ECOLOGICAL CALENDARS OF WARREN COUNTY AND THEIR MATHEMATICAL IMPLICATIONS

A sketch for an Undergraduate Honors Thesis

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by

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ABSTRACT

This thesis investigates the relationship between time and seasonal indicators in Warren County by developing an Ecological Calendar and analyzing its mathematical implications. By integrating mathematical inquiry with the ecological knowledge of hunters, fishers, gardeners, farmers, recreationalists, and local residents, this study aims to capture the nuances of local climate dynamics over time. The research highlights how traditional and experiential knowledge, when combined with quantitative analysis, can provide insights into patterns of environmental change. Furthermore, this work explores the role of ecological calendars as tools for fostering Warren County community resilience and adaptive strategies in the face of climate change, demonstrating the interplay between cultural practices and scientific methodologies.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The effects of climate change are becoming increasingly evident across the globe, and localities are facing growing challenges in adapting to shifting weather patterns and environmental conditions. Warren County, like many regions, must contend with the implications of these changes, which may include altered precipitation patterns, rising temperatures, and shifting seasonal indicators. As the local environment continues to change, it is crucial to anticipate how these variations will impact the community, agriculture, and natural ecosystems.

The questions that arise are: How do we anticipate local climate change in Warren County, particularly with respect to its unique ecological characteristics? And moreover, in order to better prepare for these changes, how can we build a robust mechanism that structures anticipatory climate change in Warren County, taking into account the passage of time and the evolving nature of climate data using mathematics? This mechanism should allow stakeholders to not only understand the risks associated with future climate scenarios but also to act in ways that promote long-term resilience and sustainability for the Warren County community.

1.2 Objectives of The Paper

The primary objective of this paper is to provide a relevant understanding of the local seasonal indication dynamics of Warren County. By analyzing these indicators, the paper

seeks to build a framework that integrates both the dynamic nature of these indicators and the long-term implications for the community, agriculture, and natural ecosystems.

A key objective is to establish a mechanism for anticipatory climate change that incorporates the evolving nature of climate data. This mechanism will utilize mathematical modeling to track shifts in seasonal indicators, providing stakeholders with the tools to anticipate and adapt to future climate scenarios. Ultimately, the goal is to enhance the resilience of Warren County by fostering a better understanding of how climate variations unfold over time and how they can be addressed through informed, proactive decision-making.

1.3 Mapping The Layout of The Paper

This paper is organized into several chapters, each addressing a different aspect of the research and analysis concerning the anticipatory mechanism for climate change in Warren County. The introduction presents the problem statement and outlines the objectives, emphasizing the need for a framework to understand and adapt to local climate changes. The subsequent chapter focuses on the research methodology and literature review, providing a detailed explanation of the process employed to undertake this study, as well as key insights derived from existing research.

The findings and analysis chapter is where the results of the study are presented, including visual representations of the ecological calendar and seasonal indicators in Warren County. This chapter also delves into how these findings align with the human ecological lens, offering a deeper understanding of the interconnectedness between human and environmental systems.

Following the findings, the discussion and conclusion section highlights any short-

comings in the research and suggests further areas of investigation. The concluding remarks tie together the main points of the study and reflect on the implications for Warren County's future climate resilience. Finally, an appendix provides additional resources, including the first chapter of the supporting material, and a bibliography lists all sources cited throughout the paper.

Each section of the paper contributes to the overall goal of understanding the dynamic nature of climate change indicators and establishing a mechanism for anticipatory climate change that can guide decision-making in Warren County.

CHAPTER 2

RESEARCH METHODOLOGY & LITERATURE REVIEW

2.1 Process For Undertaking This Research

The research methodology for this study is structured as a stepwise, interconnected process designed to build an Ecological Calendar not specific to Warren County. The workflow begins with creating a consent form, ensuring ethical engagement with participants. This is followed by practice interviews, which refine the actual interview process and approach to asking guiding questions to the participant. Once interviews are conducted, they are transcribed and are reviewed. The sections labeled in blue are implications from the data supported by the seasonal rounds and analysis labeled in orange in Figure 2.1.

