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Seeing Shifts: Ecologists' Lived Experiences of Climate Change in Mountains of the American West

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Date Approved by all committee members: April 25, 2009

Date Submitted to the Registrar's Office:

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SEEING SHIFTS:

ECOLOGISTS' LIVED EXPERIENCES

OF CLIMATE CHANGE IN MOUNTAINS OF THE AMERICAN WEST

By

Kimberly F. Langmaid

A dissertation submitted in partial fulfillment of

the requirements for the degree of

Doctor of Philosophy

Environmental Studies

at

Antioch University New England

2009

ACKNOWLEDGMENTS

There are many people who deserve recognition for their support toward this dissertation. The ecologists who gave generously of their time and expertise have given me more than information; they have given me hope and a sense of purpose in my work.

My professors at Antioch University New England opened my mind to seeing the world in new ways. My advisor Dr. Mitchell Thomashow has inspired me to think about place-based education in new ways. His generosity is much appreciated. My other committee members, Dr. Joy Ackerman and Dr. John Tallmadge, were very helpful in helping me synthesize my ideas and find the greater meanings in this project.

My cohort friends at Antioch were truly an inspiration, and every academic gathering was an event to look forward to. My colleagues at Gore Range Natural Science School in Colorado, Prescott College in Arizona, and Teton Science Schools in Wyoming were always a source of encouragement. Without the generosity and wisdom of these inspired people always surrounding me, I would not have found as much reason and dedication for this dissertation.

My family has been a wellspring of support. They have encouraged me to follow my passions. My father and stepmother, my mother, my sister, and especially my grandmother have each shared their love and encouragement. There are simply no words that can convey the sense of appreciation I feel for my husband Peter Casabonne. His tireless dedication to seeing me through the Ph.D. process and to our loving canine companions, Osa and Tarn, is truly what made this dissertation possible. Now we can share our passions for the mountains together!

ABSTRACT

This study explores the lived experiences of field ecologists who research the effects of global climate change on mountain species and ecosystems in the American West. The purpose is to generate narrative descriptions of ecologists' experiences in order to communicate about both the scientific ecology and human ecology of climate change. Twenty prominent field ecologists participated in this study. Interviews with ecologists were transcribed and analyzed using a hermeneutic phenomenological methodology. Eight experiential themes emerged through the process of data analysis, and these themes provide the structure for presenting narratives of ecologists' experiences. The eight themes are: thinking ecologically, the place-based ecologist, seeing shifts, coping with complexity, a paleo-perspective, crossing thresholds, triage, and silver linings. Each theme is presented through the stories of the particular ecologists who exemplify that theme. The series of narrative descriptions reveals a process of scientific inquiry embedded within human experience and the social construction of global climate change. The life histories, personal motivations, and values of ecologists are found to be an integral aspect of their scientific work. By bringing to life the way these scientists see, understand, realize, and care about their work, the narrative descriptions may connect readers to the seemingly esoteric science of climate change. In addition, the experiences of field ecologists reveal this group of scientists as exemplars of human resilience in the face of complexity and adversity. This research contributes to the human dimensions of climate change by offering place-based and personal stories of scientists' experiences. Deeper questions for society emerge about: a) the future role of ecologists in education and b) making choices about the kind of world we want to live in.

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INTRODUCTION

Background and Context

Earth's climate is always in the process of changing. From where I sit, on the western slope of Colorado's Rocky Mountains, I see evidence of a warmer, wetter climate that existed 350 million years ago. This climatic past is revealed to me in the layers of rocks lined with ancient stromatolites and fossilized ferns. The waves of an inland sea once lapped on the shores of this now mountainous place. Another look and I see the story of more recent and colder climates. The U-shaped valleys embracing my home were carved 15,000 years ago when rivers of glacial ice reached out like fingers from high elevations. Yet today, evidence of current climate change is not as easily observed on the landscape. For the first time in earth's five billion year history, the climate is rapidly changing, not due to the natural influences of the sun, a meteor, or the astronomical position of the earth, but, rather, due to the habits of humankind. The significance and consequences of this new kind of human-caused—or anthropogenic—climate change are different both for humans and the earth itself. There are issues related to human attitudes, values, and choices, in addition to the very survival of earth's ecosystems as we know them. In the context of current climate change, industrialized nations are responsible for the fate of millions of species and billions peoples around the world. Those of us whose livelihoods are deeply intertwined with the creation of climate-warming carbon emissions are responsible for how the story unfolds. We live in a time of deep existential confrontation, and we face a very uncertain future.

The resolve to reduce our consumptive behaviors, and the wherewithal to live well with the uncertainties of climate change, will not be found entirely in technological, political, or economic systems. Coping with climate change calls for people to respond at more basic levels; it requires a reconsideration of our most essential *relationships* with the earth and one another. At this moment in human history, when most people living in industrialized nations are increasingly disconnected from the natural world, there is a need to reflect on and make meaning of our most basic encounters with nature.

By shifting our attention to the *relational space* between ourselves and the world around us, we can turn our thinking more precisely inward and outward at the same time. The relational space that exists between our inward and outward reflections about the changing earth can evoke an *experiential* sense of global climate change. By grappling with questions about what it means to be alive at this moment and how it might be to exist in the future, we come closer to understanding the significance of global climate change in our lives. Global climate change becomes a "teachable moment," an opportunity for human learning and adaptation.

To better understand this relational space between person and world, in this dissertation I ask: *What is it like to experience global anthropogenic climate change?* I explore the lived experiences of mountain field ecologists who dedicate themselves, in large part, to understanding how earth's species and ecological systems are changing. I've turned to ecologists in particular because they perceive the world in terms of systems and they view humans as an integral part of earth's systems. They are also able to convey both scientific and personal perspectives on their experience of global climate change. A deeper understanding of how field ecologists observe, experience, and respond to global climate change can also help us in our efforts to communicate the significance of climate change in more personal and place-based ways than are traditionally found in scientist's own peer-reviewed literature.

During the mid-1990s ecologists began to observe a "globally coherent ecological fingerprint" of climate change; two such signals of the effects of global climate change are: 1) changes in plant and animal species' phenology and 2) changes in species' geographic distribution (Parmesan & Yohe, 2003, p. 204). Ecologists suggest that species will be forced to adapt and/or migrate in order to survive rising temperatures. If global average temperatures exceed 1.5-2.5 degrees Celsius, scientists predict that "approximately 20-30% of plant and animal species assessed so far are likely to be at increased risk of extinction (Intergovernmental Panel on Climate Change, 2007, p. 6). Despite the growing scientific evidence of climate change, there is still a disparity between the ecological reality of climate change and the perceptions of many human beings.

Problem Statement

Recent research in the social science of climate change suggests that people don't lack the information they need in order to believe climate change is affecting earth's ecosystems, yet they don't feel a sense of urgency to address the issue (Leiserowitz, 2006). There are cognitive disconnects in the way people perceive and understand climate change, and these cognitive disconnects prevent people from taking responsible environmental action (Grotzer & Lincoln, 2007; Moser & Dilling, 2007; Pawlik, 1991; Stern, 1992; Williams & Parkman, 2003). There is a need for more effective communication that makes the scientific information about global climate change relevant to United States citizens' local everyday lives.

When most United States citizens think about climate change, their perceptions are filtered through the media and social groups they interact with. The majority of people in the United States are likely to think about rising oceans, hurricanes, drowning polar bears, abnormally hot weather, and catastrophic forest fires. These are indeed some of the physical impacts of climatic change, but, for many people who are not living amidst these environmental scenarios, the ecological risks inherent in climate change may be difficult to perceive and even more so to understand. Because our human perceptual faculties are not geared toward sensing environmental phenomena at global scales (Uzzell, 2000) it can be difficult to make sense of how such a diffuse and distant phenomenon as climate change is relevant to one's everyday local life.

Understanding the science behind global anthropogenic climate change is important in order for people to grasp how their individual actions add up to such a large-scale problem, but it is also important to take into account the scientific traditions, biases, assumptions, and social conditions that have led to our current beliefs about earth's systems. Science provides one way, among others, of interpreting and making meaning of the world. This dissertation complements the natural science of climate change in a unique and important way. By exploring the personal thoughts, feelings, and experiences of field ecologists, this research opens up new possibilities for understanding human-environment relationships in the context of today's climate change.

Statement of Purpose and Research Questions

The purpose of this dissertation is to explore and describe what it is like for field ecologists to experience climate change and its effects on mountain species and ecosystems. The research reveals compelling themes and descriptions that can be used more broadly, beyond the scope of this dissertation, to more effectively communicate and educate about climate change. In order to generate descriptive place-based stories of climate change in mountains of the American West, I posed the following research questions:

- How do mountain field ecologists describe what it is like to think ecologically as compared to a lay person?
- What kinds of perceptual practices and procedures do mountain field ecologists engage with in order to observe the effects of climate change?
- How do mountain field ecologists describe their experiences of researching the effects of climate change?

Research Approach

In order to define the methodological boundaries for this dissertation, I've limited my study to researching the experiences of ecologists whose work takes place in mountains of the western United States. I have determined this for several reasons. First, due to their distinct climatic gradients, narrow elevational life zones, topographic diversity, and high frequency of endemic biodiversity, mountain ecosystems are important indicators of global climatic change (Fagre & Peterson, 2002). Like earth's polar regions, they are also "canaries in the coalmine" or early warning signals of the ecological effects of climate change. There is greater climatic variability in mountains, and in the past century mountains have seen a greater rate of climate change than their lowland counterparts (Diaz, Eischeid, Duncan, & Bradly, 2003). In addition, changes in temperature and precipitation throughout the North American West exceed the global average rate of change (Mote, 2003). Second, because of where I live in the Rocky Mountains and my professional experience, I am most familiar with mountain ecology and the ecologists who work in mountains. Third, the importance of mountains for survival of life on earth is often unrecognized. Mountains supply 50% of earth's fresh water, and they are core areas of global biodiversity (Price, 1999). Mountains warrant special attention, but, unlike other ecosystems such as oceans, forests, and rivers, they have not traditionally received such focused disciplinary study.

With recent evidence of a changing global climate, mountains are gaining greater attention in scientific communities. There are reports from the field of how mountain species such as birds (Inouye, Barr, Armitage, & Inouye, 2000), mammals (Beever, Brussard, & Berger, 2003), insects (Parmesan et al., 1999), amphibians (Blaustein et al., 2001), trees (Dale et al., 2001; Logan & Powell, 2001; Williams & Liebhold, 2002), and wildflowers (Inouye, Morales, & Dodge, 2002) are impacted by current climate change. Other studies reveal how climate change impacts mountain ecosystems differently from the lowlands (Guralnick, 2007; Peterson, 2003). The authors of these studies are the kinds of scientists whose experiences I explore and describe in this dissertation.

There is much to be learned from a deeper analysis of individuals' experiences including their perceptions, imaginations, and reflections as they relate to environmental phenomena. My assumption is that by synthesizing experiential inquiry with a place-based study of climate change scientists, new insights into the human dimensions of climate change may emerge. This approach embraces the phenomenological claim that humans are immersed in the world, always a product of their historical and cultural contexts. The science of climate change is no exception. Even climate change is understood through a socially-constructed set of scientific theories and practices. Understanding how humans perceive and respond to current climate change is such a complex issue that it calls for innovations in social research, communication, and education. My purpose in developing this dissertation is a response to the need for innovative human-environment research. I see this research as novel and interdisciplinary while building on the strong philosophical and methodological framework of phenomenology.

Human-environment researcher David Seamon (2000) defines phenomenology as "the exploration and description of phenomena, where *phenomena* refers to things or experiences as human beings experience them…the aim is to use…descriptions as a groundstone from which to discover underlying commonalities that mark the essential core of the phenomenon" (pp. 158-159). Phenomenology is a tradition in philosophy that rejects treating human "consciousness as an empirical phenomenon that can be investigated by the quantitative methods of natural science" (Stewart & Mickunas, 1990, p. 4). The phenomenological method offers a process of inquiry that reveals how people *make meaning* of their experiences. Phenomenological studies inquire about the nature of people's perceptions, imaginations, reflections, and interpretations of phenomena. The phenomenologist thinks critically about the nature of our human existence. For example, in this dissertation a phenomenological stance requires that I ask questions about my own sources of knowledge, my most basic assumptions about the sciences of ecology and climate change, and related human dimensions. This way of thinking about climate change is an experiential, critical, and reflective endeavor.

Assumptions

Entering into this dissertation my premise is that place-based descriptions of mountain ecologists' lived experiences of the ecological effects of climate change will help convey this diffuse global scale phenomenon in salient and relevant ways. This position is drawn from my seventeen years of experience as an environmental educator and is inspired by the writing of my doctoral advisor Dr. Mitchell Thomashow. In his book *Bringing the Biosphere Home,* Thomashow (2002) offers place-based practices and curricular ideas for perceiving global environmental change. He also suggests probing "qualitative interviews with ecologists to ascertain how they think in biospheric terms" (p. 198-199).

My interest in exploring the human dimensions of climate change has also been spurred by my observations and reflections as an amateur naturalist. I have lived in the Rocky Mountains for almost all of my life, and my experiences and perceptions of climate change have been influenced by observations of my surroundings. I live next to a lodgepole pine *(Pinus contorta)* forest that is dying due to a massive bark beetle outbreak. I've also noticed the seemingly early spring arrival of birds and butterflies, the shifting blooming dates and abundances of wildflowers, and the year-round occurrence of American robins (*Turdus migratorius)*. As I observe these changes, and reflect upon my perception of these changes, I consider what life will be like in the future. I wonder if, and how, other people perceive such ecological change. How do their perceptions of climate change influence their everyday lives, if at all?

I illuminate how my past experiences and biases inform this dissertation because, consistent with the hermeneutic phenomenological methodology of researching lived experience, Van Manen (1990) suggests “a phenomenological question must not only be made clear, understood, but also ‘lived’ by the researcher” (p. 44). My own experiences of ecological change are also increasingly informed by the scientific research I read and hear about. It is difficult to understand the full extent of how one’s perceptions are influenced by one’s social and cultural milieu. Throughout the process of talking with the ecologists who participated in this dissertation, I have strived to set aside my biases and listen carefully to their voices. My focus is on describing their experiences, not my own.

Rationale and Significance

In this dissertation I explore and communicate the intersections of climate and humanity in a compelling and novel way. I bring the important, though little used, methodological approach of phenomenology to the interdisciplinary study of the human dimensions of climate change. By exploring mountain field ecologists’ lived experiences of climate change, my dissertation documents history in the making. Never before in the history of humanity has anthropogenic climate change so saliently revealed itself through the life histories of species and the life stories of scientists.

My research also builds on recent findings about the role of experience, affect, and imagery in elevating people’s perceptions of the risks of climate change (Leiserowitz, 2006). This dissertation aims to communicate affective narratives of locally relevant ecological change. I offer descriptive insights into the personal experiences, feelings, and emotions of one group of people who are intimately aware of the impending ecological threats of climate change. Although ecologists are not a representative sample of the general United States public, a glimpse into their experiences may shed light on what is to come for others as climate change encroaches on people's lives in more visible and tangible ways.

There are two kinds of information this phenomenological study develops. First, the research reveals relevant and experiential themes about human experiences that can be used by policy makers, land and wildlife managers, environmental educators, and communicators. Second, the research generates narrative descriptions, or stories, of personal experiences as told by field ecologists. These stories can be useful in post-dissertation publications, educational curricula, and educational science exhibits. Stories can provide a more effective way of educating the public about climate change (Dunwoody, 2007; Kearney, 1994) and ecological systems (Anderson, Mohan, & Sharma, 2005; Bowen & Roth, 2007). If individuals are "absorbed in a story or transported into a narrative world, they may show effects of the story on their real-world beliefs" (Green & Brock, 2000, p. 701).

This dissertation is timely and relevant. Not only will it add to the discourse in the human dimensions of climate change, it will also provide *practical descriptions* of what life is like for some people who experience global climate change. Insights from these ecologists may prove useful toward facilitating human adaptation to and mitigation of climate change. I conceive of this research as an ethical imperative driven by my own observations of ecological change and knowledge of what may come to pass if no broad-based action in response to climate change is taken. At the same time, I embrace the methodological sensitivity and openness of hermeneutic phenomenology to generate understandings about the meanings of other people's experiences. In order for citizens to effectively respond and adapt to climate change impacts in their lives, there is a need for understanding people's experiences of climate change in the local places where they spend their time. The local level is where individual actions add up to create global solutions (Rayner & Malone, 1998b).

Further clarification of some of my own biases and assumptions in undertaking this exposition is needed. I come to the field of environmental studies with an educational background in the natural sciences. It is through the natural sciences that I have developed a rich and meaningful relationship with the natural world. Yet in my professional life, as an environmental educator, I recognize a lack of humanistic and philosophical perspectives in addressing practical environmental issues. It is my belief that even *interdisciplinary* environmental studies cannot entirely fulfill its intentions of offering more productive solutions until it more explicitly integrates humanistic and philosophic disciplines. This is my impetus for turning toward phenomenology. What phenomenology brings to the table is its ability to reveal underlying themes and patterns of meaning that structure our distinctly human experiences and ways of constructing the very disciplines we seek to integrate. It is my belief that through a synthesis of phenomenological inquiry with the ecological effects of climate change, new initiatives for environmental education, communication, and sustainable relationships with the natural world may emerge.

LITERATURE REVIEW

Introduction

In this literature review I lay the conceptual framework for my dissertation. Because global climate change is such a complex environmental issue, it requires a creative interdisciplinary approach to problem solving. In fact, global climate change may be such a complex issue that it forces people to think in new ways. Like the discovery of DNA in the 1970s, global climate change is spawning a "cognitive revolution" and reconfiguring academic disciplines (Klein, 2004). New ways of creating knowledge are emerging, and my literature is reflective of this situation. I've aimed to write a succinct review while weaving together disciplinary connections where they may have been lacking before.

First, I review relevant literature from the philosophy and research methodology of *phenomenology*. Here I have focused on the *epistemological orientation* of phenomenology rather than examples of phenomenological research because I want to clarify the unique and important perspective that this little-used methodology brings to the field of environmental studies. Second, I review literature from the *human dimensions of climate change.* I provide a basic overview of this vast and quickly growing field of inquiry, and then I focus on examples of studies that are closely related to my own. Finally, I review literature from the *social studies of science* and particularly studies of climate change scientists and ecologists. This final piece of literature explores ways that other scholars have investigated the lived experiences of scientists. When combined, these three areas of literature—phenomenology, human dimensions of climate change, and social studies of scientists—make up an interdisciplinary conceptual framework that leads to new ways of apprehending the complex issue of global climate change.

Phenomenology

Although phenomenology is a little-used methodology in environmental studies, it offers a more holistic, less atomistic and compartmentalized, approach to understanding humans and their environments (Evernden, 1993). With its emphasis on seeking *meaning* through a rigorous process of analyzing human *experience,* phenomenology is used to investigate acts of consciousness that are not readily available through natural science methods. Because phenomenology strives to develop precise descriptions of phenomena (things) as they present themselves to human experience, the phenomenologist begins by setting aside her scientifically-based theories and abstract mental models.

Phenomenology is a form of philosophy that was first conceptualized during the 1940s in Germany as a critique in response to *positivism*. Positivism is a complex set of beliefs stemming from the idea that only natural science (with empirical quantifiable data) can be the true source of knowledge (Bentz & Shapiro, 1998). Edmund Husserl, known as the founder of phenomenology, proclaimed phenomenology "as a bold, radically new way of doing philosophy, an attempt to bring philosophy back from abstract metaphysical speculation wrapped up in pseudo-problems, in order to come into contact with the matters themselves, with concrete living experience" (Moran, 2000, p. xiii). Drawing from both his background as a mathematician and from the psychological philosophy of Franz Brentano, Husserl aimed to create a philosophy free of presuppositions. Whereas Brentano's psychological philosophy was based on the premise that reality could be known by studying the psychological processes involved in consciousness, Husserl proposed that consciousness cannot be separated from that which it is conscious of, and therefore a more accurate understanding of reality could be gained through description of conscious *experiences*.

Husserl's phenomenology sought to reveal the meaning of phenomena (objects, events, emotions, etc.) by the way they present themselves through human experience. Because the distinction between subject and object is minimized and the space of meaning-making between the person and the phenomenon becomes the focus of inquiry, "analyzing the phenomena, in turn, reveals the basic structures of consciousness itself" (Stewart & Mickunas, 1990, p. 36). Central to Husserl's methodology was the reflective practice of setting aside all presuppositions and prejudgments—be they scientific, historical, or cultural. A phenomenon could not be known in its entirety without first accounting for its essence, the way it presents itself to consciousness. Husserl's phenomenology is known as "pure phenomenology" because of its claim to be free from all abstractions.

A prominent student of Husserl's, Martin Heidegger, recognized the sheer impossibility of freeing oneself *completely* of presuppositions. Depending on how one interprets Heidegger's writing about phenomenology, it can be considered as either *existential* phenomenology, because of his emphasis on *being in the world*, or as *hermeneutic* phenomenology, because it rests upon the idea that people are essentially temporal beings. The word "hermeneutic" implies that all human understandings and descriptions are essentially *interpretations*; humans can never view the world completely free of their historical and cultural contexts.

Heidegger defines the project of phenomenology as "to let that which shows itself be seen from itself in the very way in which it shows itself from itself…expressing nothing else than the maxim…'To the things themselves!'" (Heidegger, 1962, p. 34). Heidegger turned to the early philosophies of Plato and Aristotle and the question of *the meaning of Being*. In his first major work *Being and Time* he wrote, "Every inquiry is a seeking. Every seeking gets guided beforehand by what is sought. Inquiry is a cognizant seeking for an entity both with regard to the fact that it is and with regard to its Being as it is" (1962, p. 24). Heidegger used the ideas *Dasein* and *being-in-the-world* on which to base his ontological analysis.

Dasein implies that people have a fundamental pre-reflective level of being where the phenomena of the world are always perceived and ascribed with meaning; thus, humans are always conscious of something whether we are thinking about it or not. As our most basic way of being, we are always in relationship with the world around us, preconditioned to live authentically with care toward "other." Heidegger also proposed that people are always actively engaged as co-participants in the creation of meaning with the phenomena that surround us.

If we think about ourselves as inherently meaning-making beings who are always in relationship with one another and the phenomena around us, then we are predisposed toward more conscious, thoughtful, and caring relations with others (Evernden, 1993). The process of phenomenology is to carefully describe these fundamental relationships between people and the world without using the support of theoretical abstractions. The phenomenologist describes "what is" and in the process comes to know herself in more meaningful ways.

> Phenomenology insists that identity and intelligibility are available in things, and that we ourselves are defined as the ones to whom such identities and intelligibilities are given. We can evidence the way things are; when we do so, we discover objects, but we also discover ourselves, precisely as datives of disclosure, as those to whom things appear. Not only can we think the things given to us in experience; we can also understand ourselves as thinking them. Phenomenology is precisely this sort of understanding: phenomenology is reason's self-discovery in the presence of intelligible objects. (Sokolowski, 2000, p. 5)

Heidegger's phenomenology is radically different from the mode of inquiry in the natural sciences where theories are employed to create cause-and-effect hypotheses.

Eco-phenomenology integrates phenomenology with environmental studies. Eco-phenomenologists propose that phenomenological thinking fosters more value-oriented relationships with the natural world. The editors of the book *Eco-Phenomenology: Back to the Earth Itself* write:

> Phenomenology is set apart from other theoretical methods by its unique capacity for bringing to expression, rather than silencing, our relation with nature and the experience of value rooted in this relation…eco-phenomenology offers a methodological bridge between the natural world and our own, or rather the rediscovery of the bridge that we are and have always been. (Brown & Toadvine, 2003, pp. xii-xxi)

Other scholars have drawn from these philosophical ideas and developed human research methodologies.

Phenomenological geographer, David Seamon, promotes phenomenology as a qualitative research methodology that offers deeper insights into human-world relationships within both natural and human-built environments. His body of work reflects a diversity of ways to research people's environmental experiences (Seamon, 2000). In one of his notable examples (1979), Seamon reports his research findings based on observations of what he called *environmental experience groups.* After 1,500 observational encounters with these groups, Seamon discovered *movement, rest,* and *encounter* as the primary experiences of everyday existence.

Phenomenology is sometimes criticized for being too narrowly focused on individual experience and for generating overly simplistic descriptions that don't address the complexities of society. Some critics have claimed that phenomenology "makes no mention of class or gender…substitutes nostalgia…and pins its hopes for the future on an almost mystical moment of realization when the scales of scientific thinking drop from people's eyes" (Peet, 1998, p. 63). But there are numerous examples where phenomenology has been used as tool for cultural analysis and understanding (Frykman & Gilje, 2003; Herda, 1999; Jackson, 1996). But phenomenology is not appropriate for every kind of inquiry.

Phenomenology is known as a *philosophy of beginnings*. Ever since Husserl established this tradition of philosophy, phenomenologists have proposed that, before any other kind of scientific analysis is appropriate, one should first understand the *basic essence* of the phenomenon one is dealing with. This basic essence, or understanding, can be developed through phenomenological analysis and description. Within the broad spectrum of human-environment research, not all inquiries can be appropriately approached through phenomenology. But when the impetus is to understand people's lived experiences and ask questions about essential *relationships* between people and the phenomena they are engaged with, then phenomenology provides an important starting point.

Philosopher Don Ihde (1997) asks, "How many phenomenologists does it take to detect a greenhouse effect?" and he explains how the project of environmental phenomenology is problematic with respect to perceiving global climate change. Ihde says that from a phenomenological standpoint if "our very knowledge is constituted by way of our *bodies* and through *perception*…then what is claimed about whole earth measurements becomes problematic" because ones bodily senses cannot "sufficiently encompass" (p. 64) a global scale and the invisible nature of carbon gases. He proposes that, by incorporating the ideas of *technoscience* and *earth-as-planet* into the repertoire of environmental phenomenology, phenomenologists can indeed detect a greenhouse effect.

The technoscientist "operate[s] through *instrumental realism* which allows a *mediated* bodily perception of micro-entities " (p. 64). "Earth-as-planet" is a "measurable…finite sphere" that is perceivable (p. 69) to limited human perceptions. Ihde also says "the ability to get closer to synchronic whole earth measurements must also be related to diachronic readings of the past…made possible by the material 'calendars'…tree rings…deep glacial ice…etc…suggesting a 'hermeneutics of things'"(p. 71). He proposes that photographic images of earth from space are phenomenal *surfaces* which people are engaged with; therefore, even technologically derived surfaces provide the basis for studying human experience. Visual mathematical graphs of earth's accumulating greenhouse gases and increasing temperatures can also be surfaces that engage human relationship. Ihde's perspective is important because it allows our concept of human *perception* and *experience* of climate change to expand and include those perceptions and experiences that are aided by the tools of science. At the same time, the phenomenologist should consider the tool itself (its epistemological basis) and think critically about how that tool may enable some perceptions (e.g. vision) while marginalizing others.

Recent examples of phenomenological research related to environmental studies include: research on visitors' lived experiences of public lands (Brooks, 2003; Glaspell, 2002; Patterson, Watson, Williams, & Roggenbuck, 1998; Patterson & Williams, 2002), researching the lived experience of adolescents enrolled in a outdoor environmental education program to inductively develop an environmental ethics theory (Beringer, 1992), and an exploration of pilgrims' experiences at Walden Pond (Ackerman, 2005). Researching people's lived experiences employs the construction of narratives, or stories, based on in-depth interviews that are then analyzed through a vigorous process developed from the philosophical precepts of phenomenology. The goal is to generate increased understanding about how people construct meaning of particular phenomena in their everyday lives. Van Manen (1990) has described lived experience as a "certain way of being in the world" (p. 39). Rather than relying on prescribed *theories* derived from sociology, psychology, or anthropology, the phenomenologist attempts to set aside, or bracket, all of her assumptions and preconceived notions while she *collaborates* with research participants in order to generate shared understanding of what a particular experience is like.

This review of literature suggests two ways that phenomenology can advance an understanding of the human dimensions of climate change. First, as a rigorous analytical thinking process, phenomenology can aid us in understanding climate change as a socially-constructed idea that is a byproduct of the people (e.g. scientists, politicians, and media) who have been and are involved in the way it is portrayed. Second, as a methodology used to research human-environment relationships, phenomenology provides a descriptive approach that generates rich, multi-dimensional understandings of *what is* rather than *why it is*. This is a useful starting point for any research on human experience because this way of approaching a phenomenon does not impose any misguided assumptions or theories. In the next section of this literature review I explore some of the theories that have been used to understand the human dimensions of climate change, and I situate phenomenology among other social science methodologies.

Human Dimensions of Climate Change

Global climate change is one form of global environmental change. In this section of the literature review I first provide an overview of the multiple social research perspectives within the field of global environmental change. Second, I narrow my consideration to studies that link more closely with understanding the lives of individuals rather than of larger groups or whole societies; this points me toward the psychology of global environmental change. Finally, I make an argument for using phenomenology as a new way to understand the human dimensions of climate change.

Studies of the human dimensions of climate change draw from the perspectives of human *adaptation* to environmental change (Easterling, Hurd, & Smith, 2004; Moser, 1997; Norgaard, 2006; Orlove, 2005; Smit, Burton, Klein, & Wandel, 2000; Tompkins & Adger, 2004), *ecological sustainability* (Costanza, 1999), *epistemology* (Jones, 2002; Norgaard & Baer, 2005), *ethics* (Athanasiou & Baer, 2002; Brown, 2003; Jamieson, 1996), and the *role of media* (Boykoff & Boykoff, 2004; Zehr, 2000). Those studies having to do with *psychology* (Halford & Sheehan, 1991; Pawlik, 1991; Stern, 1992; Stoll-Kleemann, O'Riordan, & Jaeger, 2001; Uzzell, 2000) do not specifically address climate change per se. Rather, they discuss the psychology of *global environmental change* in general.

Stern (1992) reviews existing psychological research and calls for interdisciplinary approaches that help connect global scale phenomena to individuals' everyday lives. He suggests, from the standpoint of adaptation, that it is important to understand how individuals respond to the *stress* of environmental change. In order to understand human stress related to global environmental change, it has been important for some researchers to simply understand the perceptual challenges related to the kinds of environmental change that happen on such spatially large and relatively slow time frames.

Pawlik (1991) proposes five psychological characteristics related to global environmental change: "low signal-to-noise ratio…extreme masking and delay of cause-effect gradients…psychophysics of low probability events…social distance between actors and victims of global change…[and] low subjective cost-effectiveness of environment-conserving behavior" (pp. 559-562). He also proposes three fundamental methodological challenges: "most of the relevant variables and processes are part of *complex interactive systems*, with different cross-lagging of effects over time in different variables…[plus] research on the *causes and effects of global change* has to be truly interdisciplinary…finally, *research on global change* has to be truly global itself, i.e. international" (pp. 553-554). Finally, Halford and Sheehan (1991) discuss similar issues while addressing the influence of media and claiming that people are much more likely to understand climate change "to the extent that it impacts on everyday life" (p. 599).

A search of the literature reveals very little research conducted specifically on the psychological effects of climate change and even less on individuals' perceptions of climate change. One of the predominant approaches toward understanding how climate change affects people's experiences is through the disciplinary lens of *risk perception* (Leiserowitz, 2006; Lorenzoni, Leiserowitz, de Franca Doria, Poortinga, & Pidgeon, 2006; McDaniels, Axelrod, & Slovic, 1996; Niemeyer, Petts, & Hobson, 2005). Leiserowitz's survey of United States citizens found "public perceptions are influenced not only by scientific and technical descriptions of danger, but also by a variety of psychological and social factors, including personal experience, affect and emotion, imagery, trust, values and worldviews" (2006, p. 62). The findings of Leiserowitz and others (Blennow & Persson, 2009; Whitmarsh, 2009) suggest that further research is needed and that a qualitative interpretative approach would be beneficial.

Another research approach is oriented toward understanding the mental models of people and how these models influence perceptions of environmental problems. Kempton's *ethnographic study* (1997) demonstrates that people develop their opinions about climate change, and other complex environmental problems, based upon pre-existing conceptions (e.g. cultural models) about how the world works. He believes that understanding the cultural models of individuals and groups can help communicators and educators more effectively make their case for climate change mitigation and adaptation. Lorenzoni et al. (2005) offer insights into how the United States public views climate change: they don't understand the science behind it, they are not opposed to government policies to mitigate against it, and they recognize that climate change has become a bipartisan issue. Overall the authors surmise that public perception of dangerous climate change is context specific. Among the handful of suggestions for future research these authors highlight are "studies...on the influence of affect on individual beliefs and imagery, and the implications of this for future climate change communication and behavior change" (p. 1395).

Another ethnographic study that comes closer to researching lived experiences of climate change is Norgaard's (2006) ethnographic study of a Norwegian community. She selected one particular community in Norway because the people who live there are well informed and aware of how human greenhouse gas emissions contribute to current global climate change. They know about and believe in the reality of anthropogenic climate change, yet Norgaard's study shows how even well-informed citizens avoid addressing the issue. She specifically sought to understand *emotional* response to climate change. She discovered how people rely upon cultural narratives to construct socially acceptable denial of climate change. Although this study illuminates how one Norwegian community is coping with climate change, it takes a socio-psychological approach and makes sense of ethnographic data through a variety of pre-given sociological theories.

