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Modeling the Impact of the Pleistocene Park with System Dynamics

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Abstract: Climate change is a major concern of the international community. Scientists have formed international teams to try to tackle the problem, and various solutions now exist. One of the more radical approaches comes from Russian scientist Sergei Zimov who is attempting to reintroduce megafauna such as mammoths to alter the ecosystem of northern Siberia to slow climate change. By reintroducing megafauna, Zimov hopes to slow carbon emissions by harnessing the natural process of the carbon cycle. Zimov, who helped identify a store of carbon larger than that in all forests and the atmosphere combined, already established a wildlife refuge in Siberia to test his theory. By addressing the issue of snow insulation and permafrost thawing, Zimov aims to keep carbon trapped in Siberian permafrost, slowing and even reversing climate warming. This paper's model examines the feasibility of Pleistocene Park, determining when the park will produce significant results, and how effective this approach could be. After evaluating the model's policy output compared to the baseline results, the results indicate that Pleistocene Park is a viable option, and although it is impossible to predict all the implications, the research indicates that it could help slow, and even reverse, climate change over the next thousand, or even as early as next couple hundred, years.

Keywords: Pleistocene Park, Climate Change, Mammoths, Microbes, Zimov, Siberia, Carbon

1. Introduction

Pleistocene Park is the brainchild of Sergei Zimov, a Russian ecologist and director of the Northeast Science Station is Cherskiy in the Republic of Sakha (Andersen, 2017). The park is named for the era that ended 12000 years ago, commonly known as the Ice Age (Andersen, 2017). While a conservation effort exists within the park's purpose, the real purpose is to slow the thawing of permafrost, leading to fewer carbon emissions (Andersen, 2017). Sergei Zimov and his son Nikita's goal is encouraging the return of the Mammoth Steppe ecosystem, aided by Arctic megafauna and even mammoths (Andersen, 2017). A sharp rise in Arctic carbon emissions was attributed to the disappearance of the mammoth-steppe ecosystem (Zimov S. A., 2005). The park is an attempt to slow natural cycles that have been accelerated due to climate change, and maybe even reverse them. Zimov's experiment consists of three key factors: grasslands, the megafauna that call them home and the natural carbon cycle impacted by both the grasslands and the animals that roam them (Andersen, 2017). Zimov is attempting to bring animals back from the Pleistocene era to modify the landscape to resemble the mammoth steppe in northern Siberia, trapping atmospheric carbon in the vast permafrost that covers Siberia and much of the North (Andersen, 2017). Using the work of geneticists and natural selection, Zimov hopes to bring back megafauna such as woolly mammoths to act as the tools that would achieve his goal of reducing Arctic carbon emissions (Zimov S. A., 2005). In this paper, I examine the historical and potential effects of imprisoned carbon, while considering the process of reintroducing the woolly mammoth and other species, as well as the potential consequences of each of these actions.

The remainder of the paper includes a literature section, methodology section on system dynamics, model findings and analysis, and a conclusion. The background literature is important to understand since it enhances readers' understanding of the system dynamics model and the overall outcome. The model began with a causal loop diagram, which is a simplified initial concept of the model. The stock and flow diagram follow, which is the visual representation of the model. The paper also analyzes how the model formulation and calibration, and the subsequent runs after the initial baseline run. The final run and output is presented after, along with the recommendation on the viability of Pleistocene Park.

2. Background Literature

Testing the feasibility of Pleistocene Park began with increasing my understanding of the processes at play. In my literature review, I examined the potential impact of megafauna, and the implications of reintroducing extinct species. Rewilding the Arctic has several conservation considerations, so I dove deeper into the topic. After understanding the dynamics of the megafauna, I turned to the carbon cycle, since the process of natural carbon flow is what Zimov hopes to impact. Several natural systems play into the carbon cycle, making it complex and difficult to understand. The background literature reviewed gives the reader enough base understanding to understand the system dynamics model and its findings.

2.1 Megafauna

"Give [Nikita Zimov] 100 mammoths and come back in a few years…you won't recognize this place" (Andersen, 2017). Megafauna are the basis of Pleistocene Park. Bring back the giant herbivores, bring back the grasslands, and the result is reduced carbon emissions (Donlan J. , 2005). The theory that supports Pleistocene Park is that once megafauna are reintroduced to Siberia, the park's supporters would only have to manage the park like they would a nature preserve to see results (Andersen, 2017). The theory holds that in the winter, megafauna would migrate, searching for grasses and trampling snow in their search, removing the top layer of permafrost insulation (Andersen, 2017). In the summer, the megafauna would continue to graze, destroying trees and forests as they continue their migrations (Andersen, 2017). From there, the natural processes, specifically the carbon cycle, kick into effect and make their impact on climate change (Andersen, 2017).

