NATURAL AND NATIONAL RECOVERY:
THE RISE OF ECOLOGICAL RESTORATION IN THE UNITED STATES, 1930-1975

A Dissertation

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

by

Laura Jane Martin

August 2015

NATURAL AND NATIONAL RECOVERY:

THE RISE OF ECOLOGICAL RESTORATION IN THE UNITED STATES, 1930-1975

Laura Jane Martin, Ph. D.

Cornell University 2015

This dissertation integrates methods from Science and Technology Studies (STS), Environmental History, and Ecology to ask how scientific models, natural resources management, and the natural world influence one another. Chapter 1 explores the ecological and evolutionary impacts of whitetail deer overpopulation – a phenomenon challenging land managers across the eastern United States. Broadening the theme of land management, Chapter 2 applies methods from STS and geography to critique the systematic biases in the global distribution of ecological field sites. Chapters 3 through 9 analyze the intellectual and political history of ecological restoration in the United States from the 1920s to 1970. This portion of the dissertation traces previously obscured relationships among individual ecologists, The Nature Conservancy, the U.S. Fish and Wildlife Service, the U.S. Atomic Energy Commission, and particular organisms, technologies, and landscapes. It contends that for decades, American ideas about ecological restoration have been conceptually and materially linked to ideas about ecological destruction and the related expansion of environmentally relevant spaces from meter-square field sites to the biosphere as a whole. More broadly, it uses ecological restoration as a lens through which to examine how Americans have understood the relationship between the past and the present.

BIOGRAPHICAL SKETCH

Laura Jane Martin grew up in Manville, Rhode Island. She received an Sc.B. (with honors) in biophysics from Brown University in 2006 and an M.S. in natural resources from Cornell University in 2010. While at Cornell, she received national fellowships in both the sciences and the humanities. She is interested in the interwoven technical, cultural, and political dimensions of ecological interventions. Through fieldwork, she studied the impact of human activities on the ecology and evolution of wetland species, publishing in *Journal of Ecology*, *Conservation Biology*, *Trends in Ecology and the Environment*, and elsewhere. Through archival research, she investigated the history of ecological restoration in the 20^{th}-century United States. Her current work is situated at the nexus of environmental history and science and technology studies. Following graduation, Laura will join the Harvard University Center for the Environment as a postdoctoral fellow housed in the Department of the History of Science. She is also a poet; her poems have recently appeared in *Prairie Schooner*, *Fourth River*, *Briar Cliff Review*, and elsewhere.

ACKNOWLEDGMENTS

In completing this dissertation I would like to thank my committee for their extraordinary generosity. I am indebted to Clifford Kraft for his unflagging support, guidance, and intellect. Anybody who has had a conversation with Cliff knows it is impossible not to be inspired by his interest in everything strange and wonderful in the natural world. Cliff has also been a thoughtful and rigorous editor. I thank Sara Pritchard for teaching me how to be a scholar. This project has been deeply shaped by Sara's insights and feedback. I thank Sara, too, for her scholarship at the nexus of Environmental History and STS, which has opened up a space for many to explore. I owe a great deal to Aaron Sachs for warmly welcoming a confused Natural Resources student into his office in 2008. Aaron introduced me to the profession of history and, in turn, to the patient cultivation of words. Our conversations, and his kindness, have sustained me through this project and many others. Anurag Agrawal and Harry Greene have not only given me valuable feedback, they have given me attention, advice, and intellectual support for as long as I've known them. I thank them for their labor on my behalf.

In my eight years in Ithaca I have been fortunate to work with amazing people. Thank you to Ezra Feldman for his partnership and his razor-sharp editing. For his contributions to this project, his wit, and his friendship, I thank Daegan Miller. For excellent feedback and support, I thank Barbara Bedford, Susan Cook-Patton, Jillian Cohen, Ellen Crocker, Jeremy Dietrich, Janis Dickinson, Laura Eierman, Darrick Evensen, Liza Flum, Heather Furnas, Chuck Geisler, Karim-Aly Kassam, Ron Kline, Barb Knuth, Amy Kohout, Brandon Kraft, Bruce Lewenstein, Michael Lynch, Nancy Menning, Paul Nadasdy, Rachel Neugarten, Trevor Pinch, Margaret Rossiter, Suman Seth, Sue Stein, Taza Schaming, Jim Tantillo, Josi Ward, MG Weber, Steven Wolf, and Wendy Wolford.

Two communities – the Cornell Roundtable on Environmental Studies (CREST) and Historians are Writers (HAW) –provided warm intellectual homes. At Cornell I also benefited from the Americanist colloquium, the STS Science Studies Research Group, the Cornell Institute for Social Sciences "Contested Global Landscapes" theme project, and the Departments of Natural Resources, Ecology and Evolutionary Biology, History, and Science & Technology Studies.

Beyond Ithaca's hills, I thank many for their valuable insights, including Peter Algona, Stephen Bocking, Angelo Caglioti, Zachary Caple, Kate Christen, Gene Cittadino, Alan Covich, Bill Cronon, Ron Doel, Sam Dolbee, Rob Dunn, Nathan Ela, Erle Ellis, David Fedman, Simon Feldman, the late Mark Finlay, Scott Frickel, Peter Galison, Jenny Goldstein, Nick Haddad, Marcus Hall, Donna Haraway, Steven Harrell, Richard Hobbs, Tim Johnson, Dolly Jørgensen, Holly Menninger, Gregg Mitman, Michelle Murphy, Zoe Nyssa, Peter Perdue, Henrique Pereira, John Quinn, Megan Raby, Harriet Ritvo, Helen Rozwadowski, Paul Sabin, Dov Sax, Caterina Scaramelli, James Skillen, M. Rebecca Shaw, Sverker Sörlin, Maria Taylor, Greg Thaler, Jay Turner, and Carina Wyborn. Portions of this work were presented at meetings of the American Society for Environmental History, the Society for Social Studies of Science, the International Congress for Conservation Biology, and the Ecological Society of America, as well as the Yale "New Perspectives in Environmental History" conference and the University of Pittsburgh "Life Sciences After WWII" conference.

I am grateful to the staff of the Cornell Rare and Manuscript Collections; the Yale Sterling Memorial Library; the University of Washington Special Collections, especially John Bolcer; the University of Georgia Archives, especially Gilbert Head and Margie Compton; the National Archives at College Park, especially Joe Schwartz; and the New York State Library.

And for providing comfy couches and hospitality, I thank Susan and Zack Cook-Patton, Erle Ellis and Ariane de Bremond, Ilina Chaudhuri and Kristin Sternowski, Jenny Richens, Stephanie Hainley, Aimee Martin and Kevin Toon, John and Jane Martin, Tom Martin, Simon Feldman, Noah Feldman, Roy and Penny Feldman, and Kyle Richard.

While a graduate student I was supported by fellowships from the National Science Foundation, the Doris Duke Conservation Leadership program, and Cornell University. Research funding for this project was provided by the Cornell Graduate School, the Cornell Institute for Social Sciences, the Cornell Society for the Humanities sustainability grant, a Social Science Research Council Dissertation Proposal Development Grant, and a National Science Foundation Dissertation Improvement Grant (Award No. 1329750) from the Program in Science, Technology, and Society.

TABLE OF CONTENTS

Biographical Sketch	iv
Acknowledgments	v
Preface	viii
Chapter 1. Evolution of Tolerance to Deer Herbivory: A Comparative Study of Historically Browsed and Protected Plant Populations	1
Chapter 2. Mapping Where Ecologists Work: Biases in the Global Distribution of Terrestrial Ecological Observations	22
Chapter 3. The Long History of Ecological Restoration	43
Chapter 4. After the Dust Bowl: Ecologists' Roles in National and Natural Recovery	56
Chapter 5. Tools for Time Travel: Reconstructing America's Ecological Past	104
Chapter 6. Atoms for Ecology: Restoring Salmon and Domesticating the Sea	149
Chapter 7. From Communities to Ecosystems: Changing Conceptions of Ecological Connectedness	200
Chapter 8. Recovery After Attack: 1960s Radioecology and Shifting Conceptions of Humans as Agents of Ecosystem Change	248
Chapter 9. Conclusion	296

PREFACE

When I tell people that I am earning a Ph.D. in Natural Resources, they often respond, "What's that?"

Over the past five years, I, too, have struggled to define the discipline of Natural Resources. I entered Cornell's Department of Natural Resources in 2007 as a master's student. I was interested in plants – not plants that people eat or make things out of or grow in gardens, but plants that are just out in the world, living their own mysterious lives. I joined a group of scholars asking whether native plant species were impacted by the presence of *Phragmites australis*, a wetland grass that was introduced to this area at the turn of the twentieth century. I decided that I wanted to study ecology, as many Natural Resources graduate students do.

But I soon encountered questions that I couldn't quite address with my newly acquired skills. By measuring plant parts in the field and employing statistical tests I could make inferences about the influence of *Phragmites* on native plants. Quantification enabled me to describe what I had seen in the field in succinct and interesting ways. But it didn't provide any answers as to what *should be done* with *Phragmites*. It seemed like a huge and troublesome leap from an observation – that wetlands with *Phragmites* have, on average, 40% fewer plant species than wetlands without *Phragmites* – to a conclusion that the U.S. Fish and Wildlife Service should spray thousands of acres of wetlands with herbicide to get rid of *Phragmites*. I found myself asking new questions: Why, for example, do so many people assume that ecologists are experts in natural resources management? How do cultural understandings of invasive species shape the science of invasive species? More broadly, how does an "environmental problem" become just that?

After much wandering, I was fortunate enough to find communities of scholars asking these questions from the disciplines of Geography, Environmental History, and Science and Technology Studies. The approaches of these disciplines are rarely taught in Natural Resources departments, which tend to emphasize ecology and sociology. And yet geographers, historians, and STS scholars routinely ask questions that lie at the very core of Natural Resources management. Through the methods of these disciplines, it is possible to study how ecological knowledge is produced and how it is used to justify certain environmental interventions.

The organization of this dissertation mirrors my intellectual journey. The first chapter employs quantitative methods from ecology and evolution to study a common wetland plant, *Impatiens capensis*, and how it has been changed by a species of great concern to natural resources managers: white-tailed deer. The second chapter employs quantitative methods from Geography and STS to study the global distribution of ecological field sites. It contends that most ecological data is collected in protected areas in temperate regions, and that it is important to reflect on how this geographical bias shapes our current ecological knowledge. The following chapters employ methods from Environmental History and STS to study the emergence of ecological restoration as a concept and a management practice in the United States.

I once expected that immersing myself in both scientific and humanistic methods would lead me to a grand interdisciplinary synthesis of "The Two Cultures." Interdisciplinarity, after all, is increasingly advocated as a means of solving complex environmental problems. As Dominic Boyer wrote in a 2005 Cornell Society for the Humanities booklet on whether the humanities are facing a crisis: "The price we pay for our specialization of labor, as Adam Smith and Karl Marx observed so long ago, is the receding horizon of the whole, our experiential sense of how all the productive parts fit together." Yet, perhaps ironically, writing this dissertation has increased my appreciation for disciplinary specialization. I would not have been able to study the evolution of *Impatiens capensis* by analyzing archival sources. I would not have been able to study the history of ecological restoration by measuring plant stems.

But writing this dissertation has also increased my appreciation for multi-disciplinarity. I believe that it is crucial that Natural Resources programs – and all environmentally themed programs – expand to encompass the environmental humanities. The myth that science is outside of society is politically convenient. But I am not convinced that it makes the world a better place for humans or for other species. And Natural Resources is a discipline that cares about both.

CHAPTER 1

EVOLUTION OF TOLERANCE TO DEER HERBIVORY: A COMPARATIVE STUDY OF HISTORICALLY BROWSED AND PROTECTED PLANT POPULATIONS

Abstract

Browsing by overabundant white-tailed deer (*Odocoileus virginianus*) has altered ecological relationships in forest communities across eastern North America. Recent but limited work suggests that deer browsing also selects for particular plant defensive traits. We hypothesized that browsing by deer has imposed selection on defensive traits in an annual native wildflower, orange jewelweed (*Impatiens capensis*). To test this hypothesis, we collected individuals from 26 natural populations across a 5000 km^2 area in New York State, USA. Half of these populations were historically protected from deer and half were exposed to heavy browsing. We planted individuals in common gardens subjected to natural deer browsing or no browsing. Individuals from historically browsed populations exhibited significantly higher tolerance than those from historically protected populations. Herbivory by deer reduced lifetime fruit production by only 20% in historically browsed populations, as opposed to 57% in historically protected populations. Two mechanisms were correlated with this increased tolerance: increased number of flowering days and increased fruits per flowering node. The increased tolerance of historically browsed populations suggests that these populations evolved increased tolerance or that historically protected populations lost tolerance over time. Variation in tolerance traits in native plant species may allow them to persist in the face of rapid ecological change.

Introduction

Over the past 80 years, white-tailed deer (*Odocoileus virginianus*) densities have exploded across eastern North America. In the Great Lakes region, current deer densities are approximately five times greater than they were prior to European settlement (Rooney & Waller 2003). The ecological impacts of this overabundance, especially on plant community composition, have been studied since the 1970s. Because deer forage selectively, they alter competitive relationships among plant species (for review, see Côté *et al.* 2004). In doing so, they alter ecosystem processes such as soil development and nutrient cycles (Hobbs 1996).

Recent work suggests that deer are also important agents of natural selection in these systems (Stinchcombe & Rausher 2001; McGraw & Furedi 2005). Plants browsed by deer tend to be smaller, less likely to flower, and less likely to survive than those protected from deer (Augustine & Frelich 1998; Knight 2004). In theory, such effects on individual plants should lead to divergence among populations in diverse traits, including defensive traits. Defensive traits are broadly categorized in terms of resistance, which reduces the preference or performance of herbivores, and tolerance, which allows plants to replace browsed tissue or reproduce after damage. However, little is known about whether herbivores rapidly select for predictable parallel changes in defensive traits across natural plant populations (Agrawal *et al.* 2012).

Two previous studies have sought evidence for the evolution of plant defensive traits in response to deer browsing. A feeding trial showed that Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) preferred western red cedar (*Thuja plicata*) seedlings from a site on an island historically lacking large mammalian herbivores to a mainland site where deer had been present for millennia (Vourc'h *et al.* 2001). In another experiment, sika deer (*Cervus nippon*) preferred nettles (*Urtica thunbergiana*) from a historically unbrowsed population over ones from a population subject to browsing for more than 1200 years in Japan (Kato *et al*. 2008). Although the results of these two experiments are intriguing, they are limited by lack of replication at the population level. Lennartsson, Tuomi and Nilsson (1997) found that individuals from five populations of field gentian (*Gentianella campestris*) that were historically grazed by cattle or mown exhibited overcompensation in response to simulated grazing (clipping), suggesting the evolution of tolerance to damage in these populations.

The evolution of tolerance could explain why some plant species that are palatable to white-tailed deer have persisted in areas of high deer density in eastern North America. Tolerance, the degree to which plant fitness is affected by herbivore damage relative to fitness in the undamaged state (Strauss & Agrawal 1999), can involve at least two mechanisms: pre-damage investment in resources (analogous to constitutive defences) and post-damage alteration in resource allocation (analogous to induced defences) (Hochwender *et al.* 2012). The best studied mechanisms of tolerance include enhanced leaf photosynthetic activity following herbivore damage, increased branching or tillering following damage, and greater utilization of stored reserves following damage (Tiffin 2000; Núñez-Farfán *et al.* 2007).

In this study we evaluated whether populations of a native annual plant, orange jewelweed (*Impatiens capensis* Meerb*;* Balsaminaceae), show evidence of divergence in their tolerance of deer herbivory. We collected individuals from 26 natural populations with contrasting browsing histories. We hypothesized that individuals from populations historically accessible to deer would better tolerate deer herbivory than individuals from populations historically protected from deer – a result that would constitute evidence for a response to past selection. We then evaluated pre- and post-damage mechanisms of tolerance.

Materials and Methods

Study Organism

Orange jewelweed, an annual herb of forested wetlands, is a preferred food plant of deer (Williams *et al.* 2000). This species has seeds that typically disperse <1.5 m from parent plants (Argyres & Schmitt 1991) and exhibits well-studied local adaptation in morphological and life-history traits among natural populations (Schmitt *et al.* 1985). It has a mixed-mating system, producing two distinct types of flower: tiny, obligately self-pollinating cleistogamous flowers and showy, protandrous chasmogamous flowers (Gleason & Cronquist 1963). In addition to deer, invertebrates occasionally feed upon *I. capensis* in the eastern United States, including chrysomelid beetles, leaf miners, caterpillars, aphids, grasshoppers, and katydids (Steets *et al.* 2006).

Collection Sites

In 2012 we identified 15 "historically protected" and 15 "historically unprotected" *I. capensis* populations from four regions in New York State across a 5000-km^2 area. "Historically protected" populations were located in sites inaccessible to deer because of physical barriers such as steep slopes (>70 degrees), fences, or dense urban development. "Historically unprotected" populations were located in sites with no physical barriers preventing access by deer. Because deer are hyper-abundant in this region, we assumed that accessible sites have a history of moderate or intense browsing, whereas inaccessible sites have not.

Our unit of replication was the population, and we attempted to collect plants from as many populations as possible. We chose to infer the histories of contemporaneous populations because there are no long-term records of management, browsing damage, or fine-scale deer densities for multiple populations in the eastern United States. Faced with similar experimental constraints, others have employed similar methods (e.g., Lennartsson, Tuomi & Nilsson 1997; Vourc'h *et al.* 2001; Kato *et al*. 2008), although with fewer populations. To corroborate our inferences, we surveyed sites for evidence of browsing in summer 2013. We observed no evidence of browse at any of the "historically protected" sites. In "historically unprotected" sites, between 20% and 100% of individuals had been browsed by deer. In the final experiment we excluded plants from two "historically protected" sites that exhibited signs of disease and plants from the two "historically unprotected" sites with <30% browsed.

From 6 to 20 May 2012 we collected 100 seedlings with 2 true leaves at random from each population. Once seedlings were collected, their roots were gently washed and they were planted in plug trays filled with potting soil (Espoma organic potting mix, Millville, NJ). Seedlings were held in partial sun in a screened enclosure in trays that were rotated every three days until the experiment began.

Common Garden

The experiment was conducted at the Cornell Mundy Wildflower Garden (42.75 N, 76.78 W), a forested floodplain in Ithaca, NY, within a deer exclosure area established in 2007. On 23 May 2012 we planted 10 seedlings from each population with 4-6 true leaves inside the deer exclosure ("fenced treatment") and 10 outside the deer exclosure ("unfenced treatment") in a balanced randomized design. The two treatments were 120 meters apart. Seedlings were spaced at a low density, 15 cm apart (Huber *et al.* 2004) in grids covered in porous weed barrier (DeWitt Pro Premium weed fabric). A border row of non-experimental seedlings was established around each common garden to avoid edge effects. We replaced seedlings that died within the first week of the experiment.

Deer naturally browsed all but 16 plants in the unfenced site between 3 and 13 July 2012. The 16 unbrowsed plants were excluded from subsequent analyses (6.2%, 8 individuals each from historically unprotected and historically protected populations).

In order to ensure that growing conditions were similar in the fenced treatment site and the unfenced treatment site, we (1) compared growth rates before browsing and (2) planted two fenced control blocks (of 30 and 10 plants, respectively) adjacent to the unfenced site. Both lines of evidence indicated that growing conditions were similar in both sites. Before deer browsing occurred, plants in each treatment had produced the same number of seeds (Table 1). On the day 40 census, mean height was slightly greater in the fenced site (mean±1SE = 24.1±0.6 cm) than in the unfenced site (23.0±0.7 cm), but the treatment*history interaction was not significant (Table 1). On the day 69 census, mean height of control plants in the unfenced site (40.8±14.2 cm) was not significantly different from that of the fenced plants (38.6±10.4) (Table 1). We therefore interpreted the presence or absence of browsing by deer to be the key explanatory variable in this experiment.

Table 1. Three comparisons between growing conditions in the protected and unprotected common garden. Influence of treatment (fenced or unfenced), history (historically unprotected or historically protected), treatment*history, region, and population nested within history and region on (a) seed production pre-browsing, (b.) height before browsing, and (c.) height of protected and control plants on 30 July 2012

Response variable	**Effect**	**Statistic**	***P*-value**
Seed production before browsing (25 June 2012)	Treatment	χ^2=0.15	0.6979
	History	χ^2=0.13	0.7205
	Treatment*History	χ^2=0.50	0.4777
	Region	χ^2=0.16	0.9969
	Pop [History, Region]	χ^2=461.09	**<0.0001**
Height before browsing (18 June 2012)	Treatment	$F_{1,402.8}$=4.68	**0.0311**
	History	$F_{1,21.1}$=0.01	0.9120
	Treatment*History	$F_{1,402.8}$=0.15	0.7024
	Region	χ^2=12.67	**0.0004**
	Pop [History, Region]	χ^2=105.86	**<0.0001**
Height 30 July 2012	Treatment	$F_{1,63.1}$=1.75	0.1900
	History	$F_{1,6.1}$=0.04	0.8557
	Treatment*History	$F_{1,63.6}$=3.68	0.0596
	Region	χ^2=0.90	0.1714
	Pop [History, Region]	χ^2=1.39	0.1190

We assessed plants weekly for survival and damage from deer browsing and measured plant height on 24 May, 5 June, 18 June, 3 July, 30 July, 22 August, and 19 September. We assessed plants weekly for date, height, and node of first self-pollinating flower; date of first self-pollinating fruit; date, height, and node of first open-pollinating flower; and date of first open-pollinated fruit. To obtain total fruit counts we counted intact and dehisced self-pollinated fruits (pedicels persist on the stem) on 5 June, 25 June, 13 July, 22 August, 19 September, 26 September, 3 October, and 10 October, and intact and dehisced open-pollinated fruits on 9 September and 19 September. Total flowering days were calculated as the days from first self-pollinating flower until death.

For each individual, the last fruit count before death was considered lifetime fruit production. Number of fruits was used as an estimate of number of seeds. Seeds per self-pollinated fruit were estimated as the mean of a subsample of fruits (N=54). Seeds per open-pollinated fruit were estimated as the mean of a subsample of fruits (N=19). An individual's lifetime seed production, a proxy of fitness, was calculated as total self-pollinated fruits * mean seeds per self-pollinated fruit + total open-pollinated fruits * mean seeds per open-pollinated fruit (Steets *et al.* 2006). Population means were then calculated for lifetime seed production and all performance metrics. We used a ratio (lifetime seed production when unprotected divided by that when protected) to calculate tolerance, which was correlated with absolute difference (R^2=0.81, $F_{1,24}$=5.84, P<0.0001).

Data Analysis

Generalized linear mixed-effects models of measured traits (fitness, growth, phenology, mixed mating, architecture) were constructed in JMP Pro 11 (SAS Institute Inc., Cary, NC, USA) using restricted maximum likelihood (REML) estimation (Littell *et al.* 1996). Models of these traits included browsing history ("historically unprotected" or "historically protected"), treatment ("fenced" or "unfenced"), and their interaction as fixed effects, and geographical region and population nested within history and geographical region as random effects.

We first tested whether historically unprotected populations were more able to tolerate browsing than historically protected populations (a significant treatment*history interaction term) by modelling lifetime seed production. Because of overdispersion we modelled count data (number of flowers, number of seeds) using a zero-inflated negative binomial distribution (O'Hara & Kotze 2010). Other variables were normally distributed. We then constructed models to test for effects of history on phenological traits (days to first flower, total flowering days) and architectural traits (height of lowest flower, number of flowering nodes, closed-pollinated seeds per flowering node). Again, we included the same fixed and random effects. To determine whether history affected mixed mating expression (likelihood of developing open-pollinating flowers) we constructed a logistic regression model with history, treatment, history*treatment, region, and population [history, region] as effects.

Mean population tolerance was calculated as the mean lifetime seed production of a population in an unprotected treatment divided by its lifetime seed production in the protected treatment. Finally, we constructed a GLM to evaluate the influence of history and three responses to browsing (ratio of browsed to unbrowsed traits for total flowering days, number of flowering nodes, and seeds per flowering node) upon mean population tolerance. This GLM analysis also evaluated two-way interactions of the three browsing responses with history. We did not include time to first flower or height of first flower in this analysis because plants commenced flowering before browsing was first observed.

Results

Historically unprotected populations were more tolerant of browsing than historically protected populations. Deer browsing reduced mean lifetime seed production by 57% in historically protected populations but only 20% in historically unprotected populations (Fig. 1b; treatment*history interaction in Table 2). Six of 13 historically unprotected populations produced more seeds when damaged than when protected, whereas only one of 13 historically protected populations showed such overcompensation (Fig. 1a) (Williams' corrected $G=5.29$, $P=0.0267$).

Browsing decreased mean plant height by 6.8±0.8% (range: 0-41.7%), and browsed plants did not produce open-pollinating flowers.

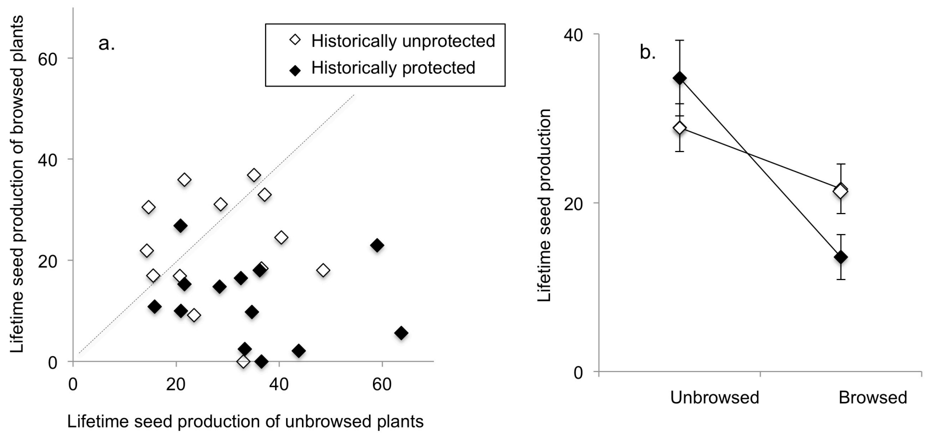


Figure 1 (a.) Lifetime seed production of 26 populations of *Impatiens capensis* in the fenced (unbrowsed) versus unfenced (browsed) treatment. The unity line depicts full compensation (fitness of a plant population in the browsed state equals fitness in unbrowsed state): overcompensation was observed in populations above the line. (b.) Mean (± 1 SE) lifetime seed production as predicted by population history and treatment.

Historically unprotected and historically protected populations did not differ in days to first flower (Table 2), but other reproductive traits were impacted by plant browsing history and browsing itself. For example, browsing reduced the total number of flowering days by 20% for historically protected populations (protected: 87.4±26.6, unprotected: 68.1±30.4) but did not affect historically unprotected populations (protected: 81.5±23.2, unprotected: 79.8±28.2) (Table 2). Contrary to our expectations, browsing history did not influence mixed mating system expression (the probability of producing one or more open-pollinating flowers (Table 2). When browsed, plants produced first flowers that were 29% closer to the ground regardless of browsing history (protected: 26.4±1.9 cm, unprotected: 18.7±1.9 cm) (Table 2). Both historically unprotected and protected populations also flowered at significantly fewer nodes when browsed

(Table 2), but historically unprotected populations produced 160% more seeds per flowering node when damaged (14.3±1.3) compared to when fenced (5.5±1.3) (Table 2).

Table 2. Influence of treatment (fenced or unfenced), history (historically protected or historically unprotected), treatment*history, region, and population nested within history and region on lifetime seed production, measures of phenology, mixed mating system expression, and measures of architecture

Response variable	**Effect**	**Statistic**	***P*-value**
Lifetime seed production	Treatment	χ^2=11.88	**0.0006**
	History	χ^2=4.83	**0.0280**
	Treatment*History	χ^2=4.71	**0.0301**
	Region	χ^2=7.83	0.0979
	Pop [History, Region]	χ^2=41.65	**0.0266**
Days to first flower	Treatment	$F_{1,387.5}$=3.12	0.0780
	History	$F_{1,21.17}$=1.96	0.1759
	Treatment * History	$F_{1,387.8}$ =0.54	0.4647
	Region	χ^2=2.29	0.1305
	Pop [History, Region]	χ^2=130.14	**<0.0001**
Total flowering days	Treatment	$F_{1,381.9}$=21.67	**<0.0001**
	History	$F_{1,21.2}$= 0.98	0.3323
	Treatment*History	$F_{1,382}$=13.41	**0.0003**
	Region	χ^2=3.76	0.05243
	Pop [History, Region]	χ^2=30.09	**<0.0001**
Probability of producing open-pollinating flowers	Treatment	χ^2=80.10	**<0.0001**
	History	χ^2=0.00	0.9997
	Treatment*History	χ^2=0.00	0.9997
Height of lowest flower	Treatment	$F_{1,368.6}$=85.01	**<0.0001**
	History	$F_{1,22.04}$=3.16	0.0892
	Treatment*History	$F_{1,368.6}$=1.28	0.2594
	Region	χ^2=0.56	0.4531
	Pop [History, Region]	χ^2=128.19	**<0.0001**
Number of flowering nodes	Treatment	$F_{1,351.4}$=511.44	**<0.0001**
	History	$F_{1,21.8}$=2.11	0.1605
	Treatment*History	$F_{1,351.7}$=0.66	0.4171
	Region	χ^2=0.36	0.5485
	Pop [History, Region]	χ^2=44.95	**<0.0001**
Seeds per flowering node	Treatment	χ^2=13.19	**0.0003**
	History	χ^2=1.09	0.2959
	Treatment*History	χ^2=0.77	0.3792
	Region	χ^2=12.91	**0.0117**
	Pop [History, Region]	χ^2=42.13	**0.0238**

In testing for mechanisms of tolerance in seed production we found all three responses (ratio of browsed to unbrowsed traits for total flowering days, number of flowering nodes, and seeds per flowering node) were positive predictors of tolerance when included in a single model (Table 3). Populations that were more tolerant to browsing in terms of seed production achieved this by increased flowering days and seeds per flowering node when browsed compared to when protected (Fig. 2). The ratio of the number of flowering nodes when browsed compared to when protected was also positively correlated with tolerance, but only in historically unprotected populations (Fig. 2). These three specific plant responses influenced tolerance to herbivory independently, as they were not significantly correlated with each other (n=26 for the three pairwise correlations, Ps>0.05).

Table 3. Influence of history (historically unprotected or historically protected), responses to browsing (ratio of browsed to unbrowsed traits), and two-way interactions on tolerance of *Impatiens capensis* in terms of lifetime seed production

Response variable	**Effect**	**t ratio**	***P*-value**
Tolerance	History	0.58	0.5661
	Response in total flowering days	3.77	**0.0014**
	Response in number of flowering nodes	4.80	**0.0001**
	Response in seeds per flowering node	4.42	**0.0003**
	History * Response in total flowering days	-0.22	0.8277
	History * Response in number of flowering nodes	2.85	**0.0106**
	History * Response in seeds per flowering node	1.66	0.1147

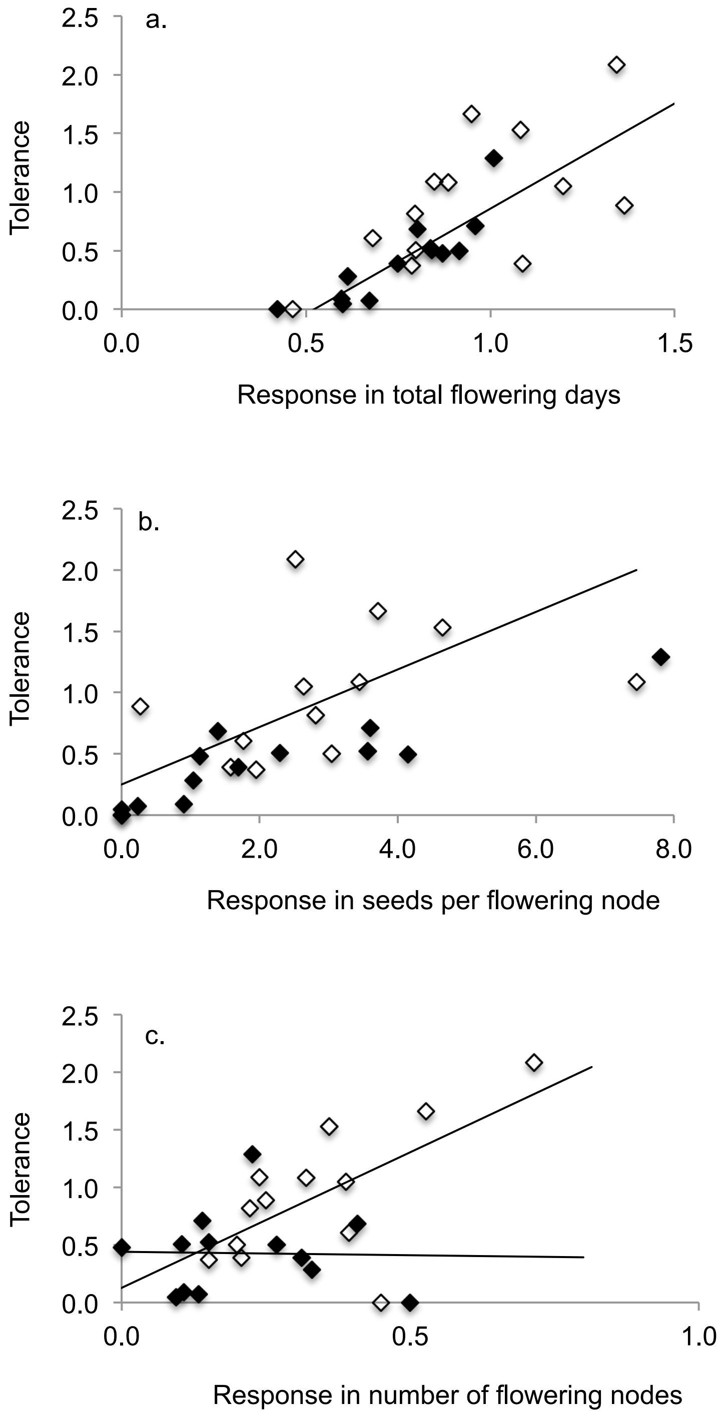


Figure 2. Relationship between population mean tolerance and responses to browsing (ratio of browsed to unbrowsed traits for total flowering days, number of flowering nodes, and seeds per flowering node). Filled symbols represent historically protected populations and unfilled symbols represent historically unprotected populations. One best fit line is shown in panels A and B, where historically unprotected and historically protected populations had the same relationship, whereas two lines are shown for panel C where there was a significant interaction

between browsing history and the extent to which response in number of flowering nodes predicted tolerance.

Discussion

Individuals from historically unprotected populations of *I. capensis* were nearly three times as tolerant (in the currency of lifetime seed production) as those from historically protected populations. Herbivory also reduced mean number of flowering days for historically protected populations but not for historically unprotected populations. These results point toward two plausible historical scenarios: (1) heavily browsed *I. capensis* populations have recently evolved tolerance to browsing, or (2) protected populations have lost the ability to tolerate browsing. Overall, the results of this study provide the first evidence that the overabundance of deer has led to the evolution of reproductive traits that allow for compensation following browsing.

Because response to browsing in flowering duration and number of seeds produced per flowering node were highly correlated with tolerance in plants from both histories, these could well be targets of natural selection in response to herbivory by white-tail deer. Additionally, the ability of historically unprotected populations to produce more flowering nodes seems to be diverging from that of historically protected populations. The high degree of phenotypic variation among populations for all of these traits (when measured in a common environment) suggests that the traits are heritable. Together, our results suggest that historically unprotected *I. capensis* populations have evolved an increased ability to branch at secondary meristems when the apical meristem is damaged, as has been demonstrated in other species subject to vertebrate or invertebrate herbivory (Rosenthal & Welter 1995; Lennartsson *et al.* 1997; Juenger *et al.* 2000). Lennartsson, Tuomi and Nilsson (1997) found that some historically damaged (mowed or grazed) populations of field gentian exhibited higher tolerance than historically undamaged populations. Although there was pronounced variation in both their results and ours, together they show the power of replicated population studies, which can suggest evolutionary change as well as the potential mechanisms that plants employ to adapt to a changing environment.

In contrast to expectations from previous studies, historically unprotected populations did not produce a greater proportion of self-pollinating flowers than historically protected populations. Herbivory has been reported in other contexts to both increase and decrease selfing rates, reflecting selection for reproductive assurance or for increased genetic variation under stress, respectively (Campbell *et al.* 2013). Across 10 natural populations of *I. capensis*, Steets *et al.* (2004) found that the proportion of self-pollinating flowers had a significant positive relationship with herbivory. In another experiment, Steets *et al.* (2006) demonstrated that insect herbivory in the field reduced the production of open-pollinating flowers by 59-70% and that of self-pollinating flowers by 16-23%. In our experiment, browsing decreased mean plant and browsed plants did not produce open-pollinating flowers. This may occur because only plants with adequate resources are capable of producing open-pollinating flowers (Waller 1984). If a height threshold must be reached for *I. capensis* to initiate open-pollinating flowers, then a lack of open-pollinating flower production in browsed plants could also be a passive consequence of reduction in plant size (Schmitt *et al.* 1987).

It is worth noting that our experiment utilized field-collected seedlings, not descendants from a common environment. Accordingly, we cannot definitively conclude whether differences among populations are due to genetic differentiation, maternal environmental effects, or early plasticity. Indeed, we detected population and regional differences early in the life cycle (Table 1), and Steets & Ashman (2010) found that *I. capensis* maternal plants experiencing high rates of herbivory produced offspring that were larger in size. For these reasons, we restricted our analyses to comparisons of damaged and undamaged states within populations. The extent of our population replication across regions reduces the potential for a systematic bias in environmental conditions. Nevertheless, it is possible that an unmeasured environmental variable co-varied with browsing history. If this is the case, browsing history was nevertheless predictive of tolerance.

It should be noted that white-tailed deer are not the only herbivores of *I. capensis* in the study area. Although we observed negligible damage by other herbivores in the field and in the common garden experiment, many natural populations of *I. capensis* are subject to damage by insects, fungi, and other natural enemies. In a classic paper, Schemske (1984) found significant genetic differentiation between two populations of *Impatiens pallida*, a closely related species to *I. capensis*, that were differentially attacked by a host-specific beetle, *Rhabdopterus praetexus*. Recent work has questioned whether multispecies assemblages of herbivores select for "pairwise" coevolution (in which specific plant traits are paired with specific herbivores) or "diffuse" coevolution (in which defences against various enemies were positively genetically correlated) (Strauss et al. 2005). In a common garden experiment, for example, Stinchcombe & Rausher (2001) found a negative genetic correlation between resistance to deer herbivory and resistance to generalist insect herbivory in ivyleaf morning glory (*Ipomoea hederacea*) that suggested diffuse coevolution. Future experiments could test whether the exclusion of insect herbivores affects the expression of tolerance to deer herbivory in *I. capensis*.

Our results suggest a correlation between previous browsing and tolerance to deer herbivory in a common native wildflower. This relatively rapid divergence could be due to the fact that *I. capensis* is a strict annual with a limited seed bank. In the eastern United States and other forested regions where the removal of carnivores and habitat modifications have led to increases in herbivore abundance, the persistence of a plant species will depend on its ability to evolve defensive traits. The evolution of defensive traits in one species may also have indirect effects on community composition (Lennartsson *et al.* 1997; Chase *et al.* 2000). The evolution of tolerance over short time scales (Agrawal *et al.* 2012) represents a previously unappreciated factor enhancing the ability of some native plants to persist in the face of rapid ecological changes.

REFERENCES

Agrawal, A.A., Hastings, A. P., Johnson, M. T., Maron, J. L. & Salminen, J. (2012) Insect herbivores drive real-time ecological and evolutionary change in plant populations. *Science*, **338**, 113–116.

Argyres, A.Z. & Schmitt, J. (1991) Microgeographic genetic structure of morphological and life history traits in a natural population of *Impatiens capensis*. *Evolution*, **45**, 178–189.

Augustine, D. J. & Frelich, L.E. (1998) Effects of white-tailed deer on populations of an understory forb in fragmented deciduous forests. *Conservation Biology*, **12**, 995–1004.

Campbell, S. A., Thaler, J. S. & Kessler, A. (2013) Plant chemistry underlies herbivore-mediated inbreeding depression in nature. *Ecology Letters*, **16**, 252–260.

Chase, J. M., Leibold, M. A. & Simms, E. (2000) Plant tolerance and resistance in food webs: community-level predictions and evolutionary implications. *Evolutionary Ecology*, **14**, 289–314.

Côté, S. D., Rooney, T. P. Tremblay, J. Dussault, C. & Waller, D.M. (2004) Ecological impacts of deer overabundance. *Annual Review of Ecology, Evolution, and Systematics*, **35**, 113–147.

Gleason, H.A. & Cronquist, A. (1963) *Manual of Vascular Plants of Northeastern United States and Adjacent Canada*. New York Botanical Garden Press, New York.

Hobbs, N. T. (1996) Modification of ecosystems by ungulates. *Journal of Wildlife Management* 60: 695-713.

Hochwender, C. G., Dong, H. C., Czesak, M. E., Fritz, R. S., Smyth, R. R., Kaufman, A. D., Warren, B. & Neuman, A. (2012) Protein storage and root:shoot reallocation provide tolerance to damage in a hybrid willow system. *Oecologia*, **169**, 49-60.

Huber, H., Kane, N. C., Heshel, M. S., von Wettberg, E. J., Banta, J., Leuck, A. & Schmitt, J. (2004) Frequency and microenvironmental pattern of selection on plastic shade-avoidance traits in a natural population of *Impatiens capensis*. *American Naturalist*, **163**, 548-563.

Juenger, T., Lennartsson, T. & Tuomi, J. (2000) The evolution of tolerance to damage in *Gentianella campestris*: natural selection and the quantitative genetics of tolerance. *Evolutionary Ecology*, **14**, 393–419.

Kato, T., Ishida, K. & Sato, H. (2008) The evolution of nettle resistance to heavy deer browsing. *Ecological Research*, **23**, 339–345.

Knight, T.M. (2004) The effects of herbivory and pollen limitation on a declining population of *Trillium grandiflorum*. *Ecological Applications*, **14**, 915–928.

Lennartsson, T., Tuomi, J. & Nilsson, P. (1997) Evidence for an evolutionary history of overcompensation in the grassland biennial *Gentianella campestris* (Gentianaceae). *American Naturalist,* **149**, 1147–1155.

Littell, R.C., Milliken, G. A., Stroup, W. W. & Wolfinger, R. D. (1996) *SAS System for Mixed Models.* SAS Institute, Cary.

McGraw, J. B. & Furedi, M. A. (2005) Deer browsing and population viability of a forest understory plant. *Science*, **307**, 920–922.

Núñez-Farfán, J., Fornoni, J. & Valverde. P. L. (2007) The evolution of resistance and tolerance to herbivores. *Annual Review of Ecology, Evolution, and Systematics*, **38**, 541–566.

O'Hara, R.B. & Kotze, D. J. (2010) Do not log-transform count data. *Methods in Ecology and Evolution*, **1**, 118-122.

Parker, J.D., Salminen, J. & and Agrawal, A.A. (2010) Herbivory enhances positive effects of plant genotypic diversity. *Ecology Letters*, **13**, 553-563.

Rooney, T. P. & Waller. D. M. (2003) Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management*, **181**, 165–176.

Rosenthal, J.P. & Welter, S. C. (1995) Tolerance to herbivory by a stemboring caterpillar in architecturally distinct maizes and wild relatives. *Oecologia*, **102**, 146–155.

Schemske, D.W. (1984) Population structure and local selection in *Impatiens pallida* (Balsaminaceae), a selfing annual. *Evolution*, **38**, 817-832.

Schmitt, J., Ehrhardt, D. & Swartz, D. (1985) Differential dispersal of self-fertilized and outcrossed progeny in jewelweed (*Impatiens capensis*). *American Naturalist*, **126**, 570–575.

Schmitt, J., Eccleston, J. & Ehrhardt, D. W. (1987) Density-dependent flowering phenology, outcrossing, and reproduction in Impatiens capensis. *Oecologia*, **72**, 341–347.

Steets, J. A. & Ashman, T. L. (2004) Herbivory alters the expression of a mixed-mating system. *American Journal of Botany*, **91**, 1046–1051.

Steets, J. A. & Ashman, T. L. (2010) Maternal effects of herbivory in *Impatiens capensis*. *International Journal of Plant Science*, **171**, 509–518.

Steets, J.A., Salla, R. & Ashman, T.L. (2006) Herbivory and competition interact to affect reproductive traits and mating system expression in Impatiens capensis. *American Naturalist*, **167**, 591–600.

Stinchcombe, J. R. & Rausher. M. D. (2001) Diffuse selection on resistance to deer herbivory in the ivyleaf morning glory, *Ipomoea hederacea*. *American Naturalist*, **158**, 376-388.

Strauss, S.Y. & Agrawal, A.A. (1999) The ecology and evolution of plant tolerance to herbivory. *Trends in Ecology and Evolution*, **14**, 179–185.

Strauss, S.Y., Sahli, H., & Conner, J.K. (2005) Toward a more trait-centered approach to diffuse (co)evolution. *New Phytologist*, **165**, 81-89.

Tiffin, P. (2000) Mechanisms of tolerance to herbivore damage: what do we know? *Evolutionary Ecology*, **14**, 523–536.

Vourc'h, G., Martin, J., Duncan, P., Escarré, J. & Clausen, T.P. (2001) Defensive adaptations of *Thuja plicata* to ungulate browsing: a comparative study between mainland and island populations. *Oecologia*, **126**, 84–93.

Waller, D. M. (1984) Differences in fitness between seedlings derived from cleistogamous and chasmogamous flowers in *Impatiens capensis*. *Evolution*, **38**, 427–440.

Williams, C.E ., Mosbacher, E. V. & Moriarity, W. J. (2000) Use of turtlehead (*Chelone glabra* L.) and other herbaceous plants to assess intensity of white-tailed deer browsing on Allegheny Plateau riparian forests, USA. *Biological Conservation*, **92**, 207–215.

Wulff, R.D. (1986) Seed size variation in *Desmodium paniculatum*: I. factors affecting seed size. *Journal of Ecology*, **74**, 87–97.

CHAPTER 2

MAPPING WHERE ECOLOGISTS WORK: BIASES IN THE GLOBAL DISTRIBUTION OF TERRESTRIAL ECOLOGICAL OBSERVATIONS

Abstract

Although ecological observations and theories are fundamentally shaped by geographical context, their global distribution has never been analyzed. Here we document the global distribution and context (protected status, biome, anthrome, and NPP) of terrestrial study sites reported in recent publications (June 2004-2009; N = 2,573) of ten highly cited ecology journals. We find evidence of a number of geographical biases, including the overrepresentation of protected areas, temperate deciduous woodlands, and wealthy countries. Even within densely settled or agricultural regions, ecologists tend to study “natural” fragments: few explicitly study ecological processes in the surrounding matrix. Such biases in trend-setting journals may limit the scalability of ecological theory and hinder conservation efforts in the 75% of the world where humans live and work.

Introduction

The geographical context of field study sites greatly influences the ecological patterns, processes and dynamics observed in them. For this reason, the disciplines of ecology and conservation biology have been criticized for disproportionately conducting field observations in temperate zones (Schoener 1983, Platnick 1991, Collen *et al.* 2008), biodiversity hotspots (Metrick and Weitzman 1994, Kier *et al.* 2005) and unpopulated areas (Botkin 1992, Collins *et al.* 2000). And though ecologists increasingly recognize the importance of urban ecology and "novel ecosystems" (Botkin and Beveridge 1997, Hobbs *et al.* 2006), ecological studies of urban and suburban areas represent just 0.4-6.0% of the ecological literature (Collins *et al.* 2000, Miller and Hobbs 2002). In contrast, landscapes transformed by agriculture and human settlements cover roughly 75% of Earth's ice-free land and incorporate nearly 90% of terrestrial net primary productivity (Ellis and Ramankutty 2008).

While past critiques of the global distribution of field sites have been based on intimate knowledge of the discipline, few have been backed with quantitative assessment. There are three reasons why such quantification matters. First, since ecological field studies are costly in time and resources, they will always be in limited supply; the geographical distribution of this relatively small set of study sites can therefore dramatically shape conclusions reached by ecological theorists. Quantifying that distribution would enable those working to synthesize ecological knowledge across study sites to account for uneven sampling across geographies. Second, ecological knowledge is often used to prioritize conservation projects; it is therefore critical to know which biomes, regions, and landscapes remain understudied and undervalued. For example, the indicator framework of the Convention on Biological Diversity was recently critiqued for incorporating a disproportionate amount of data from Europe and North America (Butchart *et al.* 2010, Pereira *et al.* 2010). There is also a complex relationship between "conservation attention" and the accumulation of ecological knowledge: better or longer protected sites are often more intensively studied, leaving open the question of whether protection follows study or vice versa (Ahrends *et al.* 2011). Third, the geographical distribution of study sites is telling of the disciplinary norms of ecology: the selection of field sites for study by ecologists is influenced by a wide array of physical, financial, and institutional constraints, as well as the discipline's philosophical underpinnings, values, and history (Evans and Foster

2011). With these three considerations in mind, we set out to analyze the global distribution and environmental context of terrestrial field studies published in ten highly cited ecology journals over the past five years.

Methods

We reviewed the methods sections of all papers published between June 2004-2009 in ten journals with an ISI Web of Knowledge 2009 Journal Citation Report 5-year impact factor ≥4.5 and in which >30% of published articles are ecological field studies (N=8,040, Journals: *American Naturalist, Conservation Biology, Ecological Applications, Ecological Monographs, Ecology, Ecology Letters, Global Change Biology, Journal of Animal Ecology, Journal of Applied Ecology, Journal of Ecology*). By selecting frequently cited journals, and by individually reviewing each article rather than relying on keyword searches, we were able to capture a comprehensive snapshot of the range of trendsetting research.

We analyzed the geographical distribution and environmental context of all terrestrial field sites reported in these journals (N=2,573) using two meta-knowledge methods: content analysis and zonal statistics in Geographic Information System (GIS). We defined terrestrial field sites as experimental or observational studies located outdoors, exclusive of laboratory experiments, models, or studies of water bodies. In order to avoid double counting, we included synthetic studies of original data but not literature reviews or meta-analyses of previously published data.

We first did a content analysis of the methods sections in which we used all information contained in authors' site descriptions to categorize the site as "protected," "densely settled," or "agriculture / rangeland." If a site description included a field station name or geographical coordinates we then corroborated our categorization with Google Earth (Google Inc.) and the UN World Database on Protected Areas (UN WDPA 2010). We defined "protected" as a site under one of the six IUCN Protected Area Management Categories (*sensu* Jenkins and Joppa 2009). We categorized sites described as urban, peri-urban, city, suburban, village, or exurban as "densely settled," and descriptions of active or fallow crop or rangelands as "agriculture / rangeland." We categorized a site as "unspecified" if it we were unable to assign a protection status based on the descriptive or geographical information provided by authors and it was definitively not densely settled or agriculture / rangeland.

Our second analysis investigated the global geographic context of studies. We entered the locations of study sites for all 1,330 articles that reported geographical coordinates or the names of georeferenced field stations into a GIS. When a publication referenced multiple sites we treated each site as independent (N=1,476 sites). We determined the global environmental context of each site using zonal statistics in GIS using spatially explicit global data on biomes (potential vegetation, Ramankutty and Foley 1999), anthromes (anthropogenic biomes, Ellis *et al.* 2010), net primary productivity (potential NPP, Haberl *et al.* 2007), political borders, and gross national income (binned decile of GNI, World Bank 2010).

We then compared the site distributions generated from the first and second analyses (observed distributions) with the expected distributions given two hypothetical scenarios: (1) an even distribution of study sites across global ice-free terrestrial area, and (2) an equal number of study sites in each geographical category (e.g. the same number of studies are conducted in each biome). Although these hypothetical distributions are likely unachievable and perhaps undesirable, they are useful in describing the relative study effort in each geographical context.

To test for significant differences between these observed and expected distributions, we calculated chi-square values in JMP 8.0 (SAS Institute Inc., Cary, NC, USA).

Finally, in order to visualize the global distribution of georeferenced field sites, we fitted a kernel density function to point locations, indicating the number of studies expected within a given 100 km x 100 km area (approximately 1 geographic degree), smoothed to a search radius of 500 km (approximately 10 geographic degrees) using a quadratic kernel function (Silverman 1986).

Results

Site distribution by protected status

Although less than 13% of the earth's ice-free land falls under some form of legal protection (Jenkins and Joppa 2009), over 63% of study sites we reviewed were situated in a protected area—significantly more than would be expected by their global extent (χ^2=5066.9, P<0.0001, Figure 3). Meanwhile, only 12.5% of sites were described as agricultural or rangeland areas, many fewer than expected by global extent (χ^2=485.3, P<0.0001). Similarly, many fewer sites were described as densely settled areas (3.9%) than expected by global extent of this type (χ^2=34.7, P<0.0001). There were 774 "unspecified" sites which, while definitively not agriculture /rangeland or densely settled sites, were not sufficiently described and did not include enough geographical information to allow us to determine their protected statuses. It is likely that some of these sites, the majority of which were in forest settings, were also protected, suggesting that 63-84% of study sites were located in protected areas.

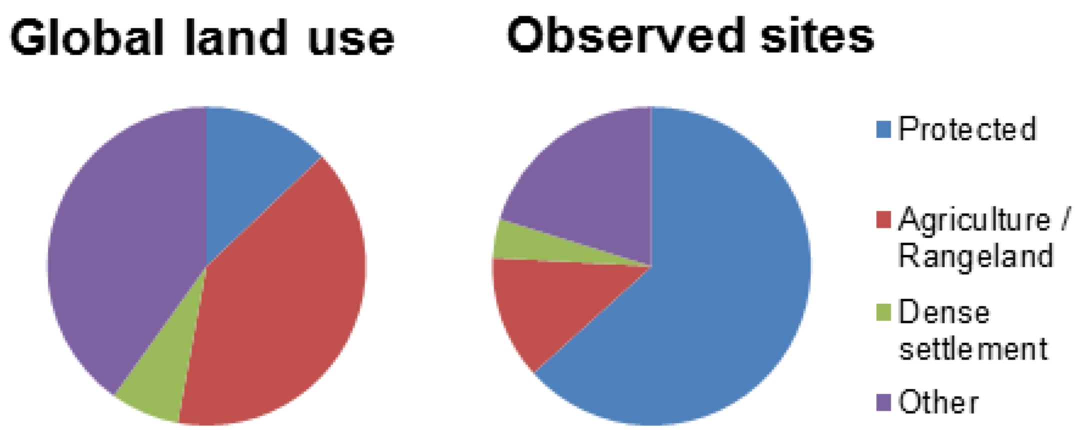


Figure 3. The percentage of global ice-free terrestrial area in each anthrome category (left) compared to the percentage of ecological sites situated in each anthrome category (N=2573, right). On right, "other" refers to sites that were not densely settled or agriculture /rangeland but which did not contain enough information to assign a protected status. Estimate of protected sites is therefore conservative.

Ecological Monographs published the highest percentage of studies conducted in protected areas (87-93%), followed by *Ecology* (72-93%) and *Ecology Letters* (70-87%). *Journal of Applied Ecology* published the highest percentage of studies conducted in agriculture / rangeland (41%), followed by *Conservation Biology* (16%) and *Ecological Applications* (16%). *Ecological Applications* published the highest percentage of studies conducted in densely settled areas (10%), followed by *Conservation Biology* (9%) and *Journal of Applied Ecology* (7%).

Site distribution by biome and NPP

Analysis of the georeferenced dataset revealed that field sites were situated in temperate deciduous woodlands over four times as frequently as expected by global extent of this biome (Figures 4, 5). Tropical deciduous woodland was the least frequently studied biome relative to global area (1.7% of sites), while the desert/barren biome was the most understudied (2.8% of sites, 12.4% of global area). Savanna, open shrubland, and deserts were also significantly understudied by area (Figures 4, 5).

Comparing the observed study distribution to an expected distribution with an equal number of studies conducted in each biome, regardless of global extent, temperate deciduous woodlands, tropical evergreen woodlands, and mixed woodlands were studied approximately twice as frequently as would be expected, while tundra and deserts were among the most understudied biomes (Figures 4, 5). Furthermore, most studies were conducted in high-productivity sites: approximately 65% of sites fell within the top five deciles of NPP.

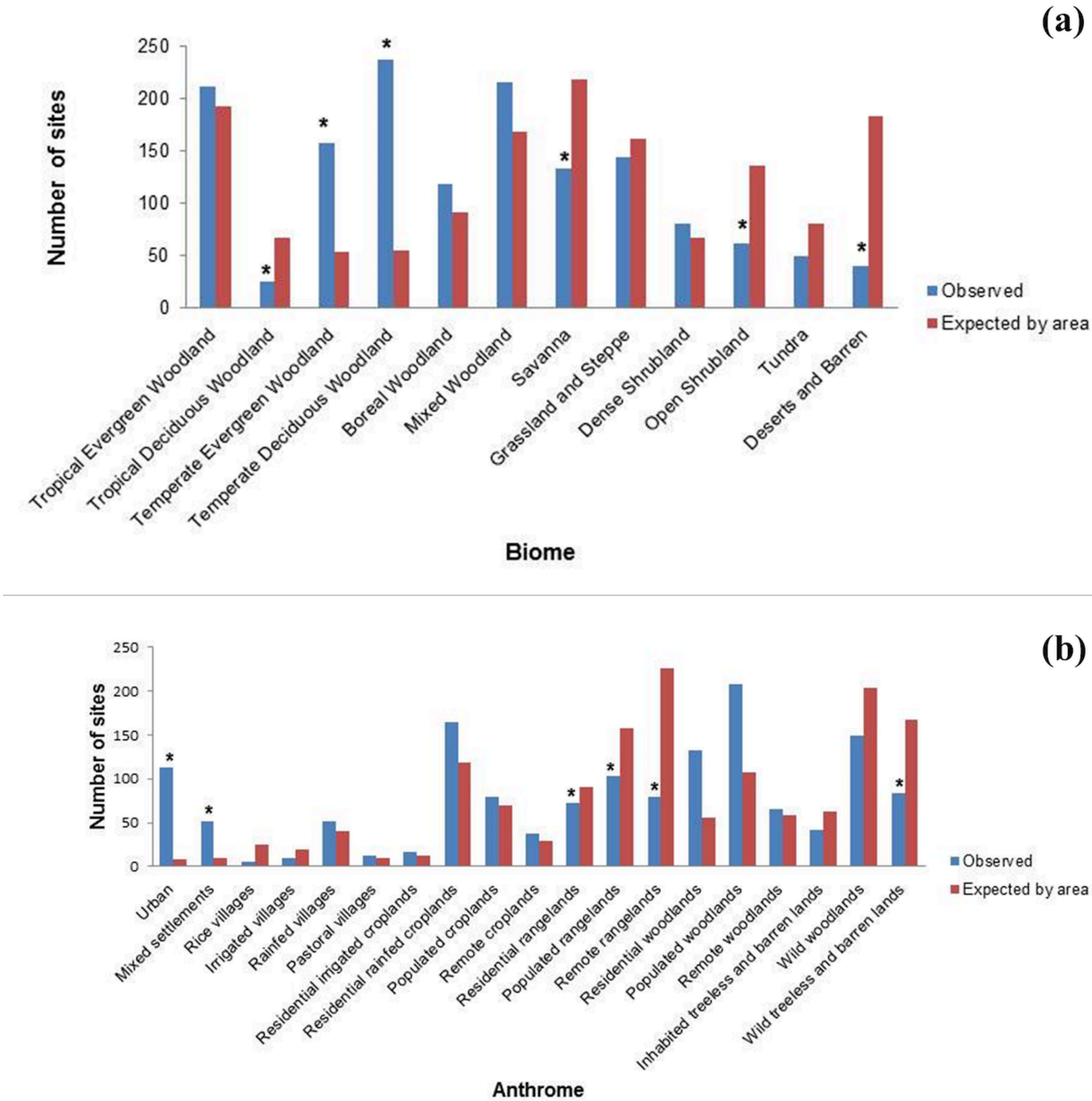


Figure 4. Number of observed ecological field sites (blue) compared to the number of expected field sites given an even distribution across global area (red) by (*a*) biome and (*b*) anthrome (N=1476). Significant difference between distributions indicated by (*) (chi-square test, $P \leq 0.05$). See Tables S3, S4 for exact values.

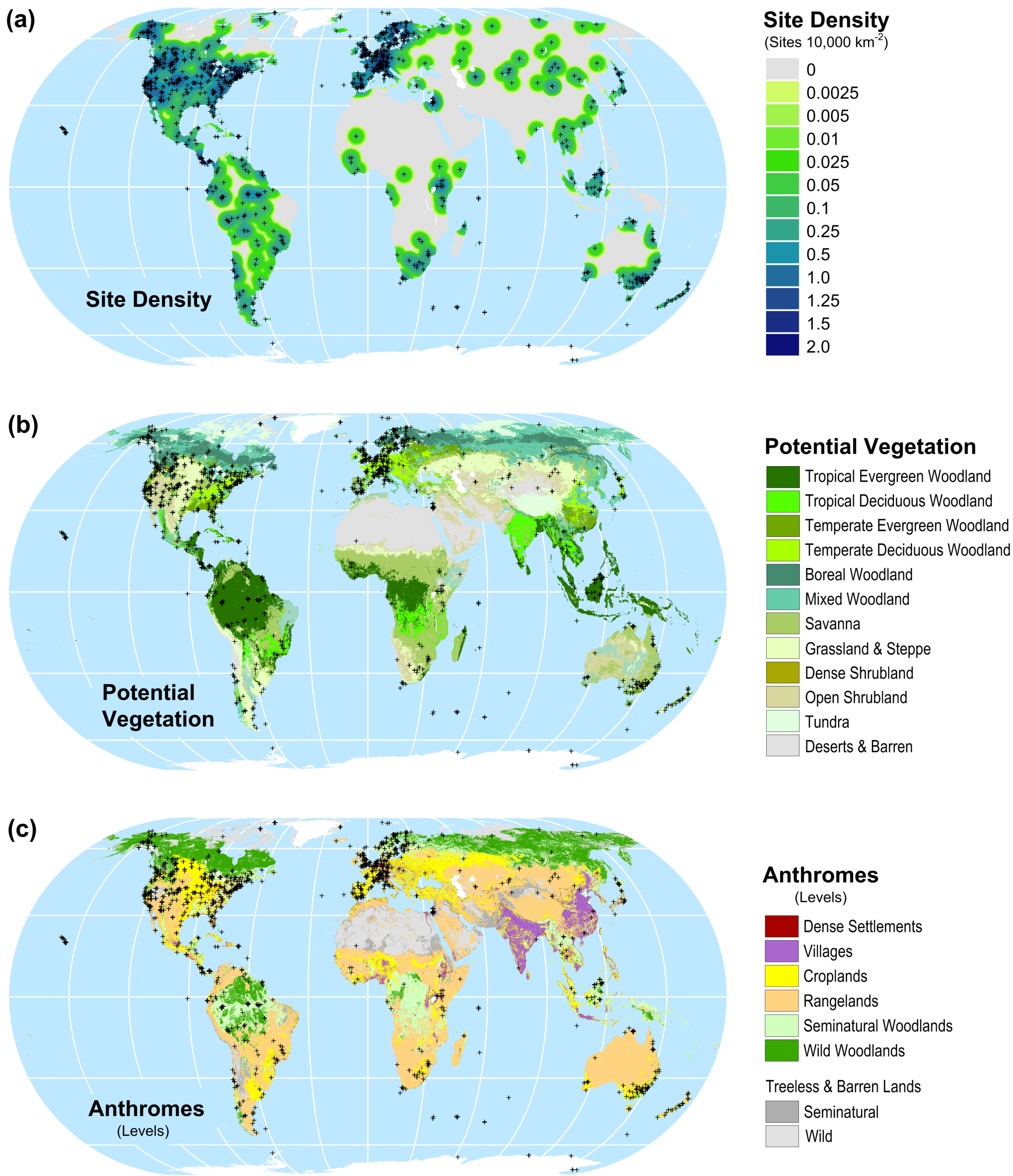


Figure 5. Maps of (*a*) the global distribution of ecological field sites (kernel densities), (*b*) study site position (crosses) overlaid on the distribution of potential vegetation biomes (Ramankutty and Foley 1999), and (*c*) study site position (crosses) overlaid on the distribution of anthromes (Ellis et al. 2010). All maps in Eckert IV Equal Area projection.

Site distribution by anthrome

Anthromes represent the globally significant ecological patterns created by sustained direct human interactions with ecosystems (Ellis and Ramankutty 2008). By comparing site distributions with those expected by anthrome global extents, we found that the urban anthromes were sampled ~14x more frequently than expected. Mixed settlements, populated rangelands, and remote rangelands were also overrepresented relative to their global area, while residential rangelands and wild treeless and barren lands were underrepresented (Figures 4, 5). While these results may seem to contradict the results of the content analysis, when we integrate data from both analyses we find that only 19% of studies categorized as dense settlements by geographical coordinates were actually described by authors as dense settlements; 45% of these sites were described as protected; 16% were described as cropland or rangeland; and 20% were described as forest or open lands with unverifiable protected status.

Site distribution by country

Studies with published geographical coordinates were conducted in 73 countries (Tables S7, S8), nine of which contributed significantly more sites than expected by their ice-free land areas: Greenland (1085x), Costa Rica (49x), Switzerland (47x), Israel (43x), Panama (33x), the UK (20x), Sweden (12x), Germany (10x), and the USA (5x). The Middle East was the most significantly understudied region based on land area by a factor of 8.3, followed by Africa, Asia, and South America. Central America was the most overstudied by a factor of 8, followed by Europe and North America. Unsurprisingly, countries with the lowest gross national income

(GNI) were underrepresented, whereas countries with the highest GNI were overrepresented. Approximately 90% of studies were conducted in countries within the 70-100th percentiles GNI; 41% were conducted in the five countries with the highest GNIs: USA, Japan, China, Germany, and France.

Discussion

Our results reveal multiple biases in the geographical distribution of terrestrial study sites. Most dramatically, ecologists overselected protected areas, temperate deciduous woodlands, and wealthy countries. Despite the indication of the geospatial analysis that many sites were located in urban areas, content analysis revealed that many of these were protected fragments situated in densely settled zones—in other words, many of these studies were not conducted for the explicit purpose of understanding ecology of densely settled places. Taken together, these results lead us to a number of recommendations on how funding agencies, policy-makers, publishers, and researchers could help advance ecological research in currently understudied areas (Panel 1).

Systematic regularities within a discipline can signal ghost theories: unspoken shared assumptions that shape research trajectories (Smail 2008). Within ecology, the overwhelming bias toward the study of certain sites constitutes one such pattern. In choosing study sites, ecologists are influenced by cultural precedents as well as institutional pressures. During the past 150 years, the majority of ecologists have assumed that (seemingly) unpeopled environments better represent ecological and evolutionary processes, and are therefore better objects of study (Worster 1977, Botkin 1992, Pickett and McDonnell 1993, Collins 2000, Kohler 2002). It seems plausible that this position has shaped the global distribution of ecological study sites, as scientific precedent is known to create “microparadigms” around established hubs of knowledge in other contexts (Rzhetsky et al. 2006, Evans and Forster 2011). It is also a well-documented phenomenon that scientific institutions, and therefore scientific outputs, tend to be concentrated in countries with high GNI and long histories of institutionalization (Hefler *et al.* 1999, Thompson *et al.* 1999). Finally, many conservation institutions encourage ecological research on their lands, perpetuating the dominance of certain field sites (for example, 22% of the studies published in Central America were conducted at La Selva Biological Station, CR). Meanwhile it can be extremely time-consuming for an individual to gain permission to work on private property, and the risk that a study site will be "tampered with" is higher, or at least perceived as higher, on such parcels. These factors may lead ecologists to intentionally avoid sites perceivably used by humans—a trend which, as Metzger *et al.* (2010) conclude in their analysis of European LTER site selection, illustrates "a bias for traditional ecological research away from human activity."

