elephants_60+_years" = 0	Elephants		
	"Male_Juvenile_Elephants_3-8_years_old"(t)	"Male_Juvenile_Elephants_3-8_years_old"(t - dt) + (Maturation_Rate_Male_2_to_3_years + "Immigration_Rate_Male_Juvenile_3-8" - Maturation_Rate_Male_8_to_9_years - "ILLEGAL_Killing_Flow_Male_Juvenile_3-8" - "Legal_Killing_Rate_Male_Juvenile_3-8" - "Natural_Death_Flow_Male_Juvenile_3-8" - "Emigration_Flow_Male_Juvenile_3-8") * dt	INIT "Male_Juvenile_Elephants_3-8_years_old" = 11, 11, 11, 11, 11, 11 TRANSIT TIME = 6 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for male juveniles – defined as those individuals between the ages of 3 to 8 years old (the lower bound for primiparity in the population) Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR
	"Male_Mature_Adult_Elephants_36+_years"(t)	"Male_Mature_Adult_Elephants_36+_years"(t - dt) + (Maturation_Rate_Male_35_to_36_years + "Immigration_Rate_Male_Mature_Adult_36+" - "Maturation_Male_Rate_60+_years" - "Legal_Killing_Rate_Male_Mature_Adult_36+" - "Natural_Death_Flow_Male_Mature_Adult_36+" - "ILLEGAL_Killing_Flow_Male_Mature_Adult_36+" - "Emigration_Flow_Male_Mature_Adult_36+") * dt	INIT "Male_Mature_Adult_Elephants_36+_years" = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,0 TRANSIT TIME = 25 CONTINUOUS ACCEPT MULTIPLE BATCHES	Elephants	Conveyor stock for male mature adults over the age of 36 years, being the stage-class during which females lead family units (Wittemyer, Douglas-Hamilton, et al., 2005) and males are in their prime reproductive ages (Rasmussen et al., 2008). Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	CONVEYOR
	"Male_Prewean_Elephants_1-2_years_old"(t)	"Male_Prewean_Elephants_1-2_years_old"(t - dt) + ("Immigration_Rate_Male_Prewean_1-2" + Male_Births - Maturation_Rate_Male_2_to_3_years - "ILLEGAL_Killing_Flow_Male_Prewean_1-2" - "Natural_Death_Flow_Male_Prewean_1-2" -	INIT "Male_Prewean_Elephants_1-2_years_old" = 7, 7 TRANSIT TIME = 2 CONTINUOUS ACCEPT	Elephants	Conveyor stock for male dependent calves – defined as individuals 2 years and under (ages of lactational dependence for survival) Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low	CONVEYOR

		"Legal_Killing_Rate_Male_Prewean_1-2" - "Emigration_Rate_Male_Prewean_1-2") * dt	MULTIPLE BATCHES		human impact on a wild African elephant population. Manuscript in Review. Conveyor stock for female dependent calves – defined as individuals 2 years and under (ages of lactational dependence for survival) Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Given elephant fecundity and survival were expected to change in relation to 192 developmental stages in elephant life history, metrics of interest were summarized by age-based 193 stages: (1) dependent calves – defined as individuals 2 years and under (ages of lactational 194 dependence for survival); (2) juveniles – defined as those individuals between the ages of 3 to 8 195 years old (the lower bound for primiparity in the population); (3) young adults – defined as 196 individuals between the ages of 9 and 18 years (the span of age during which females produce 197 their first calf and males disperse from their natal groups); (4) adults – between the ages of 19 198 and 35 years; and (5) mature adults over the age of 36 years, being the stage-class during which 199 females lead family units (Wittemyer, Douglas-Hamilton, et al., 2005) and males are in their 200 prime reproductive ages (Rasmussen et al., 2008).	
	"Male_Young_Adult_Elephants_9-18_years_old"(t)	"Male_Young_Adult_Elephants_9-18_years_old"(t - dt) + (Maturation_Rate_Male_8_to_9_years + "Immigration_Rate_Male_Young_Adult_9-18" - Maturation_Rate_Male_18_to_19_years -	INIT "Male_Young_Adult_Elephants_9-18_years_old" = 2, 2, 2, 2, 2, 3, 3, 3, 3, 3 TRANSIT TIME	Elephants	Conveyor stock for male young adults – defined as individuals between the ages of 9 and 18 years (the span of age during which females produce their first calf and males disperse from their natal groups)	CONVEYOR

		"ILLEGAL_Killing_Flow_Male_Young_Adult_9-18" - "Legal_Killing_Rate_Male_Young_Adult_9-18" - "Natural_Death_Flow_Male_Young_Adult_9-18" - "Emigration_Flow_Young_Male_Adult_9-18") * dt	= 10 CONTINUOUS ACCEPT MULTIPLE BATCHES		Age class definitions from: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	
	"Emigration_Flow_Female_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Female_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Flow_Female_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Female_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Flow_Female_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Female_Mature_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Flow_Female_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Female_Young_Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100%	Elephants/Years	Emigration outflow (variable included for future use)	

			OUTFLOW PRIORITY: 5			
	"Emigration_Flow_Male_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Male_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Flow_Male_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Male_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Flow_Male_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Male_Mature_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Flow_Young_Male_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Male_Young_Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	"Emigration_Rate_Female_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Female_Prewean_1-	Elephants/Years	Emigration outflow (variable included for future use)	

			2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5			
	"Emigration_Rate_Male_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Emigration_Fraction_Male_Prewean_1-2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 5	Elephants/Years	Emigration outflow (variable included for future use)	
	Female_Births	(("Total_Female_Young_Adults_9-18"*"Fecundity_Adult_Female_9-18")+("Total_Female_Adults_19-35"*"Fecundity_Adult_Female_19-35")+("Total_Female_Mature_Adults_36+"*"Fecundity_Adult_Female_36+"))*Availability_of_Mature_Male_Elephants_for_Breeding	INFLOW PRIORITY: 2	Elephants/Years	Female births are calculated from product of fecundity and the reproductive female elephant population.	UNIFLOW
	Female_Maturation_Rate_18_to_19_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	Female_Maturation_Rate_2_to_3_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	Female_Maturation_Rate_35_to_36_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	"Female_Maturation_Rate_60+_years"	CONVEYOR OUTFLOW	OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	Female_Maturation_Rate_8_to_9_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	