Harvard geneticist George Church and his team of scientists began modifying elephant DNA in 2014 using CRISPR, the genome-editing technology (Andersen, 2017). Scientists have comprehensively catalogued the hundreds of genetic variations that differentiate modern Asian elephants from the mammoths of the Pleistocene (Callaway, 2015). Natural selection enables serves to maintain and improve a population by adapting it to its environment, and in a relatively short time after megafauna is reintroduced, it will be adapted to its environment (Andersen, 2017). Three million years ago, elephants left Africa, and by the time they crossed the land bridge to the Americas they had grown coats of fur (Andersen, 2017). Realistically, scientists would only need to work to the point where proxy species exist (Donlan, et al., 2006).

2.2 The Carbon Cycle

Permafrost contains the largest store of organic carbon (C) in the terrestrial system (Koven, Riley, & Stern, 2013). The terrestrial permafrost area contains up to 1700 Pg (billion metric tons) of organic carbon (OC), more than twice the estimated carbon in the atmosphere's C pool (Spencer, et al., 2015). More than a quarter of this (>500 Pg C) is stored in Siberian-Arctic Pleistocene-age permafrost, called yedoma (Vonk, et al., 2013). Warming the permafrost would likely release the stored carbon, in the form of carbon dioxide (CO_2) and methane (CH_4) (Soussana, et al., 2004). If greenhouse-gas induced climate warming continues, the permafrost will melt and about 500 petagrams (Pg) of carbon, or 2.5 times that of all rainforests combined, will release into the atmosphere (Zimov S. A., 2005), more greenhouse gas than all the world's forests would if they burned to the ground (Church, 2013). When permafrost thaws, microbes consume the organic contents, emitting carbon dioxide (Andersen, 2017).

During the shift from the Pleistocene to the Holocene, about 11-18 thousand years ago, in northern Siberia alone, local permafrost thawing contributed up to 25 Tg (.025Pg) Carbon per year, added to similar amounts from American, European, west and south Siberian, and Chinese permafrost, as well as that of the southern hemisphere such as Patagonian permafrost (Zimov & Zimov, 2014). During the entire deglaciation of Siberia, permafrost is estimated to have emitted 400 Pg of methane (300 Pg of carbon) into the atmosphere (Zimov & Zimov, 2014). When compared to current global methane emissions of 500 to 600 Tg of methane per year, that number is immense (Dlugokenchy, Nisbet, Fisher, & Lowry, 2011). Current risk assessments estimate that up to 100 Pg of carbon could be released from its permafrost prison by 2100 due to rising temperatures (Schuur, et al., 2008). Based on estimates and experiments, a group of scientists estimated the potential release in Siberia to be 40 Pg C over four decades if Siberian soils thawed to 5°C (Schuur, et al., 2008). While carbon emissions continue, the global increase of CO_2 levels has been less than anticipated, indicating the existence of a carbon sink in continental ecosystems (Soussana, et al., 2004). Due to the cycling of carbon being stored and released, natural processes could mitigate the doom and gloom presented above (Soussana, et al., 2004). Grasslands are the sink, and Soussana, et al. suggest that storage rates are between 0.2 and 0.5 tons C per hectare per year (Soussana, et al., 2004).

In the grasslands of the mammoth-steppe, megafauna consume the carbon stored in grasses, returning it to the soil in the form of dung (Andersen, 2017). In the mammoth-steppe, megafauna are the primary focus due to the impact the large animals have on the ecosystem. The grasses absorb the nutrients, storing them in the ground below, eventually turning into yedoma as new soils cover them (Andersen, 2017). This process, repeating constantly over millions of years, is why such a large store of carbon exists in Siberia and other regions in the Arctic (Andersen, 2017). Snow cover significantly impacts the

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dynamics of Siberian carbon, acting as an insulator of soils in winter (Groffman, et al., 2001). Kreyling and Henry (2011) believe that overwinter processes can have significant effects on ecosystems that are seasonally covered in snow. Air and soil temperatures can vary due to snow cover, and reduced snow cover increases soil freezing in some regions (Kreyling & Henry, 2011). Reduction in snow cover exposes the soils to freezing temperatures, allowing permafrost to penetrate deeper and last longer during the warm summer months (Groffman, et al., 2001).