Panel 1. Recommendations for promoting ecological research in understudied areas

Funding agencies and policy makers

- Direct funding and institutional support to long-term, multidisciplinary field studies in anthropogenic landscapes, including agricultural and settled ecosystems; long-term studies are especially challenging in dynamic human landscapes
    - Support programs that aim to generalize globally from observations made locally, such as observational networks and multidisciplinary collaborations
    - Support research that investigates "land sharing": the integration of biodiversity conservation and goods production within landscapes (eg Phalan *et al.* 2011)

Publishers

- Incentivize the publication of "applied" ecological research that explicitly includes a human context; overcome the current bias toward rewarding "basic" research conducted in "human-free" settings
- Require contributors to report the geospatial coordinates and landscape contexts of field studies (history of human use, including the status of surrounding ecosystems); only 52% of terrestrial field studies published geographically explicit data

Researchers

- Consider human influence on the ecology of all field sites, including historical land uses and the influence of neighboring systems
- Encourage graduate students to pursue research in intensively used anthromes and "novel ecosystems" (Hobbs *et al.* 2006), particularly international collaborations

- Conduct spatially explicit studies beyond the plot scale; study functions, communities, and populations within “used” and “novel” ecosystems
- Rather than lamenting “human domination” of “pristine ecosystems”, embrace the wide range of possible future ecosystems that human agency enables

While this review clearly does not sample the entire canon of ecological literature, it is an important first step toward applying meta-knowledge techniques to the discipline of ecology (Evans and Foster 2011). By basing our journal selection on citation rate we were able to capture influential, interdisciplinary ecological studies. Such journals are sources of information and inspiration for scholars, journalists, text book editors, and policy makers: it is therefore critically important to understand any underlying biases in “snapshots” of the ecological world. The number of journals included was constrained by the time required to review >8,000 articles, and it is worth noting that all journals were English language journals and that our selection did not include publications with a particular geographic or taxonomic focus. This leaves open the question of how representative our results are of ecology writ large. Based on an informal review of other ecological journals, the very large differences between observed and expected site distributions, and the agreement of our results with past critiques, we would expect broadly similar results if this analysis were extended to other journals. Nevertheless, our results are a snapshot of the most highly cited ecological research rather than a representation of the entirety or even the average of global ecological research.

In these analyses we have considered two null models: an even site distribution across terrestrial area, and an equal distribution of sites across geographical categories (e.g. biomes, NPP). We chose these null models because they are based upon robust global datasets. It is also reasonable to assume that an unbiased distribution would be spatially random. Of course, there are a number of alternative ways to describe distributional bias. For example, are studies evenly distributed by biodiversity level? By provisioning of ecosystem services? Are authors' addresses correlated with the distribution of study sites, or do ecologists tend to study farther away places? Analysis of these alternative null models would require higher-quality global datasets that at present do not exist. Hopefully an increasing enthusiasm for meta-data research, along with collaborations between ecologists and computer programmers, will make such alternative ways of describing failings in global observational processes accessible.

The choice to advocate a more spatially even distribution of field studies raises an important question: What are the advantages of refocusing ecological study on anthropogenic landscapes – especially agricultural lands managed at large spatial scales? The most extensive used lands on Earth are remote rangelands not fully transformed by intensive cultivation, in which many species are capable of sustaining populations. These are clearly worthy of ecological study and conservation, as we know little about the impacts of agricultural processes on resident communities and processes. Even where land use is intensive, anthropogenic landscapes are rarely homogeneous; instead, anthromes are mosaics of used and novel ecosystems (Ellis et al. 2010). While humans have transformed three quarters of Earth's ice-free land into anthromes, only about half of this area is actually in use directly for crops and pastures – the other half comprises remnant, recovering, and less intensively used "novel" ecosystems embedded within used landscapes. At present we tend to fetishize rare and "undisturbed" areas, but in a dynamic human-inhabited world, one of our most pressing questions is how to manage vast areas of novel biotic assemblages (Hobbs *et al.* 2006). Only through comparing the ecological effects of "land sharing" (integrating biodiversity conservation and goods production on the same land) and "land sparing" (separating land for conservation from human use land—i.e. strict protection) can we decide how best to allocate limited conservation resources (Phalan *et al.* 2011). The ten journals considered here tend to oversample the ecology of "land sparing" at the expense of "land sharing." Large scale corn or wheat fields are not all identical, and should be of interest to ecologists. Remarkably, our study suggests that many ecologists actually *are* studying the ecology of intensively used anthropogenic landscapes, with the proviso that they are intentionally choosing the "least disturbed" or "most protected" areas within such geographic contexts for purposes other than understanding anthropogenic ecosystems.

The paucity of ecological field sites under explicit human use raises a number of concerns. First, it is an unresolved philosophical question whether we should discount human activity as external to ecosystems. If we recognize human activity as an integral force in the biosphere, then clearly it should fall within the purview of ecology. While ecologists are increasingly addressing this knowledge gap through experimental design (McDonnell and Pickett 1990, Fetridge *et al.* 2008, Pavao-Zuckerman and Byrne 2009), and while efforts such as urban long-term ecological research programs (LTERs) have made great strides in considering humans as integral organisms of ecosystems (Pickett *et al.* 1997, Grimm *et al.* 2000), our data suggest that human use sites have yet to be fully incorporated into at least ten highly cited ecology journals. It also remains unclear whether ecological theory developed from observations in protected areas is extensible to other land-use categories or whether new theory must be developed for these areas (Collins 2000, Pickett *et al.* 2008). And even if we maintain a distinction between natural and human activity, confining ecology to the non-human world sharply curtails its global relevance, as there are few, if any, places on earth that have not been impacted by human activity (Redman 1999, Sanderson *et al.* 2002, Ellis and Ramankutty 2008).

Inferences about global ecology that are based upon the current body of ecological literature are by default based upon a small sampling of the actual spectrum of global ecosystems. A narrow geographical distribution of study sites has certainly shaped scientific consensus in other field-based disciplines; for example, while >90% of geologists with southern hemisphere experience supported plate tectonic theory in the 1960s, only 48% of those with northern hemisphere experience did (Solomon 1992). Arguably, the geographical context of ecological study sites affects the content of ecology in similar ways.

But perhaps the most problematic aspect of the current site distribution is that the underrepresentation of lived-in landscapes in the mainstream ecological literature leaves us with little robust data about ecological relationships in our immediate habitat, the 75% of the world most influenced by our actions. This lack of ecological work in human-use areas is untenable: while global protected area has increased significantly, biodiversity continues to decline (Rodrigues *et al*. 2004, Ceballos 2007, Wiersma and Nudds 2009, Butchart *et al.* 2010, CBD 2010). If we recognize humans as embedded within ecosystems, there is no reason to limit the scope of ecology and conservation to the 13% of the globe that is protected. To do so is to misrepresent our world.

REFERENCES

Ahrends A, Burgess ND, Gereau R, *et al.* 2011. Funding begets biodiversity. *Divers Distrib* **17**:191–200.

Botkin DB. 1992. Discordant harmonies: a new ecology for the 21st century Oxford, UK: Oxford University Press.

Botkin DB and Beveridge CE. 1997. Cities as environments. *Urban Ecosys* **1**:3–19.

Butchart SHM, Walpole M, Collen B, *et al.* 2010. Global biodiversity: indicators of recent declines. *Science* **328**:1164–1168.

Convention on Biological Diversity. 2010. *Global Biodiversity Outlook 3*.

Ceballos G. 2007. Conservation priorities for mammals in megadiverse Mexico: the efficiency of reserve networks. *Ecol Appl* **17**:569–578.

Collen B, Ram M, Zamin T, and McRae L. 2008. The tropical biodiversity data gap: addressing disparity in global monitoring. *Trop Conserv Sci* **1**: 75–88.

Collins JP, Kinzig A, Grimm NB, *et al.* 2000. A new urban ecology: modeling human communities as integral parts of ecosystems poses special problems for the development and testing of ecological theory. *Am Sci* **88**:416–426.

Ellis EC and Ramankutty N. 2008. Putting people in the map: anthropogenic biomes of the world. *Front Ecol Environ* **6**:439–447.

Ellis EC, Goldewijk KK, Siebert S, *et al.* 2010. Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecol Biogeogr* **19**:589–606.

Evans JE and Foster JG. 2011.Metaknowledge. *Science* **331**:721–725.

Fetridge ED, Ascher JS, and Langellotto GA. 2008. The bee fauna of residential gardens in a suburb of New York City (Hymenoptera: Apoidea). *Ann Entomol Soc Am* **101**:1067–1077.

Grimm NB, Grove JM, Pickett STA, and Redman CL. 2000. Integrated approaches to long–term studies of urban ecological systems. *Bioscience* **50**:571–584.

Haberl K, Erb H, Krausmann F, *et al.* 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. *Proc Natl Acad Sci USA* **104**:12942–12947.

Hefler L, Tempfer C, and Kainz C. 1999. Geography of biomedical publications in the European Union, 1990–1998. *Lancet* **353**:1856.

Hobbs RJ, Arico S, Aronson J, *et al*. 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecol Biogeogr* **15**:1–7.

Jenkins C and Joppa L. 2009. Expansion of the global terrestrial protected area system. *Biol Conserv* **142**:2166–2174.

Kier G, Mutke J, Dinerstein E, *et al.* 2005. Global patterns of plant diversity and floristic knowledge. *J Biogeogr* **32**:1107–1116.

Kohler RE. 2002. Landscapes and labscapes: exploring the lab–field border in biology. Chicago, IL: University of Chicago Press.

McDonnell MJ and Pickett STA. 1990. Ecosystem structure and function along urban–rural gradients: an unexploited opportunity for ecology. *Ecology* **71**:1232–1237.

Metrick A and Weitzman ML. 1994. Patterns of behavior in biodiversity preservation: policy research working paper 1358. NYC, NY: World Bank Policy Research Department.

Metzger MJ, Bunce RGH, van Eupen M, and Mirtl M. 2010. An assessment of long term research activities across European socio–ecological gradients. *J Enviorn Manage* **91**:1357–1365.

Miller JR and Hobbs RJ. 2002. Conservation where people live and work. *Conserv Biol* **16**:330–-337.

Pavao-Zuckerman MA and Byrne LB. 2009. Scratching the surface and digging deeper: exploring ecological theories in urban soils. *Urban Ecosyst* **12**:9–20.

Pereira HM, Belnap J, Bummitt JN, *et al*. 2010. Global biodiversity monitoring. *Front Ecol Environ* **8**:459–460.

Phalan B, Onial M, Balmford A, and Green RE. 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science* **333**: 1289–1291.

Pickett STA, Cadenasso ML, Grove JM, *et al.* 2008. Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore ecosystem study. *Bioscience* **58**:139–150.

Pickett STA and McDonnell MJ. 1993. Humans as components of ecosystems: a synthesis. Pages 310–316 in McDonnell MJ and Pickett STA (eds.). Humans as components of ecosystems: the ecology of subtle human effects and populated areas. NYC, NY: Springer–Verlag.

Pickett STA, Burch WR, Dalton SE, and Foresman TW. 1997. Integrated urban ecosystem research. *Urban ecosyst* **1**:183–184.

Platnick NI. 1991. Patterns of biodiversity: tropical vs. temperate. *J Nat Hist* **25**:1083–1088.

Ramankutty N and Foley JA. 1999. Estimating historical changes in global land cover: croplands from 1700 to 1992. *Global Biogeochem Cy* **13**:997–1027.

Redman CL. 1999. Human impact on ancient environments. Tuscon, AZ: University of Arizona Press.

Rodrigues ASL, Andelman SJ, Bakaar MI, *et al.* 2004. Effectiveness of the global protected area network in representing species diversity. *Nature* **428**:640–643.

Rzhetsky A, Iossifov I, Loh JM, and White KP. 2006. Microparadigms: Chains of collective reasoning in publications about molecular interactions. *Proc Natl Acad Sci USA* **103**:4940–4945.

Sanderson EW, Redford KH, Vedder A, *et al.* 2002. The human footprint and the last of the wild. *Bioscience* **52:**891–904.

Schoener TW. 1983. Field experiments on interspecific competition. *Am Nat* **122**:240–285.

Silverman BW. 1986. Density Estimation for Statistics and Data Analysis. NYC, NY: Chapman and Hall. p. 76 eq. 4.5.

Smail DL. 2008. On Deep History and the Brain. Berkley, CA: University of California Press.

Solomon M. 1992. Scientific rationality and human reasoning. *Philos Sci* **59**:439–455.

Thompson DF. 1999. Geography of U.S. biomedical publications, 1990 to 1997. *N Engl J Med* **340**:817–818.

UN World Database on Protected Areas. http://www.wdpa.org

Wiersma YF and Nudds TD. 2009. Efficiency and effectiveness in representative reserve design in Canada: the contribution of existing protected areas. *Biol Conserv* **142**:1639–1646.

World Bank *GNI ranking, Atlas method*. http://siteresources.worldbank.org/DATASTATISTICS/Resources/GNI.pdf

Worster D. 1977. Nature's economy: a history of ecological ideas. Cambridge, UK: Cambridge University Press.

CHAPTER 3

THE LONG HISTORY OF ECOLOGICAL RESTORATION

"The next century will, I believe, be the era of restoration in ecology."
-E.O. Wilson, *The Diversity of Life* (New York: W. W. Norton & Company, 1992), 340.

I grew up on the Blackstone River, the birthplace of America's industrial revolution. Samuel Slater opened the first water-powered cotton mill in North America on the Blackstone in 1793. Since then, the goods produced on the Blackstone's banks have ranged from textiles to barbed wire to space suits to Mr. Potato Heads. In 1990, when I was six, the U.S. Environmental Protection Agency (EPA) named the Blackstone the most polluted river in the United States.[1]

The story of the Blackstone could end there, as many of our environmental narratives do, with the implication that environmental decline is an inevitable step in industrialization and modernization. But in 2002, the EPA decided to include the Blackstone River in its new Urban Rivers Restoration Initiative. In conjunction with the EPA, a coalition of state agencies, federal agencies, and local steering committees dedicated $2.05 million to restoring the "ecological connection" between the Blackstone watershed and its outlet, the Narragansett Bay. Toward this end, they constructed ladders and channels to allow migrating fish to bypass dams; they stocked the river with tens of thousands of hatchery-reared shad and herring; they recruited volunteers to dig up non-native plants, like Bittersweet and Japanese Knotweed, that had invaded the

[1] Winthrop Packard, "America's Hardest Working River," *The Technical World Magazine* 12 (1909): 121-130; Worcester Historical Museum, *Landscape of Industry: An Industrial History of*

watershed.[2] In just a few years, Great Blue Heron, Brook Trout, Redfin Pickerel, and other species returned to the watershed. Less trash littered the river's banks. People biked, rollerbladed, and jogged alongside the Blackstone on a new recreational trail.

The Blackstone points to a seemingly new type of environmental narrative – one characterized by restoration, recovery, and maybe even redemption. Today ecological restoration encompasses a wide range of practices and goals. A 2012 document from the International Union for the Conservation of Nature (IUCN) details many examples of ecological restoration, including the reinstatement of fire in Scandinavian parks to increase populations of rare insect species, the extermination of invasive rabbits on Santa Barbara Island, California to maintain viable populations of an endemic plant, and the re-introduction of the Black rhinoceros across southern Africa following the population's decline from hunting.[3] In short, ecological restoration is the practice of acting to establish a particular community of species in a place that is perceived to be damaged. Whether the desired community should be modeled on those that once inhabited an area or on those that would best thrive under future conditions is a matter of ongoing debate.[4]

---

[2] U.S. Army Corps of Engineers, *Blackstone River Watershed Reconnaissance Investigation*, August 1997, available at http://www.epa.gov/region1/superfund/sites/peterson/266279.pdf; John H. Chafee Blackstone River Valley National Heritage Corridor, "New Life for the Blackstone: 30 Years of the Clean Water Act Produce Results," 2002, available at http://www.nps.gov/blac/naturescience/upload/newlifeBlackstone.pdf; Narragansett Bay Estuary Program, "Blackstone River Fisheries Restoration Plan," May 2002, available at http://www.edc.uri.edu/restoration/html/intro/Blackstone%20River%20Fisheries%20Restoration%20Plan.pdf.

[3] Karen Keenleyside et al. *Ecological Restoration for Protected Areas: Principles, Guidelines and Best Practices* (Gland, Switzerland: IUCN, 2012). For a contemporary definition see Society for Restoration Ecology International, Science and Policy Working group, SER International Primer on Ecological Restoration 2004. Accessible at: http://www.cbd.int/doc/meetings/sbstta/sbstta-15/official/sbstta-15-04-en.pdf.

[4] I explore this debate in more detail in later chapters. In 2009, two prominent restoration ecologists, Steven Jackson and Richard Hobbs, summarized why historical baselines were under scrutiny in "Ecological Restoration in the Light of Ecological History," *Science* 325 (2009): 567-

Nevertheless, ecological restoration is currently one of the most widespread land management practices in the world. Billions of dollars are spent each year on restoration projects, which bring together scientists, corporations, governments, and environmental NGOs. In the United States, restoration projects have enjoyed wide support, which is remarkable given the controversy around other environmental proposals such as those to reduce greenhouse gas emissions, and around projects that call for social restoration like reparations for African-American enslavement.[5]

In the following pages I ask how ecological restoration became such a widespread and popular mode of environmental management. Ecologists and natural resources managers often treat restoration as ahistorical. And given the vast and influential scholarship on the history of the American preservation and conservation movements, surprisingly few environmental histories have explored ecological restoration. In *Earth Repair*, a comparative study of nineteenth-century reforestation projects in the Alps and the Rocky Mountains, Marcus Hall roots both restoration and landscape architecture in gardening traditions. In Italy, gardens were formal spaces that included symmetrical plant rows. In America, gardeners preferred "naturalistic" designs. Thus Italian restorationists, building on their cultural model of ecological health, aimed at "returning order to an unkempt garden," whereas American restorationists "simulated samples of untouched

569. See also Emma Marris, *Rambunctious Garden: Saving Nature in a Post-Wild World* (New York: Bloomsbury, 2011); Joy B. Zedler, J. Doherty, and N. A. Miller, "Shifting Restoration Policy to Address Landscape Change, Novel Ecosystems, and Monitoring," *Ecology and Society* 17 (2012): 36.

[5] Storm Cunningham, *The Restoration Economy* (San Francisco: Berrett-Koehler, 2002); E. O. Wilson, *Diversity of Life* (Cambridge: Harvard University Press, 1992), 340; Rebecca Lave, *Fields and Streams: Stream Restoration, Neoliberalism, and the Future of Environmental Science* (Athens: University of Georgia Press, 2012).

nature." Ian Tyrell, moreover, has studied environmental reform movements in California and Australia that worked to "renovate" post-mining landscapes into idealized gardens.[6]

Meanwhile, ecologists have generally framed restoration as a new endeavor, one that began with the establishment of the Society for Ecological Restoration (SER) in 1987, barely the stuff of history. Histories of restoration that do consider earlier decades typically cite Aldo Leopold, former Forest Service employee and author of the classic 1949 collection of essays, *A Sand County Almanac*, as the "father" of restoration ecology. William Jordan III and George Lubick, for example, described the history of ecological restoration as a case of "arrested development" in which Leopold's ideas were lost for half a century – "a lull during which Americans concluded a war, embarked on a cold war, moved to the suburbs, and went shopping" – before they were taken up again by the founders of the SER.[7]

---

[6] Marcus Hall, *Earth Repair: A Transatlantic History of Environmental Restoration* (Charlottesville: University of Virginia Press, 2005), 9-10. Ian Tyrrell, *True Gardens of the Gods: California-Australian Environmental Reform, 1860-1930* (Berkeley: University of California Press, 1999). See also Philip J. Pauly, *Fruits and Plains: The Horticultural Transformation of America* (Cambridge: Harvard University Press, 2007); Marcus Hall, ed. *Restoration and History: The Search for a Usable Environmental Past* (New York: Routledge, 2009); David Lowenthal, "Eden, Earth Day, and Ecology: Landscape Restoration as Metaphor and Mission," *Landscape Research* 38 (2013): 5-31; Helen Anne Curry, "Radiation and Restoration: Or, How Best to Make a Blight-resistant Chestnut Tree," *Environmental History* 19 (2014): 1-22.

[7] William R. Jordan III and George M. Lubick, *Making Nature Whole: A History of Ecological Restoration* (Washington DC: Island Press, 2011), 105. Aldo Leopold, *A Sand County Almanac and Sketches Here and There* (New York: Oxford University Press, 1949). Kevin Dann and Gregg Mitman have noted that "America has continually had to reinvent the business of 'ecological restoration'; seemingly something brand new, it is instead an activity with a history." Kevin Dann and Gregg Mitman, "Essay Review: Exploring the Borders of Environmental History and the History of Ecology," Journal of the History of Biology 30 (1997): 296. For an ecologist's history, see .T.A. Pickett and V. Thomas Parker, "Avoiding the Old Pitfalls: Opportunities in a New Discipline," *Restoration Ecology* 2 (1994): 75-79; William R. Jordan III, *The Sunflower Forest: Ecological Restoration and the New Communion with Nature* (Berkeley: University of California Press, 2003).

Alternatively, I contend that ecological restoration has a long history in the United States that can be traced back at least to the Dust Bowl, if not earlier. I root this narrative in a history of ecological science rather than a history of gardening. I see Leopold and other ecologists as actors in a larger network of people, forces, and objects that contributed to the emergence of scientific conceptions of environmental restoration. And I argue that, like the American preservation and conservation movements, the American restoration movement is best envisioned as a cable of entwined threads; over time, restoration has meant many different things to many different people.[8] I question whether it is possible to consider ecological restoration a unified concept and practice while at the same time appreciating its heterogeneity.

This treatment allows me to ask two other big questions. First, what can restoration tell us about how Americans relate to their past? In the case of the Blackstone: What does it mean to erase evidence of past industrialization in the birthplace of the American Industrial Revolution? Is this a radical critique of past events? A problematic erasure of past injustice? A naïve elision of the cultural context of environments?

Such questions have high stakes in postcolonial landscapes such as the United States. In 1990, the Society for Ecological Restoration defined restoration as "intentionally altering a site to establish a defined, indigenous, historic ecosystem." Many ecologists promoted the restoration

---

[8] Recent literature on the history of endangered species management is also relevant to the history of ecological restoration. See: David Takacs, *The Idea of Biodiversity* (Baltimore: Johns Hopkins University Press, 1996); Jerry C. Towle, Authored Ecosystems: Livingston Stone and the Transformation of California Fisheries," Environmental History 5(1) (2000): 54-74; Christopher J. Manganiello, "From a howling wilderness to howling safaris: Science, policy, and red wolves in the American South," *Journal of the History of Biology* 42 (2009): 325-359. Robert M Wilson, *Seeking Refuge: Birds and Landscapes of the Pacific Flyway* (Seattle: University of Washington, 2010); Irus Braverman, *Zooland: The Institution of Captivity* (Palo Alto: Stanford University Press, 2012); Peter S. Alagona, *After the Grizzly: Endangered Species and the Politics of Place in California* (Berkeley: University of California Press, 2013).

of pre-colonial conditions in North America, considering the year 1492 to be the "baseline" and species that arrived after European colonization to be unnatural. In an article in the journal *Ecological Restoration* titled "Simulated Indigenous Management," ecologists M. Kat Anderson and Michael Barbour argued that the National Park Service should restore "specific Indian-ecosystem associations, such as gathering and management regimes" in national parks once inhabited by Native Americans.[9] But can ecological fieldwork substitute for human lives? Can ecological restoration undo the consequences of genocide, and if it can, will it be an act of radical critique – or of radical denial?

In recent years, some humanists and ecologists have challenged the 1492 baseline. Historical and archeological scholarship has shown that present ecological communities have been shaped by human actions that long pre-date 1492. It is mistaken to think of pre-colonial lands as empty or pristine.[10] Also, many "Anthropocene" scholars have challenged the feasibility of restoring areas to any past state. Atomic waste may persist for tens of thousands of years. Extinction may be permanent. In the end there may be no returning to the past.[11] Thus, in 2002,

---

[9] M. Kat Anderson and Michael Barbour, "Simulated Indigenous Management: A New Model for Ecological Restoration in National Parks," *Ecological Restoration* 21 (2003): 269-277.

[10] See, for example, William Cronon, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," in *Uncommon Ground: Rethinking the Human Place in Nature*, ed. William Cronon (New York; W W. Norton & Co., 1995), 69-90; J. Baird Callicott and Michael P. Nelson, eds., *The Great New Wilderness Debate* (Athens: University of Georgia Press, 1998); Shepard Krech III, *The Ecological Indian: Myth and History* (New York: W. W. Norton and Company, 1999); Mark David Spence, *Dispossessing the Wilderness: Indian Removal and the Making of the National Parks* (New York: Oxford University Press, 2000).

[11] In 2009, two prominent restoration ecologists, Steven Jackson and Richard Hobbs, summarized why historical baselines were under scrutiny in "Ecological Restoration in the Light of Ecological History," *Science* 325 (2009): 567-569. See also Daniel Botkin, *Discordant Harmonies: A New Ecology for the 21st Century* (Oxford: Oxford University Press, 1990); D. Bowman, "The Impact of Aboriginal Landscape Burning on the Australian Biota," *New Phytologist* 140 (1998): 385-410; Paul J. Crutzen, "Geology of Mankind." *Nature* 415 (2002): 23-32; Camille Parmesan and Gary Yohe, "A Globally Coherent Fingerprint of Climate Change

the SER revised its definition of ecological restoration to "assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed," leaving open the question of historical baselines. Since then, ecologists have proposed more than twenty ways to re-orient ecological restoration to the age of the Anthropocene. These proposals have looked both forward and back in time. Proponents of "Pleistocene Re-wilding," for example, have argued for the reintroduction of Pleistocene megafauna – large animals that disappeared some 13,000 years ago – to the Western United States. Thus they mark not European arrival, but the arrival of humans in specific habitats. Meanwhile, proponents of "novel ecosystems" contend that not only should people accept non-historical ecosystems, but they should also design new ecosystems to have desired functions and services. Still others promote "de-extinction," also known as resurrection biology or species revivalism.[12]

Impacts across Natural Systems," *Nature* 421 (2003): 37–42; Will Steffen, Jacques Grinevald, Paul Crutzen, and John McNeill, "The Anthropocene: Conceptual and Historical Perspectives," *Philosophical Transactions of the Royal Society A* 369 (2011): 842-867.

[12] I have reviewed this literature elsewhere. See Laura J. Martin *et al.,* "Conservation Opportunities across the World's Anthromes," *Diversity and Distributions* 20 (2014): 745-755. See also Thomas W. Swetnam, Craig D. Allen, and Julio L. Betancourt, "Applied Historical Ecology: Using the Past to Manage the Future," Ecological Applications 9 (1999): 1189–1206; J. Baird Callicott, "Choosing Appropriate Temporal and Spatial Scales for Ecological Restoration." *Journal of Biosciences* 27 (2002): 410–420; James A. Harris et al., "Ecological Restoration and Global Climate Change," *Restoration Ecology* 14 (2006): 170–176; Stephen T. Jackson and Richard J. Hobbs, "Ecological Restoration in the Light of Ecological History," *Science* 31 (2009): 567-569; Emma Marris, *Rambunctious Garden: Saving Nature in a Post-Wild World* (New York: Bloomsbury, 2011); Mark Davis et al., "Don't Judge Species on their Origins," *Nature* 474 (2012): 153-154; Joy B. Zedler, J. Doherty, and N. A. Miller, "Shifting Restoration Policy to Address Landscape Change, Novel Ecosystems, and Monitoring," *Ecology and Society* 17(2012): 36; Carl Zimmer, "Bringing Them Back to Life," *National Geographic*, April 2013. Available at http://ngm.nationalgeographic.com/2013/04/125-species-revival/zimmer-text; Joanna Radin, "Latent Life: Concepts and Practices of Human Tissue Preservation in the International Biological Program," *Social Studies of Science* 43 (2013): 484-508; Nathaniel Rich, "The Mammoth Cometh," *The New York Times Magazine*, February 27, 2014. Available at http://www.nytimes.com/2014/03/02/magazine/the-mammoth-cometh.html

In analyzing archival and published material, I find that what restorationists were attempting to undo shifted with the political and cultural concerns of the United States. Over the twentieth century, ecological restoration both shaped, and was shaped by, concerns over soil erosion, nuclear war, and non-native species introductions, among other forces. Although ecological restoration and ecological destruction seem to represent opposite processes, they are in fact deeply intertwined.

This contention leads to this project's second broad question: How do scientific ideas and environmental management influence one another? Within the discipline of Environmental History, many have studied the history of material landscapes. A smaller subset has studied the history of ecological ideas. But few have studied the intersection of ideational and material change.[13] This is where the discipline of Science and Technology Studies has much to offer.[14]

---

[13] For a classic exchange on this topic, see Worster (1990) and Cronon (1990). Worster (1990) divided environmental histories into those that analyze material nature, those that analyze political economies, and those that analyze beliefs – and argues that environmental historians should focus on material nature. In response, Cronon (1990), argued that ideas and materials belong to the same histories, that "[h]ow and why people choose to eat what they do depends as much on what they think – about themselves, their relations to each other, their work, their plants and animals, their gods – as on the organisms they actually eat." McEvoy (1986) is often cited as a rare example of a project that simultaneously analyzes ideational and material environmental histories. Donald Worster, "Transformations of the Earth: Toward an Agroecological Perspective in History," *The Journal of American History* 76 (1990): 1087–1106; William Cronon, "Modes of Prophecy and Production: Placing Nature in History," *The Journal of American History* 76 (1990): 1122–1131; Arthur F. McEvoy, *The Fisherman's Problem: Ecology and Law in the California Fisheries, 1850-1980* (Cambridge: Cambridge University Press, 1990).

[14] On the intersection of Environmental History and Science and Technology Studies, see Steven Yearley, "Nature and the Environment in Science and Technology Studies." in *The Handbook of Science and Technology Studies*, Third edition, ed. E. Hackett, O. Amsterdamska, M. Lynch and J. Wajcman (Cambridge: MIT Press, 2008), and Sara Pritchard, Dolly Jørgensen, and Finn Arne Jørgensen, eds., *New Natures: Joining Environmental History with Science and Technology Studies* (Pittsburgh: University of Pittsburgh Press, 2013). For work at this intersection, see Gregg Mitman, *The State of Nature: Ecology, Community, and American Social Thought, 1900-1950* (Chicago: University of Chicago Press, 1992); David E. Nye, *American Technological Sublime* (Cambridge, MA: MIT Press, 1994); Richard White, *The Organic Machine: The*

Environmental historians have convincingly shown that humans and their societies are not the only agents of historical change. In doing so, they have drawn from the ecological sciences. But STS – which has long been concerned with the relationship between scientific knowledge and society, material and ideas – suggests that ecological knowledge is not a stable or objective source.

This dissertation engages historical ontology – the study of how objects like ecosystems, extinct species, and populations come into being. Studies of historical ontology typically contend that what counts as "truth" is contingent on historically specific practices and materials such as laboratory instruments, statistical methods, and classification systems. For example, only with the advent of germ theory did microbes become perceivable objects, objects that were subsequently feared and managed.[15] For the restoration of ecological communities to become a practice, ecological communities had to become a thing.[16]

Remaking of the Columbia River (Hill & Wang, 1995); Mark Fiege, *Irrigated Eden: The Making of an Agricultural Landscape in the American West* (Seattle: University of Washington Press, 1999); Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-field Border in Biology* (Chicago: University of Chicago Press, 2002); Gregg Mitman, Michelle Murphy, and Christopher Sellers, eds., *Landscapes of Exposure: Knowledge and Illness in Modern Environments* (Chicago: University of Chicago Press, 2004); Helen M. Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Harvard University Press, 2005); Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Durham, NC: Duke University Press, 2006); Linda Nash, *Inescapable Ecologies: A History of Environment, Disease, and Knowledge* (Berkeley: University of California Press, 2006); Benjamin R. Cohen, *Notes from the Ground: Science, Soil, and Society in the American Countryside* (New Haven, CT: Yale University Press, 2009); Jeremy Vetter, ed., *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (New Brunswick: Rutgers University Press, 2010); Sara B. Pritchard, *Confluence: The Nature of Technology and the Remaking of the Rhône* (Cambridge, MA: Harvard University Press, 2011); Megan Raby, "Making Biology Tropical: American Science in the Caribbean, 1898-1963." PhD dissertation, University of Wisconsin-Madison, 2012.

[15] On the historical ontology of germs see Nancy Tomes, *The Gospel of Germs: Men, Women, and the Microbe in American Life* (Cambridge: Harvard University Press, 1999). Michelle

The history of ecological restoration reveals an intricate mutual causation between ecological ideas and material changes in landscapes. Over time restorationists have shifted their focus from restoring single species to restoring habitats, assemblages of species, ecosystems, and, more recently, "ecosystem services," like productivity and pollination. Thus in writing this history I focus on how arrangements of specific technologies, discourses, practices, and objects gave rise to particular understandings of biological organization (e.g., species, communities, ecosystems) and the American ecological past. As new ecological understandings came into being, so, too, did systems for managing those new entities.

This history moves quickly across geographies – including the Great Plains, Connecticut lakes, Washington streams, Pacific atolls, and the Florida Everglades – and considers a number of individuals and organizations. The chapters are arranged thematically and ordered by a rough chronology. Their purpose is not to provide an exhaustive history, but to analyze how ecological science has come to shape natural resources management in the United States. Some of the

---

Murphy's *Sick Building Syndrome* extends historical ontology to environmental studies. Murphy presents a history of the heterogeneous practices through which indoor chemical exposures "were granted or not granted existence." Particularly useful to my dissertation is her concept of "regimes of perceptibility." In her case study, she contends that specific arrangements of discourses, objects, practices, and subject positions "made perceptible specific qualities, capacities, and possibilities for buildings and bodies." Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty* (Durham: Duke University Press, 2006), 7, 12. See also: Michel Foucault, *The Archaeology of Knowledge* (New York: Pantheon Books, 1972); Lorraine Daston and Peter Galison, "The Image of Objectivity," *Representations* 40 (1992): 81–128; Bruno Latour, *We Have Never Been Modern* (Cambridge: Harvard University Press, 1993); Ian Hacking, *Historical Ontology* (Cambridge: Harvard University Press, 2004).

[16] For an excellent overview of contemporary community ecology, see Gary G. Mittelbach, *Community Ecology* (New York: Sinauer, 2012). This places my work in dialogue with historians of community ecology Gregg Mitman and Sharon Kingsland. Gregg Mitman, *The State of Nature: Ecology, Community, and American Social Thought, 1900-1950* (Chicago: University of Chicago Press, 1992); Sharon E. Kingsland, *Modeling Nature* (Chicago: University of Chicago Press, 1995), and *The Evolution of American Ecology, 1890-2000* (Baltimore: Johns Hopkins University Press, 2005).

examples of ecological restoration I include are not what we would today recognize as restoration – the introduction of non-native, genetically modified salmon to streams, for example – but at the time they were conceived as restoration projects.

In Chapter 4 I argue that the idea and the practice of ecological restoration emerged from ecologists' efforts to secure permanent study sites in the 1930s. The chapter centers on the history of the Ecological Society of America's "Committee on the Preservation of Natural Conditions for Ecological Study," the precursor of The Nature Conservancy. As the Dust Bowl escalated, and Roosevelt's New Deal reformed federal land management, ecologists recast succession theory, which had been an influential ecological theory within the sciences, as a management tool and nature reserves as areas for experimental restoration. Through exploring the history of a famous restoration project, the University of Wisconsin-Madison Arboretum, and a halted one, the Great Plains National Monument, I further elaborate the network of scientific practices, political ambitions, and federal policies that enabled the rise of ecological restoration.

Chapter 5 addresses developing conceptions of ecological time and their consequences for how ecologists positioned themselves as advisers to land managers in the interwar era. In it I analyze how peat stratigraphy – the identification of fossil pollen in vertical samples from bogs – became the preferred method for reconstructing a site's ecological history. I argue that the Dust Bowl solidified interest in the method, as Americans questioned whether the Midwest was naturally a desert. But by the end of World War II, the sub-discipline found itself with new tools and in a different political climate. In 1946, a group of ecologists working with peat stratigraphy, including G. Evelyn Hutchinson, collaborated with the Atomic Energy Commission (AEC)-funded physicist Willard Libby to develop methods to date biological specimens with carbon-14. Carbon dating increased the credibility of scientists' ecological histories, even as it revised them, and enabled ecologists to reconstruct historical ecological communities – an innovation crucial to future restoration projects.

Focused on the 1940s, Chapter 6 further elaborates the connection between ecological restoration and the AEC. It follows the work of Lauren Donaldson, a fisheries biologist who was contracted by the Manhattan Project in 1943 to study the environmental effects of radioactive effluent. After WWII, when the United States began detonating atomic weapons in the Pacific atolls, Donaldson was put in charge of biological fieldwork there. At the Pacific Proving Grounds, he used radioisotopes from nuclear detonations to follow the movement of minerals among marine organisms. It was a new way of visualizing the connection between organisms and environments, one that was important to the emergence of the ecosystem concept. Donaldson also applied atomic technologies to fish stocking, his original interest, recasting those technologies as tools for restoration: he argued that by irradiating salmon, scientists could breed fish that would survive in degraded environments. By 1980, "Donaldson trout" were farmed across the world. This intersection of ecological, geopolitical, and commercial interests characterized postwar restoration ecology.

In Chapter 7 I explore how ecological fieldwork funded by the AEC in the 1950s intersected with the rhetorical work of G. Evelyn Hutchinson, Eugene Odum, and Tom Odum in replacing the ecological community concept with the ecosystem concept that today dominates restoration discourse. I argue that through atomic fieldwork, ecologists materialized ecosystems as objects of study and concern, facilitating 1960s grassroots environmentalism and restoration ecology – movements of the "Age of Ecology" that are typically contrasted with the "Atomic Age."

In the 1960s, ecologists began studying the reassembly of ecological communities after simulated atomic disasters. In the tradition of succession studies from the 1930s, they studied the re-assembly of communities after a disturbance – but rather than study drought and other "natural disturbances," as they had in the 1930s, they studied "anthropogenic disturbances," including nuclear contamination. In Chapter 8 I consider these experiments, arguing that Cold War narratives about ecological destruction must be considered alongside those about ecological restoration. During this period, the AEC's interests in nuclear waste-containment, ecologists' interests in community metabolism, and the specter of WWIII formed a network of people, forces, and objects that were crucial to the development and popularization of ecological restoration. Importantly to restoration practice today, the Cold War idea of irreversible change made ecosystem *functioning* the target of some restoration, especially when it was difficult or impossible to restore particular assemblages of species.

One of the most prominent changes that occurred in ecological restoration between the 1930s and present was a change in the relationship between the site of ecological "damage" and the site of restoration. The first restoration projects in the United States occurred on sites perceived to be damaged by plowing, drought, or industrialization. But by the 1970s, the concept of compensatory or off-site mitigation has begun to emerge. This dissertation thus concludes with a reflection on the political and material outcomes of the "sacrifice zone/protected zone" duality that today underlies many biodiversity interventions, including wetlands mitigation and carbon off-setting.

It is my hope that reflecting on ecological restoration's history will help twenty-first-century restorationists as they face quite the tangled question: Should restoration look to the past or to the future?

CHAPTER 4

AFTER THE DUST BOWL:

ECOLOGISTS' ROLES IN NATIONAL AND NATURAL RECOVERY

Figure 6. Dust Storm, Baca County, Colorado, c. 1936. Farm Security Administration, LC-DIG-fsa-8b26998, Library of Congress Prints and Photographs Division.

The 1930s opened with dust, drought, and depression, with gray grass that crunched underfoot. Their fields barren, their homes ruined, Iowans, Missourians, Arkansans, Oklahomans, Texans, Nebraskans, and Kansans went west. Drought turned the loamy soil into fine dust, and wind drove that dust into massive clouds, "black blizzards" that rolled as far East as New York City. One evening in 1934, dust fell over Chicago like snow, four pounds for each person in the city. It was a natural and a national disaster.

Americans were left with a question they couldn't shake: What had caused the Dust Bowl? National recovery seemed to hinge on the answer. As the United States experienced one of the largest migrations in its history, some claimed that drought was normal in the Great Plains, that the previous wet years had been an anomalous boon. Others supposed that soil erosion had been caused by new technologies like gasoline-powered tractors and one-way disc plows. Still others blamed farmers for recklessness.

In debating whether the Dust Bowl's causes were climatic, technical, or social, Americans also debated whether the government should respond: Should the Great Plains be permanently abandoned? Should federal officials determine where citizens could and could not farm? Should farmers be compelled to complete agricultural education programs?[17]

Or, as a handful of ecologists began to argue, should Americans work to restore the prairie community?

The Rise of Ecology

The concept of ecology was slow to catch on, and in the United States, some of its earliest adopters were those who went on to theorize ecological restoration. In 1866 the German

---

[17] For cultural histories of this era, see Studs Terkel, *Hard Times: An Oral History of the Great Depression* (New York: Pantheon Books, 1970); Donald Worster, *Dust Bowl: The Southern Plains in the 1930s* (New York: Oxford University Press, 1979); The collection of essays in *Great Plains Quarterly* 6 (1986); James Gregory, *American Exodus: The Dust Bowl Migration and Okie Culture in California* (New York: Oxford University Press, 1989); Jani Scandura, *Down in the Dumps: Place, Modernity, American Depression* (Duke University Press, 2008); Alexander J. Field, *A Great Leap Forward: 1930s Depression and U.S. Economic Growth* (New Haven: Yale University Press, 2011).

zoologist Ernst Haeckel coined the term "ökologie." Reinforcing Darwin's theory of natural selection, published just a few years earlier in *The Origin of Species by Means of Natural Selection* (1859), Haeckel contended that his colleagues, who up until that point had focused on organismal nutrition and reproduction, should turn their attention to the relationship between a species and its environment: "all those complex interrelations referred to by Darwin as the conditions of the struggle for existence."[18] Some thirty years later, American botanists began borrowing the term from German botanical texts that strove to identify the factors that caused different plant species to grow in different places.[19] It was not until 1913 that botanists, zoologists, and geographers came together to organize the British Ecological Society, and in 1915, the Ecological Society of America.[20]

---

[18] A successful neologist, Haeckel was also the inventor of "phylogeny," "word riddle," and "the first world war." Today he has two mountains and an asteroid named after him. An English translation of Haeckel can be found in Robert C. Stauffer, "Haeckel, Darwin, and Ecology," *Quarterly Review of Biology* 32 (1957): 138-414.

[19] On early American ecology and connections to European biology and geography, see Donald Worster, *Nature's Economy: A History of Ecological Ideas* (Cambridge: Cambridge University Press, 1977), Chapters 1-9; Janet Browne, *The Secular Ark: Studies in the History of Biogeography* (New Haven: Yale University Press, 1983); Eugene Cittadino, *Nature as the Laboratory: Darwinian Plant Ecology in the German Empire, 1880-1900* (Cambridge: Cambridge University Press, 1990); Lynn K. Nyhart, *Biology Takes Form: Animal Morphology and the German Universities, 1800-1900* (Chicago: University of Chicago Press, 1995); Malcolm Nicolson, "Humboldtian Plant Geography after Humboldt: The Link to Ecology," *British Journal for the History of Science* 29 (1996): 289-310; Peder Anker, *Imperial Ecology: Environmental Order in the British Empire, 1895-1945* (Cambridge: Harvard University Press, 2002); Aaron Sachs, *The Humboldt Current: Nineteenth Century Exploration and the Roots of American Environmentalism* (New York: Viking, 2006).

[20] On December 28, 1915, in Columbus, Ohio, at the annual meeting of the American Association for the Advancement of Science (AAAS), a group of about fifty botanists and zoologists voted to form the Ecological Society of America (ESA). By 1916, the ESA had recruited over 200 members and had elected Victor Shelford its first president. Other founding members included Henry Cowles, Frederic Clements, W. C. Allee, John William Harshberger, and Charles C. Adams. On the history of ecology between 1890 and World War II, see Howard S. Reed, "A Brief History of Ecological Work in Botany," *Plant World* 8 (1905): 163-208; Barrington Moore, "The Scope of Ecology," *Ecology* 1 (1920): 3-5; Eduard Rubel, "Ecology,

Two of the first American biologists to call themselves ecologists were Henry Chandler Cowles and Frederick Clements. In 1896, while a second-year graduate student at the University of Chicago, Cowles was assigned the book *Plantesamfund* (*Plant Ecology*), published the year prior by Danish botanist Eugenius Warming.[21] The book proved immensely important to how he analyzed plant communities. In *Plantesamfund*, Warming posited that plant communities were dynamic in the short-term, whereas in the long-term they reached "climax communities" that were determined by physiographic factors like humidity, moisture, wind, and soil.[22] His argument engaged a conversation about "succession" that extended back to the mid-nineteenth century. Charles Darwin had supposed that communities of plants, animals, and humans progressed slowly through predictable stages of development. Just as soil had been deposited in successive layers, Alexander von Humboldt wrote in 1849, so too did communities pass through different stages of civilization: plant communities succeeded one another from lichens to grasses to forest, human communities from nomads to farmers to urbanites.[23]

Plant Geography, and Geobotany; Their History and Aim," Botanical Gazette 84 (1927): 428-429; Victor E. Shelford, "The Organization of the Ecological Society of America 1914-19," *Ecology* 19 (1938): 164-166; Arthur G Tansley, "The Early History of Modern Plant Ecology in Britain," *Journal of Ecology* 35 (1947): 130-137; Norman Taylor, "The Beginnings of Ecology," *Ecology* 19 (1938): 352; Worster, *Nature's Economy*, chapters 10-11; Frank N. Edgerton, ed., *History of American Ecology* (New York: Arno Press, 1977); Tobey, *Saving the Prairies*; Robert W. Croker, *Pioneer Ecologist: The Life and Work of Victor Ernest Shelford, 1877–1968* (Washington D.C.: Smithsonian Institution Press, 1991); Gregg Mitman, *The State of Nature: Ecology, Community, and American Social Thought, 1900-1950* (Chicago: University of Chicago Press, 1992); Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology* (Chicago: University of Chicago Press, 2002); Sharon Kingsland, *The Evolution of American Ecology*, chapters 1-5.

[21] Victor M. Cassidy, *Henry Chandler Cowles: Pioneer Ecologist* (Chicago: Kedzie Sigel Press, 2007).

[22] Warming's 1895 book was translated into other languages and appeared in English as *Oecology of Plants: An Introduction to the Study of Plant Communities* (Oxford: Clarendon Press, 1909).

[23] See Joe D. Burchfield. "Darwin and the Dilemma of Geological Time," *Isis* 65 (1974): 300-

Intrigued by Warming's work, Cowles decided to use the idea of "climax communities" to frame his graduate fieldwork on the flora of Lake Michigan's southern shore. While exploring the Indiana Dunes the previous summer, Cowles had observed that the dunes closest to the beach supported only grasses, whereas cottonwood, juniper, and pine trees thrived further from the lake. Using Warming's framework, Cowles identified the cottonwood-juniper-pine community as a climax community and the grass community closest to the lake as a disturbed community. He hypothesized that the composition of the climax community was determined by climate, whereas the composition of the grass community was determined by "physiographic disturbance" – in this case, blowing sand.[24]

Like Cowles, Frederic Clements discovered the concept of plant succession by reading German botanical texts. While conducting fieldwork in the Colorado foothills, Clements read *Phytogeography* (1898) by Oscar Drude, a botanist at the Dresden Botanical Garden. Summarizing the physiographical work of Alexander von Humboldt and other German naturalists, Drude wrote that the development of plant communities was determined by geological structures and by regional climate, both of which changed gradually over time. As plants were adapted to their environments, it stood to reason that plant communities had also replaced one another gradually over time.[25]

321; Martin J. S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists* (Chicago: University of Chicago Press, 1988); Malcolm Nicolson, "Humboldtian Plant Geography after Humboldt: The Link to Ecology," *British Journal for the History of Science* 29 (1996): 289-310; Aaron Sachs, *The Humboldt Current: Nineteenth Century Exploration and the Roots of American Environmentalism* (New York: Viking, 2006).

[24] Henry Chandler Cowles, "The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan," *Botanical Gazette* 27 (1899): 95-117, 167-202.

[25] Ronald Tobey traces this connection in *Saving the Prairies: The Life Cycle of the Founding School of American Plant Ecology, 1895-1955* (Berkeley: University of California Press, 1981),

Cowles's innovation was a space-for-time substitution. Just as modern geologists could interpret the series of physical events in the layers of a sedimentary rock, Cowles contended, ecologists could reconstruct the progression of biotic communities through time by studying the series of plant communities at a site like the Indiana Dunes. As Cowles walked from the forest to the shore of Lake Michigan, he imagined he walked through time. Clements, meanwhile, focused on the promise that succession theory held for uncovering the factors that determined the distribution of plant species. Clements conceptualized the plant community as a "complex organism with structures and with functions susceptible of exact methods of study." He argued that the adaptation of this "organism" to its environment could be studied by characterizing the plant communities that grew along a gradient of physical factors.[26]

Thus in the two decades preceding the Dust Bowl, American ecologists sought to locate and study landscapes that exhibited gradients of physical factors. Cowles's analyses depended on the comparison between the wind-swept shore and the seemingly stable forest. Clements worked in the scree slopes of the Rocky Mountains' front range, writing that following vegetation zones up mountain slopes was "a long look backward into the past and forward into the future of the biome." Extending work on succession from plants to animals, Victor Shelford, one of Cowles's first students, hypothesized that a river's history could be reconstructed by examining the fish species in a stream from source to mouth, from clean sand to weedy muck.[27]

Chapter 4.

[26] Frederick E. Clements, *Research Methods in Ecology* (Lincoln: University of Nebraska Press, 1905), quotes on p. 5.

[27] Cowles, "The Ecological Relations," 194-196; Frederick E. Clements, "The Relict Method in Dynamic Ecology," *Journal of Ecology* 22 (1934): 39-68, quote on p. 41; Victor E. Shelford, "Ecological Succession, I: Stream Fishes and the Method of Physiographic Analysis," *Biological Bulletin* 21 (1911): 9-34; Alfred Ernst, The New Flora of the Volcano Island of Krakatau (Cambridge: Cambridge University Press, 1908); Conway MacMilan, "On the Formation of

In interpreting places such as dunes, river bottoms, or the landscape of the recently erupted Krakatau, early American ecologists emphasized the dynamism of the seemingly static landscape. This shifted in the 1920s, when a graduate student in botany at the University of Nebraska, Henry Allan Gleason, argued that if succession occurred when physical conditions at a site changed such that the resident species could no longer thrive, then it should be possible to identify areas of "retreating migrations" as well as "advancing migrations" across a region.[28] He hypothesized that plant communities in the Great Plains had moved back and forth across a band he estimated at 500 miles wide in the estimated 10,000 to 40,000 years since the retreat of the Wisconsin glacier.[29]

As ecologists became interested in Gleason's conception of the appearance of new communities as a function of migration, they began to seek out new types of field sites. Rather than study a linear transect, like Clements' dunes or Shelford's streams, they began to study isolated patches containing vegetation unlike that of the surrounding area. Observing that small patches of prairie were common across the Midwest, Gleason hypothesized that in the past the prairie had been "entirely continuous over the whole area." In his words, these patches were "relic colonies," stragglers in the prairie's migration to a new region:

> The relic colonies linger behind in the habitats least suited to the invading flora. As a corollary to this, it is also evident than an advancing flora moves forward most rapidly in

---

Circular Muskeag in Tamarack Swamps," *Bulletin of the Torrey Botanical Club* 23 (1896): 500-507.

[28] Frederic E. Clements, *Plant Succession: An Analysis of the Development of Vegetation* (Washington DC: Carnegie Institution, 1916).

[29] Henry Gleason, "An Isolated Prairie Grove and its Phytogeographical Significance," *Botanical Gazette* 53 (1912): 38-49. Gleason elaborated on relationship between migration and succession in "The Structure and Development of the Plant Association," *Bulletin of the Torrey Club* 44 (1917): 463-481. He was strongly influenced by Frederic E. Clements, *Plant Succession: An Analysis of the Development of Vegetation* (Washington DC: Carnegie Institution, 1916).

> the habitats best adapted to itself. Human migrations follow exactly the same principles. To the victor belong the spoils; the loser must be content with what is left.[30]

Gleason argued that the analysis of relic colonies was the best method available to botanists trying to understand the floristic history of the Great Plains. Whereas in Europe written records preserved "trustworthy accounts of some of the original features of the vegetation," American scientists had to use the landscape as a record. And although the new method of studying fossilized pollen held promise, too few sites had been sampled to develop broad generalizations. By studying relict communities, Gleason contended, botanists would be able to reconstruct the ecological history of a region.[31] Ecologists could visualize temporal dynamism through a seemingly static landscape.

Importantly, ecology's focus shifted from studying linear "disturbance" gradients to studying disjointed patches of rare plants. And as the Dust Bowl escalated, ecologists found themselves arguing for the preservation of such patches as "yardsticks" against which to assess

---

30 Henry Allan Gleason and Arthur Cronquist, *The Natural Geography of Plants* (New York: Columbia University Press, 1964), 212.

31 In "A Letter from Dr. Gleason," *Brittonia* 39 (1987): 205-209, Gleason identified this distinction as his main contribution to succession theory. Within the discipline of environmental history, however, Gleason is known for rejecting Clements's analogizing plant communities and individual organisms. Instead, the argument goes, Gleason argued that individual plant species establish themselves independently of others. Those who contrast Clements "superorganismal" and Gleason's "individualistic" concepts of ecology include: Worster, *Nature's Economy*; Tobey, *Saving the Prairies*; Michael G. Barbour, "Ecological Fragmentation in the Fifties," in *Uncommon Ground: Rethinking the Human Place in Nature*, ed. William Cronon (New York: W.W. Norton & Co., 1995), 233-255; Sharon Kingsland, *The Evolution of American Ecology, 1890-2000* (Baltimore: Johns Hopkins University Press, 2005). Christopher Eliot convincingly argues that such accounts have inaccurately radicalized the views of Clements and Gleason: "The Legend of Order and Chaos: Communities and Early Community Ecology," in *Philosophy of Ecology*, ed. Kevin deLaplante *et al.* (New York: Elsevier, 2011), 49–108. As Eliot notes, unlike a simple climate-begets-climax law, Clements's theory attempts to offer explanations by drawing on a variety of causes.

federal recovery efforts. An interest in securing permanent field sites led ecologists to join the American preservation movement and, later, to develop the concept of ecological restoration.

The Committee on the Preservation of Natural Conditions for Ecological Study

By 1930 prairie plant species occupied less than 4% of their extent in 1800, and the deep layer of topsoil associated with prairie had been blown or washed away from great swaths of the Midwest. Through decades of war and federal re-appropriation, settlers across the Great Plains had replaced bison and prairie dogs with cattle, big bluestem with corn and wheat, and Indian communities with their own.[32] Henry Gleason was concerned that field biologists were losing their field sites to the plow, and in this he was not alone.

Victor Shelford began a professorship at the University of Illinois in 1914. Like Gleason, Shelford was worried about the destruction of potential field sites in the Midwest. If field biologists did not take action soon, he argued in 1929, agricultural encroachment, roadside mowing and burning, and marsh draining would destroy landscapes that contained valuable ecological information.[33] Other members of the new Ecological Society of America agreed. "As the settlement of the country progresses, and the original aspect of nature is altered," wrote Joseph Grinnell, the first director of the University of California's Museum of Vertebrate Zoology, nature reservations would soon be "the only areas unspoiled for scientific study."[34]

---

[32] U.S. Bureau of the Census, *Historical Statistics of the United States, Colonial Times to 1970* (Washington D.C.: Government Printing Office, 1975); F. B. Samson and F. L. Knopf, eds., *Prairie Conservation: Preserving North America's Most Endangered Ecosystem* (Washington D.C.: Island Press, 1996).

[33] Charles C. Adams to William E. Ritter, 21 Dec 1929, quoted in Kohler, *Landscapes and Labscapes*, 55; See also "Proceedings," *Ecology* 2 (1921): 155-160; Victor E. Shelford, "Nature's Sanctuaries," *Science* 6 (1932): 481-482.

[34] Ecological Society of America, *Preservation of Natural Conditions* (Springfield: Schnepp &

Charles C. Adams, likewise, argued that ecologists needed access to "what might be called a bionomic baseline, an idea of conditions which existed before man came upon the scene, the conditions which would again supervene if the human inhabitants were withdrawn."[35]

In 1917, through the newly organized Ecological Society of America, Shelford founded the Committee on the Preservation of Natural Conditions for Ecological Study. The stated purpose of the Committee was to secure information on natural areas in the United States and Canada "of such outstanding ecological interest as to be worthy of perpetual preservation for scientific purposes." The Committee would then use this information to lobby for the creation of permanent outdoor research areas, "nature reserves," "nature reservations" or "nature sanctuaries."[36] Within the year, the Committee had seventeen members. By the time they issued their first published report, in 1921, they had grown to seventy members.[37]

As historian of science Robert Kohler has highlighted, a number of new types of spaces for biological research emerged at the turn of the twentieth century, including vivaria, marine

---

Barnes, 1922).

[35] Charles C. Adams, *Guide to the Study of Animal Ecology* (New York: Macmillan, 1913), 25.

[36] In 1932 the committee was renamed the "Committee for the Preservation of Natural Conditions in the United States." For clarity I use its original name throughout the chapter. On its history, see "A New Committee," *Bulletin of the Ecological Society of America* 1 (1917), no. 4; "Committee on the Preservation of Natural Conditions for Ecological Study," *Bulletin of the Ecological Society of America* 1 (1917) no. 6/9; Victor E. Shelford, "Committee for Preservation of Natural Conditions,'' *Bulletin of the Ecological Society of America* 2 (1918); Victor E. Shelford, "Preserves of Natural Conditions," *Transactions of the Illinois Academy of Science* 13 (1920): 57-58; Robert Burgess, "Historical Data and Some Preliminary Analyses," (Washington D.C.: Ecological Society of America, c. 1976); Sara F. Tjossem, "Preservation of Nature and the Ecological Society of America, 1915-1979" (PhD diss., Cornell University, 1994); Abby J. Kinchy, "On the Borders of Post-War Ecology: Struggles Over the Ecological Society of America's Preservation Committee, 1917–1946," *Science as Culture* 15 (2012): 23–44.

[37] Mark V. Barrow, *Nature's Ghosts: Confronting Extinction from the Age of Jefferson to the Age of Ecology* (Chicago: University of Chicago Press, 2009), Chapter 7.

laboratories, and field stations.[38] These facilities differed in their functions. Vivaria were buildings for keeping living animals on campus. Marine laboratories were places to bring morphologists closer to the source of their material. The first were established in the 1870s in Europe, and not long after in the United States.[39] Inland field stations began in Europe, too, with state-run forestry experiment stations in Germany.[40] By 1910, the U.S. Forest Service and a handful of universities had established inland field stations at dozens of sites.[41]

In arguing for the establishment of what they called nature reservations, Shelford and other ecologists were pressing for yet another type of scientific infrastructure, one that would cater to ecologists. Field stations were rare in the Midwest, and those that existed did not encompass the "relic colonies" that Gleason, Shelford, and others wished to study. In 1925,

---

[38] Kohler, *Landscapes and Labscapes*, 41-55.

[39] Phillip J. Pauly, "Summer Resort and Scientific Discipline: Woods Hole and the Structure of American Biology, 1882-1925," in *The American Development of Biology*, ed. Ronald Rainger *et al.* (Philadelphia: University of Pennsylvania Press, 1988); Helen Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Cambridge: Harvard University Press, 2005).

[40] The U.S. Forest Service began establishing its own field stations in 1908 at the behest of Raphael Zon. By the 1870s, Germany had set up forest experiment stations across the country. Bernhard Fernow, a German immigrant and U.S. Forestry Chief from 1886 to 1898, brought the model to the United States. The first state-run forest experiment stations were commissioned in 1887. But it was Zon, a graduate of Fernow's new school, the New York State College of Forestry at Cornell, who lobbied for federally run experiment stations. When Gifford Pinchot authorized the creation of U.S. Forest Service experiment stations in 1908, it took Zon only three months to open the first one. By 1915 there were twelve Experiment Stations.

[41] On history of the U.S. Forest Service, see Alison T. Otis, William D. Honey, Thomas C. Hogg, and Kimberly K. Lakin, *The Forest Service and the Civilian Conservation Corps: 1933-42* (Washington D.C.: Government Printing Office, 1986); Hal K. Rothman, "'A Regular Ding-Dong Fight': Agency Culture and Evolution in the NPS-USFS Dispute, 1916-1937," *Western Historical Quarterly* 20 (1989): 141-162; Henry Lowood, "The Calculating Forester: Quantification, Cameral Science, and the Emergence of Scientific Forestry Management in Germany," in *The Quantifying Spirit in the Eighteenth Century*, Tore Frangsmyr, J.L. Heilbron, and Robin E. Rider, eds. (University of California Press, 1991), 315-342;
Jeremy Cameron Young, "Warrior of Science: Raphael Zon and the Origins of Forest Experiment Stations," *Forest History Today* (2010): 4-12.

Charles C. Adams complained in a letter in *The Scientific Monthly* that extant field stations were too close to roads and towns for ecologists to properly study plant succession at them. National Forests might be suited to long-term studies of succession, he argued, only if the U.S. Bureau of Fisheries and U.S. Forest Service weren't harvesting timber, grazing cattle and sheep, stocking fish, and constructing roads and dams.[42] Meanwhile Shelford contended that even in national parks, federal agencies practiced "control," "modification," and "improvement," including the introduction of plants and animals, and predator extermination, and that the "pampering of herbivores" on federal lands had left ecologists with few sites in which to study "original nature."[43]

In a particularly forceful editorial in a 1919 issue of *Science*, Willard Van Name, a curator at the American Museum of Natural History, argued that postwar economic expansion had made "demands on natural resources to an extent that was never before approached," so that it had become necessary for ecologists to lobby for the preservation "of the hundreds of interesting species of animals and plants and the many places of unusual scientific interest that are being sacrificed for the selfish interest of a few, or even merely by neglect and indifference." Like Shelford, Van Name believed that existing conservation organizations had different goals than these:

> No one should delude himself with the idea that because there are in this country certain societies for the protection of birds and animals or because the federal government has at length begun to take a small part in it, that there is nothing more to be done by others.[44]

---

[42] Charles C. Adams, "Ecological Conditions in National Forests and in National Parks," *The Scientific Monthly* 20 (1925): 561-593.
[43] Victor E. Shelford, "The Preservation of Natural Biotic Communities," *Ecology* 14 (1933): 240-245.
[44] Willard G. Van Name, "Zoological Aims and Opportunities," *Science* 50 (1919): 81-84.

And so between 1917 and 1926, the Committee on the Preservation of Natural Conditions for Ecological Study compiled a list of about a thousand potential sites for nature reservations in the United States, Canada, and Central America. Shelford published the list as the 761-page *Naturalist's Guide to the Americas*.[45] As it turned out, the Committee on the Preservation of Natural Conditions for Ecological Study was more successful at compiling information than they were at lobbying. Between 1917 and 1926, their lobbying led to the establishment of only one study site: Glacier Bay National Monument in Alaska.[46] Shelford was clearly frustrated. But the Dust Bowl was about to reshape the political landscape of the nation, and in doing so, provide ecologists with a new justification for the establishment of long-term study sites.

Dust, Continued

By 1932, more than one quarter of the American workforce was unemployed. When President Franklin Roosevelt took office in 1933, he promised to address this depression with "direct, vigorous" action, and in his first 100 days in office he oversaw the passage of the

---

[45] Victor E. Shelford, *Naturalist's Guide to the Americas* (Baltimore: Williams & Wilkins Co., 1926).

[46] Gina Rumore, "Preservation for Science: The Ecological Society of America and the Campaign for Glacier Bay National Monument," *Journal of the History of Biology* 45 (2011): 613-650. In 1923 the Committee recruited Raphael Zon, a former USFS forester and ESA member, to discourage the Forest Service from acquiring the Alaskan site. The Committee worried that the Forest Service would dedicate most of the land to timber production and recreation, and instead wanted the Department of the Interior to manage the site. The Committee also convinced scientific and popular societies to write Department of the Interior, including the AAAS, the National Research Council, the National Geographic Society, and the American Forestry Association. In response to this letter-writing campaign, President Coolidge withdrew approximately 2.5 million acres encompassing Glacier Bay from the public holding in 1924. The Department of the Interior established the Glacier Bay National Monument later that year. But the Committee's success was short-lived. In 1936, under pressure from mining interests, the federal government opened Glacier Bay Monument to mineral prospecting, threatening the research material the Committee had sought to protect.

Agricultural Adjustment Act, the Tennessee Valley Authority Act, the National Industrial Recovery Act, and twelve other major laws. In order to prevent young men "from becoming semi-criminal hitch-hikers," in the words of one *New Republic* article, the administration set up work camps under the auspices of the Civilian Conservation Corps (CCC), a New Deal program supervised by the Departments of Labor, War, Agriculture, and Interior. For one dollar per day, CCC workers, unmarried men aged eighteen to twenty-five, performed manual labor for the U.S. Forest Service and the National Park Service, building roads and fire lookout towers, damming streams, stocking fish, and constructing picnic grounds across the country. As historian Neil Maher has detailed, these projects were undertaken on an unprecedented scale.[47] From April 1933, when CCC enrollees first began working, to 1942, when Congress terminated the New Deal Program, the CCC had employed more than three million men, a mobilization that dwarfed U.S. World War I military mobilization. The CCC was responsible for establishing 800 state parks, constructing 10,000 reservoirs, erecting one million miles of fence, stocking rivers with one million fish, and eradicating almost 400,000 predators.[48]

Many prominent members of the Ecological Society of America were critical of CCC projects. In 1935, ESA president Walter P. Taylor addressed the Society's 21st annual meeting. Citing soil erosion, soil exhaustion, overgrazing, wasteful logging, and marshland draining, he explained that "civilized man has taken Nature on a number of sprees, and the poor lady is a bit

---

[47] Maher, *Nature's New Deal*, demonstrates how President Roosevelt employed the CCC strategically to build support in necessary regions in order to promote the New Deal and get reelected. Driving the CCC and therefore, the New Deal, was a conservation ethic that sprung from multiple sources in American culture: the progressive conservationists, the influences of both Gifford Pinchot and Frederick Law Olmsted, the Boy Scouts, and the childhood and governorship of FDR. See also Sarah Phillips, *This Land, This Nation: Conservation, Rural America, and the New Deal* (Cambridge: Cambridge University Press, 2007).
[48] Quoted in Neil M. Maher, *Nature's New Deal: The Civilian Conservation Corps and the Roots of the American Environmental Movement* (New York: Oxford University Press, 2008), 18.

bedraggled." An ecologist, Taylor continued, could diagnose Nature's "infirmities" and alleviate them, much as a doctor could diagnose human sickness:

> The man who is sick and in need of medical attention needs a physician who can see his difficulties as a whole. It is disturbing to consult two or three specialists in as many different organs of the body and to be given a regimen for the improvement of each which cannot possibly be carried out in view of what has been prescribed already for the others. Some master practitioner must harmonize the various proposed cures or the sufferer is headed for difficulty.
>
> I like to think of ecology as a sort of master diagnostician who tries not to lose sight of the fact that Nature, the patient, is not an accidental collection of independent and unrelated objects, but is normally an organized and functioning whole.