	"ILLEGAL_Killing_Flow_Female_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Female_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Female_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Female_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Prewean_1-2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Female_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Young_Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100%	Elephants/Years	Illegal killing outflow	

			OUTFLOW PRIORITY: 2			
	"ILLEGAL_Killing_Flow_Male_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Male_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Male_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Male_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Male_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Male_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Male_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Male_Prewean_1-2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2	Elephants/Years	Illegal killing outflow	
	"ILLEGAL_Killing_Flow_Male_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "ILLEGAL_Killing_Male_Young_Adult_9-18" EXPONENTIAL	Elephants/Years	Illegal killing outflow	

			LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2			
	"Immigration_Rate_Female_Adult_19-35"	"Immigration_Fraction_Female_Adult_19-35"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Immigration_Rate_Female_Juvenile_3-8"	"Immigration_Fraction_Female_Juvenile_3-8"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Immigration_Rate_Female_Mature_Adult_36+"	"Immigration_Fraction_Female_Mature_Adult_36+"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Immigration_Rate_Female_Prewean_1-2"	"Immigration_Fraction_Female_Prewean_1-2"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 1	Elephants/Years		UNIFLOW
	"Immigration_Rate_Female_Young_Adult_9-18"	"Immigration_Fraction_Female_Young_Adult_9-18"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Immigration_Rate_Male_Adult_19-35"	"Immigration_Fraction_Male_Adult_19-35"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Immigration_Rate_Male_Juvenile_3-8"	"Immigration_Fraction_Male_Juvenile_3-8"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW

	"Immigration_Rate_Male_Mature_Adult_36+"	"Immigration_Fraction_Malle_Mature_Adult_36+"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Immigration_Rate_Male_Prewean_1-2"	"Immigration_Fraction_Male_Prewean_1-2"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 1	Elephants/Years		UNIFLOW
	"Immigration_Rate_Male_Young_Adult_9-18"	"Immigration_Fraction_Young_Adult_9-18_1"	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 2	Elephants/Years		UNIFLOW
	"Legal_Killing_Rate_Female_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Female_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Female_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Female_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Female_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Female_Mature_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100%	Elephants/Years	Legal killing outflow	

			OUTFLOW PRIORITY: 2			
	"Legal_Killing_Rate_Female_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Female_Prewean_1-2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Female_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Female_Sub-Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Male_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Male_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Male_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Male_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Male_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Male	Elephants/Years	Legal killing outflow	

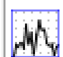
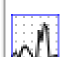
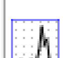
			_Mature_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 2			
	"Legal_Killing_Rate_Male_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Male_Prewean_1-2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Legal killing outflow	
	"Legal_Killing_Rate_Male_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Legal_Killing_Fraction_Male_Sub-Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Legal killing outflow	
	Male_Births	(("Total_Female_Young_Adults_9-18"*"Fecundity_Adult_Female_for_Male_Calf_9-18")+("Total_Female_Adults_19-35"*"Fecundity_Adult_Female_for_Male_Calf_19-35")+("Total_Female_Mature_Adults_36+"*"Fecundity_Adult_Female_for_Male_Calf_36_+"))*Availability_of_Mature_Male_Elephants_for_Breeding	INFLOW PRIORITY: 2	Elephants/Years	Male births are calculated from product of fecundity adjusted for males and the reproductive female elephant population.	UNIFLOW
	"Maturation_Male_Rate_60+_years"	CONVEYOR OUTFLOW	OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	Maturation_Rate_Male_18_to_19_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	

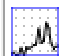
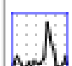
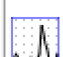
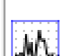
	Maturation_Rate_Male_2_to_3_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	Maturation_Rate_Male_35_to_36_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	Maturation_Rate_Male_8_to_9_years	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	Elephants/Years	Maturation flow	
	"Natural_Death_Flow_Female_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Female_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Female_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Female_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Female_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Female_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Female_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Female_Prewean_0-2" EXPONENTIAL LEAKAGE	Elephants/Years	Natural death outflow	

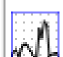
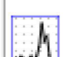
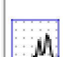
			LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3			
	"Natural_Death_Flow_Female_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Female_Young_Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Male_Adult_19-35"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Male_Adult_19-35" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Male_Juvenile_3-8"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Male_Juvenile_3-8" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Male_Mature_Adult_36+"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Male_Adult_36+" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3	Elephants/Years	Natural death outflow	
	"Natural_Death_Flow_Male_Prewean_1-2"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Male_Prew	Elephants/Years	Natural death outflow	

			ean_0-2" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 3			
	"Natural_Death_Flow_Male_Young_Adult_9-18"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "Natural_Death_Male_Young_Adult_9-18" EXPONENTIAL LEAKAGE LEAK ZONE = 0% to 100% OUTFLOW PRIORITY: 4	Elephants/Years	Natural death outflow	
	Old_Age_Female_Deaths	"Female_Adult_Elephants_60+_years"*Death_Rate_Old_Females		Elephants/Years		UNIFLOW
	Old_Age_Male_Deaths	"Male_Adult_Elephants_60+_years"*Death_Rate_Old_Males		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Female_Adult_19-35"	"Annual_ILLEGAL_Killed_Female_Adult_19-35"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Female_Juvenile_3-8"	"Annual_ILLEGAL_Killed_Female_Juvenile_3-8"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Female_Mature_Adult_36+"	"Annual_ILLEGAL_Killed_Female_Mature_Adult_36+"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Female_Prewean_1-2"	"Annual_ILLEGAL_Killed_Female_Prewean_1-2"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Female_Young_Adult_9-18"	"Annual_ILLEGAL_Killed_Female_Young_Adult_9-18"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Male_Adult_19-35"	"Annual_ILLEGAL_Killed_Male_Adult_19-35"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW

	"Total_ILLEGAL_Killing_Flow_Male_Juvenile_3-8"	"Annual_ILLEGAL_Killed_Male_Juvenile_3-8"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Male_Mature_Adult_36+"	"Annual_ILLEGAL_Killed_Male_Mature_Adult_36+"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Male_Prewean_1-2"	"Annual_ILLEGAL_Killed_Male_Prewean_1-2"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_ILLEGAL_Killing_Flow_Male_Young_Adult_9-18"	"Annual_ILLEGAL_Killed_Male_Young_Adult_9-18"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Female_Adult_19-35"	"Annual_Natural_Dead_Female_Adult_19-35"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Female_Juvenile_3-8"	"Annual_Natural_Dead_Female_Juvenile_3-8"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Female_Mature_Adult_36+"	"Annual_Natural_Dead_Female_Mature_Adult_36+"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Female_Prewean_1-2"	"Annual_Natural_Dead_Female_Prewean_1-2"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Female_Young_Adult_9-18"	"Annual_Natural_Dead_Female_Young_Adult_9-18"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Male_Adult_19-35"	"Annual_Natural_Dead_Male_Adult_19-35"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Male_Juvenile_3-8"	"Annual_Natural_Dead_Male_Juvenile_3-8"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Male_Mature_Adult_36+"	"Annual_Natural_Dead_Male_Mature_Adult_36+"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Total_Natural_Death_Flow_Male_Prewean_1-2"	"Annual_Natural_Dead_Male_Prewean_1-2"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW

	"Total_Natural_Death_Flow_Male_Young_Adult_9-18"	"Annual_Natural_Dead_Male_Young_Adult_9-18"/PIKE_Measurement_Period		Elephants/Years		UNIFLOW
	"Adjusted_Actual_Natural_Death_Female_Adult_19-35"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Female_Adult_36+"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Female_Juvenile_3-8"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	

	"Adjusted_Actual_Natural_Death_Female_Young_Adult_9-18"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Fraction_Female_Prewean_0-2"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Fraction_Male_Prewean_0-2"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Male_Adult_19-35"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African	

					elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Male_Adult_36+"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Male_Juvenile_3-8"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Adjusted_Actual_Natural_Death_Male_Young_Adult_9-18"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared.	

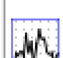
					Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
○	Annual_ILLEGAL_Killed_Elephants	Annual_ILLEGAL_Killed_Female_Elephants+Annual_ILLEGAL_Killed_Male_Elephants		Elephants		
⊕	Annual_ILLEGAL_Killed_Female_Elephants	"Annual_ILLEGAL_Killed_Female_Adult_19-35" + "Annual_ILLEGAL_Killed_Female_Juvenile_3-8" + "Annual_ILLEGAL_Killed_Female_Mature_Adult_36+" + "Annual_ILLEGAL_Killed_Female_Prewean_1-2" + "Annual_ILLEGAL_Killed_Female_Young_Adult_9-18"	REPORT IN TABLE AS STOCK	Elephants		SUMMING CONVERTER
⊕	Annual_ILLEGAL_Killed_Male_Elephants	"Annual_ILLEGAL_Killed_Male_Adult_19-35" + "Annual_ILLEGAL_Killed_Male_Juvenile_3-8" + "Annual_ILLEGAL_Killed_Male_Mature_Adult_36+" + "Annual_ILLEGAL_Killed_Male_Prewean_1-2" + "Annual_ILLEGAL_Killed_Male_Young_Adult_9-18"		Elephants		SUMMING CONVERTER
○	Annual_Natural_Dead_Elephants	Annual_Natural_Dead_Male_Elephants+Annual_Natural_Dead_Female_Elephants		Elephants		
⊕	Annual_Natural_Dead_Female_Elephants	"Annual_Natural_Dead_Female_Adult_19-35" + "Annual_Natural_Dead_Female_Juvenile_3-8" + "Annual_Natural_Dead_Female_Mature_Adult_36+" + "Annual_Natural_Dead_Female_Prewean_1-2" + "Annual_Natural_Dead_Female_Young_Adult_9-18"	REPORT IN TABLE AS STOCK	Elephants		SUMMING CONVERTER
⊕	Annual_Natural_Dead_Male_Elephants	"Annual_Natural_Dead_Male_Adult_19-35" + "Annual_Natural_Dead_Male_Juvenile_3-8" + "Annual_Natural_Dead_Male_Mature_Adult_36+" + "Annual_Natural_Dead_Male_Prewean_1-2" +		Elephants		SUMMING CONVERTER

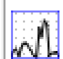
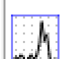
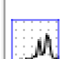
		"Annual_Natural_Dead_Male_Young_Adult_9-18"				
○	Annual_PIKE	IF (Annual_ILLEGAL_Killed_Elephants=0) THEN 0 ELSE (SAFEDIV(Annual_ILLEGAL_Killed_Elephants, (Annual_ILLEGAL_Killed_Elephants+Annual_Natural_Dead_Elephants)))		unitless	PIKE is the measure of proportion of Illegally Killed Elephants divided by total dead elephants (annually). If illegally killed elephants =0 then PIKE must also =0	
○	Availability_of_Mature_Male_Elephants_for_Breeding	IF"Male_Mature_Adult_Elephants_36+_years" <= 0 THEN 0 ELSE 1		unitless	Kenyan Elephant Researcher Sandy Odour advised 5 August 2021 that mature male elephants are the prime breeders among the males. If there are no mature adult males remaining then breeding will drops. This conditional factor was introduced to ensure that in future use of the mode it will not continue to generate births if data is included that has no mature adult males. This is an extreme conditional case and can be adjusted based on actual adult male breading data if available (not available for this population).	
○	Ave_Ratio_Male_to_Female_Births	0.839		unitless	Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data & analysis. Average ratio of male to female calves born is 0.839. Factor is required to estimate births of male calves relative to female calves.	
○	Average_Fecundity_Model	Total_Fecundity/2		Per Year	The actual combined average fecundity inputs to calculate male and female births is slightly lower (0.92) than the Average Input Fecundity Factor. This is because there is an adjustment for male births (Ave Ratio Male to Female Births) that is included as actual fecundity for male births was unknown.	