3. Methodology – System Dynamics

System Dynamics assists in modeling scenarios that that are difficult to recreate and can project the results of a system. System Dynamics using stocks, flows, and feedback loops to simulate the effects of a complex system, matching current reference modes to the model before projecting out hundreds, even thousands of years. In my model, I determine whether Nikolai Zimov's experiment for Pleistocene Park is viable and use it to later propose a policy to combat climate change.

3.1 Background on System Dynamics

We live in continuous, circular environment where the feedback of one cycle influences the effects of another (Forrester, 1991). One of the primary goals of system dynamics is understanding the nature of systems in which we live and impact and how they subsequently impact us (Forrester, 2009). Systems are interrelated, creating complex feedback loops, which is part of the reason policies fail so frequently (Forrester, 2009). System dynamics is applicable to any system characterized by interdependence, mutual interaction, information feedback, and circular causality (Strickan, n.d.). This is one of the primary reasons this paper uses a system dynamics model to evaluate the feasibility of Pleistocene Park. System dynamics begins with defining a dynamic problem, later modeling it to gain a better understanding of the underlying systems impacting certain variables (Strickan, n.d.). In this case, that is Arctic carbon emissions and the variables are related both directly and indirectly to the processes contributing to those emissions. System dynamics places an emphasis on endogenous behavior, like how an engineer designs an oil refinery (Forrester, 1991). "The engineer looks at the individual working characteristics of the chemical reactors, evaporators, and distillation towers; considers how they are interconnected and controlled; and evaluates the dynamic behavior implied by their feedback loops" (Forrester, 1991). Pleistocene has enough different components that affect each other in different enough ways that using coupled differential equations is the best way to study the effects of the park and the possible policies.

3.2 Causal Loop Diagram

To create the causal loop diagram that the model is based off, I examined my research on all the natural processes at play in Pleistocene Park. I began with the carbon cycle loop and expanded out to include the effects of Arctic snow on the process. Then, I included the effects of megafauna migrations, examining how the population is affected by changing temperatures. The megafauna population followed, which is based off other population models, which affects the ecosystem balance specific to the Arctic. That completed the general cycle that Zimov's experiment hopes to influence, with favorable outcomes.

The *Carbon Cycle* is the base loop for the Pleistocene Park model. When soil microbes thaw in the permafrost they become *Active Microbes* and eat whatever organic material they can find in the yedoma, the Arctic permafrost. The microbes release stored carbon when they consume the organic material, which is released into the atmosphere, adding to the atmospheric carbon stock. With more *Permafrost Thaw*, there is more carbon emission, and with less *Permafrost Thaw*, there are less carbon emissions. The higher the concentration of *Atmospheric Carbon*, the more the average *Global Temperatures* increase, which thaws more permafrost in the warm summer months. In the arctic, *Permafrost Thaw* is the catalyst for microbe activity. Arctic snow provides *Snow Insulation* for the soil, keeping the soil warm. Introduction of a *Megafauna Population* into the Arctic adds on to the two natural loops of *Arctic Carbon* and the *Carbon Cycle*, altering the effects. This affects the carbon cycle, lessening the effect of *Arctic Carbon Emissions*.

Rising *Global Temperatures* reduce *Megafauna Resource Adequacy*, which increases the *Fractional Megafauna Death Rate*, reducing the *Megafauna Population* in the long run. However, should the average *Global Temperatures* stay relatively close to its current level, the *Megafauna Population* in Pleistocene Park will have a chance to grow and affect the carbon cycle and arctic carbon stores, possibly slowing climate warming and maybe even reversing it. The greater the population of megafauna, the greater the *Megafauna Migrations*, increasing the amount of snow trampled, affecting the *Arctic Carbon* loop. Since the theory of Pleistocene Park rests on the reintroduction of mammoths to have the greatest effect, I use the birth and death rates of the mammoth's closest living relative, the Asian Elephant.