Ecologists were better positioned to address the crises of the Dust Bowl than CCC "laymen," Taylor continued, who were busy applying "certain 'obvious' remedies to cure the ills of exploitation," as though they were "trying to cure a headache with headache powders and persisting in a round of night life." Unlike ecologists, Taylor contended, CCC federal agency scientists were not equipped to understand how different landscape problems related to one another:

> These gutted areas are now handed over to specialists for rehabilitation. The faith of some of the farmers and business men in science and scientific men is almost pathetic. Many seem to believe that various artificial measures, erosion control, reseeding, replanting, weed control, rodent control, or other measures will suffice to repair the obvious damage, even in the absence of removal of the over-heavy pressure from livestock which in the case of the grazing range is the fundamental and continuing cause of many of the difficulties. […]
>
> Formulas for the quickest repair of the damage done are now being sought by engineers in cooperation with ecologists. Who better than the ecologists, after all, can be counted on to see clearly through the processes which have been going on, to picture accurately the land as it ought to look, and to advise safely what should be done?[49]

[49] Walter P. Taylor, "What is Ecology and What Good is It?" *Ecology* 17 (1936): 333-346. See also Horace M. Albright, "Research in the National Parks," *The Scientific Monthly* 36 (1933): 483-501; Walter P. Taylor, "'Man and Nature'— A Contemporary View," *The Scientific Monthly* 41 (1935): 350-362.

One of the most prolific critics of New Deal land management was Aldo Leopold, author of the environmental classic *A Sand County Almanac*.[50] Leopold, too, who had spent his entire professional life in the U.S. Forest Service, critiqued the lack of coordination among CCC projects in a series of public lectures in 1934:

> The road crew cutting a grade along a clay bank so as permanently to roil the troutstream which another crew was improving with dams and shelters; the silvicultural crew felling the "wolf trees" and border shrubbery needed for game food; the roadside-cleanup crew burning all the down oak fuel wood available to the fireplaces being built by the recreation-ground crew; the planting crew setting pines all over the only open clover-patch available to the deer and partridges; the fire-line crew burning up all the hollow snags on a wild-life refuge, or worse yet, felling the gnarled veterans which were about the only scenic thing along a "scenic road."[51]

Similarly, Jay "Ding" Darling, a nationally syndicated political cartoonist, a noted conservationist, and close friend of Leopold, wrote in the *Saturday Evening Post* in 1938: "All the while we have been trying through the Biological Survey to *create* marshes, other agencies, other bureaus of Government have been spending vaster sums than we controlled to *dry up existing marshes*."[52]

[50] Neil Maher elaborates on some of Leopold's critiques of the CCC in Maher, *Nature's New Deal*, 165-173.
[51] Aldo Leopold, "Conservation Economics," *Journal of Forestry* 32 (1934): 537-544.
[52] Emphasis in the original. Quoted in Maher, *Nature's New Deal*, 44. See also Robert Wilson, *Seeking Refuge: Birds and Landscapes of the Pacific Flyway* (University of Washington Press, 2010).

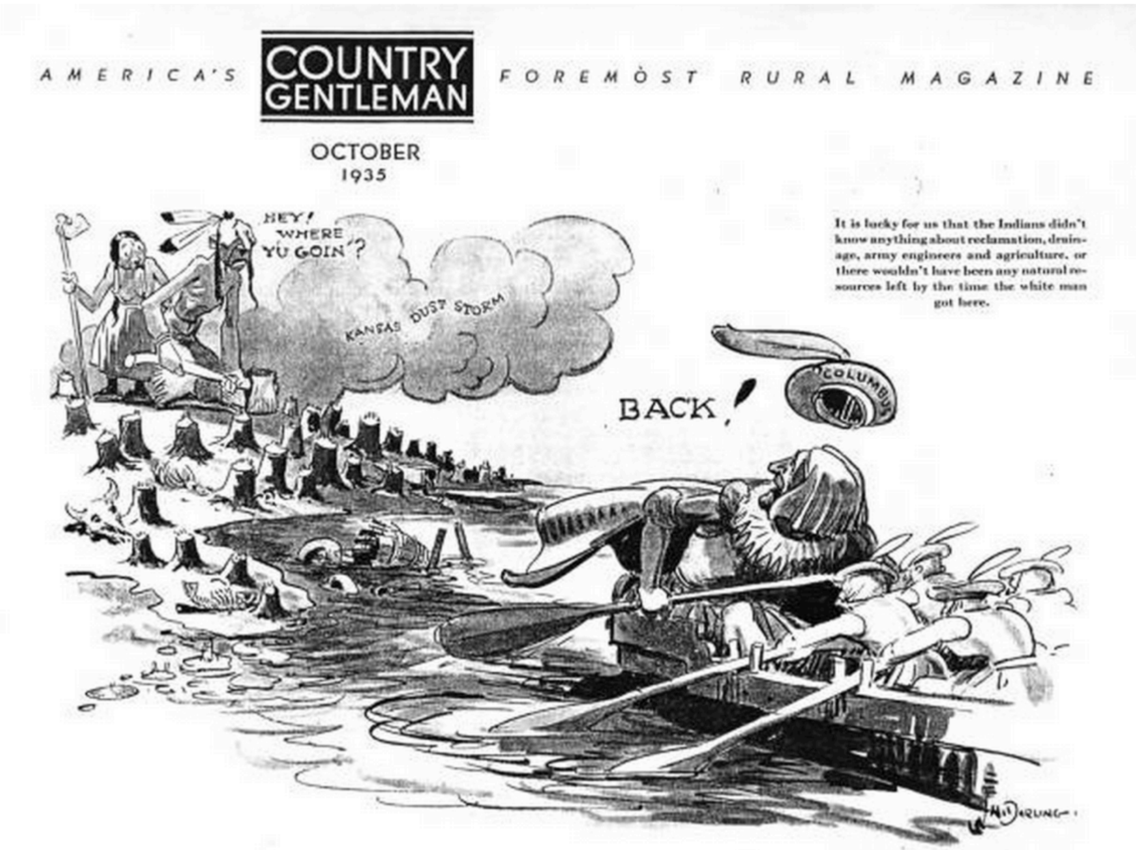


Figure 7. A cartoon by Ding Darling, 1938, critiquing New Deal land management. The caption reads: "It is lucky for us that the Indians didn't know anything about reclamation, drainage, army engineers and agriculture, or there wouldn't have been any natural resources left by the time the white man got here." The cartoon was used to illustrate the "Desert Makers" article published in the October 1935 issue of Country Gentleman, written by Darling as chief of the U.S. Bureau of Biological Survey.

Today Leopold is often credited with "inventing" ecological restoration at the University of Wisconsin Arboretum. Roderick Nash titled a chapter in his classic 1967 book *Wilderness and the American Mind* simply "Aldo Leopold, Prophet." In 1985, Wallace Stegner described *A Sand County Almanac* as "one of the prophetic books, the utterance of an American Isaiah." The 1990 book *Restoration Ecology: A Synthetic Approach to Ecological Research* described Leopold as "both a prophet and a pioneer."[53]

But Leopold was embedded in a much larger debate among federal employees and academic ecologists. By the 1920s, a generation of U.S. Forest Service leadership had been recruited from the nation's first three professional forestry schools: Yale Forest School (Leopold's alma mater), the New York State College of Forestry at Cornell, and the Biltmore Forest School. Ecological studies were a part of these schools' curricula, but forestry was considered its own discipline. Thus early ecologists were, in essence, trying to recruit foresters away from forestry. This led to tension among the professional societies. For example, in a 1919 letter to Charles C. Adams, a charter member of the ESA, Raphael Zon, the newly appointed first director of the Forest Service Experiment Station program, expressed his skepticism toward ecology as a discipline:

> As to your 'boosting' the Ecological Society and incidentally ecology, I think it was the proper thing to do at the time the article was written. I was greatly interested in the ecological movement in this country. Possibly, because I expected so much more of it, I feel at present somewhat disappointed. Where the ecologists got deeper into the subject they invariably landed in the field of physiology or the minuter adjustment of plant life processes and the environment. Where the ecologists stuck to the surface they have produced only generalities. The best example of it is Prof. Clements' work.[54]

Early in the New Deal, many federal environmental projects emphasized recreational development and national planning. The National Park Service, for example, employed nearly

---

[53] Roderick Frazier Nash, *Wilderness and the American Mind* (New Haven: Yale University Press, 1967); Walace Stegner, "Living on Our Principal," *Wilderness* 48 (1985): 5-21; William Jordan II, Michael E. Gilpin, and John D. Aber (eds.), *Restoration Ecology: A Synthetic Approach to Ecological Research* (Cambridge: University of Cambridge Press, 1990), 3. Curt Meine lists other examples of Leopold being described as a prophet in *Correction Lines: Essays on Land, Leopold, and Conservation* (Washington DC: Island Press, 2004), 172-183.
[54] Raphael Zon to Charles C. Adams, 6 March 1919, Charles C. Adams Papers, Box 4, Folder 17, New York State Library Archives, Albany, New York.

400 landscape architects but only 27 biologists, and of these biologists, only four were paid with National Park Service appropriations. This emphasis on recreation led some ecologists to complain that the Service was becoming a "glorified playground commission."[55] As Taylor had concluded in his 1935 address to the ESA: "Who but a geo-bio-ecologist, one who knows something of interrelationships and of plant and animal indicators and soils, is qualified for the important tasks of land classification?"[56] Thus in critiquing the lack of coordination of CCC projects, ESA members were essentially lobbying for influence over the development and implementation of federal environmental policy.

Mounting tensions between the ESA and the main professional society of the U.S. Forest Service, the Society of American Foresters, came to a head around the President Roosevelt's "Shelter-Belt Program." In 1934, Roosevelt established a federal program to plant a belt of trees from the Canadian border to the Texas panhandle. The administration contended that this belt would reduce dust storming and decrease evaporation across the Great Plains. Roosevelt placed Raphael Zon in charge of the program. Under the auspices of the Shelter-Belt Program, the Forest Service, in coordination with the Works Progress Administration and the CCC, paid CCC workers and private farmers to plant trees in one hundred parallel strips a mile apart. By 1936, 23.7 million trees had been planted on 57,000 acres.[57]

---

[55] Richard West Sellars, *Preserving Nature in the National Parks: A History* (New Haven: Yale University Press, 1997), 131, 142-143.
[56] Taylor, "What is Ecology and What Good is It?"
[57] See U.S. Forest Service, *Report of the Chief of the Forest Service* (Washington D.C.: United States Forest Service,, 1934); Jonathan Mitchell, "Shelter Belt Realities," *New Republic* 90 (1934): 69; "Fighting the Drouth," *Popular Mechanics Magazine* 62 (1934): 483-485; Raphael Zon, "Shelterbelts – Futile Dream or Workable Plan," *Science* 81 (1935): 391-394; "Possibilities of Shelterbelt Planting in the Plains Region" (Washington D.C.: United States Forest Service, 1935); Paul B. Sears, "The Great American Shelter-belt: Review of Possibilities of Shelterbelt Planting in the Plains Region by R. Zon," *Ecology* 17 (1936): 683-684; Thomas Wessel,

As the Shelter-Belt program began, many ecologists argued that it was doomed to fail. Grass, not trees, grew naturally on the Great Plains, some contended, and the program's failure would be a great embarrassment to the Forest Service. Other ecologists considered the project to be an over-simplified conservation plan, and they contended that no matter what measures government took, only rain would end the Dust Bowl. Ecologist Royal S. Kellogg contended that no one had proven that tree planting and cultivation increased precipitation, and the theory was at best "problematical." Kellogg entered a public dispute with Zon, voicing his opposition within the Society of American Foresters and in the *New York Times*.[58] An anonymous Zon supporter wrote a poem to explain the confrontation:

Kellogg lives in New York City,
Far away from drought and wind.
Broadway dandies never fancy
Any need for shelter belts.

When he hears about the project
He sits down and writes the TIMES
In a letter: "I know better.
They don't need a shelter belt."

"Planted trees will die on prairie,
Eighteen inches not enough.
Suffocation, radiation
Kill the trees in shelter belt."

"Zon should move to New York City,
Live with me on old Broadway
Here it's cozy, here it's rozy

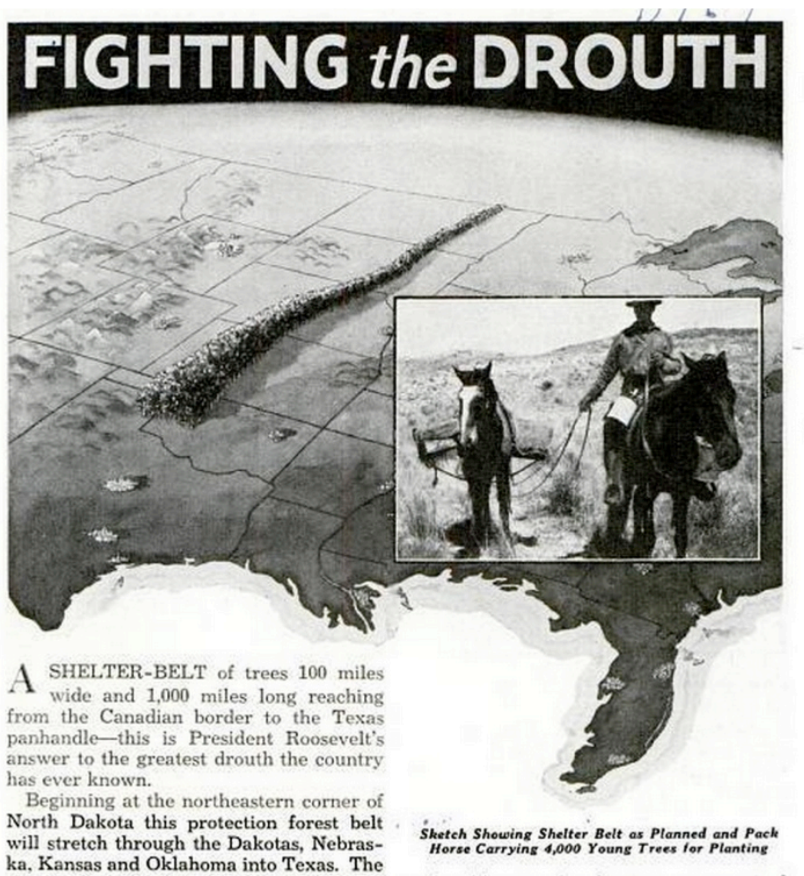
"Roosevelt and the Great Plains Shelterbelt," *Great Plains Journal* 8 (1969): 57-74; Wilmon Henry Droze, *Trees, Prairies, and People: A History of Tree Planting in the Plains States* (PhD diss.: Texas Woman's University, 1977).

[58] Raphael Zon, *Forests and Water in the Light of Scientific Investigation* (Washington D.C.: Government Printing Office, 1927); Raphael Zon, "Relation of the Forests in the Atlantic Plain to the Humidity of the Central States and Prairie Region, *Science* 38 (1913): 63-75. Royal S. Kellogg, "Forest Planting in Western Kansas," *Forest Service Circular* 161 (1909); Royal S. Kellogg, "The Shelterbelt Scheme," *Journal of Forestry* 32 (1934): 974-977.

And forget his shelter belt."

What will happen in the future,
Zon and Kellogg only know.
Will they conquer or debunker?
I predict a shelter belt!

Chorus:
Thousand miles of living fences,
Pinus, Ulmus, Fraxinus,
Ponderosa, Resinosa,
Soon will grow in shelter belt.[59]



FIGHTING *the* DROUTH

A SHELTER-BELT of trees 100 miles wide and 1,000 miles long reaching from the Canadian border to the Texas panhandle—this is President Roosevelt's answer to the greatest drouth the country has ever known.

Beginning at the northeastern corner of North Dakota this protection forest belt will stretch through the Dakotas, Nebraska, Kansas and Oklahoma into Texas. The

Sketch Showing Shelter Belt as Planned and Pack Horse Carrying 4,000 Young Trees for Planting

Figure 8. An illustration from the article, "Fighting the Drouth," *Popular Mechanics* 62 (October 1934): 483-485.

[59] Poem quoted in Norman J Schmaltz, "Forest Research Raphael Zon," *Journal of Forest History* 24 (1980): 24-39.

At its core, the controversy was a debate over whether the Shelter-Belt program should be supervised by foresters or by ecologists. Reviewing the controversy, ecologist Paul B. Sears wrote in 1936:

> Newcomer to the traditional bed of politics, ecology is not therefore to be judged a mere transient. The entire problem of modern civilization is emerging into its true light, as a vast, ecologically conditioned enterprise. It is essential under the circumstances that the ecologist distinguish clearly between his function as an adviser in determining broad policy and his task when called upon to execute any policy, once it is promulgated. So far as the record before us is concerned, the Forest Service has acted in the latter role with respect to the Great American Shelter-Belt.[60]

If ecologists were critical of the Forest Service's projects, Sears contended, they should strive to influence them.

In a 1935 article, "Experimental Ecology in the Public Service," Frederic Clements asked ecologists to consider the opportunities that the Shelter Belt and other large-scale federal recovery projects afforded ecologists: "With the present great expansion of federal projects has gone a corresponding increase in the utilization of ecological methods and concepts, even when this term has not been employed." Clements then argued that the planting and maintenance of windbreaks for the Shelter Belt project would be "almost wholly dependent" on understanding plant succession – a subject on which Clements was conveniently expert. The "tragic process" that had led to the Dust Bowl, Clements concluded, would continue "until the clear evidence of climate and climax is heeded."[61]

In 1937, the ESA Committee on the Preservation of Natural Conditions sent "a warning" to all state representatives to watch for "destruction of natural conditions in state parks and forests" by CCC camps. The Committee also contacted Clements, "who has acted as advisor in

---

[60] Paul B. Sears, "The Great American Shelter-Belt," *Ecology* 17 (1936): 683-684.
[61] Frederic E. Clements, "Experimental Ecology in the Public Service," *Ecology* 16 (1935): 342-363.

soil conservation projects," and urged him to "try to influence the administration as much as possible in the direction of improving the training of personnel, and the application of correct ecological principles." That year the Committee contacted the head of the U. S. Biological Survey to inquire if the ESA "could be of any service" in helping to save game or natural areas under the Taylor Grazing Act. Apparently the agency was uninterested; the Committee reported that they "did not indicate that any assistance was needed, but rather the contrary."[62]

Establishing Long-Term Ecological Field Sites

Thus by the mid-1930s a number of prominent ecologists were working to establish themselves as experts on land management – and restoration – claiming that the key to national recovery lay in research on ecological succession. The efforts of the CCC were a temporary fix, "headache powders," as Taylor had called them, rather than a permanent solution. Ecologists seized on the federal government's acquisition of over ten million acres of "exhausted" farmland in the Great Plains as a starting point for their proposed solution. In 1935, Roosevelt established the Resettlement Administration by executive order. The Resettlement Administration, an agency independent of any existing federal department, was charged with the resettlement of "destitute or low-income families" to government-planned communities. Consolidating previous New Deal efforts to fight rural poverty and intervene in farming practices, the Resettlement Administration became one of the largest New Deal agencies.[63]

---

[62] G. A. Pearson, "Preservation of Natural Areas in the National Forests," *Ecology* 3 (1922): 284-287; "Proceedings," *Ecology* 18 (1937): 307-309, reprint found in Aldo Leopold Papers, 10-2, Box 2, Folder 9, University of Wisconsin Archives, Madison, Wisconsin.

[63] R. Douglas Hurt, "Federal Land Reclamation in the Dust Bowl," *Great Plains Quarterly* 6 (1986): 94-106; Dan L. Flores, "A Long Love Affair with an Uncommon Country: Environmental History and the Great Plains," in *Prairie Conservation*; Daniel S. Licht, *Ecology*

Ecologists soon recognized the opportunity these lands afforded. Prior to the 1930s, biologists had used the term "restoration" in three senses. Its most common usage was medical: biologists described how the restoration of the physiological health of the body could be accomplished. Borrowing from its common use in art, it was also used to describe reconstructive dioramas of former habitats. Finally the term was also occasionally used in fisheries biology, in which "restoration" meant the introduction or re-introduction of commercially valuable fishes to bodies of water.[64] In response to the Dust Bowl and the professional opportunities afforded by the New Deal, ecologists began to use the term restoration to refer to the reestablishment of plant or animal communities on lands that they formerly occupied.

---

and Economics of the Great Plains (Lincoln: University of Nebraska Press, 1997).

[64] For some early examples of the uses of "restoration," see John Muir, "The Establishment on McCloud River – John Muir, the Naturalist, Gives a Graphic Description of What is Being Done," *Daily Evening Bulletin* (San Francisco), 29 October 1874; "The Restoration of Prints," *The Art Amateur* 1 (1879): 7; E. E. Laslett, "Restoration of the Heart Beat," *The British Medical Journal* 1 (1923): 882; J. Austen Bancroft, "Restoration of the Oldest Known Forest," *Science* 61 (1925): 507-508; Percy Viosca Jr., "Louisiana Wet Lands and the Value of their Wild Life and Fishery Resources," *Ecology* 9 (1928): 216-229.

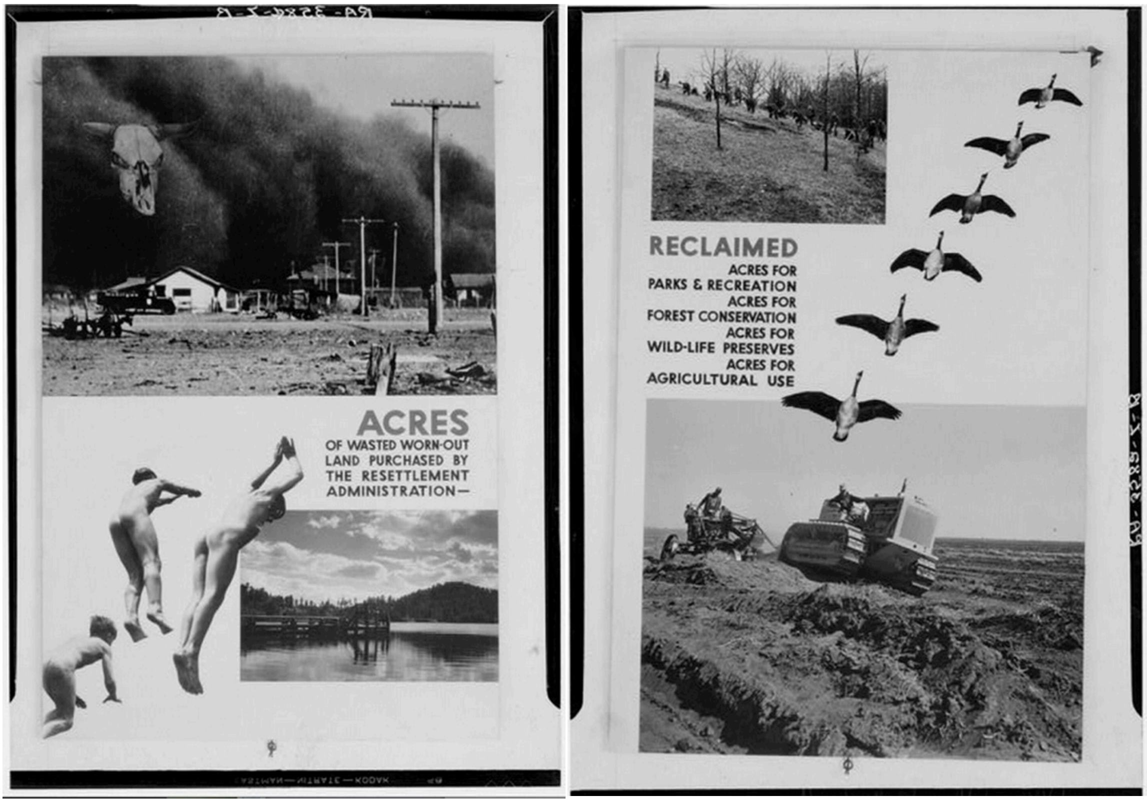


Figure 9. Posters advertising the Reclamation Administration, 1936. Captions read: "Acres of Wasted Worn-out Land Purchased by the Resettlement Administration – Reclaimed Acres for Parks & Recreation, Acres for Forest Conservation, Acres for Wild-life Preserves, Acres for Agricultural Use." "Reclaimed Soil and shelter exhibit. United States Resettlement Administration, LC-USF344-003582-ZB, Library of Congress Prints and Photographs Division.

But by no means was restoration a monolithic concept. To some ecologists, restoration meant setting areas aside so that "natural" successional processes would restore the native ecological community. For others, restoration was an active process, in which ecologists would re-plant the prairie, or re-stock game animals. The differences in proposals largely came down to how ecologists imagined that the federal government should utilize recently acquired farmland. Some ecologists, like Clements and Leopold, argued that recently acquired federal lands in the Great Plains could be used as experimental sites to study how ecologists could manipulate successional dynamics in order to restore previous ecological communities.

Into the late 1930s, an increasing number of ecologists sought to identify "indicator species" – plant species that ecologists could use to predict which use land was best suited to. The presence of a hemlock forest community, for example, was supposed to indicate a cool and moist climate and low soil nutrients, whereas a tall-grass prairie indicated a warm and moderate climate and fertile soils.[65] Others conducted manipulative experiments. At the University of Nebraska, for example, ecologists compared the movement of water through native prairie vegetation, pasture vegetation in which the "climax prairie of little bluestem had been mowed annually," and bare ground. Using an "interceptometer" – an iron can set downslope from their research plots – they concluded that native prairie vegetation held soil in place with deep root systems and that fallen plant material formed miniature dams and terraces that held the water and would "promote percolation." The solution to the "national menace" of soil erosion, they concluded, was not the engineering of check-dams and other soil erosion prevention technologies, but the restoration of prairie plant communities.[66]

---

[65] Arthur W. Sampson, "Plant Indicators – Concept and Status," *The Botanical Review* 5 (1939): 155-206; On land classification see also G.A. Pearson, "What is the Proper Basis for the Classification of Forest Land into Types?" *Proceedings of the Society of American Foresters* 8 (1913): 79-84; Arthur G. Tansley and T. F. Chipp, *Aims and Methods in the Study of Vegetation* (London: Whitefriars Press, 1926); Frederick E. Clements, *Plant Succession and Indicators* (New York: The H. W. Wilson Company, 1928).

[66] J. E. Weaver and W. C. Noll, *Bulletin 11: Comparison of Runoff and Erosion in Prairie, Pasture, and Cultivated Land* (Lincoln: Conservation and Survey Division of the University of Nebraska, 1935).

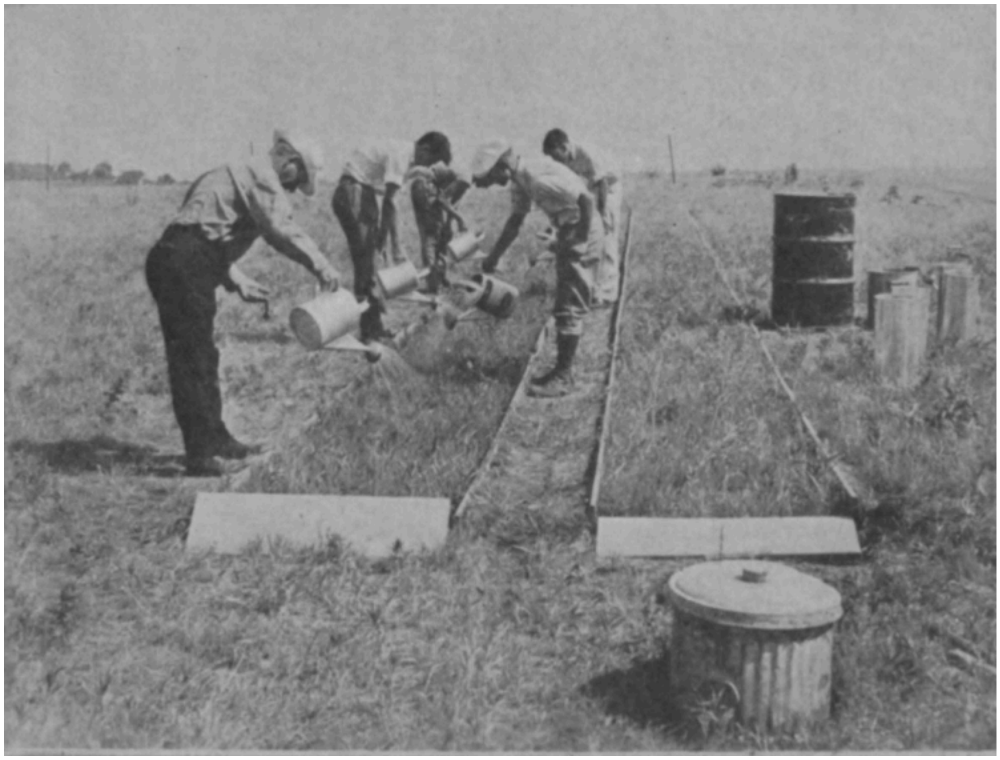


Figure 10. An experiment comparing the movement of water through prairie vegetation and pasture vegetation. Figure from Weaver and Noll (1935).

Other ecologists argued that reclaimed areas should be set aside and allowed to regenerate "naturally." Through the Dust Bowl era, Shelford and his colleagues continued to argue for the establishment of field sites at which to conduct long-term studies of ecological succession, as they had since the 1910s. But they changed their argument. Compare the arguments of the Committee's 1922 book, *Preservation of Natural Conditions*, with those they used in the late 1930s to lobby for the creation of a Midwestern national park. The 1922 book listed a number of individual testimonies that emphasized the importance of protecting patches of rare species for natural history studies:

> Park areas should be conserved unmodified in the interest of research and natural history. For, as the settlement of the country progresses, and the original aspect of nature is altered, the parks will probably be the only areas unspoiled for scientific study, and this is of the more significance when we consider how far the scientific methods of

investigating nature then obtaining will be in advance of those now applied to the same study. –J. Grinnell[67]

The science of ecology, for example, depends upon undisturbed patches of nature as its 'material.' More important still, all that we have learned of geographic distribution and geographic variation has come from the study of native species taken in their original habitats. This work is far from being practically completed throughout our country, as some may be included to think. […] I know that there are other biologists who believe, as I do, that the problems of heredity and evolution are not all to be solved by rearing pedigree-cultures of the fruit-fly and evening-primrose. We must study the actual products of evolution as they have arisen *in nature*. – F.B. Sumner[68]

One of the areas the Committee on the Preservation of Natural Conditions for Ecological Study tried hardest to and failed to protect was a large swath of prairie in southwestern South Dakota. In 1930, the Committee worked to convince the National Park Service to establish a park there by emphasizing the disparity between forest research sites, of which there were dozens, and grassland research sites, of which there were five. But the NPS had focused instead on the establishment of parks near population centers: the Florida Everglades, Great Smoky Mountains, and the Olympic Peninsula in Washington. Then, around 1938, the federal government acquired the land through reclamation. Shelford and his colleagues again lobbied for the establishment of a grasslands research site. But they adopted a new approach: they framed it as a "check-area" for restoration projects.

In a *Scientific Monthly* article, Herbert Hanson, director of the North Dakota Agricultural Experimental Station, explained the rationale behind check-areas to a popular audience. "Much has been written and said about the depletion of our natural resources," he began. The soil had been mined and its nutrients drained, native plants and animals had been destroyed, and streams

---

67 Ecological Society of America, *Preservation of Natural Conditions* (Springfield: Schnepp & Barnes, 1922), 4

68 Emphasis in original. ibid, 10. On the relationship between indoor studies of evolution and outdoor fieldwork, see Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-field Border in Biology* (Chicago: University of Chicago Press, 2002)

had been polluted. But "statements regarding the extent of the losses have been based largely upon memory of former conditions not upon accurate records," Hanson lamented. In some places it was possible to interview "old-timers" to get from them "hints as to the early condition of the country," but such interviews did not constitute conclusive evidence. It would have been "more scientific" to have taken photographs and written descriptions in the past. But in most places nature's record had been "hopelessly obscured by the heavy hand of man."[69]

In the absence of historical records, Hanson continued, "check-areas" were the next best thing, areas still "in their primeval condition, as man found them before alteration with axe or plow or both," to which "land under various uses could be compared." Scientists could use these check areas to measure the erosion rates and the leaching of minerals from soil, as well as the influence of plants and animals on habitat. Clements, Shelford, and other ecologists had been arguing for years the need for "adequate controls in the form of undisturbed areas," Hanson wrote, quoting a recent letter in the *Journal of Forestry*:

> It is to the original climax communities of plants and animals that we must go to observe nature in a state of maximum stability, and it is toward the restoration of as close an approximation of these communities as is possible that we must go if we are to insure permanent productivity of the land on which man's continued tenure of it depends. […] Let us not be so short-sighted as to fail to profit from past mistakes, in not preserving a study area in undisturbed state in each great biotic region of the country. It is not yet too late to save a few, and far from being a luxury, it may be one of the wisest investments that the country has ever made – natural yardsticks to measure man's land management by.[70]

---

[69] Herbert C. Hanson, "Check-areas as Controls in Land Use," *The Scientific Monthly* 48 (1939): 130-146.
[70] "Correspondence," *Journal of Forestry* 34 (1936): 1077-1078.

—*Photograph by V. T. Heidenreich*

THE AREA ON THE LEFT HAS BEEN PROTECTED FROM WILD HORSES FOR TWO SEASONS. NEAR TOPPENISH, WASHINGTON.

Figure 11. A figure from Hanson (1939) explaining the concept of a check-area.

At the 1938 annual meeting in Richmond, Virginia, the ESA voted to endorse the action of the Preservation Committee to lobby the federal government to establish a Great Plains National Monument. They decided to argue that the National Monument would "serve as a check area, which may be managed on a hands-off basis and defended because of its historical value while being available for scientific research."[71] The "serious need for continuous observation of grassland, for the restoration of perennial grasses to hold the soil against wind erosion, and for restoration of grasses on plowed lands" was obvious, Shelford contended.[72]

[71] "Proceedings: Business Meetings of the Ecological Society of America at Richmond, Virginia, December 27 and 29, 1938," *Ecology* 20 (1939): 317-334.
[72] V. E. Shelford and R. E. Yeatter, "Land Holdings of North American Universities with Particular Reference to Grassland," *Ecology* 20 (1939): 450-454.

The Committee on the Preservation of Natural Conditions for Ecological Study recognized that the area of the proposed Great Plains National Monument was far from a pristine wilderness; much of the landscape had been seriously damaged by plowing or overgrazing. The Committee advocated restoration of these lands. Managers would replant native prairie species. They would reintroduce "small numbers of the more conspicuous mammals now exterminated," such as bison, elk, and antelope. Even the wolf could be restored – a revolutionary proposal – if, of course, "a tight fence could be constructed around the project."[73]

Indeed, Shelford believed that through "remedial measures" like replanting native species, ecologists would be able to slowly restore the biotic community until the point at which nature was able "to take its course." If ecologists worked only in pristine areas, they would have very few study sites, Shelford noted, and in eastern North America no such sites existed, because wolves, bears, and other large predators had been extirpated. And state parks, national monuments, and private holdings were also extensively modified. But Shelford wanted as many sites as possible available to theorists of succession – these "second class" and "third class" nature sanctuaries could be restored. It was essential that ecologists have access to all three types of sanctuaries, Shelford wrote in an article in *Ecology*: "The experiment of letting areas essentially alone, so successful in a few of our parks, is worthy of repetition."[74]

---

[73] Victor H. Cahalane, "A Proposed Great Plains National Monument," *The Scientific Monthly* 51 (1940): 125-139; Cahalane would later join The Nature Conservancy's Eastern New York Chapter. See NYS Archives, George R. Cooley Papers, SC18858, Box 11, Folder 23.
[74] Victor E. Shelford, "The Preservation of Natural Biotic Communities," *Ecology* 14 (1933): 240-245.

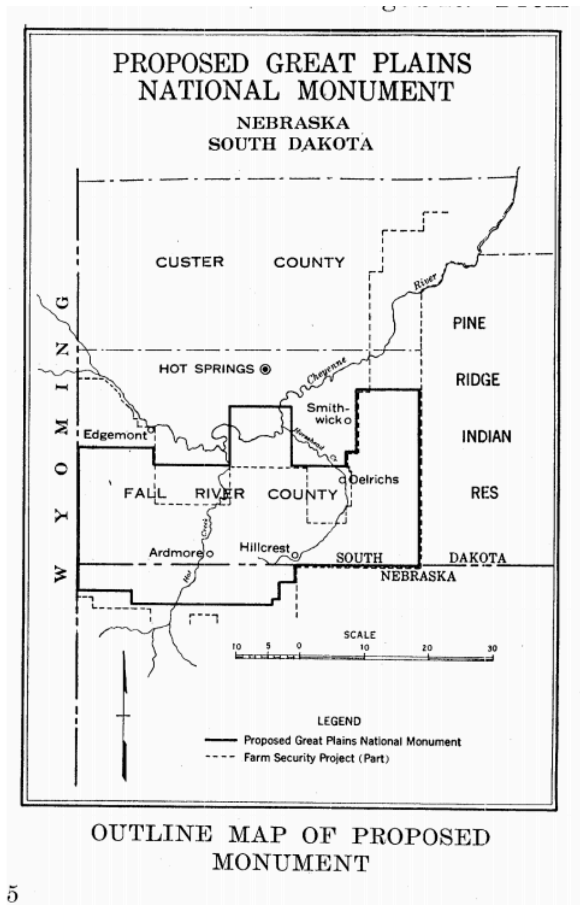


Figure 12. Map from Cahalane (1940) of the ESA's Committee for the Preservation of Natural Conditions proposal for a Great Plains National Monument.

Like Shelford, Clements believed that ecologists could use succession theory to aid the restoration of Great Plains. In 1935 he wrote:

> From the very nature of climax and succession, development is immediately resumed when the disturbing cause ceases, and in this fact lies the basic principle of all restoration or rehabilitation. Left undisturbed, every bare, denuded or seral area begins its slow but inevitable movement to the climax wherever the latter has not been destroyed over too large a territory to permit the mobilization of the successive populations.[75]

Such processes would take an extremely long time, Clements continued. ("For the city can be rebuilt with relative ease and speed, while soils, forests and watersheds can often be

[75] Frederic E. Clements, "Experimental Ecology in the Public Service," *Ecology* 16 (1935): 342-363.

restored only with extreme difficulty, if at all; and such restoration requires a very long time," a reporter wrote in *The Scientific Monthly* in 1935.)[76] However, Clements argued, once ecologists better understood succession, they would be able to retard or accelerate it, to "deflect it in any one of several possible directions." It was only necessary for the ecologist "to know the course and rate of migration" of each plant community "in order to control it or at least shape it to the desired purpose."[77]

In order to build this understanding, essential to national recovery, Clements concluded, ecologists would treat New Deal projects as large-scale experiments:

> It is evident that great national projects that promise a lengthy or indefinite period for their realization constitute an opportunity for experimental succession that may never come again. […] The immediate and larger reward must spring from the service that ecological concepts and methods alone can render, but along with this is the chance to carry out experiments in vegetation on a scale and for a period never before possible.[78]

The University of Wisconsin-Madison Arboretum

The Great Plains Monument never materialized. Under the 1937 Bankhead-Jones Farm Tenant Act, 2.64 million acres of the area the Committee on the Preservation of Natural Conditions for Ecological Study was interested in were placed under U.S. Forest Service management. Only one National Park would be established in the Great Plains before 1950: Badlands National Monument in South Dakota.[79] Meanwhile The Shelter Belt Program weathered the controversy, and by 1942, 30,233 shelterbelts had been planted that contained 220

---

[76] Taylor, "'Man and Nature'— A contemporary view."
[77] Clements, "Experimental Ecology in the Public Service."
[78] Clements, "Experimental Ecology in the Public Service."
[79] Committee on the Ecology of North American Grasslands, "Background Report for Western Nebraska Meeting" (Washington D.C.: National Research Council, 22 April 1937); "Great Plains National Monument Project," *The Council Ring*, 8 January 1940; James Lester Swint, *The Proposed Prairie National Park: A Case Study of the Controversial NPS* (Master's thesis, Kansas State University, 1971).

million trees and stretched for 18,600 miles. But the involvement of ecologists in both projects helps explain the history of another, more enduring project – the University of Wisconsin Arboretum – which most contemporary ecologists cite as the first ecological restoration project.[80]

In 1932, the University of Wisconsin-Madison purchased a swampy 430-acre property on the edge of Lake Wingra. The university planned to use the property to establish an arboretum as part of an initiative to hire Aldo Leopold, who had become well known for his work on game species management. From 1909 to 1924, Leopold worked as a forester with the U.S. Forest Service in the Arizona and New Mexico Territories, where his main duties involved management of fire, tourists, and animals that ate game species.[81] When wartime shifted the Forest Service's priorities toward food production, Leopold brainstormed ways to augment game populations. At the time the accepted method of promoting game species like deer and elk was to kill anything that preyed upon them, and Leopold's District was a leader in exterminating bears, wolves, and mountain lions – the "skulking marauders of the forest," as Leopold called them.[82] During World War I, Leopold began to contemplate an alternative method of managing game. Drawing upon established research in ecological succession, he envisioned a self-sustaining system in which

---

[80] In "Some reflections on Curtis Prairie," Jordan calls the Arboretum the "Kitty Hawk" of ecological restoration.

[81] On Leopold's life, see Susan L. Flader, *Thinking Like A Mountain: Aldo Leopold and the Evolution of an Ecological Attitude toward Deer, Wolves, and Forests* (Madison: University of Wisconsin Press, 1974); Curt Meine, *Aldo Leopold: His Life and Work* (Madison: University of Wisconsin Press, 1988); Susan Flader and J. Baird Callicott, *The River of mother God and Other Essays by Aldo Leopold* (Madison: University of Wisconsin Press, 1991); Louis S. Warren, *The Hunter's Game*: *Poachers and Conservationists in Twentieth-Century America* (New Haven: Yale University Press, 1999); Marybeth Loribiecki, *A Fierce Green Fire* (Helena: Falcon, 2004); Julianne Newton, *Aldo Leopold's Odyssey: Rediscovering the Author of A Sand County Almanac* (New York: Shearwater, 2008); J. Baird Callicott, *Thinking Like a Planet: The Land Ethic and the Earth Ethic* (New York: Oxford University Press, 2014).

[82] Quoted in Meine, *Aldo Leopold*, 155.

federal agents did not "farm" game, but rather regulated the "natural factors of productivity" so that "game farms itself."[83]

Figure 13. Aldo Leopold upon joining the United States Forest Service, 1909. X25 1266, Series 3/1, Box 86, Folder 2, Aldo Leopold Archives, UW Madison.

When Leopold was transferred from New Mexico to the U.S. Forest Products Laboratory near Madison, Wisconsin, in 1924, he continued to study game management as a consultant. In 1931, he completed *Report on a Game Survey of the North Central States* for the Sporting Arms and Ammunition Manufacturers' Institute, in which he argued that game populations could be augmented through the restoration of habitat, rather than predator control or hunting restrictions,

[83] Aldo Leopold, draft of "Southwestern Game Fields" (1927), quoted in Meine, *Aldo Leopold*, 254.

which many prominent conservationists recommended.[84] A reviewer for *Ecology* summarized Leopold's view thusly: "The author does not advocate a return to the former conditions, but the restoration of brush in waste and odd corners."[85]

Leopold contributed this perspective to the "President's Committee on Wild Life Restoration," which he was asked to join in 1933. Another member of the President's Committee, Thomas H. Beck, chairman of the Connecticut State Board of Fisheries and Game and a close friend of the President, proposed that the federal government rear and then artificially stock game birds on reclaimed Midwestern lands. Alternatively, Leopold proposed "the restoration of submarginal and other lands suitable for development for game, nongame, fur and other species."[86] Although Congress appropriated only a fraction of the funds it requested, the

[84] Aldo Leopold, *Report on a Game Survey of the North Central States* (Madison: Sporting Arms and Ammunition Manufacturers' Institute, 1931). Leopold would later credit Herbert L. Stoddard, a Wisconsin naturalist and collector for the Milwaukee public museum, with the "fundamental theory," the theory that wildlife can be "decimated by destroying the balance of its environment" and "restored by readjusting this balance." "New Wisconsin Plan Underway for Conservation," *Oshkosh Daily Northwestern*, 6 April 1934, p 11. Leopold corresponded with Stoddard about quail in the 1920s when Stoddard worked for the USDA Bureau of Biological Survey. In 1930, Stoddard wrote to Leopold that the restoration of cover and food would restore quail populations as many times as three fold. Herbert L. Stoddard to Aldo Leopold, 3 April 1930, Aldo Leopold Papers, Series 9/25/10-1, Correspondence, Box 003, Folder 004, UW Archives.

[85] Barrington Moore, "Review on a Game Survey of the North Central States," *Ecology* 12 (1931): 748-749.

[86] "Minutes of a Meeting with the Senate Wild Life Committee at the Capitol, Washington D.C., 9 January 1934," Records Concerning the President's Committee on Wildlife, Records of Bureau of Biological Survey, Entry 144, Record Group 22, National Archives; Thomas Beck, "What President's Committee Intends To Do," in *American Game Conference, Transactions of the Twentieth American Game Conference* (Washington: American Game Protective Association, 1934); Theodore W. Cart, "'New Deal' for Wildlife: A Perspective on Federal Conservation Policy, 1933-40," *The Pacific Northwest Quarterly* 63 (1972): 113-120; Michael W Giese, *A Federal Foundation for Wildlife Conservation: The Evolution of the National Wildlife Refuge System, 1920-1968* (PhD diss., American University, 2008).

President's Committee's report influenced the Migratory Bird Hunting Stamp Act (popularly known as the Duck Stamp Act) and the National Forest Refuge Act, both passed in 1934.[87]

Figure 14. Jay "Ding" Darling, "Another breathing spell for the sake of recovery," *Des Moines Register*, 30 November 1935. Portrays "Duck Recovery" and "Restoration" coming to the aid of a Wild Duck knocked out by "A Million Shooters," "Law Violators," "Drainage," and "Drought."

[87] President Herbert Hoover had signed the Migratory Bird Conservation Act in 1929 to authorize the federal acquisition of wetlands as waterfowl habitat. The law, however, did not provide a permanent source of money to purchase land. Under the Duck Stamp Act, any person who hunted ducks, geese, swans, or brant had to carry a Duck Stamp, which cost $1. The proceeds went into a special treasury account, the Migratory Bird Conservation Fund. The National Forest Refuge Act permitted tracts of national forest to be set aside as game refuges with state permission.

In 1933, the University of Wisconsin hired Leopold as the research director of its new Arboretum, and landscape architect William Longenecker as its executive director. Leopold and Longenecker immediately clashed. Longenecker believed the Arboretum should plant ornamental trees that would inspire Wisconsinites to beautify their backyards. As was the fashion in horticulture at the time, these trees would be organized by taxa. Leopold, meanwhile, was uninterested in what he derided as "a collection of imported trees."[88] Instead, he proposed that the Arboretum try something "new and different" by using its grounds for wildlife research.[89] The Arboretum could furnish a "non-farm or nearly wild" comparison to "used land," Leopold argued. In a report to the University President, he explained that the technique of "building up populations by improving the environment" had never been directly tested, and that, if managed as an experimental site, the Arboretum could provide insight in how to augment "any animal or plant" – whether a game species or not.[90]

Leopold and Longenecker wouldn't reconcile their visions for the Arboretum, and in 1934, the University gave each responsibility for half of the property. That June, Leopold described his vision for the grounds at the Arboretum dedication ceremony to a crowd of 200 sitting in a heavy-beamed barn, chatting over a breakfast that students had prepared over a

---

[88] Their debate is discussed in Phillip J. Pauly, *Fruits and Plains: The Horticultural Transformation of America* (Cambridge: Harvard University Press, 2008), 190-194. On the history of American arboretums see also Emily Bloom Griswold, "The Origin and Development of Ecogeographic Displays in North American Botanic Gardens" (Master's thesis, University of Washington, 2002).
[89] Thomas J. Blewett and Grant Cottam, "History of the University of Wisconsin Arboretum Prairies," *Transactions of the Wisconsin Academy of Sciences, Arts and Letters* 72 (1984): 130-144; "Memorandum, Proposed Chair of Conservation," 1933, Series 38/3/2, General Files, J. W. Jackson, UW Archives; Aldo Leopold, "Memorandum for President Dykstra on A Research Program for the University of Wisconsin Arboretum," 10 July 1938, Aldo Leopold Papers, Box 001, Folder 001, UW Archives.
[90] Aldo Leopold, "University Arboretum Wild Life Management Plan," 25 October 1933, Aldo Leopold Papers, Box 001, Folder 001, UW Archives.

charcoal fire. Unlike a typical arboretum, designed to exhibit apples, lilacs, roses, and the like, the University of Wisconsin would attempt to reconstruct "a sample of old Wisconsin." He asked the audience to imagine the surrounding landscape as it would have appeared in 1840: the orchard-like stands of oaks, interspersed with shrubs and prairie flowers and populated with sharp-tailed grouse and partridges, elk, and deer. The Arboretum researchers would try to re-create this lost landscape.[91]

In justifying his plans for the Arboretum, Leopold stressed its relevance to the dust storms plaguing the Great Plains. To reconstruct Wisconsin's past landscape, to "dig up these ecological graves," would be to illuminate those changes "which threaten to undermine the future capacity of the soil to support our civilization," he maintained. A reconstructed prairie sample would "serve as a bench mark," as "a starting point" in understanding how to reduce soil erosion.[92]

Leopold's plans were delayed as the University appealed to the U.S. Bureau of Biological Survey and the U.S. Forest Service for funding, to no avail.[93] Then, in 1935, the University was assigned a unit of CCC workers. That summer, "Camp Madison" began to plant prairie vegetation in Leopold's section of the Arboretum. The best place to find prairie species was in what Leopold and other ecologists referred to as "prairie remnants" – patches of untilled ground in cemeteries and railroad right-of-ways. The CCC workers cut out chunks of sod with long-

---

[91] Leopold wrote many versions of this talk. A draft written a few weeks after the dedication ceremony is quoted in Franklin E. Court, *Pioneers of Ecological Restoration: The People and the Legacy of the University of Wisconsin Arboretum* (Madison, University of Wisconsin Press: 2012), 75-76. For another version see Aldo Leopold, "What is the Arboretum?" Address to Nakoma Women's Club, 20 September 1934, Series 38/7/2, Aldo Leopold Papers, UW Archives.
[92] ibid
[93] Court, *Pioneers of Ecological Restoration*, 79-85.

handled shovels from remnant sites and trucked them to the Arboretum. They tore up common species like Quack Grass and Goldenrod, and poisonous ones like Prairie Larkspur and Sundial Lupine. In their place they planted icons of the prairie: Blazing Star, Big Bluestem, Purple Coneflower, Hairy Grama, Prairie Tickseed, Rattlesnake Master, Cut Leaf Violet, and Bur Oak.[94]

Figure 15. CCC workers water a recently planted pine tree at the Arboretum, 1936.
S07045, UW-Madison Collection

By 1938, Camp Madison workers had moved 186,000 yards of dirt, planted 100,000 trees and 9 acres of prairie plants, and dug 14 acres of lagoons. Leopold placed Theodore Sperry, a “sandy-haired, unassuming” graduate of the University of Illinois botany department, in charge

[94] Theodore Sperry, “Prairie Restoration on the University of Wisconsin Arboretum,” Spring 1939, G. William Longenecker, Papers, Series 38/7/2, General Files, Box 1, UW Archives; D. C. Peattie, “Norman Carter Fassett, 1900-1954,” *Rhodora* 56 (1954): 233-242; Roger C. Anderson, *The Use of Fire as a Management Tool on the Curtis Prairie* (Madison: University of Wisconsin Arboretum, 1972); William R. Jordan III, “Some Reflections on Curtis Prairie and the Genesis of Ecological Restoration,” *Ecological Management and Restoration* 11 (2010): 99-107.

of managing the restoration project. Leopold negotiated Sperry's transfer within the CCC from the Forest Service in Illinois to the National Park Service in Madison after reading a condensed version of Sperry's dissertation on the root systems of prairie plants. In two years, Sperry, Leopold, and their CCC crew had successfully transplanted 49 species of prairie flowers and grasses. A 1939 newspaper article, "Clod by Clod, Historical Prairie Returns to Madison's Yard" explained that the Arboretum was working to restore prairie species that had been brought to the brink of extinction by the "settler's plow."[95]

Figure 16. A group of CCC workers dig at the Arboretum, 1936. S07031, UW-Madison Collection.

[95] Russell B. Pyre, "Clod by Clod, Historical Prairie Returns to Madison's Yard: CCC, Dr. Sperry Undo Plow's Work," *Madison Wisconsin State Journal*, 12 November 1939. The CCC remained at Camp Madison until November 1941. See Aldo Leopold to Roberts Mann, 5 November 1941, Aldo Leopold Papers, Series 9/25/10-1, Box 003, Folder 003, UW Archives.

In describing the Arboretum's restoration work, Leopold echoed the language of the ESA Committee on the Preservation of Natural Conditions for Ecological Study. He envisioned the Arboretum as a testing ground for methods of game management and for theories of plant succession. He wrote to the University president in 1938 that the purpose of the Arboretum was "to become an outdoor classroom and research laboratory or 'experimental farm' for the biological sciences bearing on conservation." By manipulating soil, animals, and cultural methods, "agricultural research men" at land grant universities had learned "how soil and crops are put together," Leopold continued. Ecologists were now pursuing something analogous. He emphasized that the Arboretum's aim was "not to build a museum piece, but to learn the hidden mechanisms which underlie conservation use." The Arboretum would be a new type of research site, somewhere between a laboratory and a field station, an outdoor laboratory. "Conservation research needs an area of its own," he wrote, "on which long-time experiments can be undertaken without risk of disruption or interference."[96]

National Recovery, Ecological Restoration

In 1939, Leopold accepted an invitation to deliver a plenary address in a session organized by Paul Sears at the annual American Association for the Advancement of Science (AAAS) meeting that brought together members of the Society of American Foresters and the ESA.[97] While Leopold had been a long time member of the American Society of Foresters, this

---

[96] Emphasis in original. Aldo Leopold, "Memorandum for President Dykstra on A Research Program for the University of Wisconsin Arboretum," 10 July 1938, Aldo Leopold Papers, Box 001, Folder 001, UW Archives; Russ Pyre, "Hook, Line, and Sinker," *Madison Wisconsin State Journal*, 26 December 1943, 25.
[97] Discussed in Mark V. Barrow, *Nature's Ghosts: Confronting Extinction from the Age of Jefferson to the Age of Ecology* (Chicago: University of Chicago Press, 2009). See also Paul B.

meeting solidified his visibility within the ESA.[98] In his presentation, which he titled "A Biotic View of Land," Leopold postulated that in ecological management, "the less violent the man-made changes, the greater the probability of successful readjustment":

> In America, the protests against radical 'timber stand improvement' by the C.C.C. are […] a return to nonviolent forestry. So is the growing skepticism about the ultimate utility of exotic plantations. So is the […] growing realization that only wolves and lions can insure the forest against destruction by deer and insure the deer against self-destruction. We have a whole group of discontents about the sacrifice of rare species: condors and grizzles, prairie flora and bog flora.
>
> These, on their face, are protests against biotic violence. Some have gone beyond the protest stage: witness the Audubon researches for methods of restoring the ivory-billed woodpecker and the desert bighorn; the researches at […] Wisconsin for methods of managing wildflowers. The wilderness movement, the Ecological Society's campaign for natural areas… and the international committees for wildlife protection all seek to preserve samples of original biota as standards against which to measure the effects of violence.[99]

Unlike evolutionary changes, which were "slow and local," as Leopold put it, recent changes were of an "unprecedented violence, rapidity, and scope." (Leopold did not mention World War I, but he and his generation were intimately familiar with the innovations of tanks, flamethrowers, poison gas, bomber planes, and the nine million killed between 1914 and 1918).[100] The problem confronting scientists, Leopold continued, was that ecologists would not

---

Sears, "Report of the Committee on Summer Symposia," *Ecology* 20 (1939): 323-24; "The Milwaukee meeting," *Bulletin of the Ecological Society of America* 20 (1939): 3.

[98] Leopold was elected ESA Vice President in 1945 and president in 1946. Leopold was surprised by his election, and wrote to the ESA Secretary, "I had supposed…that any nominee failing to show up at the meeting would automatically be out of the running." Quoted in Curt Meine, "Aldo Leopold: Connecting Conservation Science, Ethics, Policy, and Practice," in *Linking Ecology and Ethics for a Changing World: Values, Philosophy, and Action,* eds. Ricardo Rozzi, S.T.A. Pickett, Clare Palmer, Juan J. Armesto, J. Baird Callicott (New York: Springer, 2013), 173-186, quote on 174.

[99] Aldo Leopold, "A Biotic View of Land," *Journal of Forestry* 37 (1939): 727-730.

[100] For intellectual histories of the early twentieth century United States, see T. J. Jackson Lears, *No Place of Grace: Antimodernism and the Transformation of American Culture* (Chicago: University of Chicago, 1981); James T. Kloppenberg, *Uncertain Victory: Social Democracy and*

know "how good a performance to expect of healthy land" unless they were able to access "a wild area for comparison with sick ones." A science of restoring land health would require "a base datum of normality, a picture of how healthy land maintains itself as an organism."[101]

Into the 1940s, ecologists and federal agents began to credit one another with the idea of restoration. The ESA noted that the Forest Service had already experimented with reforestation. Aldo Leopold pointed out that the idea for scientific preservation was not his, but had first been recommended by "the American Ecological Society."[102] Although he got the ESA's name wrong, Leopold's choice to frame the Wisconsin Arboretum as an outdoor laboratory drew its force from the work of ESA members promoting the establishment of check-areas. By comparing check-areas with managed areas, ecologists contended, they would be able to correct ecological problems like soil erosion, agricultural pests, and overgrazing.[103] Ecologists argued that the U.S. government should preserve natural areas not for their own sake, but as "yardsticks" against which management could be evaluated. Ecologists thus advocated for preservation in the name of restoration. It was "too haphazard to place trust in finding field-corners, railroad rights-of-way, cemeteries," ecologist S.A. Graham explained in 1935.[104]

Progressivism in European and American Thought, 1870-1920 (New York: Oxford University Press, 1986); Gail Bederman, *Manliness and Civilization: A Cultural History of Gender and Race in the United States, 1880-1917* (Chicago: University of Chicago Press, 1996); Edwin Black, *War Against the Weak: Eugenics and America's Campaign to Create a Master Race* (New York: Dialog Press, 2012).

[101] Leopold, *A Sand County Almanac*, 197, 196.

[102] Quoted in Sutter, *Driven Wild*, 73.

[103] For examples of such arguments, see C. T. Vorhies and W. P. Taylor, *Technical Bulletin 39* (Tucson: Arizona Agricultural Experimentation Station, 1933); J. E. Weaver and E. L. Flory, "Stability of Climax Prairie and Some Environmental Changes Resulting from Breaking," *Ecology* 15 (1934): 333-347.

[104] S. A. Graham, quoted in Hanson, "Check-areas as Controls in Land Use," 134.

Disciplinary ecologists have never fit well into environmental history's canonical claim that two environmental movements arose in the 20th century: conservation and wilderness preservation.[105] Noting that the ESA Committee on the Preservation of Natural Conditions for Ecological Study was founded in the 1910s, historians Sara Tjossem and Robert Croker have situated it in the Progressive Era conservation movement.[106] In contrast, sociologist Abby Kinchy has argued that the Committee's position seems more closely related to the wilderness preservation movement.[107] Whereas conservationists argued that natural areas needed to be

---

[105] To delve into the vast literature on the American conservation and preservation movements, see Henry Nash Smith, *Virgin Land: The American West as Symbol and Myth* (Cambridge: Harvard University Press, 1950); Samuel P. Hays, *Conservation and the Gospel of Efficiency: The Progressive Conservation Movement, 1890-1920* (Cambridge: Harvard University Press, 1959); Roderick Frazier Nash, *Wilderness and the American Mind* (New Haven: Yale University Press, 1967); Lee Clark Mitchell, *Witnesses to a Vanishing America: The Nineteenth-Century Response* (Princeton: Princeton University Press, 1981); William Cronon, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," in *Uncommon Ground: Rethinking the Human Place in Nature*, ed. William Cronon (New York; W W. Norton & Co., 1995), 69-90; Louis Warren, *The Hunter's Game: Poachers and Conservationists in Twentieth-Century America* (New Haven: Yale University Press, 1997); J. Baird Callicott and Michael P. Nelson, eds., *The Great New Wilderness Debate* (Athens: University of Georgia Press, 1998); Mark David Spence, *Dispossessing the Wilderness: Indian Removal and the Making of the National Parks* (New York: Oxford University Press, 2000); Adam Rome, *The Bulldozer in the Countryside: Suburban Sprawl and the Rise of American Environmentalism* (Cambridge: Cambridge University Press, 2001); Paul Sutter, *Driven Wild: How the Fight against Automobiles Launched the Modern Wilderness Movement* (Seattle: University of Washington Press, 2002); Carolyn Merchant, *Reinventing Eden: The Fate of Nature in Western Culture* (New York: Routledge, 2003); Karl Jacoby, *Crimes against Nature: Squatters, Poachers, Thieves and the Hidden History of American Conservation* (Berkeley: University of California Press, 2003).

[106] Robert W. Croker, *Pioneer Ecologist: The Life and Work of Victor Ernest Shelford, 1877–1968* (Washington D.C.: Smithsonian Institution Press, 1991); Sara F. Tjossem, "Preservation of Nature and the Ecological Society of America, 1915-1979" (PhD diss., Cornell University, 1994). As Gina Rumore (2011) points out, Russian ecologists were engaged in a parallel movement, beginning in the 1890s, to preserve tracts of nature for scientific study, but there is no evidence that they influenced the ESA. See Douglas Weiner, *Models of Nature: Ecology, Conservation, and Cultural Revolution in Soviet Russia* (Pittsburgh: University of Pittsburgh Press, 1988).

[107] Abby J. Kinchy, "On the Borders of Post-War Ecology: Struggles Over the Ecological Society of America's Preservation Committee, 1917–1946," *Science as Culture* 15 (2012): 23-

managed for long-term use, she explains, preservationists argued that natural areas should be protected from human interference. But, as Paul Sutter and others have shown, the Preservation Committee did not have a comfortable relationship with societies that lobbied for wilderness preservation for aesthetic and recreational purposes.[108]

The key to understanding how the ESA's efforts map onto the histories of conservation and wilderness preservation lies in a third concept that developed over the 1920s and 30s: restoration. Certainly, ecologists borrowed from others' arguments that the government needed to act quickly to save natural communities for aesthetic, recreational, and cultural reasons. But they also developed a new language about restoration, recovery, and rehabilitation; check-areas, baselines, and yardsticks. Once ecologists had learned about succession through permanent field sites, Clements wrote in 1935, they could then restore eroded lands using the same tool "by which nature reclothes bare areas."[109]

The Legacies of Failed Projects

44.

[108] Paul Sutter, *Driven Wild: How the Fight against Automobiles Launched the Modern Wilderness Movement* (Seattle: University of Washington Press, 2002); Julianne Lutz Warren, "Science, Recreation, and Leopold's Quest for a Durable Scale," in Michael P. Nelson and J. Baird Callicott (eds.), *The Wilderness Debate Rages On* (Athens: University of Georgia Press, 2008), 97-118. Historian Paul Sutter has contended that above all else, early wilderness advocates were motivated by their distress over the proliferation of automobiles in the 1920s – a distress that reflected discomfort with rapid modernization, industrialism, and mass consumerism. Indeed, the interwar era was a time of aggressive road construction across the country. On Forest Service property alone, the extent of roads increased from a few thousand miles in 1916 to almost 90,000 miles by 1935. While today we think of wilderness areas as areas dedicated to species protection, Sutter suggests this was not the intention of early wilderness advocates – that in fact "ecological concerns were not a central causative agent or a major component in the founders' definition of modern wilderness." Sutter, *Driven Wild*, 14.

[109] Clements, "Experimental Ecology in the Public Service."

The impact of the Committee on the Preservation of Natural Conditions for Ecological Study on the American landscape was trivial, or colossal, depending on how one looks at it. From its founding in 1917 through World War II, the Committee only managed to set aside a few areas for ecological study. In 1937, ESA President R. E. Coker addressed a crowd at the annual dinner of the ESA in Indianapolis:

> That natural areas are necessary for research *in situ* and for controls against research conducted elsewhere and against our agricultural and industrial developments has little meaning to the ordinary sojourner in this great land that we appropriated some three hundred years ago from its original guardians and conservators […] Nowhere in this country, at least, has there ever been expressly set aside a single adequate area of grassland as a control or check plot. This is an extraordinary condition, and it might seem even more so were it not for the fact that we see so many other indications, in respect to war for example, that modern man is still at the beginning and not at or beyond the end of the real Renaissance.[110]

But in 1950, the Committee changed its name to The Nature Conservancy. By 1980 The Nature Conservancy was an international organization. Today it is the largest environmental NGO in the world, with one million members, assets of more than six billion dollars, and ownership or oversight of thousands of protected areas that, if combined, would cover an area larger than Sweden.[111]

The Committee's work also laid the groundwork for debates regarding the role of ecologists in federal environmental policy and implementation. The headway that ecologists made in the 1930s would lead Paul Sears to proclaim, a decade later, that "young growing

[110] R. E. Coker, "Functions of an Ecological Society," *Science* 87 (1938): 309-315.
[111] Bill Birchard, *Nature's Keepers: The Remarkable Story of How the Nature Conservancy Became the Largest Environmental Group in the World* (New York: Jossey-Bass, 2005); Mark Dowie, *Conservation Refugees: The Hundred-Year Conflict between Global Conservation and Native Peoples* (Cambridge: MIT Press, 2011).

Ecology" could "rescue man from the blinding dust storm, the burning drouth, the swirling flood, the disasters of erosion and enable him to live more happily with his fellowmen."[112]

And as this chapter explores, the concept of ecological restoration emerged, in large part, from the Committee's efforts. Embedded in this story is a change in how ecologists envisioned their field sites. In the early twentieth century Cowles and other theorists of succession had sought linear tracts along which to study gradients of wind, water, and other physical factors. By the end of the 1930s, ecologists strove to work in two types of sites: patches of rare species, also known as "relict colonies," and experimental sites at which ecologists could study the effects of physical factors *and* human activity. Plant communities represented "the best of all natural experiments," Clements wrote in 1934, because they integrated a range of natural processes – migration, settlement, competition – with human disturbances. "The interaction of all these climatic and human processes impart to the biome a quasi-experimental value that is not often to be matched by actual experiments," he concluded.[113]

To understand the emergence of this new mode – restoration – we must turn back to the Dust Bowl, to the question of what to do with the ruined plains and their displaced residents. If drought was the new climatic state, then the Midwest was no longer suited to wheat and corn production. But if it was temporary, then the Midwest could be repopulated, as long as experts figured out how to restore and maintain the productivity of the once-promising soil.

---

[112] Paul B. Sears, "A Foreword to the First Report of the Committee of The Ecological Society of America for an Endowment Policy and Program," c. 1947, Box 13, Folder 225, Paul Bigelow Sears Collection (MS455), Special Collections at the University of Arizona Libraries, Tucson, Arizona [hereafter PSC]; Arthur G. Tansley, "The Classification of Vegetation and the Concept of Development," *Journal of Ecology* 8 (1920): 118-149; Arthur G. Tansley, "Succession: The Concept and its Values," *Proceedings of the International Congress of Plant Sciences* 1 (1926): 677-686.
[113] Frederic E. Clements, "The Relict Method in Dynamic Ecology," *Journal of Ecology* 22 (1934): 39-68.

CHAPTER 5

TOOLS FOR TIME TRAVEL:

RECONSTRUCTING AMERICA'S ECOLOGICAL PAST

"The historical factor, as it is called, has become indispensable to the interpretation of the living landscape." –Paul B. Sears addressing the Ecological Society of America, 1949

Ecology and the Past

The disasters of the Dust Bowl spurred a new interest in America's ecological past. Had drought been anomalous, cyclical, or frequent in the past? Was erosion a natural process, or were the black blizzards the fault of new, too-powerful technologies like gasoline-powered tractors, one-way disc plows, and combines? Or was the cause of the dust storms neither climatic nor technological, but social, the poor decisions of (often poor, immigrant) farmers, as suggested by the United States Resettlement Administration's 1936 documentary film, "The Plow that Broke the Plains"? Ecologists weighed in, vying with other scientists to be considered the experts on that past. As they did, succession theory gave way to paleolimnology and then radiocarbon dating as methods of envisioning past ecological communities. From this change a new type of restoration benchmark emerged – one that was temporal rather than spatial.