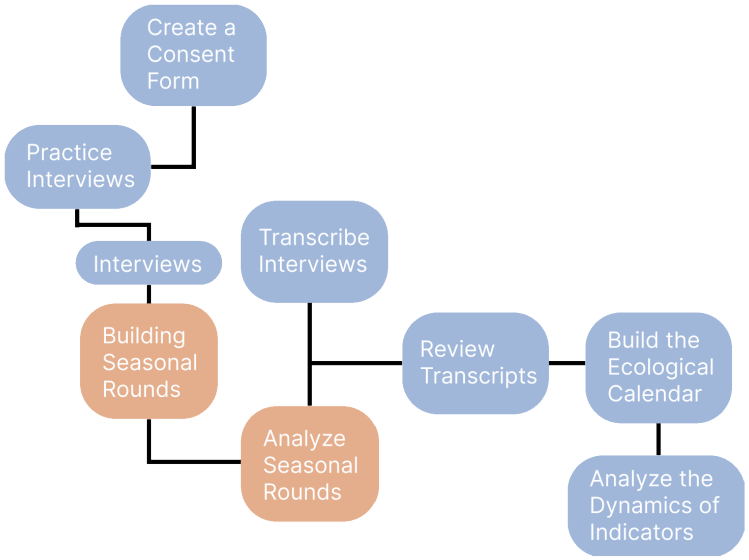

Figure 2.1: Research Architecture

The next phase involves building seasonal rounds, which professor Kassam defines as, ”verbal articulations and visual representations of a community’s sociocultural re-

lations with their habitat. They express knowledge from engagement with spatial and temporal aspects of ecological cycles through the seasons" (Kassam 2022: 16). Through this definition of seasonal round the spatial dimension of Warren County encapsulates the communities use of land, such as moving ice-fishing in the winter, hunting in the fall, or gardening in the summer and spring. The temporal dimension is expressed through seasonal indicators that guide the timing of these activities such as weather patterns, the appearance of certain animals, or the growing of a particular flower.

Using insights from the seasonal rounds and reviewed transcriptions, after they have informed one another in an inductive and deductive analysis, an Ecological Calendar is developed. An ecological calendar is a context-specific, cyclic timeline of phenological knowledge that integrates the social and physical environment. These calendars serve as tools for measuring seasonal changes and other periodic occurrences, providing a framework to align human activities with natural rhythms.

From a mathematical lens, the ecological calendar provides a strong foundation for a structured representation of temporal and spatial data. The cyclic nature of the calendar aligns with concepts in mathematics such as periodic functions and oscillatory dynamics. Seasonal indicators, such as plant blooming cycles or migratory behaviors, can be analyzed using techniques like Fourier analysis to identify repeating patterns or nonlinear dynamics to model complex ecological interactions. Moreover, the spatial dimensions of the calendar, such as movement across landscapes, invite applications of graph theory and optimization to explore efficient pathways and resource allocation. I will discuss more on these topics in my honors thesis.

By incorporating these mathematical approaches, the ecological calendar not only captures phenological knowledge but also enables predictions of future trends, aiding in anticipatory climate adaptation. This interdisciplinary integration of traditional ecological knowledge and mathematical tools opens new pathways for understanding the dynamics

of human-environment interactions.

This methodology integrates qualitative insights with ecological observations, fostering a participatory and context-sensitive approach to climate adaptation planning.

2.2 Key Issues That Arise From The Literature/Research

As cultural practices and ecological systems face disruption from climate change, there is a risk that valuable knowledge about seasonal indicators may be lost. Professor Kassam adds that knowledge is context-dependent, in 'knowing how' sustains a livelihood from the land and sea for the management of the household and community—it is a product of the interplay of the cultural, social, ecological, and physical context (Kassam 2009: 196). The erosion of this knowledge reduces the ability of communities to adapt to ecological shifts. When communities lose their understanding of seasonal cycles, they may also lose the ability to engage in sustainable stewardship practices, leading to environmental degradation over time.

The indicators identified are not static; climate variability can lead to misalignment between traditional seasonal activities and emerging ecological realities. For example, earlier snowmelts or delayed migrations challenge the reliability of specific indicators. In the case of Warren County, the loss of phenological knowledge has particularly significant implications for the community's ability to maintain its traditional practices and adapt to shifting ecological patterns. Warren County, located in upstate New York, is a region where people have historically relied on their environment to guide their fishing, hunting, gardening, and other seasonal activities (The First National People of Color Environmental Leadership Summit, Atwater 2023). The seasonal indicators that have long shaped these activities, such as the first appearance of migratory birds, the blooming of

certain plants, or the onset of specific weather patterns, are integral to how people interact with the land and understand time.