Norgaard's dissertation (2003) draws on Kempton's *theory of cultural models* (Kempton, Boster, & Hartley, 1995), Lifton's (1982) *theory of psychic numbing*, Eliasoph's (1998) *theory of apathy*, Swindler's (1986) *theory of "cultural toolkit"*, and Zerubavel's (2002) *theory of socially constructed denial*. I highlight Norgaard's use of sociological theories not because I intend to use similar theoretical constructs in my own research, but rather to highlight the variety and types of theories that have been employed toward interpreting the human dimensions of climate change.

Despite the substantial efforts of social scientists to make sense of how people respond and adapt to climate change, very little is known about the effects of climate change on the everyday lives of individuals (Rayner & Malone, 1998b). A 1998 four-volume series titled *Human Choice and Climate Change* reports on a major international research initiative to "assess the state of the art of social sciences in terms of their contribution to research on, and understanding of, the climate change issue" (Rayner & Malone, 1998a, p. xi). The findings of the project are summarized in the fourth volume titled *Human Choice and Climate Change: What Have We Learned?* and research priorities that are consistent with this dissertation are proposed. Of special note is the absence of any sort of basic understanding about how individuals function with respect to climate change at *local levels*. In addition, the authors identified a divided social research community consisting of two camps: those whose research can be considered "descriptive" and those whose research is "interpretive."

The division between these two social research camps, interpretive and descriptive, hinders the flow and production of knowledge that could be gained by linking top-down descriptive and bottom-up interpretive inquiries. Rayner and Malone acknowledge that this problematic situation is not unique to studies of climate change; it is a "division of intellectual labor that has dominated Western science since the Enlightenment" (1998b, p. 28). Another point that Rayner and Malone emphasize is the likeness of predominant large-scale descriptive social science that seeks to understand human behavior by employing the same kinds of mathematical and computer models that natural scientists apply to understand global earth systems. They equate the descriptive research paradigm to "research that analyzes social systems in terms of natural science metaphors" (p. 28) (e.g. in terms of mass balances, thermodynamics, or stocks and flows).

In contrast, the interpretive approach refers to the analysis of the "values, meanings, and motivation of human agents" (Rayner & Malone, 1998b, p. 37). Despite the challenges inherent in conveying the significance of human-scale interpretive research to such a global scale problem, Rayner and Malone make the case for local, place-based, interpretive research. They contend that "in the last analysis, the activities that drive anthropogenic greenhouse gas emissions are always local, and whatever impacts of climate change affect human populations they will be experienced at the local level" (p. 46). Although phenomenology is not explicitly recommended, it is an appropriate methodology that incorporates several of Rayner and Malone's "emerging" tools for climate change analysis, such as those that address "human needs and wants...vulnerability...cultural discourses…[and] values" (1998b, p. 55). Specifically, phenomenology can help develop a better understanding of the human experience of climate change by seeking to understand the lived experiences of individuals. Rayner and Malone conclude "social scientists have the opportunity in the global climate change debate to develop tools—perhaps an integrated set of interpretive and descriptive tools—that can contribute to understanding and practical guidance for policymakers" (1998b, pp. 66-67). By applying phenomenology, my research reveals themes and generates patterns of meaning that may help fill gaps in understanding the human dimensions of climate change.

Studies of Climate Scientists and Ecologists

At the outset of this dissertation I decided to interview *field ecologists* who work in mountains of the American West. I wanted to select a particular group of people who could discuss their actual observations and lived experiences of climate change. Because mountain ecologists are likely among the first group of people in the lower 48 states of the United States to observe and communicate the effects of climate change, I thought they could offer more in-depth insights. Also, because I have lived in the mountains of Colorado and Wyoming for most of my life, I have studied the ecology of these mountains and felt I could participate in well-informed conversations with this group of scientists. Finally, in a practical sense, within the constraints of limited money and time, I would be able to visit with this group of people at the field sites where they study the ecological effects of climate change. Due to my selection of scientists as the key group of people whose experiences I studied, it was important to understand how other scholars have gone about researching the lives of scientists. For this reason I next review the literature on social studies of climate scientists and ecologists.

Social studies of scientists fit within the broader discipline of *science and technology studies* (STS). Ecology, as I discuss it in this dissertation, is a scientific discipline that informs a way of knowing and being in the world. In his book *Making Sense of Science: Understanding the Social Study of Science*, Yearley (2005b) claims that "the sociology of science is essentially about two things: the sociology of scientific community itself…and the sociology of that community's relationship to the rest of society" (p. xiv). Yearley also makes the link between *science studies* and environmental issues (2008). He outlines how STS scholars have approached "environmental controversies…the relationship between research and environmental policy…environmental modeling…ecosystem management practices…citizen participation in environmental understanding and decision-making…the shaping of environmental research…and the development of innovative institutions" like the

Intergovernmental Panel on Climate Change (p. 921). He explains that the "environment" and "nature" are considered *socially-constructed* phenomena, thus "one cannot build the idea of humanly induced climate change without constructing what the 'natural climate' would, counterfactually, have been" (p. 921).

In his discussion of how STS scholars have approached climate change issues specifically, Yearley provides a chronological overview. Earlier studies looked at how the science of climate change relied on rapid-rate computer modeling that could only be conducted at very few facilities. These studies tended to focus on how scientists in the climate modeling community produced knowledge and made it credible and useful for environmental policy-makers (Miller & Edwards, 2001; Shackley & Wynne, 1996). In her ethnographic studies of climate modeling scientists, Lahsen (2005) described how the "unreality" of climate models is made real. She also explores why a subset of scientists "the physicist founders and leaders" of the anti-environmental George C. Marshall Institute, "chose to lend their scientific authority…to defend their preferred understandings of science modernity, and of themselves as a physicist elite" (Lahsen, 2008, p. 204). Shackley (2001) attributes the political positions that climate modeling scientists take to their "epistemic lifestyles" and their relationships with funding agencies. For example, in a broader study that compares the "epistemic cultures" of high energy physics and molecular biology, Knorr Cetina (1999) illuminates how "Western societies are becoming (or have already become) 'knowledge societies'…run on expert processes and expert systems epitomized by science but are structured into all areas of social life" (p. 1). Overall, this group of studies tends to highlight how varying *scientific cultures* operate within the context of larger socio-political systems.

Despite the large and emerging STS scholarship on climate change and other large-scale environmental issues, such as genetically modified crops and food and human genomics, there are very few studies that explore the contemporary experiences of *ecologists*. Ecologists have been studied at the margins between social studies of science, environmental sociology (Yearley, 2005a), and case studies of ecologists' roles in environmental problem solving (Bocking, 1997; Shrader-Frechette & McCoy, 1993). There are also historical studies of ecologists and field biologists and how their work contributed to the discipline of ecology and the modern ecological worldview (Golley, 1993; Kohler, 2002; Worster, 1994). There have been numerous texts written on the lives of well-known ecologists such as Aldo Leopold (Callicott, 1987; Flader, 1974; Meine, 1988) and Rachel Carson (Lear, 1997; Lytle, 2007) and how their scientific work has informed North American environmental values. There are five scholars whose work stands out for their research on the contemporary lives of ecologists and conservation biologists: Scarce (2000), Takacs (1996), Kevorkian (2004) and Roth and Bowen (2001) .

Scarce studied salmon biologists in the Pacific Northwest in order to understand how economic and political forces influence the social construction of salmon. He interviewed 24 salmon biologists and observed biologists during conferences and working in their everyday professional environments. He used grounded theory methodology to analyze interviews and observational data. Scarce discovered that there are both "macrostructure" and microstructure" controls that affect the experiences of biologists and the social meanings of salmon (Scarce, 1999). On the macro level, salmon biology is controlled by powerful institutional political and economic forces. For example, the largest financial contributor to salmon research is the Bonneville Power

Administration, the "federal agency that sells electricity produced by 29 of the largest hydroelectric dams in the Pacific Northwest. Those dams have been implicated in the precipitous decline in salmon numbers over the past six decades" (Scarce, 1999, p. 768). On the micro level, Scarce found that the salmon biologists were politically and socially savvy in order to navigate and succeed within the political and economic structures. There existed a "good ole boys" network within the salmon biology network that influenced which individual biologists would secure portions of the limited funding available for research. Scarce concludes:

> Policy and profit compel salmon biology with disturbing completeness, resulting in a narrowing construction of salmon…science holds the solution to creating more salmon…the fish are not pure products of nature transmitted through an objective, dispassionate science…salmon exist, as they would even absent society. But interjecting society leads to the creation of certain salmon, be they sacred symbols or symbols of political power, economic greed, or scholarly status. (1999, pp. 773-774)

Scarce's study of salmon biologists is a useful example of social science that explores the lives of contemporary biologists. His intent, from a sociological perspective, was to understand how institutional forces influence the lives of biologists and the meanings they construct for the species they study.

From a more interdisciplinary perspective that draws upon environmental history, conservation biology, and science studies, Takacs (1996) interviewed 23 prominent biologists and ecologists who were associated with conservation biology and the *idea of biodiversity*. Takacs also went to Costa Rica's National Institute of Biodiversity, where he interviewed and observed 17 additional people involved with the emerging *practice of biodiversity* in the creation of nature preserves. His overall aim in this study was to understand the social construction of *biodiversity*, a powerful idea and ecological conservation agenda that links scientists tightly with values they espouse. Takacs claims:

> Conservation biologists have generated and disseminated the term *biodiversity* specifically to change the terrain of your mental map, reasoning that if you were to conceive of nature differently, you would view and value it differently…the term *biodiversity* is a tool for a zealous defense of a particular social construction of nature. (1996, pp. 1-2)

Through his analysis of interviews, Takacs discovered that the biologists in his study were "putting an end to the frankly metaphysical notion of an objective, value-neutral search for knowledge" (1996, p. 332). He discovered a positive feedback loop between the biologists' professional work and their values, a relationship between some scientists and the organisms they study that was so tight that "dualisms disappear" and the identity of the scientist becomes bound up with the foci of their ecological research. Takacs concludes the "bounds of science are shifting and contingent," both scientists and the public are always at work in this process, and "observers of science should especially be aware that scientists may be engaged in this process" (1996, pp. 334-335). His study offers a window into the complex nature of science and the lives of a particular group of biologists who are intimately involved in transforming what it means to be a scientist working against the currents of global biodiversity loss.

Another social scientist whose work focuses on the inter-subjectivity between scientists and the natural world they study is Kevorkian (2004). Kevorkian is a thanatologist, someone who studies death and dying, "including grief and loss, suicide, euthanasia, hospice, medical ethics, and pain" (2004, p. 2). Kevorkian set out to integrate the field of thanatology with that of environmental problems. Her premise was that if she could create a name for the experience of grief related to environmental loss, then she could offer people a way to validate their feelings. Kevorkian had been personally concerned with whales (*Cetaceans*) for much of her lifetime. She held in-depth interviews with eight members of the American Cetacean Society, biologists who were well aware of the plight of a resident killer whale (*Orcinus orca*) population in the Pacific Northwest.

Kevorkian used a heuristic research methodology involving deep personal reflection as a process of creating and analyzing data. She discovered that seven out of eight of her research participants experienced environmental grief. She describes the following reactions expressed by whale biologists as consistent with environmental grief: anger, frustration, helplessness, hopefulness at times, sadness, and depression. Kevorkian's research of biologists provides a different, more humanistic, perspective than the others studies reviewed here (Kevorkian, 2004). She integrates thanology, ecopsychology, and deep ecology in order to offer society a new way of naming environmental emotions. Kevorkian considers the sense of loss over endangered species, or familiar places, as a form of "disenfranchised grief" (Doka, 2002) where: a) the relationship between the person and what is lost is not recognized, b) the loss is not acknowledged, c) the griever is excluded from the grieving process, and d) circumstances of the loss influence the nature of the grief and may inhibit grief responses. Kevorkian's study of whale biologists is a unique contribution that developed a theory and structure to support her profession as a social worker.

Another approach to researching the experiences of ecologists is that of Roth and Bowen (2001). During a two-year ethnographic study of field ecologists, Roth and Bowen observed that becoming a field ecologist "involves a disciplining by means of which mind and body become intertwined and domesticated into the scientific discipline" (2001, p. 460). Based upon their observations, interviews, and attendance at ecological gatherings, the researchers discovered several salient themes that distinguish *field* ecologists from theoretical and laboratory ecologists. Roth and Bowen emphasize the hardships of field ecology and the "mental and physical discipline this work requires" such as exhaustion, illness, stress, threats of danger, and physical isolation (p. 461). As difficult as field ecology may be, Roth and Bowen interpret field experiences as a "rites of passage" that lead to "more holistic understandings that distinguish field ecologists from other scientists" (p. 468).

Roth and Bowen also found that field ecologists develop an "intuitive" and "embodied" sense of the field sites where they work, which becomes an informal resource for them to draw upon and complement their scientific studies and publications. They report that field ecologists primarily work outdoors because of their love of the natural world but that this breed of ecologist "generally felt inferior to theoretical ecologists" (2001, p. 463). The researchers also discovered "an inverse relationship between the level of formality of the context and the amount of 'anecdotal' information that characterizes fieldwork narratives…'anecdotal' information is increasingly purged as narratives are formalized to make them 'scientific'" (p. 474). Roth and Bowen found that "storytelling" about field experiences was an important part of a field ecologist's identity and that such stories offered lessons for novice field ecologists. They report two different functions of fieldwork narratives: membership in the discipline and transmission of ecological lessons from old-timers to newcomers. Roth and Bowen's study offers insight into the lived experiences of contemporary field ecologists. It demonstrates an ethnomethodological interpretation that incorporates both intellectual and embodied aspects of scientific work.

Throughout this literature review I have developed a conceptual framework for my dissertation. First, I examined phenomenology as a philosophy and human-environment research methodology that can offer rich descriptions and deeper understandings of the things (phenomena) that people encounter in their lives. Second, I explored the multiple ways that the human dimensions of global climate change can be conceptualized and researched. Finally, within the broad field of social studies of science, I proposed that there have been relatively few studies of ecologists and even fewer of contemporary field ecologists' experiences. In the next chapter I describe in more detail the specific data collection methods that I used within an overarching hermeneutic phenomenological methodology.

METHODOLOGY AND METHODS

Hermeneutic Phenomenological Methodology

In this chapter I explain the research methodology and methods that I used for this dissertation. I begin with a discussion of hermeneutic phenomenological methodology, and then I describe my data collection procedures, including selection of research participants and interview protocol. I explain how I analyzed my interview transcripts, how I thematically organized my findings, and how I have presented my findings as descriptive narratives of select ecologists and their experiences.

Methodology can be thought of as a window or lens through which to filter ideas and considerations. From a phenomenological orientation it would be inappropriate to apply a rigid structure that organizes the research process. There are research *methods* of data collection such as focus groups, interviews, and observational writing that can be used sequentially by the phenomenological researcher to generate reliable data. Edward Relph, a phenomenological geographer, explains:

> Phenomenology is quite unlike biology, theology or other "-ologies" because it neither characterizes its subject matter in advance nor indicates the object of its research…the elucidation of Being requires not a rejection of scientific knowledge so much as an attempt to understand the relationships between scientific and prescientific consciousness…one of the aims of a phenomenology of geography should be to retrieve these experiences from the academic netherworld and to return them to everyone by reawakening a sense of wonder about the earth and its places. (Relph, 1989, pp. 15-16)

Another phenomenological researcher, Max Van Manen, points out that "the proper subject matter for…the human world [includes]—mind, thoughts, consciousness, values, feelings, emotions, actions, and purposes, which find their objectifications in languages, beliefs, arts, and institutions…human science involves description, interpretation, and self reflective or critical analysis" (1990, pp. 3-4). Phenomenology can be a "philosophy of action…[that] deepens thought and therefore radicalizes thinking and the acting that flows from it…the thoughtfulness phenomenology sponsors is more likely to lead to an indignation, concern, or commitment" (Van Manen, 1990, p. 154).

I have selected *hermeneutic* phenomenology for my research because the philosophical foundations upon which it rests are consistent with my own assumptions about how meaning is constructed. Social scientists Patterson and Williams (2002) suggest that a researcher's normative philosophical commitments should guide the selection of their methodology. The researcher must understand the "ontological, epistemological, and axiological foundations" of her methodology (Patterson & Williams, 2002, p. 37). Ontological questions have to do with our philosophical assumptions about the nature of reality. Epistemological questions have to do with the methods we used to create knowledge and the resulting limits to and nature of that knowledge. Axiological questions relate to the research *goals* within each different scientific paradigm (Patterson & Williams, 2002). In the following discussion I address these philosophical questions.

My research design draws from the proven approach of Patterson and Williams (2002) whose research employs a hermeneutic methodology to understand people's *experiences of places*, primarily visitors' experiences of public lands (Patterson, Watson, Williams, & Roggenbuck, 1998). They describe hermeneutics as an "interpretive approach to science" (2002, p. 4). Generally defined hermeneutics "is an approach to the analysis of texts that stresses how prior understanding and prejudices shape the interpretive process" (Denzin & Lincoln, 2005, p. 27). Polkinghorne (2000) describes the evolution of hermeneutics from its original purpose as a method to interpret biblical texts, to its current philosophical articulation as a way of generating understanding about human experiences. Polkinghorne clarifies the ontological, epistemological, and axiological foundations of a hermeneutic phenomenological perspective:

- Hermeneutics focuses on “questions concerning what human beings are”
- Hermeneutics suggests “human knowledge is always an interpretive clarification of the world, not pure interest-free theory”
- Hermeneutics claims that “knowledge occurs within a fore-understanding or prejudgment about its object…prejudgment serve[s] a positive function in that its anticipations enable understanding to develop”
- Hermeneutics claims that “understanding occurs through an interaction with others and with documents…through dialogue, a fusion of one’s own initial prejudgments are transformed in a manner that closely resembles an educational process” (2000, p. 121).

Central to hermeneutic phenomenology is the notion that “understanding…always reflects broader cultural viewpoints that are implicitly conveyed through language…expressions of personal meaning should be viewed as self-interpretations in which these more general cultural viewpoints are adapted to the unique contexts of one’s life” (Thompson, Pollio, & Locander, 1994, p. 432). Patterson and Williams (2002) state that “rather than viewing the world as being comprised of a single, objective reality (as in biology) hermeneutic philosophy maintains that there are multiple realities that vary across time, cultures, and individuals” (p. 14). At the same time, hermeneutics should not be considered as absolute relativism because fundamental to this interpretive epistemology is the idea that there is structure to the world and that meaning is shared by individuals (Patterson & Williams, 2002).

Patterson and Williams’ approach not only creates new understandings, it aims to provide action-oriented solutions for land managers and policy-makers (2002) . Their hermeneutic research generates narrative accounts based on in-depth interviews about the meanings people associate with environmental experiences. Through the process of interviewing, the hermeneutic researcher and research participants engage in dialogue to co-construct narratives that convey meanings and illuminate salient themes.

Data Collection and Selection of Participants

I began my research by conducting one pilot focus group with four ecologists to help me refine my semi-structured interview guide (see Appendix A). Data was collected in the form of qualitative semi-structured interviews drawing upon the methods of narrative research described by Bruner (1990), Kvale (1996), and Mishler (1986). In this tradition interviews are conceived of as conversations, or dialogues, where researcher and participant collaborate in the construction of meaning and understanding. Interviews were audio recorded and transcribed using the transcription service escriptionist.com. Transcribed interviews were then checked for editorial accuracy against the original audio recording. The transcripts were then sent via email to the corresponding research participant for an additional check for accuracy and to give the participant the opportunity to withdraw any excerpts for confidentiality purposes.

A purposeful "criterion" sampling strategy (Miles & Huberman, 1994) was used to select research participants. Criterion sampling is used when the researcher wants all participants to have experienced the particular phenomenon under investigation. Participants were limited to ecologists who are currently engaged in ecological research documenting the ecological effects of climate change on mountain species and ecosystems. Participants were identified through a search of scientific publications listed in the most recent review article on the "ecological fingerprints" of climate change by Parmesan (2006) and other articles mentioned in the literature review. (See Appendix B: Research Participants and Interview Schedule).

In order to guarantee that participants were engaged with the phenomena of researching the ecological effects of climate change, I also limited my selection to ecologists who hold a Ph.D. and who were employed at universities, government agencies, or other ecological field research organizations. Because my goal was to ultimately generate narratives that highlight place-based experiences of global ecological change, and because my personal and professional life is immersed in the Rocky Mountain West, I narrowed my selection of participants to those ecologists who conduct their field work in mountains of the western United States. Whenever possible, interviews were conducted in person on location at ecologists' field sites. When this was not possible due to time and scheduling logistics, office visits or telephone interviews were done. Prior to contacting participants, I conducted textual research on their life and work. Using the internet as a source of data, I read participants' peer-reviewed publications and any other pertinent information available such as curriculum vitae, interviews, and videos.

Participants were contacted initially via email. I provided them with a brief explanation of my study and asked them each to participate in a one-hour interview. For this type of study it is standard practice for researchers to interview up to 10 participants (Creswell, 1998). However, for my own purposes, due to the limited number of ecologists who fit the criterion described above, I strived to interview all ecologists who fit the criterion. The total number of participants was 20. In addition to the first round of interviews with the 20 participants, eight follow-up interviews were conducted in order to confirm themes and develop more in-depth perspectives of those themes.

I asked participants to provide non-confidential interviews for two reasons. First, because the research narratives are published here in my dissertation and may be published in other research-related publications and because these narratives will contain descriptions of specific species and ecosystems in mountain regions of the West, it would not be possible to guarantee confidentiality. The number of prospective ecologists who conduct such work is limited, and their identities would likely become known for that reason. Second, because the ultimate purpose of this research is to generate narratives that will be useful toward communicating and educating the public about the ecological impacts of climate change, it is my belief that additional credibility is gained if the identities of the scientists are revealed. I recognize that requesting non-confidentiality potentially limits the depth of personal experience that ecologists are willing to divulge, and I accept this limitation. I explained my justification for non-confidentiality to each participant upon initial contact and again before each interview. Prior to each interview I clarified my research goals and asked each participant to sign an informed consent form (see Appendix C: Informed Consent Form).

The semi-structured interviews began with a brief explanation of my study and the kind of information I hoped to gain from participants. The focus was on understanding ecologists' lived experiences as they engage in their work documenting the "ecological fingerprints" of climate change. Drawing from Thomashow's (2002) suggestion to probe "qualitative interviews with ecologists to ascertain how they think in biospheric terms" (p. 198-199), I strived to gain an understanding of the ecological, experiential, and emotional dimensions of their work.

Data Analysis

Hermeneutic phenomenological data analysis proceeds according to the metaphorical idea of a *hermeneutic circle*. The researcher enters into a circular process of seeking thematic meanings within the text and considering how these meanings are *related* to the overarching research question and purpose. The researcher considers relationships between *parts and wholes*. Moving forward in the analysis, the researcher also returns to earlier interpretations to gain further clarifications and insights. Analysis is a circuitous process of *revealing* meanings and *relating* meanings to one another and the phenomena as a whole under consideration. Patterson and Williams (2002) clarify that the hermeneutic process of *identifying themes* differs significantly from the process of *coding* that is employed in content analysis and grounded theory research. The difference is that the hermeneutic researcher is just as interested in the *relationships* between themes as she is in the individual themes themselves. In this way, hermeneutics is understood as more *holistic* than other types of coding analyses because of its emphasis on understanding interrelationships.

I used Patterson and Williams' (2002) framework for hermeneutic analysis and adapted it to include the use of NVivo qualitative research software as a data management tool. The following is an outline of the steps I took to analyze my data:

1) Interviews were recorded using a digital audio recorder.
2) I personally transcribed the first three interviews and subsequently used a transcription service (www.etranscriptionist.com) for the remainder.
3) I read each transcript carefully and checked it for accuracy against the original audio recording of the interview.

4) I emailed a copy of each interview transcript to the corresponding research participant and asked him or her to check for accuracy and to tell me if there were any portions of the interview that she or he did not want me to include for reasons of confidentiality.
5) After my initial reading and proofing of each transcript, I uploaded it into the NVivo qualitative research computer program. I then began to identify and code *meaning units,* or main ideas in the interview that stood on their own. I did not identify all meaning units; rather, I coded only the meaning units that were related to my research questions.
6) Next, I created *thematic labels* to help organize the individual meaning units. Thematic labels expressed the essence of my interpretation of the meaning unit.
7) I identified eight major themes from the thematic labels to organize my write up of ecologists' experiences. I then selected several ecologists who best exemplified each theme in order to construct place-based narratives. Not all ecologists who participated in interviews are included in the narrative results, but their transcripts informed my interpretations.

Writing and Data Management

I supported my research process with a regular practice of reflective writing and note taking. I kept a research journal that contains personal reflections and observations on climate change and insights gleaned during and after interviews and from reading related texts. I strived to deepen my understanding of phenomenology as a philosophy in order to engage with the research data from the perspective of a phenomenologist. There are five kinds of information that I recorded in my research journal notes:

- Reflections on my own experiences and insights about experiencing climate change
- Notes on relevant literature
- Notes on logistics (correspondence with co-participants, interview dates and locations)
- Notes about my experiences conducting interviews
- Notes taken while analyzing each transcript to determine and interpret meaning units

This regular practice of writing supported my findings and the development of this dissertation. I have kept the idea in mind that the final narrative that flows from this research process should be a series of compelling stories in order for them to eventually become useful in communicating with a broader audience. Van Manen (1990) states that "the aim…is to transform lived experience into a textual expression of its essence—in such a way that the effect of the text is at once a reflexive re-living and a reflective appropriation of something meaningful" (p. 36). The following eight chapters of this dissertation comprise the results of my data analysis and writing as described above.

The eight experiential themes that emerged are: thinking ecologically, place-based ecologist, seeing shifts, coping with complexity, paleo-perspective, crossing thresholds, triage, and silver lining. Each chapter highlights the ecologists whose personal stories best exemplify the most salient themes that I discovered during analysis. Prior to the description, or account, of the ecologists' experiences, each chapter includes a brief introduction that orients readers to the theme being described. I have deliberately chosen not to include personal communication citations in the text. In effect, one might consider the following eight chapters as a *field guide* to mountain ecologists, their methods, and lived experiences.

RESULTS THEME ONE: THINKING ECOLOGICALLY

Introduction

In this chapter I address the first of three major research questions guiding the dissertation: How do ecologists describe the experience of thinking ecologically as compared to a lay person? Before we can understand what it is like for ecologists to experience the effects of global climate change, we must first understand how these scientists perceive and make sense of the world around them. This chapter considers ecology as an epistemology, a way of knowing and apprehending knowledge about life on earth and issues such as climate change.

I organize the chapter using subthemes related to the experience of thinking ecologically. Analysis across all interviews revealed four characteristics of ecological thinking. First, ecologists describe their research projects as complex "puzzles" with "interconnected pieces and processes." Second, in order to solve such puzzles, ecologists use a process of "critical thinking" to "figure out cause and effect." Third, throughout their thinking process, ecologists employ a variety of "tools" and look at their research projects from multiple "angles." Fourth, ecologists suggest that they experience *time* differently than lay people do. Because many of them monitor seasonal and annual changes in ecological processes, ecologists suspect they have a longer-term perspective.

In order to convey the above characteristics of ecological thinking in a place-based narrative form, I tell the story of Dr. Jill Baron who oversees research on the "longest running subalpine study site" in the world. I present Baron here because her project is a classic example of ecosystem studies. She considers her work in Rocky Mountain National Park as a multi-faceted "program" located at the "epicenter" of field research on global environmental change and mountain ecosystems. While Baron's experiences are the focus of this chapter, my interpretations draw from interviews with other ecologists who shared their insights on what it is like to *think ecologically*.

Dr. Jill Baron

It is 7:00 on a mid August morning, and the headquarters parking lot at Rocky Mountain National Park is empty. Weeks beforehand, Dr. Jill Baron and several other scientists made plans to meet here for a data collection outing to Baron's long-term study site. As I wait for the ecologists to show up, a small group of hikers equipped with poles, binoculars, and backpacks, enters the lot and carpools to a nearby trailhead. A few moments later a non-descript beige sedan pulls into the lot and three people get out, one woman and two men. Then, from around the headquarters building, a slender, tall, young man in Park Service uniform walks out and greets them. The group of scientists has arrived.

Dr. Jill Baron is a petite, wiry, energetic woman. She has short brown hair, and this morning she proudly wears a worn-in, floppy white, safari-style hat adorned with a colorfully woven band. "I found this hat a couple weeks ago when I was hiking with Jesse in Montana." (Jesse Logan is another ecologist who researches the effects of climate change on mountain ecosystems.) Baron's baggy, khaki field pants, t-shirt, and sturdy leather hiking boots lend themselves to her casual yet directed demeanor. Her gentle command of the moment, amongst a group of male colleagues, hints at her scientific stature. Every Tuesday since 1983, Baron, or one of her assistants, has made the 3.6 mile hiking, or winter skiing, ascent to gather data for the Loch Vale Watershed

Project at the longest running subalpine research site in the world. I join the group. We get into the beige sedan and head for Glacier Gorge Trailhead.

Baron's list of scientific accomplishments includes awards from the federal government, appointments on scientific advisory committees, and testifying before Congress. She grew up in the aura of the 1970s environmental movement, and her family played a large role in inspiring her to make a difference in the world. "I came from a long family philosophy of wanting to give back—that we're placed on this earth to make it better. I wanted to work in nice places, and I wanted to help the environment." When she was eighteen, Baron landed a job as a volunteer for the National Park Service and was employed by a "wonderful woman and mentor" who involved Baron early on in scientific research. That's how Baron began her career with the federal government.

Over time she "realized that the more intellectually satisfying way" to make a difference in the world would not be as an environmental activist but as a scientist who could provide the "grounded rock-hard information that people could use." Baron also attributes her passion for science to an inspirational high school biology teacher in Madison, Wisconsin who led field trips over spring breaks. He took students to the mountains, coast, and deserts to compare ecosystems. Baron says a huge number of his students went on to get Ph.D.s in environmental studies because of his influence.

Baron's own field research in mountain ecosystems began 28 years ago when she was working for the National Park Service in Washington D.C. In order to get out of the city and into the mountains, Baron pitched to her supervisors a novel way to study air pollution. She proposed to analyze *sediment cores* collected from the bottoms of lakes located high in Rocky Mountain National Park. Baron knew that the fine particle debris on lake bottoms could point to evidence of atmospheric change, evidence that might have important implications for managing National Parks. She explains that the oldest sediments are found in the bottom layers of a lake with sequentially more recent sediments found toward the upper layers. Each layer of sediment corresponds to a historical time period, providing a microscopic snapshot of the surrounding environment during that time period.

Baron and her colleagues collected and dated hundreds of sediment cores. The oldest sediments date back to 12,000 years ago when mountain glaciers retreated and left U-shaped valleys and alpine tarns, or lakes, in their former paths. Baron describes her discovery of “an initial period of environmental change that was about 1,000 years ago” when the glacial topography settled into its current form. By observing the size of the particles in the sediment cores, Baron could correlate the debris with the atmospheric temperature during that time period. Larger particles were found during warmer periods when glaciers above the lakes melted rapidly. During cooler periods, glacial ice remained more intact and slowly released more finely grained sediments. But at that time, during the 1990s, Baron was less interested in atmospheric temperature change than she was in finding evidence of air pollution. She looked for signs of chemicals and metals such as lead, cadmium, zinc, and copper that would have come from power plant smokestacks coinciding with the onset of industrialization in the region. She also looked for changes in diatom biodiversity. When lake diatoms die, they leave behind their glass cell walls. Since the cell walls are species specific, and each diatom species has varying degrees of tolerance to chemicals, the diatoms provide a historical index of lake chemistry.

Baron says, “starting about 1950 we saw almost a complete change in the algal diatom flora in these lakes.” Before the change, diatoms were indicative of very nutrient-poor alpine lakes. After the change, over a period of six to ten years, they became indicative of more nutrient-rich lake environments.

> Two species came to dominate the flora…before there had been a hundred-and-some…they had been in these sediments and lakes all along, but conditions were ripe for them to take over…they are responsive to atmospheric nitrogen deposition…We showed that even though we don’t have dead fish floating in the water yet, we’re on a trajectory of change, and we caught it early enough.

Baron’s discovery of nitrogen pollution was a wake-up call for the National Park Service. The federal government started talking with the Colorado government, and now there is legislation to reduce nitrogen emissions. Baron considers her discovery of nitrogen pollution, and the resulting changes to legislation, as one of her greatest contributions to science and society. Now she would “like to be part of that same movement for climate change.” Today, Baron continues to devote her professional life to understanding mountain ecosystems. She is an Ecosystem Ecologist with the United States Geological Survey (USGS) and a Senior Research Scientist with the National Resource Ecology Laboratory at Colorado State University.

Baron’s study of lake sediment cores also led to an expanded research program looking at global environmental change in Rocky Mountain National Park, including the long-term ecological monitoring of Loch Vale Watershed.

Loch Vale Watershed: A Dynamic Ecological Puzzle

In contrast to the quiet, empty parking lot at the headquarters, the lot at Glacier Gorge Trailhead is bustling with eager hikers. Apparently we aren’t the only group that wants to reach our alpine destination before the typical afternoon thunderstorms and lightning move in. Before we set out on the trail we divide up the weekly load of research equipment that Baron and her team use to monitor Loch Vale Watershed. The watershed has been “instrumented” with data collection devices,gauges and sensors that measure biogeochemical processes. The Loch Vale study site is like a long-term ecological puzzle. Baron and her research team use a variety of scientific “tools” and perspectives to piece together intricate ecological patterns of environmental change.