Historians like to trace the study of human history back to ancient Greece and the writings of Herodotus. The study of biological history is a much more recent phenomenon. But for denizens of the nineteenth century, time was in flux. Railroads collapsed the amount of time it took to travel between towns. Industrial jobs standardized daily schedules. And the rise of secular science popularized new ideas about the age of the world. In 1895, John Burroughs described these changes as "like being fairly turned out into the cold, and made to face without shield or shelter the eternities and the infinities of geologic time and sidereal space."[114]

The science of evolutionary biology emerged in this time of temporal tumult. In 1796, George Cuvier published a paper arguing that fossils were the remains of animals that no longer existed. Prior to Cuvier's work, naturalists assumed that bizarre fossils were the remains of species from the tropics, or perhaps the deep sea, that had simply yet to be discovered. In response, Cuvier's leading critic, the British naturalist Charles Lyell, argued that no one had ever observed the kind of global-scale catastrophic events that Cuvier's theory of extinction relied upon. Instead, all evidence suggested that the Earth changed very gradually. And this meant the age of the earth must be millions of years, not six thousand.[115]

---

[114] John Burroughs, "An Open Door," in *The Writings of John Burroughs* (Boston: Houghton, Mifflin, and Co., 1889); On shifting conceptions of time over the past few centuries, see Wolfgang Schivelbusch, *The Railroad Journey: The Industrialization of Time and Space in the 19th Century* (Berkeley: University of California Press, 1977); Peter Galison, *Einstein's Clocks and Poincare's Maps* (W. W. Norton & Co., 2003).

[115] On the history of geological time see A. R. Wallace, "The Measurement of Geological Time," *Nature* 1 (1870): 399-401; Stephen Toulmin and June Goodfield, *The Discovery of Time* (Chicago: University of Chicago Press, 1982); John McPhee, *Basin and Range* (New York: Farrar, Straus and Giroux, 1982); Paolo Rossi, *The Dark Abyss of Time: The History of the Earth and the History of Nations from Hooke to Vico* (Chicago: University of Chicago Press, 1984); Stephen Jay Gould, *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time* (Cambridge: Harvard University Press, 1988); Stephen Jay Gould, *Wonderful Life: The Burgess Shale and the Nature of History* (New York: Norton, 1989); Martin Rudwick, *Scenes from Deep Time: Early Pictorial Representations of the Prehistorical World* (University of Chicago Press 1992); William H. Stiebing, *Uncovering the Past: A History of Archaeology* (New York: Prometheus Books, 1993); Henry Gee, *In Search of Deep Time: Beyond the Fossil Record to a New History of Life* (Ithaca: Cornell University Press, 2000); Mircea Eliade, *The Myth of the Eternal Return: Cosmos and History* (Princeton: Princeton University Press, 2005); Robert Kubicek, "Ages in Chaos: James Hutton and the Discovery of Deep Time," *The Historian* 70 (2008): 142–143; Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: University of Chicago Press, 2008); Elizabeth Kolbert, "The Lost World: The Mastodon's Molars" *The New Yorker* (16 December 2013 and 23 December 2013): 28-38, 48-56.

Charles Darwin came to his theory of natural selection in part through the work of Lyell. Darwin and others who believed in gradualism searched for the history of species in landscapes, hypothesizing that older environments housed more developed communities of species, that plants, animals, and humans alike progressed through successive stages of development.[116] By the late 1800s, natural history museums were displaying fossil animals and plants, inviting their viewers to imagine organisms that looked much different from those in the present.[117] For decades, the most popular way to study evolutionary history was to characterize the morphological variation among samples within samples. With this method, Raphael Weldon and other early biometricians attempted to test popular biogeographical theories like the theory that animals in colder regions had evolved to be larger than those in warmer regions.[118]

---

[116] The greatest objections to Darwin's theory of natural selection critiqued his calculation of the length of time that had passed since the beginning of the Cambrian, which one geologist called "an abuse of arithmetic." Debate over the age of the Earth continued through Darwin's life, and Darwin struggled to reconcile the contracts between the brevity of geological time and the slowness of organic change. See Loren Eiseley, *Darwin's Century: Evolution and the Men who Discovered It* (New York: Anchor, 1961); Joe D. Burchfield. "Darwin and the dilemma of geological time," *Isis* 65 (1974): 300-321; Martin J.S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists* (Chicago: University of Chicago Press, 1988).

[117] Ronald Rainger, "Representing Nature: The Portrayal of Prehistoric Life at the American Museum," in *An Agenda for Antiquity: Henry Fairfield Osborn and Vertebrate Paleontology at the American Museum of Natural History, 1890 –1935* (Tuscaloosa: University of Alabama Press, 1991), 152–182; Lynn K. Nyhart, "Science, Art, and Authenticity in Natural History Displays," in Soraya de Chadarevian and Nick Hopwood (eds.), *Models: The Third Dimension of Science* (Stanford: Stanford University Press, 2004), 307–335; Ralph O'Connor, *The Earth on Show: Fossils and the Poetics of Popular Science, 1802–1856* (Chicago: University of Chicago Press, 2007); Paul Brinkman, *The Second Jurassic Dinosaur Rush: Museums and Paleontology in America at the Turn of the Twentieth Century* (Chicago: University of Chicago Press, 2010); Lukas Rieppel, "Brining Dinosaurs Back to Life: Exhibiting Prehistory at the American Museum of Natural History," *Isis* 103 (2012)" 460-490.

[118] I have written about the relationship between biometry and early ecology in Martin, "Mathematizing Nature's Messiness: Graphical Representations of Variation in Ecology, 1930-present," *in review*. See also Theodore M. Porter, *The Rise of Statistical Thinking*, *1820-1900* (Princeton: Princeton University Press, 1986); Charles C. Camic and Yu Xie, "The Statistical

In 1913, the British Ecological Society (BES) emerged from the British Vegetation Committee, which had been founded in 1904 to promote the study of plants on the British Isles. The following year, a group of about fifty zoologists and botanists at the American Association for the Advancement of Science annual meeting voted to form the Ecological Society of America (ESA). Early adopters of the label "ecologist" came from backgrounds previously defined by taxa or habitat – botany, zoology, anthropology, limnology, forestry – and were united by the common goal of understanding how environments shaped the form and function of species. In a 1919 address to the newly formed ESA, Barrington Moore asked his audience: "Will we be content to remain zoologists, botanists, and foresters, with little understanding of one another's problems, or will we endeavor to become ecologists in the broad sense of the term?"[119] But in large part, early ecologists continued to study only plants or only animals, seeking to identify the conditions that explained their current distributions. It was not until the 1940s that the sub-discipline of ecological history emerged from the rather obscure pursuits of "pollen stratigraphy" and "paleolimnology," and in doing so, changed the baseline for ecological restoration.

In many ways, Leopold's *A Sand County Almanac* is a snapshot of the transition explored in this chapter. In this book, Leopold would describe "a sense of history" as "the most precious gift of science and of the arts."[120] Indeed, much of *A Sand County Almanac* is a meditation on the relationship between American history and the history of its landscapes, especially its relict plant communities – the railroad right-of-ways, cemeteries, and other fragments that Shelford,

---

Turn in American Social Science: Columbia University, 1890 to 1915," *American Sociological Review* 59 (1994): 773-805; D. R. Cox, "Biometrika: The First 100 Years," *Biometrika* 88 (2011): 3-11.

119 Moore's speech is reproduced in Barrington Moore, "The Scope of Ecology," *Ecology* 1 (1920): 3-5. The meeting program is published in the same issue.

120 Aldo Leopold, *A Sand County Almanac and Sketches Here and There* (New York: Oxford University Press, 1949), 161.

Clements, and other ecologists had tried to protect. In his essay "The Land Ethic," Leopold wrote:

> Historians wonder what would have happened if the English at Detroit had thrown a little more weight into the Indian side of those tipsy scales which decided the outcome of the colonial migration into the cane-lands of Kentucky. It is time now to ponder the fact that the cane-lands, when subjected to the particular mixture of forces represented by the cow, plow, fire, and axe of the pioneer, became bluegrass. What if the plant succession inherent in this dark and bloody ground had, under the impact of these forces, given us some worthless sedge, shrub, or weed? Would Boone and Kenton have held out? Would there have been any overflow into Ohio, Indiana, Illinois, and Missouri? Any Louisiana Purchase? Any transcontinental union of new states? Any Civil War?[121]

While Leopold brought up plant succession many times in *A Sand County Almanac*, he mentioned pollen stratigraphy only once. In the essay, "Bur Oak," which Leopold wrote around 1941, he explains that botanists could now reconstruct plant communities 20,000 years into the past by studying the pollen fossilized in peat bogs: "The record consists partly of pollen grains embedded in peats, partly of relic plants interned […] and there forgotten."[122]

Peat Stratigraphy

German scientists first identified fossil pollen in coal seams with compound microscopes in the 1830s, but it was not until the 1910s that botanists began to study the pollen "interned" in peat – a soil-like sediment consisting of partially decayed plant matter that collects in acidic bogs, fens, mires, and moors. The Swedish geologist Lennart von Post first developed a method of extracting fossil pollen grains from peat while working for the Swedish Geological Survey in the early 1900s. His interest in pollen was motivated by an interest in geology – he hoped to reconstruct the history of bog formation in southern Sweden. Mixing peat samples with a strong

---

[121] Leopold, *A Sand County Almanac*, 184.
[122] Aldo Leopold, "Bur Oak is Badge of Wisconsin," *Wisconsin Agriculturist and Farmer* 68 (5 April 1941): 10.

base in order to separate pollen grains from other material, and then staining the pollen with safranin or gentian violet, von Post and his assistants worked to classify and count grains under a microscope. They found a layer of spruce pollen in most of the bogs they sampled, and hypothesized that they could use this "spruce boundary" to determine the relative ages of the sites.[123]

Von Post's methodology remained obscure until 1921, when the dissertation of one of his students, Otto Gunnar Erdtman, "An Introduction to Pollen Analysis," was published in German. It quickly circulated among botanists in Europe and the United States.[124] The first to make it his career specialty in North America was Paul Bigelow Sears, an ambitious young botanist from Bucyrus, Ohio. As a graduate student at the University of Nebraska, Sears studied used dandelions as a model species to study the development of pollen cells under the instruction of Charles E. Bessey, Frederic Clements's former advisor. After receiving an M.A. in 1915, he began a Ph.D. program at the University of Chicago under Henry Cowles.[125]

---

[123] Lennart von Post, "Einige Sudschwedischen Quellmoore," *Bulletin of the Geological Institute of the University of Uppsala* 15 (1916): 219-278. On the history of palynology, the study of pollen, see R. P. Wodehouse, *Pollen Grains: Their Structure, Identification and Significance in Science and Medicine* (New York: McGraw Hill, 1935); A. A. Manten, "Lennart von Post and the Foundation of Modern Palynology," *Review of Paleobotany and Palynology* 1 (1967): 11-22; G. Erdtman, "Glimpses of Palynology, 1916-1966," *Review of Paleobotany and Palynology* 1 (1967): 23-29; Unnamed, "On the Earliest Microscopical Observations of Pollen Grains," *Review of Palaeobotany and Palynology* 9 (1969): 5-16.

[124] O. Erdtman, *Pollenanalytische Untersuchungen von Torfmooren und marinen Sedimenten in Südwest-Schweden* (PhD Dissertation, Stockholms Högskola, 1921).

[125] On Sears's biography, see John F. Disinger, "Paul B. Sears: The Role of Ecology in Conservation" *Ohio Journal of Science* 109 (2009): 88-90; Sallie Harris Sears, "Paul B. Sears: Through a Daughter's Eyes," *Ohio Journal of Science* 109 (2010): 119-127. More has been written about Bessey. See Thomas R. Walsh, "Charles E. Bessey: Land-Grant Professor" (PhD Dissertation, University of Nebraska Lincoln, 1972); Ronald Tobey, "Theoretical Science and Technology in American Ecology," *Technology and Culture* 17 (1976): 718-28; Richard A. Overfield, "Trees for the Great Plains: Charles E. Bessey and Forestry," *Journal of Forest History* 23 (1979): 18-31; Ronald Tobey, *Saving the Prairies: The Life Cycle of the Founding*

At Chicago, Sears was trained in the plant successional theory that Cowles promoted while he continued his work in pollen cytology. After serving in the Army from 1917 to 1919, he worked briefly as a botany instructor at Ohio State University. There he continued a project he had begun on "a reconstruction of the vegetation of Ohio as it was before European settlement."[126] Using the records of Columbia's General Land Office, he studied records made by federal land surveyors after the Northwest Territory was opened to European settlement in 1786. Those surveyors divided the land into mile-square sections, and at each corner, they noted the location of the most prominent or "witness" trees.[127] Sears realized that the vegetation of the region before European settlement could be inferred from these records. He supplemented this information by visiting "prairie remnants" in cemeteries and railroad right-of-ways and applying Cowles' successional theory.[128]

Sears first explained this work in 1918 in a short paper in *Science*. In the article he also described what might be the first example of remote sensing for ecology. He writes that while stationed at Door Field, Arcadia, Florida, in 1918, he had "the excellent opportunity to test the utility of the airplane as an aid in vegetation reconnaissance and mapping." He continued:

> It goes without saying that experience of this sort came as a by-product of other duties which fairly filled the time. There are two basic facts to emphasize in connection with airplane reconnaissance—first, the tremendous increase in perspective made possible,

---

School of American Plant Ecology, 1895-1955 (Berkeley: University of California Press, 1981), Chapter 1.

126 Paul B. Sears, "Vegetation Mapping," *Science* 53 (1921): 325-327.

127 On the history of witness trees and their significance to Environmental History, see Daegan Miller, "Witness Tree: Landscape and Dissent in the Nineteenth-Century United States" (PhD Dissertation, Cornell University, 2013).

128 Sears published this work in 1925 and 1926 in a series titled "The Natural Vegetation of Ohio." Paul B. Sears, "The Natural Vegetation of Ohio," *The Ohio Journal of Science* 25 (1925): 139-149. See also Ronald L. Stuckey, "Contributions of Paul B. Sears to Natural Vegetation Mapping in Ohio," *The Ohio Journal of Science* 109 (2009): 91-98.

and second, the fact that each type of vegetation preserves its distinctive shade of color, and often a distinctive texture, so long as it remains visible. […]

[O]ne has only to examine mosaic airplane maps made with one of the excellent automatic cameras now available to realize that this method can be just as useful for mapping vegetation as for locating gunpits or analyzing topography. Because of the cost it is not likely that extensive photographic maps will often be undertaken by individuals, but pressure from individuals may be highly instrumental in getting organized agencies to undertake methodical mapping of this kind while native vegetation still remains.

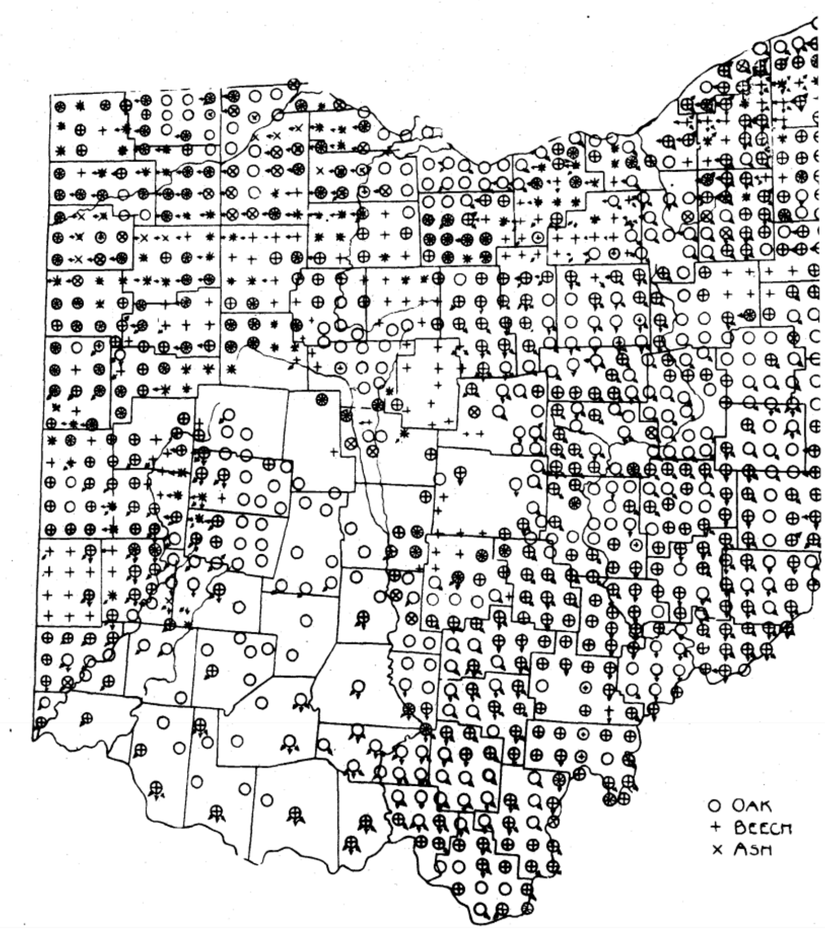


Fig. 2. Map of the Ohio Virgin Forest.

Figure 17. Figure from Paul B. Sears, "The Natural Vegetation of Ohio," *The Ohio Journal of Science* 25 (1925): 128-146.

As Sears worked on the Ohio project, he was struck by the number of relict plant communities that seemed more characteristic of the grasslands of the continental interior than of the forests of Ohio. A friend from Ohio State University, E. N. Transeau, suggested that he read Henry Gleason's recent article, "Vegetational History of the Midwest," which contended that after the Ice Age, there had been a warmer and dryer climate than that of the present. Sears' summary of Gleason's article read:

- Migration of a species depends on an environmental change within or beyond its range.
- Species of similar environmental demands migrate together.
- Former migrations are indicated by the occurrence and distribution of relict colonies and species, by ecological and taxonomic evidence as stated by Adams, by glacial history and topography, by fossils, and by inferences as to former climate.[129]

Around this time, Sears also read Erdtman's dissertation on peat stratigraphy. Sears's work on pollen cytology had connected him with a small network of pollen morphologists.[130] In the juxtaposition of Gleason's and Erdtman's work, Sears realized a new application for peat stratigraphy.[131] Unlike the handful of other scientists who were using peat stratigraphy to determine the relative dates of bogs, mostly in Europe, and mostly for the coal industry, Sears would use it to study the ecological history of the Midwest.

The first bog that Sears sampled was in his hometown of Bucyrus, Ohio. In the peat from Bucyrus Bog he found fir, spruce, cattail, rushes, sedges, juniper, hemlock, oak, elm, ambrosia, maple, ash, and other genera. Graphing the relative proportions of four genera by depth – *Quercus* (oak), *Pinus* (pine), *Picea* (spruce), and *Abies* (fir) – he hypothesized that since the Wisconsin glaciation, the climate had progressed from cold-wet to cool-dry to cool-moist to warm-moist.

---

129 Sears's notes on Gleason (1923), Box 5, Folder 2, PSC.
130 See, for example, correspondence with R. P. Wodehouse in Folder 23, Box 1 PSC.
131 Paul B. Sears, "A Record of Post-Glacial Climate in Northern Ohio," *The Ohio Journal of Science* 30 (1930): 205-217.

The peat profiles seemed to correspond with a hypothesis recently put forth by Richard Foster Flint, a geologist at Yale, that glacial retreat consisted of an alternation of retreats and re-advances, rather than a continuous retreat, causing a cycling of moist and dry episodes.[132] "Great shifts in climate do not occur smoothly," Sears explained to *The Literary Digest* in 1934. "They may rather be likened to the progress of a drunken man, staggering from side to side as he goes forward along the path. Oscillations of slight degree occur every few years, those of more intense character every few decades, while larger changes may require respectively centuries or millenniums."[133]

---

[132] Sears mentioned this connection in notes for lecture he delivered before the Mexican Society of Natural History, 3 June 1955, Box 3 Folder 27, PSC.
[133] Paul Sears, "Climate in Northern Hemisphere Since Ice Ages," *Literary Digest*, 6 Jan 1934. Clipping in Box 5, Folder 6, PSC.

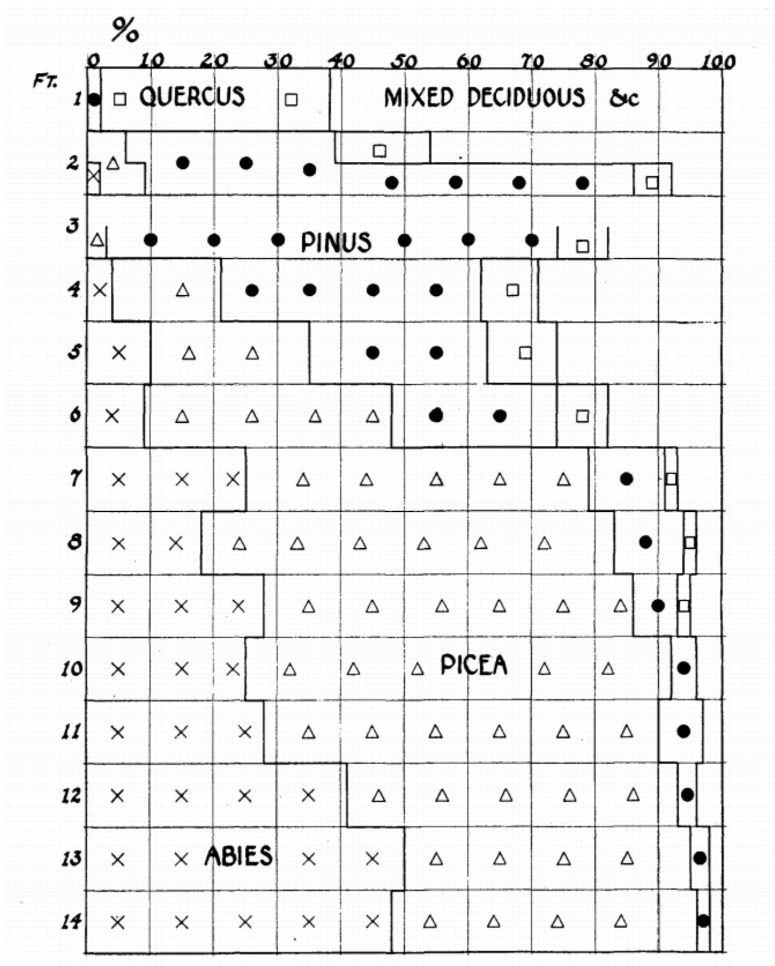


FIG. 1. POLLEN DIAGRAM OF THE BUCYRUS BOG.

Figure 18. A figure from Paul B. Sears, "A Record of Post-Glacial Climate in Northern Ohio," *The Ohio Journal of Science* 30 (1930): 205-217.

In his new position as a lecturer at the University of Nebraska, Sears set out to refine the von Post method and to construct an identification key for North American pollen.[134] In an interview for the *Arkansas Gazette*, Sears explained his fieldwork. First he would locate a peat bog, which usually formed in basins carved during the last ice age. Standing on the floating moss mat, he pushed a large hollow rod into the springy *Sphagnum* moss and removed cylindrical

[134] He describes this project in Paul B. Sears, "Common Fossil Pollen of the Erie Basin," *Botanical Gazette* 89 (1930): 95-106.

sections until he hit the bottom of the deposit. He then wrapped these sections in butter parchment. Back at the laboratory, he would take samples from every six inches of this cylinder. Through "chemical methods," usually shaking with an acid such as HCl, shaking with mineral oil, and placing the oil extracts on filter paper, he extracted the pollen from the muck. He then mounted the grains on slides and identified them under a microscope.[135]

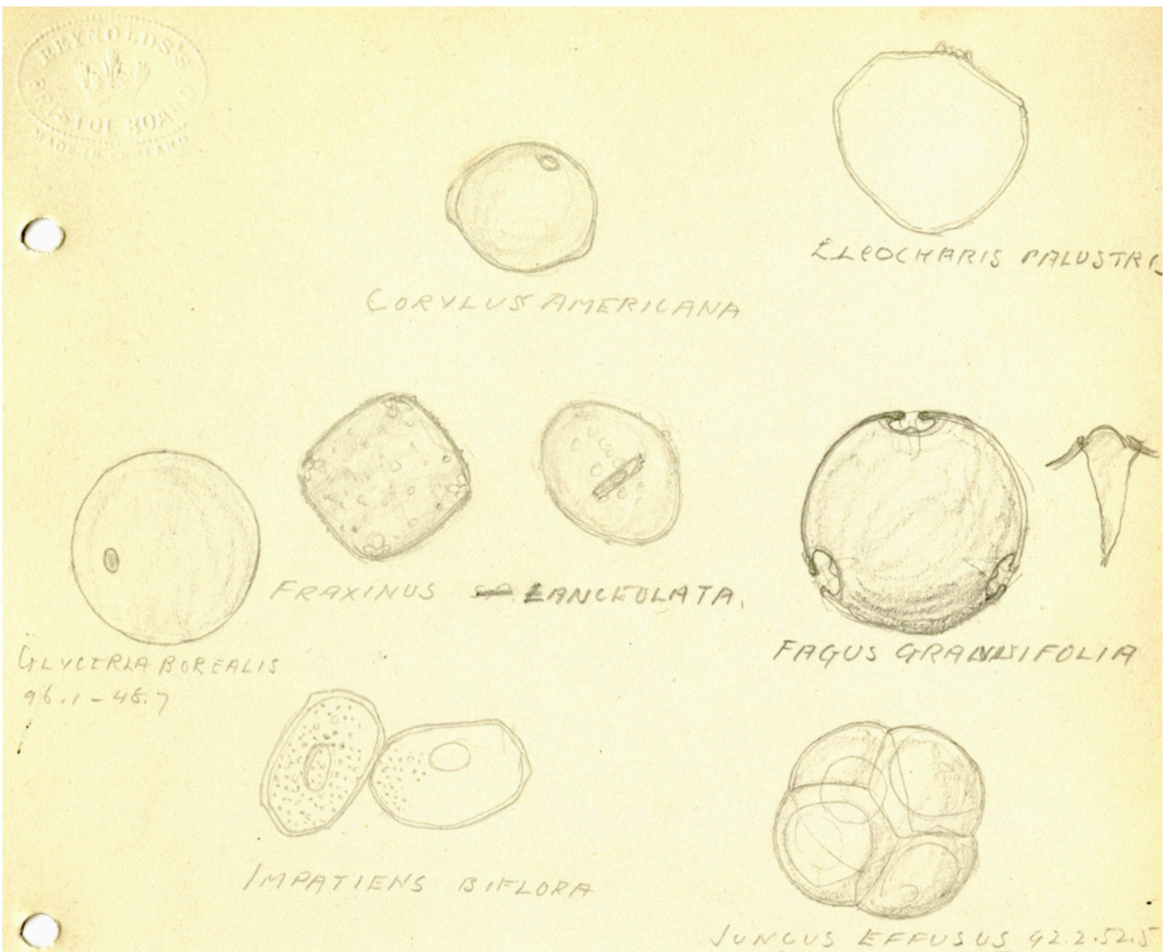


Figure 19. Sketches of pollen grains from Sears's notebook, c. 1925. Box 6, Folder 79, PSC.

[135] Clipping in Paul B. Sears to Mr. Johnny Erp (University of Arkansas, Fayetteville), 25 May 1934, Box 1, Folder 6, PSC.

Using the changing proportions of these pollens, Sears inferred how the plant community had changed over time, and therefore, how the climate had changed. Certain species, like hemlocks, he and other ecologists reasoned, grew in moist conditions. Others, like oaks, grew in dry conditions.[136] In a talk later in his career, Sears explained: "Plant communities are the direct reflection of environment, expanding their numbers to climax stage under favorable conditions of topography, soil, and climate. […] Records of environmental changes are contained in both the biotic and mineral deposits.[137]

Opportunities in the Dust Bowl

In 1928, Sears moved to the Botany Department at the University of Oklahoma, where he would remain until 1938. From Oklahoma, he worked to expand his collection of peat cores beyond Ohio. By 1930 he had collected from bogs in Indiana and Michigan. By 1933, he added Pennsylvania, Tennessee, and Oklahoma to that list.

But it was the Dust Bowl that would solidify Sears's influence and network. In the mid-1930s, scientists debated whether the dust storms had been inevitable. Some felt that drought was part of a natural cyclical cycle. But those critical of farming practices felt that plowing had loosened the soil. As the drought worsened, more and more people became interested in Sears's work. Sears, who had begun studying peat cores to understand vegetational history, found himself increasingly answering questions about climatic history. By 1938, Sears had obtained samples or been sent samples from Arizona, California, Colorado, Connecticut, Delaware, Illinois, Iowa, Minnesota, Montana, New Hampshire, New Jersey, New Mexico, New York,

---

[136] Paul B. Sears to Mr. Johnny Erp, 18 May 1934, Box 1, Folder 6, PSC.
[137] Draft of talk at Symposium on Bottom Sediments – Joint Session Ecological and Limnological Societies of America, 31 Dec 1947, Chicago, Box 6, Folder 26, PSC.

Oregon, South Carolina, Texas, Washington, and Wyoming. Many of these samples were sent to Sears from employees of the U.S. Forest Service and the new Soil Conservation Service.[138]

Figure 20. Photograph from Josephine Robertson, "Reads Future in Pollen of Past," The Cleveland Plain Dealer, c. 1935. Clipping in Box 5, Folder 6, PSC.

[138] The logbook with the codes for Sears's peat collections is in Box 6, Folder 82, PSC. 1935 archaeologists learned of Sears through "American Men of Science." Could date mastodon tusk, pottery shards. Clarence R. Smith to Paul B. Sears, 27 June 1935, MS455 Box 1 Folder 20.

Figure 21. Photograph from Charles Fitzhugh Talman, “Tracing Prehistoric Weather,” unknown publication, July 28, 1935. Clipping in Box 5, Folder 6, PSC.

Sears’s work began to receive national news coverage. Much of this reporting framed pollen analysis as having demonstrated that climate change was nothing new. In 1933, the Science Service wrote of Sears’s research:

> The great American corn belt, that rich agricultural empire that now centers in eastern Iowa and western Illinois with its borders extending from Indiana to central Nebraska, seems to have been more or less of a migrant during past ages, swinging from west to east and back again in sensitive response to changes in climate.[139]

Another article on Sears’s work explained:

> Recent attempts to convert cattle ranges into farms on the western Great Plains have been a failure, because the climate is too dry for farming. But between 5500 and 2000 B.C. bumper crops of corn might have been raised in that region, which then had plenty of rain. […] The man in the street may cherish an exaggerated idea of climatic instability, yet his familiar assertion, ‘The climate has changed,’ is literally true. Climates are always

[139] Science Service, “An Oscillating Corn Belt,” 6 Sept 1933. Reprint in Box 5, Folder 5, PSC.

> changing. There have been at least four tremendous ice ages in the history of our planet, and we are now living in a mild stage of one of them.[140]

Increasingly, Sears and his colleagues framed pollen analysis as a tool for predicting the ecological future. "The future weather and possible fate of the midwest's dust bowl can be foretold by a 'pollen grain calendar,'" the Associated Press reported in 1937, which gave scientists "the clues to past economic disasters or prosperity of prehistoric men." Pollen deposits may "contain the answer to the dust bowl's future," Sears explained to the reporter.[141] "Land must be classified on the basis of optimum permanent use," Clements wrote in *Ecology* in 1935; "No such convincing proof of the unwisdom of attempting to settle land by the trial-and-error method has ever been afforded as that now available throughout the Great Plains."[142] In his widely popular 1935 book, *Deserts on the March*, Sears argued that if vegetation could not be restored to the Great Plains, the result would be the irreplaceable loss of topsoil, to the detriment of the world's food supply:

> While the county agent instructs his patrons in the more practical problems which they encounter – handling of livestock and crops, marketing, and farm engineering – the ecologist should devote his energy to study and his thought to the future. Thus would he supplement the work of his colleague and furnish the sustaining background of policy which, as we have seen, is too often lacking in the daily strain of meeting problems directly. From the studies of the local ecologist, whether he serves one county or a group of them, must come the data indispensable to state and national planning.[143]

---

[140] Charles Fitzhugh Talman, "Tracing Prehistoric Weather," unknown publication, 28 July 1935. Clipping in Box 5, Folder 6, PSC.

[141] Associated Press, "Sears Reads Dust History in Peat Bogs: Pollen Grain May Give Clue to Dust Bowl's Fate," 17 March 1937, clipping in Box 5, Folder 6, PSC.

[142] Frederic E. Clements, "Experimental Ecology in the Public Service," *Ecology* 16 (1935): 342-363. On ecologists' arguments that they should advise public land planning, see also Donald Worster, *Dust Bowl: The Southern Plains in the 1930s* (New York: Oxford University Press, 1979), 198-201.

[143] Paul B. Sears, *Deserts on the March* (1935) (Norman: University of Oklahoma Press), quote on 229. See also G. Edward Pendray (Science Editor, *Literary Digest*) to Paul B. Sears, 21 July 1936, Box 1 Folder 17: "The Country Gentleman has asked me to prepare a piece on whether or not the climate is changing. I wonder if you can say from your studies whether there seems to be

Sears acknowledged, however, that his pollen work did not extend to the arid West. These states might be very sensitive to changes in climatic conditions, he explained in a 1930 talk, as evidenced by the "agricultural and economic adjustments which invariably follow series of 'wet years' or 'dry years' in the region west of the deciduous forest limits." Ecologists had shown the ability of virgin blue-stem prairie to "to hold latent many species for long periods of time, until a set of favorable conditions calls them forth." But "banks and speculators fattened on this system" of cropping in wet years until "the traffic could bear it no more." He would have liked to study the vegetative history of the arid West, but was hindered by the scarcity of peat bogs with their fossil records.[144] To add to the difficulty of studying pollen profiles in the "great grassland states," oxidation processes in hot, dry climates often destroyed pollen before it was fossilized.

It was through limnology – the study of freshwater environments – that Sears would find collaborators developing methods of extracting fossil pollen from sediments other than peat.

The Rise of Paleolimnology

---

any cyclical changes in climate and weather from that, is it possible to prognosticate. What is your opinion about the climate? Is it changing?" Also Paul B. Sears to Professor F. W. Oliver (Egypt), 15 September 1936, Box 2, Folder 16, PSC: "You will be interested to know that my statement of the menace here in North America is really quite conservative. In spite of the fact that our politicians are becoming semi-hysterical and bending every effort to arrest the damage, it is a serious question whether much of the western grassland will not become a ghost area comparable with the ghost mining towns of the Rocky Mountains. I do not think it is yet too late to arrest the damage, but it seems very difficult in practice to get the engineer and politicians to realize the problem is essentially a matter of ecology."

[144] Paul B. Sears's notes for talk "Constructive Evidence of Climatic Change in the Prairie States," c. 1930, Box 3, Folder 28, PSC.

The discipline of limnology emerged at the turn of the twentieth century in parallel with ecology. Between 1892 and 1904, Swiss physiologist François-Alphonse Forel published a three-volume treatise on Lake Geneva in which he coined limnology as "the oceanography of lakes."[145] And like oceanography, early limnology emphasized the physical environment, integrating ideas from geography, physics, and chemistry to study phenomena like temperature stratification.[146] Two of the earliest contributors to limnology in the United States were E. A. Birge, a zoologist who trained with Louis Agassiz before moving to the University of Wisconsin Madison, and Chancey Juday, who moved from the first lake biological station in the United States, at Indiana University, to the Wisconsin natural history survey in 1900. By then there were a handful of freshwater biological stations in the Midwestern United States. A review in *The American Naturalist* in 1898 explained:

> The fundamental purpose of all biological stations, both marine and fresh-water, is essentially the same. They serve to bring the student and the investigator into closer connection with nature, with living things in their native environment. […] They encourage in this day of microtome morphology the existence and development of the old natural history or, in modern terms, oecology, in the scheme of biological education.[147]

---

145 François-Alphonse Forel, *Le Léman* (Geneva: F. Rouge Lausanne, 1892). Often Forbes (1887) is cited as the first limnology paper, but it was published in an obscure journal and was not republished until 1925. Stephen Alfred Forbes, "The Lake as a Microcosm," *Bulletin of the Science Association of Peoria Illinois* (1887): 77-87, reprinted in *Illinois Natural History Survey Bulletin* 15 (1925): 537-550.

146 On the history of limnology, see David G. Frey (ed.) *Limnology in North America* (Madison: University of Wisconsin Press, 1963). On the history of oceanography, see Helen M. Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Harvard University Press, 2005). In 1922, German zoologist August Thienemann and Swedish botanist Einar Naumann co-founded the Societas Internationalis Limnologiae.

147 Charles A. Kofoid, "The Fresh-Water Biological Stations of America," *The American Naturalist* 32 (1898): 391-406.

Figure 22. Edward A Birge and Chancey Juday with plankton trap on Lake Mendota in Madison, Wisconsin, c. 1917. The History of Limnology at the University of Wisconsin-Madison, UW.uwlimn0070.bib

G. Evelyn Hutchinson was a polymath, who, like Paul Sears, found his way to ecology through cell physiology. While an undergraduate at the University of Cambridge, where his father was a professor of geology, Hutchinson discovered the new field of biochemistry through physiologist J. B. S. Haldane, who worked on salt metabolism (and would later became famous for his mathematical theory of natural selection). After graduating from the zoology program at Cambridge, Hutchinson studied the brachial gland of the octopus at the Stazione Zoologica in

Naples, hoping to establish evidence of endocrine function in higher invertebrates. From there he accepted a position as a biology lecturer at the University of Witwatersrand in Johannesburg, South Africa. His girlfriend, Grace Pickford, a fellow zoology student from Cambridge, joined him there. Together, Hutchinson and Pickford researched the correlation between physical lake conditions like pH and the occurrence of invertebrate species in shallow lakes near Cape Town.

Figure 23. G. Evelyn Hutchinson collcting insects at Cherryhinton Chalk Pits, Cambridgeshire, England, 1920. Yale University Archives.

In 1928 Hutchinson applied for a graduate fellowship to work with embryologist Ross Granville Harrison at Yale University. Although the fellowship was spoken for, Harrison offered

Hutchinson a position as an instructor in the Osborne Zoological Laboratory. Hutchinson quickly accepted. There he was tasked with teaching a course on "freshwater biology." At the time, the components that came to constitute limnology were taught separately: hydrobiology, physiology, zoology, chemistry, geology. It was in 1929, when he read British zoologist Charles Elton's *Animal Ecology*, that Hutchinson began to think of himself as a limnologist rather than a zoologist, believing that this new discipline best encapsulated his interest in the adaptations of invertebrates to different types of lakes. Despite his lack of a Ph.D., the chair of the zoology department selected Hutchinson as lead biologist for the Yale North India Expedition in 1932, and then to asked him to join the department as a professor, to the chagrin of some members of the department.

Hutchinson's first graduate advisee, Gordon Riley, studied how crustaceans acquired the copper that was contained in the hemocyanin in their blood. It was his second student, Edward Deevey, who would connect Hutchinson to pollen stratigraphy work. As an undergraduate in Yale's Botany Department in 1934, Edward Deevey became interested in the history of human land use in New England. He suspected the same techniques that Paul Sears was using to analyze peat cores could be used to analyze the "treasure of information being cumulatively buried in the mud of lakes." While Deevey was unable to find an advisor in his department, his idea sparked Hutchinson's interest.[148]

Deevey began working on analyzing pollen in lake sediments collected by Hutchinson on the Yale North India Expedition, and then pollen in mud cores from Connecticut lakes, with funding from the Connecticut State Board of Fisheries and Game (the chairman of which was

[148] Letters between Deevey and Hutchinson can be found in Box 11, Folder 194, Series I, G. Evelyn Hutchinson Papers, Manuscripts and Archives, Yale Sterling Memorial Library, New Haven, Connecticut [hereafter GEHP].

Thomas Beck, who was serving with Leopold on the President's Committee on Wild Life Restoration). Deevey and Hutchinson were both interested in using stratigraphic methods to reconstruct the historical development of lakes and their surroundings. As Deevey later wrote, they viewed "the face of the earth" as "a single frame in a continuous moving picture film."[149] The analogy echoed Frederic Clements's 1909 description of successional theory: "the various stages of forest structure are shown up in their proper sequence, and give a picture of the life movement of a forest much as the individual films give motion in a moving picture."[150]

In 1938, at the age of 23, Deevey received a Ph.D. for his work on "stratigraphic inquiry into the nature of typological succession" of five southern Connecticut lakes. From his analyses he concluded that after the glaciers of the ice age retreated, and the landscape was uncovered from south to north, the New England landscape was first dominated by spruce and fir, then by birch, then pine, suggesting a warmer and drier period. In the *Yale Scientific Magazine*, Hutchinson explained how Deevey's dissertation traced a lake's history from a newly formed body of water to its "moment of death." To do this, Hutchinson continued, a scientist needed to be "something of a geologist, botanist, chemist, zoologist, and climatologist.":

> In ecological field work there are two ways of treating the dimension of time. In most of the botanical ecology of the past, a series of stands of vegetation have been selected, beginning with bare ground, and ending with the most permanent kind of plant cover

---

[149] W.T. Edmondson, "Edward Smith Deevey, Jr. Dec 3 1914 - November 29 1988," *National Academy of Sciences Press Biographical Memoirs* (1988); Edward S. Deevey, Jr., "Pollen from Interglacial Beds in the Panggong Valley and its Climatic Interpretation," *American Journal of Science* 237 (1937): 44-56; Edward S. Deevey, Jr., "Studies of Connecticut Lake Sediments. I. A Postglacial Climatic Chronology for Southern New England," *American Journal of Science* 237 (1939): 691-724; Edward S. Deevey, Jr., "Limnological Studies in Connecticut: VI. The Quantity and Composition of the Bottom Fauna of Thirty-Six Connecticut and New York Lakes," *Ecological Monographs* 11 (1941): 413-455; Edward S. Deevey, Jr., "Some Geographic Aspects of Limnology," *The Scientific Monthly* 55 (1942): 423-434.

[150] Frederick E. Clements, "Plant Formations and Forest Types," *Proceedings of the Society of American Foresters* 4 (1909): 50-63.

> known in the region under investigation. […] The second method consists in a study of sediments containing the fossilized remains of the earlier associations, so that the dimension of time is here treated in a direct, albeit at present relative, way.[151]

In 1937, Deevey began corresponding with Paul Sears. At first they discussed two controversies in their new field: the debate as to whether oak was actually a good indicator of dry conditions, or whether the genera could be found in moist conditions, and the debate around the terminology of mud. What were their opinions on terms like "sludge," "silt," "gyttja," "ooze," and "slime"?[152] Encouraged by Deevey's success at extracting enough pollen from lake sediments to count and diagram, Sears began to make plans to collect cores from the arid West.

But World War II stalled those plans. Meanwhile Sears continued to expand his networks. In 1943, Sears began producing and distributing "The Pollen Analysis Circular" to an increasing number of "pollen workers." Its recipients included academics such as Deevey and Hutchinson, natural history museum employees, U.S. Geological Survey and U.S. Bureau of Mines employees, and, as war in Europe intensified, employees of companies such as the Shell Development Company and the Magnolia Petroleum Company. The first Circular excerpted a note from H. Godwin, of the Cambridge Botany School: "It is useful to consider ecology as contributory to the war effort: it comes in more than one might suppose at first."[153] A call for papers for the 1944 Botanical Society of America Paleobotanical Section meetings explained that the war increased the need for information that would assist in "detailed geological correlation of

---

[151] G. Evelyn Hutchinson "The History of a Lake" *Yale Scientific Magazine* 16 (1942).
[152] Edward S. Deevey to Paul B. Sears, 31 October 1939, Box 1, Folder 5, PSC; Edward S. Deevey to Paul B. Sears, 9 April 1937, Box 1, Folder 5, PSC.
[153] Copies of the *Pollen Analysis Circular* are in Box 5, Folders 27-30, PSC.

coal beds," the "understanding of coal origin," and in some localities, the use of peat "as a substitute fuel when coal is difficult to obtain."[154]

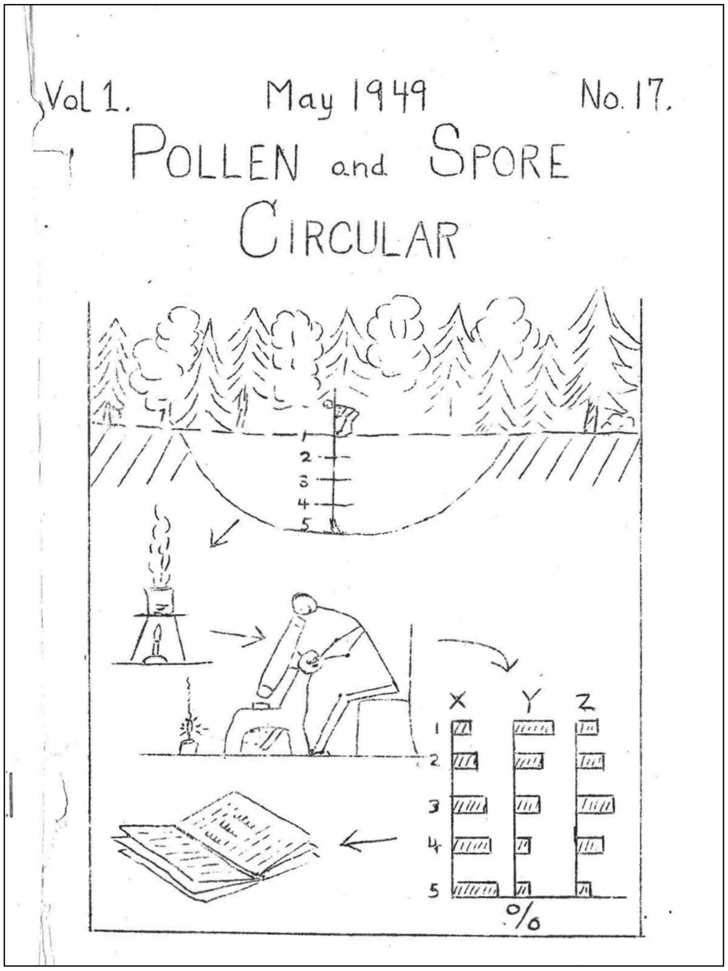


Figure 24. Cover of the Pollen and Spore Circular from 1949. Courtesy of Scott Anderson.

[154] "The Botanical Society of America Paleobotanical Section," 15 May 1944, Box 1, Folder 19, PSC. In 1957 Estella Leopold wrote to Sears: "We have had several Oil Company visitors here this winter scouting for new people in the pollen field. I told them of your student, Pete Ogden, and a couple at Harvard. In the fall they will go out on a scouting tour of universities looking for prospective people. But I gather that the pollen business is a darn lucrative one IF one joins oil firms… for they are prepared to pay people with experience up to 10,000/yr, and PhD's without experience ca 8,000/yr. Of all the companys [sic] that are in the pollen business, it is my feeling that Shell and Carter are by FAR the best places to work. They have extensive pollen programs, as you know, and have awfully good staff. Students might be reminded that they can always make money in this field." Estella B. Leopold to Dr. Sears, 16 May 1957, Box 2, Folder 13, PSC.

Radiocarbon Dating and the Yale Geochronometric Laboratory

In 1939, Albert Einstein wrote a letter to President Franklin D. Roosevelt, urging him to invest in research into nuclear chain reactions. Physicists had described uranium fission a few months prior, highlighting the possibility of Nazi Germany developing "extremely powerful bombs of a new type." On June 28, 1941, faced with mounting instability in Europe, Roosevelt created the Office of Scientific Research and Development. The "S-1 Uranium Committee" held its first meeting on 18 December 1941, eleven days after the Japanese attack on Pearl Harbor, ten days after the United States declared war on Japan, and seven days after Germany declared war on the United States in solidarity with Japan. As the United States entered the war, the S-1 Committee contracted physicists at the University of California, Berkeley, Columbia University, and the Carnegie Institution of Washington, and later the University of Chicago, to work on the fission problem. In 1942, the project became known as the "Manhattan Engineer District."

From 1942 to 1946, the Manhattan Engineer District constructed laboratories and plants at more than a dozen sites. After the surrender of Japan, the sites were transferred to a new civilian agency, the Atomic Energy Commission (AEC), charged with continuing atomic weapons production while developing peaceful uses of atomic energy. As Angela Creager has detailed, the AEC focused on distributing radioisotopes for scientific research. The first cyclotron, or "proton merry-go-round," had been constructed at the University of California, Berkeley, in 1930, and in 1934, Frédéric and Irène Joliot-Curie produced the first artificial radioactivity by bombarding aluminum with alpha particles. By 1947, AEC sites were producing large quantities of radioisotopes for distribution to scientists across the country.[155] Most of the recipients of radioisotopes were medical researchers, but a few were ecologists; Hutchinson was among the first.

In 1946, Willard Libby, an AEC-funded chemist at the Argonne Laboratory at the University of Chicago, published a paper in which he proposed that the carbon in living matter might include small amounts of a naturally occurring radioisotope, carbon-14, which researchers at Berkeley had recently observed to be created continuously through collisions of neutrons from cosmic rays with nitrogen in the upper atmosphere. Libby hypothesized that if carbon-14 was a trace element in atmospheric carbon dioxide, then plants should assimilate a small amount of the isotope into their tissues. An animal would then consume the plants, and eventually die, at which point it would cease to take in new carbon. If scientists could determine the rate of decay of carbon-14, Libby concluded, then they should be able to determine the time elapsed since the death of an organism.[156]

---

[155] AEC Fourth Semiannual Report (1948), quoted in Angela N. H. Creager, *Life Atomic: A History of Radioisotopes in Science and Medicine* (Chicago: University of Chicago Press, 2013), 3. See also Robert E. Kohler, *Partners in Science: Foundations and Natural Scientists, 1900-1945* (Chicago: University of Chicago Press, 1991).

[156] In 1955, TIME magazine described Libby as a "strapping reddish-haired man" known as "Wild Bill" for his intensity in the laboratory. "The Philosophers' Stone," *TIME*, 15 August 1955, 48. On carbon dating see Willard Frank Libby, "Atmospheric Helium Three and Radiocarbon from Cosmic Radiation," *Physical Review* 69 (1946): 671-672; E. C. Anderson, W. F. Libby, S. Weinhouse, A. F. Reid, A. D. Kirshenbaum, A. V. Grosse, "Radiocarbon from Cosmic Radiation," *Science* 72 (1947): 931-936; J. R. Arnold, W. F. Libby, "Age Determinations by Radiocarbon Content: Checks with Samples of Known Age," *Science* 110 (1949): 678-680; Willard Frank Libby, *Radiocarbon Dating* (Chicago: University of Chicago Press, 1955); Willard Frank Libby, "Radiocarbon Dating, Memories, and Hopes," (Washington D.C.: National Science Foundation, 1972). It wasn't until 1931 that the National Research Council of the U.S. National Academy of Sciences appointed a committee to address the age of the Earth.

Edward Deevey and G. Evelyn Hutchinson were among Willard Libby's first collaborators. Deevey first met Libby at a meeting at Chicago's Institute for Nuclear Studies in 1949. There he agreed to supply Libby's lab with peat samples from the Eastern United States. A few months later, at the Ecological Society of America's annual meeting, he described his and Hutchinson's plans to apply Libby's radiocarbon dating methods to peat samples from the Eastern United States. Soon thereafter, Libby wrote to Hutchinson, warning him that the technology of radiocarbon dating was "about as difficult as an appendectomy, or baking a really good cake."[157]

In 1951, with funding from the Office of Naval Research and the Rockefeller Foundation, Deevey (who was now a lecturer at Yale), Hutchinson, and geologist Richard Foster Flint established the Yale University Geochronometric Laboratory. In collaboration with Libby's laboratory, they worked to tackle the methodological problems of sampling biological materials for carbon-14, of which there were many.[158] Enthusiasm for the project was mixed. A 1952 newspaper article lauded the "atomic calendar" that enabled scientists "to tell the age of objects dating as far back as 20,000 years." But at a meeting to discuss the establishment of a National Advisory Committee on radiocarbon dating that same year, one researcher claimed that "interest

---

[157] Hutchinison describes this meeting in "Report of the Ad Hoc Committee on Ecology of the Yale Biology Department," c. 1966, Box 50, Folder 50, Series II, GEHP. See also Edward Smith Deevey, Jr., "Biogeography of the Pleistocene. Part 1. Europe and North America," *Bulletin of the Geological Society of America* 60 (1949): 1315-1416; "Program of the New York Meeting with Abstracts of Papers, Thirty-Fourth Annual Meeting of the Ecological Society of America," *Bulletin of the Ecological Society of America* 30 (1949): 45-72; Edward Smith Deevey, Jr., "Radiocarbon Dating," *Scientific American* 186 (1952): 24-28.

[158] Richard Foster Flint and Edward S. Deevey, "Radiocarbon Dating of Late-Pleistocene Events," *American Journal of Science* 249 (1951): 257-300; Edward S. Deevey, J. Gralenski, and Vaino Hoffren, "Yale Natural Radiocarbon Measurements IV," *American Journal of Science Radiocarbon Supplement* 1 (1959): 144-172.

in radiocarbon is declining so rapidly that [scientists] should do nothing but express sympathy."[159]

Nevertheless, in 1954 the Geochronometric Laboratory was able to secure stable funding from the National Science Foundation, which had been established by Congress four years prior "to promote the progress of science; to advance the national health, prosperity, and welfare and to secure the national defense." In his proposal to NSF, Deevey asserted that the Geochronometric Laboratory would succeed because of Yale's flourishing school of "Pleistocene studies." Besides himself and Flint, Paul Sears had accepted a professorship at Yale in 1950.[160] Deevey wrote:

> The historian deals with a very small segment of the history of man, at most about 6,000 years. The study of at least ninety-five per cent of our existence as a species belongs to prehistory. This period, the Pleistocene, during which the human mind began to operate, is also characterized by the most dramatic oscillations in environmental variables that have occurred on Earth during the past 200 million years. […] If we are to get a clear idea of what human development, physical and cultural, and human history, really imply, we must develop a vastly improved absolute chronology, interrelating events in widely separated parts of the world. Only when we know something of the past, and of the cultural and physical forces that have shaped it, can we venture any predictions.[161]

---

[159] Hutchinson probably learned about radiocarbon dating at the National Academy of Sciences in 1946 or 1947, as he was connected to a group who discussed "cosmochemistry." Edward Deevey attended a meeting of archaeologists and radiochemists in 1952 on the refinement of radiocarbon dating. See Edward S. Deevey, "A Brief Discussion of the Relation of Some Radiocarbon Dates to the Pollen Chronology," *Memoirs of the Society for American Archaeology* 8 (1951): 56-58; Deevey's notes from "Conference on Radiocarbon Dating: Meeting of Society for American Archaeology at Columbus, Ohio on May 3, 1952," can be found in Box 11, Folder 194, Series I, GEHP. "'Atomic Calendar' Enables Savants to Verify Old Dates," *The Spokesman Review*, 10 March 1952, Spokane Washington.

[160] By then Sears was a well-known figure. "Sears" was the answer to a New York Times magazine crossword question of 21 September 1952: "Soil erosion expert. Author of Deserts on the March."

[161] "Proposal for an Interdisciplinary Program of Study of the Past Million Years," 1954, Box 58, Folder 51, Series II, GEHP.

While a professor at Yale from 1950 to 1960, Sears worked with the Geochronometric Laboratory to analyze cores from the arid West.[162] His first opportunity to study an excellent core from the arid West had arisen in 1948 "by the merest accident," according to Sears, when an acquaintance on The Pollen Circular sent him some samples from a mining site near the San Augustin Plains of western New Mexico.[163] The samples, reaching nearly 200 feet deep, "were taken in somewhat haphazard fashion at wide intervals," but Sears was confident than an intact core from the site would yield invaluable information. Unlike peat samples from the northern United States, a sample from the San Augustin Plains, a former lakebed, would contain a pollen record that extended earlier than the Wisconsin glaciation. And so, in 1950, Sears began submitting proposals to funders to visit the New Mexico site and "secure sets of cores with considerable precision to permit us to make a more or less continuous study of this record."[164]

It was a difficult sell, however. To the Carnegie Institution he pitched the project as a study of the "close correlation between climatic history and cultural shifts," but they declined.[165] To the Office of Naval Research he explained that research into past climatic cycles of the earth could improve climatic forecasting, which might be "helpful information in the strategic planning of the Navy in some of the areas of its global responsibilities."[166] The ONR was not persuaded. The Geological Society he found to be concerned chiefly with "what is known in the trade as 'hard-rock' problems," not ecological problems.[167] Finally, he secured a few thousand

---

[162] D. Simon, "At Our Feet: The Yale Conservation Program, 1950-1960," Senior Thesis, New Haven: Yale University, 1985.
[163] Paul B. Sears to Dr. Russell Nappen, 23 May 1950, Box 2, Folder 12, PSC.
[164] Paul B Sears to Warren Weaver, 25 May 1950, Box 1, Folder 23, PSC.
[165] Warren Weaver to Paul B. Sears, 31 May 1950, Box 1, Folder 23, PSC.
[166] C. C. Furnas (Director of Cornell Aeronautical Lab) to Admiral C M. Bolster (Director of Earth Sciences Division, Office of Naval Research), 19 September 1952, Box 1, Folder 3, PSC.
[167] John N. Adkins (Director, Earth Sciences Division, Office of Naval Research) to Dr. C. C.

dollars from the Wenner-Gren Foundation for Anthropological Research to study "a stratigraphic scale for human cultural sequences."[168]

Sears tasked his former laboratory assistant, Kathryn Clisby, a research assistant at Oberlin, with developing methods for extracting pollen from the sediments. Like Sears, Clisby had found her way to ecology via cell physiology, but unlike Sears, she had no formal schooling. After high school she worked as a laboratory assistant analyzing the blood of dogs injected with *E. coli* at Toledo Hospital in Toledo, Ohio; studying lead poisoning at Oberlin College; and investigating cell metabolism in rats at Johns Hopkins Medical School. At Oberlin she audited classes in Botany and Geography.[169] Her participation in the laboratory was unusual – women were actively and systematically excluded from the sciences, including ecology, through the 1960s (and one might argue, through today). Clisby's presence in the field was unusual enough for Sears to write in his notebook in 1952: "Magnificent dinner at Don Pablos that evening – Kathryn Clisby only woman."[170] And even though Sears was relatively progressive in collaborating with a number of female scientists, his letter of recommendation for Estella Leopold, Aldo Leopold's daughter, whose Ph.D. he advised from 1950 to 1955:

> I have seen her get along beautifully under conditions more trying than any she is likely to encounter in Washington. You can depend upon her never to get ugly or henny. […] Beside being sure to make clear to her the nature of her obligations, I should talk to her

---

Furnas, 6 October 1952, Box 1, Folder 3, PSC.

[168] Box 1, Folder 7, PSC.

[169] Kathryn Clisby to Paul B. Sears, 1 Nov 1951, MS Box 6, Folder 30, PSC. "Climate Scientist: Wellington Woman Reads Story of Past in Samples of Earth," Newspaper clipping without publication information, Box 6, Folder 31, PSC. Today the Palynological Society's website states only: "Kathryn Clisby was an associate of Paul B. Sears at Oberlin College, Ohio. Apparently she ran the pollen lab, because she is thanked profusely in Sears' 1950 note." http://www.palynology.org/katherine-clisby

[170] Paul B. Sears, "Journal, Mexican Field Trip," July 1952, Box 4, Folder 46, PSC.

> brother, Dr. Luna Leopold, explaining the situation and asking his frank opinion. I can assure you he'll give it.[171]

It is possible, though, to uncover some of Clisby's contributions to ecology through the archival record. Clisby's innovations in extracting pollen from silt and clay soils allowed her and Sears to study sediment cores further west than ever before.[172] Through the 1950s, Clisby and Sears travelled to New Mexico, Arizona, and Mexico to collect new sediment cores. The next difficulty they faced was finding a drill that could excavate such a deep core. The price of hiring a commercial driller to drill so deep into hard sediments proved prohibitive. But in 1952, an opportunity cropped up through the Division of Raw Materials of the AEC. A geologist in Los Alamos who had been working on an AEC uranium reconnaissance project in west-central New Mexico was given permission to give Sears samples from a 645-foot deep core.[173] The only stipulation was that Sears could not refer to AEC activities in his publications. And so the draft of his manuscript, "Two Long Climatic Records," eventually published in *Science*, was edited by the AEC to read:

> Our left-hand profile is based upon a reconnaissance drilling ~~by Dr. H. T. Stearns of the Atomic Energy Commission~~ in Valle Grande, a caldera and former lake bed shown in the Jemez Springs and Santa Clara Quadrangles, northern New Mexico ~~and here reported by permission of the Atomic Energy Commission.~~[174]

As Sears and Clisby worked on identifying pollen from the San Augustin core, Deevey suggested that their material might contain enough organic material to date with carbon-14.[175]

---

[171] Paul B. Sears to George Sprugel Jr. (NSF), 26 July 1956, Box 2, Folder 20, PSC.
[172] Clisby's methods for studying "non-calcareous silts and clays" in Box 6, Folder 1, PSC.
[173] Copy of Chas V. Theis (District Geologist, Geological Survey, New Mexico Department of Interior) to Mr. L. G. Mohr (AEC Special Projects Branch, Los Alamos), 9 August 1950, Box 1, Folder 21, PSC.
[174] Clyde S. Conover (District Engineer, U.S. Department of the Interior, Geological Survey) to Paul B. Sears, 10 June 1952, Box 1, Folder 4, PSC.
[175] Paul B. Sears to the Committee in Charge, Geochronometric Laboratory, 14 May 1952, Box

But this effort, too, was complicated by a lack of funding and by methodological problems. The Atomic Energy Commission would not fund the work, despite Sears's claim that it would "give us a clue as to climatic and physiographic events that can be associated with the concentration of radioactive material."[176] The NSF declined their study of the history of how the weathering of high-elevation rocks could carry Uranium into lakebeds.[177] Finally, in 1955, the Magnolia Petroleum Company agreed to work on the project. "It happens that we are interested in late Pleistocene and Recent events in connection with our Geological Research on Recent sedimentation," they replied to Sears.[178]

The results of Sears and Clisby's pollen stratigraphy, together with the radiocarbon dates estimated by the Magnolia Petroleum Company, were reported in *Science* in 1956. They reported their results in feet depth, not time, but explained that "a carbon-14 date of 19,700 +/- 1600 years at the 19-ft level has been determined."[179] One draft of Sears's summary of their work read:

> The pattern of climatic fluctuations, both short and long-term, is a matter of great scientific and practical importance. Much economic and social distress could have been avoided by a better adjustment of land-use in the semi-arid West to the basic pattern of climate. ~~A clear understanding of climatic fluctuations during the past century is basic to intelligent land use. Whether such long time records as are now being studied at Oberlin will eventually shed light on future trends remains to be seen, but the possibility cannot be ignored~~. […] This core is yielding one of the longest continuous records of ~~climate~~ vegetation ever obtained.[180]

2, Folder 8, PSC.
176 Paul B. Sears to Atomic Energy Commission, 24 March 1954, Box 2, Folder 1, PSC.
177 D. L. Anderson (Oberlin College Physics Department), "Appendix: Report on Exploratory Investigations on Radioactivity of Core Samples," 1953, Box 6, Folder 4, PSC.
178 D. H. Clewell (Magnolia Petroleum Company Field Research Laboratories, Dallas TX) to Paul B. Sears, 28 April 1955, Box 1, Folder 3, PSC; Paul B. Sears to W. H. Burke (Magnolia Petroleum Company), 22 April 1955, Box 2, Folder 2, PSC. Paul B. Sears to Kathryn Clisby, 5 July 1955, Box 2, Folder 4, PSC.
179 Kathryn H. Clisby and Paul B. Sears, "San Augustin Plains – Pleistocene Climatic Changes," *Science* 124 (1956): 537-539.
180 Draft manuscript in Box 6, Folder 23, PSC.

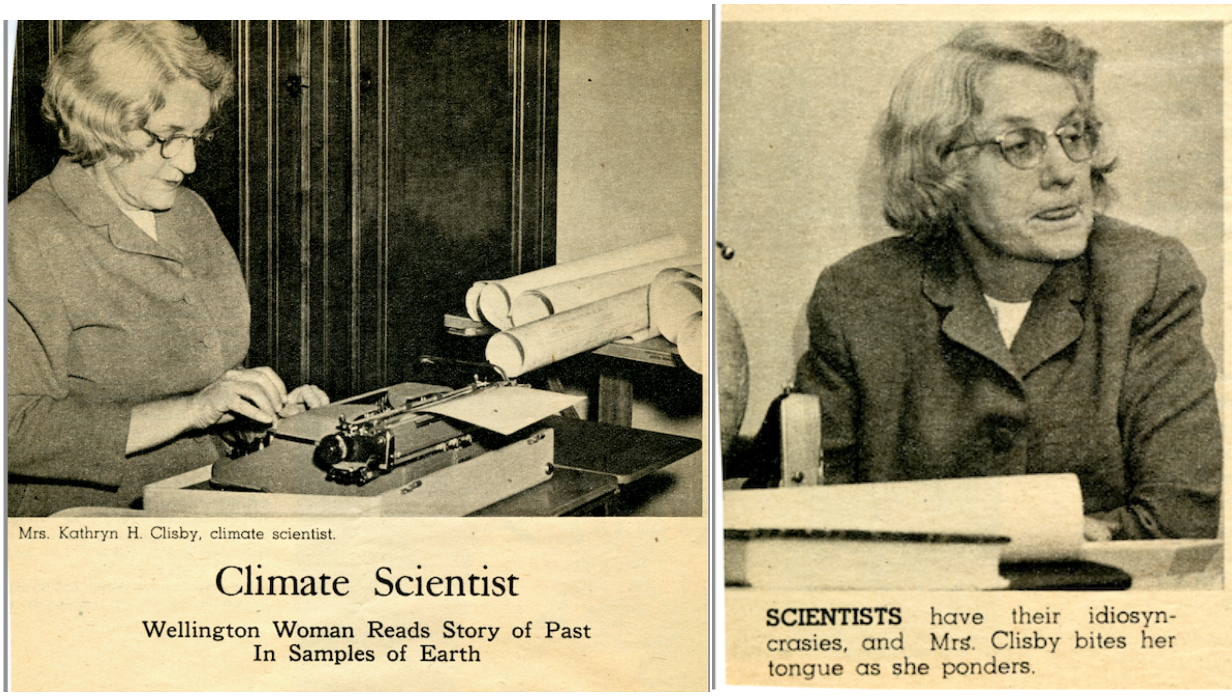


Figure 25. Clipping of a news article on Kathryn Clisby, unknown publication. Box 6, Folder 31, Paul Bigelow Sears Collection, Special Collections at the University of Arizona Libraries, Tucson, Arizona.

Changing Conceptions of America's Ecological History

By the second half of the 1950s, radiocarbon dating had become popular among palynologists. There were no presentations on radiocarbon dating at the Second National Pollen Conference, a joint session of AAAS Botanical Sciences Section and the Ecological Society of America held in Storrs, Connecticut, in December 1953.[181] But at the Third National Pollen Conference, organized by Clisby and Sears and held at Oberlin in May 1956, almost every presentation discussed radiocarbon dating, with titles like "Postglacial Chronology in the Light of Radiocarbon Dates" and "A Carbon-dated Pollen Profile from Umiat."[182] The conference

[181] Box 6, Folder 22, PSC.
[182] Final Program for Third National Pollen Conference, Oberlin, 18-20 May 1956, Box 6, Folder 23, PSC.

program explained that although, since 1927, pollen diagrams had advanced understandings of plant migration and environmental changes, carbon-14 dating was "rapidly being perfected as an exact tool."[183]

For more than twenty years, those in the palynology field had worked to correspond samples from distant sites using stratigraphic positioning. For example, if a "spruce horizon" was found in a sample from Massachusetts and a sample from New York, they were assumed to have been deposited at the same time-point. But there were limitations to such inferences. Geological uplift could move older samples closer to the surface, confounding the stratigraphy. "I'm frankly scared of even guessing at time or past climates in the belt of the volcanoes," geographer Carl O. Sauer wrote to Sears in 1949.[184]

Now, however, radiocarbon analysis provided another method of correlating samples, one dependent on an invisible quality of the sediments. The information opened up new puzzles in old samples, which ecologists debated heatedly, mostly in private correspondence.[185] Archaeologist Frederick Johnson wrote in Libby's 1955 reference book on radiocarbon dating that radiocarbon dating allowed archeologists, geologists, and ecologists to correlate their disciplines' data because "dates have been determined by a single method" and because it allowed for "measures made by different laboratories on identical samples" rather than inferences from field sites.[186]

---

[183] Drafts in Calvin J. Heusser to Paul B. Sears, 13 June 1956, Box 1, Folder 9, PSC.
[184] Carl Sauer to Dr. Sears, 8 July 1949, Box 1, Folder 19, PSC.
[185] See, for example, Phil C. Orr (Western Speleological Institute, Inc., Museum of Natural History, Santa Barbara CA) to Dr. Paul B. Sears, 1 June 1955, Box 1, Folder 16, PSC.
[186] Frederick Johnson, "Reflections upon the Significance of Radiocarbon Date," in Willard F. Libby, *Radiocarbon Dating*, 2nd ed. (University of Chicago Press, 1955).