Building ecological calendars requires active community participation. However, in some communities, there may be barriers to engagement, such as lack of trust, limited accessibility, or competing priorities. In the Warren County PCB protests, Rachel Seidman, curator at Anacostia Community Museum for Women's Environmental History states, "The [environmental justice] movement has had a profound impact on the way that environmentalists, policymakers, activists and the general public" (Seidman 2023; Atwater 2023). This highlights the need for ongoing collaboration and participatory research approaches to ensure the ecological calendar remains relevant and widely accepted. As she notes, the movement has shifted the way environmentalists, policymakers, activists, and the general public understand and approach environmental issues, emphasizing the need for inclusive, community-driven solutions. In the context of Warren County, it's crucial to involve local residents in every step of the ecological calendar's creation, ensuring that their knowledge and experiences are incorporated into the final product.

CHAPTER 3

FINDINGS AND ANALYSIS

3.1 Findings

There is a plethora of seasonal indicators identified by the 21 participants in this research. I split these indicators into five main categories: Plants, Animals, Insects, Activities, Weather, Patterns, and Environmental Changes (Table 3.1).

Plants

Participants identified a variety of plants as indicators of seasonal change, ranging from common crops (e.g., Garlic, Eggplant, Melons) to wild flora (e.g., Witch Hazel, Asters, Crabapples). These plants signal not only agricultural activities like planting and harvesting but also natural cycles such as the first blooms (Snowdrop, Crocus) or foliage changes.

Animals

Animals emerged as significant indicators, especially migratory and behavioral patterns of species such as Coyotes, Geese, Woodcock, and Rainbow Trout. For instance, participants noted the Black Bears' hibernation cycles, mating periods, and birthing seasons as critical temporal markers. Similarly, bird migrations (e.g., Eastern Blue Bird, Robins) were commonly mentioned as aligning with specific weather or environmental changes.

Insects

Insects such as Moths, Fireflies, and Hoverflies serve as sensitive indicators of seasonal transitions. Their presence or activity was often associated with warming temperatures or particular seasonal events like summer evenings (Fireflies) or pollination periods.

Activities

Human activities, such as Maple Tapping, Skiing, Kayaking, or Rifle Hunting, directly reflect ecological rhythms and seasonal availability. These activities not only mark time but also emphasize the interdependence between human culture and natural systems. For example, Maple Tapping signals the onset of spring, while Ice Fishing is deeply tied to winter conditions.

Weather

Seasonal weather phenomena like Rain, Thunderstorms, Snowfall, and High Humidity emerged as crucial markers. Participants particularly highlighted recurring patterns, such as Heavy Snowfall leading to Frozen Ponds or Thunderstorms coinciding with Thermocline Changes.

Patterns

Participants observed dynamic environmental patterns, including celestial indicators (Ursa Major), wildlife movements (Flocking Birds, Animal Tracks in Snow), and ecosystem changes (Wind Pattern Increases, Slushy Snow). These patterns reflect the intricate feedback mechanisms between biological and climatic systems.

Environmental Changes

Key environmental changes included Freeze Overs, Ground Freezing, Lakes Freezing, and Ice Out on Lakes. These transitions, noted for their visual and physical impact on the environment, serve as temporal markers for human activity, wildlife behavior, and ecosystem responses.

Each category represents a distinct yet interconnected aspect of the ecological calendar, showcasing the intricate relationships between environmental cues and human experiences. For example, plants such as eggplant, garlic, and buckwheat signify seasonal changes, while animals like coyotes, black bears, and geese offer additional markers tied to wildlife behavior. Complementing these indicators are patterns in nature, such as bird

migrations, black bear mating cycles, and wildflower blooms, which reflect the deep interconnectedness of living systems. Together, these indicators serve as critical signposts within the ecological calendar, linking natural observations to human cultural practices and reinforcing the dynamic relationship between people and their environment.