This particular morning, Baron carries a dark blue expedition-size backpack with two 7-gallon sterilized buckets wrapped in clear plastic. Every week Baron, or someone on her research team, collects the two buckets that gather precipitation at Loch Vale and replaces them with two new fresh sterilized buckets. The used buckets are then carried back down the trail and sent to a special laboratory for analysis of atmospheric chemicals and heavy metals. Through Baron’s regular systematic analysis of the contents of the buckets, she can account for any particulates that fell from the sky the week prior to their collection. At this point in time, Baron has approximately 1,300 weeks’ worth of Loch Vale precipitation data. She considers her monitoring of Loch Vale as a research “program” that integrates many different kinds of tools and data that are synthesized to create a “body of understanding.” She says that running the Loch Vale Project is “like running a household.” Baron “tucks away” all of the various bits of scientific information so she can use the data as it becomes pertinent. Despite fairly dramatic decreases in funding, Baron has kept the project going for 23 years. Federal financial support is now only a fraction of what it used to be. But, at least for now, Baron remains committed to securing resources and maintaining this important mountain study site.

The ascent to Loch Vale Watershed begins through a mixed forest of Engelmann spruce (*Picea engelmanni*), subalpine fir (*Abies lasiocarpa*), and small groves of quaking aspen (*Pupulus tremuloides*). After we've hiked for almost an hour, the trail forks, and we climb a bit further into the sparsely treed subalpine zone, the lower boundary of the watershed. Spanning five miles in length, and at almost 3,000 feet in elevation, the shape and form of Loch Vale Watershed is evidence of its glacial past. The surface of the watershed is a mosaic of bare rock, boulder fields, snow, and ice. There are also small patches of alpine tundra, subalpine meadows, and forests. Up to 80 percent of the watershed's annual precipitation is snow (Baron, 1992). With its uppermost boundary at 13,153 feet and its lower boundary at 10,200 feet, Loch Vale's elevational and spatial configuration provides a geographically delineated "ecological system" for scientific research.

Baron defines Loch Vale watershed as an *ecosystem*—an ecological concept that sits within a nested hierarchy of other ecological systems. From smallest to largest these systems include: organism, population, community, ecosystem, landscape, biome, and ecosphere (Odum & Barrett, 2005). The ecosystem concept provides a way of organizing scientific ideas and creating an *object of study* with defined boundaries. As is the case with Loch Vale, an ecosystem can be considered a puzzle of interconnected pieces and processes that scientists monitor for evidence of environmental change. Along the hierarchical spectrum of professional niches, Baron considers herself an "ecosystem ecologist" who looks primarily at biogeochemical processes, "a fancy name for looking at carbon and nitrogen cycling."

Baron and her team use the "small watershed technique" originally developed in the 1900s by the U.S. Forest Service at Wagon Wheel Gap in Colorado. The technique became well known later, in the 1970s, when scientists applied it to a long-term study of

Hubbard Brook ecosystem in New Hampshire (Baron, 1992). The Hubbard Brook study is a classic example of ecosystem research, and authors of ecology textbooks commonly cite it as a model design (see Odum & Barrett, 2005). Based on the small watershed ecosystem design, Baron and her colleagues have developed a “conceptual biogeochemical flowpath model” of Loch Vale. The flowpath model is portrayed in an organizational diagram that shows interconnections between: precipitation, vegetation, soils, bedrock, freshwater, biota, and sediments operating within the ecosystem (Baron, 1992). Whereas the casual hiker visiting Loch Vale might experience the place as scenery—a pristine alpine landscape with crystal blue lakes and craggy steep peaks—Baron also experiences the place through the lens of ecology. For example, by scientifically tracking the flow of nitrogen molecules through Loch Vale, Baron is able to perceive how this nutrient is intricately related to all of the other components in the ecosystem.

Baron describes ecological thinking as a “way of approaching issues or questions critically that sets scientists apart, unfortunately, from everybody else.” She says that ecologists question everything they are exposed to, and ask “Is this logical?” and then try to come up with a train of thought that enables them to move from point A to point B to point C. “You delve into everything you look at logically and try to figure out cause and effect.”

Other ecologists interviewed for this dissertation elaborate on what it is like to think ecologically as compared to how a lay person thinks:

> “One of the things we try to do is think about the whole system and how the pieces interrelate…we’re trying to figure out how all these pieces fit together and its pretty messy…there are too many variables.”

> "The way I think about things is sort of that those linkages, the system, is something where one thing is linked to another. One thing may be linked to many different things, and then the other thing that they're linked to might be linked to many other things. Systems can be incredibly complex!"
>
> "So, what's it like to think systemically? I don't know exactly how to answer that…you can think in terms of geometric interconnections. There's a way of picturing a system that can be aesthetically pleasing and enlightening. You can think about it in terms of analogs with physical systems like electrical networks and things. But you can't forget the fact that many of the components of the system are living and possibly evolving creatures."
>
> It's like "thinking about issues in physics…the understanding of complexity that lies behind relationships as well as the uncertainty."
>
> "It's hard, but that's what science is; you're trying to push things forward and understand things in a way that other people don't understand them, so you have to look at them in a different way…a different angle."
>
> "We tend to see things as bi-directional…to think about resilience in a system…to think about persistence."
>
> "We don't really need to solve everything at once. Science can advance by incremental steps…tackle a complex problem by inching forward."
>
> "The reductionist way of doing science is that you try to hold everything constant and play with one variable at a time, and that gives you an insufficient answer, so the frustration is large…trying to find a sane way of dealing with this complexity is truly the challenge."
>
> "I'm sensitive to the fact that there is a lot of year-to-year variation that happens on a regular basis, and therefore it's necessary to step back and see what happens on a longer-term basis, both in terms of trying to explain things and to see patterns."
>
> "Humans have a great effect on systems…we're not starting from a starting point of a natural landscape…we have to know something about those landscapes and their history, and the disturbance history…it's a tough job and it's humbling to know how much we know and then on the other side of the equation how much we just don't know."

These ecologists paint a picture of what it is like to think ecologically. Their epistemology is founded on conceptualizing the world as a dynamic, interconnected, complex, and *whole* system. This whole system is comprised of multitudinous pieces, or variables, that constantly interact and change. In order for ecologists to understand how the whole system operates, they isolate the individual pieces and work toward understanding the relationships between them. Ecologists look for patterns. They persevere, one incremental step at a time, as if they are solving living puzzles that never stop changing.

In order to approach the living puzzle of Loch Vale Watershed, Baron and her team have developed four *research objectives* geared toward one of the National Park Service's most pertinent management issues—climate change. These objectives help them create boundaries for asking questions about the Loch Vale system. The objectives are: 1) to understand the difference between natural environmental change and human-caused change, 2) to understand and quantify the role of climatic change, 3) to apply new research methods for looking at the effect of climate on winter snowpack, and 4) to estimate how changes in regional and global climate can potentially change the subalpine and alpine ecosystem. These research objectives, simply stated here, may not convey the ecological intricacies and complexities lying behind them. Baron and her team need to carefully approach each objective using a variety of ecological tools and perspectives.

Solving Puzzles with Ecological Tools

Baron says she and her team use as many ecological *tools* as possible to support their observations, add new evidence, or give more insight. She describes five different kinds of tools used at Loch Vale: paleoecology, long-term monitoring, experiments, surveys, and computer modeling. Paleoecological tools are used by ecologists to apply "ecological concepts to fossil and sedimentary evidence" in order to understand earth's environmental history during prehistoric times (Allaby, 1994, p. 286). For example, Baron's use of *paleolimnology*, a subset of paleoecology that focuses on lake sediments, provided her with insight into how lake chemistries changed after glaciers receded 12,000 years ago. Baron says *long-term monitoring* is another very important tool because it allows her to see the kinds of changes that occur over seasons and gives evidence of long-term trends. She also points out that "monitoring is only as valuable as the interpretation of data…my soapbox is monitoring without assessment…we need to gather knowledge not just data."

Baron and her team also use *experiments* because, as she puts it, "that's really the only rigorous way you can test cause and effect." She describes "really cool experiments with fertilization where in the lakes we set up mesocosms made out of hoola hoops with plastic sheeting." In their classic textbook *Fundamentals of Ecology*, Odum and Barrett (2005) explain that *microcosms* are "little self-contained worlds…in bottles or other containers, such as aquaria" where ecologists can "simulate in miniature the nature of ecosystems." *Mesocosms* then, are "large experimental tanks or outdoor enclosures—mid-sized worlds" that are "more realistic experimental models because they are subjected to naturally pulsing environmental factors" (p. 60). Baron and her team added nitrogen and phosphorus to their floating mesocosms and then watched the ecological events unfold. Subsequent algal growth hinted at the kind of ecosystem change that would occur if industrial atmospheric particulates were not curtailed. As ecologists have seen with other ecosystems, nitrogen loading leads to lake eutrophication.

The last two ecological tools Baron and her team use are *surveys* and *computer models*. "Surveys are important because they give you credibility if what you're seeing is representative or not." In order to know if what she is seeing at Loch Vale is typical of other Rocky Mountain watersheds, Baron has surveyed other subalpine lakes and forests, both east and west of the Continental Divide, in Colorado and Wyoming. Finally, computer models are also an important component of Baron's work because they represent a quantitative understanding of the Loch Vale ecosystem. She says:

> If you can't describe it mathematically, then you're missing the boat…[a model] represents how close or how far off we are from understanding what actually goes on…you can ask questions of it that would take many years to actually observe on the ground: What would happen if the climate warmed? What happens if precipitation declines by 50% each year? We can play those kinds of "what if" games without actually doing something drastic on the landscape.

Baron says that by using these tools she has recently seen some interesting phenomena in the Loch Vale system that she thinks "are due to climate change." Starting about 1999, Baron and her team discovered an intensive episode of warm temperatures and low precipitation that was recorded throughout much of the western U.S. She says "it caused earlier snowmelt" and "at least in a couple of years, more discharge." Baron observed more stream flow *leaving* the watershed than was *entering* as precipitation.

> This wasn't a mistake of our not measuring enough precipitation. What we were seeing was warm enough temperatures that started melting out glaciers, permanent snow and ice…we're doing ecosystem modeling to find out how long it would take for our systems to lose all of their permanent snow and ice.

If the trend continues, Baron anticipates she will see changes in the hydrologic cycle, "and that will have big implications for the biology." She and her colleagues have already observed changes in lake chemistry due to the melting glacier "exposing delicious sediments…active microbial cells…with a whole lot of mineralization going on."

The ecological tools that Baron describes are also used by other scientists interviewed throughout this dissertation. In subsequent chapters I go into more detail on ecologists' experiences using a variety of these tools. But in addition to using a process of critical thinking and approaching issues as complex ecological puzzles, how else might *thinking ecologically* influence an ecologist's experience of the world? Baron and other ecologists suggest that thinking ecologically lends itself to a different experience of *time.*

Experience of Time

Baron suspects that having an ecosystem perspective gives her a different sense of time than a layperson would have. Given that her work involves looking at biogeochemical processes in the mountains, processes that can only be understood by looking at patterns of environmental change over long periods of time, she has gained patience and a long-term perspective. She says:

> I think that is a really important perspective. I read a wonderful book, *The River that Flows Uphill*, about human thinking and brain patterns. The author was a neurobiologist who said that people have a perspective that is usually about four years before they forget what things were like. Unless we train people to think longer and take a more environmentally realistic view of what's going on around them, we're continually trying to change their minds. There's lots of cynical ways of looking at that; people think in terms of political cycles. I think it's hard-wired in the human brain to *not* think long-term necessarily, until you have children. I think a lot of people think inter-generationally once they have a child.

Having children may help but so does the kind of perseverance that Baron brings to her ecological research at Loch Vale. Her close observation of lake sediments, the relic cell walls of diatoms and glacial silt that settled out of lake waters thousands of years ago, presents Baron with hard evidence that the mountains are in a constant state of flux.

Baron's recent discovery of glacial melting due to climatic warming could only be observed as a measurable signal of environmental change within a larger pattern of annual variation, a pattern that emerged across two decades of data collection. As a result, Baron is a strong advocate for long-term monitoring, especially in National Parks. She says:

> There's no substitute for these long-term data. They are the evidence of what's going on…the legacy is extremely important. And it's cause for concern—who is going to keep these projects going?...As the country becomes ever more developed, parks become an important stand-out of natural processes.

Bringing this point home, Baron was recently the lead author of a chapter on National Parks in a report to Congress titled *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources* (Baron, et al., 2008). In this report she emphasizes not only that National Park ecosystems are certain to change in the coming decades but also that it is important for park managers to adopt pro-active strategies in order to maintain biodiversity and functioning ecological communities. As we walk along the trail, Baron engages in conversation with the young park ecologist who has joined our outing. The park ecologist is relatively new to his position, and Baron takes care to explain the importance of long-term ecological monitoring within National Parks and the precarious nature of both human and financial resources to keep the Loch Vale Project up and running. Just like running a household, Baron nurtures her research project and works carefully to enroll support from as many people as possible.

Chapter Conclusion

This chapter provides a narrative description of what it is like for Dr. Jill Baron and other ecologists to think ecologically. Baron's long-term research at Loch Vale Watershed in Rocky Mountain National Park highlights how ecological thinking, or ecological epistemology, can be thought of as a process of critical thinking about complex ecological issues. Baron perceives the watershed as an ecosystem, cycling at differing spatial and temporal scales, with natural and anthropogenic biogeochemicals.

The natural world is understood by breaking it into pieces, objects of study. Information gathered by ecologists is synthesized and looked at from different angles. Ecologists want to make a difference in the world, they are personally committed to long-term monitoring projects, and they consider their long-term data as legacies. Because of their understanding of earth's geologic and ecologic history, ecologists suggest that they may have a different, longer-term, perspective on time than a lay person would. Two other ecologists, whose long-time presence in two different western mountain ranges, shed light on what it is like to be a *place-based ecologist*. I turn to their stories in the next chapter.

RESULTS THEME TWO: THE PLACE-BASED ECOLOGIST

Introduction

In this chapter I explore the experience of being a *place-based ecologist*. Most of the ecologists interviewed for this dissertation have spent a large part of their careers studying ecology in one, or at least very few, particular places. Their long-term research at specific places gives them insights that they might not otherwise have. A place-based ecologist is someone who inadvertently "specializes in a place" in addition to their emphasis on a particular species or ecological scale. The place-based ecologist tends to be "broadly curious" and pulls together many perspectives and lines of evidence to understand landscape change and ecological events. Because they must always find ways of keeping their long-term research projects going despite limited funding, they are resourceful, and they involve other people in their efforts. They develop an attachment to their places and feel a sense of loss when faced with irreversible ecological changes, such as the loss of individual trees or species they have come to consider as "friends."

I present the field research and experiences of Dr. Craig Allen and Dr. Nate Stephenson. Their work offers insights into what it is like for ecologists to experience climate change impacts at specific places they have grown to intimately understand and love. Their stories also demonstrate how it is that some ecologists come to be immersed in and attached to one place and how they come to understand their place within the larger context of global environmental change.

Dr. Craig Allen

Dr. Craig Allen is a self-proclaimed "place-based ecologist." His professional title is Research Ecologist and Station Leader at the USGS Jemez Mountains Field Station at

Bandelier National Monument in northern New Mexico. Allen grew up in rural Wisconsin, and, during a spring break from his junior year in college he landed a volunteer teaching position in Espanola, New Mexico. This was in 1979. As it turns out, Allen soon found himself falling in love with one of the classroom teachers in Espanola. Although he did eventually return to Wisconsin later that year to finish his bachelor's degree in cultural geography, Allen came back to the mountains and mesas of New Mexico to marry that teacher, and he has been there ever since. He completed his master's degree in biogeography from University of Wisconsin and his Ph.D. in forest ecology from University of California at Berkeley, always returning to New Mexico whenever he could. He conducted his research for both graduate degrees in the Jemez Mountain Range where he still spends most of his time today.

"Fortuitously," Allen says his doctoral research on forested landscapes in the Jemez Range led to a permanent position working for the National Park Service at Bandelier National Monument. Allen attributes his good fortune to being physically present on-site and making himself useful to land managers. His friendly face, his sandy-brown, bowl-cut hair, big round glasses, and dimpled-chin give him a deceptively boyish look. One might not suspect the brilliant scientific mind and encyclopedic memory behind his appearance. When he speaks it is as if his mouth can barely keep up with his thoughts.

Allen's office within the headquarters of Bandelier National Monument has a small adobe fireplace in one corner and a shower stall in the other. Reference books line the walls, and the sheer volume of information packed into the tiny space makes the room feel like it might cave in on itself. This small space is a treasure trove of information about Bandelier and a subtle reminder of Bandelier's more recent history. Built in the 1930s by the Civilian Conservation Corps, Allen's office was once a sleeping quarters for a popular guest lodge through the 1950s. On the outside, the Pueblo revival-style structure, with its low-profile and red bricks, is camouflaged within the steep canyon walls and ancient cliff dwellings surrounding it. Located one hour's drive from Santa Fe and five miles from downtown Los Alamos, Bandelier National Monument can be a very busy place in the summer. Allen says the parking lot is typically full by mid-day, crowded with tour buses and summer vacationers. Because of its lack of any substantial roadways, Bandelier is known as a "hiker's park." There is only one three-mile road that steeply descends into Frijolito Canyon, the site of the park's visitor center headquarters (Hoard, 1989). Otherwise there are 70 miles of hiking trails weaving throughout the 33,750 acre monument. Allen says that Bandelier National Monument is, by far, the smallest property managed by the National Park Service that has its own *in-house scientist*.

Even though Bandelier is a very small monument, known more for its archeology than its ecology, Allen's discoveries have placed it on the maps of climate change scientists around the world. Beginning with his Ph.D. research, Allen was "explicitly looking at the big picture of landscape change" in the Jemez Mountains, including ecological patterns and processes and cultural trends in land-use change. With his first-hand knowledge, he created an "initial framework" of how the place had changed during the last century and a half, and what Allen found suggested there were "significant issues" to address. Allen now sees himself located at the ecological "epicenter" of large-scale disturbances due to climate change. He is working in the midst of unprecedented catastrophic forest fires, drought-induced forest dieback, extreme insect outbreaks, and rapid soil erosion. “If you think of these four big disturbances…this is a great place to study those things…it’s been a lucky place to be…scientifically because they are right here in our face…and it turns out that these things are relevant in other places as well.” Allen’s research starts at the local level, but he collaborates with other scientists around the world, piecing together discoveries that connect to broader regional and global issues. Right now he is working with people in Mediterranean Europe, particularly in Spain, where especially warm, dry climatic trends are driving similar ecological disturbances.

It is difficult to convey the magnitude and complexity of landscape-scale disturbance that Allen has observed over his 20-plus years in the Jemez Mountains, but a microcosm of these events exists in a one-hectare study site that he has kept close watch of for over 15 years. The Frijolito Watershed is easily accessible from Allen’s office. In contrast to the cool shelter of ponderosa pine (*Pinus ponderosa*) and narrowleaf cottonwood trees (*Populus angustifolia*) growing along the canyon floor where the visitor center is, the Frijolito Watershed sits higher up above the canyon walls on a sun-baked mesa top.

The centuries-old trail leading up to Allen’s study site is a series of sandstone stairs and switchbacks. While taking a moment to catch our breath and cool off in the shade of a piñyon pine tree (*Pinus edulis*), Allen points out ancient cave dwellings on the other side of the canyon. The hand-carved ruins are evidence of almost 500 years of Indian occupation (Hoard, 1989). The enduring yet silent presence of these dwellings is a reminder of what it means to be *place-based*. Before the science of ecology was ever conceived, the people who lived here centuries ago must have had an intimate understanding of the relationships between land, climate, and fire, the same kinds of ecological connections that Allen mulls over today. We continue climbing the switchbacks. Once we reach the canyon rim, we head west toward Allen's Frijolito Watershed study plot. Located near a prominent archeological site, it is nearly impossible to take even one footstep without crushing a potsherd or other archeological relic into the soil. Like a mosaic of memories, dime-sized chips of stone and clay speckle the hot bare ground.

Within the spatially-defined ecological study site of Frijolito Watershed, Allen and his research team have mapped each and every shrub and tree. They number in the thousands. Allen's team has also installed a network of drain pipes and a series of small catchment basins to monitor soil erosion rates. Segments of rebar mark an underground labyrinth of PVC pipe. Casual hikers might stumble upon Allen's study site and think they have entered some kind of archaic booby-trap system. But the focus here is on looking at long-term "patterning of vegetation and how it drives runoff and erosion." Allen's discoveries are reinforced with other ecological tools. His study of tree rings reveals a series of land-use changes and disturbances over the past 150 years.

The area was once covered with a ponderosa pine forest. Then a heavy pulse of sheep grazing began in the late 1850s and ran through the early 1900s. Due to grazing and the subsequent decrease of grasses on the forest floor, natural surface fires that were once historically ignited by lightning waned in frequency. The grasses prevented soil erosion and kept out invading plant species. Once the grass was mostly gone, the forest floor became transformed into a series of interconnected patches of bare ground. In 1950 a severe drought killed each of the 100 ponderosa pine trees within the watershed. The trees were hundreds of years old, and none of them regenerated after the drought. By default, a more drought tolerant piñyon-juniper woodland took hold in the bare soil. Now, in more recent decades, Allen says another drought has killed almost all of the piñyon trees. The watershed now hosts junipers, shrubs and weedy forbs. Allen says there have also been “really dynamic changes in the runoff and erosion processes.” Given the rate of erosion he is observing now, the 100,000-year-old soils will be gone from all the mesa tops in 200 years. The land use history of livestock grazing and fire suppression has “basically desertified inner spaces between the woody plants.” The highly connected bare soil patches are slowly washing away with the rains, and they don’t heal themselves on their own.

Without Allen’s keen watchful presence at Bandelier Monument, the details of this ecological chain of events could not have been so well explained and documented. Recently, Allen published his observations in an article titled *Interactions Across Spatial Scales Among Forest Dieback, Fire, and Erosion in Northern New Mexico Landscapes* (2007). The article describes the complex ecological shockwaves—disturbance processes and ecological thresholds—that emanate from Allen’s epicenter of place-based research at Bandelier.

As a result of working in the same place continuously for almost three decades, Allen says he has come to know the place better than the world he grew up in back in Wisconsin. He remarks, “I’m not just a repository of scientific perspectives, and data, and history about this place, but, effectively, I’m the institutional memory for a lot of things.” As a self-proclaimed “place-based ecologist,” Allen exemplifies the kind of field scientist who ends up specializing in a particular place rather than a specific species or ecological process. Place-based ecologists may be specialists of one place "but that tends to be pretty generalized at some level." A large part of what Allen has done at Bandelier is facilitating research by other people, helping them get established, and supplying them with background information. Through the process of such scientific networking, Allen says he "ends up learning from all the other people that come through and do work in this landscape." He points out that being a place-based ecologist takes a certain kind of temperament, and the scientists who have been most successful at it in the National Parks are "user-friendly" in terms of working with managers. "Another part of it is just being kind of broadly curious…liking to help and manage all these different little lines of evidence…learning from other people… and being able to put all of that stuff that you learn…into a framework for this place…it selects for a certain kind of thinking style."

Although Allen considers his long-term presence at Bandelier somewhat of an "accident," he has thoroughly enjoyed the opportunity and "come to love this place." Even when there is no funding to keep his long-term research running, he finds ways to keep taking measurements. The long-term data sets are "powerful…hard to get…and relatively rare." Allen attributes the model for his place-based approach to Jan van Wagtendonk and other ecologists at Sequoia-Kings Canyon National Park and Yosemite National Park. He says Van Wagtendock has been at Yosemite for "probably 35 years or more…there's a few of us left, these place-based scientists."

Allen considers his place-based perspective like a kind of "perceptual weaving." He admits he has never truly woven anything, but, like a Navaho weaver

> with the warp and the weft, you start out with this kind of coarse-grained framework, and then you weave in more threads through time and develop some increasingly intricate patterns…I'm able to weave some little piece…into that

> tapestry and say, "Oh, I can see how that connects with something else over here."

Allen views his perceptual weaving as part of the service function of his job with the Park Service. "The public pays my salary to have this chance to learn about this place, and part of what I should do is helping people gain some benefit from those connections." So Allen takes his role as a weaver seriously, pointing other people in the right direction so that "they can follow that thread back to the source…and get the full perspective of whatever it is they're interested in." Reflecting on his role, Allen says it is an…

> …odd thing to be still pretty young, but for a long time to have been considered *the* expert in this landscape…I have a breadth and depth of perspective and knowledge that I'll never replicate anywhere else…transfer me to South Florida to support the Everglades, and I wouldn't be worth a damn there for a long time.

The information Allen has gathered ranges from "little factoids" and "founts of eco-trivia" to some "fairly strong perspectives about what's really important process or pattern-wise in this landscape."

Part of what has enabled Allen to stay at Bandelier for so long is that he still learns something new every time he walks around, "even when it's just a casual, fun walk," which he does a lot. He says he is "not even close to getting bored yet…the learning curve hasn't really flattened out." Allen admits that sometimes he toys with the idea of working somewhere else, but, he says, "it would hurt to leave this place, this landscape…I'll never have this kind of relationship to a particular landscape again…life's too short…I've got a lot of years yet, but I'm not going to be able to really burrow into a place and work so hard again." As a result of being in one place so long Allen also says he has many "loose ends," and much of what he spends his time doing these days is trying to keep his long-term monitoring projects alive. They give him a "finger on the pulse of some interesting things that are going on."

Like many other ecologists interviewed for this dissertation, whether there is funding or not, Allen finds ways of keeping his projects going. Right now he is associated with the Western Mountain Initiative, a consortium of scientists "looking at climate-induced ecosystem responses and disturbance processes." Allen has been able to use that initiative as an umbrella to secure some funding. He has also trying hard to get the word out about what he has seen. "I've got a lot of cool stuff I'm working on these days and trying to figure out a way to make that useful and have some impact." Last summer at the Ecological Society of America's annual meeting, Allen organized a session on *Climate-Induced Forest Dieback as an Emergent Global Phenomenon*. He gathered colleagues from Australia, Europe and Africa, who presented their own findings of climate-driven forest dieback process, a global phenomenon that Allen considers an "underappreciated risk." Changes in forest ecosystems due to drought could lead to fundamental shifts in species worldwide. Allen's global perspective is grounded in place-based observations.

Over the years Allen has closely studied the Jemez Mountain landscape, and he has developed an attachment to place that transcends the scientific:

> I guess as a human being, we get feelings, we get nostalgic about things, and attached to…patterns on the landscape…that we attribute value to in various ways, and so some of the changes, like the big dieback events of various tree species in 2002…And it's still continuing to some extent…but the first trees for a lot of species on a lot of sites that die are the biggest, oldest trees…There's a part of me that is saddened to see certain kinds of changes, just because I like big old trees on landscapes…There's this interesting scientific phenomena going on…There are important implications, and they are of societal and scientific interest as well. So it's a great science opportunity, but there's another part of you that, you know, places that you know well, that you've walked in hundreds of

> times…Well anyway, again, I've lost a lot of trees that I considered, you know, kind of friends that I paid attention to on the landscape that have died.

Allen is not the only mountain field ecologist with such a deep connection to place. In fact, most of the ecologists interviewed expressed their own attachments to different places they have come to know and love. Another ecologist who stands out because of his life-long presence in one mountain range and his observation of fundamental forest ecosystem changes is Dr. Nate Stephenson.

Dr. Nate Stephenson

Dr. Nate Stephenson has a very strong sense of place. Stephenson is a fifth generation resident of California's southern Sierra Nevada mountain range, and he began working at Sequoia-Kings Canyon National Park in 1979. Like Dr. Craig Allen, Stephenson is a USGS Research Ecologist who works out of a field station located within a U.S. Department of Interior property. He is also Director of the USGS Sierra Nevada Global Change Research Program. Stephenson says "though I am mostly a…global change biologist, a forest ecologist , and a fire ecologist, I have worked a little more broadly than that…like a backcountry campsite inventory…ecology of the foothills…acid deposition, things like that."

Stephenson grew up spending time in the outdoors. He says "I chose my dissertation topic purposely as an excuse to get myself backpacking in the Sierra Nevada…I wanted to be out there collecting the data myself." That dissertation which he finished in 1988 eventually led him to the important climate change related work he is involved with today. He explains:

> The topic was how climate controls the distribution of vegetation types. I was really primed to think about climate and how it affects trees…1988 also happened to be the same year that Jim Hansen spoke before Congress…My supervisor at

> the time put together a proposal for climatic change research…We got that funding…I was left in charge of that program…Now it's been integrated into a larger program called the Western Mountain Initiative.

The long-term forest monitoring plots that Stephenson began his research with have given him "insights about just how dynamic forests are and how they're changing all the time." He distinctly remembers thinking about the early forest monitoring plots established in the 1980s and realizing that they wouldn't give "any quick answers…They were mostly concentrated at one elevation…and around 1990…I said, 'one way to figure out how climate affects forests is to look at a natural experiment'…how forests behave along an entire elevational gradient." Then, to Stephenson's "surprise" the "greatly expanded" forest plot network began to show a "very strong pattern."

The high elevation forest, or the "cold forest" as Stephenson likes to call it, changes in "slow motion…Everything happens slowly there. You grow slowly, your birth rate is really low, but also your death rate is really slow so…just a really slow turnover rate going on there." The other end of the plot network, the lower elevation forest, Stephenson calls the "fast motion" forest where "birth is fast and death is fast." With this discovery of a slow-motion forest at the colder higher elevations and a fast-motion forest at the warmer lower elevations, Stephenson says that he began to "wonder if this is a global phenomenon and the tropical forests might be a fast-motion forest relative to the temperate forests." So he gathered a large global database of information about forest turnover rates and did an analysis. Sure enough, Stephenson found a pattern. And he says, "that is of interest because as the globe warms, even if it is in an area where there is plenty of water so that warming might be pretty benign, it makes trees grow faster." It also might make forests more likely to dieback faster. One reason trees dieback quickly in warmer climates is because things that “eat trees, like fungus and insects” tend to thrive in warmer climates. Stephenson says:

> The other really neat thing…literally fresh off the press…is that we find a correlation with the data. You can look at long-term trends and work out…what has been going on in the Sierra Nevada…Mortality rates almost doubled over the last decade…and if we start to investigate “well why might that be?”…We tried to correlate it with changes in…air pollution concentrations, and there was no correlation…We tried to correlate it with internal stand dynamics…and there was no correlation there. And there wasn’t a correlation with precipitation because that’s been pretty flat over the last quarter century. It varies wildly from year to year, but statistically there was no trend. But it does correlate with years that the temperature has been going up and more specifically…drought…how much evaporates in the air…Evaporation is a function of temperature, and so drought had been increasing not because of precipitation going down but because temperature has been going up.

In effect, Stephenson predicts that warming trends into the future will lead to rising forest mortality rates.

Stephenson says that “it’s been gratifying” to see the public taking climate change more seriously now. He feels climate change “may be the biggest issue of our times” and says, “I’ll be very relieved if it turns out we are all wrong…but at least it is getting the attention it deserves.” In the short term, he says, “It has made my life awfully complex because now the federal agencies are taking climate change very seriously and…those of us who have been studying climatic change for a while are in greater demand than we used to be.” Stephenson says that he has been “feeling a little bit spread thin” with requests from the National Park Service to help them come up with ideas about how to plan for climatic change. He considers his most valuable contribution to be providing “the facts that society needs to make decisions…the cold hard facts.”

For Stephenson, the day-to-day work of providing scientific information is rewarding. He says, “I guess I get a personal reward when I get the ‘AHA’ moment…Here is an aspect of how the world works that no one has discovered yet, and certain things fall into place." But his work as an ecologist is not the only thing that keeps him motivated. The other reward is that Stephenson is "just madly in love with these mountains" and would like them "managed as sustainably as possible." He clarifies to me,

> I am not an advocate out there telling the world how to manage the mountains but I am providing the information that I hope society as a whole will take…to understand how to manage the mountains sustainably into the future so future generations can enjoy them.

But over time, especially over the last four to five years, Stephenson's sense of urgency has grown. He says:

> Before then a lot of the ideas about climatic change were an abstract future…The interpretive staff at the National Park would ask me "are we seeing effects of climatic changes here in the Sierra Nevada?" And my answer was always "not yet…We haven't detected anything yet…We don't know." Over the last four to five years there has been a whole bunch of evidence that we are seeing the influence of climatic change here in the Sierra Nevada. And that has certainly ramped up my sense of urgency.

Stephenson's sense of urgency is also tempered with his commitment to working with the Park Service toward future management solutions. He says something he dwells on these days is "how uncertain the future is," and he says that he is "coming to embrace it." He describes "scenario planning" as a new approach to managing National Parks in such uncertain times. "You very formally name out possible futures…realistic futures, real possibilities…Here in the Sierra Nevada we are not sure if it is going to be warmer and wetter or warmer and drier." Stephenson says that with scenario planning you plan for both conditions and see if there is an overlap, "sort of a win-win management response….So it doesn't matter whether it gets warmer and wetter or warmer and drier because you've done your best covering your bases."

But in addition to the effects of climate change on forests in the southern Sierra Nevada, Stephenson says that he has seen other kinds of ecological changes that are disturbing.

> Once you've been in a place long enough you come to notice these things happening. I've noticed invasive species come in, and that is disturbing…Also in the watershed I live in…Kaweha Watershed. I used to catch mountain yellow-legged frogs (*Rana sierrae*) up in the lakes and streams. They are gone…That is disappointing because you are fond of those little critters, and they are friends, and your friends are gone, and this is a very disturbing shock.