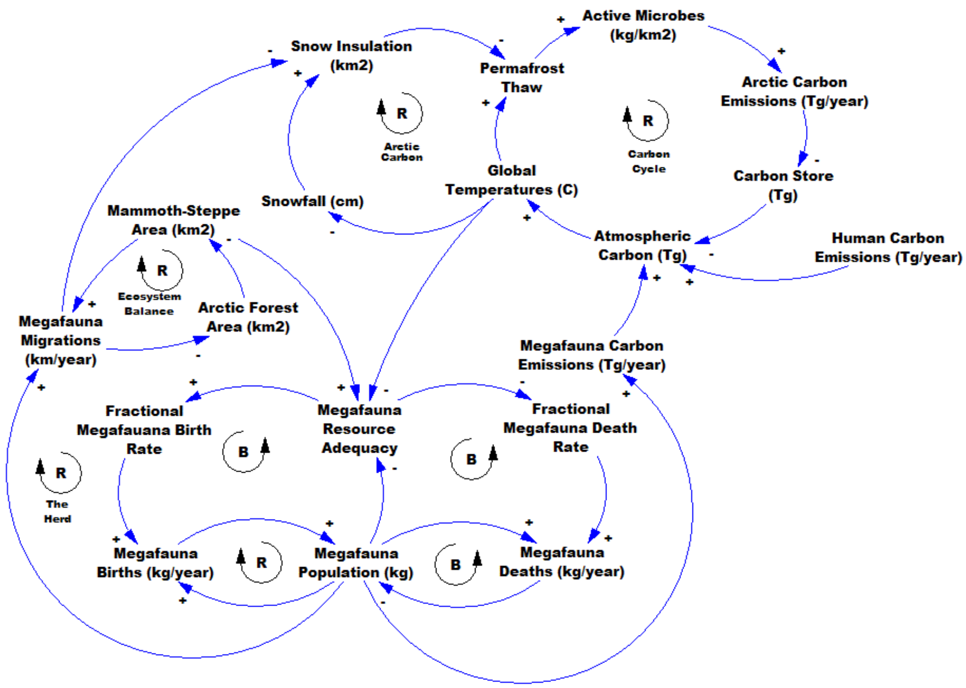

Figure 1. Pleistocene Park Causal Loop Diagram

The *Megafauna Population* increases and decreases according to *Megafauna Births* and *Megafauna Deaths*, or the birth and death rate. As the *Mammoth Population* increases, the *Megafauna Resource Adequacy* decreases, which decreases the *Fractional Megafauna Birth Rate* and increases the *Fractional Megafauna Death Rate*. These impact *Megafauna Births* and *Megafauna Deaths*, completing the birth and death cycles. It is difficult to determine where the megafauna population would stabilize but based on my research it will take several hundred years, if not thousands.

The megafauna population contributes to atmospheric carbon levels, emitting carbon through their bodies natural processing of carbon by eating, noted as *Megafauna Carbon Emissions*. While the megafauna contributes a significant level of carbon to the atmosphere, the population has an overall favorable effect on carbon emissions by influencing the *Arctic Carbon* cycle. Forests are the natural enemy of the mammoth's habitat, the mammoth-steppe which is noted at *Mammoth-Steppe Area*. As the *Megafauna Population* migrates, they rub against trees and knock down saplings, reducing forests to flat grasslands. Overall, the effect is a reinforcing loop favoring the *Mammoth-Steppe Area* and *Megafauna Population*. As the mammoth-steppe area increases, so does *Megafauna Resource Adequacy*, bolstering the *Megafauna Population*, increasing migrations and affecting the rest of the cycles at play in Pleistocene Park.

3.3 Stock and Flow Modeling

Modeling the problem as a stock and flow diagram began with the carbon cycle since it is the foundation for the model and the system which Zimov hopes to impact. The *Atmospheric Carbon* stock is the focus of the model, and the stock constantly shifts according to emissions and consumption by natural processes. The stock has an inflow of *Actual Carbon Emissions* and an outflow of *Natural Carbon Cycle*. The *Natural Carbon Cycle* is impacted by the *Normal Fractional Absorption*, which means that every year, a fractional amount of carbon is absorbed through natural processes. The *Natural Carbon Cycle* impacts the rate of *Arctic Absorption*, which is different than that of the *Natural Carbon Cycle*. The carbon that is absorbed is stored in the *Arctic Carbon Stock*, which is released as an outflow due to *Arctic Carbon Emissions*. The *Arctic Carbon* also impacts the *Arctic Carbon Consumption* by *Active Microbes*, at a ratio of *Microbe Carbon Consumption*.