Plants	Animals	Insects	Activities	Weather	Patterns	Environm- ental Changes
Eggplant	Coyotes	Moths	Tourist Activities	Hot & Sunny	Ursa Majora and Cassiopeia	Trophic Cascade
Garlic	Black Bears	Fireflies	Fireman Fields Day	Rain	Cherrie Drops on Roads	Wind Pattern Increase
Buckwheat	White Tail	Butterflies	Kayaking	Thunder- storms	Thermocline Goes Deeper	Freeze Over
Raddish	Phoebe	Hoverflies	Ice Skating	High Humidity	Tourists Come Back	Skim of Ice on Ponds
Japanese Knotweed	Eastern Blue Bird	Black Fly	Skiing	Snow	Birds Flock Together	Ground Begins to Freeze
Cucumbers	Geese	Crickets	Tapping	Cloudy	Larger Diversity of Birds Together	Ground Freezes
Cherries	Coyotes		Thurman Maple Days	Heavy Snow Fall	Last Snow Fall	Ponds Freeze
Catalpas	Woodcock		Ice Fishing	Warm	Pyke Season	Lakes Freeze
Evening Primrose	Peepers		Mulching	Lots of Rain	Less Animals	Last Snow
Siberian Iris	Robins		Prepare Garden Beds	Thunder Storms	Days Become Shorter	Ice Out on Lakes
Climbing Hydrangea	Salmon		Tourist Activities	Cooler Weather	Cold Snap	
Shrubby Cinquefoil	Rainbow Trout		Gardening		Animal Tracks in Snow	First Frost
Asters	Brooke Trout		Planting Season		Black Bears Give Birth	Foliage
Asiatic Lily	Pyke		Putting Permethrin		Tourists Come Back	
Azaleas			Maple Tapping		Last Frost	
Lavender			Bow Hunting		Trees Start to Bud	
Mustard Greens			Muzzle Loader		Slushy Snow	
Dandelions			Rifle Hunting		Fawn Spawning	
Daffodils			Deer Season		Maple Blossoms	
Oriental Bittersweet			October Festival		Birds Migrating Back	
Cucurbit Leaves			Kayaking		Black Bears Mate	
Melons					Wind Speed Increase	
Crocus					Rodents Hide Food	
Hellebore					Grass Growth Slows	
Snowdrop					First Snow Fall	
Azaleas					Leaves Start to Fall	
Lilies					Foliage	
Squill					Wild Flower Blooms	
Crabapples					Brooke Trout Spawning Phase	
Dogwood						
Ferns						
Witch Hazel						
Hamamelis						
Garlic						
Winter Squash						
Lettuce						
Beets						
Raddish						
Pumpkins						
Squash						
Asters						
Crocus						
Ragweed						

Table 3.1: A table of indicators grouped by category.

The seasonal indicators and icon-based figures (Table 3.1 and Figure 3.2) form the

foundation for constructing the ecological calendar. By identifying patterns in plants, animals, insects, weather, and other environmental changes, we can mark the passage of time based on natural cues rather than abstract, linear systems like the Gregorian calendar. For instance, observations such as the appearance of fireflies, black bear migrations, or ground freezes become temporal markers, each tied to specific periods or transitions within the year (Figure 3.1). This roots time in the observable and recurring processes of nature.