Stephenson says the changes he has seen have affected him. He says that, even though the idea and effects of climate change were at one point abstract to him, he explains that he "actually started to get depressed…I was facing the loss of things I valued in this place. I realized that 'Oh my gosh, within my lifetime I am going to see a lot of these things I value go away.'"

It is particularly difficult for Stephenson because he is such a strong believer in the mission of the National Park Service to restore and maintain natural functions of ecosystems. And he says, "that is just not going to be possible…It's going to be impossible to maintain natural conditions in the future. And it probably is right now." That idea depressed Stephenson, and he says that for years he had "this anger…this bad feeling about the future." Eventually his depressed feeling went away on its own. He says it might have something to do with the stages of grief that people go through. But what he attributes his improved outlook most to is his enduring connection to the Sierra Nevada. Every year he makes sure to go on a long backpacking trip. He says this experience "grounds me; it brings me back…I am working for the mountains, the Sierras, and for society both."

Chapter Conclusion

This chapter provides a narrative description of what it is like to be a place-based ecologist. The thoughts and experiences of Dr. Craig Allen and Dr. Nate Stephenson convey that, in addition to the hierarchy of ecological perspectives, from organism to biosphere, there is another way to conceptualize ecological change. Allen considers himself a “perceptual weaver” who incrementally adds detail and texture to his understanding of ecological patterns. Stephenson’s almost spiritual connection to his place in the Sierra Nevada keeps him going despite a nagging sense of despair. Because of their long-term gaze upon one particular place, these place-based ecologists develop an emotional attachment to their study sites. The individual organisms, such as trees or frogs, that they have observed and come to know so well, become “friends.” This deep kind of relationship with place takes a long time to develop and may only happen once over the course of one’s lifetime. While Allen and Stephenson both live year-round immersed in their field sites, other ecologists, who visit their sites seasonally in the summer, also develop a special relationship to place. In the next chapter I explore the lived experiences of ecologists whose summer field sites reveal more subtle shifts attributed to climate change.

RESULTS THEME THREE: SEEING SHIFTS

Introduction

In this chapter I describe ecologists' experiences of *seeing* the ecological effects of climate change. I use the verb *to see* here in order to express the act of scientifically observing subtle shifts in ecological patterns over time. There are three possible ways that wild plant and animal species shift in response to climatic change; they can: move with the change, stay in place and adapt, or go extinct (Parmesan, 2003). In order to see shifts, the individual organisms that ecologists observe in the field become mathematical data points. When these data points are statistically analyzed against long-term weather data, they create representative patterns of ecological change due to climate. This chapter conveys what it is like for mountain field ecologists to immerse themselves in this type of scientific inquiry.

I present the work and thoughts of Dr. David Inouye, Dr. Carol Boggs, and Dr. Chris Ray. Their stories exemplify the kinds of field methods used to collect long-term data from ecological transects and correlate it with climatic trends. Their stories also reveal personal experiences of witnessing changes in species and places they have come to love. Thus, throughout the chapter, I aim to convey the scientific practice of seeing ecological shifts and how such practice is *experienced* in the lives of these three ecologists. When combined, the stories of Inouye, Boggs, and Ray illustrate some of the issues that ecologists face as they grapple with the deeper philosophical dimensions involved with their scientific discoveries. What comes to light is this: practicing scientific objectivity happens within an emotional landscape of witnessing environmental change.

Dr. David Inouye

On a late July day in Gothic, Colorado, Dr. David Inouye sets out to do what he does every other summer day. He wears field clothes—a white brimmed hat protecting him from high elevation sun, worn-in hiking shoes, and a daypack filled with scientific gear and provisions. We meet outside the library of Rocky Mountain Biological Laboratory, and he invites me to join him on his hike up to Virginia Basin, a place where Inouye has set up one of his long-term ecological monitoring plots. The field site is one of several mapped out along a 2,000-foot elevational gradient, and Inouye has recently detected a strong signal of ecological change occurring from one end of the gradient to the other. The evidence appears in patterns of a sunflower population. Inouye's observations of aspen sunflowers (*Helianthella quinquenervis*) are telling: the sunflowers along the *bottom half* of his elevational gradient have been consistently damaged by late spring season frosts, while sunflowers at the *top half* of the gradient have not. At one site in particular, the number of sunflowers has dropped from 1,376 to 493 in just seven years. Inouye's discovery would not have been possible without his disciplined approach and the scientific infrastructure available in the tiny town of Gothic.

Approaching Gothic through a verdant meadow of colorful wildflowers, the casual mountain tourist would hardly guess at the caliber and abundance of science emanating from the place. There are small wooden cabins scattered along a lush valley floor, and the setting seems strangely guarded by the dark, steep, jagged peaks rising all around. Like a stone sentry, Gothic Mountain looms vigilant over this fragile mountain ecosystem. The collection of cabins that comprise Rocky Mountain Biological Laboratory appear serene on the outside; but inside, ecologists are bustling with scientific activity. The snow-free summer field season at Gothic is short, and visiting scholars make the most of it. In the montane meadows surrounding the cabins, more scientists, intent on gathering data, patiently stoop over plots of vegetation recording information. Brightly colored flagging outlines transects where ecologists monitor living indicators of a rapidly changing world. To the untrained eye these transects may not mean much, but, for the scientists, they are precious tools for solving ecological puzzles. Inouye's transects provide important pieces toward understanding a larger pattern of environmental change at work in these mountains.

Inouye is Professor of Biology and Director of the Graduate Program in Sustainable Development and Conservation Biology at the University of Maryland. Since 1971, just after he graduated from college, Inouye has come to Gothic every summer to do field research. Located at an elevation of 9,500 feet in a remote region of the Southern Rocky Mountains, the Rocky Mountain Biological Laboratory at Gothic is renowned among ecologists for its pristine ecosystem and scientific legacy. Each summer, for the past 80 years, university scientists and students from across the country have gathered here to learn and discover. They study diverse species and processes, carefully piecing together the intricacies of mountain ecology.

As a college graduate in the early 1970s, Inouye arrived at Gothic to take a few field courses, and by the end of the summer he had fallen "in love with the place." From that point on he determined to find a doctoral dissertation project that would keep him coming back and spending summers in the mountains. Now, after 35 consecutive field seasons, Inouye's overarching goal at Gothic has been to illuminate patterns of change in wildflower populations and the insects that depend on them for sustenance. He has published studies on wildflowers including species of larkspur (*Delphinium barbeyi,* *Delphinium nelsonii*, *Delphinium nuttallianum*), primrose (*Androsace septentrionalis*), gentian (*Frasera speciosa*), and sunflower (*Helianthella quinquenervis*). Inouye's research has also shed important light on pollination ecology and more recently on changes in mountain species' phenology.

Inouye has kept close watch of each individual wildflower growing within a series of two-by-two meter plots. Every other day, during the spring and summer field season, Inouye or one of his graduate students, counts the number of individual flowers that are blooming. For example, *Delphinium nelsonii* is a bright purple larkspur with individual blossoms arranged on a spike. In his field notes, Inouye records "open" flowers as those that are just the right size and shape for visiting bumblebees and hummingbirds. If the blossoms are not open enough or they have begun to shed their petals, then they are recorded as "not open." By keeping such detailed field notes on the number of individual blossoms, Inouye can calculate the mean date of first flowering each spring in each of his plots. He can also determine the peak number of flowers each summer. He then correlates his data with local climatic records and compares flowering dates to snow depth and temperature. By doing this, Inouye has discovered a relationship between snowpack depth and wildflower fecundity. In years when the snowpack is shallow around Gothic, there is less above-ground insulation protecting emerging young plants from the damaging cold spring temperatures and frost. Playing this scenario out against predictions of global warming, Inouye predicts that decreases in spring snowpack, as a result of climate change, could seriously influence larkspur populations. He also predicts that fewer flowers in the future, combined with changes in their blooming dates, or flowering phenology, will impact the hummingbirds and bumblebees that feed on and pollinate them (Inouye & McGuire, 1991).

Like other ecologists whose long-term data has recently revealed the effects of climate change, Inouye describes his discoveries as fortuitous:

> I can't claim that I started out being a climate change biologist or that I started any of these long-term projects with that in mind, but it has turned out that some of the projects that I set up as a grad student here provide good baseline data, in some cases continuous data since 1973.

In Inouye's case, as with many other field ecologists, collecting data consistently every summer requires commitment. With or without funding, ecologists like Inouye do whatever it takes to keep their long-term monitoring projects going.

About a half an hour up the trail from where we started at the library, Inouye stoops down along the side of the trail and points at evidence of what he suspects to be climate change. "One of the things happening, at this point and lower along the elevational transect, is that there is a lot less reproduction because frost has been killing flower buds on a regular basis." He has seen this situation eight out of the last ten years. The lower elevation flowers damaged by frost don't make seedlings, so their numbers have dwindled, and Inouye has the hard data to prove it. He says "around Gothic this summer, close to 100% of the buds got killed by frost, but up at 11,300 feet, where we are going, most of the buds are OK."

The individual sunflower on the side of the trail is shriveled and brown in the center. Inouye says this population of sunflowers is changing both in terms of its *phenology* (seasonal events such as date of first flowering) and *demography* (geographic distribution). Decreasing winter snowpacks have hastened spring bloom dates, and the first flowers to emerge are those growing lower on Inouye's transect. The snow at lower elevations melts earlier, exposing emerging sunflowers to frost and damaging them. And fewer sunflowers means less food for insects. Inouye elaborates on the ensuing ecological chain of events:

> Some of these sunflowers secrete extra floral nectar that attracts ants. So the ants lose a source of nutrients in the form of this nectar. The ants chase away flies that are seed predators trying to lay their eggs in the sunflowers. In a year like this they have no resources for their larvae so their populations are probably lower than they used to be. There are also parasitoid wasps that feed on the seed predators. At least three levels of herbivores are potentially affected. Last summer was kind of interesting. Right around Gothic they were almost all killed by frost, but you only had to go up maybe a hundred to two hundred feet in altitude and there they were OK. So right here we are at the borderline. I've done a transect two thousand feet in altitude, stopping at about eight sites along the way and monitoring what proportion of the buds are killed by frost. It's zero percent at the high altitude site and essentially a hundred percent at the bottom site, and it's a reasonably good straight line in between. All the sunflowers are being frosted at lower altitudes, and that is a harbinger of things to come.

Listening to Inouye explain the intricate climate-related relationships surrounding just this one species of flower gives the impression that this is just the tip of the ecological iceberg. Most likely there are many more unseen effects of climate change that have escaped scientists' scrutiny. Inouye's suggestion of "harbinger" unleashes the imagination in terms of what may come to pass in these mountains as global temperatures continue to rise. One cannot help but sense an emotional tug linked with Inouye's discovery.

Inouye's connection to the Gothic landscape is more than scientific. He admits he "likes seeing meadows full of sunflowers and, some years, although not for about the last ten years, the meadows around here are chock full of blossoms…but in a year like this there are just a handful of flowers." Inouye's sense of care for these mountains and his commitment to long-term studies of them is a legacy that he hopes future scientists can learn from. With the future in mind, he has begun to include high-resolution GPS mapping in his data collection procedures so that other scientists can "find the plots and have the historical record of what was in those plots for a 35- or 40-year period." Inouye reflects on how his research experiences at Gothic have influenced his outlook on time and place:

> I think maybe I have a longer-term perspective than many people partly because my work spans 37 years at the same place…I can think back about how things have changed at this one site that I've become very familiar with…If I had spent one summer at each of 37 different places I think I would have a very different perspective on time than I do. I think that has something to do with a sense of place…If you have a lot of sense of place you probably think about how things have changed in that place more than somebody who doesn't have a sense of place.

Deepening his understanding of ecological trends around Gothic, Inouye describes another project that adds yet another dimension to his perspective. Collaborating with Dr. Graham Pyke, an Australian scientist, who gathered data on bumblebee populations in the mid 1970s, Inouye is re-running the same transects. The two of them think they might find some trends by comparing data sets collected more than 30 years apart. Inouye describes what he has noticed so far:

> Partly it turns out in flower distributions and then partly in the bumblebee distributions. There is one species of Mertensia, a bluebell, that seems to have disappeared from most of the sites where Graham saw it back in the 1970s. It has also disappeared pretty much from my phenology sites over the past eight years, and that was a pretty significant resource for at least one of the bumblebee species, and so we are trying in part to see what other data we can find that will allow us to see whether there are other species that are also changing their distribution or abundance that significantly…It seems to be dependent on relatively moist habitats and things have gotten drier over the last eight or nine years since the winter snowpack started to decline. So I can still go to wet areas where there are usually good Mertensia populations…but around here it has declined dramatically.

Inouye's discoveries of ecological change have focused his research and fueled his cause for concern. Climate change has created a "focus and a context" for some of the work he has been doing all along. "I've oriented my research more in that direction although it could have been oriented, using the same studies, in a variety of different perspectives." Inouye's place-based observations have prompted him to look more closely at the longer term context of weather. He thinks the weather has changed pretty dramatically in the last eight or nine years, but he says that it is difficult to know for sure. The changes could be due to a North Pacific oscillation, or they could be due to global climate change. Inouye's research with Pyke sets a historical baseline. Ultimately they'll be able to say "what's going on now really isn't all that much different from what happened in the 1930s, or we can say it is actually very different from what was happening back then and therefore we should be worried." Inouye expresses a sense of urgency:

> We have a limited amount of time to make some pretty significant changes in the way our [human] species is relating to the environment if we are going to try and minimize some of the potential major impacts in the future. There may be some urgency in trying to, for instance, influence the political process to educate people and legislators about the problems and potential solutions.

Motivated, in part, by his sense of urgency, Inouye spends increasing amounts of time talking with reporters, writing articles for local newspapers, and teaching his undergraduate students about climate change. He says, "I'm trying to use my skills as both a researcher and as a teacher to have an influence."

In summary, Inouye's research experiences show how he has capitalized on his long-term ecological studies by framing them in the context of climate change. The timing of climate change, for him, has been fortuitous in his role as a professional scientist. As a result of his commitment to learning about a specific place, he has developed a "sense of place" including a historical perspective and dedication to archiving a legacy of data so that future generations can build upon it and learn from it.

He has a sense that the "dramatic" changes taking place at Gothic are only "harbingers" of things to come in the mountains. He feels a sense of urgency, and he reaches out to the public, hoping to promote political action that will curtail greenhouse gas emissions. Inouye's experiences offer a glimpse into what it is like to experience the ecological effects of climate change. I now turn to another scientist whose research is directly linked to Inouye's. She also spends her summers at Gothic and has discovered shifts in butterfly populations.

Dr. Carol Boggs

Dr. Carol Boggs is Professor of Biological Sciences and Director of the Program in Human Biology at Stanford University's Center for Conservation Biology. She is also a Fellow of the California Academy of Sciences and of the American Association for the Advancement of Science. Her field research focuses on Lepidoptera (butterflies and moths) and how environmental variations, both natural and human caused, affect these insects. Because scientists have studied North American butterflies in great detail, these insects serve as important *model systems* for understanding ecological processes and relationships. Butterflies have also become important signals of global climate change (Ehrlich, 2003; Parmesan et al., 1999). Boggs is among the most preeminent and prolific scholars of North American butterflies, their ecology, and conservation.

One of Boggs' research projects at Gothic ties in nicely with Inouye's discoveries of shifts in sunflowers. Boggs explains her research on the Mormon fritillary butterfly (*Speyeria mormonia*) and how it links up with Inouye's observations:

> He's got the data that shows earlier snow melt timing has led to earlier coming up of plants…If they come up early they have the possibility of getting hit by early-July frosts, and it causes the flower heads to abort, which means that there's not as much nectar for the butterflies. I have previously shown that nectar was a

> determining factor in numbers of eggs a female could lay…We've put the whole thing together to ask whether or not…the numbers of flowers available controls the butterfly population size. It turns out it does.

Through their collaboration, Boggs and Inouye demonstrate how a shift in one species' phenology can lead to subsequent shifts in its own and other species' demography. In this case an important food source for adult butterflies has decreased as a result of climate change. Representative of how science often evolves, through a collaboration of multiple scholars gaining insights from one another, a chain reaction of results, understanding, and meaning unfolds.

Another of Boggs' long-term studies involves an intriguing and unexpected collaboration with a different scholar. This time the butterfly is the Gillette's checkerspot (*Euphydryas gillettii*), and the scientist is ecological arch-druid Dr. Paul Ehrlich. Boggs explains:

> The story here is a little complicated; this butterfly normally has a distribution from southern Wyoming to central Alberta in the Rockies. It's an incredible habitat specialist. It needs south and east-facing slopes so that it can get morning sun, which makes a difference in how fast its eggs hatch. It has to have a wet environment, so a swamp is great, or even a stream if necessary. It needs its particular host plant which is *Lonicera*, a honeysuckle bush…It has to be in an area where there's a lot of it, but not too many willows…It also needs scattered spruce or scattered tall willows for the males to perch on to find females. So we're talking, Why is this species still around?

In the 1970s Paul Ehrlich and a colleague received permission to conduct an experiment that they would not be able to get permission for today. They introduced 10,000 eggs and larvae from Wyoming to an area at Gothic. They were testing the idea that empty ecological niches exist. An ecological niche is how a species makes its living or "the functional position of an organism in its environment" (Allaby, 1994, p. 269).

To Ehrlich, the Gothic landscape looked like perfect habitat, and the question was: Why isn't the Gillette's checkerspot in the Southern Rockies of Colorado when it occupies similar habitat in the Central Rockies of Wyoming? Apparently Ehrlich and his colleagues thought it was because the butterfly could not cross the 500-mile dry sagebrush habitat of the Wyoming Basin that divides the Central Rockies from the Southern Rockies. But Boggs thinks Ehrlich was asking the wrong question back then. She says the question should be: Why did Gillette's checkerspot go extinct in the Southern Rockies after the last ice age? Since the time it was introduced to Gothic thirty years ago, the butterfly had generally persisted as a small population, between 25 and 150 individuals.

One morning in 2002 as Boggs walked between her cabin and one of the laboratories at Gothic, she caught a glimpse of what she thought was a Gillette's checkerspot. At the time, she had never actually seen one in Gothic, and she called Ehrlich to confirm her suspicions. That is when she first got involved in the study. Her estimates for that summer's population were 3,000 individuals. It turns out the population of Gillette's checkerspot had multiplied and spread over a 70-hectare area. In addition, Boggs found another Gillette's checkerspot while working on a different project six and a half kilometers from the main site at Gothic. She says "It was a female and…when last seen it was headed south…Since then we've been trying to figure out: a) if there are any new populations and…b) why it only went south and not north." Boggs says it is possible that Gothic is the butterfly's upper-elevation limit and "the question then is: Is it climate change?" She now has good data beginning in 2002, and she says that she will keep monitoring the Gillette's. But she also says that determining just which environmental variables are responsible for the population explosion is a complex proposition.

Boggs has a mathematical model that explains the Gillette's population dynamics based on climate in the 1980s, but it does not explain the situation in 2000, and the population continues to fluctuate. She says:

> It's hung out around 1,500 for the last six years except for one year when it went down to 100 and last year [2007], when there were 8,500 butterflies in two hectares. What it looks like from our data is that they're now having unusually good over-winter survivorship, but I probably need five more years of data before I…can really fit the climate model. At the moment there are too many parameters to test given the number of years of data that I have. But what it's looking like to me…is either…increasing warmth in the winter, particularly at night, or the drought that we've had since 1998, or the slight increase in temperatures during the summers…has lifted some constraint on population growth that was operating in the 1980s. There are other factors controlling the population size now and controlling it at a higher level.

Boggs' explanation reinforces the difficulty in pinning down cause and effect when it comes to understanding complex ecological issues such as climate change. Variables must be isolated and "teased apart" to understand how the pieces contribute to and influence the whole.

I ask Boggs how climate change has impacted her life and she replies in practical, rather than philosophical or emotional terms. Some of the butterfly species she studies were naturally synchronized with the Stanford University quarter system.

> We don't get out until the middle of June, they don't get out until the middle of June, they're still flying until early September, and we don't have to be back until the end of September. Now May is the new June, and October is the new September…There's much more of a panic of getting out there so I don't miss the early events.

Boggs says climate change also impacts her field experiences at Gothic. The temperatures, at least during the last several years, have gone up considerably, and particularly at night, so in terms of living and working at Gothic, the whole environment feels like a lower elevation field site.

> If you're working in a swamp it's a little bit different if the average temperature [changes] and you've got lots of biting flies. It's different if the temperature is 80 degrees than if the temperature is 85 degrees in terms of comfort level. You've got to be wearing long sleeve shirts, and it's nice not to be roasting while you're doing it.

Boggs sees climate change as a professional inconvenience, but she also shares more deeply seated feelings about how climate change has affected her personally.

In the impassioned way that Boggs expresses herself, it is clear she deeply appreciates the time she spends at Gothic, not only because it affords her with opportunities for scientific discovery, but also because it sustains her in an aesthetic way, a more spiritual way. This time she reflects more philosophically on the consequences of climate change on her life:

> I think we're performing an uncomfortable experiment on ourselves. We don't know enough about how communities and ecosystems function to be able to know what would happen, if, for example, all of the bees moved 500 meters up the mountainside. If we disassemble communities and reassemble them in different sorts of ways, we're messing with food webs, losing some species in the process, creating new food webs where possible. The system will be simplified, and it will take it a long time to get back to something that's more complex…Causing ecosystems to be simplified to the point where they don't function properly anymore is something that we don't know the answer to. It's an experiment that we're in the process of performing, and I would just as soon not perform it…It's not just the ecosystem goods and services, but it's also the aesthetics and the complexity and some of the phenomenon that I think for anybody who is an ecologist, it becomes very important to them, because you become attached to your study systems, and it's fine for them to change, but you don't want them to change in ways that are permanently depauperating [sic].

Boggs' perspective on what it means to experience climate change is both critical and emotional. She points out the deeper philosophical issue of what it means for humans to roll back the work of evolution. Her lament is for a future that holds fewer species.

Boggs' experience of seeing ecological shifts is made possible, in part, through collaboration with other ecologists. Understanding the ecological effects of climate change is a complex process that involves testing multiple variables, yet there is a sense that "higher level controls" are at work. Boggs' reflections on the impact of climate change on her own life are both practical and philosophical. She expresses multiple values of wild species and the ecosystems that sustain them. Her belief is that environmental change is okay, but only up to a certain point. With current climate change, humans have pushed earth's rate of change beyond its natural tendencies. Although she is not directly observing an imminent demise in the species of butterflies she studies, she is keenly aware of the possibilities as longtime ecosystem interactions begin to unravel. Now I turn to an ecologist who sees the strong possibility of extinction lying on the horizon of the small mammals she studies.

Dr. Chris Ray

Dr. Chris Ray is a Research Associate at University of Colorado at Boulder. She earned her Ph.D. in Population Biology from University of California, Davis, and since 1998 she has directed the Bristlecone Institute for Ecological Research, an organization she founded that is dedicated to long-term population studies. Ray's professional interests focus on understanding the dynamics of threatened species with fragmented populations. One of her most important long-term projects is on the American pika (*Ochotona princeps*) and understanding climatic and other effects on the pika's pre-historic and recent local extinctions.

Pikas are members of the rabbit family. They are six to eight inches long with no visible tail and smaller ears than a traditional rabbit. Known for their loud, high-pitched, alarm calls, you typically hear a pika before seeing one. The geographic range of pikas is restricted to high elevation alpine talus slopes, and they are very sensitive to warm temperatures (Smith, 1974). As a result, Ray spends much of her summers hiking in the high country of Colorado and Montana. Over the years she has become well accustomed to scrambling over rocky talus fields searching for sign of pika.

Today Ray has come to lead a field education program for Gore Range Natural Science School near Vail, Colorado. After an interview the previous day, I join her and a small group of participants along the trail to Notch Mountain in the Holy Cross Wilderness Area. This is a place known for its historical, recreational, and ecological significance in the heart of Colorado's largest mountain range, the Sawatch. After hiking a half hour through a cool thick forest of Engelmann spruce and subalpine fir, we come to a rocky, east-facing, sunny clearing. At approximately 11,000 feet in elevation we have reached the first talus field along the trail.

After spending so much time observing pika in the mountains, Ray has a keen sense of where she will and will not see them. The small Lagomorphs need a very specific kind of talus pile with spaces amongst the rocks that are just the right size for refuge from predators and shelter from summer's heat and winter's cold and snow. Pika spend much of their summers gathering forbs and stashing them as hay piles that serve as a winter food source. Standing at the edge of the talus pile, Ray explains that if pika are present we will find dried-up hay piles and tiny scat pellets interspersed among the rocks. Ray challenges the group of participants with a prize for the first person to find any sign of pika. The group begins to scour the rocky area, and it does not take long before we hear the first loud nasal sounding "peek" from the far corner of the talus field.

Before she knew what a pika was, Ray was introduced to the concept of meta-population studies in ecology. Her graduate advisor at University of California Davis was Dr. Michael Gilpin, one of the "forefathers" of conservation biology. Gilpin was seeking a model species in order to study meta-population dynamics (a kind of population viability analysis) in ecology. The idea was to find a species with isolated meta-populations, then disturb the population, and see how the individuals within that population would respond. Building on the classic theory of island biogeography, pika are essentially island inhabitants living on isolated mountaintop talus piles. Gilpin had proposed to Ray that pika would be a perfect species to conduct this kind of experiment on because their populations are restricted solely to alpine talus piles. Pika cannot migrate. During the winter they must stay warm under the insulation of their talus fields, and in summer they won't travel to lower elevations due to heat sensitivity and exposure to predators.

Ray explains that the pika's "habitat is patchy naturally, and so Gilpin wanted to learn how a species that is naturally fragmented actually survive [sic], because we're fragmenting species all over the world. How are its population dynamics affected by its patchy habitat?" She says that her data on pika is "now probably the most valuable thing I can offer science—to keep this thing going." Ray has become so close with this particular population of pika in the Gallatin Range of Montana that she feels she has "learned their language." As she dug deeper into the research available on pikas she discovered a trend. Over the past 10,000 years, especially in the western U.S., paleoecological evidence shows that whole pika meta-populations have gone extinct. So Ray set out to look for clues that would explain the extinctions of individual populations on isolated mountaintops in the Great Basin of Nevada. She explains that she started out thinking about it theoretically and quickly came to the idea that the most constant change over the last century has been climate. Ten thousand years ago, glaciers and a cooler climate made it possible for pika to move between mountaintops. As the glaciers retreated, isolated pika populations became marooned at the higher elevations with cooler temperatures and suitable rocky habitat. Today, if a meta-population of pika goes extinct from a mountain there is no chance of re-colonization unless humans help.

Using historical pika data collected from early 20th century naturalist explorers, Ray determined that there were originally 25 isolated pika populations in the mountain ranges of the Great Basin. A more recent census of pika in the area suggests that eight of those 25 populations have gone extinct. In addition, by studying tree rings from 8,000 year-old Great Basin bristlecone pine (*Pinus longaeva*) trees, Ray correlated the dates of pika population extirpation with changes in climate. The bristlecone trees provide a compelling story of climate change in their annual growth rings. During years with abundant winter precipitation the rings are wide, but if the winter is dry and cold then the rings are narrow. It turns out that these same climatic conditions also control the winter survival rate of pika. A pika's winter survival depends on an insulating blanket of deep snow falling on its talus field.

When Ray discovered the geographic pattern of the pika population extinctions she found a trend contrary to what would be anticipated if extinctions were due to isolation, or small population size and subsequent lower levels of genetic fitness. At this point Ray began collaborating with another scientist, Dr. Erik Beever, who was just beginning his research on pika in mountains of the Great Basin. What Beever "decided to do was to go out to places where pika had been recorded in the early 1900s, even late 1800s, and see if they were still there and see if there's an elevational signature." If climate warming was a factor in their survival rate, then more of the remaining meta-populations would be found at cooler higher elevational sites. Indeed, Beever and his colleagues found a trend. Of all the sites studied, those where pika habitat was lowest in elevation were the ones where populations had gone extinct (Beever, Brussard, & Berger, 2003). Ray sums up the situation:

> Of those 25 populations, eight have gone extinct in the last 100 years. Two of those have gone extinct in the last five years. And if a third were going extinct…every 100 years, they would have been gone many thousands of years ago…and it looks like the rate is accelerating in this last decade…The lower limit has been moving uphill at a meter per year. I'm just going to use simple numbers…that is actually screaming uphill compared to anything else in the literature…Unfortunately in this last decade, they're moving uphill well over 10 meters per year…So the highest elevation of any mountain range where they still persist is about 12,000, and the lower limit of their distribution is getting close to 10,000, which means they only have 2,000 to go. And at ten meters per year, that means they're going to be gone in less than 200 years. And they've been out there for more than 20,000. And that's just not acceptable!

Although the pika's rate of extinction can be correlated indirectly with climate, Ray is still not sure which direct climatic variables have led to the pika's decline. She gives four hypotheses: a) the direct influence of heat in the summertime, b) the absence of a thick winter blanket of snow to keep them warm in the winter, c) changes in other species' distribution and abundance such as food vegetation type or predator occurrence, and d) changes in how diseases persist and are transmitted. Ray leans toward the second hypothesis. "You can escape heat…but you can't escape cold unless you have the gift of fire. They don't have it. So my favorite hypothesis is that it might be cold, but there are many other things." It will take many more years of close observation and data collection to get to the bottom of which climatic variable kills the pikas.

Ray says her long-term study of the pika combined with their disappearance from lower elevation sites is what keeps her going. All of a sudden the pika has become one of the nation's most well-known harbingers of climate change, something she did not foresee when she started learning about them 20 years ago. It was only once she and her colleagues realized, "My God, they're disappearing really rapidly…and if they had been disappearing at the rate they are now over the past 10,000 years, they would have been gone many thousands of years ago."

Ray's perspective emphasizes meta-population theory in ecology. She is interested in understanding the population dynamics of threatened and fragmented species. In her studies of pika, she and her colleagues have discovered an accelerating rate of pika extinction that is linked with climate change. To her, this situation is "not acceptable," and she is motivated to continue her long-term studies of pika to get to the bottom of it.

Chapter Conclusion

Inouye, Boggs, and Ray's experiences of seeing ecological shifts are not unlike other field ecologists interviewed for this dissertation, but they are exemplary. Most ecologists have studied a specific species or place over a long period of time. Eventually they have begun to observe patterns in their data that correlate with changes in climate. They consider it "fortuitous" to have been in the right place at the right time with respect to researching climate change. Seeing shifts requires a commitment to careful observation over many years. But another way to see shifts is to force them. In the next chapter I tell the stories of two ecologists who use *experimental* methods to tease apart the tangled webs of ecological complexity associated with global climate change.

RESULTS THEME FOUR: COPING WITH COMPLEXITY

Introduction

In this chapter I explore what it is like for ecologists to use *field experiments* to apprehend the current and future effects of climate change. They describe how coping with the complexity of climate change is like "teasing apart" a tangled web of ecological pieces and processes. The idea of "teasing apart" conveys a theme that many ecologists in this dissertation described, the scientific process of isolating and testing environmental variables to determine cause and effect relationships. In contrast to the kinds of long-term monitoring studies described in the previous chapter, this chapter explores *causational* field studies, in which ecologists manipulate the environment and observe the ensuing effects. Within this context, I explore several salient experiences expressed by ecologists: thinking in terms of systems, setting system boundaries, discovering ecological feedback loops, maintaining transparency when reporting results, and using results to address pressing environmental issues.

I present the work and thoughts of Dr. John Harte and Dr. Andrew Blaustein. Harte is an exemplar among mountain field ecologists, well known for developing a montane *meadow warming experiment* 20 years ago. Today, scientists around the world have replicated his experimental design. Harte believes that, when combined, both long-term monitoring projects *and* experiments can shed even more light on the ecological impacts of climate change. By using experiments scientists can more precisely pinpoint cause and effect relationships. Harte grapples with a multitude of complex environmental interactions and ecosystem feedback systems. His meadow warming experiment is a simplified simulation of climate change. He uses electric heaters to artificially warm a subalpine meadow.

Dr. Andrew Blaustein studies the ecology, behavior, and conservation biology of small mammals and amphibians. His recent work has focused on the worldwide decline of amphibians. In order to determine the source of amphibian decline, Blaustein has looked at the issue from multiple points of view and tested many different hypotheses including climate change. In the 1980s Blaustein realized that many of the species of frogs and toads that were disappearing were "mountain-dwelling amphibians that laid their eggs in the open" (Blaustein, 1994, p. 32). Through an experimental research project on four species of amphibians in the Cascade Range of Oregon, Blaustein and his colleague Robert Worrest discovered a link between amphibian egg survival and UV-B radiation, but he says the story behind amphibian declines is far more complex and has to do with a number of interacting variables related to global environmental change.

Throughout this chapter I tell the stories of both Harte and Blaustein's research experiences, providing insight into what it is like for these two field ecologists to tease apart tangled webs of ecological complexity related to climate change. Although other ecologists in this dissertation shared their thoughts about using field experiments and coping with ecological complexity, their stories are not included here. Rather, the themes expressed throughout multiple interviews are conveyed, in essence, through Harte and Blaustein's experiences as experimental field ecologists working in mountains of the West.