Collaborations among ecologists and archeologists led to a revision of America's ecological history. In 1952, for example, in collaboration with archeologists at Harvard, Clisby and Sears dated maize pollen found in a core drilled underneath Mexico City. "We shall have to hunt the ancestors of Mexican man, as well as those of corn, much earlier than had been thought necessary," Sears said in a press release. "There is increasing evidence, […] dated by the radiocarbon calendar, that man lived in Mexico during the last of the Pleistocene Age."[187]

Over just a few years, carbon-14 data led many scientists to believe that the glaciers in North America had retreated 14,000 years later than previously thought, and that humans migrated to the Western Hemisphere thousands of years earlier. In other words, humans had shaped the ecology of America for millennia. In his 1951 paper, "Radio-carbon Dating of Late-Pleistocene Events," Deevey announced that samples assumed to be from 25,000 years ago proved to date from about 11,000 years ago. The ecological changes that captured Deevey's imagination were even more recent than he had supposed. He described with passion the potential for radiocarbon dating to unlock "a complete and incontrovertible time-sequence" of past ecological events.[188]

One of the most controversial hypotheses to come out of such work was Paul S. Martin's "Pleistocene overkill hypothesis" – the hypothesis that around 11,000 years ago, newly arrived humans hunted North America's megafuana, including ground sloths, camels, and mastodons, to

---

[187] Draft of press release on discovery of maize pollen grains under Mexico City, Ann Ewing to Paul B. Sears, 12 May 1952, Box 1, Folder 6, PSC. "Botanists Establish Origin of Corn," *The Harvard Crimson*, 1 March 1954.
[188] Richard Foster Flint and Edward S. Deevey, "Radiocarbon Dating of Late-Pleistocene Events," *American Journal of Science* 249 (1951): 257-300.

extinction.[189] As a postdoc in zoology at Yale in 1956, Martin attempted to unite the recent findings in "the related fields of Pleistocene chronology, biogeography, palynology, and prehistory" that "methods of isotope dating" and "the application of pollen stratigraphy to archeological and chronological problems" had unlocked.[190]

"Radiocarbon dates confirm the fact, evident to Darwin and Lyell, that extinction [in North America] was mainly a Post-glacial event," Martin explained to an audience at the AAAS meeting in 1958. But the cause or causes of extinction remained a major unsolved problem in biology. Had climate change destroyed these species? Perhaps, Martin speculated, but what was remarkable to him was that there had been "extinction without replacement": North and South American *Equus* went extinct in the late Pleistocene, and then, "for perhaps 3000 to 6000 years in the Americas the horse life-form was absent." If climate were behind these disappearances, wouldn't other species have taken their place? After eight years of collecting radiocarbon dates associated with extinct animals, Martin believed that the climate change hypothesis "does injustice both to the differential loss of large forms, to the narrow chronological range when extinction occurred, and to the phenomenon of removal without replacement." Instead, he proposed, humans had been the main extinction agent.[191]

---

[189] Sears and Martin had corresponded since at least 1952: Paul S. Martin (University of Michigan) to Dr. Sears, 28 April 1952, Box 1, Folder 14, PSC.
Many felt that Martin overreached with his hypothesis. One student wrote to Sears of Martin's paper, "It is an impressive documentation, but again he wields a sharp axe. In some instances, I don't think he has justification, unless it is just to stir up argument." Pete J. Gordon Ogden II (Ohio Wesleyan) to Paul B. Sears, 6 December 1958, Box 2, Folder 16. PSC.
[190] Paul S. Martin, "Pleistocene Ecology and Biogeography of North America," in: C. L. Hubbs (ed.), *Zoogeography* (Washington D.C.: American Association for the Advancement of Science, 1958), 375–420.
[191] A copy of the paper Martin presented at the AAAS Program on Unsolved Problems in Biology can be found in Box 6, Folder 53, PSC. See also Paul S. Martin and H. W. Wright (eds.), *Pleistocene Extinctions: The Search for a Cause* (New Haven: Yale University Press,

Reconstructing the Ecological Past

These new understandings of America's ecological past found their way into land management by direct and indirect paths. From 1950 to 1960, Sears was director of Yale's new Conservation program. During this time he wrote popular pieces and editorials in professional journals on the importance of ecology to natural resources management. Deevey and Hutchinson were founding members of The Nature Conservancy and the Conservation Foundation and consulted for the U.S. Fish and Wildlife Service and the National Park Service. Leopold was president of the ESA in 1947; Sears succeeded him as president in 1948. In April 1948, just one week after receiving word that *A Sand County Almanac* would be published, Aldo Leopold died of a heart attack while fighting a neighbor's grass fire. Sears read Leopold's unpublished essay, "The Land Ethic," at the ESA's annual dinner. Sears then served as the ESA's representative to the Natural Resources Council of America in 1951 and 1952. These are only a few examples of the increasing influence ecology had on land management.

Through stratigraphy and then radiocarbon dating, ecologists began to grapple with questions of native plant and animal species, historical human impacts on ecological communities, and the role of the environment in human history. In his presidential address to the ESA, Sears said:

> City and forest, village and marsh, are more, too, than systems of current, contemporary activity. All are expressions of a past, and none are to be understood except in these terms. Why is Cincinnati famed for its music and its parks, Cleveland for its civic spirit? The historical factor, as it is called, has become indispensable to the interpretation of the living landscape. Little patches of prairie, complete with bluestem grass, rattlesnakes, and

---

1967); David A. Burney and Timothy F. Flannery, "Fifty Millennia of Catastrophic Extinctions after Human Contact," *Trends in Ecology & Evolution* 20 (2005), 395-401.

western insects, were found studding the wooded expanse of Ohio. They seem strangely out of place in that forest climate until we invoke the historical factor.[192]

In *A Sand County Almanac*, Leopold, too, wrote of an increased appreciation for the ecological past:

> Our appreciation of the crane grows with the slow unraveling of earthly history. His tribe, we now know, stems out of the remote Eocene. The other members of the fauna in which he originated are long since entombed within the hills. When we hear his call we hear no mere bird. We hear the trumpet in the orchestra of evolution. He is the symbol of our untamable past, of that incredible sweep of millennia which underlies and conditions the daily affairs of birds and men. And so they live and have their being — these cranes — not in the constricted present, but in the wilder reaches of evolutionary time.[193]

But for the most part, ecologists understood "restoration" to be the environment's self-healing. Calls for restoration were calls for patience and *rest*, not for active interventions. In a 1941 paper, geographer J. R. Whitaker described four modern sequences of natural resources "depletion" and "renewal":

use → deterioration or depletion → human want and even distress
depletion → rest and natural recuperation → depletion
destruction → scarcity → restrictions on take → restocking → management of the habitat
reclamation → deterioration of reclaimed resources through use or failure to maintain improvements → period of want → rise of responsible, able authority

Whitaker distinguished "between natural restoration and that aided by man." He also noted that there was a difference between "reversible" and "irreversible" sequences, the latter being sequences in which "complete renewal or restoration" was impossible because "certain original elements have been destroyed" – as in the case of the passenger pigeon's extinction. In the case of damage that was reversible, "waiting" was "an essential" in the "cycles of

[192] Paul B. Sears, "The Living Landscape," President's Address to the ESA, 28 December 1949, Copy in Box 40, Ecological Society of America Archives (Accession 97-061), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, GA.
[193] Leopold (1949), p. 96-97.

restoration"; Whitaker wrote, for example, that "the jungle garden is used for perhaps a fourth as long a time as is required for fallowing; and forests may be cut in a few weeks that required centuries to grow." As population increased, Whitaker concluded, the task for land managers would be to "displace this long-time cycle of restoration with an equally conservational short-time cycle."[194]

In speaking about the restoration of post-war Europe, geographers and ecologists also spoke of thresholds beyond which "natural" restoration needed assistance. In an article titled "The Effect of War Destruction upon the Ecology of Cities," for example, Fred Iklé wrote in 1951:

> There seems to be a certain limit beyond which destruction cannot go without jeopardizing the restoration of an area. […] [W]hen the basic utilities and means of transportation have not been restored by the community, the "cultural component" alone is not strong enough to bring about the rehabilitation of an area.[195]

But those promoting ecological restoration tended to focus on the ability of nature to heal itself. A 1945 paper in *Ecological Monographs* stated that "Although a re-seeding or re-planting program in some instances may speed the establishment of cover plants on denuded marshes or on newly restored areas, natural reproduction from dormant seeds, wind, animal and water carried seeds, tubers and other reproductive parts are usually sufficient to re-vegetate the marshes."[196] A 1951 paper explained that restoration of mid-height grasses in the Midwestern prairie states would "be slow since sand dropseed was the only mid grass with ample viable seed

---

[194] J. R. Whitaker, "Sequence and Equilibrium in Destruction and Conservation of Natural Resources," *Annals of the Association of American Geographers* 31 (1941): 129-144.
[195] Fred Charles Iklé, "The Effect of War Destruction upon the Ecology of Cities," *Social Forces* 29 (1951): 383-391.
[196] Jessop B. Low, "Ecology and Management of the Redhead, *Nyroca americana*, in Iowa," *Ecological Monographs* 15 (1945): 35-69.

on the ground after the drought to restore its cover."[197] At the 1956 Symposium on Applications of Ecology, ecologist David Costello remarked: "We need to curb our ecological impatience. We took 150 years to tear down our range and grasslands. Why expect to rebuild them in 5 years?"[198]

But slowly and steadily, ecologists began exploring the idea of augmenting or facilitating natural restoration. In 1948, G. Evelyn Hutchinson argued that "it ought to be possible to show that it is as much fun to repair the biosphere and the human societies within it as it is to mend the radio or the family car."[199] The "man who manages wild land" could "work with nature to bring about desired results," H. L. Shantz wrote in *Ecological Monographs*, through "artificial reseeding" of species appropriate to an area's successional history.[200]

At first such restoration projects were mostly focused on single animal species. For example, in 1939, The Illinois Natural History Survey, with funding from the Federal Aid in Wildlife Restoration Act, installed 56 den boxes in Urbana citizens' fencerows and hedges. A report explained that Urbana was typical of the "best Illinois cornbelt farmland" in that intensive agriculture had decreased available habitat for fox squirrels, screech owls, and sparrow hawks, which inhabit tree cavities.[201] This effort successfully increased the number of all three species in the local area.

---

[197] Harold H. Hopkins, "Ecology of the Native Vegetation of the Loess Hills in Central Nebraska," *Ecological Monographs* 21 (1951): 125-147.
[198] David F. Costello, "Application of Ecology to Range Management," *Ecology* 38 (1957): 49-53.
[199] G. Evelyn Hutchinson, "On Living in the Biosphere," *The Scientific Monthly* 67 (1948): 393-397.
[200] H. L. Shantz, "The Relation of Plant Ecology to Human Welfare," *Ecological Monographs* 10 (1940): 311-342.
[201] Robert E. Hesselschwerdt, "Use of Den Boxes in Wildlife Restoration on Intensively Farmed Areas," *The Journal of Wildlife Management* 6 (1942): 31-37.

Plate 2. Some of the 56 den boxes used in the study, showing details of construction.

Figure 26. Photograph from Robert E. Hesselschwerdt, "Use of Den Boxes in Wildlife Restoration on Intensively Farmed Areas," *The Journal of Wildlife Management* 6 (1942): 31-37. Caption reads "Some of the 56 den boxes used in the study, showing details of construction."

Another example is of the Nene (*Branta sandvicensis*), a goose endemic to Hawaii. By 1944 there were fewer than 50 geese alive, all of them in the Kau Territorial Forest Reserve on Mauna Loa. By 1949, the only known Nenes were a pair at the Honolulu Zoo and 14 at the beach home of a "wealthy senator." That year, with funding from the Federal Aid in Wildlife Restoration Act, the Hawaii Board of Commissioners of Agriculture and Forestry began a venture to breed Nene in order to maintain "something of 'Old Hawaii' for the education of tourists and local residents alike."[202] A 1957 paper estimated that, thanks to these breeding efforts, there were 35 Nene in the wild and 45 in captivity. With funding from the International Committee for Bird Preservation, the Guggenheim Foundation, and Yale University, ecologists were now trying to correlate historical population sizes with historical ecological changes, especially increased cane sugar production and the introduction of rats and pigs.[203]

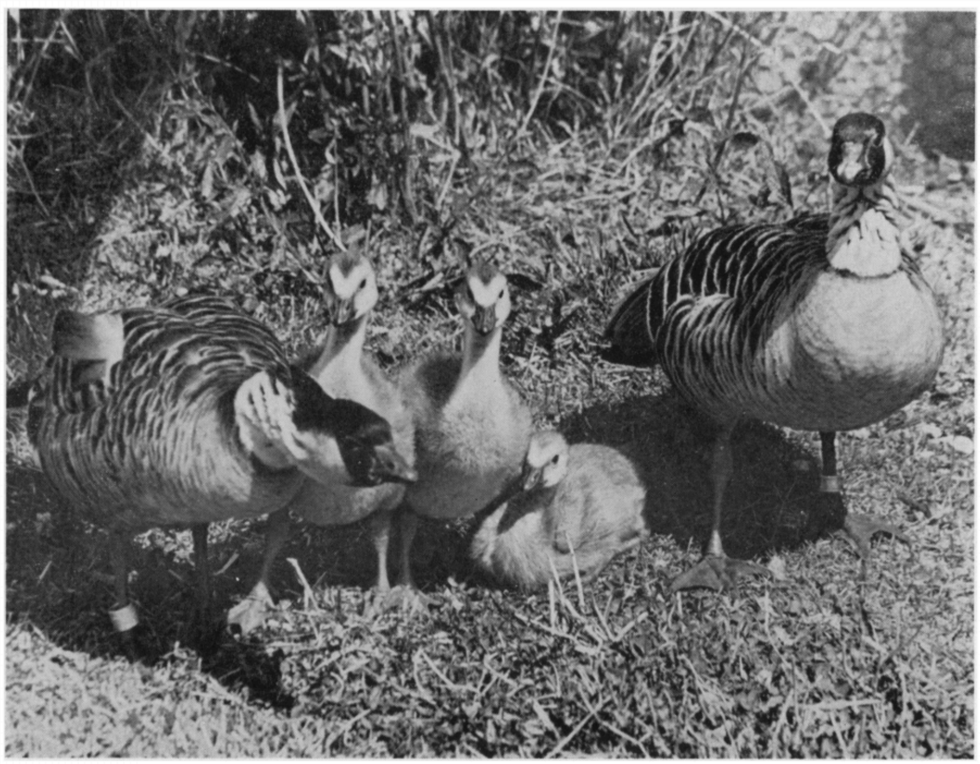


PLATE 1. Nene family. Goslings hatched January 23, 1951, and three weeks old when photographed.

Figure 27. Figure from J. Donald Smith, "The Hawaiian Goose (Nene) Restoration Program," *The Journal of Wildlife Management* 16 (1952): 1-9.

---

[202] Paul H. Baldwin, "The Hawaiian Goose-Its Distribution and Reduction in Numbers," *The Condor* 47 (1945): 27-37; J. Donald Smith, "The Hawaiian Goose (Nene) Restoration Program," *The Journal of Wildlife Management* 16 (1952): 1-9.

[203] William H. Elder, "Ne-ne in Hawaii: Preliminary Report of the Ne-ne in Hawaii," *The Wildfowl Trust Ninth Annual Report, 1956-1957* (Gloucestershire: Wildfowl & Wetlands Trust, 1957), 112-117.

At the 1956 "Symposium on Applications of Ecology," Paul Hickie noted that ecologists had advanced wildlife management "by organizing and interpreting information about environmental changes historically, successionally, qualitatively, and quantitatively":

> For the eastern United States, they have pieced together from past records the story of the clearing away of the big timber by logging and burning and of the primitive-to-modern farming that followed, a process that drove out the wolf, puma, lynx, bison, elk, caribou, and moose, that permitted the deer, black bear, turkey, and grouse to linger awhile longer then retreat to second growth forests, and that finally established the cottontail and bobwhite and such foreigners as the pheasant and Hungarian partridge, true farm game species. […]
>
> In the western United States, where modifications of primitive habitats have been less apparent than in the East but, nevertheless real, their story has been shorter but similar. They relate how large herds of cattle, sheep, and goats brought in to graze on fenced rangelands wrote the death warrant to bison and wolves on the range, dictated reduction of coyotes, pumas, and bears, and crowded pronghorns, elk, and deer; how intensive farming of the prairies and increasing scarcity of water in small streams, ponds, and marshlands eliminated large areas suitable for prairie chickens and waterfowl; and how, although there are still extensive areas for big game and such smaller species as blue grouse, ptarmigan, sharptails, and sage hens, farming has created suitable conditions for farm game species, and quail, cottontails, pheasants, and Hungarian partridges have moved in.[204]

Gustav Swanson, the former chief of wildlife research for the U.S. Fish and Wildlife Service, noted a disciplinary shift away from hunting regulations and toward "habitat improvement" in 1951:

> In game management, Leopold recognized five main types of controls: control of the take by hunting; control of predators; the establishment of refuges and other reserved lands; artificial stocking with animals trapped elsewhere or reared in confinement; and, finally, improvement of the habitat. Twenty years ago the emphasis was overwhelmingly upon restrictions of the take, predator control (mostly through payment of bounties), and artificial stocking, usually from game farms. During the past two decades the recognition and application of ecological knowledge have resulted in deemphasizing the importance

---

[204] Paul Hickie, "The Application of Ecology to Wildlife Management," *Ecology* 38 (1957): 53-56.

> of predator control and artificial stocking, and in increasing recognition of the importance of habitat improvement.[205]

An interest in America's ecological history that manifested itself during the Dust Bowl was gradually incorporated into both conservation and restoration work. In a 1956 article, "Botanists and the Conservation of Natural Resources," Sears distinguished the views of applied ecologists from the Progressive Era conservation movement, which focused on "wise use" of harvested resources. Sears contended that few botanists were involved in the early conservation movement, which he derided as "the belief that an expanding and accelerating economy must be served at whatever cost in resources, since science will find ways and means to keep the process going." Rather, the ESA's Committee for the Preservation of Natural Conditions for Ecological Study – which, in 1932, was tellingly renamed the Committee for the Preservation of Natural Conditions in the United States – had developed a mode of conservation interested in the maintenance of ecological integrity:

> As resources we should include many processes and relationships in nature, for conservation is in fact concerned not only with problems of *depletion*, but those of *disruption* as well. There is also a concern in many quarters to conserve facilities and conditions whose values are intangible – historical, scientific, ethical, and aesthetic.[206]

Notably, the discourse around atomic technologies at this time was one of redemption. In 1955 the United Nations convened the International Conference on Peaceful Uses of Atomic Energy in Geneva, Switzerland. The Conference gathered 1,200 scientists from 72 nations to explore non-military applications of nuclear energy. A *TIME* feature on the Conference reported that from the "dark but necessary secrecy" and "power for ruination" of atomic weaponry, the "story of the

---

[205] Gustav A. Swanson, "Wildlife Management and Ecology," *The Scientific Monthly* 72 (1951): 230-232.

[206] Paul B. Sears, "Botanists and the Conservation of Natural Resources," *American Journal of Botany* 43 (1956): 731-735. Emphasis in original.

peaceful atom" had begun to unfold. The list of redemptive applications of nuclear technology included the production of better crop varieties, measuring tobacco in cigarettes, tracing the flow of oil in pipelines, and following chemical reactions within living cells. It concluded:

> The assembling of such an array of facts, brains and machines dedicated to a peaceful atomic age was an event to excite the imagination. It suggested to the world, even the poorest, most desperate parts of it, that in the atom lies not just menace but hope, a new start, a new future. […] No possibility is too small or too big. The atom can ultimately move mountain ranges, drain seas, irrigate entire deserts, transmute poverty into plenty, misery into mercy.[207]

[207] "The Philosophers' Stone," *TIME*, 15 August 1955, 48. See also Carolyn Kopp, "The Origins of the American Scientific Debate over Fallout Hazards," *Social Studies of Science* 9 (1979): 403-422; Creager, *Life Atomic* (2013).

CHAPTER 6

ATOMS FOR ECOLOGY:

RESTORING SALMON AND DOMESTICATING THE SEA

In 1946, the Ecological Society of America distributed a memo to its 700 members that argued for the importance of ecological research in light of the recent war. "The devastation of Europe by War has now not only thrown the responsibility for leadership on America," the memo concluded, "but America has also inherited the unique responsibility of putting its own ecological house in order."[208] Significantly, the authors of the memo underlined "responsibility" twice. World War II had shifted the moral position of civilian death: the new war – total war – would enlist the total industrial and human power of one civilization against another. In response, scientific organizations like the Ecological Society of America questioned their future roles and responsibilities in matters of national security.[209] Meanwhile, the federal government invested heavily in the sciences, establishing the Atomic Energy Commission (AEC) and the Office of Naval Research in 1946 and the National Science Foundation in 1950. These programs reconfigured the relationships among federal, academic, and corporate spheres and provided

---

[208] The ESA committee that wrote the memo included W.C. Allee, Ada Hayden, A. S. Pearse, A. O. Weese, Charles C. Adams. See Charles C. Adams, "Memo No. 2" and "Memo No. 4," 1947, Box 13, Folder 225, GEHP. See also Morris L. Cooke, "Scientists Should Knock at the Door of American Politics," *American Scientist* 34 (1946): 87-93.

[209] Robert Chambers, "Rehabilitation of the Biological Sciences in the Post-War Period," *The American Naturalist* 79 (1945): 44-51; Peter Paret, *Makers of Modern Strategy from Machiavelli to the Nuclear Age* (Princeton: Princeton University Press, 1986); Sharon Ghamari-Tabrizi, "Simulating the Unthinkable: Gaming Future War in the 1950s and 1960s," *Social Studies of Science* 30 (2000): 163-223; Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (Oxford: Oxford University Press, 2013).

scientists with new materials.[210] Between 1946 and 1955, for example, the AEC produced and distributed approximately 64,000 shipments of radioisotopes to American scientists, which gives a sense of the scale of the AEC's involvement.[211]

As historians of science and technology have detailed, the new technologies, new funding structures, and new understandings of war played crucial roles in the emergence of a number of disciplines, including molecular biology, atmospheric science, and oceanography.[212] Ecology, in contrast, is often framed as having emerged in opposition to the "Atomic Age." In his influential history of ecology, *Nature's Economy* (1977), Donald Worster contended that the "Age of Ecology" began when Barry Commoner, Rachel Carson, and other ecologists discovered that atomic fallout was poisoning the environment. Ecologists' discovery of "nature's vulnerability"

---

[210] Peter Galison and Bruce Hevly, eds., *Big Science: The Growth of Large-Scale Research* (Stanford: Stanford University Press, 1992); Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press, 1993); Peter Galison, *Image & Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997), Chapter 4.

[211] Angela Creager has argued that the abundance of radioisotopes after WWII consolidated the molecular and systemic vision of life in biochemistry and medicine. Angela H. Creager, *Life Atomic: A History of Radioisotopes in Science and Medicine* (Chicago: University of Chicago Press, 2013).

[212] For example, see Ronald E. Doel, "Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945," *Social Studies of Science* 33 (2003): 635-666; Ronald Rainger, "'A Wonderful Oceanographic Tool': The Atomic Bomb, Radioactivity and the Development of American Oceanography," in *The Machine in Neptune's Garden: Historical Perspectives on Technology and the Marine Environment*, eds. Helen M. Rozwadowski and David K. Van Keuren (Sagamore Beach: Science History Publications, 2004); Jacob Darwin Hamblin, *Oceanographers and the Cold War: Disciples of Marine Science* (Seattle: University of Washington Press, 2005); Jacob Hamblin, *Poison in the Well: Radioactive Waste in the Oceans at the Dawn of the Nuclear Age* (New Brunswick: Rutgers University Press, 2009); Matthias Dorries, "The Politics of the Atmospheric Sciences: 'Nuclear Winter' and Global Climate Change," *Osiris* 26 (2011): 198-223.

is supposed to have spurred citizens to organize an environmental movement and politicians to fund ecosystem ecology.[213]

However, one limitation of Worster's narrative is that it portrays ecologists as part of a closed community that was poised to respond to the concerns of the public and state. Responding to Worster, Stephen Bocking and Chunglin Kwa contended that one area of ecology, ecosystem theory, in fact developed from ecologists' direct involvement with the AEC. Bocking and Kwa both maintained that in the 1960s, ecologists funded by the AEC abandoned their natural history roots for energy diagrams and cybernetics in order to increase their respectability among AEC physicists.[214] Importantly, these historians' analyses highlighted that AEC involvement directly shaped the content of ecological theory, and thus the perceived ecological risks of atomic weaponry.

Expanding on this insight, this chapter argues that ecology had an Atomic Age of its own whose history encompasses diverse ecological practices beyond the scope of ecosystem theory. In particular, ideational and material entanglements between atomic warfare and ecological science were also central to the development of ecological restoration, especially to the transition from single-species restoration to ecosystem restoration that transpired between the 1940s and the 1960s. The work of Lauren Donaldson, a fisheries biologist at the University of Washington

---

[213] Donald Worster, *Nature's Economy: A History of Ecological Ideas* (Cambridge: Cambridge University Press, 1997), Chapter 16. Quotes on vulnerability on pp. 347, 355.

[214] Stephen Bocking, "Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory," *Journal of the History of Biology* 28 (1995): 1-47; Chunglin Kwa, "Radiation Ecology, Systems Ecology and the Management of the Environment," in *Science and Nature: Essays in the History of the Environmental Sciences*, M. Shortland, ed. (London: British Society for the History of Science, 1995). Frank Golley and Joel Hagen similarly argue that AEC funding itself helped legitimize ecosystem theory. Joel Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick: Rutgers University Press, 1992); Frank Golley, *A History of the Ecosystem Concept in Ecology* (New Haven, CT: Yale University Press, 1993).

from the 1930s through the 1970s, exemplifies this entanglement between the Age of Ecology and the Atomic Age. Donaldson's research was biological and ecological, and at the same time it responded to the operational needs of the Atomic Energy Commission, which supported it. Donaldson's work thus challenges Ronald Doel's distinction between two postwar environmental sciences, one "geophysics-centered, focused on the physical environment, and responsive to the operational needs of the military services that supported it," and the other "biology-centered, focused on problems in ecology and population studies, and funded in part by agencies and managers concerned about human threats to the environment."[215]

Plant community ecology is today so central to the discipline of restoration ecology that it might seem intuitive to look for the latter's origins in the former.[216] But the example of Donaldson reveals that fisheries biologists conducted research that substantially contributed to the emergence of ecological restoration. Indeed, the establishment of fish hatcheries in the mid-nineteenth century was the first federally sponsored ecological restoration effort. In the 1850s, naturalists began to blame industry and agriculture for a decline in the number of trout, salmon, and shad runs in the eastern United States: as they saw it, farmers had cleared forests, leading to erosion and subsequent silting of streams, and factories had dammed and fouled rivers.[217] In

---

[215] Doel (2003), 563.

[216] In a meta-analysis of restoration ecology and conservation biology literature, Young (2000) concluded "conservation biology has been more zoological, more descriptive and theoretical, and more focused on population and genetic studies than restoration ecology, which has been more botanical, more experimental, and more focused on population, community and ecosystem studies." Truman Young, "Restoration Ecology and Conservation Biology," *Biological Conservation* 92 (2000): 73-83.

[217] George Perkins Marsh, *Report Made Under Authority of the Legislature of Vermont, on the Artificial Propagation of Fish* (Burlington: Free Press, 1857), 9. See also Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (New York: Cambridge University Press, 1991), John T. Cumbler, "The Early Making of an Environmental Consciousness: Fish, Fisheries Commissions, and the Connecticut River," *Environmental*

1872, the federal government established a system of National Fish Hatcheries in order "to restore wasted waters to their primitive or more than primitive fruitfulness" and "to extend the geographical range of the more important food-fishes, such as shad, salmon and trout, by naturalizing them in new waters."[218] As Joseph E. Taylor has argued, fish hatcheries were popular in part because they obviated the need for state-imposed limits on fishing and wastewater discharge.[219]

But fish rearing was not without its difficulties: fish often died before they could be released into streams, whether from malnutrition or disease. Around efforts to improve hatchery yields, fisheries biology developed as a new discipline at the turn of the twentieth-century that borrowed primarily from zoology and the nascent field of ecology.[220] Thus, decades before Clements, Shelford, and other plant ecologists promoted ecological restoration, fisheries biologists were attempting to restore (or even exceed) a perceived historical abundance of fish.

In 1930, Lauren Donaldson began his career in fisheries biology. At the University of Washington School of Fisheries, he worked to improve the survival of salmon and trout in hatcheries. But his career took a turn when, in 1943, the Manhattan Engineering District (MED)

History Review 15 (1991): 73-91.

[218] John Muir, "The Establishment on McCloud River – John Muir, the Naturalist, Gives a Graphic Description of What is Being Done," *Daily Evening Bulletin* (San Francisco), October 29, 1874.

[219] Joseph E. Taylor, *Making Salmon: An Environmental History of the Northeast Fisheries Crisis* (Seattle: University of Washington Press, 1999).

[220] Fisheries biology and ecology were separate disciplines with their own societies and journals. But many biologists identified as both fisheries biologists and ecologists. As a result, the two disciplines deeply influenced one another. See Matthew Klingle, "Plying Atomic Waters: Lauren Donaldson and the 'Fern Lake Concept' of Fisheries Management." *Journal of the History of Biology* 31 (1998): 1–32. As Klingle notes, the subdiscipline of population ecology grew out of early twentieth-century studies of fisheries. See also Sharon Kingsland, *Modeling Nature: Episodes in the History of Population Ecology* (Chicago: University of Chicago Press, 1985); Tim D. Smith, *Scaling Fisheries: The Science of Measuring the Effects of Fishing, 1855-1955* (Cambridge: Cambridge University Press, 1994).

requested that he study whether effluent from the Hanford plutonium production site would harm the Columbia River salmon fishery. Over the next thirty years, while conducting research for the MED and then the AEC, Donaldson enthusiastically embraced atomic technologies in his pursuit of fish that could thrive in a changed world. His restoration work took three approaches: species enhancement, nutrient supplementation, and environmental sequestration. Once disentangled, these three approaches help to elucidate the complex history of restoration ecology, a discipline that harnessed the tools of the Atomic Age in its attempts to solve *pre*-atomic ecological crises, industrial and agricultural in their origins.

The first of Donaldson's restoration approaches – species enhancement – encompassed his efforts to cultivate beneficial mutations in salmon and trout through selective breeding and, later in his career, to induce beneficial mutations by irradiating fish. Taking the industrialization of streams to be inevitable, Donaldson attempted to restore species' abilities to thrive. The MED had originally contracted Donaldson to identify possible detrimental effects of radiation exposure, but around 1957, Donaldson began to identify restorative effects instead. While today most restorationists would balk at the idea of introducing "mutant salmon" into streams and lakes – indeed, the genetic purity of "native" species populations is often policed – Donaldson and his colleagues understood their work to be for the benefit of future generations of fish and of people.

The second approach to restoration pursued by Donaldson – nutrient supplementation – also stemmed from his early hatchery research. While in graduate school, Donaldson began to study how various artificial diets affected the growth and survival of salmon and trout. He abandoned this line of inquiry during the war, though he continued his selective breeding program. But Donaldson returned to the topic of fish nutrition unexpectedly in the late 1940s, when his research at the Pacific Proving Grounds – where the AEC detonated 105 atomic bombs between 1946 and 1962 – suggested that fish concentrated radioisotopes in their digestive tracts after atomic detonations. Whereas other AEC biologists continued to focus on the effects of external radiation, Donaldson began to explore the effects of ingesting radioisotopes. From this work materialized the concepts of bioaccumulation and biomagnification. Although today both terms are associated with harmful pollutants such as DDT and mercury, radioisotopes were first used to model restorative nutrients, like phosphorus and calcium. In the early 1950s, Donaldson began framing radioisotopes as tools to determine which nutrients were limiting salmon fitness in aquatic environments and, consequently, which nutrients managers could add to lakes and streams to promote salmon populations. By enabling salmon to live in new environments, scientists could mitigate destruction at other sites, Donaldson believed; and while this approach to restoration did not evolve into a worldwide practice, as stocking "improved" salmon did, it nonetheless shaped how Americans came to understand the flow of pollutants through environments.

Donaldson's third approach to restoration – environmental sequestration – also emerged from the confluence of his hatchery research and his AEC work. In the 1950s, Donaldson began to travel internationally to promote his selectively bred Rainbow-Steelhead Trout hybrid, the "Donaldson Trout." His AEC-sponsored research had connected him to academics, politicians, and business owners around the world. It also led General Mills, the food production corporation, to hire Donaldson as a consultant for their Isolated Proteins Division. Prompted by this commercial connection, Donaldson began to theorize "ocean ranching," which we know today as "fish farming." By farming fish at an industrial scale, Donaldson argued, the United

States could reduce harvesting pressure on "wild" fisheries.[221] In other words, by domesticating fish, humans could (supposedly) sequester natural populations and limit human impact to the confines of the "ocean ranch." Environmental sequestration, in fact, relied heavily on both species enhancement and nutrient supplementation, since the farmed fish themselves would be bred, and the farms would be supplemented with the artificial diets that Donaldson had been developing. Once wild fish populations had been restored, Donaldson reasoned, nutrient cycles that had been broken by industrialization would be restored. In this third approach can be seen an important shift from single-species restoration to something new, the restoration of an assemblage of species that cycled nutrients and waste – in other words, of an "ecosystem."

The key to understanding these three approaches to restoration lies in the relationship between ecological science and nuclear technologies. This chapter therefore proceeds with the story of Donaldson's involvement with the MED. It then details the histories of species enhancement, nutrient supplementation, and environmental sequestration in separate sections, each of which, nonetheless, covers overlapping geographies and events. Finally it details the significance of work like Donaldson's for radiation's transformation from a vital restoration tool to a detrimental phenomenon to be mitigated, isolated, or "cleaned up." Despite being contracted by the MED (and later the AEC) to check for damaging effects of radiation in reactor effluent, Donaldson himself never marked nuclear technologies – even weapons – as definitive ecological threats. In this sense he was like many scientists: atomic technology was not popularly understood as an ecological threat until the 1960s. Rather, Donaldson's restoration efforts and ecological fieldwork were focused on correcting problems of damming and erosion that had

[221] For an interesting parallel, see William Boyd, "Making Meat: Science, Technology, and American Poultry Production," *Technology and Culture* 42 (2001): 631-664.

materialized over the previous century. For Donaldson and other ecologists in the 1950s, atomic technologies were powerful tools that would enhance scientific understanding of nature's structure and, therefore, human ability to manage and restore the natural world.

Lauren Donaldson and the Manhattan Engineering District

In August 1943, Lauren Donaldson received an urgent telegram from the Office of Scientific Research and Development (OSRD) while on his way to British Columbia for a conference on the decline of western salmon fisheries. It stated that the "OSRD" requested his presence in Washington, D.C., to discuss a sensitive matter. It gave no further explanation.[222]

Unbeknownst to Donaldson at the time, it was not the OSRD that had sent the telegram, but the Manhattan Engineering District (MED). The federal government had recently acquired land in eastern Washington State in order to build a plutonium production site. Designs for "Hanford Works" called for large pumps to channel thirty thousand gallons of water per minute through each of three reactors. This water would come from the Columbia River, and it would be returned to the river warm and radioactive. At the time little was known about the effects of radiation exposure on mammals, let alone fish, and the MED was eager to ensure that this reactor

---

[222] Neil O. Hines recounts in *Fish of Rare Breeding: Salmon and Trout of the Donaldson Strains* (Washington, D.C.: Smithsonian Institution Press, 1976) that Donaldson was driving from Seattle to New Westminister, British Columbia, when he received a telegram around August 15, 1943, asking him to return to Seattle and proceed immediately to Washington, D.C., for an August 21 meeting. I believe the date of the telegram to be August 18 from a transcript of a phone call between Mr. Wensel of Knoxville, Tennessee (Clinton Engineering Works) and Mr. Hanford Thayer that can be found in Box 9, Folder 18, LRDP, in which Wensel instructed Thayer that he and Stafford L. Warren are to meet Donaldson in Washington, D.C., Wensel detailed: "Mr. Donaldson is not to know that the Engineers are involved. As far as he is concerned, Warren is an OSRD consultant. I am an OSRD man 100% and you are simply an intermediary bringing us together."

effluent would not damage the valuable Columbia River salmon fishery.[223] Thus the MED requested that Donaldson, the salmon physiology expert at the University of Washington School of Fisheries, study the physiological impacts of radiation on Columbia River fish.

Donaldson arrived in Washington, D.C., a few days after receiving the telegram. There "OSRD" officials asked him to lead a research grant titled "Investigation of the Use of X-rays in the Treatment of Fungoid Infections in Salmonid Fishes." They also asked him to name his laboratory the "Applied Fisheries Laboratory." Both titles concealed the project's true objective – to study whether Hanford Works' reactor effluent killed salmon. Donaldson, who was 37, and who had not been drafted, readily agreed to lead the grant.[224]

That fall, Donaldson and his research assistants – the Applied Fisheries Laboratory (AFL) – began exposing salmon eggs, embryos, and fingerlings to X-rays in Seattle.[225] The

---

[223] For histories of the Manhattan project, and Hanford Works in particular, see L. Groves, *Now It Can Be Told: The Story of the Manhattan Project* (New York: Harper, 1962). H. Thayer, *Management of the Hanford Engineer Works in World War II: How the Corps, DuPont, and Metallurgical Laboratory First Tracked the Original Plutonium Works* (New York: American Society of Civil Engineers, 1996). J. Findlay and B. Hevly, *Nuclear Technologies and Nuclear Communities: A History of Hanford and the Tri-cities, 1943–1993* (Seattle, University of Washington, 1995). John Findlay and Bruce Hevly, *Atomic Frontier Days: Hanford and the American West* (Seattle: University of Washington Press, 2011); Kate Brown, *Plutopia: Nuclear Families, Atomic Cities, and the Great Soviet and American Plutonium Disasters* (New York: Oxford University Press, 2013).

[224] Federal sponsorship of the AFL remained with the MED until the passage of the Atomic Energy Act in 1946, at which point the program was transferred to the Atomic Energy Commission. The Lab was placed under the AEC's Division of Biology and Medicine, Environmental Sciences. See Neal O. Hines, *Proving Ground: An Account of the Radiobiological Studies in the Pacific, 1946-1961* (Seattle: University of Washington Press, 1962), Chapter 1. For archival material on the establishment of the Applied Fisheries Laboratory, see Boxes 3 and 9, Laboratory of Radiation Ecology Records, 1948-1984, The University of Washington Special Collections, Seattle, Washington [hereafter LRER]; Box 17, Folder 22, LRDP; Leslie R. Groves to Lauren R. Donaldson, March 10, 1961, Box 12, Folder 46, The Laboratory of Radiation Biology Records, 1944-1970 [hereafter LRBR].

[225] Neal O. Hines, *Proving Ground: An Account of the Radiobiological Studies in the Pacific, 1946-1961* (Seattle: University of Washington Press, 1962). For more on the establishment of the

design of their initial experiments reflected the MED's belief that the major biological hazard of atomic technology was prolonged exposure to external sources of radiation. Gamma radiation, like X-rays, is a short-lived but highly penetrating electromagnetic radiation, able to travel many inches through living tissue. Borrowing practices from the industrial hygiene and toxicology programs, MED "health physicists" promoted safety at atomic production sites by shielding workers from sources of gamma radiation and by "sanitizing" the workplace environment.

Figure 28. "Navy workers cross the boundary line on the floor from 'contaminated' to 'clean' after scrubbing off radioactive dirt. Navy Contamination Center, 1946." Time & Life Pictures / Getty Images.

AFL in the archival record, see LRER.

Today images of workers showering after radiation exposure strike us as naïve, almost farcical, but health physicists were implementing what they believed to be cautious practice.[226] Not for another decade would the AFL's work lead Americans to recognize the risks of two shorter-range, but more persistent, forms of ionizing radiation: alpha and beta particles.[227]

The results of the AFL's early experiments were reassuring. At 100 rads (rads are a unit of absorbed radiation dose), the fingerlings appeared normal. At 250 rads, they were noticeably thinner. At all levels of exposure above 500 rads, the fingerlings quickly died. But an exposure of 100 rads was higher than what MED officials anticipated for radiation levels in the Columbia River. The AFL concluded that, like mammals, cold-blooded vertebrates were killed by "unusually" high doses of ionizing radiation.[228]

By 1944, 47,000 people were at work in hundreds of new buildings at Hanford Works. That year, Donaldson convinced the MED to set up a small onsite laboratory under the direction of an AFL graduate student, Richard Foster. Each of the three Hanford reactors had large basins where reactor effluent cooled before being pumped to the river. Foster built a small salmon

---

[226] Carolyn Kopp, "The Origins of the American Scientific Debate over Fallout Hazards," *Social Studies of Science* 9 (1979): 403-423; Barton C. Hacker, *Elements of Controversy: The Atomic Energy Commission and Radiation Safety in Nuclear Weapons Testing, 1947-1974* (Berkeley: University of California Press, 1994); J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (Berkeley: University of California Press, 2000).

[227] During decay, radioactive nuclei can emit alpha particles (two protons and two neutrons bound together) and beta particles (high-speed electrons or positrons). Some examples of alpha emitters are radium, radon, uranium, and thorium. Some examples of beta emitters are strontium-90, carbon-14, tritium, and sulfur-35.

[228] Kelshaw Bonham *et al*., "Lethal Effect of X-Rays on Marine Microplankton Organisms," *Science* 106 (1947): 245-246; Richard F. Foster and Lauren R. Donaldson, "The Effect on Embryos and Young of Rainbow Trout from Exposing the Parent Fish to X-Rays," *Growth* 13 (1949): 119-142; Arthur D. Welander *et al*., *The Effects of Roentgen Rays on the Embryos and Larvae of the Chinook Salmon* (Oak Ridge: Atomic Energy Commission, 1948). AFL reports on these experiments can be found in Box 9, LRER.

hatchery with troughs outside the basins into which he could pump effluent and dilute it. As he began rearing fish in concentration gradients of effluent, his early results were encouraging, too: fish died only in highly concentrated effluent, for which the radiation level was much higher than for water samples he took from downstream in the Columbia.[229] He hypothesized that chemicals – added to effluent to prevent the corrosion of fuel cells – and not radioisotopes, were the greater risk to Columbia River salmon.[230]

But Foster's position wavered three years later, when he decided to collect and dissect a few salmon from the Columbia River itself. Using a Geiger counter – a tube filled with an inert gas that briefly conducts electrical charge when struck by incident radiation – he discovered that the "concentration of active materials in tissues or organs ranged to a maximum of several thousand times that of an equal weight of river water."[231] In other words, while the water wasn't particularly radioactive, the fish were, their digestive tracts especially so. This field result was

---

[229] Richard F. Foster, "The History of Hanford and Its Contribution of Radionuclides to the Columbia River," in *The Columbia River Estuary and Adjacent Ocean Waters*, eds. A. T. Pruter and Dayton L. Alverson (Seattle: University of Washington Press, 1972).

[230] This was still the belief in 1957, when Donaldson and Foster wrote, "When potential effects of atomic energy installations upon aquatic life are considered, radiation damage resulting from the release of radioactive isotopes is probably the primary consideration. Conventional types of pollutants must not be overlooked, however. Indeed, the chemical toxicity or high temperature of effluent released into a stream or lagoon could well be of greater concern than the radioactive materials. Olson and Foster (1955) have reported that very high concentrations of effluent from the Hanford reactors are toxic to young salmon and trout, not because of the radioactive isotopes present, but because of the presence of dichromate." Lauren R. Donaldson and Richard F. Foster, "Effects of Radiation on Aquatic Organisms," in *The Effects of Atomic Radiation on Oceanography and Fisheries* (Washington, D.C.: National Academy of Sciences, 1957), 96-102.

[231] Karl E. Herde, "Radioactivity in Various Species of Fish from the Columbia and Yakima Rivers," Report HW-3-5501, May 14, 1947, Quoted in Jessee (2013), 225. E. Jerry Jessee, *Radiation Ecologies: Bombs, Bodies, and Environment during the Atmospheric Nuclear Weapons Testing Period, 1942-1965* (Ph.D. Dissertation, Montana State University, 2013). See also Laura A. Bruno, "The Bequest of the Nuclear Battlefield: Science, Nature, and the Atom During the First Decade of the Cold War," *Historical Studies in the Physical and Biological Sciences* 33 (2003): 237-260.

nothing like what the AFL had observed in its laboratory experiments.

Species Enhancement: Building Better Salmon

When Donaldson was contacted by the MED he had been at the University of Washington School of Fisheries for thirteen years.[232] Donaldson came to Seattle by way of the Montana Department of Game, where he had worked for a few years after college with the state trout hatchery program. It was in Montana that he learned about recent efforts to breed trout and salmon that better survived in hatcheries – a topic that would come to define his career.

By 1930, when Donaldson began a master's degree at the University of Washington, a nation-wide network of marine biological laboratories and fisheries research centers connected fisheries biologists and managers.[233] The burgeoning discipline of fisheries biology incorporated ideas and methods from zoology, physiology, and the new field of ecology. Like early plant ecologists, fisheries biologists conceived of their discipline as a type of outdoor physiology.[234]

---

[232] Robert R. Stickney, *Flagship: A History of Fisheries at the University of Washington* (Seattle: University of Washington Press, 1989).

[233] On the history of fisheries research centers, see N. G. Benson (ed.), *A Century of Fisheries in North America* (Washington, D.C.: American Fisheries Society, 1970); Keith R. Benson, "Laboratories on the New England Shore: The 'Somewhat Different Decision' of American Marine Biology," *New England Quarterly* 56 (1988): 53-78; Phillip J. Pauly, "Summer Resort and Scientific Discipline: Woods Hole and the Structure of American Biology, 1882-1988," in *The American Development of Biology*, ed. Ronald Rainger, Keith Benson and Jane Maienschein (New Brunswick: Rutgers University Press, 1988); Dean C. Allard, Jr., "The Fish Commission Laboratory and Its Influence on the Founding of the American Biological Laboratory," *Journal of the History of Biology* 23 (1990): 251-270; Arthur McEvoy, *The Fisherman's Problem: Ecology and Law in the California Fisheries, 1850-1980* (Cambridge: Cambridge University Press, 1990).

[234] On this connection, see Eugene Citadino, *Nature as the Laboratory: Darwinian Plant Ecology in the German Empire, 1880-1900* (Cambridge: Cambridge University Press, 1990). In 1898 Frederic E. Clements and Roscoe Pound wrote: "Ecology cannot be set off sharply from physiology. Indeed, it is simply that particular phrase of physiology which is manifested in the structure and habits of plants in their various homes." Roscoe Pound and Frederic E. Clements,

The School of Fisheries emphasized research on salmon and trout, closely related species of ray-finned fish that migrate from the ocean to freshwater in order to spawn. Salmon and trout were an important commercial and cultural resource in the Pacific Northwest, a resource that was perceived to be in decline because of damming, overfishing, and urbanization.[235] Hatcheries were meant to address this decline, and while completing his master's thesis, Donaldson became increasingly interested in rearing salmon that could flourish in a changed world.

In 1932, Donaldson decided to remain at the School of Fisheries to complete a Ph.D. That year he learned of George Charles Embody, a Cornell University zoologist, who reported that in only three generations he had selectively bred Brook Trout at the New Jersey State Hatchery that were resistant to a common hatchery disease, Furunculosis.[236] Embody's publications inspired Donaldson and his friend Clarence Pautzke, a recent biology graduate (and a future Commissioner of the U.S. Fish and Wildlife Service), to begin selectively breeding trout for West Coast waters. Together Donaldson and Pautzke collected Rainbow Trout and Steelhead Trout from Washington streams and from Washington Department of Fisheries hatcheries. They then began interbreeding the Rainbows and the Steelheads, watching for individuals that were larger or produced more eggs than their progenitors.[237]

Later in life, Donaldson would explain that he modeled his efforts to breed "improved" salmon on "modern beef production," in which carefully bred cattle were raised in controlled

---

The Phytogeography of Nebraska (Lincoln: University of Nebraska, 1898).

235 Anthony Netboy, *The Colombia River Salmon and Steelhead Trout: Their Fight for Survival* (Seattle: University of Washington Press, 1981); Richard White, *The Organic Machine: The Remaking of the Columbia River* (New York: Hill and Wang, 1996).

236 Charles O. Hayford and George C. Embody, "Further Progress in the Selective Breeding of Brook Trout at the New Jersey State Hatchery," *Transactions of the American Fisheries Society* 60 (1930): 109-113.

237 See Hines (1976).

areas and were fed pills that "defeated diet deficiencies." He recounted:

> I've always looked at the shape of fish in terms of what we're trying to accomplish. But there isn't any pattern for the ideal shape of a fish. So I go to the fair and look at the beef cattle, the Aberdeen angus and the hefherds, and the big blocks of potential meat. And then I go back and look at the fish and think "what would happen if we changed the fish? If we made them heavy?"[238]

Between 1932 and his retirement from the School of Fisheries in 1973, Donaldson indeed made fish heavy. In 1932, the fish Donaldson and Pautzke caught in Washington streams reached sexual maturity in four years, weighed 1.5 lbs. at maturity, and produced 800-1200 eggs at their first spawning. In 1955, after twenty-three years of selective breeding, Donaldson's trout breed reached maturity in two years, weighed 4.1 lbs. at maturity, and produced 3894-5123 eggs at their first spawning.[239]

During those twenty-three years, Donaldson employed traditional methods of selective breeding, choosing to mate only the fish with the most rapid growth rates. He believed that by improving salmon bodies, scientists could produce salmon that would thrive even in industrial waters:

> With the development of the West, the great rivers that were the ideal spawning and rearing areas for Chinook salmon were used more and more by industry, often in conflict with the life processes of the fish […] Fisheries management agencies have be untiring in their efforts to halt the rate of [salmon] decline. Restrictive regulations on fishing, pollution, and industrial development have been put into effect. Hatcheries have been built, blocked streams opened, fish ladders constructed at dams, and spawning channels built and put into use. To this impressive array of rehabilitation measures we propose yet another area of effort – that of selective breeding.[240]

---

[238] S. G. Morie Morrison, "Notes May 20 1965," Box 1, Folder 37, LRDP.
[239] Lauren R. Donaldson and Paul R. Olson, "Development of Rainbow Trout Brood Stock by Selective Breeding," *Transactions of the American Fisheries Society* 85 (1957): 93-101.
[240] Lauren Donaldson and Deb Menasveta, "Selective Breeding of Chinook Salmon," *Transactions of the American Fisheries Society* 90 (1961): 160-164.

Figure 29. Lauren Donaldson (center) transporting hatchery-reared salmon to the Yakima River, c. 1935. Folder 25, Box 14, Lauren R. Donaldson Papers, The University of Washington Special Collections, Seattle, Washington.

Nor did Donaldson hesitate to employ less traditional methods when they became available. In the late 1950s, through his connections at the AEC, Donaldson learned of efforts to induce beneficial mutations in species through irradiation. At Brookhaven National Laboratory, for example, biologists had recently reported that continuous irradiation with cobalt-60 had produced a 17,000-fold increase in the rate of mutation in corn.[241] H. J. Muller had first demonstrated that X-rays induced mutations in fruit flies in 1920, but interest in "mutation

[241] Helen Anne Curry, "Radiation and Restoration; or, How Best to Make a Blight-Resistant Chestnut Tree," *Environmental History* 19 (2014): 217-238.

breeding" exploded around 1955, as President Eisenhower's "Atoms for Peace" campaign expanded into an international program with the support of the United Nations.[242] The AEC began to invest heavily in research on the genetic effects of ionizing radiation.

In a 1957 review for the National Academy of Sciences, Donaldson noted that while many investigators had designed studies to determine the lethal doses of radiation for various species, few had "studied in detail the physical and pathological syndromes of damaging but non-lethal exposures to radiation."[243] He also noted that little work had been done on whether genetic mutation from ionizing radiation was passed to offspring in marine or fresh-water species. On learning of the potential for radiation to "accelerate" genetic mutation, Donaldson began reframing his laboratory's research. Since 1943, the Applied Fisheries Laboratory had been exposing salmon and trout to radioisotopes in order to document detrimental effects in individual fish, always with the idea of clearing the way for military and commercial use of atomic technologies by finding safe levels of exposure. In 1957, they began to take a multi-generation approach to fish irradiation, with a view to identifying beneficial effects.

In 1958, the AFL changed its name to the Laboratory of Radiation Biology and Donaldson began exposing Chinook salmon eggs to cobalt-60 at the campus hatchery. Many of the salmon displayed abnormalities as they developed, including fused vertebrae. But some were larger and seemingly more robust than the controls: "In certain respects the irradiated, and in

---

[242] Angela Creager and Marıa Santesmases, "Radiobiology in the Atomic Age: Changing Research Practices and Policies in Comparative Perspective," *Journal of the History of Biology* 39 (2006): 637–647. On the "Atoms for Peace" campaign, see Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953–1961: Eisenhower and the Atomic Energy Commission* (Berkeley: University of California Press, 1989); John Krige, "Atoms for Peace, Scientific Internationalism, and Scientific Intelligence," *Osiris* 21 (2006): 161–181.
[243] Lauren R. Donaldson and Richard F. Foster, "Effects of Radiation on Aquatic Organisms," in *The Effects of Atomic Radiation on Oceanography and Fisheries* (Washington, D.C.: National Academy of Sciences, 1957), 96-102, quote on 97.

others the controls, were superior," Donaldson wrote in a *Transactions of the American Fisheries Society* paper.[244] They grew these salmon to adulthood, and then, in May 1961, released 21,217 control fish and 22,273 irradiated fish into Portage Bay to migrate through Puget Sound to the ocean. In order to see whether any returned to their spawning grounds – the University of Washington hatchery – they marked the salmon by notching their fins. Over the next four years, 230 control salmon and 287 irradiated salmon returned through Portage Bay. The following year, two times more irradiated fish returned than control fish. The AFL concluded that "low levels of irradiation" (0.5 roentgen/day) actually had a beneficial effect on salmon, increasing either their ability to survive in the wild or their ability to find their original spawning grounds.[245]

While irradiating Chinook salmon, Donaldson continued to breed Rainbow Trout, as he had done continuously since 1932. In the early 1960s, Donaldson and his colleagues began experimenting with irradiating these trout and found a slight increase in survival in the irradiated group. One spawning pair could produce 15 to 20 tons of fish a year.[246] In a letter to a colleague at Los Alamos Scientific Laboratory in 1963, Donaldson wrote:

> We are having interesting experiences with our very low exposure to developing salmon embryos and have about reached the conclusion that a half roentgen/day during the developmental period of 100 days, plus or minus, is very beneficial. I am sure this will cause some of the critics to really get up on their hind legs and scream, but such is the way of living things.[247]

---

[244] Lauren R. Donaldson and Kelshaw Bonham, "Irradiation of Chinook and Coho Salmon Eggs and Alevins," *Transactions of the American Fisheries Society* 93 (1964): 333-341.
[245] Lauren R. Donaldson and Kelshaw Bonham, "Effects of Chronic Exposure of Chinook Salmon Eggs and Alevins to Gamma Irradiation," *Transactions of the American Fisheries Society* 99 (1970): 112-119.
[246] Arthur D. Welander, Gerald W. Wadley, and Douglas K. Dysart, "Growth and Fecundity of Rainbow Trout (*Salmo gairderi*) Exposed to Single Sublethal Doses of X-rays During the Eyed Embryo Stage," *Journal of the Fisheries Research Board of Canada* 28 (1971): 1181-1184.
[247] Lauren R. Donaldson to Thomas Shipman, November 21, 1963, Folder 16, Box 6, LRBR.

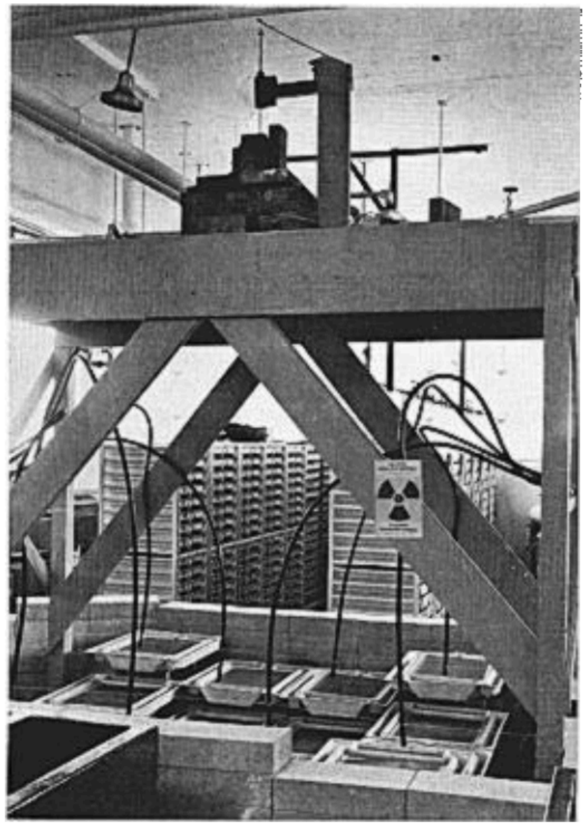


FIGURE 1.—Cobalt-60 radiation facility as it appeared on 7 October 1960 showing plastic incubating trays on a multilevel support surrounded by concrete blocks, and surmounted by the lead shield for the radioactive source. Dark curtains and shutter mechanism are lacking. In the background are tiers of incubating trays.

Figure 30. "Cobalt-60 radiation facility," from Lauren R. Donaldson and K. Bonham, "Irradiation of Chinook and Coho Salmon Eggs and Alevins," *Transactions of the American Fisheries Society* 93 (1964): 333-341.

Donaldson had reason to anticipate dispute. He had recently participated in the controversy around "Il Mondo Cane," an Italian documentary about the environment of Bikini Atoll, where Americans had been detonating atomic weapons since 1946. The film included pictures of "thousands upon thousands of unhatched [sea bird] eggs" and "giant tortoises that cannot find the sea" and eventually die of exhaustion, starvation, and heat.[248] In the summer of 1962, various news outlets reviewed the documentary.[249] "A team of Italian filmmakers reported recently on a trip made to Bikini to record animal life eight years after the first hydrogen bomb was set off there," the *San Francisco Chronicle* reported.

> [T]he movie men found that the birds were nesting on piles of eggs accumulated over the years. Either the birds had been made sterile or the eggs had been killed by the huge doses of fallout. The center of the atoll was filled with dead and dying sea turtles. These turtles, their instincts scrambled by radiation while still in the egg, had laid eggs of their own, and then plodded into the sun-backed interior instead of doing what they usually do, which is to swim back into the water, where the male awaits them. Pacific tree-climbing fish, which wriggle up trees in search of insects and then return immediately to the sea, were staying out of the water too long and dying in the trees. Apparently their instincts, too, had been destroyed by the radioactivity… Meanwhile they're testing tonight, testing tonight, testing on the old camp grounds.[250]

In short, "Il Mondo Cane" claimed that atomic technologies had perverted nature, inverting animals' basic instincts and destroying their fertility.

News of the film prompted a flurry of correspondence between Donaldson, the National Academy of Sciences, the AEC, and media outlets.[251] In one letter, Harold Coolidge, the Director of the National Academy of Sciences Pacific Science Board, wrote to Donaldson: "It seems to me that we are dealing with some clever Soviet propaganda which was trying to embarrass us into not carrying out further tests in the Pacific islands."[252] Donaldson's response to a *New York Times* inquiry demonstrated his delicate position as an AEC-funded ecologist. "We have yet to discover in or near the proving ground any biological aberration or peculiarity that is definitely ascribable to the effects of radioactivity," he wrote, "but this is not to say that some

---

248 James S. Jenkins to Mr. Allston Jenkins, May 18, 1962, Folder 16, Box 6, LRBR.
249 See, for example, "The Island That Went Wrong" *Sunday Times* (London), May 28, 1962. The film was shown in New York in March 1963 and Washington, D.C., in 1954.
250 Herb Caen, "The Voice of the Turtle," *San Francisco Chronicle*, June 17, 1962.
251 See Folder 16, Box 6, LRBR.
252 Harold Collidge to Lauren R. Donaldson, November 2, 1962, Folder 16, Box 6, LRBR.

such effects have not taken place, for radioactivity, of course, is capable of producing biological change and we always are aware that such possibilities must be followed as far as instruments and human intelligence will allow." He concluded, however, that without training in biology, "casual visitors" to Bikini would have been unable to discern any "biological changes."[253]

Into the 1960s, Donaldson actively defended the utility of radioisotopes for environmental and ecological work. He, like a number of AEC-funded ecologists, was working toward an ecological intervention that environmental historians have barely explored. Rather than protecting particular places or populations (efforts that environmental historians have frequently documented with emphasis on the Wilderness Act of 1964 and the Endangered Species Act of 1973) Donaldson sought to restore the future potential of species by genetically altering them.[254] To restore the salmon's ability to survive in a changed world, Donaldson changed salmon themselves.[255]

---

[253] Lauren R. Donaldson to John Devlin, August 3, 1962, Folder 16, Box 6, LRBR.

[254] On protection of endangered species, see Thomas R. Dunlap, *Saving America's Wildlife: Ecology and the American Mind, 1850–1990* (Princeton: Princeton University Press, 1988); Mark V. Barrow Jr., "Science, Sentiment, and the Specter of Extinction: Reconsidering Birds of Prey during America's Inter-war Years," *Environmental History* 7 (2002): 69-88; Peter S. Alagona, "Biography of a 'Feathered Pig': The California Condor Conservation Controversy," *Journal of the History of Biology* 37 (2004): 557-583; Gregg Mitman, "Pachyderm Personalities: The Media of Science, Politics, and Conservation," in *Thinking with Animals: New Perspectives on Anthropomorphism*, Lorraine Daston and Gregg Mitman, eds. (New York: Columbia University Press, 2005), 175-196; Robert M Wilson, *Seeking Refuge: Birds and Landscapes of the Pacific Flyway* (Seattle: University of Washington Press, 2010).

[255] Two recent studies that consider breeding for conservation purposes are Christopher Manganiello, "From a Howling Wilderness to Howling Safaris: Science, Policy and Red Wolves in the American South," *Journal of the History of Biology* 42 (2009): 325–359, and Helen Anne Curry, "Radiation and Restoration; or, How Best to Make a Blight-Resistant Chestnut Tree," *Environmental History* 19 (2014): 217-238. A growing literature in STS and animal studies that investigates the industrialization of organisms for agriculture and commodification informs my analysis. See Susan R. Schrepfer and Philip Scranton, *Industrializing Organisms: Introducing Evolutionary History* (New York: Routledge, 2004); Edmund Russell, "Evolutionary History: Prospectus for a New Field," *Environmental History* 8 (2003): 204-228; Edmund Russell,

Nutrient Supplementation: Creating New Salmon Habitat

In working to improve the yield of fish hatcheries, Donaldson worked to genetically modify fish. He also worked to develop artificial diets that promoted healthier hatchery fish. This had been the topic of his master's thesis, "Dried Fish Meals and Canned Carp as Food for Young Salmonoids," and his Ph.D. dissertation, "Experimental Studies in the Nutrition of the Chinook Salmon with Special Reference to Histological Changes in the Pancreas." He set aside this line of research in 1943, when the MED contracted him to study the effects of Hanford Works effluent on salmon. But he came back to it circuitously in the 1950s through the AFL's work for the AEC at the Pacific Proving Grounds.

In the weeks after the United States bombed Hiroshima and Nagasaki, the U.S. Senate and Joint Chiefs of Staff entertained proposals to test atomic weapons against naval warships, a set of plans they codenamed "Operation Crossroads." At a geopolitical level, Operation Crossroads would be a theater in which the United States could flaunt its atomic arsenal. The military's stated purpose was simpler: they would test whether atomic weaponry made the Navy obsolete. As the admiral in charge of Crossroads noted, "seapower, airpower, and perhaps humanity itself" were "at the crossroads."[256]

Evolutionary History (Cambridge: Cambridge University Press, 2011).

256 Quoted in W. A. Shurcliff, *Bombs at Bikini: The Official Report of Operation Crossroads* (New York: Wm. H. Wise & Co., Inc., 1947), 10. On the history of Operation Crossroads see also Lewis Strauss, *Men and Decisions* (New York: Doubleday, 1962); Jonathan M. Weisgall, *Operation Crossroads: The Atomic Tests at Bikini Atoll* (Annapolis: Naval Institute Press, 1994). The publicity of the tests also served the purpose of normalizing atomic testing and militarization. See Scott Kirsch, "Watching the Bombs Go Off: Photography, Nuclear Landscapes, and Spectator Democracy," *Antipode* 29 (1997): 227-255; Hal M. Friedman, *Creating an American Lake: United States Imperialism and Strategic Security in the Pacific Basin, 1945-1947* (Westport: Greenwood Press, 2001).

Evidence of widespread radiation poisoning in Hiroshima and Nagasaki made officials wary about conducting further atomic tests in the continental United States. (They had already detonated “The Gadget,” an implosion-design plutonium device, on July 16, 1945, three weeks before Hiroshima, in New Mexico’s Jornada del Muerto desert.) The Joint Chiefs of Staff decided that Operation Crossroads would be conducted “overseas.” From a suite of Pacific islands, including the Caroline Islands and the Galapagos Islands, they selected Bikini atoll, a coral “C” surrounding a deep central lagoon. To justify the displacement of Bikini’s residents, the Navy argued that the atoll was unsuitable for human inhabitation because it produced little food, and in early 1946, the U.S. government relocated the Bikini people to Rongerik Atoll – a worldly manifestation of hell, according to traditional Bikinian stories.[257]

Although the Navy described Bikini Atoll as a desolate place with few natural resources, lobbyists soon voiced their worry that weapons testing might damage valuable Pacific fisheries. To assuage their concerns, the Navy conferred with the U.S. Fish and Wildlife Service, which reported that the fisheries resources at Bikini were “negligible.” The chief medical officer of the Manhattan Engineering District then hastily convened a conference to discuss biological monitoring at the test site. There it was decided that the “Bikini Radiobiological Survey” would be led by a biologist who had been regularly producing reports for the MED: Lauren Donaldson.[258]

---

[257] Jeffrey S. Davis, “Representing Place: 'Deserted Isles' and the Reproduction of Bikini Atoll.” *Annals of the Association of American Geographers* 95 (2005): 607-625. For anthropological perspectives on American nuclear colonialism, see Barbara R. Johnston and Holly M. Barker, *The Consequential Damages of Nuclear War: The Rongelap Report* (Walnut Creek: Left Coast Press, 1998); Holly M. Barker, *Bravo for the Marshallese: Regaining Control in a Post-Nuclear, Post-Colonial World* (Belmont: Cengage Learning, 2012).
[258] See also Jessee (2013), Chapter 4. There were many military objectives of the scientific surveys of the Pacific Proving Grounds, as enumerated in “Oceanographic Program at Bikini

The Bikini Radiobiological Survey was overseen by Joint Task Force One, which was organized on January 11, 1946, and encompassed Army, Navy, and civilian scientific personnel who maintained liaison with the War and Navy Departments, the MED, and other federal agencies. Its commander, Admiral William H. P. Blandy, was charged with coordinating hundreds of civilian scientists to study "the effects of atomic explosives against ground and air targets and to acquire scientific data of general value if this is practicable."[259] Donaldson was instructed to lead a team that would observe whether radiation had any effect on marine fauna.