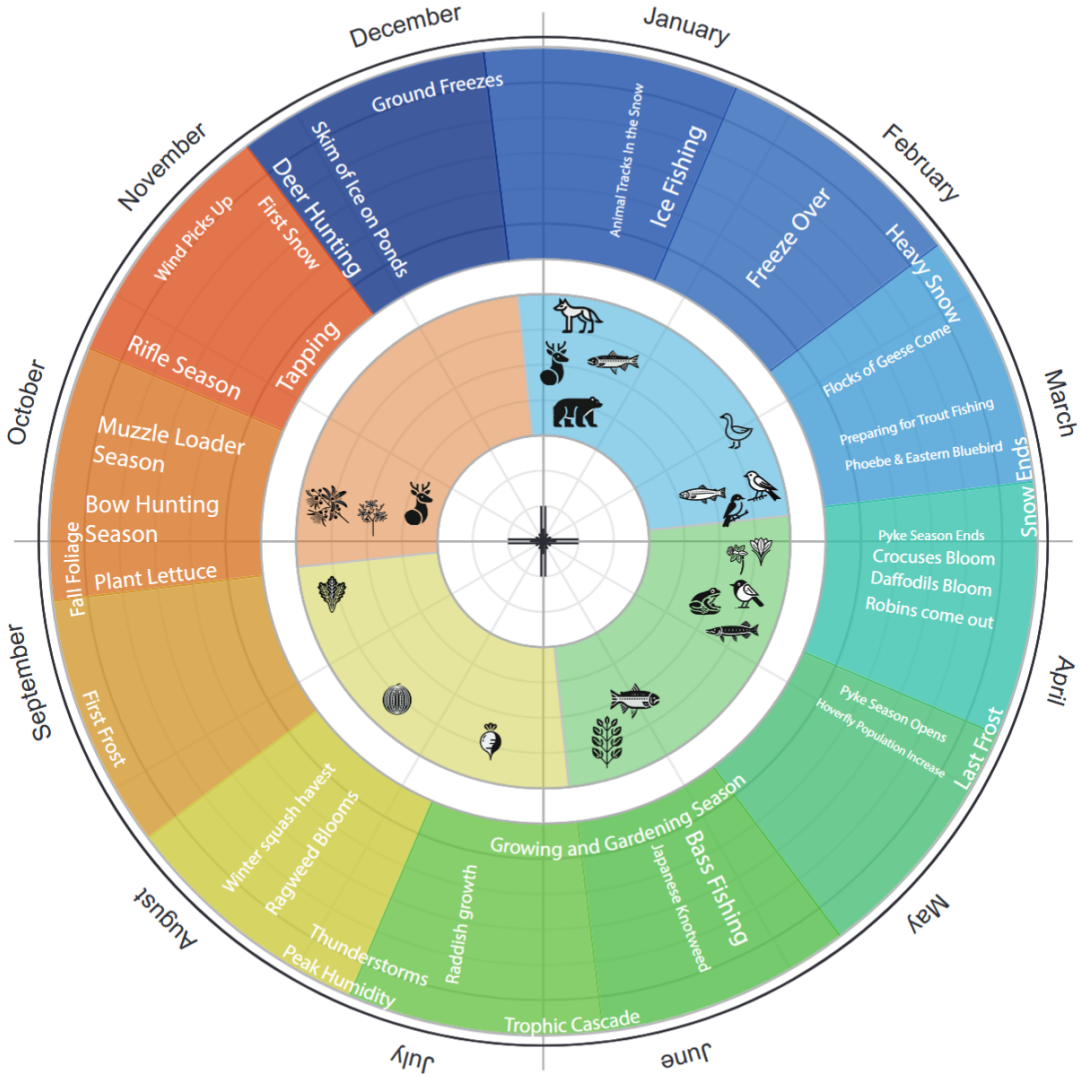

Figure 3.1: Ecological Calendar of Warren County

The ecological calendar is specifically designed to facilitate mathematical analysis. It is constructed on a polar plane, with crosshairs at the center indicating both the plane and its directional axes. The smaller, inner calendar incorporates seasonal indicator icons, representing specific points on the polar plane. This representation is particularly useful because, by treating the indicators as points, we can trace their trajectories over time and analyze how their dynamics shift within the system.