Dr. John Harte

Dr. John Harte is a tall, lean, and serious man whose scientific stature and confidence give him an air of austerity. He wears faded blue jeans and a button down shirt. His suntanned face has a tall forehead and long brown beard. His blue eyes sparkle with an inquisitive and probing gaze. When he speaks, Harte's appearance is softened by his gentle demeanor and friendly tone of voice. Harte is a Professor in the Energy and Resources Group and the Ecosystem Sciences Division of the College of Natural Resources at University of California, Berkeley. He is a physicist by academic training with degrees from Harvard and the University of Wisconsin. But in the early 70s, as he set out to establish his career, he wanted to apply himself to more practical and pressing environmental issues. Over the years he's been recognized with numerous awards including a Pew Scholars Prize in Conservation and the Environment and a Guggenheim Fellowship. He's written nearly 200 scientific publications and served on six committees of the National Academy of Sciences.

Harte's interest in ecology started as a child growing up in the suburbs of New York City. He spent his free time bird watching, collecting frogs, camping, and exploring the fields around his home. Later, in high school, Harte says he saw his favorite childhood places—woods, ponds, and fields lost to housing developments. Witnessing the disappearance of his childhood landscape led, in part, to his "motivation about environmental issues." Harte claims he was also just naturally "fascinated with the science of ecology…like what happens if you shoot the wolves and the deer proliferate and then they change the forest." Harte says he has always been more interested in ecological *systems* than with the behavior and ecology of individual organisms. The ecological lure for Harte is “the way multiple things hook together.” He is fascinated by systems in general; their positive and negative feedback loops, their conditions of stability and instability, their cycles and steady states. When he was in high school he entered a Westinghouse science competition. He was curious about the periodic occurrence of brown-capped chickadees, today known as boreal chickadees (*Parus hundsonicus*), that would, during some winters, shift their boundary south from Canada into New York State where he lived. He wanted to know if variation in climate or failure in seed crops or some other variable led the chickadees to shift their geographic distribution. Even from an early age Harte says his “fascination with the systemic way of thinking is so ingrained” that it is not something he has to switch on and off. He “just intuitively inevitably thinks about things that way.”

Harte compares his style of systems thinking to the more narrowly focused kinds of ecological studies he says most scientists were doing in the 1990s. To highlight that trend, Harte surveyed a year’s worth of scientific research articles from several prominent peer-reviewed journals of ecology. He found that most of the articles focused on only one or two animal species, with little to no mention of the larger environmental systems the organisms were part of. Harte says only 20 percent of the articles published that year discussed the “full influencing environment which would include the climate and the soil and possibly toxics or other environmental stresses…80 percent could have been done on the planet Pluto.” Thus Harte termed this phenomenon “The Pluto Effect.” He says the articles back on the 1990s represented “the purest of the pure when it comes to ecological studies, and that’s what most of the work was like” back then. But Harte says he’s seen an improvement. Now there is much more focus on the abiotic environment and its influence on the biosphere.

Harte perceives the ecological world in terms of "geometric interconnections"—a way of picturing a system that he says "can be aesthetically pleasing and enlightening." But he makes an important distinction. Even though you can think about ecological systems like you might think about "electrical networks and things…you can't forget the fact that many of the components of the system are living and possibly evolving creatures. So that makes it even more rich and interesting."

Throughout his career Harte says he's focused on "intrinsically interesting questions that have huge practical ramifications…everything from protecting a habitat…to the overall habitability of the planet for all of humanity." Even though he describes his doctoral studies in theoretical physics as "terribly fascinating…and ecology not as intellectually…gripping," Harte decided to pursue ecology because of its "relevance to the human condition…to make the world better." He intentionally turned his focus away from the "tiny fascinating but basically irrelevant questions" in order to focus his life's work on pressing environmental issues like acid rain and global warming. Almost all of Harte's work in ecology, with one exception—his work in the emerging theoretical field of macro-ecology—is based on his motivation and sense of life purpose to leave the planet better off than when he found it. A proposition which Harte declares "looks increasingly unlikely to happen."

Harte says he took an interest in the "climate change problem" when most other scientists weren't thinking about the interrelationships between earth's physical systems and ecosystems. "Even today a lot of people will just pick a variable like temperature and assume that's the driving variable rather than the whole suite of climate conditions that affect life." With his degree in physics, Harte thought about climate mathematically. In the early 1980s he made the connection between atmospheric systems and ecosystems and his work "became even more fascinating…now you have two complex systems intimately hooked together but in ways we didn't really know how to think about at that time."

Harte's insight into the ramifications of atmospheric change was reinforced during ten years of field research on tiger salamanders (*Ambystoma tigrinum*) in the 1980s. In his book *The Green Fuse* (1993), Harte describes how this particular experimental research at The Nature Conservancy's Mexican Cut Preserve in Colorado led him to fully realize the implications of atmospheric change on mountain ecosystems. He spent each summer watching "some slimy, muddy, brown creatures, splotched with faint darker brown" that live in mountain ponds (Harte, 1993, p. 52). The salamander field site was located high on Galena Mountain just eight miles north of the Rocky Mountain Biological Laboratory. For about five years in a row Harte and his colleagues observed a complete failure in salamander reproduction. "No eggs were successful. The larvae and the eggs were curled up and would die." By analyzing pond chemistry, Harte and his colleagues discovered high levels of acidity linked primarily to air pollution from coal-burning power plants in the Southwest. Harte and a colleague conducted an experiment that exposed salamander eggs to varying levels of pond water acidity. The results showed that tiger salamander eggs are highly vulnerable to increased levels of acid in the water.

Harte and his colleague published a paper on their findings titled: *Possible Effects of Acidic Deposition on a Rocky Mountain Population of Tiger Salamander (Ambystoma tigrinum)* (Harte & Hoffman, 1989). The wording of this title is important because it says something of Harte's scientific integrity. Of this tentatively worded title describing "possible effects," Harte wrote: "ecosystems are so complex that it is usually impossible to make an ironclad case that A causes B. The full measure of this ambiguity must be expressed forthrightly if scientists are to retain credibility" (Harte, 1993, p. 62). But the findings were suggestive enough for Harte to take political action. He used his salamander discoveries to influence congressional legislation that extended the 1990 Clean Air Act to cover acid-causing air pollutants in the western US. Harte makes no attempt to segregate his scientific findings from his sense of civic responsibility. "To the complaint that it is scientifically irresponsible to venture publicly beyond one's specialized area of research and into the realm of public policy and values, my reply is "Hogwash," I am certainly as qualified as anyone else to express values and political opinions" (1993, p. 63).

But Harte realized that solving the acid pollution problem for those tiger salamanders wouldn't be enough. The amphibians would be "doomed because the ponds they live in were likely to dry up under severe global warming." In fact, Harte says "in some ways global warming makes a mockery of all conservation efforts and environmental improvements we do…we're going to lose habitats and a huge portion of our biodiversity is going to literally bite the dust under global warming." So Harte began in earnest thinking about how he could design an experiment that would show just how problematic global warming might be on mountain ecosystems. Realizing he couldn't experimentally dry up the salamander ponds in a Nature Conservancy preserve, he turned his attention to a field site that would be less vulnerable and more logistically feasible. In 1990 Harte set up his meadow warming experiment on land owned by Rocky Mountain Biological Laboratory, a location where he and other scientists would have easy summertime access and a reliable source of electricity.

Harte knew enough about the climate system to understand that anthropogenic global climate change "was virtually, certainly a serious threat" and he took it very seriously, even as early as the late 1960s. But, by the 1980s Harte realized that there was a need to really try and understand the consequences of climate change on ecosystems. He also realized that correspondingly, ecosystems exert a huge influence on the climate. If the nature of ecosystems began to change because of atmospheric warming, then these ecosystem changes could possibly loop back and cause changes, again, on the climate. These ecosystem feedback loops could be ameliorative—reducing the effects of global warming, or they might respond in ways that would exaggerate or exacerbate global warming. Harte wanted to know one way or the other. He needed more tangible evidence than mathematical models on computers could produce. He wanted a "much more empirical understanding" so, he created his infamous meadow warming experiment.

In a PBS "NOW" show with Bill Moyers, Harte sits beside his experiment cross-legged amongst the wildflowers and refers to the surrounding mountains as a "cathedral." Then he explains his scientific discoveries. The purpose of the experiment is:

> To see how a particular type of habitat, the subalpine meadows, which are a large and important habitat, respond to climate change; and how those changes in the ecosystem could, especially if occurring on a larger spatial scale than just the experiment, cause feedbacks and influence the climate system either positively or negatively…the experiment itself is a simplification of global warming.

Harte says nobody knows exactly what global warming will look like, and trying to develop an experiment that replicates earth's climate exactly would be impossible. He sets the thermostats on the heaters to simulate the most widely accepted scientific projections—a global increase of 5 degrees Celsius by the year 2050. But the experiment can't possibly replicate the ecological complexity inherent in biospheric interactions. For example, carbon dioxide concentrations in the atmosphere are rising, but in Harte's meadow warming experiment, the concentration remains at ambient levels. The heated plots and the control plots don't differ in carbon dioxide concentrations but they do differ in temperature.

During the height of the summer at Gothic, the trail leading up to Harte's meadow warming experiment climbs over a small glacial moraine through a lush green meadow with yellow, white, and purple wildflowers. Harte characterizes the site as a dry, rocky subalpine meadow where sagebrush (*Artemisia tridentata* var. *vayseyana*) is the predominant shrub. There is a series of 10 three by ten meter plots set up along a slope. Five of the ten plots are controls and the others are warmed with infrared heaters. The control and experimental plots alternate with one another along the slope. Long narrow heaters hang from steel cables attached to tall posts. Each of the heaters is controlled to simulate infrared output comparable to that anticipated with a doubling of carbon dioxide in the atmosphere plus associated major ecosystem feedbacks like increased water vapor in the air. Tiny thermocouples buried underground at three depths record soil moisture and temperature every two hours (Harte & Shaw, 1995; Loik, Redar, & Harte, 2000).

When Harte and his colleagues designed the experiment they explicitly took into account the high degree of ecological complexity inherent in ecosystem processes. They strived to identify every possible variable and simplification they could. They came up with arguments for why each simplification shouldn't significantly affect their results. Harte says, in a couple of cases, they couldn't come up with an argument, and the simplification could matter. For example, if you wanted to know how herbivorous insects would respond in the heated plots, you could observe how much herbivory occurs in the heated plots versus the control plots, but there would be something wrong with your conclusions. "In the real heated world 50 years from now, every patch will be heated, and the insects won't have a choice of where to go…in today's world the insects do have the choice of where to go, so that's an oversimplification." Scientifically, this means that if you were to draw conclusions about herbivorous insects, you would have to qualify them with that condition. So the complexity of climate change isn't entirely captured in the meadow warming experiment. To make up for this situation, Harte and his research team strive to convey the oversimplifications of their experiment; they don't ignore the simplifications and when they interpret their findings, they do so in light of the fact that they haven't captured all the real complexity of a truly globally warmed meadow.

A visual image of ecological complexity is helpful in making the point of just how difficult Harte's job must be. In the book *A Primer for Environmental Literacy* (Golley, 1998) ecologist Frank B. Golley provides a "holocoenotic diagram" redrawn from that of the original sketch done by Dwight Billing in 1952 (p. 4). The diagram demonstrates how the natural environmental influences just one plant. It depicts a hypothetical plant at the center surrounded by a ring of 14 different bubbles, each representing an environmental factor that acts on the plant. There are bubbles for: temperature, solar radiation, time, atmosphere, wind, fire, water, land form, gravity, parent material, soil, other plants, animals, and micro-organisms. Solid arrows are drawn between the plant and each of these 14 environmental factors. These arrows represent *direct relationships*. In addition, there is a tangled mass of dashed arrows drawn to represent all of the other *indirect relationships* between the 14 environmental factors. The essence of the image is geometric—like a tightly woven spider's web. Looking at such a diagram, one can only venture to guess at the level of complexity that unfolds when the issue is larger than that of a single hypothetical plant. Dealing with ecological complexity is a process of methodically teasing apart a tangled web of ecological relationships, and striving to determine the cause and effect of each part within the larger whole system.

One of the challenges that Harte and other ecologists face is that of actually *describing* the whole system under consideration, including defining the boundaries of their study. One of the first things Harte says he tries to impress upon his students when they come to him with an idea for a new project is to think about the boundaries of the system they want to study. Over the years Harte has found that thinking about system boundaries is not something that comes easily to students. The problem lies in the confusion about "what one's work means and arguments amongst different researchers" who tend to make different assumptions about their system boundaries. "So somebody is including the people in the system and somebody isn't or somebody is including not just the plants but the soil and somebody else isn't." Harte says he "wrestles" with this kind of ecological complexity all the time:

> The world is as complex as you care to make it, because the more you look at the ecology, the more detail you see, and to make progress, to make plausible predictions, and develop an understanding of how an ecosystem works, and how it's going to respond to a threat, a perturbation like global warming, you have to both cope with the complexity, come to grips with it, but also simplify it, 'cause if you don't cut through the complexity, you won't be able to reach conclusions, and

> so the key to doing almost any kind of science is knowing what the inessential details are that can be dispensed with, and what is the core of the complexity that has to be retained, and then focusing on that.

Ecological complexity is not just something Harte has spent a lot of time thinking about, he's actually written a textbook on it. He found through his work mentoring students that there was a need to provide some insights and teaching tools on ways to simplify the complex world "to the point where you haven't lost the essential details, but you've thrown away or ignored the inessentials." Harte's textbook, titled *Consider a Spherical Cow: A Course in Environmental Problem Solving* (1988), develops methods for making simple models of very complex environmental systems. The book teaches by example with over 40 exercises for students to practice the techniques and strategies for dealing with complexity and arriving at simple but plausible models of complex systems. Harte's premise is that:

> It is preferable in environmental analysis to develop relatively simple, analytically tractable models, rather than complex ones requiring truckloads of parameters. The advantage of being able to "tinker" mentally with a simple penetrable model, and thus explore the consequences of a variety of assumptions, outweighs in most cases the greater realism that might be attained with a complex model…the spherical cow approach to problem solving involves the stripping away of unnecessary detail, so that only essentials remain. (1988, p. xii)

Harte describes two "basic empirical approaches" to coping with the complexity of climate change. One is correlational studies of current and paleo-ecological patterns such as those described by ecologists earlier in this dissertation; and the other is controlled experiments like his meadow warming plots. Harte has found that "the combination of those two is the most useful…the experiments are necessarily small scale…the pattern work can be arbitrary in scale depending on the kind of data sets you have available, and by combining the two, you can draw more robust conclusions."

Harte and one of his former graduate students, Dr. Jennifer Dunne, wrote a paper on the virtues and techniques for working with these empirical methods (Dunne, Saleska, Fischer, & Harte, 2004). In the paper they describe the addition of three new research sites added to the original meadow warming experiment. Within each of the newer sites there are snow removal plots and control plots. Their findings from several years of research integrating both gradient and experimental methods confirm two findings: 1) that timing of snowmelt is the most consistent predictor for timing of flower phenology, and 2) the amount of carbon in soil organic matter declines in the short-term but then rebounds as more drought tolerant plant species eventually come to predominate within the plot. Their overall advice to other researchers: "The potential complexity of terrestrial ecosystem responses to anthropogenic climate change requires that scientists develop understanding of those responses that is both mechanistic and general, facilitating robust predictions about climate-ecosystem interactions" (p. 913).

Despite all of the potential complexity surrounding his experiment, Harte's meadow warming plots have shown a relatively simple pattern: sagebrush is expanding and wildflowers are declining. Harte and his colleagues pinpoint timing of snowmelt, and subsequent decreases in summer soil moisture, as the primary culprit. Because sagebrush has deeper roots than most wildflowers in the area, it out-competes the flowers for water. In this arid subalpine site water is the precious limiting factor to plant growth. The conclusion is "species adapted to maintain water uptake and photosynthesis may avoid photosynthetic down regulation under altered climatic conditions of the future" (Loik, Redar, & Harte, 2000, p. 174).

On our second meeting, Harte takes a few moments out of his busy day to join me in his Gothic laboratory. He describes a lecture with his students earlier that morning where he had drawn on the chalkboard all of the climate-ecosystem interactions that have been studied over the years at Rocky Mountain Biological Laboratory. He waves his arms through the air gesturing at the chalk board and demonstrating the complex diagram already erased from the morning's lecture:

> I showed a series of six spaghetti-like masses of feedback diagrams where we've actually been able to identify ten key components of the system, and the linkages between them, and then in that mass of ten coupled components, like plant production, and microbial activity, and so on, amongst those then one can draw feedback loops, and we've been able to…assign the feedback, positive or negative, and quantify them to some extent, and it's a lot of knowledge about one system.

Because Harte and his colleagues at Gothic have collected so much data and generated so many results, he believes there aren't many other ecosystems in the world where so much is understood about the ecological effects of climate change. In 18 years of experiments, Harte and others have published 30 research papers "so a lot is known about a relatively few square meters of the planet." One of the most important findings from Harte's research has to do with ecosystem feedback loops.

A positive ecosystem feedback loop amplifies the effects of climate change and Harte says there is good evidence that positive feedbacks are also happening up north in the tundra and boreal forests. "They're strong and what they mean is that global warming is going to be more intense than our current models predict." Harte feels that the Intergovernmental Panel on Climate Change has underestimated the magnitude of global warming and that ultimately the problem may be easier to *solve* than it is to *understand*:

> It's inevitable when you have a committee of hundreds of people trying to reach a consensus. There is a move toward the center, but it turns out that many of the indices of climate change are showing more rapid and more intense changes over

> time than we have projected…we're also underestimating how complex the problem is…and I've come to the conclusion that solving global warming is easier than understanding it. We're dealing with an enormously complex system. We may not figure out how clouds form under different conditions…how fast the ice is melting…how the forests are going to shift…how much more forest fire activity is going to happen…how much more intense thunderstorms will be in the Gulf states. Trying to do all that in the light of how complex the system is, and how often we've underestimated the problem, or just not realized the problem is there until it hits us in the face, has made me realize that we should keep trying, we should do our best, but we shouldn't fool ourselves into thinking we're going to come up with some model that predicts what the global ecosystems are going to look like in 50 years.

Harte says "the good news is that the more I look at the available technologies, and the economics, and the opportunities to solve the problem of global warming, the more I've come to realize that that's actually easy," but he admits that it is not necessarily politically easy.

> We've got political barriers, embedded ignorance, and vested interests…but if you actually look at what we could do in the next 15, 20, 25 years to make the transition to a more efficient economy…an economy that isn't run on fossil fuels, but on clean, renewable energy, geothermal, solar, wind…the opportunities are there to both solve global warming and save the economy.

In fact Harte and his wife just finished a manuscript on solving global warming. The book proposes a "policy blueprint" for what to do about the problem, and Harte says that "compared to trying to predict what the future will look like if we don't solve it, solving it looks easy…and I really want to solve the problem, I'm dreading what the world will look like if we don't." Along with Harte, another experimental field ecologist, Dr. Andrew Blaustein, is also very concerned about what the future might hold. Like Harte, Blaustein emphasizes the extreme complexity involved with identifying specific cause and effect relationships.

Dr. Andrew Blaustein

Dr. Andrew Blaustein is a Professor in the Department of Zoology and Director of the Environmental Sciences Graduate Program at Oregon State University in Corvallis. As a young boy growing up in the New York metropolitan area Blaustein says he "was always interested in ecology." He loved animals and would go outside and collect any animals he could find. He's been fascinated with animal behavior and ecology ever since. Blaustein says his work on understanding ecological processes "Is actually fun. I love my job." Blaustein also loves teaching. I talk with him just after he's given a final exam to 1,000 undergraduates. He says "I'm getting inundated with phone calls about my final, which I just gave this morning, but I have a really good time teaching. And I have a really good time doing research. I have a lot of graduate students. It's a good job, and I think it's an important one too." Like Harte, Blaustein sees the world as ecologically complex and he uses field experiments to tease apart the multitude of interrelated variables related to environmental change. He says he began his career "doing some behavior studies" using amphibian eggs "because they are easy to manipulate and experiment with without harming them."

During the 1980s Blaustein observed that eggs which he once found readily available at field sites were becoming "harder and harder to find." And by the early 1990s he and his colleague, Dr. David Wake from U.C. Berkeley, were two of the first ecologists to publish and speak out about globally declining amphibian populations (Blaustein & Wake, 1990; Blaustein, Wake, & Sousa, 1994). The current rate of global biodiversity loss is more rapid now than in any other time in the past 100,000 years (Wilson, 1992), and the loss of amphibian populations may be "more severe than losses in other taxa" (Blaustein & Bancroft, 2007, p. 437). Since 1980, as many as 122 species of amphibians have gone extinct (Mendelson III & et al., 2006). Because they are ectotherms with permeable skins and eggs without shells, ecologists consider amphibians "excellent indicators of environmental change and contamination," and, even more alarming, amphibians are disappearing from places "relatively undisturbed by humans" (Blaustein & Bancroft, 2007, p. 437).

In order to get to the heart of what is causing such dramatic global declines in amphibians, Blaustein has conducted experiments in the laboratory and in the field. He has focused his attention on the effects of ultraviolet-B radiation (UVB). "The effects of UVB radiation on amphibians include increased mortality, reduced growth, developmental abnormalities, increased susceptibility to disease, and behavioral changes," and the effects vary by species, life stage, and interactions with other environmental variables (Bancroft, Baker, & Blaustein, 2008, p. 988). He gives the historical background on what led him to focus in on UVB radiation:

> We couldn't find anything else that was killing eggs in the field—in the lakes and ponds where they were dying. They would breed. The eggs would develop to a point, and then they would die. We tested the water for quality. We tested for contaminants. We tested for pathogens. There was an associated pathogen but even when we took the pathogen away, these amphibians would still die. And if we took the eggs from the field and brought them into the laboratory and reared them in the exact same water that we collected from those lakes where they were dying, they would do fine. So everything was ruled out that we could think of, so we figured it was sunlight. We knew that ultraviolet harmed lots of organisms, from plants to microorganisms, including amphibians.

So Blaustein devised a relatively simple field experiment to ascertain whether or not UVB was the culprit. He describes his original field experiment in a 1994 issue of *Natural History* magazine:

> We gathered freshly laid eggs from four species that deposited them in the open: Cascades frogs (*Rana cascadae*), Pacific tree frogs (*Hyla regilla*), western toads

> (*Bufo boreas*), and northwestern salamanders (*Ambystoma gracile*). We placed the eggs in the bottom of screened boxlike enclosures that allowed water to flow freely through them. Over some of the enclosures, we placed plastic filters that blocked UVB. We left a second set of enclosures uncovered, exposing the animals in them to the rays. A third set, which had a plastic filter that allowed transmission of UVB, provided a control to insure that any variation we found under the UVB-blocking model was not due to the presence of a plastic cover. We placed the enclosures randomly in the shallow water of lakes or ponds where natural breeding sites were located. (Blaustein, 1994, p. 36)

The experiment lasted two years, and by the end Blaustein says the results were both "dramatic and foreboding…more than 40 percent of the western toad and Cascades frog eggs exposed to UVB radiation died, compared with 10 to 20 percent of those that were shielded. Northwestern salamanders did not fare any better. More than 90 percent of their exposed eggs died. The Pacific tree frog, however, was unscathed" (Blaustein, 1994, p. 36). It turns out that the three species most affected by UVB had lower levels of photolyase in their cells. Photolyase is an enzyme that repairs radiation damage to DNA.

Although Blaustein's experiment revealed an important trend, he offers his conclusions with a caveat: "We've tested many hypotheses from diseases, to climate change, to ultraviolet radiation, to contaminants…We work with lots of species…and in our opinion, there's not just one cause for amphibian population declines—there's no silver bullet." He says "they're all playing some role, some are more important in some regions than others, some are more important in some species than others." Blaustein says there are "multiple insults" on amphibians including climate change, and he puts them all under the "one umbrella" of global environmental change.

Blaustein considers himself to be an "experimentalist." He looks for patterns in the natural world and tries to figure out what is happening by doing tests. He says he does not have a favorite hypothesis. "We try to use some reasoning as to what would be a very key hypothesis to examine…after the reasoning, then we do our experiments." Blaustein says his ecological perspective allows him to see earth's complexity and dynamism more so than someone who is not thinking about it:

> There's no one answer to everything. Everything is interrelated. It's very dynamic. There's a picture out there that, to be in a good ecological state, everything has to be stable. But actually, that's not exactly true…dynamic instability is more the norm than stable systems. So everything's always constantly changing, and everything's interacting with everything else. That's the way I look at the world.

Blaustein says climate change "definitely seems to be occurring…with precipitation differences on amphibians and how the eggs grow and develop…they get a pathogen when there's less water, and they get zapped by more sunlight when there's less water." He says El Nino and La Nina effects are increasing in frequency and amphibians and other wild animals are affected by it. Still, the relationships are complex and Blaustein continues to emphasize that there are "multiple insults" on amphibians worldwide.

The series of rebuttals in their scientific literature on the linkages between climate change and amphibian declines suggests that Blaustein and other ecologists are working hard to get to the bottom of the issue. In a 2001 article titled "Amphibian Breeding and Climate Change", Blaustein and colleagues assert that "climate change has not influenced the timing of breeding in amphibians in North America….The broad pattern emerging from available studies is that some temperate-zone anuran populations show a trend toward breeding earlier, whereas others do not" (p. 1804). Later, in a 2003 article titled "Amphibian Breeding and Climate Change: Importance of Snow in the Mountains" (Corn, 2003), another ecologist, Dr. Paul Stephen Corn, describes how he re-analyzed Blaustein's data for the timing of breeding of western toads and correlated the data with different temperature and snow data. Corn says, "I found significant relationships between dates of breeding and both snow accumulation and air temperature that have important implications for the effects of climate change on amphibians in the Pacific Northwest" (p. 622). Then later in a 2005 article titled "Climate Change and Amphibians" Corn concludes "analyses of existing data have generally failed to find a link between climate and amphibian declines. It is likely, however, that future climate will cause further declines of some amphibian species" (p. 59). Finally, in a 2007 article "Amphibian Population Declines: Evolutionary Considerations", Blaustein and Bancroft conclude:

> There is a complex relationship among climate change, UVB radiation, and outbreaks of disease….When water levels decrease, UVB exposure increases, and eggs become infected with *Saprolegnia* more readily than when water levels are higher. The increase in frequency and magnitude of El Nino events as a result of global climate change…could increase the exposure of amphibians to detrimental levels of UVB and raise infection rates of *Saprolegnia.* (p. 441)

This scientific process of identifying the exact cause and effect relationships related to amphibian declines is an especially good example of how scientists cope with complexity by building upon, and oftentimes refuting, one another's conclusions.

Chapter Conclusion

The accounts of Dr. John Harte and Dr. Andrew Blaustein's experiences conducting field experiments illuminates just how complicated understanding the ecological effects of climate change, and other global environmental changes, can be. The process of understanding the causes and effects, even with just one kind of ecosystem (a subalpine meadow) or one taxon (amphibians), is rife with complexity. Sorting through this complexity is like untangling a mass, or tangled web, of interconnected parts and processes of an ecological whole that is not always easy to define. In order to gain traction Harte and Blaustein, like other experimental field ecologists, design simplified simulations. While their experiences demonstrate one way of coping with the complexity of uncertainty of global environmental change, other ecologists turn to lessons from earth's long arc of geologic and ecologic time. In the next chapter I explore what it is like for ecologists to learn from the deep past, to have a paleo-perspective.

RESULTS THEME FIVE: A PALEO-PERSPECTIVE

Introduction

In this chapter I explore what it is like for ecologists to experience climate change through the paradigmatic lens of paleo-ecology, a perspective informed by earth's climatic and evolutionary history. Building on my brief discussion of ecologists' experiences of time in the *Ecological Thinking* chapter, this chapter probes more deeply into *paleo*-ecological perspectives and methods. There are several salient experiences that ecologists describe when they talk about how their paleo-perspective—or sense of deep time—pervades their worldview: a) thinking of climate in terms of cycles occurring simultaneously on varying scales, b) thinking of earth as a "dynamic" ever-changing place, c) having a strong "internal sense" of what ecosystems looked like in past centuries and millenia, and d) perceiving the world in a "periscope kind of way" where the past always informs the future.

I present these four themes throughout this chapter, and the themes are exemplified by the stories of two practicing paleo-ecologists: Dr. Connie Millar and Dr. Tom Swetnam. Both ecologists specialize in dendrochronology, the study of tree rings. They have spent the majority of their careers in the field, looking at trees and searching for clues of past climates. They piece together evidence from old trees that are dispersed across landscapes, looking for historical patterns in order to understand forest ecosystems today and what we might expect in the future. Both ecologists have also spent so much time outdoors that they say they have developed a kind of "search image" that enables them to see patterns in trees that others would not. For Millar and Swetnam, trees are keepers of stories that hold important lessons about how humans can adapt to climate change today.

Dr. Connie Millar

Dr. Connie Millar is a U.S. Forest Service Research Scientist with the Pacific Southwest Research Station based in northern California. Her primary office is based out of the San Francisco Bay area, but she spends much of her time working out of her field office near Mono Lake in the Great Basin. From there she has access to the high peaks of the Eastern Sierra Nevada. Her academic training is in forest genetics and evolutionary ecology. Throughout her career she has focused on how natural climate mechanisms affect individual tree species and forest communities.

Millar considers herself “first and foremost a *field* ecologist.” Her “brand of science” requires spending much time observing outdoors. She says:

> I guess I would call myself a naturalist, and I feel that that is where ecology obviously has its roots, but it’s lost its roots. Few people spend much time in the field, and, when they do, they go out looking for something that they expect to find…rather than letting what they see inform them about the process….If you spend the whole summer in the field or the whole year in the field, you’ll see things even more differently….A lot of things happen fortuitously because of that.

When she is out in the field, Millar uses the “tools of quaternary science,” and she considers climate change an “ecosystem architect.” The quaternary period is a chunk of time that began 1.8 million years ago and continues today. Within the quaternary period is the holocene epoch, the most recent shorter chunk of geologic time, beginning 11,000 years ago when glaciers receded across North America and left most of today’s mountain landforms in their former paths.

Millar’s real passion is studying deep evolutionary time, but recently she has been forced to shift her focus. Millar and her research team had been looking at historic climate events like the Little Ice Age that happened between 1550 and 1850 AD and its effects on forest recruitment. Now they are more concerned with recent forest shifts due to current climate change, and the patterns they have begun to see in limber pine (*Pinus flexilis*) and whitebark pine (*Pinus albicaulis*) do not correspond with prevailing scientific ideas. Much of the peer-reviewed literature reports that trees and other species will shift *upward* and northward as earth's temperature rises. But Millar has found that is not always the case. She has discovered "by far the most common trend" has been for trees to *invade* mountain meadows, both within and below current tree line. Rather than migrating up slope and tracking the cooler temperatures they prefer, limber pine forests are taking over where wildflowers cannot make it any longer. It turns out, that just like Dr. John Harte has shown with his meadow warming experiment in Colorado, fields of mountain wildflowers in California are also drying up due to earlier spring snowmelt. the The limber pine is doing at higher elevations in the Sierra Nevada what sagebrush does lower in the subalpine zone of Colorado. In some cases, Millar says the trend is counterintuitive. She is finding that in the Sierra it is actually cooler in sheltered *lower* elevations below tree-lines, especially in north-facing ravines.

Limber pine is a five-needled pine tree that grows mostly in the subalpine zone of western mountains. At Millar's study sites in the Sierra Nevada and Great Basin, the trees grow widely spaced apart, preferring "steep rocky slopes" with little vegetation. These limber pine forests appear more like a *scattering of trees* than the idea of a "forest" might suggest. The standing living trees are "old growth;" most of them 800 to 1,500 years old. Their tall and twisted trunks are scoured bare of bark by high mountain winds. On the ground, "dead wood commonly persists more than three millennia…and is evidence for stand persistence for such duration" (Millar, Westfall, & Delany, 2007, p. 2509).

Millar cites her discovery of limber pine's "counterintuitive" migration as an example of "being more focused on what the species is telling us rather than testing a hypothesis directly." Rather than looking for evidence of forests shifting upward as some of the literature suggests, Millar's naturalist tendency makes her more open to perceiving patterns on the land. She is not out there trying to pinpoint a particular situation. She is more concerned with careful observation, with how trees respond across their entire distribution. "Really the biggest question that we ask is: what do these forest systems do as climate changes?"

One might think that as the climate warms, forests would return to former conditions in accord with past climates, but Millar says that they do not. It is a more complex situation as species respond to the entire ecological community's changing composition. Trees may move up slope or down slope by changing habitat. "If things get warm, they do one thing, and, if it gets cool, they go back to where they were, but never the same, never exactly the same. There is a general trend, and then there are the specifics." There is a "taxonomy of ways" that species can respond. Because of Millar's deep time perspective, she does not see the world as black and white. She is aware of just how complexly orchestrated earth's climates and ecosystems are. For Millar, earth's natural climatic fluctuations are "a back drop of change." There are multiple "nested oscillating climate cycles," and she thinks of them "like a symphony."