Since most climate change models focus on the amount of *Atmospheric Carbon*, this is the central stock we care about, and *Arctic Carbon* is the largest stock of carbon present on the planet, which directly impacts how much carbon is in the atmosphere. The *Natural Carbon Cycle* removes carbon from the stock of *Atmospheric Carbon*, at a rate dictated by the *Normal Fractional Absorption*, determined through historical trends. The *Natural Carbon Cycle* also occurs in the Arctic, contributing to the *Arctic Absorption*, which increases the stock of *Arctic Carbon*. Thawed *Active Microbes* increase the *Arctic Carbon Consumption*, which increases the *Arctic Carbon Emissions*. The *Arctic Carbon Emissions* add on to the *Actual Carbon*

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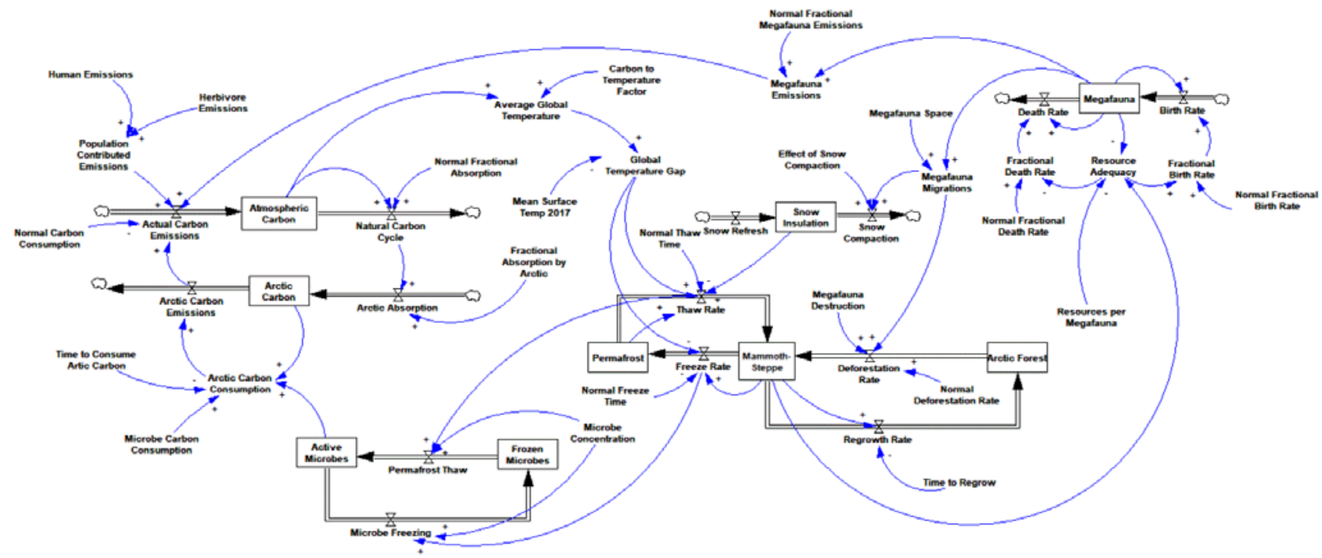

Figure 2. Pleistocene Park Stock and Flow Diagram.

Emissions, also impacted by *Normal Carbon Consumption* and *Population Contributed Emissions*. The *Megafauna Emissions* also contribute to the *Actual Carbon Emissions* since the *Megafauna* population consumes organic carbon as well, denoted by the *Normal Fractional Megafauna Emissions*. This is one of the concerns about the reintroduction of *Megafauna*, the park's hope is that the positive effects outweigh the carbon introduced by the *Megafauna*. *Active Microbes* are the catalyst for *Arctic Carbon Emissions*, since they consume the organic carbon stored in the *Permafrost.* The carbon to microbe ratio is designated by the *Microbe Carbon Consumption* and the *Time to Consume Arctic Carbon*, which then increases *Arctic Carbon Emissions* overall. In the winter, *Active Microbes* freeze according to the *Microbe Freezing* rate, which increases the stock of *Frozen Microbes*. The *Permafrost Thaw* rate is directly impacted by the *Thaw Rate* of the *Permafrost Stock*, and the *Microbe Freezing* rate is directly impacted by the *Freeze Rate* of the *Mammoth-Steppe* stock. *Permafrost* is the icy prison of the *Frozen Microbes*, keeping them dormant, which reduces the amount of *Arctic Carbon Emissions* annually. As the *Permafrost* thaws and transitions back to *Mammoth-Steppe*, the *Permafrost* releases *Active Microbes*. The *Thaw Rate* is impacted by *Snow Insulation* and *Average Global Temperature*, which is the result of *Atmospheric Carbon* and *Carbon to Temperature Factor*. As the *Mammoth-Steppe* freezes it turns into *Permafrost*, according to its *Freeze Rate* which directly impacts the rate of *Microbe Freezing*. The *Mammoth-Steppe* is dynamic, shifting according to the growth and destruction of the *Arctic Forest*, and the *Deforestation Rate* caused by *Megafauna Migrations*.