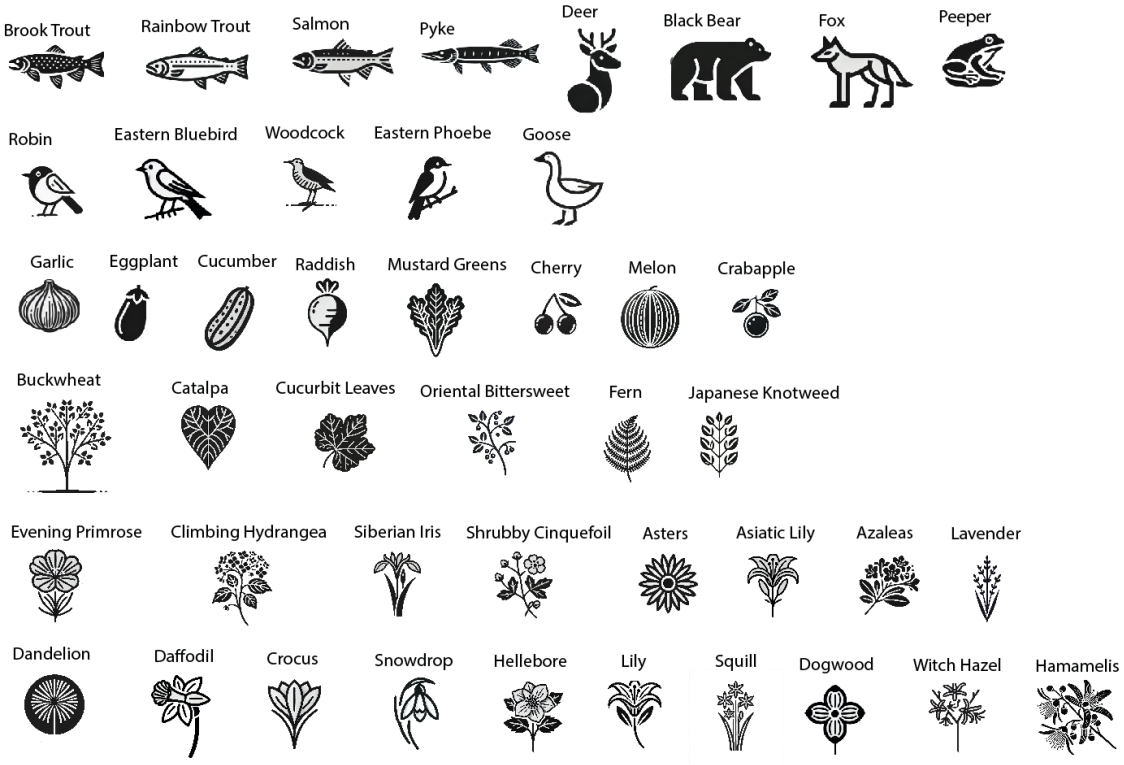

Figure 3.2: Seasonal Indicators

3.2 What These Findings Reveal About the Human Ecological Lens

Broadly, the human ecological lens can be understood as the relationships between people and their environment, serving as a narrative for how sociocultural systems develop in connection with nature. This perspective is crucial for recognizing the inherent in-

terconnectedness of cultural and biological systems—they are inseparable (Kassam 2009: 203). By adopting a more holistic approach, we come to understand that patterns emerging from ecological systems are not fixed but inherently dynamic. These patterns reflect a complex web of interrelations that cannot be captured by binary classifications or dichotomies. Instead, they embrace a multitude of interconnections that continuously shape both ecological and human systems.

As I conducted interviews during the first two weeks of my research, my understanding of the ecological calendar evolved significantly. Initially, I viewed the ecological calendar as a cyclical system that aimed to challenge the linear conception of time through the use of seasonal indicators. However, my perspective has deepened, and I now see it as something far more complex. It is through identifying these seasonal indicators that we come to understand time in relation to the space it inhabits. The ecological calendar, I've come to realize, embodies a multidimensional relationship between time and the environment, one that goes beyond mere cycles.

Through the interviews, I observed that these indicators are not static; they shift as the environment itself changes. This evolving nature of indicators highlights an essential dynamic aspect of the calendar. As Professor Kassam explains in *Rhythms of the Land*, the calendar is not simply a static tool but a system that reflects and adapts to the environmental changes it tracks (Kassam 2022: 35). This insight underscores the ecological calendar's adaptability—its continuous evolution based on feedback from environmental observations and community impacts. The ecological calendar, then, is a tool not only for understanding the present but also for anticipating future shifts in both the environment and human responses.

While the ecological calendar is designed to be a dynamic tool that evolves over time, it is crucial to also consider the scope and timeframe within which a specific ecological calendar operates. It's essential that we do not overly fixate on the notion that all indi-

cators are constantly evolving. Rather, it is important to analyze climate variation and seasonal indicator data within a defined, relevant period of time. This means that, even as the calendar is expected to evolve, it is valuable to assess the data as it is observed in the present moment—understanding it as a snapshot of the environment at a particular time.

In this sense, the ecological calendar can be viewed as a reflection of multiple dynamical systems at work. It functions as a living document—constantly shifting, adapting, and responding to the ever-changing environmental landscape. This fluidity is one of its strengths: it is both a map of the current state of the environment and a tool for anticipating its future trajectory.