A U.S. Forest Service article written about Millar's work (Rosenthal, 2003) describes how forests respond to three climatic cycles that operate on different time scales: decadal, century, and millennial. Decadal scale cycles are linked with changes in ocean current temperatures, such as the El Niño-La Niña effect and the Pacific Decadal Oscillation, which "catalyzes abrupt changes every 25 to 40 years in streamflow, snowpacks, forest productivity, and salmon abundance," says Millar (Rosenthal, 2003, p. 1). Century scale cycles have more to do with changes from the sun, including the influence of sun spots. These cycles affect the temperature relations of atmosphere and oceans. "Because forests and even individual trees span many centuries, oscillations this long are critical to forest management, especially since they can occur abruptly. Century scale oscillations were an underlying cause of the Little Ice Age" (Rosenthal, 2003, p. 5). Millennial scale cycles are due to changes in earth's orbit around the sun. Over the past two million years there have been "50 extended glacial periods interspersed with warmer interglacial episodes like that present today…such cycles set in motion important genetic and evolutionary paths, Millar explains" (Rosenthal, 2003, p. 5). When combined all three cycles create a "symphony" with "climatic peaks and valleys" that can "resculpt landscapes…continually resets the stage on which successional dynamics such as fire, flood, insect infestations, and disease play out" (Rosenthal, 2003, p. 5).

Millar thinks a decadal scale oscillation is responsible for most of the recent deaths in limber pine in the Eastern Sierra. The trees died due to a complex result of climatic stress, a short but severe drought followed by an insect epidemic that killed the stand's overstory. This was an atypical event for the limber pine. Based on evidence from tree rings, previous droughts throughout the nineteenth and twentieth centuries did not kill the trees (Millar, Westfall, & Delany, 2007). Millar describes that in the past the trees were able to "resile" or bounce back after a drought, whereas in the most recent drought they did not:

> In that species in the early twentieth century, there was drought; the trees resiled after the disturbance. In the drought that we looked at in the later twentieth century, they did not. They responded to that drought event rather than through resilience but through mortality—overstory mortality, so we were investigating the question, why did they die then and not before?

Millar and her colleagues call this recent event a "global change-type drought" whereby the interaction of drought, which previously had not been a problem for this species, combined with a number of other things, including warming background temperatures, precluded the species' capacity to resile, so the overstory trees died.

> It was a landscape scale collapse of the mature population, a case of non-resilience. Whereas earlier in the twentieth century there had been resilience…the understory of reproduction did not die, and there were some surviving mature trees, so the result of this drought in the late 1980s, and the subsequent mortality event, appeared that the stand was thinned, the young understory was released.

Despite most of the older trees dying and not bouncing back from the recent effects of climate, Millar says there was a different kind of resilience that showed up. By killing the older overstory trees, the mortality event created an opportunity for younger trees.

> It prepared the site for being more persistent on that location into the future, and, as the case was, another drought and an even warmer background that just ended a year or so ago, had absolutely no mortality effect on the stand.

This most recent warmer drought tested Millar's hunch that the limber pine forest is now actually more resilient from having shed itself of the mature stand, which was a case of non-resilience. As with her discoveries of the tree's shifting spatial patterning in response to warmer temperatures, this situation of resilience and non-resilience, again, points to the complex nature of climate change. A complexity that Millar feels can sometimes only be understood by being outdoors for long periods of time.

Millar says the current focus on "seeing climate as the key player" is a paradigm shift for scientists and managers alike. But this paradigm shift is more profound than others. Over the course of her career Millar cites changes in forest management perspectives on fire ecology, "accepting fire as an agent of change, good rather than bad" and ecosystem management. "Climate change in some ways feels like that, but I think it's far, far, far more profound and will not just be a flash in the pan, and will really be in our context for the rest of my life, I'm sure."

There is also a less profound, more practical, impact that Millar has experienced due to recent climate change. Her working environment has changed "from one of working in isolation," to being in a "limelight" working in an area of great scrutiny. Millar says she does not tend to enjoy that environment. For her "it's a bit challenging, but on the other hand, it's exciting" and she says it is what she and her colleagues have been asking for. The "bigger climate ecologist world" has, for the last 20 years, wanted people "to listen and consider the significance and gravity of the events socially." She also says that now there are more people who consider themselves climate change ecologists:

> The nature of the questions we ask become guided by current interest, and sometimes that profoundly changes the way we address our research, and sometimes it's a minor tweak. If we've been working in climate, there's of course a heightened interest in it. Now all of a sudden everybody is a climate ecologist. That's fine. That's great.

But despite the increased public attention to climate change and research, Millar wishes she could spend more time focusing on her real passion.

Millar misses the focus on paleo-processes. She says, "We've been more engulfed in the focus on twenty-first century and future changes rather than my real interest which is in past time and really deep time like tertiary—millions of years ago. But that's lost its cachet." I ask her why she is so passionate about the deep time perspective, and she says:

> It's so explanatory to me. I think there is so much that it explains that we can't understand the present without the legacy of understanding the past….We don't understand our own behavior unless we understand our evolutionary history. It's fascinating to see the expression of millennia of time in every action that we do both humans and trees, and same with the landscape. That's the physical landscape, not a product of ecological evolution, but of physical evolution. Try to imagine what processes brought the mountains to look the way they do now. What has happened over the past—to me it's just—every scientist has their own passion, and it's very difficult for others to understand why it is. It's just, basically, it's an obsession. You get obsessed with your questions, and this just happens to be my obsession.

Millar's obsession leads her to experience the world differently than others without such as deep time perspective. She has a greater sense of earth's "natural dynamism" and a greater acceptance of living in a world that cannot be controlled.

Millar's sense of time influences everything in her personal and professional life. She describes her paleo-perspective as a way of "not just living in the past," which is one way of being a paleo-scientist, but rather, thinking "in a kind of periscope way." She looks at phenomena as if they are coming out of past and into the present moment. There is always a past hovering around her shadow. When Millar looks at a landscape, she looks at the history of that landscape. When she interacts with family and friends, she thinks of the evolutionary history that led to their behavior. "Whether it's a kid asking for something or people acting aggressively in a meeting," Millar sees the world in an "evolutionary-paleo context" that influences the way she responds to whatever is happening in her everyday world. "I would say that I live in a dynamic mindset. This certainly doesn't mean I succeed in coping with change, but that comes to my mind a lot. A sense of deep time very much pervades my personal life."

Because of her sense of the past Millar thinks there is some "disservice that's been done" in many of the public communications about climate change, including Al Gore's messages in his movie *An Inconvenient Truth*. She believes the movie provides the public with a false impression of historical climate change. "There is a real sense that people feel like the changes that are happening now are novel…that any change is necessarily a reflection of humans screwing up." Millar thinks it is much more important for people to understand the world in terms of its inherent natural dynamism and then consider the human influence on top of that:

> I think I have an epi-level hope, that by bringing knowledge of dynamism—natural dynamism, humans will live in more accord with their natural and cultural environment and be more at peace with themselves and constitute ourselves more responsibly both in a stewardship way and in relationships. To me it is far more important that we learn how to live in a relationship with those natural processes….Our decisions will be better for ourselves and our families and our fellow humans….The dynamics of change are so important to me, and why I feel it's very important to infuse in the Gore message—with the pervasiveness of variability and dynamism and change—the hope that that gives, that we can make a difference.

But Millar also thinks our society needs to focus on "getting the mindset out of materialism." She sees Western society on an "ill-adaptive trajectory" that is compounded by the fact that children spend too much time inside watching TV and playing computer games. She says we need to revive a greater sense of "awe" and curiosity especially in children these days. Because today's children don't have the personal experiences that she did as a child growing up in the 1950s and going to national parks with her parents and camping, youth these days are on an ill-adaptive trajectory. "Some affluent kids are spending less and less time [outdoors] as we've become more urbanized. To me that is a really ill-adaptive trajectory for the human species. You don't find that it's good food for what humans do best." Millar is not the only ecologist whose sense of deep time gives her both hope and cause for concern. Another ecologist, Dr. Tom Swetnam, is also influenced by what he has learned from the deep past.

Dr. Tom Swetnam

Looking at earth's ecological history from a slightly different perspective than Millar, Dr. Tom Swetnam is also a dendrochronologist, but his current primary focus is on forest *fires* and climate. Swetnam is Director and Professor of Dendrochronology at the Laboratory of Tree-Ring Research at the University of Arizona. As a young boy he grew up in the footsteps of his father who was a forest ranger, an amateur naturalist, and a World War II veteran. Influenced by his father, young Swetnam earned an undergraduate degree in biology and chemistry from University of New Mexico and then went to work for three years as a firefighter in the Gila Wilderness. When he was a teenager he was influenced by what he saw while out in the forest with his father. He says there were several very large "blowup crown fires" in the Jemez Mountains during the 1960s and early 1970s that made a huge impression on him. So in 1980 when he decided to go to graduate school, he set out to study fire ecology. He went to the Laboratory of Tree-Ring Research, and he's been there ever since.

Swetnam describes the Tree-Ring Laboratory as a unique, historical, and interdisciplinary institution that pioneered the field dendrochronology. The Lab holds the largest collection of ancient timbers in the world "at least two million, maybe three million samples." There are samples of ancient wood collected from the oldest trees in the world, bristlecone pines (*Pinus longaeva*). Most of the specimens in the lab are the diameter of a pencil, collected from trees with a drill-like increment bore. There are also cross sections of tree trunks that tell the history of fire through scars across their rings. Swetnam says he and his team concentrate on gathering evidence from dead trees—stumps and logs and standing snags, but occasionally they will take a partial section from a living tree, a procedure that when carefully done does not kill the tree outright. The cross-sections collected in the field are brought back to the lab and scoured with a belt sander. Then, when viewed through a microscope, the polished pieces of wood reveal stories in their growth rings. By carefully measuring the width and pattern of the tree rings, Swetnam and his team look through a lignified window of time.

The oldest known living tree is around 4,900 years old, and it was discovered by one of the early scientists working at the lab in the 1940s. By matching up the rings from the oldest living trees to the rings of *even older* dead wood found on the ground, researchers at the Tree-Ring Lab have developed accurate chronologies of bristlecone pine going back 9,000 years. Swetnam says that that particular historical record has been extremely useful for learning about long-term climate history, treeline fluctuations, and for calibrating the radiocarbon timescale. He says "trees can be really faithful recorders of things that happen around them."

Like Millar and others field ecologists who observe natural patterns, Swetnam says "historical scientists…for the most part…are observationalists….We're more inductive-type scientists, we pull together evidences of various sorts from lots of different places, and we see what the data's telling us." Tree rings provide "a fragmentary record that is irregularly distributed across the landscape so there's quite a bit of searching involved to find the record." And Swetnam says, "It's great fun when you find a forest stand or individual trees that are particularly old….It's always an occasion for some bit of celebration." He finds the most enjoyable aspect of studying tree rings to be the process of discovery:

> Every time we learn a new date of an event in the past, or reconstruct a different pattern of change in a forest, it's a little act of discovery. So that's a lot of fun…You develop an eye for what's old and what's not so old…Tree ring people actually joke that you get…sort of "spoiled"…your perspective about trees gets completely changed once you start looking at tree rings…considering them from the point of view of history…when you go back out in the woods, you kind of see it with a different eye… It's kind of a search image that develops…Like an archeologist who learned how to find arrowheads…they see things that maybe the untrained eye doesn't see…it has a lot of subtleties that come into it, some of which you can't even really describe verbally. But it's something that you know it when you see it.

Most trees that Swetnam and his team study go back to the 16th century, and, because variations in tree rings are often controlled by climate, dendrochronologists really get to know the chronology of climate history. If there is a really wet year, they see a large ring. If there is a dry year, they see a small ring. Swetnam says dendrochronologists understand climate history "in a sort of memorized way. We basically internalize it. The 17th century, 16th century, and earlier becomes sort of familiar to us."

But despite Swetnam's grasp of historic climatic variability, he says that today's situation is different:

> I keep having to remind myself of the unusualness of the things that we are seeing. Sort of intellectually, I see it and understand it. But at a deeper level, it's kind of hard to accept, that some of the big changes that we are seeing in the tree ring record and other kinds of ecological indicators are extraordinary. And just intellectually, you can see that in the kinds of records that we've put together…So actually, it's disturbing. And it's worrisome…We've sampled many trees at relatively high elevations here in the Southwest….Most of them are above 9,000 feet in elevation. And many of these sites are showing extraordinary increased growth rates…on time scales of 1,000 to 2,000 years…We just don't see anything like it, in terms of the magnitude of increasing growth.

It appears that the increased growth is related to "extraordinary" warming conditions combined with wet episodes from the mid 1970s until the early 1990s. And Swetnam says that he looks at that situation and says ,"Oh wow…I just happen to be alive in this time period when this is happening….We're seeing some changes that are quite extraordinary on multi-millennial timescales, if not ever, and humans are likely the major driver of it."

Swetnam has interacted with many other scientists, paleoclimate scientists, climate modelers, and others who study climate change. He says the amount and diversity of evidence is "overwhelming" and "we're in extraordinary times right now." For him, in some ways "it's an honor and a privilege to be involved in recognizing what's going on" but, on the other hand, "it's also disturbing because you're hearing it firsthand….It's an extreme change, an extraordinary change, maybe not unprecedented, but in this case, it's caused by people…It's scary." Swetnam says that he has been "surprised" by how soon he had seen the climate change signal emerging in the form of large fires across the West. There have been more fires, and they are bigger than they used to be, occurring over larger areas, on the order of 100,000 to half a million acres, "an increase by an order of magnitude." Swetnam says that if someone had asked him three or four years ago whether or not warming trends were clearly causing changes in forest fire activity across the West, he would have said:

> The evidence is still very equivocal…and there are many other factors….I would have pointed primarily to fuel changes and forest changes…fire suppression, other kinds of things like that being the primary driver of the changes we're seeing in forest fire activity. But in the last couple of years…the evidence is lining up….Indeed the increases that we're seeing…are probably being driven more by climate variability and warming than by any other single factor.

With each year, the data correlating climatic warming and fire activity gets stronger, and as more time passes the trend strengthens. Swetnam says overall throughout "the whole period of the last 20 to 30 years, we see this pattern emerging."

Swetnam published a paper with Dr. Tony Westerling in the summer 2006 issue of *Science* (Westerling, Hidalgo, Cayan & Swetnam, 2006) that describes how they pulled together evidence showing trends between climate warming, earlier arrival of spring, and forest fire activity. The trends are indicative of what is to come in ponderosa pine forests in mountains of the Southwest. Large scale fires are creating huge holes in the forest canopy, and the holes are not filling back in with new trees. Swetnam says "you have a 1,000- to 5,000-acre canopy gap, where there is virtually no trees surviving….A lot of these forests are just not adapted to filling in canopy holes of that size any time soon."

Compounding the issue is the fact that ponderosa pine in particular does not have regular sources of seeds to regenerate after a fire. Unlike lodgepole pine, known for its incredible regenerative capacity, like after the Yellowstone fires of 1988, ponderosa pine produces seeds irregularly. Ponderosa seeds are also heavy and virtually wingless. The only way a large hole in a ponderosa canopy will regenerate after fire is by seed dispersal from birds and other animals, a relatively slow process. So Swetnam sees the landscape "converting" to shrub fields and grasslands. This has huge implications for the Southwest. The entire Mogollon Rim area, from New Mexico all the way south to the Gila country of Arizona, is "more or less continuous ponderosa pine," and it is going to break up and fragment. Patches of trees would still persist, but there would be a matrix with more shrubs and grasses.

Even though he sees this trend in forests he still says ,"There are many unknowns," and much of what will come to pass in the future depends on what happens with the climate, specifically with rainfall.

> The most variability and the least confidence in the regional downscaled climate change models is in precipitation…What's gonna happen with plants? Which species are gonna be winners? And which are gonna be losers? And how the communities—the plant communities—are gonna reorganize themselves is a pretty complicated situation.

But Swetnam does not like to dwell on what may come to pass if no broad human action is taken. There is important work to be done. He feels we can learn and adapt, especially if we combine human ingenuity with lessons from the past.

One of the most important things Swetnam says scientists can do these days is "to have an effect on how the public understands climate change" and specifically how managers and policy makers can deal with it in terms of adaptation and mitigation. Ultimately, he feels like some of the things he has learned have had "some real effect on people's understanding…of forest ecosystems." If he can make an impact in this public arena, then he feels he would have "done something important and useful." And he thinks there are better ways that scientists can connect with the public. "There are interesting approaches of recruiting citizens to help make observations of changing environments—ways of involving students—to engage them in looking at the natural world and thinking about it from a scientific perspective." Swetnam and his team at the Tree-Ring Lab have found that "kids just love tree rings." The Tree-Ring Lab has a fulltime staff member who talks with youth groups about some of the oldest trees and biggest trees. The collection of educational tree-ring samples have "all kinds of interesting little quirky stories to tell….Kids intuitively understand the idea of counting the rings…and the different features you can see if you start observing….Looking closely at the tree rings, you start to see more things."

Swetnam says that climate change is the "largest challenge facing us as a society, and also scientifically." If the problem is going to be solved it will somehow involve

> scientists doing things differently and the public becoming more engaged with the science. I think we really have a strong need to try to ramp up, again, our science education in this country. And that's not going to come about just from a top-down government decree. It's going to require that scientists and policy makers recognize the need for that and all of us becoming more committed to communicating better.

On the one hand Swetnam says that he is "pretty pessimistic these days…gloomy about an apocalyptic event." But on the other hand he says that there is hope if we "can act locally…and collectively….We can try to do things sustainably." Lessons for adaptation can be learned from the past.

Swetnam cites stories learned from the paleo-historical approach. One of the examples he is working on currently is looking at how people can live in harmony with forest fires. For example, "If you live in a ponderosa pine forest in the Western U.S., you should be aware that it's going to burn sooner or later. So how did people in the past live within ponderosa pine forests?" Swetnam describes places in northern New Mexico, scattered throughout ponderosa forests, where people lived for centuries in what are today considered "townhouse ruins." "They used fire, and they were smart about it. They had small gardens, and they were growing corn, beans, and squash, and these were surrounded by pine trees." They carefully manipulated their surroundings in a "thoughtful, sustainable way" in order to live there for hundreds of years.

Ultimately, Swetnam believes:

> There are hopeful lessons, as well as warnings….We have to move forward….There are some conditions with no analog, no example from the past to understand how to deal with them today….It's a very difficult challenge. It's not just about going back to the past; it's also about learning how to adapt to the unusual things that we're seeing today that are really extraordinary.

Chapter Conclusion

In this chapter I presented the stories of Dr. Connie Millar and Dr. Tom Swetnam. Both ecologists' experiences of climate change are filtered through the lens of earth's deep history. Whereas Millar finds a sense of peace and acceptance that the earth cannot be controlled, Swetnam seems more "disturbed" by the magnitude of current climate change impacts. Both ecologists express an affiliation with a type of ecology that is more "inductive," and they identify themselves as *field* ecologists as a result of spending so much time outdoors. Their time in the field has given them a special kind of "search image" that allows them to perceive patterns in trees that others would not see. Both ecologists suggest that new ways of doing science are needed. Millar focuses on working with managers, helping them think about a "toolbox" of options available to address climate change. Swetnam promotes a "new kind of science" where scientists instigate education and the public is more explicitly involved in the process of understanding. Like these two ecologists who see the significance of current climate change within patterns of tree rings, other scientists see "a fundamental shift in earth's operating system." In the next chapter I explore what it is like for two different ecologists to witness how mountain ecosystems are crossing ecological thresholds.

RESULTS THEME SIX: CROSSING THRESHOLDS

Introduction

In this chapter I explore what it is like for ecologists to witness mountain ecosystems *crossing ecological thresholds* as a result of climatic forcing. Ecologists describe the condition of crossing thresholds as “entering into a whole different system,” “a fundamental shift,” and “a basic change in the planet’s operation.” They feel they have experienced changes that they “never thought they’d see in their lifetimes,” changes that “are astounding” and “frightening.” The rapid rate of change that ecologists describe is “like flipping a switch” where adding just several degrees to the earth’s average temperature is “like every nuclear warhead on the planet going off at once.”

I present the experiences of Dr. Dan Fagre and Dr. Jesse Logan because, out of all of the ecologists I interviewed, their thoughts and discoveries best express the experience of witnessing ecosystems crossing thresholds. Fagre studies mountain ecosystems and glaciers in Glacier National Park while Logan studies whitebark pine forests and bark beetles in the Northern Rockies. Their stories reveal that witnessing ecosystems cross thresholds is more than a noteworthy scientific event; it can be a profound social, emotional, and even spiritual experience “where nothing on the planet can escape.”

Dr. Dan Fagre

On an August morning in 2008 Dr. Dan Fagre sits at his office desk juggling the social dimensions of his science. While I wait in the entry room just around the corner, I hear him intently talking with one of his colleagues about the data they will present in a report on their research. All around the room are colorful scientific posters, many with repeat photographs of shrinking glaciers—one side of the poster is a photo of a glacier taken in the early part of the 20th century and the other side is a photo taken more recently. Fagre uses these comparative images to help him hit home a point, and the mainstream public is taking notice. Later, that morning he has an interview scheduled with *U.S. News and World Report*.

Like a deer staring into headlights, Fagre has a glaze over his eyes. Perhaps it is due to the early morning hour, or maybe it is from the pace and intensity of the scientific work he sustains. For Fagre, addressing the effects of climate change on mountain ecosystems has become a personal mission and not one he would want if given the choice. He would rather "ratchet things back to when we had wooly mammoths," when there was more snow and ice so he could spend more time on one of his other passions, backcountry skiing.

Fagre is a Global Change Research Coordinator and Ecologist with the U.S. Geological Survey's Biological Resources Division at Glacier Field Station. He says his interest in ecology was "built in from the start." As a young boy growing up in Tokyo, Japan in the 1960s, Fagre didn't have much contact with the natural world, but he read much *National Geographic*. (Little did he know, four decades later, he would be featured in three issues of the magazine.) But one day, when Fagre was in seventh grade, he was flipping through a list of government jobs and came across the title "wildlife biologist." From that moment on, he held a vision and sense of purpose for his career, and he has been working hard at it ever since.

When his family moved back to the U.S. from Japan in 1968, Fagre found the "average suburban environment just wild and crazy….There were rabbits on your lawn, and squirrels….I thought I was living in a wilderness because the contrast with the highly urban environment was so stark." And Fagre describes "an innate drive" to become an ecologist. "I can't really say that I had any epiphany or any event that I can think of that really pointed me in that direction. It was pretty much right from the start." Fagre did pursue his innate desire. He earned his bachelor's degree in environmental science at Prescott College in Arizona, an institution known for its mission of social and environmental responsibility. He earned his M.S. and Ph.D. degrees in animal ecology at University of California, Davis, one of only two graduate schools in the U.S. at that time offering a program in ecology.

Today, Fagre works in the heart of North America's most intact wild mountain ecosystem, Glacier National Park within the Crown of the Continent Ecosystem. The Crown of the Continent Ecosystem stretches along the Northern Rocky Mountains, covering northwestern Montana, southwestern Alberta, and southeastern British Columbia (Prato & Fagre, 2007). Within that ecosystem Fagre has researched: alpine treeline dynamics; amphibians and aquatic systems; snow, avalanche, and glacier dynamics; tree rings; and recently the effects of climate change on mountain ecosystems. Fagre also collaborates with scientists from five other mountain areas in the western US under a large umbrella organization known as The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) and internationally with scientists on a north-south transect that encompasses North, Central and South American mountain ranges.

At Glacier National Park, Fagre says snow and glaciers "rule the ecosystem," and he has documented "dramatic reductions" in alpine glaciers due to climate change. He and his team have been focusing on glacier dynamics—how much they melt, when they melt, and how patterns of change in their meltwater affects the mountain ecosystem. In sum, Fagre looks at "the cascading effects of climate change on mountain systems….The primary one here in these temperate mountains is snow…the king of the ecosystem…because it controls so many of the processes in the mountains." Snow is *the* source of moisture, but it has many other roles. As other ecologists in this dissertation have discovered, winter snowpack controls the timing of many spring events in mountain ecosystems. It also provides habitat and insulation for plants and animals during the winter. Fagre explains that when climatic warming causes precipitation to convert from snow to rain, which it has been doing much lately, plants and animals do not have enough thermal insulation to survive the winters. "There are shifts in everything from vertebrates, like the little shrews that live under the snow, to the soil microbiota," which then leads to changes in ecosystem nutrient cycling.

Fagre says snow "has an unbelievable number of impacts on the ecosystem, and it is of course the main driver for glacier dynamics." Whether glaciers grow or recede annually is a function of both how much snow they get in the winter and how warm and dry it is in the summer. When snowpacks disappear earlier in the spring and glaciers do not melt as late into the summer months, Fagre says, "We'll have a community turnover." Snow is also a "nutrient conduit." Snow avalanches transport nutrients from high elevation ridgelines down into the valley floors. Avalanches also rip out forest trees and create open areas for wildflowers and other plants that attract butterflies, birds, and grizzly bears. A rising elevational snow line, or shallower snowpack that melts earlier in the year, eventually discontinues the ecological resetting for all of these ecosystem processes.

Fagre says his observations of shifts in snowfall, glacier dynamics, and subsequent ecological processes have been "rather astounding." Like most people, Fagre thinks of glaciers as immutable forces on the landscape:

> They just sit there, and they grind away mountains, and they seem so large and powerful….You see chunks fall off, or you hear shifts in the glacier…but you really don't expect in real time, in human time, to see them disappearing, that really is a wake-up call....When we first started hearing about global climate change in the '80s, a lot of us thought, "Oh, it can't be that big a deal. Humans can't be affecting the entire energy balance of this planet. That just seems, on the face of it, improbable," and the fact that the evidence was obviously slim at first, but plausible, and then it just kept building and building, and then I think a lot of scientists who are inherently skeptical – that's our job, is to be skeptical and find out what we need to figure out, if our skepticism was justified or not—so it became overwhelming.

Fagre says that some ecosystem processes are being pushed to their limits and *crossing thresholds*. "Once you cross a threshold, you get a whole different system…and that's what I think we're seeing in many parts of the northern Rockies." Each little increment of change, like a temperature increase, causes another response in the system. When the system reaches a threshold, the next increment of temperature increase "causes a radically different behavior." Fagre gives the example of recent mountain pine beetle outbreaks in forests. Whereas cold winter temperatures used to limit the beetles to completing *one* life cycle per year, now warmer temperatures have made it possible for them to complete *two* life cycles. These recent beetle outbreaks have killed thousands of acres of pine forests across the West. The beetle-forest system crossed a threshold, and Fagre says that the beetles "can suddenly go twice as hard at reproducing…A threshold—or a tipping point—allows behavior that wouldn't be predicted from just looking at the relationship between what the beetles do in the temperatures below that threshold." In one of his books Fagre writes:

> Climate forcing in mountain ecosystems occurs at multiple spatial and temporal scales and some of these changes are distinctly nonlinear. One type of change is expressed as a threshold effect, in which climate has relatively minor impacts until a critical level is reached, leading to rapid (and continuing) change. (2007, p. 189)

Fagre says the possibility of ecosystems crossing thresholds is "one of the scariest things about climate change for a lot of people." Scientists and land managers worry about not knowing where threshold surprises might lie in an ecosystem. These are the kind of surprises that "no one has ever seen before." Another example of an ecosystem crossing thresholds that Fagre cites has to do with tree invasion of subalpine meadows, a process similar to that which Dr. Connie Millar has seen in the Sierra Nevada. As trees continue to invade subalpine meadows, at some point there will be no more meadows, and that means there will be no habitat for many species.

> Once the final closure of those areas occurs, you'll have somewhat of an abrupt threshold because you'll suddenly have no habitat for even the small populations that remain, and it'll occur over a large area so you could have an entire region lose some species almost instantly.

Species will reach a minimum viable population and will not be able to find others of their species to reproduce with. This is the kind of scenario that keeps natural resource managers at Glacier National Park up at night. "They feel like they can deal with things that they know are happening; it's the ones they don't know about that are giving them heartburn." To compound the situation, if a *keystone species* crosses a threshold it could cause a chain reaction in other organisms and ecological processes, creating a *fundamental* shift in ecosystem operations.

To communicate with people who are not as science savvy, Fagre likes to use an analogy. He compares the earth to a human body. He says people fail to recognize that current global climate change is an increase in the *average* temperature for the *entire* earth, not like the kind of daily change people are used to when they walk outside their front doors.

> The analogy is that our bodies are at 98.6 degrees and only an extra degree gives us a fever. Only three or four degrees extra can be fatal either way…It's not about the actual degree; it's about the average temperature that allows all these processes to occur.

Fagre says that we have to talk about climate change as "a change in the basic operation of the planet, rather than just talking about it in these degree terms….Averages are paradoxically the key, and they are also sometimes an obstacle to understanding how important they are." A half-a-degree increase in the planet sounds trivial to most people, but that increase causes thermal expansion of oceans and changes in the dynamics of glaciers.

Fagre thinks glaciers are great tools for creating public awareness and understanding of climate change. They offer visible and tangible evidence. Rather than learning about climate change from temperature data on a graph, or hearing about sea level rise—a phenomenon that impacts people living on coasts but not in the mountains—glaciers really drive the message home. Describing his own experience observing receding glaciers he says:

> When I first saw Grinnell Glacier, I can show you where it was, and every year it's smaller. It's not stopped once. There hasn't even been a pause in it, and so here in 2008, 17 years later, I can walk past the open water and say, "That's where the glacier used to be, and this is how tall it used to be", and so forth and so on, and then go down to where it is now, and see areas that I'd walked on last year are gone, so that is the profound thing that really kicks you in the pants.

Fagre talks about other things that get peoples' attention in the park like one particular stream drying up that has never run dry before or things that affect their livelihood or things they have an emotional bond to such as Glacier Park itself. Human connections are what convince people there is a problem “more than charts, and data, and mean variability of springtime, nighttime freezing levels, things like that, which are incomprehensible to a lot of people.” Fagre uses another analogy, this time one that’s more shocking:

> When you’re looking at the energy that’s required to change the entire planet half a degree, it’s more like every nuclear warhead that anybody has anywhere on the planet going off all at once… it’s cataclysmic…it’s a vast, vast, vast amount of energy, and it should scare everybody…very, very small differences in the mean temperature…can vastly change the kind of planet that you’re working with.

Although there is so much uncertainty about what *kind* of changes we will see in future mountain ecosystems, Fagre says the place will definitely look different.

There will be “radical changes,” not only in species and their viability, but also in their assemblages. People tend to think about what they see on the landscape occurring in groupings that they have become accustomed to. In the future we may see “really wild differences.” Some species will move and others will not. There will be “relic populations” with other populations surrounding them. And Fagre thinks that it will be “as little as 20 or 30 years in many places” because of the confining “environmental envelopes that species can live in” that are moving in both space and time.

It turns out that things are happening faster than Fagre and other scientists had originally predicted. People are realizing that earth’s systems are more sensitive than they thought. There are fundamental shifts in earth’s systems causing profound changes in the way people think of their relationship to the planet. Fagre says, “Every week there are several reports that say, “Oh, we predicted this would happen in the year 2050, and, oops, it already happened,” or, “We’re seeing three times the rate of change in response to climate that we thought this system was capable of. It goes on and on like that.” The early assumptions that Fagre had about earth's stability are now proving to be overly optimistic. Fagre thinks that we will look back at this point in time and be amazed at the "shift in our vision of our relationship to the planet…Now we're running the show." The fact that negotiating with China is more important to earth's energy balance than things like plate tectonics or volcanism is to Fagre "mind boggling."

> We knew that things had happened in the past and will happen in the future, but a rapid change in earth's past took 1,000 years or 100,000 years. Those are considered rapid changes….From a geologic perspective, this is pretty much like an instantaneous explosion….It's just like flipping a switch. It's not a gradual change at all….Everything including here in Glacier Park, things that we predicted have occurred more quickly than our forecasts, and showed us how wrong we are….Our glaciers are a good solid ten years ahead of schedule according to an earlier model….It could be as soon as 2015 to 2020 that we might still have some little bits here and there, but functionally they're going to be gone.

For Fagre, humans have changed the dynamic of earth's natural variability, and there is no going back. He is convinced that we have "flipped the switch," and, just like on a thermostat, the heat will "go on and stay on."

Now, Fagre's mission in life is to promote the "importance of mountains to people and global society" and the fact that they are very vulnerable to climate change. He says, "We need to understand mountains in order to understand how basically the entire globe responds," and he points out that mountains are the direct source of fresh water for 50% of all humanity, and in the western United States it is 85%. He adds that western mountains have experienced three times the climate change that lower elevations and the planet as a whole have.

> The paradox is, we're very dependent on mountains for water, and they're changing more rapidly than other areas. That alone should be a wakeup call that we need to focus some scientific attention on mountains, which typically have had much, much less attention focused on them than other kinds of environments.

Fagre's parting message: mountains are important, they're vulnerable, and we need to understand them in order to respond appropriately to global climate change.

Dr. Jesse Logan

Several hundred miles south of Glacier National Park, in the Greater Yellowstone Ecoregion, another ecologist, Dr. Jesse Logan, witnesses the effects of climate change on large swaths of whitebark pine forest. Logan is a retired U.S. Forest Service entomologist well known for predicting, and then observing and documenting, massive pine bark beetle outbreaks due to climate change. Logan grew up in southern Colorado, spending summers fly fishing with his dad and his brother. He developed a "deeply ingrained sense of awe and love for the mountains" that continues to fuel his retirement routine—spending as much time as possible fly fishing, backcountry skiing, and exploring forests in the mountains near his Montana home. Logan says, "The Rocky Mountains are absolutely basic to who I am," and because of that he says climate change has had a "spiritual impact" on him. Western mountains are "the first and most severely impacted part of the country…to be affected by climate change" and it is affecting his own personal existence. Part of Logan's busy schedule these days includes reaching out to the media and others to show them first hand just how climate change is pushing some mountain forests over ecological thresholds.