Megafauna is the tool used to decrease snow insulation and boost the storing capability of the carbon cycle. The population of megafauna, denoted by the stock, *Megafauna*. The *Megafauna* population fluctuates due to its *Death Rate* and *Birth Rate*, impacted by the *Fractional Death Rate* and *Fractional Birth Rate* of other species of megafauna, relative to their size. As the *Megafauna* increase, the region's *Resource Adequacy* decreases, which is a result of the *Megafauna* consuming a ratio of resources that comes from *Resources per Megafauna*. The *Resource Adequacy* impacts the *Fractional Death Rate* and *Fractional Birth Rate*. These variables impact the *Death Rate* and *Birth Rate*, proportional to the population, and come from the *Resource Adequacy* and the *Normal Fractional Death Rate* and *Normal Fractional Birth Rate*, respectively. When the *Megafauna* population increases, the *Migration Area* increases as well since the population seeks to expand its grazing area. This goes on to decrease the *Snow Insulation*, which increases the *Thaw Rate* of *Permafrost*.

3.4 Assumptions

To effectively model Pleistocene Park's effect on climate change, I had to make simplifying assumptions. The first assumption was that atmospheric carbon is only affected by actual carbon emissions and is removed through the natural carbon cycle. This allowed me to show the emissions I am focusing on in the model, without impacting the overall results with systems that I presume have negligible effect. Furthermore, I am assuming the only emissions are the ones applicable to the issue, such as megafauna emissions, population-contributed emissions, and arctic carbon emissions. For the time steps, I assumed the effects are evaluated every year, when they are in fact continuous and cyclical. However, most of the data on the issue is put in terms of years, so that is the best way to model this for the sake of a functional model. I am assuming that temperature increases linearly according to the atmospheric carbon concentration. Additionally, human emissions currently rise every year, but since I am not modeling the human population, I am simplifying the model by setting *Human Emissions* as a constant. I based the megafauna numbers off their size and other characteristics, using the Asian Elephant since it is the closest living relative to the Wooly Mammoth. The Yakutian region experiences a significant amount of snowfall in the winter, but without modeling snowfall with its many variables it is difficult to incorporate snowfall into the model. For this reason, we use the simplifying assumption that *Snow Insulation* is equal to the area of the *Mammoth-Steppe* every year, and the *Megafauna Migrations* decrease the amount of insulation.

4. Model Findings and Analysis

4.1 Calibration and Initial Analysis

The initial model ran with an exponential increase that created a system error. To fix this, I added the stock *Snow Compaction* and its flows of *Snow Refresh* and *Snow Compaction*. This fixed the issue with the exponential increase and led to the initial output, *Baseline*. *Baseline* trends upwards as one would expect with atmospheric carbon levels, due to the rise in emissions and the reinforcing nature of the carbon cycle. I started at the initial time of year 1830, approximately 200 years before mammoths are introduced in year 2030. Global temperatures increase in the same manner, matching the reference mode of global temperature trends. I made modifications to the model modifications to get to the *Baseline*, specifically the *Resource Adequacy*, to get the model to function properly. The *Thaw Rate* and *Freeze Rate* continued to increase as expected, with the *Thaw Rate* outpacing the *Freeze Rate*, eventually leading to the decline of *Permafrost*. Once the mode functioned with the *Baseline*, I moved on to the policy analysis.

4.2 Policy Analysis

The policy the model seeks to test is the reintroduction of megafauna to Pleistocene Park. As stated above, the hope of Nikolai Zimov is to affect atmospheric Carbon levels by reintroducing megafauna, thus decreasing the thaw rate of Siberian permafrost, reducing overall carbon emissions and reducing the *Atmospheric Carbon* stock. The policy is dependent on the reintroduction of the wooly mammoth through gene editing, and while it would not be available for the next ten or so years, if the model shows that Zimov's theory is correct then his theory might work. Reducing human emissions is not enough, and even if we cut them out, atmospheric carbon levels and climate warming would still occur (Andersen, 2017). Another factor the model does not consider is the atmosphere's carrying capacity of carbon, which is currently unidentified. Reaching the carrying capacity would create an overshoot and collapse situation, where the global climate reacts in a way to reach a natural equilibrium. The model also does not quantify, in economic terms, the cost of Pleistocene Park, or the benefits.