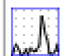
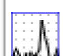
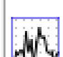
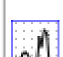
◯	Average_Female_Illegal_Killing_Model	("ILLEGAL_Killing_Prewean_1-2"+"ILLEGAL_Killing_Juvenile_3-8"+"ILLEGAL_Killing_Young_Adult_9-18"+"ILLEGAL_Killing_Adult_19-35"+"ILLEGAL_Killing_Adult_36+")/5		Per Year	For graphical comparison purposes the Average Illegal Killing data is calculated.	
◯	Average_Female_Natural_Death_Model	("Natural_Death_Female_Prewean_0-2"+"Natural_Death_Female_Juvenile_3-8"+"Natural_Death_Female_Young_Adult_9-18"+"Natural_Death_Female_Adult_19-35"+"Natural_Death_Female_Adult_36+")/5		Per Year	For graphical comparison purposes the Average Natural Death data is calculated.	
◯	Average_ILLEGAL_Killing_Model	(Average_Female_Illegal_Killing_Model+Average_Male_Illegal_Killing_Model)/2		Per Year		
◯	Average_Illegal_Killing_Rate	0*0.05+0*0.014+0*0.103+0*0.0471/2+0*0.02+0*0.018+1*0.032+0*0.03+0*0.0151+0*0.045		Per Year	CoP18 Doc. 69.2 paragraph 40 Illegal killing rate ranging 1.4% to 10.3% with an 5% average illegal killing rate.	
◯	Average_Input_Fecundity_Factor	0*0.171+0*.025+0*0.0784+0*0.149+1*0.11 +0*0.00979+0*0.208+0*0.16		Per Year	Scenario I. Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed data & analysis: 9-18 year cohort Average Fecundity 0.0737 19-35 year cohort Average Fecundity 0.1124 36+ year cohort Average Fecundity 0.116 Combined Average Fecundity 0.101 Maximum Average Fecundity across 3 cohorts 0.190 Minimum Average Fecundity across 3 cohorts 0.001 Therefore upper limit of sensitivity testing is 19% and lower limit 0.1% Scenario II.	

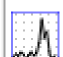
					Source: Wittemyer, G., Daballen, D., Douglas-Hamilton, I., 2013. Comparative demography of an at-risk African elephant population. PLoS ONE 8, e53726. https://doi.org/10.1371/journal.pone.0053726 "Annual natality was highly variable averaging 7.21% (S.D. = 4.10%) per annum, with a maximum of 14.4% in 2004 and a minimum of 2.1% in 2011". Therefore upper limit of sensitivity testing is 14.4% and lower limit 2.1% Average Natality 7.21% Note:the actual combined average fecundity inputs to calculate male and female births is slightly lower (0.92) than the Average Input Fecundity Factor. This is because there is an adjustment for male births (Ave Ratio Male to Female Births) that is included as actual fecundity for male births was unknown.	
	Average_Male_Illegal_Killing_Model	("ILLEGAL_Killing_Male_Preweaan_1-2"+"ILLEGAL_Killing_Male_Juvenile_3-8"+"ILLEGAL_Killing_Male_Young_Adult_9-18"+"ILLEGAL_Killing_Male_Adult_19-35"+"ILLEGAL_Killing_Male_Adult_36+")/5		Per Year	For graphical comparison purposes the Average Illegal Killing data is calculated.	
	Average_Male_Natural_Death_Model	("Natural_Death_Male_Prewean_0-2"+"Natural_Death_Male_Juvenile_3-8"+"Natural_Death_Male_Young_Adult_9-18"+"Natural_Death_Male_Adult_19-35"+"Natural_Death_Male_Adult_36+")/5		Per Year	For graphical comparison purposes the Average Natural Death data is calculated.	
	Average_Natural_Death_Model	(Average_Female_Natural_Death_Model+Average_Male_Natural_Death_Model)/2		Per Year		

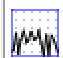
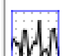
◯	Average_Natural_Death_Rate	0*0.045+0*0.015+1*0.03+0*0.032+0*0.0471/2+0*0.012+0*0.05		Per Year	CoP18 Doc. 69.2 paragraph 39 Natural mortality rates ranging from 1.5% to 4.5% with an 3% average natural mortality rate.	
⊕	Cumulative_ILLEGAL_Killed_Elephants	"Cumulative_ILLEGAL_Killed_Female_Adult_19-35" + "Cumulative_ILLEGAL_Killed_Female_Juvenile_3-8" + "Cumulative_ILLEGAL_Killed_Female_Mature_Adult_36+" + "Cumulative_ILLEGAL_Killed_Female_Prewean_1-2" + "Cumulative_ILLEGAL_Killed_Female_Young_Adult_9-18"		Elephants		SUMMING CONVERTER
⊕	Cumulative_Natural_Dead_Elephants	"Cumulative_Natural_Dead_Female_Adult_19-35" + "Cumulative_Natural_Dead_Female_Juvenile_3-8" + "Cumulative_Natural_Dead_Female_Mature_Adult_36+" + "Cumulative_Natural_Dead_Female_Prewean_1-2" + "Cumulative_Natural_Dead_Female_Young_Adult_9-18"		Elephants		SUMMING CONVERTER
◯	Cumulative_PIKE_Elephants	SAFEDIV(Cumulative_ILLEGAL_Killed_Elephants, (Cumulative_ILLEGAL_Killed_Elephants+Cumulative_Natural_Dead_Elephants))		unitless		
◯	Death_Rate_Old_Females	1/3		Per Year		
◯	Death_Rate_Old_Males	1/3		Per Year		
◯	Difference_Actual_Elephants_vs_Model	Total_Actual_Elephants-Total_Elephants_Model		Elephants		
◯	"Emigration_Fraction_Female_Adult_19-35"	Female_Emigration_Rate*0		Per Year		
◯	"Emigration_Fraction_Female_Juvenile_3-8"	Female_Emigration_Rate*0		Per Year		
◯	"Emigration_Fraction_Female_Mature_Adult_36+"	Female_Emigration_Rate*0		Per Year		
◯	"Emigration_Fraction_Female_Prewean_1-2"	Female_Emigration_Rate*0		Per Year		