Joint Task Force One took more than 25,000 Geiger counters, film badges, and other radiation safety devices to Bikini Atoll, as well as 200 pigs, 204 goats, 60 guinea pigs, 5000 rats, and 200 mice. These animals were to be placed on 22 vessels of the target fleet. After the explosions, physicians would assess the condition of these animals and whether their condition varied by distance from the detonation. Once again, the experimental emphasis was on exposure to external sources of gamma radiation.[260]

Donaldson reached Bikini Atoll on a hospital ship, the *Haven*, eighteen days before the first scheduled detonation. His first task was to collect "control material" to compare with organisms that would be collected after "Test *Able*." Over a sampling area of almost 250 square miles, Donaldson and his assistants gathered as many specimens as they could. They killed smaller fish by poisoning tide pools with derris root and caught larger fish by hook and line.

Atoll, February 21- March 28, 1946," Box 3, Folder 7, W. T. Edmondson Papers Series 3 [hereafter WTEP3], University of Washington Special Collections, Seattle, Washington.

[259] Quoted in W. A. Shurcliff, *Bombs at Bikini: The Official Report of Operation Crossroads* (New York: Wm. H. Wise & Co., 1947), 13.

[260] R. F. Foster and Lauren R. Donaldson, draft of "Effects of Ionizing Radiation on Fish and Some Other Aquatic Forms" Box 17, Folder 21, LRDP.

They picked algae, coral, clams, and sea cucumbers from the reefs at low tide.[261] As of two days before Test *Able*, the crew had collected a total of 1,926 fish to be used as "controls" in subsequent studies of Bikini fauna.[262]

Figure 31. "Feeding a goat used as a test animal during Operation Crossroads in July 1946," Fritz Goro, Time & Life Pictures / Getty Images.

On July 1, 1946, at approximately 9 a.m. (Bikini time), the B-29 aircraft *Dave's Dream*

[261] Quoted from Hines (1962). Archival materials in LRBR and LRER document the University of Washington's involvement with the Pacific Proving Grounds, including laboratory records, personnel data, trip logbooks, AEC contracts, correspondence between lab members (some redundancy with LRD), staff meeting minutes, logbooks, AEC reports.
[262] Hines (1962).

dropped an atomic bomb on a battleship stationed in Bikini lagoon. It was a choreographed international event. From thousands of applicants, Joint Task Force One had selected hundreds of reporters, scientists, and diplomats to witness the detonation. Its sound was broadcast into homes, bars, hotel lobbies, and offices. Residents of Sydney, Australia, awaited a tidal wave.

And yet most witnesses found Test *Able* to be an anticlimax. The bomb burst as planned some 500 feet over its target, but approximately 1,500 feet to the west of it. By 2:30 p.m. the next day, Admiral Blandy had declared Bikini lagoon safe for re-entry by all ships, and by July 18, the Bikini Radiobiological Survey had recovered the scientific instruments and test animals from the target fleet. Donaldson and his crew were unable to find any dead or injured fish after the blast. Instead, they caught 1,819 live fish, both to measure their radioactivity and to better catalog the lagoon's fauna. The fish included carnivores like shark, grouper, tuna, and wrasse; omnivores including parrotfish, triggerfish, and pufferfish; and fish that fed on marine vegetation and plankton including mullet and sturgeon.[263]

Unlike Test *Able*, an atmospheric detonation, Test *Baker* would be conducted underwater.[264] And unlike Test *Able*, Test *Baker* was spectacular. On July 25, an atomic bomb was detonated 90 feet below the surface of Bikini lagoon. At the moment of detonation a giant bubble burst from the surface of the water. Within seconds a hollow column 2,200 feet in diameter and containing some 10 million tons of water rose from the surface of the lagoon to a height of more than a mile. The 26,000-ton battleship *Arkansas*, more than 500 feet away, was

---

[263] Ibid.

[264] Joint Task Force One was eager to understand the effects of an underwater detonation. Many believed that an underwater detonation would be ineffective because neither the air pressure nor the water pressure would be maximized. The preparations for Test *Baker* included the rearrangement of the target ships around a small landing craft, the *LSM 60*, beneath which, at a depth of ninety feet –approximately half the distance to the lagoon bottom – the atomic device would be suspended.

lifted into the column. The descent of the water back into the lagoon set up a base surge from which rolled waves as high as eighty feet. As Donaldson wrote, "The one July 1 was awe-inspiring and in many ways beautiful, but the one today just frightened the very daylights out of one [...] it appeared as if the entire lagoon were up in the air."[265]

Figure 32. Photograph of the Baker Test from Bikini Atoll. Edward U. Condon Papers, Series IV, American Philosophical Society, Philadelphia, Pennsylvania.

After Test *Baker*, Donaldson's crew had no problem finding dead fish. They visited collection points from one of the *Haven*'s whaleboats. When beach landings were necessary, the crew used rubber rafts, which could handle the rough coral. Joint Task Force One was using plotting boards on the task force flagship to maintain records of the outlines of radioactivity developing within the lagoon. Support vessels returning to the lagoon after Test *Baker* immediately reported radioactivity in the water, in barnacles on the ships' hulls, and even in

[265] Lauren Donaldson Box 11, Folder 28, LRDP; "Report on Able and Baker Effects," Box 6, Folder 4, LRBR.

shipboard areas presumed to be inaccessible to contamination. Donaldson's crew used this information to decide where to collect samples. From July 25 to August 13, they collected an additional 1,407 fish.[266]

Before Test *Baker*, Donaldson and his crew had been looking for external damage to marine fauna and correlating it with Geiger counter readings. After Test *Baker*, they decided to use a relatively new method, "radioautography," to quantify the gross radioactivity of their samples. Emissions from a radioactive sample placed against photographic film would produce a brighter or darker image, depending on how much radiation reacted with the film's substrate. The process worked, but the images surprised the members of the AFL by suggesting that radioactivity was distributed in fish bodies unevenly. The radioautographs made visible the previously invisible phenomenon of *internal* tissue contamination. Donaldson's team decided to take samples from multiple organs of individual fish. By the end of summer, they had measured radioactivity in 1,021 tissue samples and had sent thousands more samples back to the Applied Fisheries Laboratory in Seattle for analysis.[267]

---

[266] Hines (1962).
[267] Hines (1962), chapters 2 and 3. "Appendix XIV," Box 6, Folder "Bikini 1946-1947," LRER.

Figure 33. "Unidentified biologists testing a bird for radiation exposure, 1946," Fritz Goro, Time & Life Pictures / Getty Images.

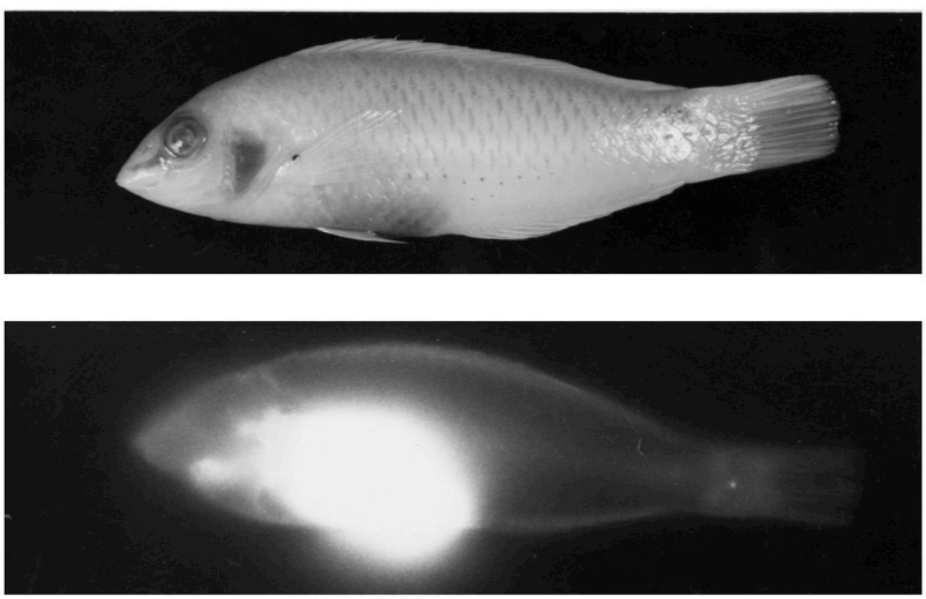


Figure 34. Radioautograph of wrasse collected from Test *Baker*, August 8, 1946, Folder 8, Box 2, Neal O. Hines Papers, The University of Washington Special Collections, Seattle, Washington.

Three events in the summer of 1947 enabled Donaldson to continue researching the puzzle of uneven distribution of radiation in fish bodies. First, Donaldson was asked to return to Bikini Atoll under the auspices of the "Bikini Scientific Resurvey," which was first conceived as a concluding phase of Operation Crossroads. Naval officials hoped to obtain detailed observations of ships a year after they were sunk in Test *Baker*, and the newly formed Atomic Energy Commission asked physicists, oceanographers, geologists, and biologists to take part. Not only the University of Washington sent biologists to participate, but also the U.S. Fish and Wildlife Service, Stanford University, the U.S. National Museum, and the Scripps Institution of Oceanography.[268]

Second, in the summer of 1947 the United States entered into an unprecedented agreement with the United Nations to govern the Trust Territory of the Pacific Islands. The Trust Territory encompassed 2,000 islands, including Bikini Atoll, spread over 3,000,000 square miles.[269] The AEC announced the establishment of the "Pacific Proving Grounds" that July, and between 1946 and 1962, the AEC would conduct 105 atmospheric and underwater nuclear

---

[268] Hines (1962). See also Neal O. Hines, "Bikini Report," *The Scientific Monthly* 72 (1951), reprint in Box 13, Folder 1, LRBR. Press releases for Bikini Resurvey Expedition can be found in Box 2, Folder 7, Neil O. Hines Papers, [hereafter NOHP]. The scrapbook of the Bikini Resurvey can be found in Box 21, LRDP. On the history of the AEC, see Richard G. Hewlett and Francis Duncan, *Atomic Shield, 1947-1952* (U.S. Atomic Energy Commission, 1972); Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953-1961* (Los Angeles: University of California Press, 1989); John Krige, "Atoms for Peace, Scientific Internationalism, and Scientific Intelligence," *Osiris* 21 (2006), 161-181.

[269] More than 50,000 people lived in the Trust Territory. See Robert Trumbull, *Paradise in Trust: A Report on the Americans in Micronesia, 1946-1958* (New York: William Sloane Associates, 1959); Roger W. Gale, *The Americanization of Micronesia: A study on the Consolidation of U.S. Rule in the Pacific* (Washington DC: University Press of America, 1979).

weapons tests there, releasing the equivalent power of at least 7,159 Hiroshima bombs.[270] Donaldson and members of the AFL would revisit the Pacific Proving Ground annually over more than a decade.

Finally, the summer of 1947 was the same summer that Richard Foster found Columbia River fish to have concentrations of radioactivity thousands of times higher than their environment. This discovery, ultimately combined with results of annual visits to the Pacific Proving Grounds between 1947 and 1962, led the AFL to conclude that radioisotopes migrated not only from water to aquatic organisms, but from aquatic organisms to terrestrial organisms.[271] In the year of the Resurvey, 1947, the AFL had expected that the expansive ocean would have dispersed any fission products. But to their surprise, they found radioactive materials incorporated into all kinds of species, from phytoplankton to terrestrial plants to fish, at concentrations much higher than in the lagoon.[272] In the Bikini lagoon as in the Columbia River, marine organisms appeared to incorporate radioisotopes through absorption and, crucially for Donaldson's future research, digestion. Interconnections among species – the objects of theoretical flow charts in the 1930s – became objects of radioautographs and Geiger counters.

In a 1954 report to the AEC, Donaldson extolled the "unparalleled scientific experiments" at the Pacific Proving Grounds (the testing of atomic weaponry) that had provided ecologists with a new tool: radioisotopes. The radioactive residue of fission bombs, and then fusion bombs, had cycled through Bikini's and Eniwetok's lagoons, enabling the AFL to

---

[270] Robert Jackson, *Guide to U.S. Atmospheric Nuclear Weapons Effects Data* (Alexandria: Defense Nuclear Agency, 1993).
[271] Donaldson speculated that the atolls represented "an unparalleled opportunity … to study the role of trace elements" in the environment. Lauren R. Donaldson, "Biological Cycles of Fission Products in Aquatic Systems as Studied at the Pacific Atolls of Bikini and Eniwetok," U.S. Atomic Energy Commission Report AECU–3412, Folder 3, Box 3, LRDP.
[272] Hines (1962).

visualize relationships among species in a "natural environment" and to make ecology "a more exact science." And because radioisotopes "did not interfere with normal metabolic processes," in Donaldson's view, they were an ideal, non-invasive observational tool.[273]

Also in 1954, an Alaskan territorial delegate asked Donaldson if the data he had collected for the AEC in the Pacific Proving Grounds on trace elements might help managers to improve salmon runs. Donaldson replied that yes, radiobiology provided the tools to measure which minerals were deficient in the salmon's environment and, accordingly, which minerals mangers could add to streams to improve salmon yields. Donaldson believed that it was inevitable that damming and logging would destroy natural salmon runs, but that the runs could be restored with "mineral regeneration" and then populated with genetically improved salmon.[274]

In 1951 and again in 1954, Donaldson proposed studies to the AEC to follow cycles of "essential food elements" in the Pacific Northwest, an environment that he figured as similar to the Pacific atolls in its "nutrient limitation." Data he would collect from radioisotopes would be valuable not only to the military, Donaldson continued, but to scientists working to restore fisheries:

> [T]he need is now to apply the knowledge, techniques, and skills to increasing the productive capacity of our fresh water areas. There is every evidence that the rewards of increased food production from aquatic resources will rival or exceed the spectacular results that have been obtained from applying these new concepts to aquaculture.[275]

The AEC rejected Donaldson's first two mineral regeneration proposals, but approved his

[273] Lauren R. Donaldson, "Biological Cycles of Fission Products in Aquatic Systems as Studied at the Pacific Atolls of Bikini and Eniwetok," U.S. Atomic Energy Commission Report AECU–3412, Box 3, Folder 7, LRDP.
[274] Fred E. Locke to Lauren R. Donaldson, October 5, 1953; Donaldson to Locke, October 7, 1953; E. L. Bartlett to Lauren R. Donaldson, August 5, 1954; Donaldson to Bartlett, August 11, 1954, Box 1, Folder 1, LRDP. For the role of trace elements in salmon physiology, see Lauren R Donaldson, "The Inorganic Elements," Box 3, Folder 3, LRDP.
[275] Ibid.

third request, in 1957. With a $20,000 AEC grant and land donated by the State of Washington Department of Game, Donaldson launched the "Fern Lake Trace Mineral Metabolism Project."[276]

Fern Lake, on the rainy Kitsap Peninsula, had been carved out of volcanic rock by glaciers, making it "mineral deficient" and "rain-leached," and there was no evidence that it had ever sustained salmon runs. Donaldson believed this made it a good site to study the effects of "artificial fertilization" on establishing a salmon population. The project divided into three stages. In the first stage, the Applied Fisheries Laboratory inventoried the lake to establish a baseline for subsequent surveys. In the second stage, they "artificially fertilized" the lake by introducing radioactively tagged elements, including phosphorus, calcium, and potassium. In the third stage, they documented the physical and chemical effects of trace element supplementation on algal growth and, later, on introduced salmon.[277]

Through this work, Donaldson came to depict the salmon as vessels that exchanged nutrients between sea and land. When salmon returned to their birthplaces to spawn and die, they transferred energy "earned in the ocean" to freshwater rivers and lakes, depositing "valuable" minerals in the terrestrial environment. In one seminar he explained:

> And one must realize that in this whole Northwest area […] life was possible really only because – many forms of life – trees would grow, true – but maybe they wouldn't – many things are possible because the salmon went to the sea and gathered the minerals, many of them trace minerals, the 16-plus elements needed for life. They carried them up the

---

[276] For an overview of the Fern Lake project, see Lauren R. Donaldson, Paul R. Olson, and John R. Donaldson, "The Fern Lake Trace Mineral Metabolism Program," *Transactions of the American Fisheries Society* 88 (1959), 1-5.

[277] Lauren R. Donaldson *et al.*, *The Fern Lake Studies* (Seattle: University of Washington Press, 1971). Matt Klingle uses the Fern Lake project to explore the connection between ecology and natural resources management, concluding: "Seeing ecology and natural resource management as allied fields on a continuum opens new questions for historians to explore." Klingle (1998), 31.

> hill. […] We know, for example, that the western red cedar won't grow unless there's calcium present. Well, how does the calcium get in these calcium-deficient areas? Well, it came up with the salmon.[278]

With the Fern Lake project, Donaldson attempted to replicate this function by supplementing "nutrient deficient" waters.

As Matthew Klingle has detailed, the Fern Lake project was riddled with failures.[279] Insufficient stream drainage skewed the concentration of trace elements and blocked migrating fish. When the AFL constructed a new outlet, beavers blocked it. Stickleback and yellow perch preyed on the experimental salmon. Neither Steelhead, nor Steelhead-Rainbow hybrids, nor Sockeye salmon seemed to thrive in the new environment of Fern Lake. But these difficulties did not deter Donaldson and other ecologists from continuing to use radioisotopes to study "community metabolism" in the field with the aim of developing the capacity to restore fish populations by nutrient supplementation.[280]

---

[278] Quotation from "A Farewell to Doc," Box 1, Folder 1, LRDP.
[279] Ibid.
[280] Nadine Levin has recently published on how contemporary metabolics researchers have developed multifactorial understandings of metabolism through multivariate statistical analyses. The notion of metabolism as a complex process is not waiting to be discovered, she argued, but instead is actively created and enacted by scientists. Nadine Levin, "Multivariate Statistics and the Enactment of Metabolic Complexity," *Social Studies of Science*, in press.

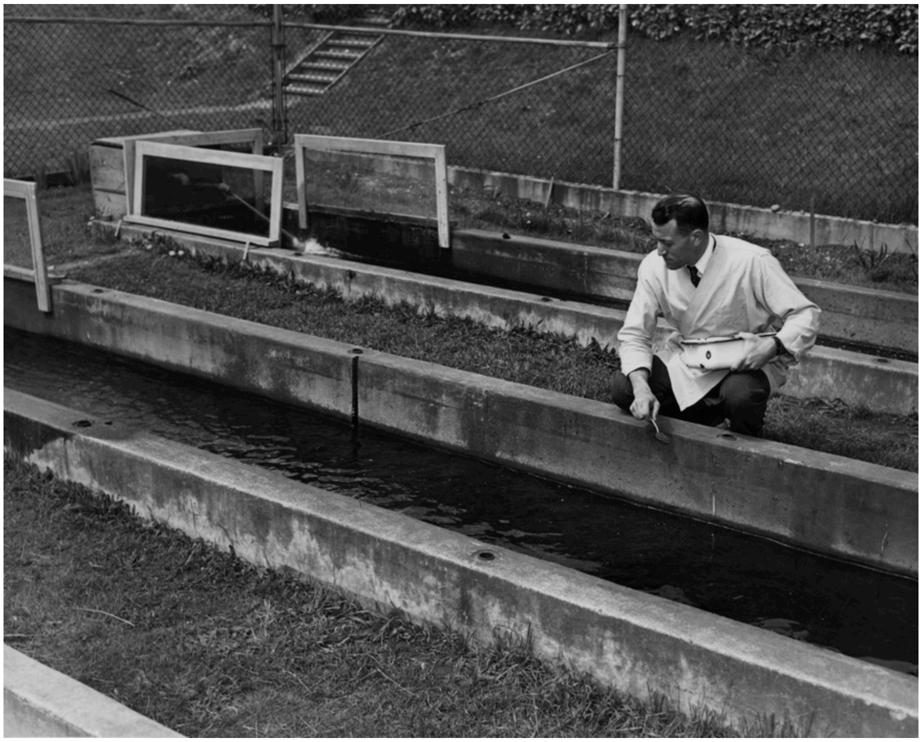


Figure 35. "Lauren Donaldson ready to feed fish at water trough," Folder 3, Box 25, Lauren R. Donaldson Papers, The University of Washington Special Collections, Seattle, Washington.

Environmental Sequestration: Restoring Wild Salmon by Domesticating the Sea

Donaldson's atomic work with trace elements involved him in discussions not only of fish nutrition, but of human nutrition as well. Food production in the United States had undergone a major transformation in the 1920s, beginning with the rise of industrial freezing. Since then, food had been produced and marketed on a new scale. In 1946, for example, the Cherry Burrell Corporation had developed a continuous pasteurization process that made it possible to create and package 7,000 pounds of butter in two hours. Cold War technologies like spray drying, freeze drying, and new preservatives led to an array of new food products. By the 1950s, processed and nationally distributed foods dominated the market.[281]

In the fall of 1963, the president of General Mills, Inc., Edwin W. Rawlings, wrote to Donaldson asking if he would be a consultant for the General Mills Isolated Proteins Division as "an expert in the field of marine life as a protein source." Food-grade soy protein had recently become commercially available, and General Mills, which owned Betty Crocker, Pillsbury, Cheerios, Bisquick, and Wheaties, among other brands, and which sponsored *The Lone Ranger* and *The Bullwinkle Show*, had a vested interest in keeping up with food industry trends. Donaldson had ties to Minnesota, where General Mills was based, Rawlings reminded him; and the project presented "possibilities in the field of conservation." Donaldson, excited by the opportunity to work with a large corporation, took Rawlings up on the offer.[282]

One of Donaldson's first assignments for General Mills was to procure information on fisheries with surplus stocks that could be "harnessed as sources for commercial protein." But such aggregated information was difficult to come by in 1963. When Donaldson wrote to the chairman of the International Whaling Commission to ask for information on worldwide whale harvesting rates, the chairman replied that exact numbers were available only for Norway, where an average of 6,300 tons of whale meat were landed per season, 45% for human consumption, the rest for animal food. Despite the paucity of concrete information, General Mills was pleased

[281] Warren J. Belasco, *Appetite for Change: How the Counterculture Took on the Food Industry* (Ithaca: Cornell University Press, 1989); Aaron Bobrow-Strain, *White Bread: A Social History of the Store-Bought Loaf* (New York: Beacon Press, 2013).

[282] Correspondence between General Mills executive offices and Lauren R. Donaldson can be found in Box 1, Folders 35-40, LRDP. Additional material can be found in Donaldson's correspondence with W. J. Mullahey (of Pan Am) in Box 6, Folder 13, LRDP and with General E. W. Rawlings in Box 6, Folder 16, LRDP.

with Donaldson's fact-finding, and in subsequent months, Rawlings sent Donaldson complementary pre-market samples of WONDRA flour and Bacon Bits.[283]

Donaldson soon befriended Rawlings through a mutual interest in trout fishing. In an invitation to join General Mills employees on a company retreat, Rawlings wrote to Donaldson:

> Your tour of duty at WONDRA ISLE, Rainy Lakes, Ontario, will be for a period not to exceed five (5) days […] Active duty under the meaning of this order should be construed to include the following: piscatorial pursuits, feeding the inner man, detailed recital of past military and civil personal accomplishments, roundtable discussions, drinking in the beauties of the surroundings with special guests Jack Daniels and Jim Beam.[284]

At the WONDRA Isle meeting, Donaldson showed "Return to Bikini," a promotional film produced by the Atomic Energy Commission and the University of Washington in 1950 that described Bikini as a "perfect aquatic laboratory." An excerpt from the script highlights the rhetorical work that, in combination with extensive scientific and military operations, transformed the environment of the atolls:

> [Picture of Moorish idol fish]
> The scientists watch the drama of radiation in this perfect aquatic laboratory… and the answers they are finding may help to answer the biggest question of all: How can man manage the atom?
>
> [Picture of Black-tip shark]
> All these representatives of Bikini's underwater world come to the laboratories aboard the Navy's LSI. They seem to belong to the aristocracy of their kind, beautiful and graceful and equipped to survive in the fierce contests for food in a Pacific atoll.
>
> [Picture of specimens in a laboratory tray]
> Even these puzzled chaps – a sea slug, a hermit crab, and a proboscis worm – may contribute to the radiation story. In fact, their contributions may be noteworthy – for the invertebrates are among the stars of the Bikini drama. Because they are usually quiet, domestic types, not given to roaming far from home, any radiation absorbed by the

[283] A. Jonsgard to Lauren Donaldson, November 12, 1963, Box 1, Folder 35, LRDP.
[284] "General Order Number 3," Folder 36, Box 1, LRDP.

> invertebrates will be held and stored until released in the normal term of life and death. They help to hold radiation despite the constant shifts of the aquatic environment.[285]

Through his connection to Rawlings, Donaldson was copied on more and more General Mills correspondence, some of which concerned the Pacific atolls with which Donaldson was so familiar. In 1965, a representative of Central and South Pacific Pan American World Airways alerted Rawlings to a recent Congressional plan to enact "economic and social development of the Trust Territories." The air service contractor for the Trust Territories, Pan Am was keenly interested in developing tourism infrastructure. As a representative of Pan Am put it to Rawlings:

> Stone-age peoples, the descendants of and the confused product of mixed racial stocks and cultures from Malaya, Asia, Spain, Germany, Japan and the U.S.A. could offer wonderful new and exciting cultural-collecting tourism opportunities to today's sophisticated multi-destination travelers.[286]

General Mills should also be interested in the fate of this legislation, Pan Am argued, because "The warm, clean, tropical seas which surround the 58,000 atolls and islets could serve as 'anchored factory bases' from which to cultivate the ocean areas for all forms of protein which the expanding populations of the Earth require." The atolls, which had been portrayed as barren of food by U.S. interests in the 1950s, were now being celebrated as the future "protein 'bread basket' of the entire world's population."[287]

General Mills was indeed interested in the idea of cultivating a tropical protein basket, and Donaldson began brainstorming. In follow-up meetings, Donaldson emphasized that food from the ocean was an excellent resource because it contained "a perfect distribution of the 14 elements of diet which are so important to human beings." He suggested that hake, "never

---

[285] Gen. E. W. Rawlings to Lauren R. Donaldson, "General Order Number 3," Box 1, Folder 36, LRDP.

[286] Gen. E.W. Rawlings to W. J. Mullahey, June 18, 1965, Box 1, Folder 37, LRDP. W. J. Mullahey to Clarence Hall, May 12, 1965, Box 1, Folder 37, LRDP.

[287] S. G. Morie Morrison, "Notes May 20 1965," Box 1, Folder 37, LRDP.

regarded as a table fish by Soviets, Japs or Americans," was packed full of concentrated protein as well as cobalt, iodine, copper, zinc, and other trace elements that were "sometimes hard to procure in controlled or budgeted amounts." Donaldson also noted that his Radiation Biology Laboratory had excellent data on the locations of "rich and non-rich marine areas" around the Pacific atolls where General Mills could establish "ocean ranches" – pens of fish reared for consumption.[288]

Donaldson's and General Mills' interests in trace elements matched broader trends in the field of nutritional research at the time. Recent debate in the Food and Drug Administration had centered on whether there was a mineral imbalance or shortage of minerals in the typical U.S. diet. The pooling of commodities from farms around the country made it increasingly difficult to generalize about the nutritional qualities of crops like grains. To address the question directly, the U.S. Department of Agriculture launched a project to analyze whether there were differences in the mineral constituents of wheat grown in different locations in the United States. The position of General Mills was that "minerals, particularly the so-called 'trace' minerals, are on the threshold of assuming a prominence in nutritional studies at least equal to that attained by vitamins and proteins to date," and that a study by Donaldson of the mineral needs of fish, the results of which were translatable to humans, "could be interesting to [Donaldson] and profitable to General Mills."[289] Donaldson's interest in hatcheries and nutrient cycling coincided with General Mills' commercial interests, and thus Donaldson began to pursue a third approach to restoration – commercial "ocean ranching."

---

[288] Ibid.
[289] Ray H. Anderson to Lauren R. Donaldson, February 3, 1967, Box 1, Folder 38, LRDP.

At a 1968 meeting, "Domesticating the Sea," hosted by the Hawaii Sugar Technologists, Donaldson argued that "ocean ranching" promised to aid species in the struggle for existence by "feeding, healing, and protecting" the environment, while at the same time feeding an expanding human population, so that "in a few generations, the result would be a balanced, healthy mixture of farm, pasture, ranch, park, and wilderness, capable of feeding and providing a living for generations of man yet to come."[290] Donaldson thus extended his vision for fish stocking beyond state government to an international and industrial scale, where the goal was the restoration of "wild fish" by the designation of the ocean ranch. He imagined that fish farming – "ocean ranching" – would sequester certain environments as it heavily utilized others.

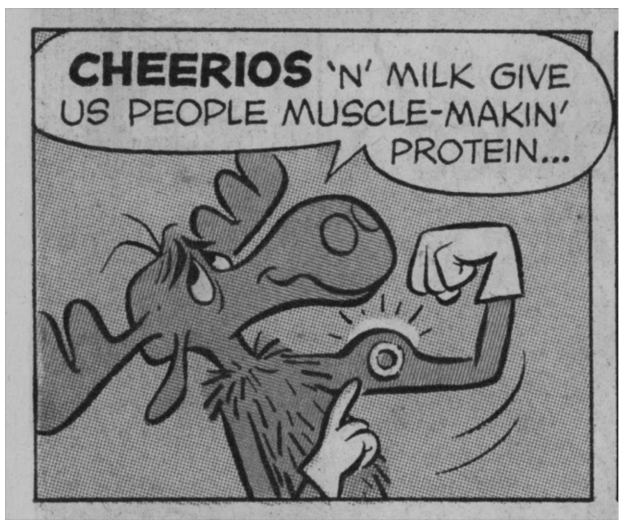


Figure 36. General Mills, Inc., advertisement for Cheerios, circa 1960.

Radiation and Restoration

[290] "Domesticating the Sea – Prospects and Problems," delivered to a meeting of the Hawaii Sugar Technologists, Folder 56, Box 3, LRDP. On "ocean ranching" see also Folder 38, Box 14, LRDP.

In *Nature's Economy*, Donald Worster argued that the emergence of the ecosystem concept in the late 1960s was convenient to agronomic and industrial concepts of nature as an exploitable resource. Indeed, it would appear that this was a time of immense faith in expert ability to engineer a better world, a philosophy Peter Taylor has referred to as "technocratic optimism" and James Scott has called "high modernism."[291] In many ways it would be easy to dismiss Donaldson and his colleagues as technocratic optimists, even opportunists. After all, Donaldson believed that he could breed a salmon that would obviate the need for government regulation. But ecological research at AEC sites facilitated more than technocratic management of the environment – it facilitated grassroots environmentalism, conservation biology, and restoration ecology – movements of the "Age of Ecology" that are typically contrasted with the "Atomic Age."[292]

The connections between atomic bombs, Bacon Bits, fish farms, U.S. Pacific colonialism, and ecological restoration are no longer obvious to a twenty-first century viewer. But as the ESA memo that opens this chapter indicates, the immediate postwar era was a time of unusual institutional constellations, ones predicated on a sense of national, or even universal, responsibility that spanned ecological, commercial, and geopolitical interests. So it happened that the AEC was the largest funder of ecological fieldwork in the United States until the National

---

[291] Taylor (1988); James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven; Yale University Press, 1999).
[292] While many scholars have explored the rise of ecological thought, few have traced the constitutive relationship between radioactive militarism and the study of the environment. Frank Golley has remarked that ecologists in the 1970s "seemed oblivious to the connection between ecosystem research and the military activity of the U.S." Golley (1993), 105. Others connecting ecosystem ecology with federal nuclear weapons programs include Scott Kirsch, "Ecologists and the Experimental Landscape: The Nature of Science at the U.S. Department of Energy's Savannah River Site," *Cultural Geographies* 14 (2007): 485-510; and E. M. DeLoughrey, "The Myth of Isolates: Ecosystem Ecology in the Nuclear Pacific," *Cultural Geographies* (2012).

Science Foundation eclipsed it around 1965. The products of this relationship were numerous. Ecologists sponsored by the AEC participated in the 1951 establishment of The Nature Conservancy, the 1955 Atoms for Peace conference in Geneva, the 1967 incorporation of the Environmental Defense Fund, and the 1971 UNESCO Man and the Biosphere Programme. Academic ecologists and employees of environmental agencies were also linked by the AEC, and Donaldson mobilized such connections in his effort to promote salmon farming abroad. In the 1950s he promoted the "Donaldson Trout," also known as "Hurry-up Trout," "Super Trout," "Fast-Growing Rainbow," and "Giant Trout," to American scientists and state hatcheries. In the 1960s, he began sending eggs to scientists abroad, and by the second half of the decade, he had forged a number of industrial ties as well. For example, in 1965 Donaldson proposed to General Mills that they establish a non-profit organization (modeled after their Wheaties Sports Association) to pursue fisheries restoration projects. General Mills was interested in the publicity, and Rawlings, an avid fisherman, was keen to establish a Great Lakes stocking program. With Donaldson and Rawling's prompting, and General Mills' backing, the Minnesota Department of Natural Resources began stocking Donaldson Trout.[293] In another venture, Donaldson convinced the Weyerhaeuser Corporation that it would be a good public relations move to expand into ocean ranching, a "sincere, constructive job for sport, conservation and wildlife." In 1972, the Weyerhaeuser Corporation purchased Oregon Aqua-Seafoods from Lauren Donaldson and his son to carry out pen-rearing of Pacific salmon. Union Carbide Corporation also invested in salmon farms, and the Inmont Corporation purchased the Thousand

---

[293] S. G. Morie Morrison, "Notes May 20 1965," Box 1, Folder 37, LRDP. Lauren R. Donaldson to E. W. Rawlings, September 15, 1967, Box 1, Folder 39, LRDP. "State of Minnesota Department of Natural Resources," Box 2, Folder 28, LRDP. Correspondence with the Michigan Department of Conservation can be found in Box 2, Folder 27, LRDP.

Springs Trout Farms in Idaho and Long Island Oyster Farms in New York.[294] By 1980, Donaldson Trout were grown in Alaska, California, Colorado, Idaho, Michigan, Minnesota, Montana, Oregon, Canada, China, Germany, Ireland, Japan, Korea, New Zealand, Norway, and Sweden. If you have eaten trout, it is very likely that you have eaten a Donaldson Trout.[295] As of 2008, farmed seafood constituted 42 percent of the world's seafood supply.[296] And as in the 1960s, today proponents of commercial fish farming cast it as both a solution to world hunger and a solution to a worldwide fisheries crisis.

---

[294] S. G. Morie Morrison, "Notes May 20 1965," Box 1, Folder 37, LRDP. Records on Oregon Aqua-Foods Inc. can be found in Box 2, Folder 44, LRDP. See also Colin Nash, *The History of Aquaculture* (New York: Wiley-Blackwell, 2011).

[295] On the 1959 trip, see Lauren R. Donaldson to Mr. Milo Moore, November 8, 1966, Box 2, Folder 30, LRDP; Lauren R. Donaldson to Richard A. Barkley, March 11, 1969, Box 3, Folder 56, LRDP. Today stocking is practiced around the world. For example, each year the NYSDEC stocks approximately 3.6 million catchable sized trout into over 10,000 km of streams in New York State. See Anders Halverson, *An Entirely Synthetic Fish: How Rainbow Trout Beguiled America and Overran the World* (New Haven: Yale University Press, 2011).

[296] Brian Halweil, "Farming Fish for the Future," Worldwatch Report 176 (Washington, D.C.: Worldwatch Institute, 2008).

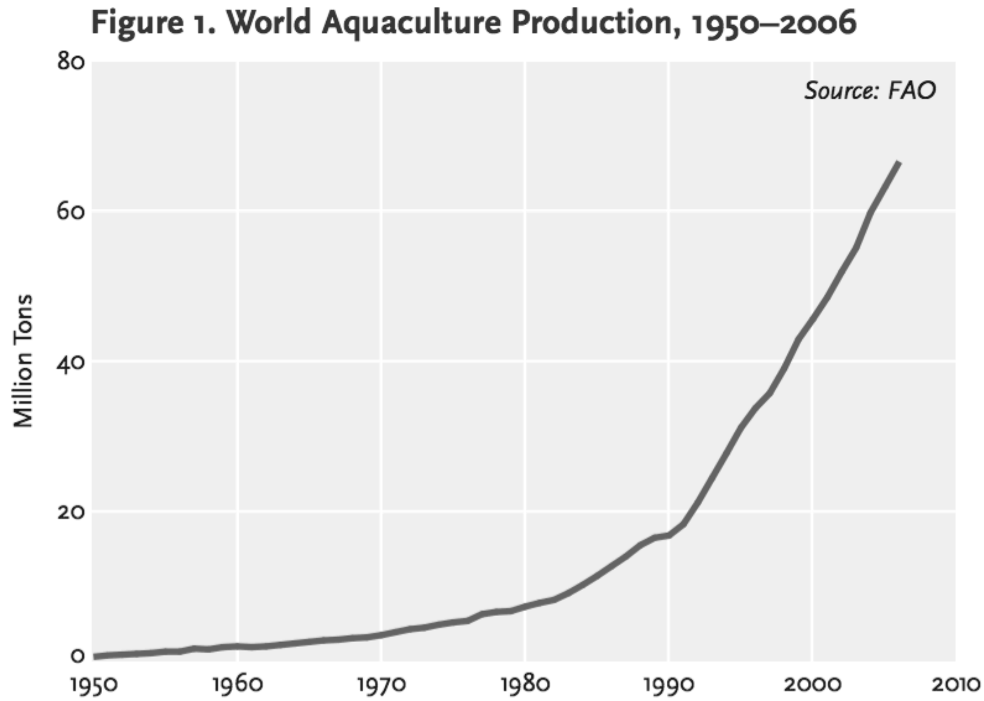


Figure 37. World aquaculture production, 1950-2006, from Brian Halweil, "Farming Fish for the Future," Worldwatch Report 176 (Washington, D.C.: Worldwatch Institute, 2008).

Today, despite the commercial popularity of fish farming, many ecological restorationists are against stocking fish in "natural areas," and in many places contemporary restoration practice is exactly opposite of Donaldson's: restorationists remove supplemental nutrients and kill non-native and "non-wild" fish. One 2004 paper began, "intentional introductions of nonnative trout into headwater lakes and streams can have numerous effects on the receiving ecosystems, potentially threatening native species and disrupting key ecological processes."[297] A 1998 paper in *Restoration Ecology* stated: "One of the goals of wilderness management is to exclude nonnative species to the extent possible. In direct conflict with this goal is the common practice

[297] Jason B. Dunham, David S. Pilliod, and Michael K. Young, "Assessing the Consequences of Nonnative Trout in Headwater Ecosystems in Western North America," *Fisheries* 29 (2004): 18-26.

by state fish and game agencies of stocking nonnative trout."[298] When and why did the momentous reversal occur?

The 1950 Federal Aid in Sport Fish Restoration Act was much in line with earlier fish restoration legislation. The Act established a mechanism for states to collect taxes on fishing supplies to fund "the rehabilitation of fishing waters through the poisoning and restocking technique." The accepted method of "rehabilitating" watery areas was to poison "trashfish" – species that might compete with or eat sport fish – and then to stock with hatchery-reared fish.[299] By 1954, states had used Sport Fish Restoration Act funds to launch more than 300 restoration projects.[300] But compare this to the experience of U.S. Fish and Wildlife Service employee Chester Mattson, who wrote to Donaldson in 1967:

> Too many fishery administrators and influential biologists cling to the myth that Alaska's streams, rivers, and lakes are in near virgin condition, hence capable of producing salmon as abundantly as they did 50 years ago. Therefore it is very foolish to introduce artificial propagation or other salmon enhancement techniques into Alaska because they are not needed nor wanted. This may be essentially true, our areas are not marred extensively by civilization. Yet our salmon stocks are not returning to former abundance levels as rapidly as expected. In fact 1967 returns were the poorest ever observed. How incredibly naïve are our fisheries administrators, who expect to maximize Alaska's salmon production using unimproved "seed" stocks spawning in uncultivated "soils" with young being reared in infertile, barren waters that are frequently heavily infested with predator and competitor species? This is the present, sad, primitive state of salmon aquaculture in Alaska. An agronomist would be amazed, yet our biologists are contented with basic research objectives having only remote "spin-off" benefits for salmon enhancement.[301]

---

[298] Roland A. Knapp and Kathleen R. Matthews, "Eradication of Nonnative Fish by Gill Netting from a Small Mountain Lake in California," *Restoration Ecology* 6 (1998): 207-213.
[299] Lauren R. Donaldson, "Biological Cycles of Fission Products in Aquatic Systems as Studied at the Pacific Atolls of Bikini and Eniwetok," U.S. Atomic Energy Commission Report AECU–3412 (1955), reprint in Box 3, Folder 3, LRDP. S. G. Morie Morrison, "Notes May 20 1965," Box 1, Folder 37, LRDP. For further discussion of early twentieth-century studies of fisheries, see also Sharon E. Kingsland, *Episodes in the History of Population Ecology* (Chicago: University of Chicago Press, 1985).
[300] "Reports of Standing Committees," *Transactions of the American Fisheries Society* 84 (1955): 330-371.
[301] Chester Mattson to Lauren R. Donaldson, December 20, 1967, Box 3, Folder 57, LRDP.

A shift in how Americans envisioned fish restoration had started in the late 1960s; by 1967, a number of fisheries biologists and managers were beginning to focus on "ecosystems" rather than individual species, as reflected in Mattson's letter.

This alteration in fish restoration practice coincides with a rethinking, in the 1960s, of the significance of nutrient cycle research like Donaldson's. What had once held out hope for informing ecological restoration began to turn up convincing evidence that human actions had poisoned ecosystems. Gradually biologists refashioned radioisotopes, which Donaldson used as model nutrients in researching the movements of elements like iron, zinc, iodine, and manganese, into model pollutants. DDT was among the first pollutants to be studied this way; later, heavy metals and hormone disruptors were identified as pollutants, too.[302] Though radioisotopes could model both nutrients and pollutants, nutrients were figured as moving in a "natural" cycle, while pollutants were figured as breaking that cycle, moving instead in a directed chain. By 1958, the language of chains, rather than cycles, appeared in J. Davis and Richard Foster's "Bioaccumulation of Radioisotopes through Aquatic Food Chains," a product of the AFL that was published in the journal *Ecology*. The article reported that the concentration of Phosphorus-32 in Columbia River salmon was 165,000 times greater than the concentration in the water. Davis and Foster hypothesized that each trophic level served as a kind of "pool or reservoir" in which elements were retained for some length of time before being passed onto the next level.[303]

---

[302] Bruno (2003), 259.
[303] "Meetings and Societies," *Science* 124 (1956): 1036-1042; J. J. Davis and Richard F. Foster, "Bioaccumulation of Radioisotopes through Aquatic Food Chains," *Ecology* 39 (1958): 530–535.

Similarly, Rachel Carson opened her 1962 book, *Silent Spring* by employing the image of a chain of accumulation to analogize the spread of the pesticide DDT to radioactive fallout:

> Strontium 90 released through nuclear explosions into the air, comes to earth in rain or drifts down as fallout, lodges in the soil, enters into the grass or corn or wheat grown there, and in time takes up its abode in the bones of a human being, there to remain until his death. Similarly, chemicals sprayed on croplands or forests or gardens lie long in soil, entering into living organisms, passing from one to another in a chain of poisoning and death.[304]

Donaldson, too, spoke of a broken cycle – although in his view it was not atomic technology that had caused the break:

> Man, in common with only one other vertebrate animal that we consider quite inconsequential, the beaver, gathers most of the food on land and dumps most of their waste into the water, and we do that with such efficiency that we are well on our way to destroying our fresh waters, and by similar contamination, destroying our mass of material produced in the sea. Then we return that material back from the sea to put it upon our land mass, to complete, in part, the cycle. While we say we can dump with impunity all of the active waste materials into the sea, particularly if we dump them out away from our immediate living zone, we can't dismiss the problem this lightly, for we harvest out of the sea both food and necessary mineral salts to return this fertility to our land.[305]

It was in this context that the President's Science Advisory Committee published a 1965

---

[304] Lauren R. Donaldson, "Speech" delivered at meeting of the Atomic Energy Project, University of California at Los Angeles, August 11, 1948, Box 3, Folder 3, LRDP. Lauren R. Donaldson, "Radiobiological Studies at Eniwetok Test Site and Adjacent Areas of the Western Pacific," Transactions of the Second Seminar on Biological Problems in Water Pollution, Cincinnati, Ohio, April 20–24, 1959, Box 3, Folder 4, LRDP. Earlier ecologists figured bodies of water as closed systems. In 1887, for example, Stephen Forbes described lakes as "microcosms" of larger ecological processes in which "all the elemental forces are at work and the play of life goes on in full, but on so small a scale as to bring it easily within the mental grasp." Stephen Forbes, "The Lake as a Microcosm," *Bulletin of the Scientific Association of Peoria* 111 (1887): 77-87. See also Aldo Leopold, "Lakes in Relation to Terrestrial Life Patterns," in J. G. Needham, Paul B. Sears, Aldo Leopold, eds., *A Symposium on Hydrobiology* (Madison: University of Wisconsin Press, 1941); S. Olsen and D. G. Chapman, "Ecological Dynamics of a Watershed," *BioScience* 23 (1972): 158-161. For an overview of the relationship between limnology and ecology, see Robert McIntosh, *The Background of Ecology: Concept and Theory* (Cambridge: Cambridge University Press, 1986).

[305] Lauren R. Donaldson, "Course in the Application of Nuclear Physics to the Biological and Medical Sciences," August 11, 1948, Folder 20, Box 17, LRDP.

report, *Restoring the Quality of Our Environment*, claiming that the very same technologies that made the United States a "nation of affluence" made vast quantities of waste that polluted the environment and impaired the nation's ability to feed itself. They defined pollution as unfavorable human-caused changes in "energy patterns, radiation levels, chemical and physical constitution and abundances of organisms." While "our ancestors settled in a fair and unspoiled land, easily capable of absorbing the wastes of its animal and human populations," the report concluded, industrial civilization represented a "vast experiment."[306]

The reversal of Donaldson's restoration practices, then, had roots in the relationship between bodies and their environments that materialized with Donaldson's own research.[307] But this materialization occurred gradually. Through the 1960s, the AFL, and indeed many ecologists, continued to see radioisotopes as a tool with which ecologists could study elements that occurred in lesser concentrations than nitrogen, calcium, phosphorus, and potassium, "trace elements," "easier, faster, or more accurately than by physical or chemical methods," as AFL researcher A.H. Seymour would write in 1961. Seymour concluded, "As the light microscope and the electron microscope are tools that extend our ability to observe small objects, similarly, radioisotopes and radiation are tools that extend our ability to detect small quantities of elements."[308]

---

[306] President's Science Advisory Committee, *Restoring the Quality of Our Environment* (Washington, D.C.: The White House, 1965).
[307] This is a main concern of Jessee (2013). See also Carole Gallangher, *American Ground Zero: The Secret Nuclear War* (Cambridge: The MIT Press, 1993).
[308] A. H. Seymour, "The Use of Radioisotopes and Radiation to Study Plant and Animal Life in Fresh and Marine Waters," Hearings on the Application of Radioisotopes and Radiation in the Life Sciences, Subcommittee on Research and Development, Joint Committee on Atomic Energy, Congress of the United States, March 27-30, 1961, reprint in Folder 87, Box 3, LRER. A. H. Seymour, "Contributions of Radionuclides to our Understanding of Aquatic Ecosystems," XV International Congress of Limnology, Madison, Wisconsin, August 20-25, 1962, Folder 32,

Radioisotopes were also regularly lauded as tools for ecological conservation and restoration. The twentieth anniversary pamphlet of the University of Washington Laboratory of Radiation Biology celebrated "man's new ability to manufacture radioactive materials in large quantities," which had enabled "comprehensive, long-term ecological investigations" of the "complex biological webs of the natural environment" and revealed "new ways to increase the productivity of natural resources."[309] A 1968 AEC promotional pamphlet featured Donaldson's irradiated salmon, concluding that across the nation, university faculty, federal and state conservationists, and fish and wildlife personnel were "beginning to take advantage of the nuclear age."[310]

The rise of ecology, contemporaneous with the Atomic Age, was not a response to nuclear threats to environmental decline, but a precondition for perceiving those threats. Tracing the history of ecological restoration through Donaldson's now-outmoded practices confirms that, far from being predicated on environmental fears about nuclear and radioactive technologies, the rise of ecology as a politically empowered and publicly lauded discipline depended on the technologies of the Atomic Age. The history of ecological restoration, then, twists and turns through the decades between the first atomic detonation and the 1963 signing of Nuclear Test Ban Treaty. As Donaldson reflected in 1987, "We talk about the environment very positively these days. But thirty years ago, 'environment' was a word that hadn't been coined yet, scarcely."[311] Indeed, terms like "environment," "restoration," and "ecosystem," along with conceptions of ecological threat, never quite stabilize. This history of the decades in which

---

Box 7, LRER.

[309] In scrapbook, Box 24, LRDP.

[310] "Sportsmen Benefitting from Atomic Energy," reprint in Folder 40, Box 3, LRDP.

[311] "A Farewell to Doc," Folder 1, Box 1, LRDP.

ecologists' views of nuclear technologies reversed polarity suggests how changing scientific ideas and practices were part of the on-going ecological and political reassessments of what American nature was and what it should be in the future.

CHAPTER 7

FROM COMMUNITIES TO ECOSYSTEMS:
CHANGING CONCEPTIONS OF ECOLOGICAL CONNECTEDNESS

An Ecological Proving Ground

On the evening of June 24, 1954, Eugene and Howard T. ("Tom") Odum deplaned onto the sands of Eniwetok Atoll with 155 pounds of scientific equipment and a desire to advance ecological theory.[312] For a month they snorkeled in the coral reefs of the atoll, taking samples and analyzing them in a new biological laboratory that also boasted a library, organized sports, and nightly movies. At night, in the Back N' Atom Bar, the Odums mingled with U. S. Atomic Energy Commission officers and other scientists from across the United States.

The opportunity to visit the Pacific Proving Grounds arose from Eugene's connection with the AEC, which began in 1951, when the AEC announced its plans to establish a plutonium production plant along the Savannah River, outside of Augusta, Georgia, and invited the University of Georgia to compete for grants to conduct "preinstillation" biological surveys of the site. Eugene Odum, a faculty member in UGA's zoology department, sought the opportunity to study plant succession in abandoned farmlands. He proposed a project that, by his description, would be more than a "mere survey" – it would be an ecological study of the "interrelationships" and "rate of change" of the "total ecological complex." The AEC rejected it, and all other proposals, eventually accepting a (much cheaper) proposal from Odum to produce a map of the

---

312 "Logbook," Box 1, Folder 1, Series 1, Eugene Odum Research Files: Eniwetok Atoll (UGA 06-032), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia [hereafter ODUM-E]. The U.S. government referred to the atoll as "Eniwetok" until 1974, when it changed its official spelling to "Enewetak" to reflect its proper pronunciation by the Marshall Islanders.

site's ecological history. The federal government was still in the process of moving 6,000 residents and their belongings off of the Savannah River site when three UGA graduate students began fieldwork there.[313] Thus Eugene entered a small but growing network of AEC-funded ecologists.

In April 1953, Eugene received a letter explaining that the Office of Naval Research and the Pacific Science Board were appraising the feasibility of establishing a permanent biological station on Eniwetok Atoll. The site was ideal for ecological studies, the AEC explained, but before they began with the plans, they wanted to gauge scientific interest with a call for project proposals.[314] Through informal letters, Eugene pitched two projects to the AEC. The first was an extension of his previous work on fat deposition in migratory birds.[315] The second would be an extension of the "community metabolism and productivity" studies that his brother, Tom, was developing at a field site in Silver Springs, Florida. With funding from the Office of Naval Research, Tom had been treating the hot springs – a popular vacation spot – as "a ready-made natural laboratory" in which species could be studied under conditions of constant temperature. It was, in Tom's words, the best option for studying an ecological community in the absence of the ability to "lift up a whole community, place it in a respirometer, measure the whole metabolism, and yet not disturb the normal influx and outflow of raw materials, energy, and waste

---

[313] "A Proposal for an Ecological Study of Land-Use, Succession, and Indicator Invertebrate and Warm-Blooded Vertebrate Populations of the Savannah River Operations Area," which the AEC approved in June 1951. See Betty Jean Craige, *Eugene Odum: Ecosystem Ecologist and Environmentalist* (Athens: University of Georgia Press, 2001), 50.
[314] Karl Wilbur (AEC) to Dr. Howard Odum, 6 April 1953, Box 1, Folder 10, Series 1, ODUM-E.
[315] Eugene P. Odum to Dr. Karl Wilbur, 11 June 1953, Box 1, Folder 10, Series 1, ODUM-E.

products."[316] In his proposal to the AEC, Eugene echoed this language, highlighting the "unique opportunity" that atomic testing created to study "entire ecological systems in the field."[317]

Figure 38. Photograph of Tom Odum's field assistants, William Ray Jr. and Ginger Stanley, at Silver Springs. Figure from Howard T. Odum, "Trophic Structure and Productivity of Silver Springs, Florida," *Ecological Monographs* 27 (1957): 55-112.

[316] Howard T. Odum, "Community Metabolism of Silver Springs, Florida," *ESA Bulletin* 34 (1953): 67; Howard T. Odum, "Trophic Structure and Productivity of Silver Springs, Florida," *Ecological Monographs* 27 (1957): 55-112.
[317] Eugene P. Odum to Dr. Karl Wilbur, 11 June 1953, Box 1, Folder 10, Series 1, ODUM-E.

The AEC office had no interest in bird fat, but was enthusiastic about Tom's community metabolism methods. After Tom requested and was granted permission from the Office of Naval Research to apply his methods on community metabolism to "reef work" in atolls, Eugene submitted a full proposal for a month long collaboration between the brothers in the Pacific Proving Ground.[318] "It sure will be fun," Tom wrote to Eugene as they prepared for the trip, "---- I think we can talk up some new theories too."[319]

We often think of scientific theory as emerging from and responding to experimental data and, in the case of ecology, field observations. But Eugene and Tom Odum worked very much in the opposite manner. In this case, they had conceptualized the coral reef as a model system, an ecosystem, before they ever arrived at Eniwetok. Their methods were not new; they had been used on individual species for decades. What was novel was that they applied them to a collection of species in the field rather than to an individual species. Unlike ecological physiological studies, like the ones Eugene conducted on individual bird species as a graduate student, this study estimated the net "function" of a grouping of species: a coral reef.

While at Eniwetok, the Odums used methods similar to Lauren Donaldson's Applied Fisheries Laboratory, but toward different ends. The AFL was interested in the distribution of radioactivity in the atoll environment: how long did it persist, and where? The Odums, meanwhile, wanted to use the radioactivity to better understand the atoll's ecological community. The Odums took advantage of visiting Eniwetok Atoll mere months after the AEC had detonated the 15 megaton Castle Bravo, and they produced radioautographs of samples from a cross-

---

[318] Eugene Odum to W. R. Boss, 27 April 1954, Box 1, Folder 8, Series 1, ODUM-E; "A proposal for studies on the productivity of Coral Reef Atolls," Box 1, Folder 8, Series 1, ODUM-E.Howard T. Odum to Sidney Galler, 14 August 1953, Box 1, Folder 8, Series 1, ODUM-E.
[319] H.T. to Gene, undated, c. 1954, Box 1, Folder 8, Series 1, ODUM-E.

section of the reef to estimate species' uptakes of radioactive nutrients and, thus, growth. Using methods from G. Evelyn Hutchinson's laboratory, they measured oxygen and nutrients in the water column at different points along the reef and used these to estimate the combined growth and respiration of the ecological community as a whole.

Figure 39. Eugene Odum at Eniwetok Atoll, 1955. Box 166, Folder 1, Eugene Odum Papers (MS 03257) Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

The Odums' fieldwork entailed snorkeling with acetate paper and sketching out maps of different types of coral with pencil. Within 20 foot by 20 foot squares, the Odums catalogued all the living things they could observe. Placing the species into categories by appearance, and sorting them into "producers," "herbivores," and "carnivores," they estimated the mass of each by weighing small samples and multiplying by area. Apparently, they were not particularly considerate laboratory mates. After their trip, the University of Washington AFL wrote to Lauren Donaldson in Seattle, complaining of the Odums' messiness. Donaldson replied:

> I was happy to hear that the Odums cleaned up their mess before departing. It always leaves a much better taste than having to make a big rumpus about some one's mess and then probably having to clean it up in the end anyway. I'm also glad you were able to get our equipment packed into two lockers where it can be identified as such for it should tend to reduce friction in the future from characters who borrow too freely.[320]

After the trip, the Odums quickly wrote a thirty-page manuscript summarizing their results, and a year later they published it in an ESA journal, *Ecological Monographs*. The article circulated widely, and won that year's ESA award for best publication.[321]

Today, this paper, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," is often considered the first ecosystem field study.[322] But

---

[320] Lauren R. Dolandson to Art and Frank, 11 August 1954, Box 6, Folder 8, Laboratory of Radiation Ecology Records, 1948-1984, The University of Washington Special Collections, Seattle, Washington [hereafter LRER].

[321] "The George Mercer Award for 1956," *Bulletin of the Ecological Society of America* 38 (1957): 2-3. Receiving the award, Eugene stated that "it was in connection with an AEC grant that my brother, with his interest in flowing water ecosystems, and I with my interest in sessile terrestrial and salt marsh systems, found a happy meeting ground on the coral reef." Tom, meanwhile, attributed his interests to "the dream of abstract conceptualization from G. Evelyn Hutchinson," "the fascination with the ecological from an older brother's early enthusiasm," and "a forecaster's resignation from the Air Force Meteorological experience."

[322] Howard T. Odum and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," *Ecological Monographs* 25 (1955): 291-320. Joel B. Hagen writes, "The Eniwetok study was a landmark in ecological research, important to both individual researchers and the discipline of ecology as a whole. The reef with its close symbiotic relationships between coral and algae was an excellent example of a highly structured, self-regulating system—a nascent view of ecosystems toward which both Odums were strongly attracted." Joel B. Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick: Rutgers University Press, 1992), 105.

neither the methods nor the term "ecosystem" were new.[323] What was new to the postwar era was precisely the popularity of the ecosystem concept.

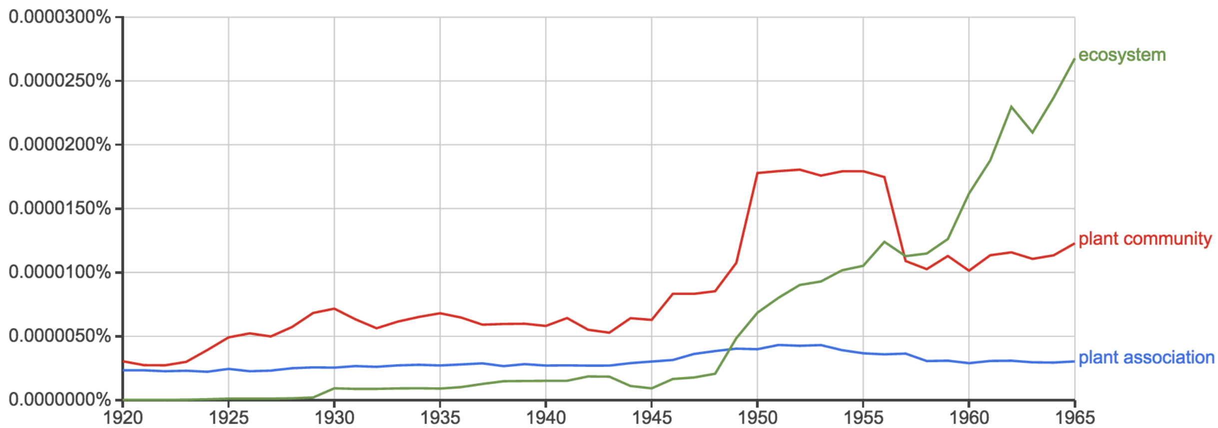


Figure 40. Google n-gram displaying the frequency of the phrases "plant association" (blue), "plant community" (red), and "ecosystem" (green), in digitized books from 1920 to 1965.

The Shift from Ecological Communities to Ecosystems

Historians of ecology have tended to frame the rise of ecosystem ecology as an effort to convert the "soft science" of ecology into a "hard science" like physics, and, in Sharon Kingsland's words, "show that the subject could command intellectual respect."[324] Even more forcefully, Donald Worster argues that the ecosystem concept "owed nothing to any of its forebears in the history of the science […] it was born of entirely different parentage: that is,

[323] See, for example, Marston C. Sargent and Thomas S. Austin, "Organic Productivity of an Atoll," *Transactions of the American Geophysical Union* 30 (1949): 245-49. On the history of coral ecology, see Alistair William Sponsel, *Coral Reef Formation and the Sciences of Earth, Life, and Sea, c. 1770-1952* (Ph.D. dissertation, Princeton University, 2009).
[324] Sharon E. Kingsland, *The Evolution of American Ecology, 1890-2000* (Baltimore: Johns Hopkins University Press, 2005), 179.

modern thermodynamic physics, not biology."[325] But an examination of the work of Eugene Odum and his colleagues suggests an alternative history of the ecosystem concept, one deeply rooted in community ecology.

The groundwork for ecosystem theory emerged in parallel in botany and limnology, two disciplines that contributed members to the new discipline of ecology.[326] In fact, many of the conversations about how to bound the new discipline of ecology played out in the question of how to define groups of species both geographically and terminologically. After the peak of imperial collection of biological specimens, many biologists imagined that all the species of the world would soon be described and catalogued. A 1914 magazine for teachers explained, "The time is near when every species will be known, and its distribution, and then the real work of the subject [of ecology] will be beginning."[327] Books by German and English botanists divided landscapes into what they called "plant formations" or "plant societies" or "plant associations," such as woodlands, grasslands, and fens.[328] Practitioners began distinguishing among

---

[325] Donald Worster, *Nature's Economy: A History of Ecological Ideas* (New York: Cambridge University Press, 1977), 304. On the intersection of cybernetics and environmental sciences, see Peter Taylor, "Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II," *Journal of the History of Biology* 21 (1988): 213-244; William Bryant, *Whole System, Whole Earth: The Convergence of Technology and Ecology in Twentieth-Century American Culture* (Ph.D. Dissertation, University of Iowa, 2006); Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, The Whole Earth Network, and the Age of Digital Utopianism* (Chicago: University of Chicago Press, 2006); Andrew J. Kirk, *Counterculture Green: The Whole Earth Catalog and American Environmentalism* (Lawrence: University of Kansas Press, 2007).

[326] In 1926, the Ecological Society of America established its fifth committee, the "Committee on Biotic Communities." In 1931, it established its sixth, the Committee on Nomenclature. See Robert L. Burgess, *The Ecological Society of America: Historical Data and Some Preliminary Analyses* (Oak Ridge: Oak Ridge National Laboratory, c. 1976).

[327] L. Baker, "Plant Geography and Ecology," *The Geographical Teacher* 7 (1914): 332-339.

[328] The idea of "plant formations" was first advanced by the German geographer August Griesbach and applied to American grasslands by Clements and Roscoe Pound in 1898 in *The Phytogeography of Nebraska* (Lincoln: University of Nebraska Press, 1898).

"autecology," or the study of processes that involved one species, such as germination, and "synecology," or the study of processes that involved multiple species, such as succession.[329]

In a 1917 *Scientific Monthly* article, "The New Science of Plant Sociology," Ronald Harper analogized synecology to the burgeoning field of sociology. The article is a snapshot of the many competing terms and emphases of early ecology:

> Plant sociology, the science of plant societies, or vegetation, is analogous in many ways to human sociology, the science of human society, or population. […] A few years ago plant sociology was partly confused with the almost equally new sciences of plant geography and ecology; and such terms as ecological plant geography, meaning the geography of plant associations, and synecology, meaning the relation of such associations to environment, are occasionally seen now. But geography deals primarily with distribution, ecology with environment, and sociology with association interrelations, three fundamentally distinct points of view.[330]

1917, of course, is also the year that the United States declared war on the German Empire, leading many Americans to question whether the Darwinian idea of "survival of the fittest" led to social progress or to devastation. As historian Gregg Mitman has argued, it is no accident that ecologists, and scholars of many other disciplines, were grappling in that era with words like "community" and "cooperation."[331] By the 1920s, plant ecologists and a smaller

---

[329] The first committees established by the Ecological Society of America, in 1916, were the "Committee on Soil Temperature," the "Committee on Climatic Conditions," and the "Committee on Fish and Fisheries." The fourth, in 1917, was the "Committee on Preservation of Natural Conditions for Ecological Study." The next two, in 1926 and 1931, respectively, were the "Committee on Biotic Communities" and the "Committee on Nomenclature." This progression of committees reflects some of the major changes in disciplinary emphases during the time Eugene and Tom were in graduate school. The ESA Committee on Nomenclature's files are in Box 126, Folder 2.10, ESA.

[330] Ronald M. Harper, "The New Science of Plant Sociology," *The Scientific Monthly* 4 (1917): 456-460.

[331] In *The State of Nature*, Gregg Mitman analyzes the work of University of Chicago ecologists on "animal societies" during the 30 years after WWI. He argues that the community ecology theories of Chicago ecologists like Walter Allee were influenced by a strong anti-German, anti-Darwinian, anti-war rhetoric that surfaced during the First World War, "tailored to fit progressive democratic ideals of community and cooperation." Gregg Mitman, *The State of*

group of animal ecologists were in heated debate over how to conceptualize groups of multiple species. The terms in contention, according to a 1923 review article in *Ecology*, included "community, society, zone, formation, association, associes, consociation, and consocies."[332]

The term "ecosystem" emerged from this debate. It was first promoted in 1935 by the prominent English plant ecologist Arthur Tansley. In an *Ecology* article, "The Use and Abuse of Vegetational Concepts and Terms," Tansley wrote: "On linguistic grounds I dislike the term biotic *community*," he wrote. "A 'community,' I think it will be generally agreed, implies *members*, and it seems to me that to lump animals and plants together as *members* of a community is to put on an equal footing things which in their whole nature and behavior are too different." And yet Tansley recognized the need for a term that referred to all the living things in a given area: "the whole webs of life adjusted to particular complexes of environmental factors." Thus he suggested that ecologists refer to the aggregate of organisms as the "organism-complex" or "biome," and the sum of the organism-complex and abiotic environment as the "ecosystem."[333]

Nature: Ecology, Community, and American Social Thought, 1900-1950 (Chicago: University of Chicago Press, 1992), quote on 4. On pragmatism and American sociology in the early 1900s, see J. David Lewis and Richard L. Smith, *American Sociology and Pragmatism: Mead, Chicago Sociology, and Symbolic Interaction* (Chicago: University of Chicago Press, 1980); Louis Menand, *The Metaphysical Club: A Story of Ideas in America* (New York: Farrar, Straus and Giroux, 2002).

332 For a review of the uses of these terms prior to 1920, see A. Booker Klugh, "A Common System of Classification in Plant and Animal Ecology," *Ecology* 4 (1923): 366-377. Alexander von Humboldt first used "plantes associées" in *Le Voyage Aux Régions Equinoxiales du Nouveau Continent* (Paris, 1807).