From a human ecological perspective, agency refers to an element's capacity to maintain its structural integrity in the face of dynamic change. Even in chaotic or fluctuating ecological systems, certain elements may show resilience, maintaining their coherence within the broader system despite external disturbances. This type of stability is indicative of resilience, where elements retain their function and structure over time, even amidst disruption. Resilient systems or elements adapt to external pressures while maintaining a coherent identity or functionality. In contrast, other systems may lose their integrity entirely depending on the time frame and spatial scale of observation, illustrating how some systems are more vulnerable to disruption than others.

At this point, I would like to pause and reflect on the space the ecological calendar occupies, not just in terms of the environment but also within our broader understanding of human-ecological relations. By considering the interplay of time, space, and environment through this lens, we gain deeper insight into the role of the calendar as both a tool for tracking ecological changes and a mechanism for guiding future actions. The calendar is not just a record; it is a means of engaging with the environment in a way that acknowledges the interdependence of all living systems.

3.3 How This Relates To My Own Experiences

During the summer of 2018, I had the privilege of engaging in work with Bioneers in the Hopi village while staying at Dine College in Arizona. As an Indigenous student, this experience was deeply personal and transformative, offering insights that resonated with my academic pursuits, particularly in pure mathematics. Working in this setting allowed me to see the interconnectedness of all things, a perspective rooted in Indigenous ways of knowing, which aligns closely with the analytical rigor required in mathematics.

Mathematics, particularly in the areas of manifolds, differential equations, and nonlinear dynamics, reveals patterns and relationships in systems. A theorem in mathematics is proof of a statement—a belief, a tool, and a law that can be understood by observing nature. However, developing a theorem is an intimate process, one that is not just meer observation, but active participation, where uncertainties and prototypes form a network. I see mathematics as an incommensurable relationship between the observer and what is being observed. Like the Earth and I, breathing in different rhythms but in harmony, mathematics reveals the vulnerabilities and truths of the universe.

In my nonlinear dynamics and chaos class (YuSheng Luo 2024), we studied the phenomenon of fireflies blinking in sync with an LED stimulus. This type of dynamical system is governed by periodic flow, and when the fireflies' natural frequency aligns with the stimulus, they become part of a system with a fixed point known as Liaponov stability (Strogatz 1994). This beautiful, interconnected behavior mirrors the ecology I witnessed in the Hopi village. Just as fireflies converge on a frequency, communities and individuals, like the fireflies in the field, navigate their environments together, constantly shifting and re-forming.

The same principles that describe natural systems also apply to the connections I have experienced in my life—connections between individuals, between cultures, and between

the Earth and humanity. My studies of topology, particularly in relation to dynamical systems, remind me of the intricate flows in nature and in society. Each element, each person, is a manifold of worlds, constantly shifting, colliding, and reforming, yet always part of something greater.

As I reflect on my journey, I see how the beauty of Indigenous knowledge and the beauty of mathematics are interwoven. I hope to continue bridging these two worlds, finding new ways to tell stories, write proofs, and construct theorems that reflect the complexity and interconnectedness of the world. Mathematics, in its purest form, is not just a tool—it is a way to understand the mysteries of the universe, to see the patterns in nature, and to honor the relationships that sustain us. Like the fireflies, we all shine at our own frequency, yet we share the same space and time, gravitating toward one another as we navigate the infinite complexity of life.

CHAPTER 4

DISCUSSION/CONCLUSION

4.1 Shortcomings From This Research

Two significant issues emerged during the course of this research, highlighting limitations that warrant further attention and discussion.

The first shortcoming in this research is a lower expected interviews from a goal of 30. While this study successfully conducted 21 interviews with community members to inform the development of the Ecological Calendar, it is important to note that this falls short of the statistically recommended sample size of 30 interviews for robust qualitative research. The insights gathered may not fully encompass the diversity of perspectives and ecological knowledge present within Warren County. Expanding the sample size in future research could provide a more comprehensive understanding of seasonal patterns and strengthen the validity of the calendar.

Additionally, environmental disruptions posed significant challenges during data collection. For community members whose work heavily depends on environmental conditions, fluctuations in the environment can directly affect their availability. Severe flooding and strong thunderstorms during the research period made it impossible to interview some scheduled participants. This underscores the complex and dynamic relationship between environmental conditions and community activities, which can, in turn, influence the research process.