	"Emigration_Fraction_Female_Young_Adult_9-18"	Female_Emigration_Rate*0		Per Year		
	"Emigration_Fraction_Male_Adult_19-35"	Emigration_Rate_Male*0		Per Year		
	"Emigration_Fraction_Male_Juvenile_3-8"	Emigration_Rate_Male*0		Per Year		
	"Emigration_Fraction_Male_Mature_Adult_36+"	Emigration_Rate_Male*0		Per Year		
	"Emigration_Fraction_Male_Prewean_1-2"	Emigration_Rate_Male*0		Per Year		
	"Emigration_Fraction_Male_Young_Adult_9-18"	Emigration_Rate_Male*0		Per Year		
	Emigration_Rate_Male	0.015		Per Year	Unused variable. For use in future model developments for elephant researchers. Wittemyer, G., Daballen, D., Douglas-Hamilton, I., 2013. Comparative demography of an at-risk African elephant population. PLoS ONE 8, e53726. https://doi.org/10.1371/journal.pone.0053726 Net change through migration (immigration plus emigration) averaged -1.5% (S.D. =1.5%) per year, predominantly in the form of young male dispersal from their natal groups. Note however - dispersed males were removed from the analysis.	
	"Estimated_Illegal_Killing_Female_Adult_19-35"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot	

					calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Female_Adult_36+"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Female_Juvenile_3-8"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Female_Young_Adult_9-18"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	

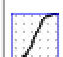
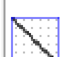
	"Estimated_Illegal_Killing_Fraction_Female_Prewean_0-2"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Fraction_Male_Prewean_0-2"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Male_Adult_19-35"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Male_Adult_36+"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African	

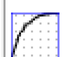
					elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Male_Juvenile_3-8"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Estimated_Illegal_Killing_Male_Young_Adult_9-18"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Raw data shared. Researcher advised: Carcasses were never found for the majority of deaths, which were determined from other means therefore causes of death is unknown. Cannot calculate natural and illegal killing rates empirically.	
	"Fecundity_Actual_Adult_Female_19-35"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	

					Detailed source data	
	"Fecundity_Actual_Adult_Female_9-18"	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data	
	Fecundity_Actual_Adult_Females_36_plus	(Detailed data points not disclosed due to confidentiality request by researcher)		Per Year	Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data	
	"Fecundity_Adult_Female_19-35"	IF("Switch_A_-_Fecundity_Reference_Data_vs_Simulation"=0) THEN ("Fecundity_Actual_Adult_Female_19-35") ELSE (Simulation_Fecundity*1.117)		Per Year	Switch for Actual Fecundity Data vs Simulation (Actual = 0 and Simulation =1). Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data Under simulation the relative weighting per cohort for the Average Fixed Fecundity Factor are as follows: Age cohort 9-18 years is 0.0737 Age cohort 19-35 years is 1.117 Age cohort 36+ years is 1.152	
	"Fecundity_Adult_Female_36+"	IF("Switch_A_-_Fecundity_Reference_Data_vs_Simulation"=0) THEN (Fecundity_Actual_Adult_Females_36_plus) ELSE (Simulation_Fecundity*1.152)		Per Year	Switch for Actual Fecundity Data vs Simulation (Actual = 0 and Simulation =1). Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African	

					elephant population. Manuscript in Review. Detailed source data Under simulation the relative weighting per cohort for the Average Fixed Fecundity Factor are as follows: Age cohort 9-18 years is 0.0737 Age cohort 19-35 years is 1.117 Age cohort 36+ years is 1.152	
○	"Fecundity_Adult_Female_9-18"	IF("Switch_A_-_Fecundity_Reference_Data_vs_Simulation"=0) THEN ("Fecundity_Actual_Adult_Female_9-18") ELSE (Simulation_Fecundity*0.732)		Per Year	Switch for Actual Fecundity Data vs Simulation (Actual = 0 and Simulation =1). Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data Under simulation the relative weighting per cohort for the Average Fixed Fecundity Factor are as follows: Age cohort 9-18 years is 0.0737 Age cohort 19-35 years is 1.117 Age cohort 36+ years is 1.152	
○	"Fecundity_Adult_Female_for_Male_Calf_19-35"	IF("Switch_A_-_Fecundity_Reference_Data_vs_Simulation"=0) THEN ("Fecundity_Actual_Adult_Female_19-35"*Ave_Ratio_Male_to_Female_Births) ELSE (Simulation_Fecundity*Ave_Ratio_Male_to_Female_Births*1.117)		Per Year	Switch for Actual Fecundity Data vs Simulation (Actual = 0 and Simulation =1). Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data Under simulation the relative weighting per cohort for the Average Fixed Fecundity Factor are as follows: Age cohort 9-18 years is 0.0737	