Running the policy model consisted of removing the nullification factor on resource adequacy, allowing the population of *Megafauna* to increase, which then impacted the rest of the model, specifically the *Atmospheric Carbon* stock through the carbon cycle. The *Atmospheric Carbon* output shown above diverges from the baseline just after the year 2030, when the megafauna are introduced into the model. As hypothesized, the *Actual Carbon Emissions* rate slows down until it begins its decline around year 2200. At that point, the concentration of *Atmospheric Carbon* decreases, signifying that Zimov's theory is correct, and the policy of Pleistocene Park is viable. The policy is already implemented in Siberia, where Zimov's Pleistocene Park began. There are still significant carbon stores in Alaska and Canada, where implementing the policy would contribute to the effects of Pleistocene Park in Siberia. As specified above, there might be mammoths roaming the mammoth-steppe in the next ten years, adding to the amount of megafauna currently present, affecting the carbon cycle in a more dramatic fashion.

In the model, it takes until 2231 for the baseline results and the policy results to differ by more than one petagram. The model does not account for the natural planetary warming and cooling cycles, which would shift the amount of *Atmospheric Carbon* slightly, which could either increase or dampen the effects of Pleistocene Park depending on how the earth's warming and cooling cycles shift. The *Average Global Temperature* follows the atmospheric carbon curve closely, since atmospheric carbon directly affects the warming potential of the atmosphere. The *Permafrost* level is the opposite of both *Atmospheric Carbon* levels and *Average Global Temperature*, since high temperatures contribute to the *Thaw Rate* of *Permafrost*. That means that the *Average Global Temperature* and *Permafrost* affect each other, which is why there is such a drastic decrease in both *Atmospheric Carbon* and *Average Global Temperature*. This is the effect of the reinforcing cycle the perpetuates the entire model, so when the *Megafauna* help remove *Snow Insulation*, a lower *Thaw Rate* means more *Permafrost*, which leads to less *Permafrost Thaw* and subsequently less *Atmospheric Carbon*, which means lower *Average Global Temperature*, which decreases the *Thaw Rate* even more, compounding the effects of the *Megafauna*.

The model's variables behaved as expected, specifically the *Megafauna*, as well as the associated *Birth Rate* and *Death Rate*. The *Birth Rate*, specifically, behaved as an overshoot reference mode, and stabilized around the year 2100. Since most

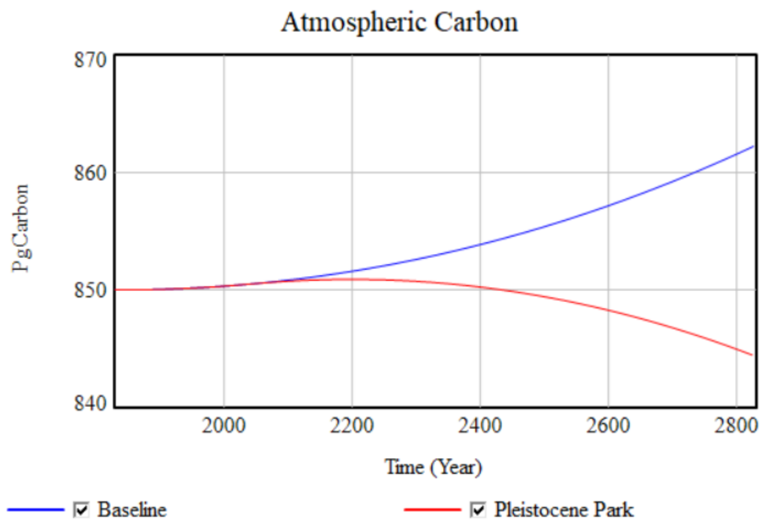

Figure 3. Outputs for Pleistocene Park Stock and Flow Model.

Megafauna species planned for Pleistocene Park have been absent for the last century, or more, it is difficult to determine what the exact carrying capacity is. While the *Megafauna* population reaches an equilibrium, it is important to note that *Atmospheric Carbon* continues to decrease after the population reaches its equilibrium. As specified above, this is the result of the reinforcing cycle that is the Carbon Cycle. The model would behave in a similar, opposite way, even if *Population Contributed Emissions* remained at the present level. The *Population Contributed Emissions* significantly impact the *Atmospheric Carbon*, since they are one of the greatest constant contributors. When *Population Contributed Emissions* are decreased, it decreases the amount of *Atmospheric Carbon*, indicating that *Human Emissions* do impact the overall *Atmospheric Carbon* level, but not to the same effect as the introduction of *Megafauna*. However, this indicates that an effort to reduce *Human Emissions* would not be fruitless.