I meet Logan at his home on an early August morning. He kindly welcomes me inside for a cup of coffee and hands me a holster of bear repellant. The mountain forest where we will be hiking is frequented by grizzly bears (*Ursus arctos*). We load into s Logan's white pick-up truck and set out on an hour-long drive up old logging roads to

Tom Miner Basin. Logan has studied the intersection of insects, weather, and forests for almost his entire career. He has always had an "inclination toward mathematics" and that has "set the tone" for his ability to develop complex computer models and predictions of changes in ecological systems. As we ascend the bumpy road, Logan explains the ecological system in question here—that of climate, mountain pine beetles, and high elevation whitebark pine forests.

Mountain pine beetles are cold-blooded predators. "They have a life history that hinges on temperature; the *thermal habitat* largely sets the boundaries of their geographic distribution" (Logan, Regniere, & Powell, 2003, p. 130). In contrast to the whitebark pine forests that Logan is concerned with, lodgepole pine forests growing at lower elevations have co-evolved with beetles. Along with fire, beetle outbreaks are a natural part of lodgepole pine forest's regenerative capacity. But in the higher elevation whitebark forests, cold temperatures and harsh conditions keep the beetles from completing their lifecycles in one year and subsequently prevent them from increasing their populations enough to "mass attack" and kill trees. This was the typical situation until recently. Now, with climate change, warmer temperatures speed up the beetle's lifecycle and the whitebark are susceptible to mass attacks. Unlike lodgepole that have co-evolved chemical defenses, whitebark are left relatively defenseless (Logan & Powell, 2001).

In 1992 while Logan was working as the leader of the U.S. Forest Service's Mountain Pine Beetle Project based in Utah, he incorporated predictions from the first Intergovernmental Panel on Climate Change (IPCC) report with his models of mountain pine beetle dynamics. He says that by 1994 "we had all the machinery in place with validated models to take weather impacts on mountain pine beetle population dynamics."

One of the first questions that he and his project team asked was: "If the first IPCC predictions were true, what would that mean for mountain pine beetles?"

Collaborating with other ecologists, Logan had shared in the discovery of a relatively small historic beetle outbreak in a whitebark forest in Idaho in the 1930s. The trees were a "ghost forest," but evidence in their dead wood told Logan that beetles were to blame, so he knew there was a possibility that whitebark were susceptible to beetles on rare occasions. Eight years later, the threshold event that Logan had predicted began to show up in real time. Logan's "first field experience" of seeing evidence of outbreak in whitebark was at a place called Snowbank Mountain in extreme western Idaho. Then again three years later and 2,000 feet higher at his Railroad Ridge site, he was "overwhelmed by what started to occur…Beginning in 2003, this massive outbreak just rolled over the top….We were on the ground observing what happened, so it was really a unique experience." Logan had predicted very accurately, "at least in a qualitative sense," how the outbreak would unfold as temperatures increased.

> We started to see some of the southern aspects, a few of those surpassing the predicted threshold from our modeling work, and we went up in the summer of 2003 at a site called our far north site. The road comes over a slight rise, and here's this whole hillside, and it's just – it's a significant, brilliant red, and that's one thing about this impact is absolutely obvious on the landscape. The year after the tree is killed by the beetles, the needles are real brilliant red…When we first got up there, in this beautiful whitebark pine forest, you could not find a tree that had recently been killed by mountain pine beetle. It just didn't happen…In 2003 when things really started to happen, and it happens amazingly fast in whitebark pine…It shocked us all to see how it happened in whitebark, and it continues to do so. It's truly a devastating sort of event.

What makes a beetle outbreak in a whitebark forest so devastating is that whitebark is a relatively long-lived keystone species in mountain ecosystems.

Logan describes a healthy whitebark forest as "such a vibrant, live place." Whitebark trees have a tight ecological interaction with Clark's nutcracker (*Nucifraga columbiana*), a member of the raucous Corvid family of birds. Whitebark seeds are an important food source for the nutcracker, and the birds create huge seed caches. When either ignored or forgotten by the birds, the seed caches are essentially the only source of whitebark seedling recruitment. Cached whitebark seeds are also a "critically important" autumn food source for grizzly bears. Logan describes the lively scene of a healthy whitebark forest with Clark's nutcrackers:

> They're flying around, squawking, raising hell. Red squirrels are up there in the fall. When you're up there in a good cone year, it's just a rain of cones, and the squirrels are squawking at you. The Clark's nutcrackers are flying around….You will see evidence of bears raiding squirrel middens….It's just a live, live place….Sharing an environment with a grizzly, that tends to keep you tuned in to what's going on….So, it's this live, wonderful place, and the forests themselves or the canopy is this broad bushy canopy of whitebark pine, so the forests are these beautiful, open, grown forests….They're a marvelous place. And you start to see it fall apart, you've got that investment, and then there are places like the first real impact that was noticed in the Greater Yellowstone is a place called Avalanche Peak….And it was just deathly quiet….There aren't birds. There aren't squirrels, no bear tracks, it's just stick forest, and that contrast is so striking, and we could see it coming…and it still continues to be just heart wrenching…It's not right what we are doing, and, you know, this is just one example, but to me it's a very important and very basic example. I mean, this is a result of our actions as a society.

Logan also explains that not only are whitebark important to grizzlies, Clark's nutcrackers, and red squirrels (*Tamiasciurus hudsonicus*), but they are also an important elk (*Cervus elaphus*) calving habitat, and they create cool shaded areas that maintain snowpack into the spring. If the whitebark canopy disappears, snowmelt happens faster, and entire watershed systems are affected.

Logan says what he has seen at the Railroad Ridge site is unprecedented in ecological time. The impact will "leave a legacy for hundreds of years and that legacy doesn't exist." The small Idaho outbreak in the 1930s was a different kind of event. Based on what Logan's colleagues could read from that situation and the dead whitebark tree rings, that event took place in one year, 1933-1934, that was "unbelievably warm and that precipitated significant mortality." But Logan says that historic situation is nothing like he is seeing today, "not even close." Logan explains that the trend line for mean annual temperature in eleven western states has steadily increased since 1975, and, when "you look back at the historic record, there's nothing like it."

Even though Logan predicted that warmer temperatures would lead to massive beetle outbreaks, he never thought it would happen as quickly as it has. The difficulty he says is in the computer modeling. Even though his models were qualitatively correct, they quantitatively, or temporally, missed the mark. "It's happened much earlier than anyone was predicting ten years ago…I felt this was something that my kids may see in their lifetime, but not something I was going to experience." Logan explains that it is very difficult to capture ecological feedbacks and indirect effects of climate change in mathematical models. The feedbacks and indirect effects are "really subtle and complex….You can't recreate the natural world inside a computer."

But Logan says there is hope, and he has begun working toward it. He has teamed up with the Natural Resource Defense Council (NRDC) to create greater awareness of the whitebark issue and involve citizens in solving the problem. Whitebark pine forests are among the most remote and inaccessible ecosystems in the lower 48 states—"an area that's not on most people's radar screen." Even if people do pass through these forests, Logan says the casual visitor either will not register the outbreak or they won't understand it. He says, "It's amazing to me the number of people you run into in

Yellowstone that say, 'What are all those sticks out there?...Even something as iconic and charismatic as…Yellowstone….How many of those people don't even recognize the remains of the 1988 fire that's still quite evident on the landscape?" Here he's referring to the lodgepole forest, but the whitebark forest is even more remote. Logan says people "see dead trees and that might bother them, but they don't know that there's a unique event or there's something they might be able to do about it." So to help educate people, Logan is coordinating with the NRDC and the U.S. Forest Service and others to "mobilize a citizen science group to document what's going on." They are supporting their observational efforts with aerial flights and covering the entire 18 million-acre Greater Yellowstone Ecoregion. Through this work Logan hopes people will begin to accept the reality and magnitude of climate change and its impact on whitebark pine forests across the West.

Chapter Conclusion

In this chapter I presented the stories of Dr. Dan Fagre and Dr. Jesse Logan. Both ecologists have witnessed mountain ecosystems crossing ecological thresholds. Ecological thresholds are non-linear responses, or tipping points, that lead to "surprises" in ecosystem dynamics. They are like flipping an ecological switch that turns on a whole new operating system. For these two ecologists, thinking about thresholds can be "frightening" and "astounding" and motivating. In order to cope with such ecological unknowns, Fagre and Logan are both working toward solutions. They see hope in learning, collaborating, and involving the public in understanding. In the next chapter I focus on another way of responding to climate change—that of conservation *triage*.

RESULTS THEME SEVEN: TRIAGE

Introduction

In this chapter I explore the theme of "triage." When asked how they deal with the ecological threats imposed by climate change, many ecologists stated *triage* as an important management response. In most basic terms, the word triage is defined as "the sorting of and allocation of treatment to patients especially battle or disaster victims according to a system of priorities designed to maximize the number of survivors" (Merriam-Webster, 2004, p. 764). In the ecological literature, triage is considered a management approach to threatened species "not as a process of giving up but as a tool for ensuring species' persistence in light of the urgency of most conservation requirements, the realities of limited biological understanding and the poor state of conservation funding" (McDonald-Madden, Baxter, & Possingham, 2008, p. 1630). Ecologist Dr. Hugh Possingham of Australia has developed a mathematical formula that conservationists can explicitly apply when faced with decisions about threatened species. In its simplest form, numerical values are assigned to: a) biodiversity benefit, b) the value of each species' phylogenetic diversity, and c) the probability of success of the conservation action. These variables are then *scored* relative to the unit cost of the conservation project. The project with the highest score is the one that managers should choose (Bottrill et al., 2008).

Here I present the work and thoughts of Dr. Terry Root and Dr. Tom Stohlgren because of all ecologists interviewed they placed the most emphasis on thinking about their work in terms of triage. They both said that furthering the idea and application of conservation triage would be one of the most meaningful professional contributions they could make in their lifetimes. At the same time, while Root sees climate change as the most pressing ecological issue, Stohlgren feels that *invasive species* in the western U.S. pose a more urgent threat. Like Dr. Dan Fagre, these two ecologists' stories reveal other examples of how ecologists use human systems, in this case the healthcare system, as analogies for how earth's operating systems can be thought of. They convey a sense of urgency, and they strongly advocate for a more objective and proactive conservation decision-making process. They concur that accepting the idea of triage is not easy for people, but it is necessary—"by ignoring triage we are doing triage."

Dr. Terry Root

Dr. Terry Root is a Senior Fellow at the Center for Environmental Science and Policy in the Institute for International Studies at Stanford University. She holds a bachelor's degree in Mathematics and Statistics, a master's degree in Biology, and a Ph.D. in Biology from Princeton University. Her large-scale research on relationships between climate and birds has earned her numerous awards including President George Bush's Presidential Young Investigator Award from the National Science Foundation and a Pew Scholars award in Conservation and the Environment.

Root attributes her fascination with large-scale ecological relationships to her father's influence as a pilot. She loved "looking at things from a very, very far distance and being able to see patterns from up in the air." After she earned her undergraduate degree she worked as a scientific programmer on the Voyager spacecraft that went to Jupiter, Saturn, and Uranus. But Root's hobby at the time was birdwatching, and serendipitously she came across a professor with a large amount of bird data on a computer tape. She used her expertise in computer programming to analyze the bird data for her master's research project, and that led her to publish the *Atlas of Wintering North American Birds: An Analysis of Christmas Bird Count Data* (1988). In 1990 Root met her now husband, the well-known climatologist, Dr. Stephen Schneider, at a U.S. Fish and Wildlife Service conference. They have been collaborating on climate change ecology research ever since. Root is known for her continental-scale research on the influence of environmental variables on the geographic ranges of animals, primarily birds. Recently her statistical meta-analyses of seasonal and demographic trends in plants and animals shows a "globally coherent fingerprint of global warming" (Root et al., 2003).

Root, like several other ecologists in this dissertation, uses the human body and human health care as an analogy to describe her experiences of dealing with climate change. When I ask her what it is like for her to experience the ecological effects of climate change she shares this story:

> My husband ended up coming down with lymphoma, and he had to have a bone marrow transplant. Before he had that happen, he had to have very radical chemotherapy. We went over for his first chemotherapy, and they knocked him out. I was sitting there, and I was watching everything like a hawk, and making sure everything was done appropriately, and on and on and on. The nurse was fantastic. She was doing great work. She was really, really good. Then, once she got everything ready and everything was working, she kind of sat back and kind of relaxed a little bit, and looked up at me, and she said, "You seem pretty uptight." I laughed and said, "Yeah, this isn't something I normally do." She says, "Well, let's chat. Tell me, what do you work on?" I said, "I work on how plants and animals are affected by global warming." She said, "That is the most depressing job I've ever heard!" We both burst out laughing, and truly that story I think says more about how I approach my job now than anything else. I see myself as being an oncologist for the planet. I see that we cannot save everything, and we have got to start working on triage.

Root says all of her upcoming scientific projects will be focused on conservation triage in order to start figuring out which species can be saved and which ones cannot.

Root has found that getting people to accept the idea of triage is "very, very, very difficult," but if we don't "we're going to lose a hell of a lot of species." Root wants to start figuring out which species *can* be saved and work on those. Her perspective is that we have already lost so many species, and many more are now "functionally extinct." She says, "unless we go out with our U-Haul trailer…and move them someplace else, and make sure that they can live someplace else and not cause other things where we're moving them to go extinct, then they're going to go extinct." Root gives the example of species living on mountaintops, where as climate warms, species will have to "move up, up, up" and "there's no place for them to go except extinct."

> When you are talking about things like the Sky Islands in the Southwest…there are many species….That aren't going make it. They can't because they need to move up in elevation as it's getting warmer….We're not going to go in and move them, so they're extinct. They're functionally extinct right now….That's what I'm saying when I'm talking about triage.

That is how she sees her job, and she says, "It's very, very, very sobering."

Root describes a key experience that led her to embrace the importance of triage. She was giving a talk at a conference to all of the directors of zoos and aquaria across the United States. She was really "excited about the opportunity" because she feels as though zoos and aquaria are important places for educating the public about biodiversity and conservation. The panel of speakers, right before Root gave her talk, presented a plan to save all the frogs and toads in North America. There are 301 frogs and toads in North America, and each zoo and aquarium had agreed to take three different species to ensure their survival. The panelists went on to explain how they would each take care of their three species. Root says, "The amount of money, effort, infrastructure, people, time—it was just astronomical, and we're talking about three frogs….If we're talking about birds and large mammals and things like that, we can't save them in zoos. It just is not going to work." That is the moment that Root decided threatened species need to be managed in new ways. They need to be managed out in the field "where they can take care of themselves." So she is looking at "those species that really are in trouble, and there's not much we can do about it because we can't put them any place where they can survive."

For example, Roots say she does not think that polar bears (*Ursus maritimus*) will ever go extinct because they "live in zoos just fine," and polar bears can "make it through on garbage dumps and things like that." But two related species that she is really concerned about are the Ross gull (*Rhodostethia rosea*) and the ivory gull (*Pagophila eburnean*), birds that rely on *wild* polar bears for their survival. The birds make their living by scavenging on the scraps that polar bears scatter when eating seals and other animals. "Their populations are going to be plummeting. Now, is there anything that we can do for them? Yes, we could go out and we could start providing food for them. Do we have the political will to do that right now? No, we don't." Root believes the gulls are examples of species that will probably go extinct "before we get our act together and realize what's happening to the world." Root says that right now, "until we have the political will and SUVs are seen as socially unacceptable, we're not going to be able to do as much as we need to be doing because we don't have enough people pushing." She says we need to do more studies to try and figure out which species we *can* save, which ones we are most easily able to manage, and then start focusing on those species with conservation projects.

In addition to prioritizing species, Root thinks that it is very important to create new ways of managing species. She gives the example of managing coastal areas in

California. In anticipation of sea level rise due to climate change, some coastal managers have begun to map out the public and private lands that will be needed by terrestrial species as the Pacific Ocean moves inland. She says coastal managers have begun to look at the physical spaces that species will need as if the habitat spaces are floating, or moving, not fixed on the ground. "It's an area that actually moves as the sea moves." Root says maybe that is what we need to start doing with all wildlife refuges. "We have got to start doing something very radical....We need to be working with managers because managers are the ones that are on the ground."

Although Root expresses a strong sense of urgency about prioritizing species and working with land managers, she gets frustrated when people say "we only have ten years" to save something. She says, "That, excuse my French, is a bunch of crap—because, if we only had ten years, I would say that we needed to say that back in 1972." She describes an experience teaching her very first conservation biology class with Dr. Michael Soulé, one of the founders of conservation biology. Root was honored to teach with him but when one of the first things that came out of his mouth was, "We have ten years to change things," Root was horrified.

> If you say we have ten years, and we don't change it in ten years, then what? We had ten years back in the early '70s to make sure nothing went extinct....Now things are going extinct, and there's nothing we can do to stop it.

She says that we still have to work as hard as we can right now, but we need people to understand the significance of the situation we are faced with.

Root says that if the global temperature rises two degrees Celsius above 1990 levels, which she does not think we will be able to prevent because we are already at about .75 to .8 degrees Celsius above that, then we will lose about 20 percent of the known species on earth. “We, right now, are standing at the edge of the sixth mass extinction of species on the planet, and it is being caused by us. We need to somehow understand what that means and get other people to understand what that means. That is where I see my work going.” She feels the ethical issues are huge. By ignoring the fact that we need to do triage, we are doing triage. “When you’re just dealing with those animals that are right in front of your nose, you’re triaging the others because they’re not right in front of your nose. You don’t have the money, the time, the energy, the effort to deal with them.” If we do not have the resources or the political will to save all species, then we need to figure out which species we have to let go of and then focus on the species we can save.

> On the whole, when you’re talking about most of the species in the world, we have got to try and provide them with the best environment that we can for them to try and survive themselves. That, to me, is what we’re going to have to do as triage….We work as hard as we can. Just like an oncologist, you work as hard as you can.

Root’s experiences studying large-scale climate related patterns in species have prompted her to consider herself an “oncologist for the planet,” and she sees conservation triage as an important trend in the way scientists and managers need to work together. Another ecologist who is also on a crusade promoting triage is Dr. Tom Stohlgren. Whereas Root focuses her energy on the threat of climate change, Stohlgren feels that there are other more pressing ecological issues that need to be triaged.

Dr. Tom Stohlgren

Dr. Tom Stohlgren is a Research Ecologist with the USGS and Senior Scientist at the Natural Resources Ecology Laboratory at Colorado State University. He has earned degrees in forestry, biology, and ecology. Like Root, Stohlgren also tends to take a large-scale perspective on ecological issues. His research focuses on the effects of land use change and on monitoring plant diversity at landscape and regional scales.

Stohlgren's office is tucked away in one of the large industrial-style buildings on the Colorado State University Campus in Fort Collins. Finding him is like navigating through a maze of hallways and corridors that could be on any large campus in the United States. But as I arrive at his office doorway, I know I have come to a special place. Sitting at his desk, Stohlgren wears a colorfully patterned shirt and a big welcoming smile. His outlook: "I wear a Hawaiian shirt every day because you've got to feel like you're on vacation." Stohlgren says that he loves his work and has fun doing it. Beginning in 1992, Stohlgren and a team of other high-level scientists (including Dr. Jill Baron) collaborated on a study of global change impacts in the Colorado Rocky Mountain biogeographical area. It was a ten-year project funded by the National Park Service and the USGS. He says, "Over ten years we had a group of about ten Ph.D. scientists swarming over Rocky Mountain National Park assessing various aspects of climate change, vegetation change, disturbance history, hydrology, snow pack, chemistry, biogeogchemistry. It was great fun!" It was this particular project that led Stohlgren to think about ecological issues in terms of triage. Stohglren says the purpose of the project was to ask:

> How are things changing right now? Is it severe? Are we seeing some drastic changes, and are they the result of climate change, disturbance history, air pollution, the myriad of other issues that affect ecosystems? It was more of a vulnerability assessment than it was a climate change assessment. It was like a triage of ecological issues because we're not faced with just one at a time. We have climate change, but we have invasive species. We have landscape legacies.

Current climate change has "greatly changed" Stohlgren's work. He says that it has taught him "to treat landscapes, National Parks, mountain ranges, and states in a triage sort of way. Like an ambulance driver coming onto the scene might say, 'Well, what are the issues that are eating our lunch today?'" Stohlgren says that he has had to switch careers because of it. He became an invasive species ecologist because he found that, rather than climate change, invasive species were the number one threat facing western land managers. He says Colorado is not like Glacier National Park where iconic and ecologically significant glaciers are disappearing. In Colorado Stohlgren says there is a different number one threat to mountain ecosystems. "So if we were doing triage in the West, it might not be climate change as the number one issue. Invasive species cost the country $120 billion a year. That's more than all natural disasters combined: floods, fires, earthquakes, hurricanes."

Stohgren stands up from the chair at his desk and shows me a postcard tacked on the wall that one of his students sent him from Wyoming. "This is the Grand Tetons, and it says, 'The valley floor takes on many colors during the spring and summer.' Yeah—because of the musk thistle from Europe, the red bromes from Europe, and the yellow sweet clover from Europe." He is making the point that, yes, the climate is changing and there may be less snow but what is really "eating the lunch" of native mountain ecosystems are invading species and plant diseases. He gives another example of white pine blister rust that is currently crossing the border from Wyoming into Colorado. This blister rust is a plant pathogen that originated in Asia. It kills five-needled pine trees. It circled around the Northwest and the Great Basin in the '30s and is now finding new North American species to infect. He says that Colorado forests have survived climate changes in the past, but they are "not resilient to these unusual bugs that come from other countries….There were 10,000 years of climate change, and no tree species were ever in any danger." In a triage sense, Stohlgren sees climate change as an important issue but not the number one issue because it is not as urgent and may not be as damaging to ecosystems in the long haul as invasive species are. He makes a point that "the glaciers got a lot of press in Glacier National Park. The fisheries did not, and yet we have lost twelve species or subspecies of cutthroat trout because of invasive species."

Stohlgren says he "goes for the proximate cause" when looking at threatening ecological issues, they're "just plain more important." But when it comes to invasive species, he says that there is no efficient organized effort to fight them. So he treats his work on invasive species "like a wildfire….If you get them while they're small, you can contain them….When a new species comes into an area, we don't have people jumping out of trucks to get it real quick. We're not well-coordinated." With this situation at hand, Stohlgren focuses on developing predictive models of where and how invasive species will spread. He is working with his students to be more predictive over shorter periods of time so that land managers can set up defenses and "get smart about control." He says, "We need to think in shorter time frames and more urgent issues."

But Stohlgren is still concerned about climate change, and he cites a joke he heard told by comedian Robin Williams about the hole in earth's ozone layer. "Don't worry about it. It might be just a slow leak." But he says the tragic thing is that

> we know so little about the very high atmosphere that some mistakes we make as a culture, as a society, right now could have very long-lasting and drastic effects….Uncertainty about the future is enough reason for me, personally, to cut down in emissions, to force coal-burning power plants to be cleaner, to look for alternative energy sources.

Stohgren says that he does not need oversimplified and uncertain climate models to guide his decisions. He knows that humans are creating 25% of the carbon dioxide emissions and greenhouse gas emissions, and, he says, "That's kind of wrong….There are ethical reasons outside of ecology…to respond to Al Gore. We ought to do that. We ought to do it anyway out of just being smarter." But he points out that policy is not his realm—"my realm is just measuring things, simple, simple science."

One of the problems is that "we don't do a triage globally." Stohlgren feels people are not managing multiple issues at the same time. "Maybe we are too simple for that; maybe humans can only focus on one at a time." Rather than giving out one Nobel Prize to Al Gore because he handled the climate change issue so well, Stohgren says there should be five prizes for the top five global issues. "One's not enough. We can't think single issues. We get attacked by a lot of them all at the same time."

Stohgren says the greatest contribution he would like to make to science and society is "to draw attention to a triage concept." He characterizes his career as working towards multiple issues and multiple scales, being smarter about how to get at proximate causes of issues.

> I'm not sure who else in the government is thinking about triage. I just don't see that concept….I'm concerned about the different vulnerabilities—our most vulnerable species, our most vulnerable habitats….Even as a society, what's going to get us? Where are our weaknesses? Are they in education? Are they in human welfare, medicine?...When I look around, I think we're missing some pretty darn good ones….We're going to get hammered—Asian Bird Flu could take out a lot of people, they say, and we're not prepared.

Stohlgren talks about his experience when he was asked to quickly come up with a model for the spread of West Nile Virus, "when crows began dropping out of the sky in New York." What he and his team found was that no one was collecting the right kind of data. Once a county got up to five dead crows, they stopped counting, so there was no way of telling how many dead crows there really were. "There could have been five, ten, five hundred or five thousand." Just knowing the virus was present was enough, and abundance was not the issue. Then Stohlgren and his team found out that over time there were actually 130 different species of birds that could carry West Nile Virus, not just the crows. And they did not know much about the other species' distributions. They didn't know enough to make maps and models to predict the spread and threat of the virus. There were also 14 different species of mosquitoes that carry the virus and infect the birds. The mosquitoes were not mapped well either. Stohlgren says:

> We didn't map ponds….We were so naïve that we thought that mosquito populations would be less in a drought year. We thought less water, less mosquitoes, so a very basic ecology. But what happens in a drought year? Water pools up. So there was less water, but more pools. More small, shallow pools perfect for mosquitoes….Some of the really basic stuff that we should have probably learned in grammar school, we didn't get, and we're still at that stage with a lot of environmental and ecological issues.

One of the issues that Stohglren wants to help address is that of understanding trends in biodiversity.

Based on his observations Stohgren feels that scientists and managers are not looking at the variables of species immigration, saturation, and extinction properly. He is writing a paper with colleagues that species "saturation is a myth….Immigration, the number of species coming into the country is huge….Extinction and extirpation are very rare." Stohlgren called around to different counties and states and asked people, "What's really gone extinct in terms of plants?" And he says that it was embarrassing how low the numbers were. But there are tens of thousands of species coming into the country through horticulture, trade, and transportation. He says that it is a "new ecology…different than Darwin….He went out on the HMS Beagle and found diversity. Now we have the Beagle coming to us every day….Darwin on steroids….Action-packed invasion….Pangaea again….Continental drift in reverse….No barriers anymore."

On the one hand, Stohlgren says that species are going to find ways of surviving because they are going to be exposed to more environments. On the other hand, he says that there are going to be "some real surprises."

> We're going to have cheatgrass (*Bromus* tectorum) come in and start more fires. That will change some forest areas into shrublands and grasslands. We're going to have different forage and different habitats for species than we do right now. Abundances will change—things that were common may become rare. Things that were rare may become common. Things are going to shift, and they're going to shift quickly. What used to take tens of thousands of years is going take a matter of a couple decades…This isn't the slow world of Charles Darwin.

Stohlren say that his sense of urgency about ecological issues is "huge…because it's what an ambulance driver might do." He says we cannot take care of all species. Some are going to die. The most important thing is to pick manageable and tractable issues and species and make progress toward sustaining native biodiversity.

Chapter Conclusion

In this chapter I explored how ecologists think about responding to ecosystem threats such as climate change and invasive species as a process of conservation triage. A social-ecological process that includes urgent, proactive, and objective care for threatened native species. My account of Dr. Terry Root reveals how she considers herself "an oncologist for the planet," and my account of Dr. Tom Stohlgren reveals how he considers himself like an "ambulance driver" who treats the threat of invasive species "like a wildfire." The salient point here is that ecologists feel that there are extremely urgent ecological threats to be dealt with, and these threats need to be addressed in new ways. Looking at science in a "business as usual" kind of way will not do. Adopting triage as a conservation strategy is the way to go, but it means people are going to have to let go; they'll have accept that some species will win and others will lose. The two ecologists in this chapter both feel that one of the greatest contributions they can make to science and society is promoting the idea of triage.

RESULTS THEME EIGHT: SILVER LININGS

Introduction

In this chapter I explore an inherent tension—or "dichotomy"—that some ecologists express about their involvement with climate change research. This dichotomy is expressed in the idea that there is actually a "silver lining" surrounding the dark cloud of global climate change. On one hand, some ecologists say they feel a sense of sadness and despair about losing familiar species and landscapes due to earth's changing climate. On the other hand, they feel like this is an exciting time for scientific discoveries. They see benefits in learning so much more than ever about how the natural world works and doing so through international collaborations. They find solace in their commitment to working on solutions and training people to become better observers of the natural world.

In the first half of the chapter I present the thoughts of several ecologists who, despite their sense of loss, convey their feelings of hope and encouragement. These ecologists include Dan Fagre, Jesse Logan, Diane Debinski, Craig Allen, Jill Baron, Tim Seastedt, and Terry Root. While each of these ecologists brings a slightly different message, they all express some sense of optimism about the climate change dilemma. In the second half of the chapter I tell the story of Dr. James Patton who is involved in the 100-year resurvey of ecological transects sampled by the great turn of the twentieth century naturalist, Joseph Grinnell, in California's Sierra Nevada. Grinnell is known for his astute field observations and reflective methodology and for his insights into ecological thinking. Patton shares his thoughts about what it is like to be working in the footsteps of Grinnell 100 years later and to live a life dedicated to field observation. I tell the story of Patton because he is an exemplar of *field observation* and *education*, two themes that almost all ecologists in this study touted as important to understanding and *adapting* to climate change. Overall, there is a sense that now, more than ever, what the world needs is a cadre of trained observers who can document and discover subtle changes taking place in the natural world.

Ecologists' Silver Linings

Dr. Dan Fagre often says there is a silver lining in everything, and the silver lining in climate change is that scientists have learned more about the planet in the last 20 years than at any other time in history. He says humans respond well to threats, and this threat has created "an explosion of knowledge." What is exciting to Fagre is that "astounding things" have been learned about the earth in such a short amount of time. Studying mountains and how they respond to climate change is "absolutely fascinating" to Fagre; it is what sustains him. He says, "We need to know better than ever how these natural systems work so we can predict the future, because we know we're going to be in the future in a different way than in the past." The focus on climate change has advanced technologies in remote sensing, and general circulation modeling, and a variety of other things due to the sense of urgency. Fagre says, "For me personally, and I think for a lot of scientists, the fact that we're working on something that's inherently depressing is to a degree at least counterbalanced by the excitement of finding out so much stuff."

People ask Fagre how he gets out of bed in the morning, inquiring: "Aren't you so depressed you just want to kill yourself?" He says that when you are *engaged* in the process you do not tend to think that way.

> You're trying to figure it out, and you're trying to document it. You're trying to start looking at solutions and how to adapt, and you're busy; you're busy dealing with the problem. In a sense, you don't really have time to dwell on it in a strictly negative sense.

Fagre likens his perspective to that of a doctor who feels "a more stable and integrated kind of concern," whereas a patient, or someone who does not understand the situation as well, might "confront it" and tend to have more of a "panic response." And preventing a panic response to climate change is important to Fagre. He thinks it is important to "have a strong education component to our adaptation." The more people understand the issue, the more capable they will be in coping with it, "both in action and emotionally coping with it."

Fagre believes that people are feeling a "sense of vulnerability" and they are ready to listen. They are experiencing their relationship with the earth in a more "visceral" way, and there is a growing sense of global community in response to climate change.

> When you get walloped by hurricanes and snow storms and droughts…you start going, "Oh yeah, the natural world is a pretty big gorilla out there, and I am part of it." I think that's where the ultimate teachable moment comes in, is that people looking around the world and seeing all these big changes, and they know at some visceral level we're all stuck on this little tiny pebble up in the universe, and it is a little bit of a humbling sense that people get. You know, we're really global; we're all bound together….I think that's where, again, the silver lining in this whole dark cloud of climate change is that we will, I think, be more truly global as a species through time, just as this is bringing us all together.

Fagre finds it exciting to work with an international community of scientists. By collaborating, scientists around the world are confirming that they have similar problems and similar ecosystem responses to climate change. Fagre says, "It's pretty neat to talk to your Swiss colleague and find out that glaciers are doing the same thing there….It's both a cultural and an intellectual and scientific interchange….We're developing a much more global science community."

Dr. Jesse Logan also expresses his sense of the “dichotomy” inherent in working on climate change. His impressions are, however, more personal and spiritual than Fagre’s. Logan says it is an interesting experience when you want for a change so bad to be wrong, and it turns out you are more right than you thought you were going to be. “Intellectually it is an interesting and an exciting time to be an ecologist, and spiritually and emotionally and every other way, you’re saying, ‘Oh, Christ, what’s going on here?’ It’s really a dichotomy.” Logan says that when you are experiencing changes that are somewhat unique in the history of earth, and you are in a position to be intellectually challenged and stimulated by trying to understand those changes; at the same time, you are devastated in a very basic spiritual sense by what is going on. “It’s very difficult to express.”

Logan says that, for him, and he believes for most ecologists, you just find a way of living with this tension. You become resigned to it. “There is no reconciliation.” You just accept it. His sense is that there are “some things you cannot do anything about in life, and this dichotomy is part of it.” But what Logan says that you *can* do is make an impact on the world in any way that you can. “That’s what’s so great about science. You don’t have to be an Einstein to make a contribution. In fact, most of us don’t.” He says that scientists make very small incremental contributions, but anyone can influence the world. In fact, Logan believes we have “an ethical responsibility not to be stupid, not to be dumb, and not to do things out of ignorance and arrogance.” For him, understanding the effects of climate change on whitebark pine forests and involving people in citizen science is where he feels he can make the greatest contribution. But he says, “As far as the impact of being emotionally broken and intellectually challenged, that's just the way the world is right now."