					Age cohort 19-35 years is 1.117 Age cohort 36+ years is 1.152	
	"Fecundity_Adult_Female_for_Male_Calf_36_+"	IF("Switch_A_-_Fecundity_Reference_Data_vs_Simulation"=0) THEN (Fecundity_Actual_Adult_Females_36_plus*Ave_Ratio_Male_to_Female_Births) ELSE (Simulation_Fecundity*Ave_Ratio_Male_to_Female_Births*1.152)		Per Year	Switch for Actual Fecundity Data vs Simulation (Actual = 0 and Simulation =1). Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data Under simulation the relative weighting per cohort for the Average Fixed Fecundity Factor are as follows: Age cohort 9-18 years is 0.0737 Age cohort 19-35 years is 1.117 Age cohort 36+ years is 1.152	
	"Fecundity_Adult_Female_for_Male_Calf_9-18"	IF("Switch_A_-_Fecundity_Reference_Data_vs_Simulation"=0) THEN ("Fecundity_Actual_Adult_Female_9-18"*Ave_Ratio_Male_to_Female_Births) ELSE (Simulation_Fecundity*Ave_Ratio_Male_to_Female_Births*0.732)		Per Year	Switch for Actual Fecundity Data vs Simulation (Actual = 0 and Simulation =1). Data Source: Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed source data Under simulation the relative weighting per cohort for the Average Fixed Fecundity Factor are as follows: Age cohort 9-18 years is 0.0737 Age cohort 19-35 years is 1.117 Age cohort 36+ years is 1.152	
	Female_Adult_Legal_Killing_Rate	0		Per Year	For use in future model developments as requested by MIKE.	
	Female_Emigration_Rate	0.015		Per Year	Unused variable. For use in future model developments for elephant researchers.	

					Wittemyer, G., Daballen, D., Douglas-Hamilton, I., 2013. Comparative demography of an at-risk African elephant population. PLoS ONE 8, e53726. https://doi.org/10.1371/journal.pone.0053726 Net change through migration (immigration plus emigration) averaged -1.5% (S.D. =1.5%) per year, predominantly in the form of young male dispersal from their natal groups. Note however - this is not expected to be relevant for females and in the case of dispersed males they were removed from the analysis.	
	Female_Immigration_Rate	0		Elephants/Years	Unused variable. For use in future model developments for elephant researchers.	
	Graphical_Simulation_Illegal_Killing_Rate			Per Year	CoP18 Doc. 69.2 paragraph 40 Illegal killing rate ranging 1.4% to 10.3% with an 5% average illegal killing rate.	
	Graphical_Varying_Fecundity			Per Year	Scenario I. Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review. Detailed data & analysis: 9-18 year cohort Average Fecundity 0.0737 19-35 year cohort Average Fecundity 0.1124 36+ year cohort Average Fecundity 0.116 Combined Average Fecundity 0.101 Maximum Average Fecundity across 3 cohorts 0.190 Minimum Average Fecundity across 3 cohorts 0.001 Therefore upper limit of sensitivity testing is 19% and lower limit 0.1% Scenario II.	

					Source: Wittemyer, G., Daballen, D., Douglas-Hamilton, I., 2013. Comparative demography of an at-risk African elephant population. PLoS ONE 8, e53726. https://doi.org/10.1371/journal.pone.0053726 "Annual natality was highly variable averaging 7.21% (S.D. = 4.10%) per annum, with a maximum of 14.4% in 2004 and a minimum of 2.1% in 2011". Therefore upper limit of sensitivity testing is 14.4% and lower limit 2.1% Average Natality 7.21%	
	Graphical_Varying_Natural_Death_Rate			Per Year	CoP18 Doc. 69.2 paragraph 39 Natural mortality rates ranging from 1.5% to 4.5% with an 3% average natural mortality rate.	
	Illegal_Killing_Adjustment	1*1+0*2.65+0*2.25+0*1.935		unitless	Estimated illegal killing multiplier for experimenting with changing illegal killing against actual fecundity and adjusted actual natural deaths.	
	"ILLEGAL_Killing_Adult_19-35"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Female_Adult_19-35"*Illegal_Killing_Adjustment) ELSE(Simulation_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
	"ILLEGAL_Killing_Adult_36+"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Female_Adult_36+"*Illegal_Killing_Adjustment) ELSE(Simulation_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
	"ILLEGAL_Killing_Juvenile_3-8"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Female_Juvenile_3-8"*Illegal_Killing_Adjustment)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included	

		ELSE(Simulation_Illegal_Killing_Rate)			although no actual Illegal Killing data is available in this analysis.	
○	"ILLEGAL_Killing_Male_Adult_19-35"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Male_Adult_19-35"*Illegal_Killing_Adjustment) ELSE(Simulation_Male_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
○	"ILLEGAL_Killing_Male_Adult_36+"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Male_Adult_36+"*Illegal_Killing_Adjustment) ELSE(Simulation_Male_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
○	"ILLEGAL_Killing_Male_Juvenile_3-8"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Male_Juvenile_3-8"*Illegal_Killing_Adjustment) ELSE(Simulation_Male_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
○	"ILLEGAL_Killing_Male_Prewean_1-2"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Fraction_Male_Prewean_0-2"*Illegal_Killing_Adjustment) ELSE(Simulation_Male_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
○	"ILLEGAL_Killing_Male_Young_Adult_9-18"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Male_Young_Adult_9-18"*Illegal_Killing_Adjustment) ELSE(Simulation_Male_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
○	"ILLEGAL_Killing_Prewean_1-2"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Fraction_Female_Prewean_0-		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included	