5. Conclusion

Pleistocene Park is an imperfect idea, but it might be able to slow the release of carbon to the atmosphere from vast stores locked in Siberian permafrost. Sergei Zimov submitted a paper to the journal, Science, in 1999, about the store of carbon in the Arctic and was rejected (Andersen, 2017). The paper was rejected, and in 2006 the journal contacted him asking him to resubmit his work (Andersen, 2017). Thanks to his effort and the efforts of others it is no longer a secret that the Arctic permafrost holds more carbon than all the planet's forests and the rest of the atmosphere combined (Andersen, 2017). Currently, the park is 50 acres, and expanding. Within a relatively short time, the park might be large enough to have a significant impact on carbon emissions, altering the Siberian ecosystem and slowing climate change. My model indicates that Pleistocene Park is viable and could be implemented in North America as well to combat rising global temperatures due to carbon emissions. While models are only representations of reality, this policy has a chance to affect the process that ultimately contributes the most to climate warming and carbon emissions, the carbon cycle. If mammoths once again roam in the next decade or so, I expect that the level of change predicted by my model is likely, but the only way to be sure is implementing the policy as specified by Zimov.

6. References

Andersen, R. (2017, April). Welcome to Pleistocene Park. The Atlantic.
Callaway, E. (2015). PALAEOGENETICS Mammoth genomes hold recipe for Arctic elephants. *521*(7550). Nature.
Church, G. (2013, September 1). Please reanimate. Scientific American.
Dlugokenchy, E. J., Nisbet, E. G., Fisher, R., & Lowry, D. (2011, May 28). Global atmospheric methane: budget, changes and dangers. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences.

Donlan, C. J., Berger, J., Bock, C. E., Bock, J. H., Burney, D. A., Estes, J. A., . . . Greene, H. W. (2006, November). Pleistocene Rewilding: An Optimistic Agenda for Twenty-First Century Conservation. *The American Naturalist. 168*(5).

Donlan, J. (2005, August 17). Re-wilding North America. *Nature.* (7053).

Forrester, J. W. (1991, April 29). System Dynamics and the Lessons of 35 Years. (B. K. De Greene, Ed.)

Forrester, J. W. (2009, July 29). Learning through System Dynamics as Preparation for the 21st Century.

Groffman, P. M., Driscoll, C. T., Fahey, T. J., Hardy, J. P., Fitzhugh, R. D., & Tierney, G. L. (2001, November). Colder Soils in a Warmer World: A Snow Manipulation Study in a Norther Hardwood Forest Ecosystem. *Springer. 56*(2).

Koven, C. D., Riley, W. J., & Stern, A. (2013, March 22). Analysis of Permafrost Thermal Dynamics and Response to Climate Change in the CMIP5 Earth System Models. Berkely, CA, USA: Lawrence Berkeley National Laboratory.

Kreyling, J., & Henry, H. A. (2011, May 19). Vanishing winters in Germany: soil frost dynamics and snow cover trends, and ecological implications. *Climatte Research, 46*(3).

Schuur, E. A., Bockheim, J., Canadell, J. G., Euskirchen, E., Field, C. B., Goryachkin, S. V., . . . Zimov, S. A. (2008, September). Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle. *AIBS Bulletin. 58*(8).

Soussana, J. F., Loiseau, P., Vuichard, N., Ceschia, E., Balesdent, J., Chevallier, T., & Arrouays, D. (2004). Carbon cycling and sequestration opportunities in temperate grasslands. *Soil use and management. 20*(2).

Spencer, R. G., Mann, P. J., Dittmar, T., Eglinton, T. I., McIntyre, C., Holmes, R. M., . . . Stubbins, A. (2015, April 28). Detecting the signature of permafrost thaw in Arctic rivers. *Geophysical Research Letters. 42*(8).

Strickan, C. (n.d.). *What is SD*. Retrieved from System Dynamics: https://www.systemdynamics.org/what-is-sd

Vonk, J. E., Mann, P. J., Davydov, S., Davydova, A., Spencer, R. G., Schade, J., . . . Holmes, R. M. (2013, June 14). High biolability of ancient permafrost carbon upon thaw. *Geophysical Research Letters. 40*(11).

Zimmer, C. (2013, April). Bringing them back to life. *National Geographic. 223*(4).

Zimov, S. A. (2005, May 6). Pleistocene Park: Return of the Mammoth's Ecosystem. *Science. 308*(5723).

Zimov, S., & Zimov, N. (2014, April 2). Role of Megafauna and Frozen Soil in the Atmospheric CH4 Dynamics. *PLoS ONE. 9*(4).