333 Arthur G. Tansley, "The Use and Abuse of Vegetational Concepts and Terms," *Ecology* 16 (1935): 284-307. In the paper that motivated Tansley (1935), John Phillips stated, "A biotic community in many respects behaves as a complex organism—in its origin, growth, development, common response, common reaction, and its reproduction. […] the biotic community is something more than the mere sum of its parts." John Phillips, "The Biotic Community," *Journal of Ecology* 19 (1931), 1-24. On Tansley (1935) see Joel Hagen, *An*

By the time Tansley wrote "The Use and Abuse of Vegetational Concepts and Terms," he was well known as a critic of Frederic Clements's "superorganism" concept. Tansley contended that succession was better thought of as multi-directional than as progressing toward "one 'true' climax in each 'climatic region,'" as Clements and many other American ecologists had argued. It was certain that the plant assemblage of a sand dune would change, but it would not necessarily change into a forest. Today much work in the history of ecology has focused on this debate between proponents of "organismal theory" and those of "individualistic theory."[334] Less appreciated is the point that Tansley was making about ecological history. Drawing on recent work in paleobotany, Tansley promoted a vision of "an infinitely complex history of the

---

Entangled Bank: The Origins of Ecosystem Ecology (New Brunswick: Rutgers University Press, 1992), 80-87. Tom Odum, for one, did not read Tansley's paper until years after its publication. Eugene Odum likely suggested it to him while drafting *Fundamentals of Ecology*. In 1950, Tom wrote to Eugene: "Interestingly enough, on reading Tansley (1935) I find that in the course of discussion he speaks of applying natural selection to an ecosystem though not emphatically and not carrying it to the logical sequence of using it on any natural system. In a way it is disappointing to keep finding parts of what one considered original in the works of others." Tom to Eugene, Marther, und Will, c. 1950, Folder 22, Carton 3, Series 3, Eugene P. Odum Papers (MS 3257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia [hereafter EPOP].

334 Most historical work on Clements has contrasted his "organismal theory" – the idea that vegetation develops in any given area in a way comparable to or identical with the development of an individual organism – with Henry Gleason's "individualistic concept of ecology" – the idea that plant species disperse and establish themselves independently of others. (Frederic E. Clements, *Plant Succession: An Analysis of the Development of Vegetation* (Washington D.C.: The Carnegie Institute of Washington, 1916); H. A. Gleason, 'The Individualistic Concept of the Plant Association," *Bulletin of the Torrey Botanical Club* 53 (1926): 7-26.) See, for example, Robert P. McIntosh. "H.A. Gleason – 'Individualistic Ecologist,' 1882-1975: His Contributions to Ecological Theory," *Bulletin of the Torrey Botanical Club* 102 (1975): 253-273; Ronald C. Tobey, *Saving the Prairies: The Life Cycle of the Founding School of American Plant Ecology, 1895-1955* (Berkeley, University of California Press, 1981); Donald Worster, *Nature's Economy*; Michael G. Barbour, "Ecological Fragmentation in the Fifties," in William Cronon, (ed.), *Uncommon Ground: Rethinking the Human Place in Nature*, (New York: W.W. Norton & Co, 1995), 233-255.

formation and destruction of ecosystems," one influenced not only by changes in geology and climate, but also by other organisms. Importantly, these organisms included humans:

> It is obvious that modern civilized man upsets the 'natural' ecosystems or 'biotic communities' on a very large scale. But it would be difficult, not to say impossible, to draw a natural line between the activities of the human tribes which presumably fitted into and formed parts of 'biotic communities' and the destructive human activities of the modern world. Is man part of 'nature' or not? […] Regarded as an exceptionally powerful biotic factor which increasingly upsets the equilibrium of preexisting ecosystems and eventually destroys them, at the same time forming new ones of very different nature, human activity finds its proper place in ecology. […] We cannot confine ourselves to the so-called 'natural' entities and ignore the processes and expressions of vegetation now so abundantly provided us by the activities of man.

Thus Tansley, like many ecologists in the 1930s, was broadening the list of factors that determined the distribution of plant species. Early ecologists asked how plant communities were determined by light, water, temperature, and soil – in other words, how the physical environment drove organic change. It was not until the 1920s that many ecologists began considering the influence of soil chemistry and of "biological factors" like competition and predation on the distribution of species.[335] By the 1930s, these "biological factors" included human actions.

Those promoting the discipline of limnology were also interested in studying climate, soil, and organisms – and water – in connection with each other. In 1887, American entomologist Stephen Forbes contended that any lake was "an organic complex" and a "whole assemblage." In 1904, Swiss medical doctor François-Alphonse Forel described the "circulation" of food in lakes from dissolved minerals to autotrophic plants, to herbivores, to carnivores, to bacteria, and back to dissolved minerals. Victor Shelford portrayed such aquatic "food cycles" in a 1913 paper, and that same year, Lawrence J. Henderson argued for the importance of chemical processes for

---

[335] I write about this transition in Laura Jane Martin, Mathematizing Nature's Messiness: Graphical Representations of Variation in Ecology,
1930-present, article manuscript in review.

understanding biological ones in *The Fitness of the Environment*. The Russian mineralogist Vladimir Vernadsky summarized this research in his 1926 book *The Biosphere*, imagining the earth as a chemical system where elements cycled between various parts.[336]

In the late 1930s, Raymond Lindeman, a post-doc working with G. Evelyn Hutchinson, directly bridged the conversations that were happening in parallel in botany and limnology. Lindeman pursued the hypothesis that succession in aquatic ecosystems was driven by dramatic changes in the productivity of photosynthetic plankton. Through hundreds of cores from Cedar Creek Bog in Minnesota, Lindeman hoped to describe not only past communities of plants and animals, but also their metabolic productivities and trophic relations. The ratio of organic matter to inorganic silt could be used to approximate rates of photosynthetic activity, he reasoned, assuming that the silting rate was constant.[337]

Lindeman began his foundational 1942 paper, "The Trophic-dynamic Aspect of Ecology," with an overview of schools of thought around "synecology." He contrasted Clements's "organismal approach," in which ecological communities "re-acted" to the non-living environment, to Tansley's ecosystem concept and to Vernadsky's "biogeochemical" approach. In Tansley's vision, the "organism-complex" and "physical factors" were considered together; in Vernadsky's, a lake was considered a primary ecological unit and organic and inorganic entities were connected through food cycles. Lindeman then quoted from a locally

---

[336] G. Evelyn Hutchinson wrote that the idea of the biosphere was first used by geologist Eduard Suess to describe various envelopes of earth in his book on the genesis of the Alps published in 1875 (Notes, Folder 442, Box 90, Series III, G. Evelyn Hutchinson Papers, Manuscripts and Archives, Yale Sterling Memorial Library, New Haven, Connecticut). But it was Vernadsky that most influenced Hutchinson.
[337] Raymond L. Lindeman, "Seasonal Food-cycle Dynamics in a Senescent Lake," *American Midland Naturalist* 26 (1941): 636-673; Raymond L. Lindeman, "The Developmental History of Cedar Creek Bog, Minnesota," *American Midland Naturalist* 25 (1941): 101-112.

published set of lecture notes by Hutchinson that expressed nutrient cycling in terms of energy flows.[338] Synthesizing these botanical and limnological literatures, Lindeman stressed the importance of studying physical, chemical, and biological processes together “within a space-time unit.” This new way of studying the natural world would reveal discrete “trophic levels” – producers, primary consumers, and secondary consumers, each dependent on the preceding level as a source of energy, with the producers directly dependent on solar radiation. Productivity and efficiency increased, Lindeman hypothesized, as succession progressed.[339]

---

[338] Robert Cook, “Raymond Lindeman and the Trophic-Dynamic Concept in Ecology,” *Science* 198 (1977): 22-26.
[339] Raymond L. Lindeman, “The Trophic-dynamic Aspect of Ecology,” *Ecology* 23 (1942): 399-417.

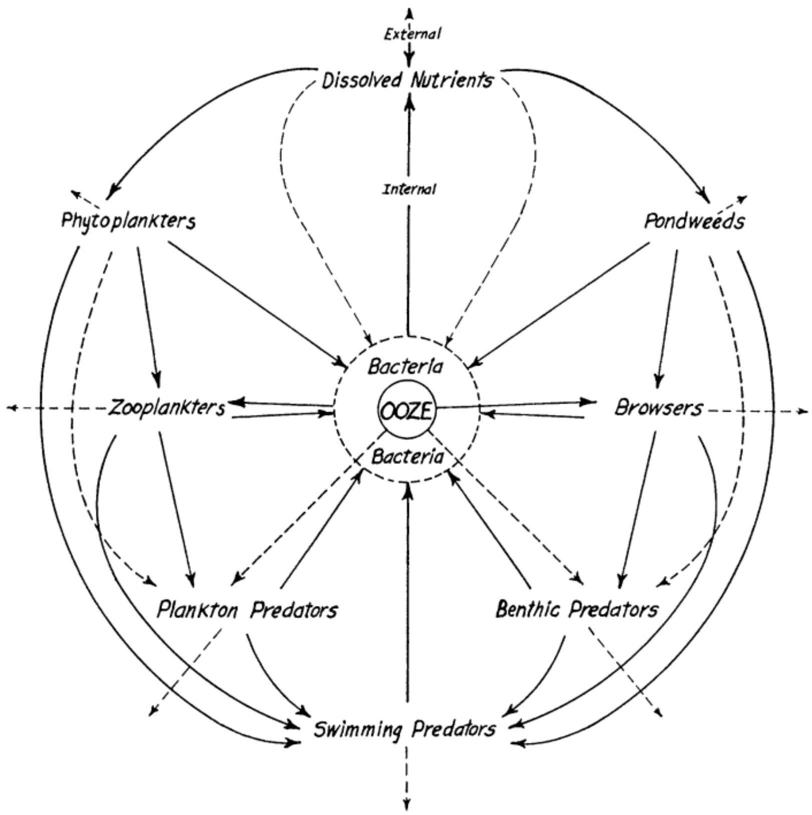


Fig. 1. Food-Cycle Relationships in a Senescent Lake.

Figure 41. Figure of "Food-Cycle Relationships in a Senescent Lake," from Raymond L. Lindeman, "The Trophic-dynamic Aspect of Ecology," *Ecology* 23 (1942): 399-417.

Cycles and Circulation in the Hutchinson Laboratory

In the 1940s, G. Evelyn Hutchinson's laboratory began to examine the circulation of elements like carbon and nitrogen and nutrients like thiamin and niacin in bodies of water. When Yale constructed a cyclotron in 1939, Hutchinson had immediately pursued the idea of using radioactive phosphorus and nitrogen to "explore the metabolism of the plankton community," requesting phosphorus-32 for his studies of Lindsley Pond. For years he had been puzzled by his observation that lakes often displayed several pulses of plankton per summer, although it would seem that phosphorus should have been depleted by the time of later pulses. In 1941, he and his graduate student W. T. Edmondson took out "a small rowboat with a hand-powered winch" and several five-gallon glass carboys of phosphorus-32. Their initial results were promising: they were able to detect radioactivity in later water samples in a pattern consistent with algae taking up available phosphorus and then settling to the bottom of the lake.[340]

Such work remained small-scale for a time, because radioisotopes remained virtually impossible to acquire until after the war. But by 1946, Hutchinson was able to obtain large amounts of phosphorus-32 incorporated into phosphoric acid. He and his graduate student Vaughan Bowen converted it into sodium phosphate, which they poured into Lindsley Pond. A week later they collected water from four depths of the lake, evaporated the water, precipitated the phosphate, and measured the radioactivity with a Geiger counter.[341] Thus Hutchinson's laboratory was introducing radioisotopes into environments at the same time that Donaldson and the Applied Fisheries laboratory were tracing the movement of radioisotopes from atomic weaponry in the Pacific Proving Grounds.

During this time, Hutchinson began drafting a "treatise on limnology," which, when published a decade later, would become a foundational text. Hutchinson argued that limnology required an integration of physical, chemical, and biological studies. Biologists could not

---

[340] Quoted in Angela N. H. Creager, *Life Atomic: A History of Radioisotopes in Science and Medicine* (Chicago: University of Chicago Press, 2013), 358; See also "P cycle" Folder, Box 8, W. T. Edmondson Papers (Acc. No. 2024-006), The University of Washington Special Collections, Seattle, Washington; G. Evelyn Hutchinson, "Bio-ecology," *Ecology* 21 (1940): 267-268; G. Evelyn Hutchinson, "Limnological Studies in Connecticut IV: Mechanism of Intermediary Metabolism in Stratified Lakes," *Ecological Monographs* 11 (1941): 21–60.
[341] G. Evelyn Hutchinson and V. T. Bowen, "A Direct Demonstration of the Phosphorous Cycle in a Small Lake," *Proceedings of the National Academy of Sciences* 33 (1947):148–153; G. Evelyn Hutchinson and V. T. Bowen, "Limnological Studies of Connecticut IX: A Quantitative Radiochemical Study of the Phosphorous Cycle in Linsley Pond," *Ecology* 31 (1950): 194–203.

understand evolution without knowledge of the "physiochemical environment," while geologists could not understand the history of the earth without knowledge of the "record of inland waters." Through collaboration, Hutchinson argued, biologists and geologists could interpret records of past ecological communities to reconstruct history. Lakes were the ideal habitat in which to conduct such work because they formed "more or less closed systems," that "provide a series of varying possible ecological worlds which permit a truly comparative approach to the mechanics of nature."[342]

But not all limnologists agreed with Hutchinson's characterization of their field. One of Hutchinson's detractors was Chancey Juday, a professor at the University of Wisconsin, which had become an important center of limnology and fisheries research during the Great Depression. Juday, who co-founded the Limnological Society of America in 1934, disagreed with Hutchinson's characterization of lakes as replicates of each other. As one of the assigned reviewers of Lindeman's "The Trophic-dynamic Aspect of Ecology," Juday argued that "lakes are rank individuals and are very stubborn about fitting into mathematical formulae and artificial schemes proposed by man." Hutchinson disputed Juday's review, writing to the editor of *Ecology* that generalizations could be "far more valuable than an unending number of marks on a paper indicating that a quantity of rather unrelated observations has been made." In a 1942 letter to one of his graduate students, Juday wrote, "In a short time I shall expect [Deevey and Hutchinson] to tell all about a lake thermally and chemically just by sticking one, perhaps two,

[342] G. Evelyn Hutchinson, *A Treatise on Limnology, Vol. 1* (New York: John Wiley and Sons, 1957). Hutchinson began writing this series in the early 1940s, aiming to cover all aspects of physical, chemical, and biological limnology. During the 1940s Hutchinson also worked as "consultant of biogeochemistry" for the American Museum of Natural History.

fingers into the water, then go into a mathematical trance and figure out all its biological characteristic."[343]

Along with Lauren Donaldson, Hutchinson and his colleagues were the vanguard of ecologists working on the circulation of elements within a "system." As Joel Hagen has argued, it is no coincidence that many ecologists became interested in the idea of organic self-regulation or "homeostasis" during the 1940s – the idea dominated biological research.[344] The term "homeostasis" was popularized by Harvard physiologist Walter Cannon in his influential 1932 book *The Wisdom of the Body*, which described how the human body maintains a steady temperature and other vital conditions.[345] Around this time, some prominent ecologists began to argue that ecological populations and communities were homeostatic. Others, like Hutchinson, began describing the cycles in which matter moves through the environment as self-regulating. In 1946, Hutchinson described these two forms of "circular causal systems" in a talk delivered at a New York Academy of Science conference on the new concept of cybernetics.

The idea of homeostasis became central to the MIT mathematician Norbert Weiner's work on cybernetic theory. During World War II, Weiner worked on an ambitious calculating device called the "antiaircraft predictor" that would anticipate an enemy plane's future position

---

343 Nancy G. Slack, *G. Evelyn Hutchinson and the Invention of Modern Ecology* (New Haven: Yale University Press, 2011), pp. 149-150. E. A. Birge and Chancey Juday of the University of Wisconsin founded the Limnological Society of America at a 1934 meeting of the American Association for the Advancement of Science in St. Louis. Hutchinson was a charter member. Chancey Juday would become the first to scientist present a lake assessment in the form of an energy budget: Chancey Juday, "The Annual Budget of an Inland Lake," *Ecology* 21 (1940): 438-450.

344 Joel B. Hagen, "Eugene Odum and the Homeostatic Ecosystem: The Resilience of an Idea," in *Traditions of Systems Theory: Major Figures and Contemporary Developments*, ed. Darrell P. Arnold (New York: Routledge, 2014), 179-193. See also Debora Hammond, *The Science of Synthesis: Exploring the Social Implications of General Systems Theory* (Boulder: University Press of Colorado, 2003).

345 Walter B. Cannon, *The Wisdom of the Body* (New York: Norton, 1932).

and fire at it. But as Peter Galison has argued, Weiner's vision did not stop with halting Nazi air attacks. He instead expanded his model into a new science, cybernetics, premised on a vision of a mechanized enemy "at home in the world of strategy, tactics, and maneuver." Cyberneticists analogized the organismal brain to a self-guided missile that gathered information and used that information to correct itself en route. This blurring of the human-machine boundary was central to cybernetic theory, which came to encompass ideas about information exchange, non-linear processes, intentionality, and feedback systems. Homeostasis as it related to cybernetics was a process of self-preservation. Homeostasis was achieved through a system's ability to monitor and respond to information about its own changing status within its environment.[346]

In 1946, the Josiah Macy, Jr. Foundation gathered a group of psychologists, anthropologists, mathematicians, and physicians to discuss the topic of circular causal systems. This turned out to be the first of many meetings between 1946 and 1953, today known as the "Cybernetics Conferences." The conferences' topics included self-regulating mechanisms and how computers might learn. The mathematics group was led by Norbert Weiner and the cryptologist Claude Shannon, while the social sciences group was led by the anthropologist

---

[346] Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994): 228-266. On the history of cybernetic theory see also Otto Mayr, *The Origins of Feedback Control* (Cambridge: The MIT Press, 1970); Steve J. Heims, *The Cybernetics Group* (Cambridge: MIT Press, 1991); Geof Bowker, "How to Be Universal: Some Cybernetic Strategies, 1943-70," *Social Studies of Science* 23 (1993):107-127; Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (MIT Press, 1996); N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago: University of Chicago Press, 1999); David A. Mindell, *Between Human and Machine: Feedback, Control, and Computing before Cybernetics* (Baltimore: Johns Hopkins University Press, 2002); Jennifer Light, "Taking Games Seriously," Technology and Culture 49 (2008): 347-375; Andrew Pickering, *The Cybernetic Brain: Sketches of Another Future* (Chicago: University of Chicago Press, 2009); Ronald Kline, *The Cybernetics Moment: Or Why We Call Our Age the Information Age* (Baltimore: Johns Hopkins University Press, 2015).

Gregory Bateson. One of the people Bateson invited to join the meetings was his longtime friend G. Evelyn Hutchinson.[347] Through the Cybernetics Conferences, Hutchinson linked his limnological studies to a broader range of disciplines. After the first conference, he wrote to his former student W. T. Edmondson:

> Last week I was at a conference in New York on circular causal systems of the biological and social sciences. It was very largely devoted to the nervous system but we had some population cycle discussion. Subsequently Dr. Spiegelmann of St. Louis came through and tells me that he has worked out a prey-predator type of relationship for computing enzymes in cells and thinks the old Volterra theory holds very well in intracellular biochemistry even if it doesn't hold in population dynamics. I think that there will be a lot of interesting developments along these lines and strongly recommend your examining such of Spiegelmann's papers that you can get.[348]

Hutchinson's experiences at the Cybernetics Conferences inspired him to write "Circular Causal Systems in Ecology," published in 1948.[349] In this article Hutchinson wrote that "the study of conditions under which *groups* of organisms exist" could be approached through two branches of research: biogeochemistry and biodemography. Citing Weiner's mathematical work,

---

[347] Hutchinson, Bateson, and influential anthropologist Margaret Mead became friends as students at Cambridge, where they founded the "Biological Tea Club" in 1922. See Lawrence B. Slobodkin and Nancy G. Slack, "George Evelyn Hutchinson: 20th Century Ecologist," *Endeavour* 23 (1999): 24-30.

[348] G. Evelyn Hutchinson to W. T. Edmondson, 18 March 1946, Folder 230, Box 13, Series I, G. Evelyn Hutchinson Papers, Manuscripts and Archives, Yale Sterling Memorial Library, New Haven, Connecticut. Decades later, former Hutchinson student and influential philosopher of biology Donna Haraway would refect: "I needed to locate biology in its intersection with many other communities of practice, made up of entangled humans and others, living and not. Evelyn Hutchinson's lab made that possible. In his lab we read things like Simone Weil, Shannon and Weaver, and Virginia Woolf – those were the 'biology' texts that we read as part of his lab group. It was not a biology lab group in the narrow sense. It was a 'what's interesting the world' lab group. […] Anyway, a lot of people came out of Evelyn's lab deeply interested in various aspects of cybernetics, including me. But how could you not be interested in that stuff in those years?" Nicholas Gane, "When We Have Never Been Human, What Is to Be Done? Interview with Donna Haraway," *Theory, Culture & Society* 23 (2006): 135-158.

[349] G. Evelyn Hutchinson, "Circular Causal Systems in Ecology," *Annals of the New York Academy of Science* 40 (1948): 221-246. See also Charles Elton, *Voles, Mice, and Lemmings* (Oxford: Clarendon Press, 1942).

Hutchinson contended that it is usual to find “self-correcting mechanisms” in nature. He went on to describe the passage of carbon and phosphorus through cyclical paths involving living matter, as well as English zoologist Charles Elton’s work on the seasonal cycles of rodent populations. Engaging the distinction that cyberneticists made between external forces and internal intention, Hutchinson argued that extrinsic causes of population oscillations – such as tidal fluctuations – could be distinguished from intrinsic controls – such as disease, competition for resources, and predator-prey relationships.

While it is true that postwar interest in cybernetics influenced how ecologists asked questions and designed experiments in the 1950s (as I discuss in Chapters 7 and 8), it is important to note that in “Circular Causal Systems,” Hutchinson was working to fit *previous* work into a cybernetic framework.[350] Indeed, American ecologists’ interest in cyclical systems dated to the Great Depression. Aldo Leopold concluded his 1931 *Game Survey* with the contention that “until science discovers the cause and mechanism of the cycle, all efforts to manage and conserve the cyclic species must necessarily grope in darkness.”[351]

---

[350] The concept of feedback was not new. What was new was the generalization of these ideas into universal principles, which overlapped with the interests of communications theorists, computer scientists, and operation researchers. Evelyn Fox Keller named these disciplines “cyberscience” – those disciplines that analyze complex systems. Evelyn Fox Keller, Reconfiguring Life: Metaphors of Twentieth-Century Biology (New York: Columbia University Press, 1995).

[351] Aldo Leopold, *Report on a Game Survey of the North Central States* (Madison: Sporting Arms and Ammunition Manufacturers’’ Institute, 1931), 134. The report is significant for its argument that game populations could be augmented through preservation and rehabilitation of habitat, rather than, as many prominent conservationists at the time advocated, further restricting hunting. As summarized in a review in *Ecology*, “The author does not advocate a return to the former conditions, but the restoration of brush in waste and odd corners.” Leopold arguing that by managing habitat, managers could augment species of interest. Barrington Moore, “Review on a Game Survey of the North Central States,” *Ecology* 12 (1931): 748-749.

Also in 1931, Leopold attended the "Matamek Conference" on circular systems. Late in July of 1931, scientists – including mammologists, entomologists, ornithologists, foresters, bacteriologists, and astronomers – and government officials from North America and Europe convened at a trading-post-turned-summer-retreat north of the Gulf of St. Lawrence, Labrador, to follow up on a series of Smithsonian Institution conferences. Their goal was to identify evidence of cyclical relationships between biological, physical, and social phenomena: phenomena such as the 11.2-year sunspot cycle, the 6-year cycle of grouse in Leopold's Wisconsin, the 18.6-year cycle of U.S. agricultural productivity, and the 18.4-year cycle of financial panics. Scientists, industrialists, and governments should be equally interested in cycles of abundance and scarcity, the conference organizers contended.[352] As one journalist wrote, "who would suppose that the whole world, including man, would be upset by booms and crashes in the lives of some of the rat family?"[353]

For nine July days the participants compared notes, presented reports, and fished for salmon and trout. It was here that Leopold first met Charles Elton, a British ecologist made famous by his publication of his book, *Animal Ecology,* at the age of 27. At the time of the conference, Elton was working with the Hudson's Bay Company, analyzing their fur trapping records in order to reconstruct the population dynamics of arctic species over hundreds of years.

---

352 Ellsworth Huntington, "The Matamek Conference on Biological Cycles, 1931," *Science* 74 (1931): 229-235. See also H. Helm Clayton, *Variation in Solar Radiation and the Weather* (Washington DC: Smithsonian Institution, 1920); Aldo Leopold and J. N. Ball, "British and American Grouse Cycles," *Canadian Field Naturalist* 45 (1931): 162-167; R. G. Green and C. A. Evans, "Studies on a Population Cycle of Snowshoe Hares on the Lake Alexander Area I," *Journal of Wildlife Management* 4 (1940): 220-238; Robert Cushman Murphy, "Conservation and Scientific Forecast," *Science* 93 (1941): 603-609.

353 "Science Finds that Everything Goes Up and Goes Down Once Every 10 Years," *American Weekly* 1931, clipping in Folder 2, Box 5, Series 10-2, Aldo Leopold Papers, University of Wisconsin-Madison Archives and Records, Madison, Wisconsin [hereafter ALP].

Leopold and Elton would become lifelong correspondents and friends. Years later, Leopold would describe the conference as "the best thing of its kind that I have ever attended."[354]

Figure 42. Aldo Leopold (left) at the Matamek Conference in Labrador, Canada, July 1931, with Charles Elton (center) and William Rowan (right). Charles later visited Leopold at his now-famous Wisconsin shack in 1938—an oak that Charles planted on his visit grows at the site. Source: The Aldo Leopold Foundation report of the first annual Leopold Conference, April 20, 2007.

[354] Leopold to Herb Stoddard, quoted in Curt Meine, *Aldo Leopold: His Life and Work* (Madison: University of Wisconsin Press, 1988), 284, fn 61. The two main biographies of Elton are Peter Crowcroft, *Elton's Ecologists: A History of the Bureau of Animal Population* (Chicago: University of Chicago Press, 1991); Richard Southwood and J. R. Clarke, "Charles Sutherland Elton. 29 March 1900-1 May 1991," *Biographical Memoirs of Fellows of the Royal Society* 45 (1999): 131- 146. For more on Charles Elton and his contemporaries, see Sharon E. Kingsland, *Modeling Nature: Episodes in the History of Population Ecology* (Chicago: University of Chicago Press, 1985). Charles E. Elton, "Fluctuations in the numbers of animals: their causes and effects," *British Journal of Experimental Biology* 2 (1924): 119-163.

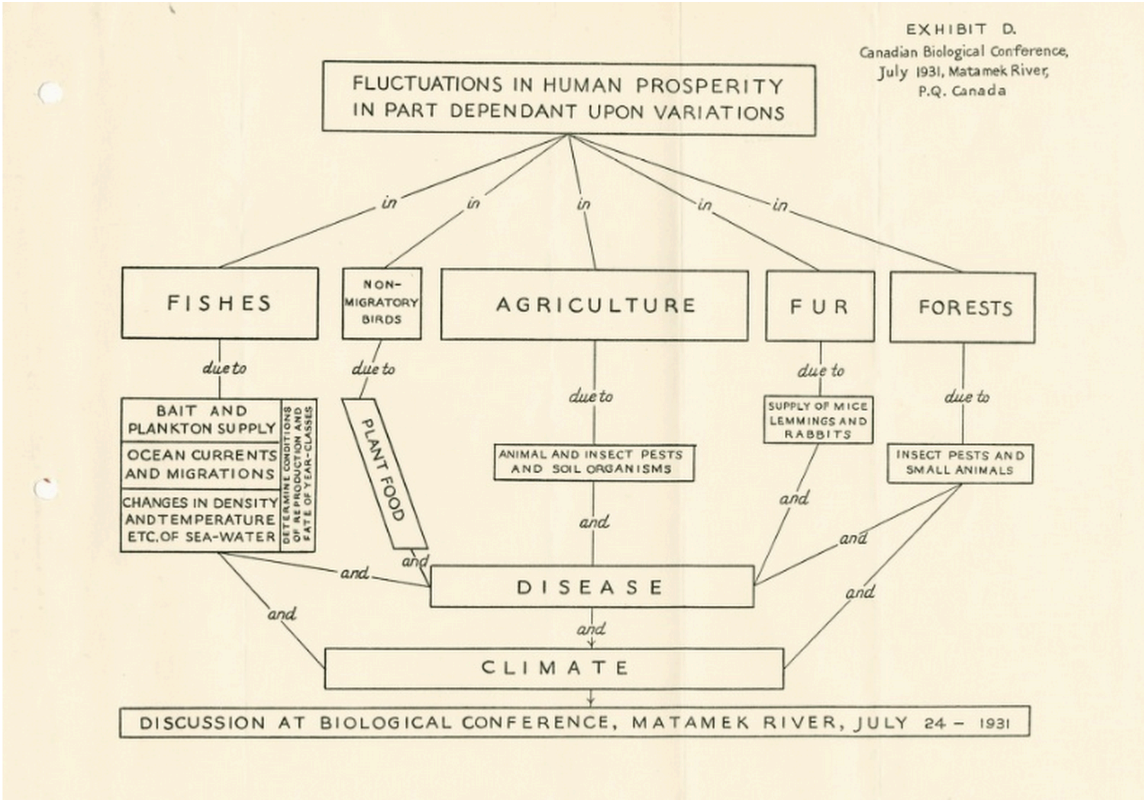


Figure 43. Handout from Aldo Leopold's notes on the Matamek conference, July 1931. Folder 2, Box 5, Series 10-2, Aldo Leopold Papers, University of Wisconsin-Madison Archives and Records, Madison, Wisconsin.

Worldwide depression had generated an interest in cycles across disciplines. As one newspaper put it: "As everyone knows to his sorrow just now, the world is in a business depression – at the bottom of one of those economic cycles which seem to follow each other almost as regularly as the ebb and flow of the tides."[355] Scientists and journalists sought to naturalize booms and busts. Articles described how animals and plants were subject to regular cycles of prosperity and poverty. In asking permission to attend the Matamek conference, Leopold explained to his employer at the time, the Western Cartridge Company, that if biological cycles were "found to be hitched to some relatively permanent cause like sun spots,"

[355] "Science Finds that Everything Goes Up and Goes Down Once Every 10 Years."

then scientists would be able to predict the future with certainty. This would be of value to both game administrators and the ammunition industry. If the cause were an environmental factor like disease or weather, scientists might even be able to control it.[356]

The participants left the Matamek conference with feelings of success. One post-conference report stated:

> One of the astounding features of the conference was the frequency with which one member or another emphasized the fact that in spite of minor differences the general reactions of men, animals and even plants to physical environment are essentially the same. Certain great laws seem to run all the way through the whole realm of life, and one result of the working of these laws is that cycles are very wide-spread phenomena.[357]

Thus by the late 1940s, Hutchinson and his colleagues were drawing on decades of ecological research into cyclical phenomena. In 1948, Hutchinson published "On Living in the Biosphere," in which he marveled at the number of cyclical processes on earth that operated because a continuous supply of solar energy was fed into them, moving the between thirty and forty chemical elements that were the material requirements of life. Water and nitrogen were the "most nearly perfect cyclical processes." He speculated that the earth might become phosphorus limited because "there is probably a slow loss in the form of sharks' teeth and the ear bones of whales, which are very resistant and which are known to be littered about on the floor of the abysses of the ocean."[358]

---

[356] Aldo Leopold to Mr. John M. Olin, Western Cartridge Company, 9 May 1931, Folder 2, Box 5, ALP. In October 1930, Leopold exchanged letters with Frederic Clements, who had written an article on cyclic phenomenon for *Outdoor America*. The tone of the correspondence suggests earlier contact. See Aldo Leopold to Frederic E. Clements, 2 October 1930; Frederic E. Clements to Aldo Leopold, 12 October 1930, ALP. See also Frederic E. Clements, "Drought Periods and Climatic Cycles," *Ecology* 2 (1921): 181-188; Frederick E Clements, "Climatic Cycles and Human Populations in the Great Plains," *The Scientific Monthly* 47 (1938): 193-210.

[357] Ellsworth Huntington, "The Matamek Conference on Biological Cycles, 1931," *Science* 74 (1931): 229-235

[358] G. Evelyn Hutchinson, "On Living in the Biosphere," *Scientific Monthly* 67 (1948): 393-397.

Notably, Hutchinson connected biogeochemical cycling to societal change:

> Looking at man from a strictly geochemical standpoint, his most striking character is that he demands so much — not merely thirty or forty elements for physiological activity, but nearly all the others for cultural activity […] We find man scurrying about the planet looking for places where certain substances are abundance; then removing them elsewhere, often producing local artificial concentrations far greater than are known in nature.[359]

Such concentrations could look as different as a cube of sodium in a bottle in the laboratory or the George Washington Bridge. In either case, Hutchinson concluded, humans were collecting a great quantity of materials only to place them in city dumps and automobile cemeteries: "Man, the miner, increases the cyclicity of the geochemical process."[360]

In *A Sand County Almanac*, Leopold drew on Hutchinson and other ecologists' work on biogeochemical cycling, describing land as "a fountain of energy flowing through a circuit of soils, plants, and animals." Importantly, he asked his readers to consider how human action had changed this cycling. In "Odyssey," Leopold described two atoms, X and Y. Atom X had been locked in rock since the Paleozoic era until it was taken up by a Bur Oak root, which decayed to help build a flower, which became an acorn, which fattened a deer, which fed an Indian. Now, however, "a new animal had arrived and begun redding up the prairie to fit his own notions of law and order": As an oxteam turned up the prairie sod, Atom Y "began a succession of dizzy annual trips through a new grass called wheat," yet soon washed away to a wing-dam, then to a sewer, so that the atoms "that once grew pasque-flowers to greet the returning plovers now lie inert, confused, imprisoned in oily sludge."[361]

---

[359] G. Evelyn Hutchinson, "On Living in the Biosphere," *Scientific Monthly* 67 (1948): 393-397.
[360] G. Evelyn Hutchinson, "On Living in the Biosphere," *Scientific Monthly* 67 (1948): 393-397.
[361] Leopold, *A Sand County Alamac*,104-108. On page 218 Leopold writes: "Recent discoveries in mineral and vitamin nutrition reveal unsuspected dependencies in the up-circuit: incredibly minute quantities of certain substances determine the value of soils to plants, of plants to

Eugene Odum's Path from Communities to Ecosystems

Like Paul Sears, G. Evelyn Hutchinson, and Lauren Donaldson, Eugene Odum came to community ecology by way of organismal physiology. Growing up in Chapel Hill, North Carolina, where his father, Howard W. Odum, was a prominent professor of sociology, Eugene discovered a passion for bird watching.[362] In 1930 he entered the Department of Zoology at the University of North Carolina, from which he graduated in 1936 with a master's degree. He then applied to Ph.D. programs across the country in zoology, but was rejected from all of them. He instead took jobs in Cleveland, Ohio, teaching introductory biology at Western Reserve University and banding birds for the Ohio Fish and Wildlife Commission.

In Cleveland Eugene befriended S. Charles Kendeigh, a former student of Victor Shelford, who was studying nesting behavior in birds at Western Reserve University. Kendeigh, who was about to move to the University of Illinois to begin a faculty position, asked Eugene if he wanted to take over one of his local projects. A Cleveland-based company had asked him to test whether their piezoelectric crystals, which converted vibrations into electric charges, could

---

animals. What of the down-circuit? What of the vanishing species, the preservation of which we now regard as an esthetic luxury? They helped build the soil; in what unsuspected ways they may be essential to its maintenance?" Both Leopold and Hutchinson were concerned over the rapidity of change in the landscape during World War II. Leopold contrasted the pace of evolution and that of technological change, contending that evolution was "usually slow and local," whereas technology led to changes "of unprecedented violence, rapidity, and scope." Hutchinson, meanwhile, wrote that Americans needed to transition "from the pioneering to the old, settled community"; the current "plenty more where these came from" attitude, whether lumber or buffalo tongues or copper, was "now completely destructive." G. Evelyn Hutchinson to Laurence Irving, Folder 388, Box 23, Series 1, GEHP.

[362] In grade school, Eugene wanted to be a plumber so that he could work without having to talk to people. Years later, he purported that this was how he become interested in streams, disappearing under the house to study networks of water. Craige, *Eugene Odum: Ecosystem Ecologist and Environmentalist*, 12.

be marketed to field biologists. Eugene was interested in the technology and took up Kendeigh's offer. He followed Kendeigh to Urbana-Champaign soon thereafter, once Kendeigh had negotiated to admit him as a Ph.D. student.[363]

Like many ecologists at the time, Eugene was interested in describing the physiological traits of individual species and extrapolating how these traits adapted them to their environment.[364] Eugene used piezoelectric crystals to build a "cardio-vibrometer," with which he recorded the heart rates of birds while they sat in their nests. The technology allowed him to study the heart rates of birds "at rest" in the field, as a "'physiology-of-the-whole' indicator," rather than "disturbed" birds in a laboratory. He was also able to observe cyclic changes in heart rate correlated with temperature and time of day. Summarizing his results in the journal *Ecological Monographs*, Eugene emphasized that ecologists, unlike other physiologists, should be most concerned with the function of an organism as a whole:

> Although the study of physiology quite logically is concerned at first with the study of the functions of various parts, organs, and systems as separate units, the ultimate aim is an understanding of their function in the organism as a whole. Furthermore, it is the physiology of the whole organism that is of the greatest interest to the ecologist in understanding how organisms are related to and function in their environments.[365]

---

[363] Kendeigh received his Ph.D. at the University of Nebraska under Victor Shelford in 1930. He had to argue to convince the department to accept Odum. He also made an argument for admission of a student rejected by the Botany Department, Robert Whittaker. Kendeigh was also one of the founders of The Nature Conservancy.

[364] Letters between Tom Odum and Eugene Odum 1940-1957 can be found in Carton 3, Series 3:1, EPOP.

[365] Eugene P. Odum, "Variations in the Heart Rate of Birds: A Study in Physiological Ecology," *Ecological Monographs* 11 (1941): 299-326; Eugene P. Odum, "The Heart Rate of Small Birds," *Science* 101 (1945): 153-154.

Figure 44. Eugene Odum feeding a bird, c. 1937. Folder 1, Box 163, Series 1, Eugene Odum Papers (MS 03257) Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

In thinking about the discipline of ecology, Eugene was heavily influenced by Victor Shelford. After graduating in 1939, Odum accompanied Shelford and his class of Illinois undergraduates on an expedition across the grasslands of western Canada. In teaching both undergraduate and graduate students, Shelford emphasized the equal importance of animal ecology and plant ecology. In the classroom he referred to assemblages of species with names like the "spruce-moose biome." One of Shelford's favorite lessons was that birds contributed to forest expansion by dropping seeds into holes that small rodents made in prairie sod. In this and other ways, species both "reacted to" their habitats and "co-acted" with one another – and, in doing so, modified habitat and produced new reactions.[366] It was a framework that Shelford had been refining over the previous ten years while writing an undergraduate textbook with Frederic Clements.

Figure 45. University of Illinois Summer Field Ecology Course, 1939. Shelford is second from left in the back row. Odum is second from the left in the front row. Folder 1, Box 166, Series 1, Eugene Odum Papers (MS 03257) Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

Shelford and Clements's textbook, *Bio-Ecology*, came out in 1939, the year that Eugene was assisting with the Canada course. It began with the argument that plant and animal ecology should be united, as "there are no habitats in which both plant and animal organisms are able to

---

[366] Robert A. Crocker, *Pioneer Ecologist: The Life and Work of Victor Ernest Shelford, 1877-1968* (Washington D.C.: Smithsonian Institution Press, 1991).

live, in which both do not occur and influence each other." While plant ecologists had developed a deep understanding of the "cyclic process" of life's development, it continued, animal ecologists had focused on organisms' internal processes to the detriment of their understanding of how organisms existed in their external environments. As a consequence of this internal divide, nobody was studying the physiology of interactions *among* species – "the biotic community itself." The biotic community could not be understood by studying its components in isolation, they explained. It was more than the sum of its parts. In telling this history of community ecology, Clements and Shelford credited themselves as the first to theorize the concept.[367]

When Eugene left Illinois in 1940 for Rensselaerville, New York, to work as a resident naturalist at the Edmund Niles Huyck Preserve, he set out to apply Clements and Shelford's community framework to his fieldwork. During the fall he developed a system of habitat classification for use by zoologists studying bird behavior. Progress in animal ecology was hindered by a lack of standardized habitat classification, he wrote in a draft manuscript. Wildlife researchers classified habitat by overly simple "cover types" like "beech-maple forest" and "cattail marsh." Meanwhile foresters had developed over forty "forest types," too specialized for the purposes of animal ecologists. And the jargon of plant successional theory was even worse, with hundreds of classification types. To complicate matters further, Eugene wrote, ecologists used the term "habitat" to refer to two separate entities – the place where a particular species lived ("the autecological viewpoint") and the place occupied by a biological community ("the

[367] Frederic E. Clements and Victor E. Shelford, *Bio-ecology* (New York: J. Wiley & Sons, Inc., 1939), Preface and Chapter 1.

synecological viewpoint”).[368] Interested himself in the community approach, Eugene developed his own “habitat formula” that used botanical data to categorize habitats within Clements and Shelford’s “bio-ecological viewpoint.” But the project failed to convince Odum’s peers. When he submitted the habitat formula manuscript to the journal *Ecology*, it was rapidly rejected. One reviewer wrote: “It seems futile to imagine that any formula could suitably describe so complex a situation as a community or a habitat.” Another wrote that publication of the paper would be “a scientific tragedy.”[369]

It would be a year of rejections for Eugene, as he was also rejected from the fifty or so faculty jobs to which he applied.[370] Finally, as fall approached, his well-connected father secured him a job as a temporary instructor of biology at the University of Georgia. In September Eugene moved to Athens, Georgia, with his new wife, Martha Huff, whom he had met at the University of Illinois. A few years later, in 1942, as the United States entered war with Japan, Germany, and Italy, Eugene was promoted to assistant professor, to the chagrin of some of his colleagues. The local draft board had granted him deferment to train nurses and pharmacists, and his course load was upped significantly; he now taught zoology, human anatomy, physiology, genetics, and ecology.

Apart from Shelford, Eugene’s other major interlocutor was his brother, Tom, eleven years his junior. Whereas Eugene came to community ecology via organismal physiology, Tom came to it through limnology. As a child Tom emulated Eugene’s interest in birds, and like Eugene, he entered the Department of Zoology at the University of North Carolina. But the war

---

[368] “Plant Communities and Classification of Animal Habitats by Use of the Habitat Formula,” File 21, Box 13, Series I, EPOP.
[369] Thomas Park to E.P. Odum, 8 November 1940, File 21, Box 13, Series I, EPOP.
[370] Notes in Folder 18, Carton 3, Series 3:1, EPOP.

interrupted his studies. In 1943, Tom joined the Army Air Force, for which he served as an instructor at the Air Force Tropical Weather School in Panama until 1946. When he returned to Chapel Hill he quickly finished his coursework, and in 1947, he was accepted to Yale University's graduate program in zoology.

Tom moved to New Haven intending to study bird physiology like his brother. But during his first semester, he was charmed by Hutchinson. He wrote to Eugene: "The far and above highlight here is G. E. Hutchinson. He is a small, fully British speaking, middle-aged man with penetrating though kindly eyes. He has a great diversity of abilities and knowledge."[371] Within the year, Tom had decided to work in Hutchinson's laboratory:

> Professor Hutinson [sic] is most enjoyable. I believe that there will be a really chance there. He has a lot of problems already in mind and equipment on hand. For example he has mentioned some spectrographic approaches to biological problems. Another was study of the strontium cycle of the sea etc. It looks pretty definitely like Oceanography with micro problems of p[hysical] chem[istry] and macro problems of application to the world is my field if I can make it.[372]

For his Ph.D. research Tom explored the circulation of strontium in oceans, more than a decade before the fallout of radioactive Strontium-90 catalyzed a national controversy over atmospheric nuclear weapons testing. As Tom worked on his dissertation, he wrote to Eugene

---

[371] Tom to Eugene, Dec 1947, Folder 25, Carton 3, Series III, EPOP.

[372] Tom to Eugene, summer 1948, Folder 25, Carton 3, Series III, EPOP. By the following year his relationship with Hutchinson had soured: "There is a very ticklish situation such that I may or may not get through depending not only on how much I can get done but on how I can handle Prof. Hutchinson. I became aware last year of his real method and habits of dealing with students. It is typical of the Yale Profs and most uncomplimentary. They are exceedingly cut throat as far as any aid they will give students. They will help as long as they can figure an angle for themselves. This sounds bitter but is just a statement of case. The difference between the ones here and many profs elsewhere is that here they are not interested in the persons as persons. The reason for bringing up this old story is that I have had to politic about trying to get out [...] My idea of life is not all that so called fame but to live a more normal life. […] Hutchinson is hard to work for because of his disorganization and artistic moody temperament. He is always implying or angling rather than speaking directly. " Tom to Eugene, Fall 1949, Folder 25, Carton 3, Series III, EPOP.

frequently, sharing his lecture notes, news from Hutchinson's laboratory, and gossip about other young ecologists.[373] These updates informally linked Eugene to one of the leading zoology programs in the country and would shape his future work.

While Tom was studying for his preliminary exams in geochemistry and "biochemistry of skeletons," Eugene asked him if he'd consider co-authoring a general ecology textbook that he was drafting.[374] The textbook, a summary of "the broad viewpoint of ecology," was one that Eugene and Tom's father had suggested years prior.[375] Always involved in Eugene's endeavors, Howard W. Odum had started contacting his friends in the publishing business in the early 1940s, asking if they'd be interested in contracting his son to write a textbook.[376]

In the end Tom declined co-authorship – he said he was too young and that he owed his interest in biology to Eugene – but he did write chapters on the topics that the Hutchinson laboratory had best trained him in – population biology, biogeochemistry, and methods for measuring biological productivity.[377] Tom's way of thinking about ecological communities was

---

[373] A copy of Tom's comprehensive exams can be found in Folder 25, Carton 3, Series III, EPOP.
Howard T. Odum, "The Stability of the World Strontium Cycle," *Science* 114 (1951): 407-411.
[374] Tom to Eugene, Fall 1949, Folder 25, Carton 3, Series III, EPOP.
[375] In 1937, Eugene wrote to his father, "Suffice to say that there seems to be nothing in print which summarizes a broad viewpoint of ecology (many of the people who call themselves ecologists do not have any broad viewpoint). Dr. Shelford says he hopes to write one someday." EP to Pop, 12 December 1937, Folder 14, Box 3, Series III, EPOP. Eugene agreed that it was a good idea; he believed the discipline's popular textbooks – A. S. Pearse's 1926 *Animal Ecology*, Charles Elton's 1927 *Animal Ecology*, and John E. Weaver and Clements's 1929 *Plant Ecology* – did not capture the new emphasis on how plants, animals, and elements of physical environment functioned in relation to one another. When, recognizing the same gap in the literature, Clements and Shelford published *Bio-Ecology* in 1939, Eugene remained undeterred.
[376] Folder 14, Carton 3, Series III, EPOP.
[377] HT to Eugene and Martha, Summer 1951, Folder 25, Carton 3, Series III, EPOP. Tom later wrote: "Your offer about the ecology text was most generous. Certainly after all the time and energy you have put into my education, you should get some return. However by now you have acculdulated (sic.) years of preparation so that my contribution would in no way match. How

particularly influenced by cybernetic theory – Tom had attended one of the Macy meetings as a guest of Hutchinson to talk about his strontium research. In his dissertation, he described ecology as one part of the study of "mechanisms of steady states in all types of system," quoting Wiener's definition of cybernetics.[378]

Importantly, Tom pointed Eugene to statistician and chemist Alfred Lotka's 1925 book, *Elements of Physical Biology*.[379] In *Elements*, Lotka contended that the environment could be understood as exchanges of matter and energy subject to the laws of thermodynamics. But unlike the "ordinary structureless systems" of laboratory vials, outdoor environments had "geometrical and mechanical features" that distributed chemicals unevenly. Analysis of energy was the key to studying the biological and physical components of outdoor environments simultaneously, he concluded. As Eugene and Tom figured it, Lotka's *Elements of Physical Biology* provided a

---

about a couple of Chapters rather than co author. Then after I have done a little more work I can really contribute to cooperative ventures." H.T. to Eugene, c. spring 1953, Box 60, Eugene Odum Papers – Institute of Ecology (UA 97-045), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia [hereafter EOPI]. Tom edited the book and wrote much of Chapters 4-7. Eugene thanked Tom in the preface, but, to his chagrin, not on title page.

378 Noted in Peter J. Taylor, *Unruly Complexity: Ecology, Interpretation, Engagement* (Chicago: University of Chicago Press, 2005), 62.

379 Sharon E. Kingsland gives Lotka a central role in the history of ecosystem ecology, but Frank Golley does not. See Sharon E. Kingsland, *Modeling Nature: Episodes in the History of Population Ecology* (Chicago: University of Chicago Press, 1985), compared to Frank B. Golley, *A History of the Ecosystem Concept in Ecology: More than the Sum of the Parts* (New Haven: Yale University Press, 1993), 58: "Lotka anticipated the study of food chains, producers and consumers, cycles of water, nitrogen, carbon and other elements, and the mathematics of trophic transfer. Unfortunately, his book did not stimulate the creation of a new science of physical biology. […] Although it appears to be a precursor to ecosystem ecology, we do not know how many ecologists were familiar with the first edition of Lotka's book. It is not cited in the literature that defines the developments we have discussed, but some ecologists, other than C. C. Adams, may have been influenced by it."

method to analyze the ecological communities proposed in Clements and Shelford's *Bio-Ecology*.[380]

In 1944, Eugene secured a contract with a publisher.[381] To pitch the textbook, he had appealed to the need for ecologists to address environmental destruction after the war:

> After the war there will be a great revival of interest in ecology and in applied fields which spring from it such as conservation, forestry, and wildlife managements, etc. With all the distruction [sic] now going on, it will be practically essential for us to give more thought to our shrinking environment in more ways than one![382]

Fundamentals of Ecology and the Human Role in Shaping the Environment

Eugene correctly anticipated his textbook's success, but not its success's timing. *Fundamentals of Ecology* was published in 1953. Over the next years it sold a few thousand copies – a respectable number, considering the size of the discipline at the time. But it would be another fifteen years before the textbook took off. In 1969, annual sales were approximately 6,200 copies. In 1971, they were 42,000 copies, and *Fundamentals* was translated into twelve languages.[383] The textbook was arguably the single most influential text in the history of ecology.

In *Fundamentals*, Eugene nested community ecology within ecosystem ecology. Community ecologists studied the biological interactions among organisms, while ecosystem ecologists studied the interactions between communities and their abiotic environments:

---

[380] Hutchinson, for one, had critiqued *Bio-Ecology* for its lack of method. In a review in *Ecology*, he wrote that the textbook reviewed "mainly classificatory" principles and not method for studying communities. "If, as is insisted, the community is an organism," Hutchinson wrote, "it should be possible to study the metabolism of that organism." G. E. Hutchinson, "Bio-Ecology by F.E. Clements, V.E. Shelford," *Ecology* 21 (1940): 267-268.
[381] EP Odum to JB Bennett Jr., 7 Feb 1944, Folder 14, Carton 3, Series III, EPOP.
[382] EP Odum to JB Bennett Jr., 7 Feb 1944, Folder 14, Carton 3, Series III, EPOP.
[383] Craige, *Eugene Odum: Ecosystem Ecologist and Environmentalist*, 46-47.

> Although everyone realizes that the abiotic environment ("physical factors") controls the activities of organisms, it is not always realized that organisms influence and control the abiotic environment in many ways. […] Plants growing on a sand dune build up a soil radically different from the original substrate. A South Pacific coral island is a striking example of how organisms influence their abiotic environment. From simple raw materials of the sea, whole islands are built as the results of the activities of animals (corals, etc.) and plants. The very composition of our atmosphere is controlled by organisms.[384]

In the same breath, Eugene mentioned Cowles's sand dunes, the Pacific Proving Grounds, and the entire atmosphere.[385] His emphasis was on the co-construction of organisms and their environments, the idea that each importantly shaped the other. The textbook then overviewed production (photosynthesis), decomposition, and food chains, arguing that each level of a food chain could be represented by numbers, mass, or energy. Ecologists could therefore use laws of thermodynamics to ask questions about the structure of ecological communities. For example – did herbivores and predators differ in how efficiently they used their food? Did communities differ in their ratios of production to respiration? In contrast to *Fundamentals*, University of Michigan ecologist Lee R. Dice's textbook, *Natural Communities*, published one year earlier, in 1952, did not mention ecosystems. It instead divided larger units into community type, life zone, biome, and biotic province. The textbook's 23 chapters included chapters on the physical factors that affect communities, food relations within communities, fluctuations in populations, ecological succession, and "communities of the past."[386]

But like *Natural Communities*, *Fundamentals* focused primarily on how non-human factors shaped ecological communities. As I explore in the next chapter, it was not until later in

---

384 Eugene P. Odum, *Fundamentals of Ecology* 2nd edition (Philadelphia: Saunders Publishing, 1959), 16.
385 Odum, *Fundamentals of Ecology*, 46.
386 Frank B. Golley, *A History of the Ecosystem Concept in Ecology: More than the Sum of the Parts* (New Haven: Yale University Press, 1993), 215. Dice was the president of the Ecologist's Union 1948.

the 1950s that ecologists turned their attention to how human activity shaped ecosystems. Before then, ecologists generally organized the biotic world into "communities" that were primarily shaped by abiotic or "physiographic" forces like temperature and precipitation. In Chapter 3 of *Fundamentals*, for example, Eugene reviewed Liebig's "Law of the Minimum" and Shelford's subsequent "Law of Tolerance." The "Law of the Minimum" stated that plant growth is often limited not by materials needed in large quantities, such as carbon dioxide, but rather by trace minerals. The "Law of Tolerance" was the idea that there is a finite range of conditions (in temperature, nutrient availability, etc.) within which a given species can survive. As a corollary of these two laws, *Fundamentals of Ecology* identified temperature and precipitation as the two most important determinants of ecological communities. "Man has done very little, as yet, to change the pattern of rainfall and the climate in general," Eugene continued, "although recent experiments in rainmaking may indicate that this may not always be the case." Later in the textbook, Eugene added to these abiotic factors the "biotic" controls on communities, including predation, pathogens, and competition among species. It was not until the final section of the textbook, "Applied Ecology," that Eugene referred to three modes through which human activity shaped ecosystems: fish and wildlife management, in which (in reference to Aldo Leopold's work), it had recently been shown that the best way to "encourage or discourage" a particular organism was "to modify the community"; range management, in which "everyone suffers when land is improperly used"; and stream pollution (either chemical or sewage), which could be measured by its effects on the community.[387]

---

[387] Eugene P. Odum, *Fundamentals of Ecology* (Philadelphia: Saunders Publishing, 1953), quotes on 42, 150, 182, 321. See also Justus Liebig, *Chemistry and Its Application to Agriculture and Physiology* (London: Taylor and Walton, 1840); Victor E. Shelford, *Animal Communities in Temperate America* (Chicago: University of Chicago Press, 1913); Ruth Patrick, "A proposed

But in the first years after *Fundamentals* was released, results from radiocarbon dating studies were causing ecologists to rewrite their narratives of America's ecological past, as I contend in Chapter 5. In 1955, "Man's Role in Changing the Face of the Earth" brought together anthropologists, archeologists, geographers, and ecologists to discuss the impact of human activity on the environment.[388] Planning began in 1952, and included Carl O. Sauer, an influential geographer at University of California, Berkeley; Marston Bates, an entomologist at the University of Michigan; and Lewis Mumford, a humanist known for his analyses of technology and urban life. The question at hand, as one participant put it, was "What has been, and is, happening to the earth's surface as a result of man's having been on it for a long time."[389] Among the 52 talks were those by Bates on human agency in the spread of organisms; by Paul Sears on using pollen stratigraphy to reconstruct the ecological past; by John Curtis (of the prairie restoration project at the Wisconsin Arboretum) on the effects of timber harvest and agriculture on grassland communities; and by Sauer on new evidence of the antiquity of human habitation in North America.[390]

---

biological measure of stream conditions based on a survey of the Conestoga Basin, Lancaster County, Pennsylvania," *Proceedings of the Academy of Natural Sciences of Philadelphia* 101 (1949): 277-341.

[388] On the connection of the conference with George Perkins Marsh's work, see David Lowenthal, "Nature and Morality from George Perkins Marsh to the Millennium," *Journal of Historical Geography* 26 (2000); 3-27. As Donald Worster points out, the symposium topic also had precedent in Paul Sears's *Deserts on the March*, Graham Jacks and R. O. Whyte's *The Rape of the Earth*, Carl Sauer's "Destructive Exploitation in Modern Colonial Expansion," Fairfield Osborn's *Our Plundered Planet*, and William Vogt's *Road to Survival*. Donald Worster, "The Vulnerable Earth: Toward a Planetary History," *Environmental Review* 11 (1987); 87-103. See also Michael Williams, "Sauer and 'Man's Role in Changing the Face of the Earth," *Geological Review* 77 (1987): 218-231.

[389] Preston E. James, "Review: Man's Role in Changing the Face of the Earth," *Economic Geography* 33 (1957): 267-274.

[390] Carl O. Sauer, "A Geographic Sketch of Early Man in America," *Geographical Review* 34 (1944): 529-573; George F. Carter "Man in America: A Criticism of Scientific Thought,"

Years later, in a wonderfully titled paper, "Coaxing History to Conduct Experiments," Edward Deevey reviewed the research that had led to the conclusion that it was impossible to distinguish "a minor climatic change" from "a major or nonlocal interference with vegetation by man" in the pollen record:

> Until a few years ago, almost any ecologist would have supposed that pollen stratigraphy, resolving as it does the quantitative aspects of vegetational change on a time-scale of great sensitivity, contained all the data needed to treat the evolution of plant communities. Today, we are not so confident. In Europe it has become clear that the change resulted not from climate, but from Neolithic disturbance and forest clearance. […] As a result, some of us have become skeptical of the prairie-forest border in Minnesota and Wisconsin, and of the whole corpus of "Xerothermic theory" that rests on its supposed extension eastward into Ohio and Pennsylvania. This now sounds suspiciously like human disturbance.

This "annoying mixup between climatic and cultural events," Deevey concluded, challenged ecologists to better understand the signatures of human "disturbance."[391]

Conclusion

The Odums' trip to Eniwetok captures a critical time in the history of ecology. By 1954 ecosystems existed to some ecologists but not to all. And humans were not (yet) considered part of ecosystems. It is therefore unsurprising that the Odums described Eniewetok Atoll as an unchanging and "isolated" system: "Save for fluctuations the reef seems unchanged year after year, and reefs apparently persist, at least intermittently, for millions of years," they wrote.[392]

Scientific Monthly 73 (1951): 297-307; Carl O. Sauer, "Agency of Man on the Earth," in William L. Thomas (ed.), *Man's Role in Changing the Face of the Earth* (Chicago: University of Chicago Press, 1956). The topic is still controversial. See Tim Flannery, *The Eternal Frontier: An Ecological History of North America and its Peoples* (New York: Grove Press, 2002).

391 Edward Deevey, "Coaxing History to Conduct Experiments," *BioScience* 19 (1969): 40-43.

392 Howard T. Odum and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," *Ecological Monographs* 25 (1955): 291-320.

But in fact, in the decades before the Odum's arrival, the landscape at Eniwetok had been shaped and re-shaped by military and scientific activity. Before the nuclear testing there was the WWII. The Japanese established defenses at Eniwetok in 1943. American naval bombardment of Eniwetok began on February 17, 1944, and The Battle of Eniwetok lasted until February 23. Thirty-seven Americans and more than 800 Japanese were killed. It is the battle from which the term "thousand yard stare" derives. After WWII the U.S. Navy commandeered the island, using it as a base for later operations. Operation Ivy alone, conducted in 1952, involved 75 million gallons of fresh water, 1 million meals served, 89 thousand square feet of tent erected, 30 thousand cubic yards of coral rock crushed, and 3 million board feet of lumber.[393] As a University of Washington journalist would later write:

> The statistics cannot give a picture of the work performed—of the massive bunkers constructed, of the causeways thrown between islands, of air-strips built, roads graded, heavy equipment carried by marine craft from island to island, structures aligned precisely for test instrumentation purposes, plus the normal community and housekeeping chores incidental to keeping a large group of men reasonably happy, healthy and satisfied."[394]

Scientific activity, too, transformed the Atolls, both materially and symbolically. Take the 1951 Hollywood-produced film *Operation Greenhouse*, in which the AEC stated:

> One of the proving grounds is an outdoor laboratory: Enewetak Atoll in the Pacific. […] Since Enewetak is a distant and primitive area, men have to leave their stateside laboratories and homes for a period of months. [*Image of an American man with suitcase entering his car and waving goodbye to son and dog*]. Now the proving grounds come alive like a university campus when students return from a summer holiday . . . [*aerial view of islands from military plane*] these are the dormitories of 'Enewetak university' ... individual test islands, seemingly like so many science buildings on college grounds.[395]

---

[393] Folder 46, Box 12, University of Washington Laboratory of Radiation Biology Records, The University of Washington Special Collections, Seattle, Washington [hereafter LRBR].
[394] Folder 46, Box 12, LRBR.
[395] *Operation Greenhouse* (Lookout Mountain Laboratory, US Air Force, Hollywood, California, 1951), http://www.archive.org/details/OperationGreenhouse1951, as cited in Elizabeth

Through such rhetorical work, the Pacific Proving Grounds were transformed into potential laboratories available for any conceivable human project.[396] These activities and materials, which surrounded the Odums, went unmentioned in their scientific papers. Instead, the Odums described Eniwetok as a complex yet stable and contained ecological community, joining some of their predecessors in emphasizing the importance of interactions among many biotic and abiotic factors in a "system." And during the Cold War the size of that system was growing: for the Odums at Eniwetok in 1953, it was as big as the lagoon, but by the 1970s the concept of the "biosphere" linked the whole surface of Earth in a single system that struggled to self-regulate.

Robert Kohler and Jeremy Vetter have suggested that field sites have produced knowledge "based in place," unlike laboratories that aim to produce universal, placeless knowledge.[397] But in the Odums' case, fieldwork conducted in specific places like Eniwetok

---

DeLoughrey, "The myth of isolates: ecosystem ecologies in the Nuclear Pacific," *Cultural Geographies* (2012) doi:10.1177/1474474012463664.

[396] The Pacific Islands have long been fashioned as laboratories for western colonial interests, from James Cook to Darwin. Richard Grove has demonstrated that tropical islands around the world served as spaces of social, biological, and industrial experiment in ways that shaped modernity. See Richard Grove, *Green Imperialism: Colonial Expansion, Tropical Island Edens, and the Origins of Environmentalism, 1600-1860*. See also E. DeLoughrey, *Routes and Roots*; K. R. Howe, *The Quest for Origins: Who First Discovered and Settled New Zealand and the Pacific Islands* (New York: Penguin Books, 2003); Godfrey Baldacchino, "Islands, Island Studies," *Island Studies Journal*, 1 (2006): 3-18.

[397] In the 1970s, STS scholars went into laboratories to directly observe scientists at work. Their question: how are facts made? Many foundational STS concepts emerged from these studies, including work on negotiation among scientists; rhetorical strategies in scientific publishing; material tools for disciplining nature; and the importance of tacit knowledge in conducting experiments. Most of these studies consider physical or medical sciences; few consider biological and environmental sciences. An emerging literature on field sciences responds to this trend. Both Robert Kohler and Jeremy Vetter have advanced the argument that as laboratories gained epistemic status in the late nineteenth century, that, in Vetter's words, the field was "reconstructed as the residuum of messy, complex, and uncontrollable nature." (Vetter 2010, p.

Atoll was used to develop universalized, placeless knowledge. With the Odum's formulation of model ecosystems, places became interchangeable. Ecosystem experiments conducted in Pacific coral reefs came to serve as models for lakes in Wisconsin, rainforests in Panama, deserts in China. As Tom wrote to Eugene a few months after visiting Eniwetok, "The pyramids are very gratifying and not too different from Silver Springs, Savannah River, alfalfa-beef-boy, etc. Thus it really looks like there is an underlying constancy in these things."[398] Species also became interchangeable. The Odums wrote, for example, that at Eniwetok "the numerous beautiful schools of brilliant herbivorous fishes were indeed the 'cows' of the reef."[399]

It is perhaps due to the eventual success of *Fundamentals of Ecology* that the Odums' paper, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," came to be seen as a landmark paper in ecosystem theory. As I have shown, however, the Odums arrived at Eniwetok schooled in the community ecology of Victor Shelford and the emphases of Hutchinson on the importance of physical chemistry and its relation cybernetics. Their collaborative work extended traditions in ecology that dated back several decades, and their impact on ecological thinking was not immediate, but delayed. Nonetheless, their research at Eniwetok functions as a useful nexus for historical analysis of the history of ecology because

---

2). Robert Kohler, *Landscapes and Labscapes: Exploring the Lab-field Border in Biology*. (Chicago: University of Chicago Press, 2002); Jeremy Vetter, ed., *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (Rutgers University Press, 2011). On fieldwork see also Helen Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea*, (Cambridge: Harvard University Press, 2005); Sharon Kingsland, "Frits Went's Atomic Age Greenhouse: The Changing Labscape on the Lab-field Border." *Journal of the History of Biology* 42 (2009): 289–324; *Osiris* vol. 11; Megan Raby, "Making Biology Tropical: American Science in the Caribbean, 1898-1963" (Ph.D. dissertation, University of Wisconsin-Madison, 2012).

398 Tom to Gene, 1 November 1954, Folder 4 Box 1, ODUM-E.

399 Early draft of "A Report on Research Accomplished at the Eniwetok Marine Laboratory During the Summer of 1954 Supported by A grant from the Atomic Energy Commission," Folder 5, Box 1, ODUM-E.

of the parallels between the Odums' work and the work of Donaldson's Applied Fisheries Laboratory.

And in an important way, it was at Eniwetok that ecosystems first materialized.[400] Today we take the existence of ecosystems for granted. They appear in high school textbooks and car advertisements; they are metaphors for historical processes and the human body; they justify 171 sections of U.S. federal environmental law. Since the 1970s, federal, state, and private environmental organizations have aimed to implement "ecosystem-based management" to confront issues like species endangerment, wetlands degradation, and invasive species through "best available science."[401] It is hard to imagine the environment without imagining ecosystems.

But this wasn't always the case. To make ecosystems exist as perceived physical objects,

---

[400] Historical ontology explores how objects come into being via historically specific circumstances. For example, only with the advent of germ theory did microbes become perceivable objects, objects that were subsequently feared and managed. For an overview, see Ian Hacking, *Historical Ontology* (Cambridge: Harvard University Press, 2004). See also Lorraine Daston, "Historical Epistemology," in James Chandler, Arnold Davidson, and Harold Harootunian, eds., *Questions of Evidence: Proof, Practices, and Persuasion Across the Disciplines* (Chicago: Chicago University Press, 1994), 282-289; Lorraine Daston, "The Coming into Being of Scientific Objects," in Lorraine Daston, ed., *Biographies of Scientific Objects* (Chicago: Chicago University Press, 1999); Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge: Harvard University Press,1999); Anne Marie Mol, *The Body Multiple: Ontology in Medical Practice* (Durham, N. C., 2002); Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Durham: Duke University Press, 2006). In *Sick Building Syndrome*, Michelle Murphy presents a history of the heterogeneous practices through which chemical exposures "were granted or not granted existence." Murphy, 7. Murphy writes, "I depict materialization as the effect of power as exercised through the concrete arrangements of objects, actions, and subjects," Murphy, 181. Particularly useful to my dissertation is Murphy's discussion of how a concept - chemical exposure - became perceptible or imperceptible, existent or nonexistent, depending on the "arrangement of discourses, objects, practices, and subject positions that work together within a particular discipline or knowledge tradition," Murphy, 12.

[401] The 1973 Endangered Species Act was the first law to specifically mandate the conservation of ecosystems. The term "ecosystem management" was first used at a 1987 conference hosted by the University of Washington, the USDA Forest Service, and the National Park Service." Today, almost every land management agency in the United States United States has adopted ecosystem management into its planning and regulatory activities.