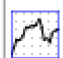
		2"*Illegal_Killing_Adjustment) ELSE(Simulation_Illegal_Killing_Rate)			although no actual Illegal Killing data is available in this analysis.	
	"ILLEGAL_Killing_Young_Adult_9-18"	IF("Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"=0) THEN("Estimated_Illegal_Killing_Female_Young_Adult_9-18"*Illegal_Killing_Adjustment) ELSE(Simulation_Illegal_Killing_Rate)		Per Year	Switch A for Actual Illegal Killing Data vs Simulation (Actual = 0 and Simulation =1). For consistency with Natural Deaths this switch was included although no actual Illegal Killing data is available in this analysis.	
	"Immigration_Fraction_Female_Adult_19-35"	Female_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Female_Juvenile_3-8"	Female_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Female_Mature_Adult_36+"	Female_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Female_Prewean_1-2"	Female_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Female_Young_Adult_9-18"	Female_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Male_Adult_19-35"	Male_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Male_Juvenile_3-8"	Male_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Male_Prewean_1-2"	Male_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Malle_Mature_Adult_36+"	Male_Immigration_Rate		Elephants/Years		
	"Immigration_Fraction_Young_Adult_9-18_1"	Male_Immigration_Rate		Elephants/Years		
	"Legal_Killing_Fraction_Female_Adult_19-35"	Female_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Female_Juvenile_3-8"	Female_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Female_Mature_Adult_36+"	Female_Adult_Legal_Killing_Rate		Per Year		

	"Legal_Killing_Fraction_Female_Prewean_1-2"	Female_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Female_Sub-Adult_9-18"	Female_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Male_Adult_19-35"	Male_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Male_Juvenile_3-8"	Male_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Male_Mature_Adult_36+"	Male_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Male_Prewean_1-2"	Male_Adult_Legal_Killing_Rate		Per Year		
	"Legal_Killing_Fraction_Male_Sub-Adult_9-18"	Male_Adult_Legal_Killing_Rate		Per Year		
	Male_Adult_Legal_Killing_Rate	0		Per Year	Unused variable. For use in future model developments as requested by MIKE.	
	Male_Immigration_Rate	0		Elephants/Years	Unused variable. For use in future model developments for elephant researchers.	
	"Natural_Death_Female_Adult_19-35"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Female_Adult_19-35") ELSE(Simulation_Female_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
	"Natural_Death_Female_Adult_36+"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Female_Adult_36+") ELSE(Simulation_Female_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
	"Natural_Death_Female_Juvenile_3-8"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Female_Juvenile_3-8") ELSE(Simulation_Female_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	

○	"Natural_Death_Female_Prewean_0-2"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Fraction_Female_Prewean_0-2") ELSE(Simulation_Female_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
○	"Natural_Death_Female_Young_Adult_9-18"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Female_Young_Adult_9-18") ELSE(Simulation_Female_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
○	"Natural_Death_Male_Adult_19-35"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Male_Adult_19-35") ELSE(Simulation_Male_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
○	"Natural_Death_Male_Adult_36+"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Male_Adult_36+") ELSE(Simulation_Male_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
○	"Natural_Death_Male_Juvenile_3-8"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Male_Juvenile_3-8") ELSE(Simulation_Male_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
○	"Natural_Death_Male_Prewean_0-2"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Fraction_Male_Prewean_0-2") ELSE(Simulation_Male_Natural_Death_Rate)		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1). Note Actual data is Total Death Data (includes Illegal Killing).	
○	"Natural_Death_Male_Young_Adult_9-18"	IF("Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"=0) THEN("Adjusted_Actual_Natural_Death_Male_Young_Adult_9-18")		Per Year	Switch A for Actual Total Death Data vs Simulation of Natural Death Data (Actual = 0 and Simulation =1).	

		ELSE(Simulation_Male_Natural_Death_Rate)			Note Actual data is Total Death Data (includes Illegal Killing).	
○	PIKE_Measurement_Period	1		Years	PIKE is measured annually. This variable is included in order to drain the preceding stock on an annual basis so that it can be used for PIKE calculations. PIKE is proportion of illegally killed elephants divided by total dead elephants measured on an annual basis.	
○	Simulation_Fecundity	IF "Switch_B_-_Simulation_Fecundity_Graphical_vs_Average" = 0 THEN Graphical_Varying_Fecundity ELSE Average_Input_Fecundity_Factor		Per Year	Switch B allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
○	Simulation_Female_Natural_Death_Rate	IF "Switch_B_-_Simulation_Natural_Death_Graphical_vs_Average" = 0 THEN Graphical_Varying_Natural_Death_Rate ELSE Average_Natural_Death_Rate		Per Year	Switch B allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
○	Simulation_Illegal_Killing_Rate	IF "Switch_B_-_Simulation_Illegal_Killing_Graphical_vs_Average" = 0 THEN Graphical_Simulation_Illegal_Killing_Rate ELSE Average_Illegal_Killing_Rate		Per Year	Switch B allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
○	Simulation_Male_Illegal_Killing_Rate	IF "Switch_B_-_Simulation_Illegal_Killing_Graphical_vs_Average" = 0 THEN Graphical_Simulation_Illegal_Killing_Rate ELSE Average_Illegal_Killing_Rate		Per Year	Switch B allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
○	Simulation_Male_Natural_Death_Rate	IF "Switch_B_-_Simulation_Natural_Death_Graphical_vs_Average" = 0 THEN Graphical_Varying_Natural_Death_Rate ELSE Average_Natural_Death_Rate		Per Year	Switch B allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
○	"Sum_Female_Adult_19-35"[Dimension_17]	"Female_Adult_Elephants_19-35_years_old"[Dimension_17]		Elephants	Summation for conveyor stock (used during testing)	
○	"Sum_Female_Juvenile_3-8"[Dimension_6]	"Female_Juvenile_Elephants_3-8_years_old"[Dimension_6]		Elephants	Summation for conveyor stock (used during testing)	