The second shortcoming is the way I structured my architecture in my methodology. The architecture developed for building the Ecological Calendar, while effective for this study, was designed as a general framework and is not exclusively tailored to Warren

County. This lack of specificity could present challenges, as the calendar may not fully capture the unique ecological, cultural, and social dynamics of the county. Instead, it offers a broad approach that could be applied to other regions with adjustments for local contexts. While this generalizability could be seen as a strength in terms of adaptability, it may also lead to issues of reduced precision and applicability to the specific needs and conditions of Warren County.

Addressing these issues in future research could involve refining the research methodology to better align with the local context and expanding the number of interviews to capture a wider range of ecological knowledge and practices.

4.2 Further Areas of Research and What Work Needs To Be Done

As this thesis explores the development of an Ecological Calendar for Warren County and anticipatory climate change mechanisms, it becomes evident that several critical areas require further exploration. First, while this work has begun to bridge Indigenous ecological knowledge with contemporary climate science, there is much more to be done to ensure that these systems of knowledge are not only respected but also fully integrated into climate change adaptation strategies (Cuthbert 2018). Future research should focus on establishing a more robust framework for combining Indigenous ecological knowledge with quantitative models, such as predictive climate modeling and resource management systems. Brain Maurer and Alfred Lotka's work could contribute a great deal understanding population and competition dynamics between particular seasonal indicators that have direct interactions to one another. This integration could yield more holistic, community-driven solutions that take into account both the immediate needs of communities and the long-term sustainability of the environment.

Second, the creation of an Ecological Calendar requires thorough, localized data collection that accurately reflects both seasonal changes and local ecological indicators. There is a need for a comprehensive climate data system that incorporates local observations, particularly from Indigenous communities who have long recognized and understood environmental patterns. A more detailed study of microclimates, biodiversity indicators, and land use changes in Warren County would offer a clearer picture of how local ecosystems are evolving in response to climate change, allowing for better anticipatory strategies.

Third, the application of Ecological Calendars could extend beyond climate modeling to areas such as agriculture, disaster preparedness, and ecosystem restoration. Future research could explore the potential for these calendars to be used as tools for community-based monitoring, providing real-time data on shifts in local ecology, such as changes in plant and animal behaviors (Galan 2023). This work could also extend to other communities with similar ecological and cultural landscapes, contributing to a more diverse, global network of climate adaptation strategies.

Finally, there is a pressing need for further research on how Ecological Calendars and other local climate adaptation strategies can influence policy and community engagement. It is essential that the research involves Indigenous voices in policy discussions, ensuring that their knowledge systems shape the development of climate action frameworks. Future work must focus on building partnerships with policymakers, community leaders, and climate scientists to ensure that the proposed strategies are not only scientifically sound but also culturally relevant and practical.

4.3 Conclusion

The role of mathematics in this process cannot be understated. Mathematics offers a powerful lens for understanding the nonlinear, dynamic systems that govern both ecological and social environments. My exploration of nonlinear dynamics and chaos, manifolds, and differential equations has provided a unique perspective on the interconnectedness of natural systems and human behavior. For example, the phenomenon of fireflies synchronizing their light through dynamical systems illustrates how individual elements can harmonize within a broader ecological framework. This mathematical insight parallels the way communities and ecosystems adapt to change, finding balance through complex interactions. By blending mathematical analysis with Indigenous knowledge, this work highlights the potential for interdisciplinary approaches to address the uncertainties of climate change.

As this research continues to evolve, there is significant potential for further work in this field to refine and expand the tools necessary for anticipatory climate adaptation. By fostering a deeper understanding of the natural world, drawing on diverse knowledge systems, and creating collaborative platforms for local communities and scientists, we can begin to build a more sustainable future that honors both the land and the people who rely on it. This research is just the beginning. As we continue to address the complex challenges of climate change, we must remember that solutions will not come from a single discipline or perspective. They will arise from the collaboration of many voices, many disciplines, and many ways of knowing. In this context, mathematics, Indigenous ecological knowledge, and community action together form a powerful foundation for understanding and addressing the ecological challenges of the future.

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