Dr. Diane Debinski who studies trends in plant communities and butterflies in Grand Teton National Park and the Greater Yellowstone Ecoregion says, "It's exciting" working on climate change from a scientific perspective. There is "intrigue" and excitement in finding patterns. But at the same time "the patterns could be depressing." The other dimensions that Debinski finds exciting are the opportunities for collaboration and looking at her research from new angles. She says many more people now consider themselves climate change scientists. There is potential for people who do different kinds of research to begin new collaborations.

Dr. Craig Allen also says that it is an exciting time to be a scientist but "It's sometimes a gallows humor kind of excitement" because much of the phenomenon that he and others care about are at risk. He says that, at some level, ecologists share the perspective that "we live in interesting times." "You start measuring something out here, you set up some kind of repeated monitoring, and bam, then you watch big things happen to it, so yeah, it's interesting." Allen says that climate change validates the importance of long-term ecological monitoring. He also expresses a sense of loss at what his monitoring is suggesting.

We've got all these things going on in this landscape….It's really interesting to study, but I don't like seeing all the old trees that I care about die….There will be something on these landscapes. But when all the 300-plus year old trees are gone, I'll feel sad about that.

Dr. Jill Baron says that once someone has been indoctrinated into the scientific way of thinking, they become more predisposed to feeling a sense of despair. She says that, although it is much fun to think scientifically because you delve into things deeply and logically "and try to figure out cause and effect," it also opens scientists up to "discouragement and despair because you can see the direction and trends things are taking, and know what the logical next step would be." Baron says that she mostly tries to ignore feeling a sense of despair. It sometimes occurs to her that her two children will inherit "a world that is depauperate in species and wild places…has increasing amounts of social unrest…one that's going to be increasingly subjected to extreme events, storms, and rising sea levels." She thinks all these things will happen, and that is depressing, but she says that we have to "keep trying to make improvements and hope that perhaps we're wrong.…You keep plugging away trying to find out as much as you can in order to maybe find a solution to prevent these kinds of things from happening."

Dr. Tim Seastedt, an ecosystem ecologist at the University of Colorado's Institute of Arctic and Alpine Research, says that he is "feeling upbeat" about our ability to adapt to climate change. He thinks people in the U.S. can live with climate change but only to the degree that they can accept the fact that we are not going to have the same kind of places that we have had in the past. In fact, most of what we have already become accustomed to Seastedt considers "novel landscapes" due to land use changes of the past. He says, "One could be the ultimate pessimist and say, 'Well, this is awful.'" But climate change is going to rearrange natural communities. It will add new species and subtract others. But Seastedt thinks that "a forward-looking management approach that exploits opportunity and hedges bets" can create desirable conditions that provide valuable ecosystem services. He says,

> I'm feeling a little upbeat in that we can deal with the changes…at least as long as we accept change.…Novel ecosystems are not only inevitable; they're already here.…Once you've decided that change is inevitable and expect it, then maybe you're better prepared to deal with it.

In addition to promoting conservation triage, Dr. Terry Root's goal in life is to "educate people to understand that there is hope." She says that there are many things to be hopeful for and we need to focus on them. Hearkening back to her analogy of being "an oncologist for the planet," she says,

> It's very similar to cancer. We can find ways to fix cancer. We're working on it. Researchers are working all the time. The thing that the oncologist told my husband was, "We want to keep you alive as long as we can so that you're alive when the research finds a cure."

Root says, with climate change, we are working under the same kind of conditions. But with climate change, we do not have the cure because we do not have the political will. She says that when we do have the political will things will start to change. "We can save more…but we can only do what we can do right now." Root also thinks that the people walking the face of the earth right now are probably the most privileged people that will ever walk the face of the planet. She feels it is going to be very different in 25 years. There will be fewer species, and there will be strict limits on human use of natural resources. But if we do not stay hopeful and support one another, then we stand the chance of losing even more. What Root does is focus on training as many people as she can. She believes that "we can do it, as long as we do it together." Another ecologist who is creating an educational silver lining out of climate change is Dr. James Patton. The second half of this chapter focuses on his recent field experiences of climate change.

Dr. James Patton

Dr. James Patton is an Emeritus Professor at University of California, Berkeley. He started on the faculty in the late 1960s and retired in 2001. Throughout his career he has been Curator of Mammals in the Museum of Vertebrate Zoology, an institution founded in 1908 by the great naturalist and early ecologist Joseph Grinnell. In addition, Patton has traveled throughout the New World, especially South America, studying mammalian systematics and conservation.

When Patton retired from the Museum in 2001, he and his colleagues wanted to indoctrinate the incoming director, Dr. Craig Moritz from Australia, in the history and legacy of the museum. They gave Moritz copies of Grinnell's early papers so that he would have a sense of the founder's vision almost a century earlier. In one of Grinnell's 1910 papers, he made a statement to the effect that the value of the museum collection and his field notes would unlikely be realized until a century had passed, a time when people of the future would be able to look back and observe his carefully scribed records and collections of California's native biota. Patton says that this statement "caused a light bulb to go off" for the new museum director. The centennial of the museum would be in 2008, and he thought it would be wonderful idea to resurvey the mammals of California in the century-old footsteps of Grinnell. And he had a hunch they might find that some things had changed since then.

Grinnell had originally set out to document the distribution of birds and mammals, and to a lesser extent amphibians and reptiles, throughout the state of California. Patton says, "He did this in a very prescribed way….He was one of the earliest ecologists before the word ecology was even defined…generally credited with the development of the concepts of ecological niche and competitive exclusion." Grinnell had a vision of sampling the terrestrial vertebrate fauna along ecological gradients, and one of those gradients was through Yosemite National Park. The transect started in the Central Valley and worked up through the western flank of the Sierra Nevada, into the park, and to the crest of the Sierras at about 10,000 feet, and then down onto the eastern slope and the Mono Basin area.

Thus the Grinnell Resurvey Project was conceived. And Patton explains how, almost simultaneously, the federal government dictated that the Park Service inventory their biological and cultural resources. So Les Chow, a biologist at Yosemite with the U.S. Geological Survey, also a former student of Patton's who was "well aware of the historical influence of Grinnell's early work in Yosemite," contacted Patton at just the same time. The idea of doing the resurvey came from two different directions, from the museum and from the park. Thus, Patton and a team of field researchers embarked on the Yosemite transect resurvey in 2003. Since then they have completed the resurvey of all of Grinnell's original sites. And because of what they have found, the Park Service wants them to do more work in the high country of Yosemite, to gather new baseline data in areas that have not yet been surveyed.

Patton says that working in the scientific legacy of Grinnell has "been an amazing experience." Right after earning his Ph.D. at the University of Arizona in Tucson, Patton went directly to work at the museum in Berkeley. He has been associated with Grinnell's legacy for the last 40 years, so "actually traveling in his boot steps and reading his notes and those of his colleagues…out in the field has been an amazing experience." Patton says that Grinnell and his team had incredible insights. The bulk of their work was done in 1915, a time when the concept of what a species was, was being overridden by people like Grinnell, who were actually out there documenting variation in populations. "A time before the statistical procedures now commonplace in all aspects of biology were employed…these guys were thinking in terms of modern concepts decades before they were actually developed…so their writings left an incredible legacy." Patton says that it is not just the specimens archived in the museum but the volumes upon volumes of handwritten field notes. Grinnell's team did not just describe what they observed, "they mused about what they were observing….Now all of this kind of information is contained within field guides."

One of Patton's favorite passages in Grinnell's collection was written by Walter Taylor, one of Grinnell's Ph.D. students who was a field leader on the Yosemite Transect. Taylor also went on to become Chief Naturalist for the U.S. Biological Survey at the Smithsonian, but in 1915 he wrote about how discouraging it was that the average Yosemite tourist only visited the park from the windows of their cars. Patton says,

> They didn't get out and sit and think and observe and listen to what's around them. This is 1915. I mean hell's bells. Cars had only been part of the American scene for 10 years. Things haven't changed at all in the last 90 years.

But Grinnell was an exceptional field observer. For example, Patton explains how Grinnell left Yosemite Valley, elevation 4,000 feet, at 6:00 one morning. He walked 25 miles and gained 7,000 feet in elevation. He then arrived at Vogelsang Lake at 11:00 that same morning; taking notes of what he saw along the way. Then Grinnell continued walking, over the crest of the Sierras, another 28 miles that same day.

Patton says that, if Grinnell were alive today, he would say that the 100-year resurvey of his Yosemite transect is exactly what he had hoped for. He would say, "What you guys are doing and what you're finding is not at all surprising to me." Grinnell had already noticed changes in California's biota, and that was what spurred him to so thoroughly and precisely document it at the time. Back then most of the changes in biota were due to land use changes, especially agricultural practices. Patton does not think that

Grinnell would have anticipated the kind of changes the resurvey team is seeing today, changes that are likely to due to climate change. What would intrigue Grinnell is how animals respond to climate variables that have been changing over the last century. With regard to Grinnell's development of the ecological niche concept, Patton says, "That's exactly how he framed it….He framed [a niche as a] matrix of abiotic and biotic factors that control the local as well as global distribution of a given species." So Grinnell was already thinking about what happens when those environmental conditions change. Patton and his team's discoveries along the Yosemite transect today are telling.

Patton explains that there are approximately 50 species of small mammals distributed across the Yosemite transect, a "narrow rectangular area, 89 and a quarter miles in length by 17 and a third miles in width" (Grinnell and Storer, 1924, qtd. in Moritz, 2007). Some of the mammals are low-elevation species that extend up into the Sierra foothills and into the lower reaches of the coniferous forest. And some of them are restricted to the high elevations. Patton says, "Many of the low elevation species have expanded their ranges upward….Their maximum elevation now is 1,000 feet or so above where they were in historic times." He has also found four new species of fauna in the park; all four are upward expansions from either the east or west slope park boundaries. Of the high-elevation fauna, most have retracted their lower elevational ranges upward, in some cases by as much as almost 2,000 feet. Grinnell describes these discoveries:

> There are seven species of chipmunks distributed on the transect. They're nicely elevationally zoned, and they have unique habitats. They replace one another ecologically by and large. There's one species of chipmunk called the alpine chipmunk that has a very small range. It's limited to the high elevations of the Central Sierra….It occurred at elevations as low as 7,800 feet in the Grinnell days….The alpine chipmunk was a very common resident in areas around Tuolomne Meadows….You can't find it there at all now. You have to…go all the way up almost to tree line at about 9,700 feet before you pick up alpine

> chipmunks today. So it's retracted up somewhere in the neighborhood of 1,800 feet or so.

Patton's team has also discovered upward retractions in pika populations and a couple of species of ground squirrel populations. At the same time they have discovered lower elevation fauna that are expanding upwards. Patton says that it is difficult to "disentangle any kind of direct climate-related response" from land use responses, but "the assumption is that these changes in small mammal distributions up high are mirroring the same kind of phenomenon" that has caused glaciers in the Sierra to melt, stream dynamics to change, and high elevation conifers to alter their growth patterns.

What impresses Patton about the shifts in mammal distributions "is the apparent rapidity with which this change is taking place." And he says, "While we only have basically two points in time, 1915 and 2005, there are differences between those two….We don't know whether it was kind of a monotonic change over that time period or some kind of step change just in the last 30 years." Nevertheless, this kind of ecological change is happening over a very short period of time, and Patton says that if it continues, "there's no skyhook up there for these animals to grab a hold of. They're going to be just pushed off the tops of the mountains," and there is nothing the Park Service can do about it.

Patton says, "The biggest thing to me is making the public aware of what their National Parks can do and what they can't do…and what these changes are and how fast they're taking place." One of the original goals of the Grinnell Resurvey Project was to create computer models of the historical records and project them to today, to go out and validate those models with today's data and do the reverse. But, Patton explains,

> There's no way to validate those models until the future happens….We have the opportunity to do that with this comparative kind of data…because of the quality of the historical record. There are very few places in the world for which the historical record is this complete.

So the overall goal of the project is to make "people aware of the quality of the information and the quality of the models…and the fact that this is happening in National Parks which are supposed to be the bastion of preserving our biotic diversity."

Patton says that Grinnell's data and precise observational methodology is "incredibly important and…what makes Grinnell's vision so impressive." There were many naturalists and there were many museums that had collectors out collecting specimens of birds and mammals in the United States, but there were relatively few of those early naturalists that had the goal in mind of thoroughly recording in such a way that you could use their information far into the future. From Patton's perspective, "Most of these other people were out there…stamp collecting….Grinnell wasn't interested in stamp collecting." Patton laments that it is hard to find such great observers of the natural world anymore. He says:

> Sadly most of them are either gone or they're certainly not being reproduced anymore….The E.O. Wilsons of the world, the Peter Ravens….Every student now wants to sequence DNA in the lab, and they don't really necessarily care about seeing that critter out in the field….Universities are training fewer and fewer….I worry about the future of our disciplines as a result.

Patton hopes the Grinnell project will help reinvigorate a keen sense of observation of the natural world. He also describes "a very famous course" that he taught for 30 years called Natural History of the Vertebrates. It was a course that Grinnell established. Every Friday and Saturday morning, rain or shine, students spend the day outdoors in one of the regional parks near the Berkeley campus. Patton says despite the large urban area near Berkeley, there is an amazing amount of parkland that is readily accessible and covers habitats from estuary and mud flat to redwood forest.

> You can engage students in those kinds of activities, and that class has been famous for inputting students into graduate programs around the country with an interest in what one would call natural history in general….Sadly there aren't very many courses like this that are taught in other universities around the country.

The fading status of field observation courses in higher education, Patton says, is due to complex issues. Over the last 30 years there has been an increase in and focus on experimental research as opposed to observational research. "A lot of ecologists will say, for example, that natural history observations aren't very useful because you can't quantify them and…[they're] not done with an explicit experimental design." So there is a tendency toward hypothesis testing rather than the observational kind of field study that Darwin did. He also says that the biological sciences as a whole have become much more reductionist. They focus on smaller and smaller elements, from genes and DNA to even smaller particles. And because of how important federal funding is to university research environments, it is relatively easy to get big funding if you are doing something like cancer research. It is almost impossible to get even small amounts of funding if you want to go out and study the vertebrates of Yosemite National Park. Patton says:

> The one program of the National Science Foundation that supports field biology…is like six or seven percent….It's just not going to support an infrastructure at universities….Environmental biology in general has been way underfunded, in part for political reasons and in part because it's not sexy science…and this is the time when we need the power of people who are trained to observe more so than we probably ever needed in our history.

Chapter Conclusion

In this chapter I explored ecologists' perceptions of a "silver lining" surrounding the threat of climate change. I also presented the story of Dr. James Patton whose centennial resurvey of Joseph Grinnell's ecological transects in the mountains of California is raising awareness about the ecological effects of climate change. Patton shares his concern about the loss of naturalists—close observers of the natural world—because right now the world needs more naturalists than ever before. The salient theme expressed throughout this chapter is that, despite the ecological loss associated with climate change, there are emerging opportunities for learning and new ways of looking, shifting our gaze back on the earth itself and thereby understanding our essential place in the nature of things. Climate change becomes a teachable moment, "simultaneously a physical transformation and a cultural project…a mutating hybrid entity in which the strained lines between the natural and the cultural are dissolving—[and it] therefore needs a new examination…with contributions from the interpretive humanities and social sciences" (Hulme, 2008, p. 5).

In the creation of this dissertation I have discovered my own "silver lining." I now experience a deeper sense of understanding of and connection with earth's global systems and the long arcs of geological and evolutionary time that are both behind us and ahead of us. I have a greater appreciation for the inherent complexity of understanding climate change and the ways it impacts ecological and social systems. I also feel a deep sense of appreciation for the ecologists that I interviewed. They are dedicating their lives to understanding how the world works while educating others in the hope that future generations can do even better. They have inspired in me, not only a new way of looking at the world, but also a new enthusiasm for science and environmental education. In the concluding chapter of this dissertation I explore the social and educational implications of my research findings.

CONCLUSION

Introduction

I began this dissertation with the goal of exploring the lived experiences of ecologists who research the effects of climate change in mountains of the American West. I wanted to understand the ecological and existential challenges that this particular group of scientists faces when witnessing global environmental change. Ultimately I hoped to create an engaging way of communicating about climate change—by humanizing science through the personal stories of field scientists. These goals have been accomplished, but I have also discovered deeper meanings and implications for this work for the fields of environmental studies and education. By standing back and reflecting on the whole of the eight experiential themes—thinking ecologically, the place-based ecologist, seeing shifts, coping with complexity, a paleo-perspective, crossing thresholds, triage, and seeing silver linings—I see a continuum of perspectives that provokes deeper consideration. There are two kinds of broader questions suggested by the results of this dissertation: questions about the future role of ecologists in education and questions about choosing the kind of world we want to live in. In this concluding chapter I briefly highlight my thoughts on each of these two areas of inquiry, and then I offer a final personal reflection.

The Future Role of Ecologists in Education

What would it look like if every human community had access to its own place-based ecologist? Or, even better, a cadre of ecologists with varying perspectives to offer? These place-based ecologists would primarily serve as conduits for learning about local ecology and global environmental change. They would be “perceptual weavers” who would integrate multiple perspectives and engage people in opportunities to learn about their own particular places.

As a result of my conversations with the ecologists who participated in this dissertation, and my in-depth studies of their work, I consider these field scientists to be role models who can help the United States. citizenry make great strides in raising its scientific and ecological literacy. A primary goal of science education in public schools is to create more opportunities for students to interact with experts in order to learn the practice of science (Lee & Roth, 2003). Dr. Tim Seastedt, in particular, reinforces an educational vision for place-based science learning. In talking about his own field research on environmental changes, he says that he would like to "find a way of taking this scientific knowledge and getting a more efficient conduit to the public." Seastedt believes that "the lag time" between the creation of scientific knowledge and use of that knowledge has increased in past decades. He says, "It is clear that we have not created societal mechanisms for this transfer of information."

Creating the infrastructure to involve place-based ecologists with communities in the specific places where they conduct their field research could serve the purpose of helping to override the slow "lag time" that Seastedt refers to. Place-based ecologists could educate citizens in the practices of using ecological tools and perspectives to understand the systems where they live. This would also promote context-based experiential education and deepen individual's engagement in situational learning (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). It could foster the connections between young people and the natural world, facilitating significant life experiences that lead to environmental citizenship (Chawla, 2007), and involve people in forms of *public ecology*.

Some scientists, especially Dr. Tom Swetnam and Dr. Jesse Logan in this dissertation, envision the practice of ecology becoming more public than it has traditionally been in the past. In response to the increasing scale and complexity of global environmental change, "the incorporation of the human dimension into ecology is reversing the century-old trend of separation and reintegrating science into the human experience" (Bradshaw & Bekoff, 2001, p. 460). This trend has implications for science education. The boundaries of what it means to be scientifically literate are expanding (Roth & Lee, 2004).

> Public ecology is an approach to environmental inquiry and decision making that does not expect scientific knowledge to be perfect or complete. Rather, public ecology requires that science be produced in collaboration with a wide variety of stakeholders in order to construct a body of knowledge that will reflect the pluralist and pragmatic context of its use (decision context), while continuing to maintain the rigor and accountability that earns scientific knowledge its privileged status in contemporary society. As such, public ecology entails both *process* and *content*...the primary goal of public ecology is to build common ground among competing beliefs and values for the environment. (Robertson & Hull, 2003, p. 399)

In addition to facilitating greater educational engagement through situational learning and fostering a more public form of ecology, a network of place-based ecologists could also serve as role models of social-ecological resilience. *Social-ecological resilience* is an emergent concept offering insights into coping with the uncertainties of global environmental change (Folke, 2006). In his article *Resilience: The Emergence of a Perspective for Social-Ecological Systems Analyses*, Carl Folke (2006) proposes the following characteristics of social-ecological resilience: a) opportunities arise out of disturbance through forms of recombination, renewal, and emergence; b) individuals and societies cope with the complexity of nature rather than trying to control it; c) there are increased capacities for social memory and learning from the past; d) there is the belief that the future is unpredictable and surprise is likely; and e) resilience is expressed in the self-organizing capacity of social and ecological systems. Through my study of ecologists' experiences, I see this kind of resilience as a way of thinking and being informed by the ecological perspective—ecological resilience is mirrored in human resilience.

I reflect on the above characteristics and the ways in which I have observed ecologists as role models of resilience. In order to respond to the challenge (disturbance) of global climate change, my research reveals how ecologists are working in interdisciplinary teams and gathering to create scientific networks such as the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT), the Western Mountain Initiative (WMI), and the National Ecological Observatory Network (NEON). Some ecologists, such as Dr. Jesse Logan, are also collaborating with agencies and offering opportunities for citizen engagement in field science. Ecologists are embracing the complexity of climate change and learning to cope with the multitude of variables through their field experiments. They are working hard at transferring their knowledge and teaching land managers how to plan for multiple climate change scenarios. I see all of these activities as examples of building social memory in order to track and understand the complexity of global environmental change. I also consider how the social memory of ecologists is recorded in their long-term monitoring projects and in their interpretations of paleo-ecological data in tree rings and lake sediments.

Having learned that nature is constantly in flux, ecologists also express how their sense of a dynamic earth gives them solace. They see change as the norm, and they anticipate surprise. I also see examples of resilience in the ecologists who were once grief stricken with loss and who have bounced back from their grief to return to their work with even greater commitment. The ecologists in this study have also come up against the boundaries of their traditional fields of inquiry. They have begun to explore the margins between the natural sciences and the social sciences. Many of the ecologists in this study have chosen the field of ecology because they want to leave the world a better place than they experienced. They are beginning to feel more confident in publicly expressing the human values related to their science. Many of them grew up in the dawn of environmentalism in the early 1970s, and now the problem of global climate change presents an even more challenging opportunity to make personal contributions. Out of this global disturbance arises an opportunity for learning more about how the world works. All of these attributes make the ecologists in this dissertation role models of social-ecological resilience and exemplars of place-based learning and adaptation to global environmental change. In addition to offering us visions for place-based learning and social-ecological resilience, the experiences of the ecologists in this dissertation provoke still deeper questions about where we might go next, questions about making choices about the kind of world we want to live and learn in.

Choosing the Kind of World We Want to Live and Learn In

On the one hand, the lived of experiences of ecologists can be thought of as a continuum leading toward social-ecological resilience, but these experiences can also be considered as a spectrum of sometimes conflicting perspectives. One such perspective involves making choices about how we adapt to global change. At one end of the spectrum there is the sense that earth is always changing and that there is little that humans can actually do to prevent change in the face of such enormous physical earth forces. At the other end of the spectrum is the idea that humans can manage and control the fate of natural communities, such as through fighting against invasions of non-native species and helping threatened native species through assisted migration. Somewhere in the middle of this spectrum of perspectives lie ideas like conservation triage and scenario planning. The questions these ideas raise are related to values and personal preferences. How do we link science with the way we make decisions about the future? Do we want future landscapes to look just like the landscapes familiar to us now? Do we want to protect as much biodiversity as possible or do we want to maximize ecosystem services? Are these two values mutually exclusive or can they be accomplished together? How much ecological change is acceptable? How much is tolerable? How much are we willing to change our ways in order for other species to flourish? These are the kinds of important questions raised in this dissertation that demand broader public conversations.

In the words of ecologist Dr. Terry Root, practicing science is a process of "pushing up against dogmas" and co-creating the way in which we know the world we are always in. It seems that the more the ecologists in the dissertation come to know about global climate change, the more they are compelled to act. And, although they may disagree about how to respond in the face of global climate change, they are still working for what they believe can be a livable future. They tell us the world will change, and there are choices that need to be made. A discussion on how humans make choices and how environmental values influence behaviors is beyond the scope of this dissertation, but it is worthwhile to return for a moment to some of the literature I reviewed on the human dimensions of climate change and consider its implications for learning and living with climate change.

Research on individuals' feelings about climate change suggests that personal experience, affect, and imagery play significant roles in people's perspectives on climate change (Leiserowitz, 2006; Moser & Dilling, 2007). By combining the results of this dissertation—stories of ecologists' experiences—with experiential learning projects related to climate change, educators can help raise awareness and prepare people for making choices about the kind of world they want to live in. Engaging students in their own research activities, such as interviewing scientists, establishing place-based ecological monitoring projects, conducting simple field experiments, and tracking species' phenology and migration patterns with established national and global networks, can foster deeper understanding of the world we live in now and the kinds of choices we are faced with when making decisions about the future. I turn to the experience of one more ecologist in order to share his insights on science and experiential learning.

Dr. Dan Blumstein is an ecologist who spends his summers at Rocky Mountain Biological Laboratory. He is a preeminent expert on the behavior of yellow-bellied marmots (*Marmota flaviventris*). His studies of these curious small mammals have taken Blumstein around the world to learn about their ecology and behavior. As a result, Blumstein says that one of his greatest contributions to science and society is "training others…and getting others to appreciate" behavioral and ecological diversity. "I think a really big and important contribution that one can make…is through educating others…and getting people…really jazzed about doing science and understanding the process." Blumstein believes that the best way of educating about biodiversity is "just getting people outside and allowing them to experience it and be immersed in it." He shares a story that led to his own enthusiasm for learning and scientific discovery:

> I spent years working in an uninhabitable meadow at 14,000 feet in Pakistan, and I loved watching the seasons change, and I felt really fortunate to be able to be there and see the seasons change…watch the snow melt and the flowers pop up and the phenology of the animals living there. I think it's really rare that people get an opportunity to spend time in one place and really feel a change….I think education is really important, but you have to get people out there. Not just for a one-day event or a couple-hour field trip, but people have to live in it and wander around different areas and see things….We don't appreciate what we're surrounded by. So getting people to go to new places often allows barriers and calluses to break down and you start seeing things afresh. I think that's important.

Drawing from Blumstein's experiences and insights on educating people, it is not only important to develop a deep learning practice of one's own home place but to also learn about and experience other places first hand. Just as Dr. Jill Baron's high school biology teacher took her class on multi-day learning adventures to compare and contrast various ecosystems, Blumstein suggests that learning about biodiversity and environmental change requires expanding one's horizons. To be sure, my own learning and perspectives on global climate change have deepened and expanded due to this dissertation project. Now I close this conclusion with a final personal reflection.

Final Reflection

As I reflect back on the conception of this dissertation, I realize this project has not only been a way of learning about climate change in the mountains and the personal experiences of ecologists, but it has also been a way of finding the deeper meanings in my own life and work. I have put myself out in the field with scientific experts in order to ground my personal sentiments about climate change. Through the process of this academic journey my outlook on climate change has shifted. In the words of phenomenological anthropologist Dr. Michael Jackson (2005), who reflects on the experience of being a researcher in the field, my "craving to know" has been replaced "with a desire to know how to live" (p. 163).

When I began this study I felt a sense of panic and angst about climate change. Now, just as some of the ecologists have expressed their own experiences of learning and transformation, the more I understand about climate change, the more my concerns are transformed. I have moved from feeling a sense of dissonance and despair toward feeling a "more stable and integrated kind of concern." I feel more resilient and prepared for the surprises that lie ahead. As an environmental educator, I can now return to my work with an increased sense of understanding, commitment, and hope for my students and for the future. My sense of purpose in helping others learn about local natural history and place-based ecology and in engaging students in first-hand studies of science in their own backyards has been reaffirmed.

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APPENDIX A

Semi-Structured Interview Guide

1. **What is it like to think ecologically?**
    a. How would you describe to a lay person what it is like to perceive and understand the world through the lens of ecology?
        i. How do you experience *time* differently?
        ii. How do you experience *space* differently?
        iii. How do you *embody* this experience differently?
        iv. How do you *relate* to things differently
    b. Does the way you perceive the world differ from how a lay person might perceive the world?
    c. What is it like to be a field ecologist today?
    d. Have you considered the historical implications of your work?
2. **What is it like to experience global ecological change as a result of current climate change?**
    a. Can you describe what it is like for you personally to experience global ecological change?
    b. What is it like to be in the world right now?
    c. How does this experience compare to the way you believe most other people experience global ecological change?
    d. What have you learned about global ecological change as a result of your work?
    e. Specifically, what is the impact of climate change on mountain biodiversity (species and ecosystems)?
    f. How do you think global climate change has affected the lives of field ecologists in general?
    g. Can you describe what it will be like for ecologists to live during this coming century?
3. **Ecologists' life purpose and meaning**
    a. Tell me how you got into the work you do.
    b. Was there a specific event or circumstance that led you to become a field ecologist researching the effects of climate change?
    c. How is your sense of purpose in the world related to your ecological research?
    d. Has your ecological research influenced your sense of purpose in the world?
    e. What motivates you to conduct research on the ecological effects of climate change?
    f. How has climate change affected the work you do? (career and daily behaviors)
    g. What keeps you going year after year?
    h. How would you describe your role in the world?
4. **Closure**
    a. Clarify meanings and interpretations
    b. Ask for any parting thoughts related to the interview themes.

APPENDIX B

RESEARCH PARTICIPANTS AND INTERVIEW SCHEDULE

Name	Interview Date & Location
Ray, Chris	Gore Range Natural Science School, CO office 7/10/07 field 7/11/07
Harte, John	Rocky Mountain Biological Laboratory, Gothic, CO on 7/30/07
Blumstein, Dan	Rocky Mountain Biological Laboratory, Gothic, CO on 7/30/07
Inouye, David	Rocky Mountain Biological Laboratory, Gothic, CO on 7/31/07
Stohlgren, Tom	Colorado State University, Fort Collins, CO. Office 10/16/07
Seastedt, Tim	University of Colorado, Boulder, CO. Office on 10/17/07
Baron, Jill	Telephone interview 10/19/07
Allen, Craig	Telephone interview on 10/26/07
Stephenson, Nate	Telephone interview on 10/26/07
Millar, Connie	Telephone interview on 10/29/07
Peterson, Dave L.	Telephone interview on 11/7/07
Boggs, Carol	Telephone interview on 11/15/07
Hicke, Jeff	Telephone interview on 11/26/07
Blaustein, Andrew	Telephone interview on 12/3/07
Fagre, Dan	Telephone interview on 12/6/07
Debinski, Diane	Telephone interview on 12/14/07
Patton, James	Telephone interview on 12/19/07
Root, Terry	Telephone interview on 12/27/07
Swetnam, Tom	Telephone interview on 1/11/08
Logan, Jesse	Telephone interview 5/16/08
Harte, John	Second interview, Rocky Mountain Biological Laboratory, 7/2/08
Allen, Craig	Second interview, Bandelier National Monument, NM, 7/3/08
Debinski, Diane	Second interview, Grand Teton National Park, WY, 7/13/08
Logan, Jesse	Second interview, Tom Miner Basin, MT, 7/14/08
Fagre, Dan	Second interview, Glacier National Park, 7/15/08
Swetnam, Tom	Second interview, Tree-Ring Research Laboratory, Univ. of AZ, 7/18/08
Baron, Jill	Second interview, Rocky Mountain National Park, CO, 7/19/08

APPENDIX C

INFORMED CONSENT FORM

Dear _________________________,
Thank you for your interest in my doctoral dissertation research. The purpose of this letter is to inform you about the nature of my study and to gather your written permission to use the information discussed in our interview.

Purpose of my research
The purpose of my research is to understand what it is like for ecologists to experience climate change and resulting ecological change. You have been chosen as a participant in my research because of your experience studying how climate change impacts species and/or ecosystems.

What we will talk about during the interview
I am asking you to participate in a one- to two-hour, audio recorded, interview to talk about your work studying the ecological effects of climate change. Through the process of interviewing you I hope to gain a better understanding of three things: 1) how climate change is affecting the ecological systems or species you study, 2) stories about your personal experiences conducting such ecological research, and 3) how your work on the ecological effects of climate change may affect you personally.

Benefits to society
I believe my research, including your personal story, will benefit society by helping to effectively communicate about climate change from a more personal perspective. The results of my dissertation research may be used after initial publication of my dissertation as the basis for literature written for a public audience and as the basis for curricula supporting environmental studies courses.

Request to use your name in my research publications
In view of the historical and scholarly value of your personal story, and the information gathered in our interview, I would like to use your name in my dissertation and any subsequent publications related to my research. I will provide an opportunity for you to examine, edit, and approve our original interview transcript. I would also like your confirmation of my interpretations of what you said. Within 30 days of the interview I will mail you a copy of the interview transcript along with any written interpretations that I make. You will then have the opportunity to make any edits and then return the transcript to me in a stamped return addressed envelope. In the case that I need further clarification about anything you said during the interview, I may contact you with follow-up questions.

Possible risks associated with this study
The foreseeable risks to you associated with this research are: 1) it may reveal personal information about your work to the public and 2) through the course of the interview we may discuss topics that evoke an emotional reaction. You are free not to respond to any questions that you feel are sensitive. You are also free to withdraw from this study at any time, and you are welcome to ask me any questions, and I will answer them. Your participation is strictly voluntary. Excerpts from our interview may be incorporated into public documents such as my doctoral dissertation, journal articles, and books. Your identity and the geographic area of your fieldwork will be divulged.

Research Consent
I, ______________________________, in view of the historical and scholarly value contained in the interview with researcher Kimberly Langmaid, knowingly and voluntarily permit Kimberly Langmaid the full use of this information (including audio tapes and transcriptions and all other materials in this accession), hereby grant and assign to Kimberly Langmaid all rights pertaining to this information, whether or not such rights are known, recognized, or contemplated.

____
(Signature of Research Participant)

____
(Date)

Understood and agreed to:

____
(Signature of Researcher Kim Langmaid)

____
(Date)

Contact Person for Questions about this Research Project:
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Contact Person for Questions about your Rights as a Research Volunteer:
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