	"Sum_Female_Mature_Adult_36+"[Dimension_25]	"Female_Mature_Female_Adult_Elephants_36+_years"[Dimension_25]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Female_Prewean_1-2"[Dimension_3]	"Female_Prewean_Elephants_1-2_years_old"[Dimension_3]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Female_Young_Adult_9-18"[Dimension_10]	"Female_Young_Adult_Elephants_9-18_years_old"[Dimension_10]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Male_Adult_19-35"[Dimension_17]	"Male_Adult_Elephants_19-35_years_old"[Dimension_17]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Male_Juvenile_3-8"[Dimension_6]	"Male_Juvenile_Elephants_3-8_years_old"[Dimension_6]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Male_Prewean_1-2"[Dimension_3]	"Male_Prewean_Elephants_1-2_years_old"[Dimension_3]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Male_Young_Adult_9-18"[Dimension_10]	"Male_Young_Adult_Elephants_9-18_years_old"[Dimension_10]		Elephants	Summation for conveyor stock (used during testing)	
	"Sum_Mature_Male_Adult_36+"[Dimension_25]	"Male_Mature_Adult_Elephants_36+_years"[Dimension_25]		Elephants	Summation for conveyor stock (used during testing)	
	"Switch_A_-_Fecundity_Reference_Data_vs_Simulation"	1		unitless	Switch A allows testing the model against actual historical reference data (Simulation Switch=0) or running the model in a simulation mode which is initially placed in equilibrium (Simulation Switch=1).	
	"Switch_A_-_Illegal_Killing_Reference_Data_vs_Simulation"	1		unitless	For consistency with Natural Deaths this switch was included although no actual Illegal Killing data was available an calculate adjustment was made using published literature.	
	"Switch_A_-_Natural_Death_Reference_Data_vs_Simulation"	1		unitless	Switch allows testing the model against actual historical reference data (Simulation Switch=0) or running the model in a simulation mode which is initially placed in equilibrium (Simulation Switch=1).	
	"Switch_B_-_Simulation_Fecundity_Graphical_vs_Average"	1		unitless	Switch B allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	

	"Switch_B_-_Simulation_Illegal_Killing_Graphical_vs_Average"	1		unitless	Switch allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
	"Switch_B_-_Simulation_Natural_Death_Graphical_vs_Average"	1		unitless	Switch allows testing the model against graphical input data (Simulation Switch=0) or running the model with a user selected average input (Simulation Switch=1).	
	Total_Actual_Elephants	(Detailed data points not disclosed due to confidentiality request by researcher)		Elephants	Wittemyer G, Daballen D, Douglas-Hamilton I (2020). Contrasting drivers of variation in demographic rate during periods of high and low human impact on a wild African elephant population. Manuscript in Review.	
	Total_Annual_Dead_Elephants	Annual_ILLEGAL_Killed_Elephants+Annual_Natural_Dead_Elephants		Elephants		
	Total_Dead_Elephants	Cumulative_Natural_Dead_Elephants+Cumulative_ILLEGAL_Killed_Elephants		Elephants		
	Total_Elephants_Model	Total_Male_Elephant_Population+Total_Female_Elephant_Population		Elephants		
	Total_Fecundity	Total_Female_Fecundity + Total_Male_Fecundity		Per Year	Summation of Total Female Fecundity and Total Male Fecundity to calculate Average Fecundity.	SUMMING CONVERTER
	"Total_Female_Adults_19-35"	"Female_Adult_Elephants_19-35_years_old"		Elephants	Total Female Adults 19-35 year old population data generated by model for calculation of male and female calf births from this cohort.	SUMMING CONVERTER
	Total_Female_Elephant_Population	"Female_Adult_Elephants_19-35_years_old" + "Female_Prewean_Elephants_1-2_years_old" + "Female_Juvenile_Elephants_3-8_years_old" + "Female_Mature_Female_Adu		Elephants		SUMMING CONVERTER

		lt_Elephants_36+_years" + "Female_Young_Adult_Elephants_9-18_years_old"				
	Total_Female_Fecundity	("Fecundity_Adult_Female_9-18"+"Fecundity_Adult_Female_19-35"+"Fecundity_Adult_Female_36+")/3		Per Year	Average female fecundity	
	"Total_Female_Mature_Adults_36+"	"Female_Mature_Female_Adult_Elephants_36+_years"		Elephants	Total Female Adults 36+ year old population data generated by model for calculation of male and female calf births from this cohort.	SUMMING CONVERTER
	"Total_Female_Young_Adults_9-18"	"Female_Young_Adult_Elephants_9-18_years_old"		Elephants	Total Female Adults 9-18 year old population data generated by model for calculation of male and female calf births from this cohort.	SUMMING CONVERTER
	Total_Male_Elephant_Population	"Male_Adult_Elephants_19-35_years_old" + "Male_Juvenile_Elephants_3-8_years_old" + "Male_Mature_Adult_Elephants_36+_years" + "Male_Prewean_Elephants_1-2_years_old" + "Male_Young_Adult_Elephants_9-18_years_old"		Elephants		SUMMING CONVERTER
	Total_Male_Fecundity	("Fecundity_Adult_Female_for_Male_Calf_9-18"+"Fecundity_Adult_Female_for_Male_Calf_19-35"+"Fecundity_Adult_Female_for_Male_Calf_36_+")/3		Per Year	Average male fecundity	

Total	Count	Including Array Elements
Variables	304	416
Sectors	14	
Stocks	72	72
Flows	84	84

Converters	148	260
Constants	40	40
Equations	192	304
Graphicals	27	27

Run Specs	
Start Time	1998
Stop Time	2017
DT	1/2
Fractional DT	True
Save Interval	1
Sim Duration	1
Time Units	Years
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	False

Array Dimension	Indexed by	Elements
Dimension_10	Number	10
Dimension_17	Number	17
Dimension_25	Number	25
Dimension_3	Number	3
Dimension_6	Number	6

Model layout.