Hutchinson, the Odums, and their colleagues negotiated with the particularities of species, field sites, technologies, funders, peers, and scientific practices. And the "ecosystem' that emerged was not one thing, one object – it was many things, a multiplicity.[402] It was indeed the ability of the ecosystem to be many things at once that explains its rising visibility in the 1960s, as I explore in the subsequent chapter.[403] Given the recent naturalization of ecosystems, it is a challenge, but an important one, to write environmental histories without taking the environment itself to be a static or ahistorical object.[404]

---

[402] On multiplicity see Donna Haraway, *Primate Visions: Gender, Race, and Nature in the World of Science* (New York: Routledge, 1989); Anne Marie Mol, *The Body Multiple: Ontology in Medical Practice* (Durham, N. C., 2002); Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Durham: Duke University Press, 2006); Annemarie Mol, "Actor-Network Theory: Sensitive Terms and Enduring Tensions," Kölner Zeitschrift für Soziologie und Sozialpsychologie 50 (2010): 253-269. Annemarie Mol explains: "The idea was that there are not just many ways of *knowing* 'an object', but rather many ways of *practising* it. Each way of practising stages – performs, does, enacts – a different *version* of 'the' object. Hence, it is not 'an object', but more than one. An object multiple. That reality might be multiple goes head on against the Euroamerican tradition in which different people may each have their own *perspective* on reality, while there is only *one* reality – singular, coherent, elusive – to have 'perspectives' *on*. To underline our break with this monorealist heritage of monotheism, we imported the old fashioned philosophical term of ontology and put it in the plural. Ontologies. That was – at the time – an unheard of oxymoron." Mol, "A Reader's Guide to the "Ontological Turn," *Somatosphere*, available at: http://somatosphere.net/2014/03/a-readers-guide-to-the-ontological-turn-part-4.html.

[403] To refer to an entity as an ecosystem is to assert something about its boundaries and its processes. But substantial flexibility is still present within the ecosystem concept. Are ecosystems structured by competition or by altruism? Are they inherently stable or precariously fragile, or naturally stable but fragile when acted upon by humans? In the absence of conceptual stability, who has the credibility to testify to the "true" or "natural" organization of ecosystems? And how does an agency or NGO implement ecosystem-based management if ecosystems are many things? Considering the historical ontology of a multiplicity such as ecosystems thus opens up an array of empirical and theoretical questions in STS and the history of science, as much work in historical ontology has analyzed single scientific objects.

[404] In telling the stories of forests, urban water systems, or cows, environmental historians often rely on texts from natural sciences like ecology, geology, and epidemiology. Alfred Crosby wrote that "the physical and life sciences can provide quantities of information and theory useful, even vital, to historical investigation." (Crosby, "The Past and Present of Environmental History," *The American Historical Review* 100 (1995), 1177-1189.) More recently Edmund

For example, fieldwork did not always go according to plan, species did not always cooperate, and ecologists needed to find ways to transform doubtful data into convincing theory. In a letter to Eugene Odum, for example, Tom Odum wrote, "We have been working very hard at Springs [field site] getting odds and ends rounded out. We are thus getting very little that is new and spectacular but mostly more repetitions on some of our doubtful points."[405] Other times observations seemed to fit favored theories perfectly. Eugene wrote of his field work at the Nevada proving ground: "I am much impressed with desert as a good system for our type studies because it is, like the old fields and marshes, relatively uniform and simplified biologically."[406] And ecologists had to agree upon not only the variables that went into ecosystems, but also about the relationships *among* those variables.[407]

Russell recommended that graduate students in environmental history should be required to take science courses. (Edmund Russell, *Evolutionary History: Uniting History and Biology to Understand Life on Earth* (New York: Cambridge University Press, 2011), "Note on Sources.") In *Seeing like a State*, James Scott premises his thesis on the contrast between reductionism and holism, the "homogenization, uniformity, grids, and heroic simplification" of states and of bureaucratic science to the "*resilience and durability of diversity*" promoted by contemporary ecology. James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven; Yale University Press, 1999), 8, 281, his emphasis. In writing more inclusive histories – histories that attend to the role of non-humans in change over time – how can we attend to the contingent, historical nature of ecological knowledge? How can we avoid naturalizing ecosystems? How can we better acknowledge, as Sara Pritchard writes, that "'nature' is actually the product of scientific and technological work, not the self-evident explanation of that work." Sara Pritchard, *Confluence: The Nature of Technology and the Remaking of the Rhône* (Harvard University Press, 2011).

405 Tom Odum to Eugene Odum, c. 14 May 1953, Folder 8, Box 1, ODUM-E.

406 Eugene Odum to family, 27 September 1957, Folder 9, Carton 3, EPOP.

407 See Laura Jane Martin, "Mathematizing Nature's Messiness: Graphical Representations of Variation in Ecology, 1930-present," *in review*. Biological STS scholarship on modelling has traditionally considered model organisms in the laboratory. But this literature has much to offer a study of a field science like ecosystem ecology. As Angela Creager outlines, an emphasis on experimental systems serves two important purposes to the historian: it provides a way to offer a more inclusive account of the social life of science, and, rather than accounting for science solely in terms of *social* construction, model organisms provide a window into the "recalcitrance of Nature." Angela Creager, *The Life of a Virus: Tobacco Mosaic Virus as an Experimental Model,*

Ecosystem ecologists also had to negotiate with each other. In 1953, Tom wrote to Eugene of a recent reviewer letter: “Pinkerton’s and our theoretical paper bounced but we are going to bounce it back to Baitsell whose quote of the referee indicates assininity or incompetence (American Scientist) of the referee.”[408] In an early draft of the coral reef manuscript, Eugene wrote: “In short, we have undertaked ~~to describe the basic ‘anatomy’ of a specific reef~~. to describe the ecological ‘anatomy’ and to measure the rate of metabolism of a ~~reef~~ normal reef which may, in the future be affected by radiation.” [409]

And ecosystem ecologists negotiated with their funders. Both the Odums and Lauren Donaldson were told by the AEC to remove words like “fallout” from their scientific articles before publication. When the Donaldson lab sent a draft script to A.E.C. officials for their promotional film quoted above, they were told that “it would be desirable to insert a brief narration to the effect that the radiation level is very low so that individuals can swim and work in the water and on the land without danger over a period of several hours.” The AFL changed their script from:

> Many of these decayed at normal rates and others were thoroughly diluted by movements of sea currents. But there still is radioactivity in Bikini’s life system.

To:

1930-1965 (Chicago: University of Chicago Press, 2002), 320-321. See also Adele E. Clarke and Joan H. Fujimura, eds., *The Right Tools for the Job: At Work in Twentieth-Century Life Sciences* (Princeton: Princeton University Press, 1992); Andrew Pickering, ed., *Science as Practice and Culture* (Chicago: University of Chicago Press, 1992); Robert E. Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Lif*e (University of Chicago Press, 1994); Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science* (Chicago: University of Chicago Press, 1995); Rachel A. Ankeny, “The Conqueror Worm: An Historical and Philosophical Examination of the Use of the Nematode *C. Elegans* as a Model Organism” (Ph.D. dissertation, University of Pittsburgh, 1997); Karen Rader, *Making Mice: Standardizing Animals for American Biomedical Research, 1900-1955* (Princeton University Press, 2004).

408 H.T. Odum to Eugene Odum, c. February 1953, Folder 8, Box 1, ODUM-E.

409 Gene Odum, “Very rough draft” of Coral M.S., Folder 7, Box 1, ODUM-E.

> Many of these decayed at normal rates and others were thoroughly diluted by movements of sea currents, so that members of the group can safely swim in the lagoon and work on the islands. But there still is radioactivity in Bikini's life system.[410]

Thus ecosystems materialized from specific arrangements of methodologies, relationships, technologies, and species.

Field sites are often thought of as inherently "messier" than laboratories. Robert Kohler, for example, has argued that "socially as well as physically and biologically, the field is a more ambiguous and unstable place than any lab."[411] Alternatively, in the following chapter I contend that not only ecosystems, but ecosystem complexity, was constructed.

It was thus prescient when in a 1948 *New Yorker* review, E. B. White described Bikini Atoll as "the world in miniature."[412] Through ecological fieldwork, Eniwetok, Bikini, and other Pacific atolls were indeed to become models of the world in miniature. Eniwetok Atoll was not just a landscape of destruction and exclusion, a symbol of modern decline: it was a landscape of ecology and, ultimately, ecological restoration.

---

410 Paul Pearson to Lauren Donaldson, 17 May 1950, Folder 20, Box 6, LRBR.
411 Kohler, *Landscapes and Labscapes*, 7.
412 E.B. White, "Journal of a contaminated man," *The New Yorker*, 4 December 1948, 171-177.

CHAPTER 8

RECOVERY AFTER ATTACK:

1960S RADIOECOLOGY AND SHIFTING CONCEPTIONS OF HUMANS AS AGENTS OF ECOSYSTEM CHANGE

When ecologist Lauren Donaldson was hired by the Manhattan Project in 1943 to study whether radioactive effluent from Hanford Works affected Columbia River fisheries, most scientists considered nuclear contamination to be a localized threat. But by the time of the Castle Bravo detonation in 1954, scientists and the public had begun to conceptualize radioactive fallout as a regional, even a global, concern. As a number of environmental historians have argued, fallout studies played a central role in the rise of ecosystem ecology and the idea of an interconnected biosphere.[413]

In this chapter I likewise aim to illuminate the relationship between the Cold War, the rise of ecosystem ecology, and the postwar environmental movement.[414] But my objects of

[413] On the connection between fallout studies and ecosystem ecology, see R. A. Divine, *Blowing on the Wind: The Nuclear Test Ban Debate, 1954-1960* (Oxford: Oxford University Press, 1978); Laura A. Bruno, "The Bequest of the Nuclear Battlefield: Science, Nature, and the Atom During the First Decade of the Cold War," *Historical Studies in the Physical and Biological Sciences* 33 (2003): 237 - 260; Joseph Masco, "Bad Weather: On Planetary Crisis," *Social Studies of Science* 40 (2009): 7-40; Emory Jerry Jessee, *Radiation Ecologies: Bombs, Bodies, and Environment during the Atmospheric Nuclear Weapons Testing Period, 1942-1965* (Ph.D. Dissertation, Montana State University, 2013). Jessee explored how environmental scientists used radiation as a tool to trace the structure of ecosystems as well as oceanic and atmospheric currents, therefore demonstrating that the earth was an integrated biosphere.

[414] To explain the postwar environmental movement, historians have pointed to (1) the growing appreciation for natural areas among newly affluent Americans, (2) the discovery and popularization of the ecosystem idea, (3) the rise of "big" environmental science, facilitated by increased international coordination and the advent of digital computing, and (4) the influence of other 1960s social movements. On the first point, see Samuel P. Hays, *Beauty, Health, and Permanence: Environmental Politics in the United States, 1955-1985* (New York: Cambridge

analysis are not fallout studies, but rather studies in which ecologists simulated nuclear attacks. Alongside the Cold War era concern over nuclear fallout was the blunter fear of World War III. In 1950, the United States had 299 weapons in its stockpile. By 1960, it had 18,638. And by 1965, it had 31,139.[415] As the United States and Russia increased both the power and the range of their nuclear weaponry, it became possible to conceive of a catastrophic, global-scale war, and the U.S. Atomic Energy Commission (AEC) funded studies to investigate the economic and environmental consequences of such a war.[416]

University Press, 1987). On the second point, see Donald Worster, *Nature's Economy: A History of Ecological Ideas* (New York: Cambridge University Press, 1977), 340-87; Thomas R. Dunlap, *DDT; Scientists, Citizens, and Public Policy* (Princeton: 1981). On the third point, see footnotes 208-214. On the fourth point, see Robert Gottlieb, *Forcing the Spring: The Transformation of the American Environmental Movement* (Washington, D.C.: Island Press, 1993); Adam Rome, *The Bulldozer in the Countryside: Suburban Sprawl and the Rise of American Environmentalism* (New York: Cambridge University Press, 2001); Adam Rome "'Give Earth a Chance': The Environmental Movement and the Sixties," *The Journal of American History* 90 (2003): 525-554. Interestingly, the introductory panelist at the 1955 conference on "Man's Role in Changing the Face of the Earth" cited the airplane as the catalyst for global environmentalism: "Our world from the air is a kaleidoscopic jumble of natural and man-made features. […] It would be a wrong assessment of the significance of the airplane if we regarded it solely as an instrument that brings home most dramatically the shrinking of the globe. This is only one side of this new venture. The airplane enables us for the first time to look down – in the truest sense of the word – on man's work from above and to see them as a still very imperfect attempt at reshaping the natural environment. It imposes upon us forcibly the insignificance of what man has done so far to the earth and the challenge of the human scale." E. A. Gutkind, "Our World From the Air: Conflict and Adaptation," in William L. Thomas (ed.), *Man's Role in Changing the Face of the Earth* (Chicago: University of Chicago Press, 1956), 11, 40.

[415] Robert J. Watson, *History of the Office of the Secretary of Defense IV: Into the Missile Age, 1956- 1960* (Washington D.C.: Office of the Secretary of Defense, 1997), 457, Table 6.

[416] Here I am in dialogue with the recent work of Edmund Russell III, Joseph Masco, Elizabeth DeLoughrey, and Jacob Darwin Hamblin on the connection between the concept of "total war" and the rise of the environmental sciences. Russell contended that between WWI and the 1960s, chemical warfare and pest control expanded each other ideologically, technologically, and organizationally, so that "the control of nature formed one root of total war, and total war helped expand the control of nature to the scale rued by modern environmentalists," in Edmund Russell, *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring* (New York: Cambridge University Press, 2001). Masco argued that the global reach of nuclear crisis enabled new visions of planetary threats, especially climate change, in Joseph

While ecologists and military planners were tasked with recognizing the immense destructive power of nuclear weaponry, they did not imagine the outcome of nuclear war as the total annihilation of life on earth. In a very definite way, there would have been no point to such a vision. Instead, ecologists and military planners envisioned the period of environmental and economic recovery after WWIII and considered how the government could hasten that recovery. Their visions both drew on and advanced ecological theory about the capacity of nature to self-regulate and to repair itself when damaged. Thus I argue that those Cold War narratives about ecological destruction, which have had such staying power, must be considered alongside those about ecological restoration. Both narratives emerged simultaneously from the ideational and material entanglements between atomic warfare and ecological science. And both would come to shape environmental management worldwide, and therefore, the material environment itself.

Before the 1960s, human action was not considered an important driver of ecological change, because human-caused change was considered reversible. At the 1955 conference on "Man's Role in Changing the Face of the Earth," for example, ecologists noted that the negative effects of intensive cropping, grazing, or lumbering could be reversed if land managers abated the damaging action: ecological communities had the "re-creative power" to "reconstitute themselves when the cause of disturbance disappears."[417] During the 1960s, however, ecologists

---

Masco, "Bad Weather: On Planetary Crisis," *Social Studies of Science* 40 (2009): 7-40. DeLoughrey argued that "American environmentalism and militarism are paradoxically and mutually imbricated" in Elizabeth M. DeLoughrey, "The Myth of Isolates: Ecosystem Ecologies in the Nuclear Pacific," *Cultural Geographies* 20 (2013): 167-184. Hamblin analyzed how Cold War military establishments funded research on environmental warfare, especially climate manipulation, in Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (Oxford: Oxford University Press, 2013).

[417] William L. Thomas (ed.), *Man's Role in Changing the Face of the Earth* (Chicago: University of Chicago Press, 1956), Part II, Modifications of Biotic Communities," 677-804. Quotes from Edward H. Graham, "The Re-creative Power of Plant Communities," in William L. Thomas

began to study how ecological communities recovered – or restored themselves – after simulated nuclear attacks. Though this work, ecologists gradually expanded the set of forces thought to shape ecosystems to include human agency – not only via nuclear technologies, but also via pollution, persistent pesticides, deforestation, and eutrophication.

Furthermore, while many ecologists remained optimistic about the capacity for life to return (and human civilization to resume) mere weeks or months after the conclusion of a nuclear war, they began to imagine that the recovered ecosystem might look somewhat different from what had gone before. It was not unreasonable to imagine, for example, the devastation of a species' entire population – which it would be impossible to replace. To make sense of "recovery" under such circumstances, some ecologists began to distinguish "ecosystem functions" – like productivity and decomposition – from "ecosystem structure" – the types and numbers of species in the system. If ecologists could not restore the exact ecosystem structure, perhaps they could restore the function. And indeed, in a military planning context in which ecologists were tasked with imagining only what was essential for human survival, ecosystem functioning seemed more important than the restoration of individual species.

Once ecosystem functions had been distinguished from ecosystem structures, humans could choose which elements of the system to restore. This meant that both critics and proponents of nuclear technologies seized on the idea of long-term, even permanent, human involvement in ecological systems. The idea's double potential made it central to the conceptions of ecological restoration that persisted and developed in subsequent decades. Perhaps

---

(ed.), *Man's Role in Changing the Face of the Earth* (Chicago: University of Chicago Press, 1956), 677-691.

surprisingly, what haunted the disciplines of radioecology and ecology more broadly was not the possibility of global annihilation, but the specter of irreversible change.

I begin this chapter by dividing the history of radioecology into three periods based on the different types of questions that ecologists and the AEC pursued. I then focus on the third period, 1962 to 1973, during which ecologists disassembled ecosystems in order to observe their reassembly. The final section of this paper considers the Cold War language of "thresholds" and recovery. This language stemmed directly from simulations of nuclear attacks and underpinned The Nature Conservancy's first applied ecological restoration project.

Unlike other environmental sciences, including atmospheric science and oceanography, ecology is often framed as having emerged in opposition to the "Atomic Age." In his influential history of ecology, *Nature's Economy* (1977), Donald Worster contended that the "Age of Ecology" began when Barry Commoner, Rachel Carson, and other ecologists discovered that atomic fallout was poisoning the environment. Ecologists' discovery of "nature's vulnerability" is supposed to have spurred citizens to organize an environmental movement and politicians to fund ecosystem ecology.[418] Alternatively, my analysis suggests that by simulating damage

---

[418] Donald Worster, *Nature's Economy: A History of Ecological Ideas* (Cambridge: Cambridge University Press, 1997), Chapter 16. Quotes on vulnerability on pp. 347, 355. Responding to Worster, Stephen Bocking and Chunglin Kwa contended that one area of ecology, ecosystem theory, in fact developed from ecologists' direct involvement with the AEC. Bocking and Kwa both maintained that in the 1960s, ecologists funded by the AEC abandoned their natural history roots for energy diagrams and cybernetics in order to increase their respectability among AEC physicists. Stephen Bocking, "Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory," *Journal of the History of Biology* 28 (1995): 1-47; Chunglin Kwa, "Radiation Ecology, Systems Ecology and the Management of the Environment," in *Science and Nature: Essays in the History of the Environmental Sciences*, M. Shortland, ed. (London: British Society for the History of Science, 1995). Frank Golley and Joel Hagen similarly argue that AEC funding itself helped legitimize ecosystem theory. Joel Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick: Rutgers University Press, 1992); Frank Golley, *A History of the Ecosystem Concept in Ecology* (New Haven, CT: Yale

beyond which ecosystems would no longer retain their ability to regenerate themselves, ecologists constructed the ecosystem as an ecological unit vulnerable to human-caused change.

The Developing Discipline of Radioecology

"Radiation ecology" or "radioecology" emerged as a sub-discipline of ecology between 1950 and 1970, the period during which the AEC was the largest funder of ecological research in the United States.[419] The history of radioecology can be split into three rough periods, defined by the modes of laboratory work and fieldwork that ecologists undertook. In the first period, from 1943 to 1954, the design of AEC-funded ecological experiments reflected the widespread belief that the major biological hazard of atomic technology was prolonged exposure to external sources of radiation. During this time a handful of AEC-sponsored ecologists began monitoring individual species to see whether they were harmed by reactor effluent (at Hanford Works) or post-detonation fallout (at the Pacific and the Nevada Proving Grounds).

University Press, 1993).

[419] In 1971, funding for environmental and biological studies by AEC was $72 million. Total funding for ecology from NSF that year was somewhat less than $20 million. David C. Coleman, *Big Ecology: The Emergence of Ecosystem Science* (Berkeley: University of California Press, 2010), 7.

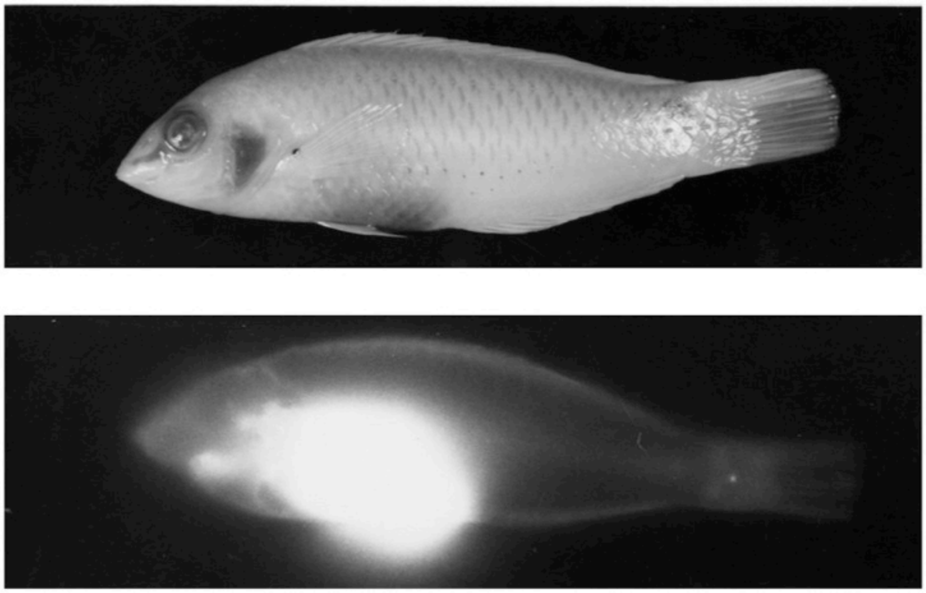


Figure 46. Radioautograph of wrasse collected from Test *Baker*, August 8, 1946, Folder 8, Box 2, Neal O. Hines Papers, The University of Washington Special Collections, Seattle, Washington.

The year 1954 marked a change in U.S. atomic policy, and with it, a change in the nature of radioecological research. Through the "Atoms for Peace" effort, civilian nuclear power became the centerpiece of an American effort to regulate atomic technology at an international scale.[420] The passage of the Atomic Energy Act in 1954 set declassification in motion, and in August 1955, the "Atoms for Peace" conference assembled under the auspices of the United

420 Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953-1961: Eisenhower and the Atomic Energy Commission* (Berkeley: University of California Press, 1989); Robert Bowie and Richard H. Immerman, *Waging Peace: How Eisenhower Shaped an Enduring Cold War Strategy* (New York: Oxford University Press, 1998); Ira Chernus, *Eisenhower's Atoms for Peace* (College Station: University of Texas Press, 2002); Ira Chernus, "Operation Candor: Fear, Faith, and Flexibility," *Diplomatic History* 29 (2005): 779–809; Kenneth A. Osgood, *Total Cold War: Eisenhower's Secret Propaganda Battle at Home and Abroad* (Lawrence: University of Kansas Press, 2006); Jacob Darwin Hamblin, "Exorcising Ghosts in the Age of Automation: United Nations Experts and Atoms for Peace," *Technology and Culture* 47 (2006): 724-256.

Nations in Geneva, Switzerland. During two weeks some 25,000 scientists, engineers, diplomats, and tourists visited presentations, trade exhibits, film showings, and a functional model reactor. A number of AEC-funded ecologists presented at the "Atoms for Peace" conference, including Lauren Donaldson's colleagues from the University of Washington, who, for the first time, presented to a public audience their findings on the "bioaccumulation" of radioisotopes in the Pacific Proving Grounds.[421]

This second period, from 1954 to 1962, was one of massive growth, in which the AEC systematically increased its investment in radioecological research. In 1955, the AEC Division of Biology and Medicine appointed John N. Wolfe, a prominent plant ecologist, as director of a new national ecology program in Washington, D.C.[422] Wolfe worked to develop radioecological programs at approximately 50 universities. By 1956, the year AEC created the "Environmental Research Branch" under the Division of Biology and Medicine, the "Oak Ridge National Laboratory Ecology Laboratory" had 11 staff members. In 1959, Wolfe approved Eugene Odum's proposal for permanent on-site "Savannah River Ecological Laboratory" at the

---

[421] Martin J. Medhurst, "Atoms for Peace and Nuclear Hegemony: The Rhetorical Structure of a Cold War Campaign," *Armed Forces and Society* 23 (1997): 571-593; John Krige, "Atoms for Peace, Scientific Internationalism, and Scientific Intelligence," *Osiris* 21 (2006): 161–181; John Krige, "Techno-Utopian Dreams, Techno-Political Realities: The Education of Desire for the Peaceful Atom," in Michael D. Gordin, Helen Tilley and Gyan Prakash (eds.), *Utopia/Dystopia: Conditions of Historical Possibility* (Princeton: Princeton University Press, 2010), 151-175. See also J. J. Davis and Richard F. Foster, "Bioaccumulation of Radioisotopes through Aquatic Food Chains," *Ecology* 39 (1958): 530–535. Eugene Odum's folder on the Geneva conference can be found in Carton 22, Series 1, Eugene P. Odum Papers (MS 3257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

[422] Stanley I. Auerbach, *A History of the Environmental Sciences Division of Oak Ridge National Laboratory* (Oak Ridge: Oak Ridge National Laboratory, 1972).

Savannah River Plant.[423] In 1961, the AEC appointed George M. Woodwell as a senior ecologist at Brookhaven National Laboratory on Long Island, New York.

Prior to 1954, ecologists had harnessed the "opportunities" afforded by nuclear waste products that the AEC had added to the landscape – whether from production (in the case of Hanford Works, the Savannah River Plant, and Oak Ridge National Laboratory) or from detonation (in the case of the Pacific and Nevada Proving Grounds) – to study the movement of elements in outdoor environments. In a 1953 proposal to the AEC to visit the Pacific Proving Grounds, Eugene Odum highlighted the "unique opportunity" that atomic testing created to study "entire ecological systems in the field."[424] In a 1954 report to the AEC, Lauren Donaldson extolled the "unparalleled scientific experiments" at the Pacific Proving Grounds (the testing of atomic weaponry) that had provided ecologists with a new tool: radiotracers. The radioactive residue of fission bombs, and then fusion bombs, had cycled through Bikini's and Eniwetok's lagoons, enabling the AFL to visualize relationships among species in a "natural environment" and to make ecology "a more exact science."[425]

---

[423] Chunglin Kwa, "Radiation Ecology, Systems Ecology and the Management of the Environment," in *Science and Nature: Essays in the History of the Environmental Sciences*, Michael Shortland (ed.) (Oxford: British Society for the History of Science, 1993).

[424] Eugene P. Odum to Dr. Karl Wilbur, 11 June 1953, Box 1, Folder 10, Series 1, Eugene Odum Research Files: Eniwetok Atoll (UGA 06-032), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia. Howard T. Odum and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," *Ecological Monographs* 25 (1955): 291-320; "The George Mercer Award for 1956," *Bulletin of the Ecological Society of America* 38 (1957): 2-3. Receiving the award, Eugene stated that "it was in connection with an AEC grant that my brother, with his interest in flowing water ecosystems, and I with my interest in sessile terrestrial and salt marsh systems, found a happy meeting ground on the coral reef." Tom, meanwhile, attributed his interests to "the dream of abstract conceptualization from G. Evelyn Hutchinson," "the fascination with the ecological from an older brother's early enthusiasm," and "a forecaster's resignation from the Air Force Meteorological experience."

[425] Lauren R. Donaldson, "Biological Cycles of Fission Products in Aquatic Systems as Studied

Thus while the AEC provided the funding and the access, ecologists were largely able to pursue their own research agendas.[426] In their report to AEC headquarters on their work at Eniwetok, for example, the Odums explained that they "were not primarily concerned with the effects of radiation," but rather with showing that the "basal metabolism" of a community could be "measured in certain very definite and precise ways, just as one can measure oxygen consumption, heart rate, etc., of an individual."[427]

By 1954, the AEC had begun mass-producing radioisotopes and distributing them to American researchers.[428] As radioisotopes became more accessible and affordable, ecologists were no longer constrained to studies of waste disposal sites and detonation sites. They began to apply radioisotopes directly to field sites. For example, in 1959, in order to study the decomposition of leaf litter, ORNL ecologists injected radionuclides into trees and then tracked the radionuclides' movement. In 1962, they expanded this effort, injecting Cesium-137 into 35 tulip poplar trees. This "cesium forest" came to be a cornerstone of ecological research at Oak Ridge.[429] Thus ecologists moved away from studying the effect of external radiation on individual organisms and toward studying the circulation of elements among organisms. In the second edition (1959) of his foundational textbook *Fundamentals of Ecology* – arguably the

---

at the Pacific Atolls of Bikini and Eniwetok," U.S. Atomic Energy Commission Report AECU–3412, Box 3, Folder 7, Lauren R. Donaldson Papers, University of Washington Special Collections, Seattle, Washington.

[426] Kwa notes this flexibility in, "Radiation Ecology, Systems Ecology and the Management of the Environment"; Joel Hagen, *An Entangled Bank*, 112-115; Stephen Bocking, *Ecologists and Environmental Politics* (New Haven: Yale University Press, 1997) explores how research with isotopic tracers at Oak Ridge made ecology more quantitative and connected it with computer simulations.

[427] Rough drafts, Folders 2-7, Box 1, ODUM-E.

[428] Angela Creager, *Life Atomic: A History of Radioisotopes in Science and Medicine* (Chicago: University of Chicago Press, 2013). By 1955, the ORNL had sent nearly 64,000 shipments of radioisotopes to scientists and physicians.

[429] Bocking, "Ecosystems, Ecologists, and the Atom."

single most influential ecology text to date – Eugene Odum explained that as human physiologists were using tracers to study individual metabolism, ecologists could use radioisotopes to better understand "community metabolism."[430] Radioisotopes enabled ecologists to study the "functions" of ecological communities using "an experimental ecosystem as a model."[431]

The confluence of ecologists' interest in "community metabolism" and the AEC's interest in containing nuclear waste led to the rise of ecosystem studies. During this period the AEC employed two principles in disposing of radioactive waste: "concentrate and contain" and "dilute and disperse." High-level wastes were stored in underground tank systems. (By 1957 highly radioactive liquid from nation's reactors amounted to 62 million gallons, most stored in underground tanks at Hanford.) Low-level wastes were diluted and then released into streams or placed in earthen pits to seep into the soil.[432] Ecologists were thus charged with studying whether "dilute and disperse" facilities impacted local flora and fauna. The arc of ecologist Stanley Auerbach's career exemplifies this shift. When Auerbach began working at ORNL in 1954, he researched the uptake of Strontium-89 by various species of earthworms.[433] But in the latter part of 1955, the headquarters of the AEC Division of Biology and Medicine advised Auerbach that

---

430 Eugene P. Odum, *Fundamentals of Ecology* 2nd edition (Philadelphia: Saunders Publishing, 1959), 469. In 1969, annual sales were approximately 6,200 copies. In 1971, they were 42,000 copies, and *Fundamentals* was translated into twelve languages. Betty Jean Craige, *Eugene Odum: Ecosystem Ecologist and Environmentalist* (Athens: University of Georgia Press, 2001), 46-47.
431 Odum. *Fundamentals of Ecology* 2nd edition, 452-486.
432 George T. Mazuzan and J. Samuel Walker, *Controlling the Atom: The Beginnings of Nuclear Regulation, 1946-1962* (Berkeley: University of California Press, 1984), Chapter 1; D. E. Reichle and S. I. Auerbach, *U.S. Radioecology Research Programs of the Atomic Energy Commission in the 1950s* (Oak Ridge: U.S. Department of Energy, 2003).
433 Stanley I. Auerbach, "The Soil Ecosystem and Radioactive Waste Disposal to the Ground," *Ecology* 39 (1958): 522–29.

he should focus on field research rather than laboratory experiments.[434] Also that year, the AEC drained White Oak Lake, the impoundment that had been the final settling basin for waste products, exposing bare soil containing Strontium-90, Cesium-137, Cobalt-60, and other radioisotopes.[435] Thus in 1956 Auerbach began to study movement of radionuclides among the plants and animals colonizing the former lakebed.[436]

Meanwhile, at the Savannah River Ecological Laboratory (SREL), ecologist Eugene Odum and his colleagues began placing "exposure chambers" in the abandoned agricultural fields around the Savannah River Plant and then spraying solutions of P-32 or I-131 on the plants. In the second edition of *Fundamentals of Ecology* (1959), Odum explained that "After the 'hot quadrat' (a new term in ecology!) has been prepared the plants and animals can be sampled at intervals to determine the fate of the isotope."[437] In other experiments, SREL ecologists injected isotopes directly into the stems of individual species. By sampling arthropods, snails

---

[434] United States Atomic Energy Commission, 19th Semi-Annual Report, Period Ending 31 January 1956, p. 70, discussed in Stephen Bocking, "Ecosystems, Ecologists, and the Atom." Bocking argues that ecologists were able to develop ecosystem science under the auspices of the AEC because (1) its quantitative perspective met the expectations of physicists, (2) it was compatible with research tools availale at a national laboratory, (3) it complemented without competing with other AEC disciplines, (4) it fostered large, cooperative projects, following the model of "big science" that Weinberg advocated for Oak Ridge, and (5) ecologists promoted research on the management of complex systems.

[435] Reichle and Auerbach, "U.S. Radioecology Research Programs."

[436] S. I. Auerbach, D. A. Crossley, P. B. Dunaway, H. F. Howden, E. R. Graham, K. K. Bohnsack, M. E. Pryor, C. Krauth, and R. M. Anderson, "Ecological Research," in *Health Physics Division Annual Progress Report for Period Ending July 31, 1958* (Oak Ridge: Oak Ridge National Laboratory, 1958), 27-41; D. A. Crossley,"Consumption of Vegetation by Insects," in V. Schultz and A. W. Klement, *Radioecology* (New York: Reinhold Publishing Company, 1963), 427-430; D. A. Crossley, "Use of Radioactive Tracers in the Study of Insect-Plant Relationships," in *Radiation and Radioisotopes Applied to Insects of Agricultural Importance* (Vienna: International Atomic Energy Agency, 1963), 43-53.

[437] Odum, *Fundamentals of Ecology* 2nd edition, 471. The field notes for the "hot quadrat" studies are in Folder 12, Carton 87, Series I, Eugene P. Odum Papers (MS 3257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

crickets, ground beetles, and other insects in the plots, the researchers could then test the bodies for radioactivity to see how rapidly phosphorus was transferred from plants to consumers.[438]

Figure 47. Eugene Odum working on experimental succession studies at Oak Ridge Institute of Nuclear Studies, 1963. Folder 7, Box 166, Series 1, Eugene P. Odum Papers (MS 03257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

By the early 1960s, radioecological techniques were integrated into graduate ecological training. In 1961, the AEC sponsored a symposium on radioecological methods in Fort Collins, Colorado.[439] The following summer, Auerbach organized a special summer course for ecologists

[438] Robert C. Pendeton and A. W. Grundmann, "Use of P-32 in Tracing Some Insect-Plant Relationships of the Thistle, *Cirsium undulatum*," *Ecology* 35 (1954): 187-191; Eugene Odum and Edward Kuenzler, "Experimental Isolation of Food Chains in an Old-Field Ecosystem with the Use of Phosphorus-32," *Radioecology* 113 (1963): 120.
[439] A second was held in Ann Arbor, Michigan, on May 15-17, 1967, and a third at Oak Ridge, Tennessee, on May 10-21 1971. Vincent Schultz and A. W. Klement, *Radioecology*.

at the ORNL.[440] There ecologists could learn how to "safely" use radioactive tracers to study ecological processes "in the landscape" – processes that included nutrient cycling, "delineation of food chains," and estimating "the interactions between the components of a community."[441]

Figure 48. Four scientists looking at a tree tagged with radioisotopes during a radioecology training class. Oak Ridge Institute of Nuclear Studies S211-6, Folder 7, Box 166, Series I, Eugene P. Odum Papers (MS 03257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

During this period most ecologists remained optimistic that the constructive peacetime uses of nuclear technologies – including ecosystem studies – outweighed their destructive potential. Ecologists described radioisotopes as useful tools with which ecologists could study

[440] Auerbach, *A History of the Environmental Sciences Division*.
[441] Stanley I. Auerbach, Jerry S. Olson, and M. D. Waller, "Landscape Investigations Using Caesium-137," *Nature* 201 (1964): 761.

elements that occurred in lesser concentrations than nitrogen, calcium, phosphorus, and potassium, “trace elements,” “easier, faster, or more accurately than by physical or chemical methods,” as AFL researcher A.H. Seymour would write in 1961. Seymour concluded, “As the light microscope and the electron microscope are tools that extend our ability to observe small objects, similarly, radioisotopes and radiation are tools that extend our ability to detect small quantities of elements.”[442]

The optimism is clear in Odum’s first revision of *Fundamentals of Ecology*, published in 1959, in which he added a chapter on the new discipline of “radiation ecology.”[443] In it he described studies from the Pacific Proving Grounds and SREL that explored how ecological communities mediated the distribution of radioactive substances in the environment.[444] In writing the chapter, he drew from his experiences at the “Atoms for Peace” conference and from his sabbatical year (1957-1958) under the auspices of a National Science Foundation Fellowship, which he spent at the University of Washington Laboratory of Radiation Biology and at the

---

[442] A. H. Seymour, “The Use of Radioisotopes and Radiation to Study Plant and Animal Life in Fresh and Marine Waters,” Hearings on the Application of Radioisotopes and Radiation in the Life Sciences, Subcommittee on Research and Development, Joint Committee on Atomic Energy, Congress of the United States, March 27-30, 1961, reprint in Folder 87, Box 3, Laboratory of Radiation Ecology Records, 1948-1984, The University of Washington Special Collections, Seattle, Washington. A. H. Seymour, “Contributions of Radionuclides to our Understanding of Aquatic Ecosystems,” XV International Congress of Limnology, Madison, Wisconsin, August 20-25, 1962, Folder 32, Box 7, Laboratory of Radiation Ecology Records, 1948-1984, The University of Washington Special Collections, Seattle, Washington.
[443] In writing the chapter Odum drew on A. Hollaender (ed.), *Radiation Biology* (New York: McGraw-Hill Book Co, Inc., 1954); C. L. Comar, *Radioisotopes in Biology And Agriculture: Principles and Practice* (New York: McGraw-Hill Book Co., Inc., 1955); Roger Revelle (ed.), *The Effects of Atomic Radiation on Oceanography and Fisheries* (Washington D.C.: National Research Council, 1957).
[444] Odum, *Fundamentals of Ecology* 2nd edition, 452-486. Drafts of the textbook can be found in File 4, Box 13, Series I, Eugene P. Odum Papers (MS 3257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

University of California – Los Angeles's radioecology program.[445] In the preface to the textbook, Odum added: "Some of the things which we fear most in the future, radioactivity, for example, if intelligently studied, help solve the very problems they create." And in the new "radiation ecology" chapter, he contended:

> Man's opportunity to learn more about environmental processes through the use of radioactive tracers balances the possible troubles he may have with environmental contamination.

But by 1971, when the third edition of *Fundamentals of Ecology* was released, Odum's attitude toward atomic technologies had shifted. He edited the above passage to read:

> Man's opportunity to learn more about environmental processes through the use of radioactive tracers balances to some extent the troubles he is having with environmental contamination.[446]

Radioecology from 1962-1973: Attacking Ecosystems

The period during which radiation ecology flourished was also the period in which the United States and the Soviet Union raced to expand their nuclear stockpiles. The AEC was also building increasingly powerful bombs. By the 1960s, the specter of a global nuclear war loomed large. In March 1954, three months after Eisenhower's "Atoms for Peace" speech and three months before the Odums' trip to the Pacific Proving Grounds, the United States detonated its first thermonuclear weapon. "Castle Bravo" had over a thousand times the destructive force of

---

[445] That year he also visited the laboratory of Charles Elton in Oxford, England. Odum personally invited Donaldson and his laboratory to participate in the Storrs meeting, but they were unable to attend. See Lauren Donaldson to E.P., 25 April 1965, Folder 34, Box 1, Odum – Correspondence (UGA 97-044), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia; EP Odum to LR Donaldson, 17 March 1956, "Radiation Ecology" Folder, Box 50, Eugene P. Odum Papers (MS 3257), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.
[446] Eugene P. Odum, *Fundamentals of Ecology* 3[nd] edition (Philadelphia: Saunders Publishing, 1971), 451-467.

the atomic bomb dropped on Hiroshima, and its fallout contaminated the Japanese tuna fishing boat *Daigo Fukuryū Maru* and the inhabited Rongelap atoll. The boat's crew, suffering from burns, headaches, nausea, bleeding from the gums, and eye pain, were diagnosed with acute radiation syndrome upon their return to Tokyo, and seven months later, one member died.

The AEC, eager to avoid international critique while still safeguarding details about the hydrogen bomb, enlisted Donaldson as a scientific ambassador to Japan and as a consultant on the diets of the Rongelap islanders.[447] From 1954 to 1973 Donaldson travelled to Japan six times to take tuna samples and meet with Japanese government officials. He contended that fish aboard the *Fukuryū Maru*, which Japanese scientists had found to be highly contaminated, were only externally coated with radioactive "ash," and that the edible parts of the fish were well within acceptable limits for consumption by humans. Atomic Energy Commission officials were aware that the Japanese monitoring would "turn up some very interesting and rather exciting material," and that, for this reason, Donaldson's work "becomes of more importance than ever."[448]

By the mid-1950s the dangers of fallout had entered the American consciousness. In spring of 1957 Congress held a series of special hearings to introduce the public to strategically selected scientific work on the biological effects of fallout. One study discussed at the hearings

---

[447] Lauren R. Donaldson, "Draft Report of Lab Activities 1958-1959," Folder 9, Box 1, Lauren R. Donaldson Papers, University of Washington Special Collections, Seattle, Washington [hereafter LRDP]. Correspondence regarding the 1954 accident can also found in Folder 38, Box 1, The Laboratory of Radiation Biology Records, 1944-1970, University of Washington Special Collections, Seattle, Washington [hereafter LRBR]. The papers of another University of Washington biologist involved in Rongelap monitoring, Stanley P. Gessel, can be found in University of Washington Special Collections Acc. No. 4147-002.

[448] Quotation from W.R. Boss to Dr. Gordon M. Dunning, 4 May 1956 , Folder 21, Box 1, LRBR. Dr. Willis R. Boss (AEC) travelled with Donaldson to Japan in summer 1954 to meet with Japanese scientists and diplomats. See Folder 12, Box 2, LRDP. See also "American Fisheries Society Committee on International Relations: Preliminary Report, September 1954," Folder 8, Box 1, LRDP; R. F. Palumbo, "Radionuclides in Foods from the Central Pacific, 1962" *Nature* 209 (1966): 1190-1192.

was Project SUNSHINE, commissioned by the AEC and the U.S. Air Force, which had sought to measure the global dispersion of strontium-90 by measuring its concentration in tissues and bones of dead citizens. As claims circulated through the media that strontium-90 could be detected in cow's milk, the U.S. anti-nuclear movement gained traction. Facing growing pressure from citizens, the United States, Soviet Union, and Great Britain signed the Limited Test Ban Treaty in 1963 ending all atmospheric, underwater, and outer space tests.[449]

Through the early 1960s ecologists, like most scientists, downplayed the differences between atomic detonations and non-atomic detonations. In lecture notes, Donaldson wrote that atomic bombs released three forms of energy:

> (1) Heat (which is present in other explosions, as the familiar injuries known as 'flash burns' on warships illustrate, but ordinarily not at high enough diffused temperatures to burn an man or set fire to combustible objects at any considerable distance from the explosion. (2) Radiation (similar to X-rays or to that from radium). (3) Blast or pressure (as from a demolition bomb). The whole discussion of the effects of the atomic bomb will be phrased in terms of these three kinds of energy. No other more mysterious or immeasurable forces acted; these were all.[450]

In a paper summarizing a symposium, "Ecological Effects of Nuclear War," at the 1963 AIBS meeting, Eugene Odum analogized nuclear detonations to storms and forest fires:

> The kinds of effects described and discussed here are not individually unique to nuclear catastrophes; most can and do result from a variety of nonnuclear forces commonplace in our biosphere. What would be unique about a large-scale nuclear catastrophe stems from (1) the interaction of several severe limiting factors, with the total effect not simply the sum of component effects, and (2) the great size of the stressed area, a quantity probably influencing the rate of recovery more than the severity of the acute forces themselves. As the writers of this symposium so ably documented their specific topics I jotted down

---

[449] See L. Machta, R. J. List, L. F. Hubert "World-wide Travel of Atomic Debris," *Science* 124 (1956): 474-477; R. A. Divine, *Blowing on the Wind: The Nuclear Test Ban Debate, 1954-1960* (Oxford: Oxford University Press, 1978), 129; Emory Jerry Jessee, *Radiation Ecologies: Bombs, Bodies, and Environment during the Atmospheric Nuclear Weapons Testing Period, 1942-1965* (Ph.D. Dissertation, Montana State University, 2013).

[450] Lauren Donaldson, Draft of "Biological effect of atomic warfare," Folder 20, Box 17, Lauren R. Donaldson Papers, University of Washington Special Collections, Seattle, Washington.

> some of the ecological sequelae of storms, forest fires, pest irruptions, gamma irradiations, and other natural, accidental, or experimental stresses that mimic, in one way or another, nuclear war.[451]

Meanwhile, studies by the RAND Corporation for the Pentagon estimated that a first Soviet attack would be aimed at 50 U.S. cities and would probably produce 90 million casualties. The government began promoting the construction of fallout shelters in state buildings, offices, and schools. "A shelter needs to be a place where a man and his family can breathe, see, drink eat, sleep and perform other bodily functions for two weeks, the critical time after nuclear attack," a 1961 *Life Magazine* article explained. "As for the people themselves, reactions to be expected under enforced confinement are high anxiety at first, then moody silences and personality conflicts before everyone settles down to await the all clear with resignation."[452]

---

[451] E. P. Odum, "Summary," in G. M. Woodwell (ed.), *Ecological Effects of Nuclear War* (Upton: Brookhaven National Laboratory, 1965).

[452] "A Shelter in Time Saves Thine and Firms Up National Will," *Life* (4 August 1961). On Cold War cultural history, see Paul Boyer, *By the Bomb's Early Light: American Thought and Culture at the Dawn of the Atomic Age* (New York: Pantheon, 1985); Elaine Tyler May, *Homeward Bound: American Families in the Cold War Era* (New York: Basic Books, 1988); Lynn Spigel, *Make Room for TV: Television and the Family Ideal in Postwar America* (Chicago: University of Chicago Press, 1992); Lynn Spigel, *Welcome to the Dreamhouse: Popular Media and Postwar Suburbs* (Durham: Duke University Press, 2001); Jennifer S. Light, *From Warfare to Welfare: Defense Intellectuals and Urban Problems in Cold War America* (Baltimore: Johns Hopkins University Press, 2005); Kirk, *Counterculture Green*. On total war, see Peter Paret, Gordon Craig, and Felix Gilbert (eds.), *Makers of Modern Strategy from Machiavelli to the Nuclear Age* (Princeton: Princeton University Press, 1986); Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994): 228-266; Sharon Ghamari-Tabrizi, "Simulating the Unthinkable: Gaming Future War in the 1950s and 1960s," *Social Studies of Science* 30 (2000): 163-223.

Figure 49. Photo from the article "A Shelter in Time Saves Thine and Firms Up National Will," *Life*, 4 August 1961.

In 1962, the RAND Corporation prepared a report for the Pentagon, "Ecological Problems and Post-War Recuperation," in which they concluded that following a nuclear attack in the United States, the two main ecological stressors would be fire and nuclear fallout. The direct result of the widespread fires would be the destruction of crops, timber, livestock, and wildlife, they concluded. The indirect result would be the destruction of ground cover, which might cause erosion and turn large areas into "dust bowls." After large, unchecked fires it would be a while before "ecological processes attain ascendancy and begin the long march back to equilibrium." In order to prepare for enemy attack, it contended, the government should consider planting forest stands "so that they will burn in a manner most conductive to their reconstruction." For guidance on how to promote the "reconstruction and reconstitution of biotic communities" after an attack, the report contended, officials could turn to previous ecological studies of "large-scale damage due to fire, drought, flood and other things."[453]

The only "quantitatively new element in the post-attack situation," the RAND Corporation contended, would be radiation. "Natural radiation" was "an integral part of the equilibrium of life," it contended. But the levels of radiation in a "post-attack" environment would "far exceed these natural radiations for a limited period of time." The effects of this radiation could be separated into "the lethal concentration of radioactive substances by plants and animals" and changes in the composition of ecological communities due to "differential radiosensitivity" among species. The first effect referred to the bioaccumulation studies that ecologists had by then been conducting for almost two decades. But the second effect referred to a set of more recent studies – ones in which ecologists purposefully destroyed ecological communities to study how they rebuilt themselves.

The first nuclear attack simulated by ecologists occurred on the Brookhaven National Laboratory grounds. In the summers of 1962 and 1963, ecologist George Woodwell exposed plant communities to continuous radiation from a point-source of Cobalt-60. He then compared their species composition to a non-irradiated control plot and concluded that under "natural

---

[453] H. H. Mitchell, *Ecological Problems and Post-War Recuperation: A Preliminary Survey from the Civil Defense Viewpoint*, RM-2801 (Santa Monica: The RAND Corporation, 1962). This followed one early report on the ecological effects of nuclear war: John N. Wolf, "Biological and Environmental Effects of Nuclear War," Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, 22-26 June 1959, published as J. N. Wolfe, *Long-Time Ecological Effects of Nuclear War*, TI-5561 (Washington D.C.: USAEC, 1959).

conditions" in the field, plant species differed in their "radiosensitivities." These differences led to less diverse communities at higher exposures.[454] In 1967, Woodwell expanded this program, establishing the "Irradiated Forest Experiment" – in which a "natural forest stand" at Brookhaven was continuously irradiated with 9500 curies of Cesium-137. The AEC Office of Civil Defense supported this project, as its primary objective was to evaluate radioactive contamination that could result from nuclear war. Woodwell justified the experiment by arguing that it was important to study the effects of nuclear war in eastern deciduous forests because bombsites had been "restricted generally to deserts and tropical atolls with limited floras." He stated that radiation exposures:

> are clearly beyond the evolutionary experience of higher plants and raise the practical question of what high radiation exposures would do to the natural communities of forest and field which form the living matrix of civilization. In addition, ionizing radiation, because it has far-reaching and fundamental effects on living systems and can be controlled easily, offers new opportunities for the study of life itself.[455]

---

[454] G. M. Woodwell and J. K. Oosting, "Effects of Chronic Gamma Irradiation on the Development of Old Field Plant Communities," *Radiation Biology* 5 (1965): 205-222. For another set of early community-irradiation studies, these at the Emory University Lockheed reactor, see J. F. McCormick and R. B. Platt, "Effects of Ionizing Radiation on a Natural Plant Community," *Radiation Biology* 2 (1962): 161-188; R. B. Platt, "Radiation and Plant Life," *Discovery* 23 (1962): 42-47; R. B. Platt, "Ionizing Radiation and Homeostasis of Ecosystems," in G. M. Woodwell (ed.), *Ecological Effects of Nuclear War* (Upton: Brookhaven National Laboratory, 1965).

[455] G. M. Woodwell and A. L. Rebuck, "Effects of Chronic Gamma Radiation on the Structure and Diversity of an Oak-Pine Forest," *Ecological Monographs* 37 (1967): 53-69.

Figure 50. Cover of *Science* with an aerial photograph of the Brookhaven irradiated field site. Caption says “Irradiated Forest.” *Science* 138 (1962): 572-577.

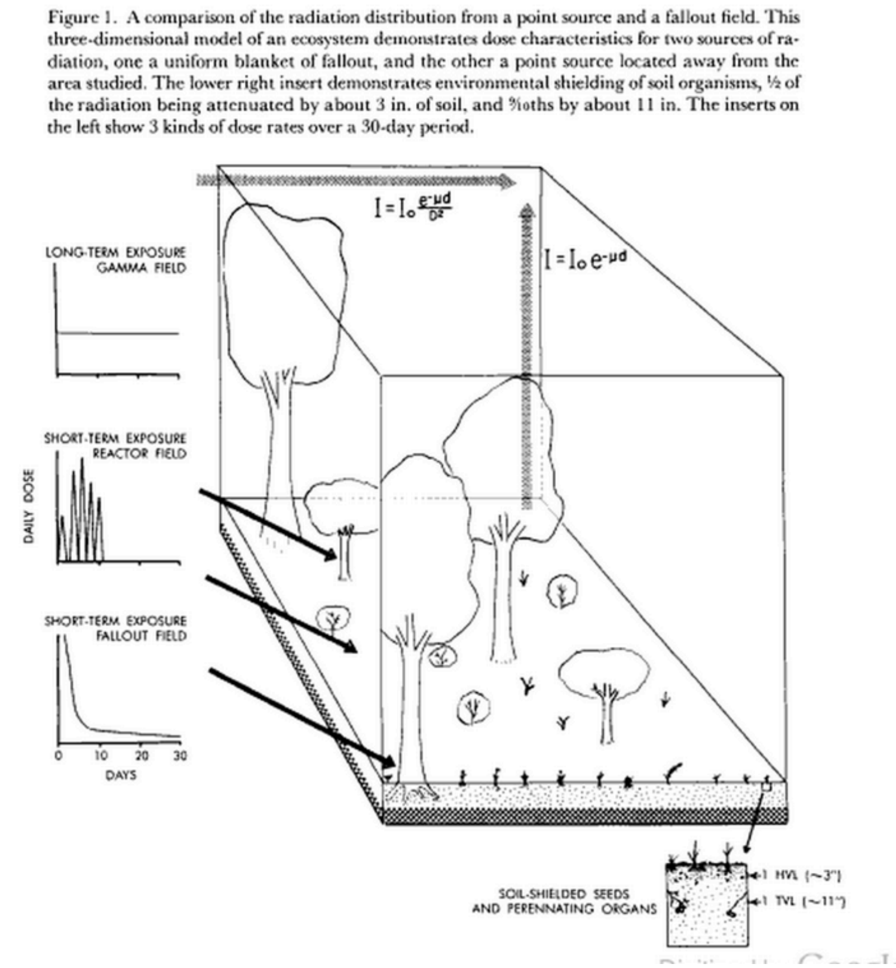


Figure 51. Diagram under the subheading of "Methods for Irradiating Ecosystems," from G. M. Woodwell (ed.), *Ecological Effects of Nuclear War* (Upton: Brookhaven National Laboratory, 1965), 41.

Meanwhile, Frank Golley, who had headed the Savannah River Ecology Laboratory since 1958, invented a field irradiator that could be carried into a forest, opened and closed behind a shield, and used to study radiation effects "on whole ecosystems *in situ*."[456] By 1970, following

[456] J. Frank McCormick and Frank B. Golley, "Irradiation of Natural Vegetation at an Experimental Facility," *Health Physics* 12 (1966): 1467-1474. In 1958 Frank Golley was hired as an instructor in zoology supported by AEC funding. In 1962 Golley accepted an offer to become resident director of a new on-site Laboratory of Radiation Ecology at the Savannah

the RAND Corporation's recommendation that studies of comparative radiosensitivity be enormously increased," ecologists had placed gamma sources in deciduous forests at Brookhaven, in a tropical rain forest in Puerto Rico (a project led by Tom Odum), in a desert in Nevada, and in former agricultural fields at Oak Ridge and Savannah River sites.[457] These were "basic" ecological studies with an eye toward post-WWIII recovery. As Eugene Odum put it: "ecologists need not feel bashful about attacking ecosystems so long as they observe the rules of good science."[458]

River Plant (later called Savannah River Ecology Laboratory, or SREL). In 1967 the SREL became the Institute of Ecology. Gary W. Barrett and Terry L. Barrett, *Holistic Science: The Evolution of the Georgia Institute of Ecology, 1940-2000* (New York: Taylor & Francis, 2001).

[457] Odum, *Fundamentals of Ecology* 3rd edition, 457-459. See also F. J. McCormick and R. B. Platt, "Effects of Ionizing Radiation on a Natural Plant Community," *Radiation Botany* 2 (1962): 161-204; George M. Woodwell, "Effects of Ionizing Radiation on Terrestrial Ecosystems," *Science* 138 (1962): 572-577; J. P. Witherspoon, "Radiation Damage to Forest Surrounding an Unshielded Fast Reactor," *Health Physics* 11 (1965): 1637-1642; F. J. McCormick and F. B. Golley, "Irradiation of Natural Vegetation – An Experimental Facility, Procedures and Dosimetry," *Health Physics* 12 (1966): 1467-1474; G. M. Woodwell, "Toxic Substances and Ecological Cycles," *Scientific American* 216 (1967): 24-31; Howard T. Odum and R. F. Pigeon (eds.) *A Tropical Rain Forest: A Study of Irradiation and Ecology at El Verde, Puerto Rico* (Springfield: National Techincal Information Service, 1970). On Tom Odum's time in Puerto Rico, see Ariel E. Lugo, "H. T. Odum and the Luquillo Experimental Forest," *Ecological Monitoring* 178 (2004): 65-74. Tom Odum visited the Luquillo Experimental Forest (LEF) for the first time in 1944. From 1963 to 1966 he managed the AEC-funded Irradiation and Ecology study site at El Verde, Puerto Rico, through the Luquillo Experimental Forest, administered by U.S. Forest Service.

[458] Eugene Odum, "Ecology and the Atomic Age," *Association of Southern Biologists Bulletin* 4 (1957): 27–29.

Figure 52. "Creation of post-nuclear attack ecology study plots in the 0800 Experimental Area at Oak Ridge National Laboratory, 1967. At top, the remote-controlled fallout spreader is moving along the track distributing 2 curies of Cs-137 tagged sand. Person crouching at left is controlling spreader." This was the last project at ORNL where radioactive substances were applied to a large area. Photo from Stanley I. Auerbach, *A History of the Environmental Sciences Division of Oak Ridge National Laboratory* (Oak Ridge: Oak Ridge National Laboratory, 1972).

Diversity, Stability, and Recovery after Attack

In 1963, radioecologists convened a symposium titled "Ecological Effects of Nuclear War" at the American Institute of Biological Sciences annual meeting. There ecologist Robert Platt invoked the "diversity-stability" hypothesis – the idea that "the greater the diversity [of species in an ecosystem], the greater the resources of the ecosystem in adjusting to stress" – to argue that following a nuclear attack, "people leaving their fallout shelters in much of the temperate portion of the world" would be "'pleasantly' surprised to find that the familiar surroundings of field and woodland looked as they did before the explosion." This was because there was redundancy built into diverse ecosystems, “replacement species” in the case that “certain species are removed by insect injury, extreme drought, ionizing radiation, or other stresses.” Platt concluded that nuclear war was “not likely to seriously limit man’s reconstruction of his renewable resources.”[459]

Robert MacArthur is often credited with first articulating the diversity-stability hypothesis. A student of G. Evelyn Hutchinson, MacArthur earned his Ph.D. from Yale in 1958. His dissertation research was on the distribution of warbler species in the conifer forests of Maine and Vermont. In 1955, MacArthur published a paper in *Ecology* in which he argued through equations that more diverse food webs were more stable – that the more interactions among species in a food web, the more probable the abundance of species would remain constant though time.[460] Three years later, British ecologist Charles Elton argued at some length that more diverse communities are also more stable, citing the occurrence of pest outbreaks in communities simplified by humans and the stability of species-rich tropical forests. Soon the diversity-stability hypothesis became a staple of ecological textbooks, including Odum’s.[461]

---

[459] R. B. Platt, “Ionizing Radiation and Homeostasis of Ecosystems,” in G. M. Woodwell (ed.), *Ecological Effects of Nuclear War* (Upton: Brookhaven National Laboratory, 1965).
[460] Robert MacArthur, “Fluctuations of Animal Populations, and a Measure of Community Stability,” *Ecology* 36 (1955): 533-536.
[461] Charles Elton, *Ecology of Invasions by Animals and Plants* (London: Chapman & Hall, 1958). Other important texts on the diversity-stability hypothesis include B. C. Patten, “Preliminary Method for Estimating Stability in Plankton,” *Science* 134 (1961): 1010-1011; J. H. Connell and E. Orias, “The Ecological Regulation of Species Diversity,” *American Naturalist* 98 (1964): 399-414; G. Woodwell and H. Smith (eds.), *Diversity and Stability in Ecological Systems* (Brookhaven: Brookhaven Laboratory, 1969); M. R. Gardner and W. R. Ashby, “Connectance of Large Dynamic (Cybernetic) Systems: Critical Values for Stability,” *Nature* 228 (1970): 784; Orie L. Loucks, “Evolution of Diversity, Efficiency, and Community Stability,” *American Zoologist* 10 (1970): 17-25; L. E. Hurd, M. V. Mellinger, L. L. Wolf, and S. J. McNaughton, “Stability and Diversity at Three Trophic Levels in Terrestrial Successional Ecosystems,” *Science* 173 (1971): 1134-1136; Robert M. May, “Will a Large Complex System be Stable?” *Nature* 238 (1972): 413-414; Frank N. Egerton, “Changing Concepts of the Balance

In 1967, MacArthur, then a professor at Princeton, and E. O. Wilson, an entomologist at Harvard, set forth a model contending that an island's size and distance from other islands or mainlands determined its diversity by determining rates of colonization and of extinction. For evidence they looked to the famous eruption of Krakatau Island in 1883, which killed everything on the island with a layer of ash, and the subsequent "recolonization episode" in which insects, birds, and mammals returned to an island that had lost two-thirds of its area. The last chapter of *The Theory of Island Biogeography* described how further testing might be done by reproducing "miniature Krakataus" – eliminating all species or all of a particular taxon from a series of islands or lakes either "manually or by poisoning" – and monitoring their return.[462]

Indeed, Wilson and one of his graduate students, Daniel Simblerloff, had set out to do just this in 1966. That year, they chose six islands in the Florida Bay, encompassed by the Great White Heron National Wildlife Refuge and Everglades National Park, on which to kill every living animal (but not plant). First, they censused the insects on each island. Then they tented the entire islands and fumigated them with methyl bromide. After this "defaunation," Simberloff re-censused the insect communities. To make sure the recolonizing insects were arriving by "natural" means, and not on Simberloff, he immersed himself in "Off" insect repellant between

---

of Nature," *Quarterly Review of Biology* 48 (1973): 322-350; Robert M. May, *Stability and Complexity in Model Ecosystems* (Princeton: Princeton University Press, 1973); D. Goodman, "The Theory of Diversity-Stability Relationships in Ecology," *Quarterly Review of Biology* 50 (1975): 237-266; E. C. Pielou, *Ecological Diversity* (New York: John Wiley & Sons, 1975). For a recent review, see Kevin McCann, "The Diversity-Stability Debate," *Nature* 405 (2000): 228-233.

[462] Robert H. MacArthur and Edward O. Wilson, *The Theory of Island Biogeography* (Princeton: Princeton University Press, 1967).

islands. The project was partially funded by the Advanced Research Projects Agency of the United States Department of Defense (DARPA).[463]

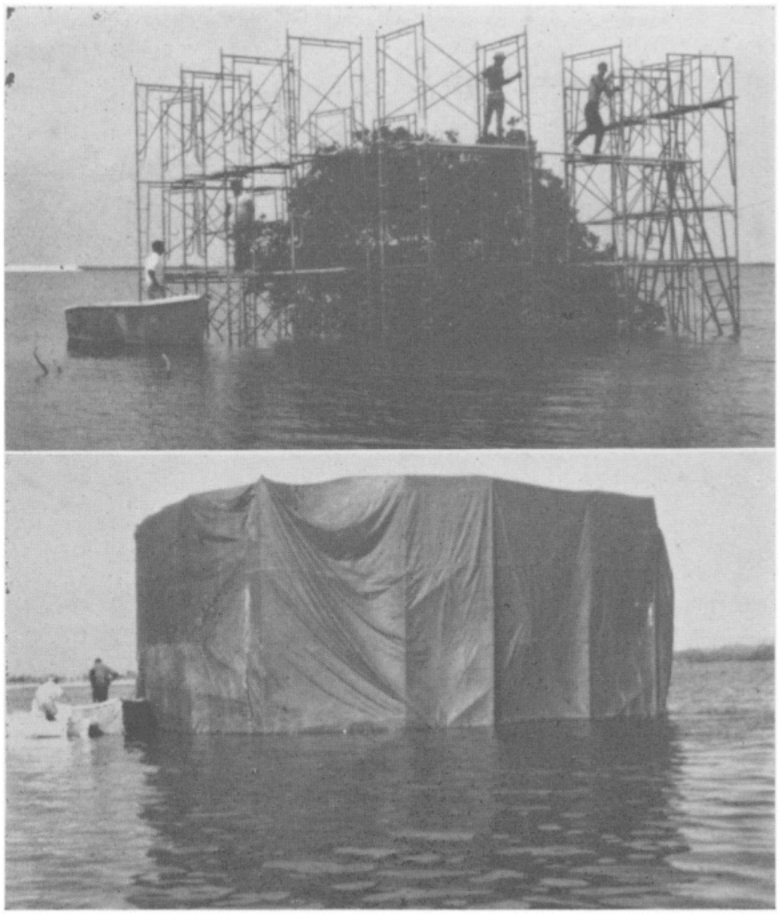


FIG. 8. *Upper:* The scaffolding constructed around E7, complete except for the top walkway. *Lower:* the fumigation tent over E7.

Figure 53. Photograph from E. O. Wilson and Daniel Simberloff, "Experimental Zoogeography of Islands: Defaunation and Monitoring Techniques," *Ecology* 50 (1969): 267-278.

[463] E. O. Wilson and Daniel Simberloff, "Experimental Zoogeography of Islands: Defaunation and Monitoring Techniques," *Ecology* 50 (1969): 267-278. Daniel Simberloff and E. O. Wilson, "Experimental Zoogeography of Islands: The Colonization of Empty Islands," *Ecology* 50 (1969): 278-296; Daniel Simberloff and E. O. Wilson, "Experimental Zoogeography of Islands: A Model of Insular Colonization," *Ecology* 50 (1969) 296-314; Daniel Simberloff and E. O. Wilson, "Experimental Zoogeography of Islands: A Two-Year Record of Colonization," *Ecology* 51 (1970): 934-937.

In the write-up of their experimental results, Simberloff and Wilson noted the precedent for their experiment in ecologists studies of abandoned agricultural fields subjected to various "perturbations," including insecticide, fire, and fertilization.[464] Ecologists were now thinking of these human-caused "disturbances" as similar in scale and consequence to natural disasters. And the materialization of ecosystems as *things* in the world made it possible to now imagine that these very things were threatened.[465] So the conception developed that a nuclear detonation might not destroy an entire species – individuals would live beyond the blast zone – but would instead destroy the unique interactions among species in a given area.

Another example of a study in which ecologists attempted to destroy an ecosystem was the Hubbard Brook Ecosystem Study. In the 1950s, plant ecologist F. Herbert Bormann of Dartmouth College began using a watershed of the White Mountain National Forest for studies of nutrient cycling. In 1963, he, ecologist Gene Likens, and geologist Noye Johnson, received a grant from the National Science Foundation to study the "Hydrological-Mineral Cycle Interaction in a Small Watershed." In November 1965, the research team clear-cut a 15.6 hectare area of beech-maple-birch forest and then routinely applied herbicide to prevent regrowth. They compared this tract to "undisturbed" forest. A news piece in *The Science News-Letter* described the experiment as a study of "the injuries – and benefits – of modern civilization upon man and

---

[464] Edward O. Wilson and Daniel S. Simberloff, "Experimental Zoogeography of Islands: Defaunation and Monitoring Techniques," *Ecology* 50 (1969): 267-278.

[465] Useful to my thinking here is Michelle Murphy's concept of "regimes of perceptibility." In her case study, she contends that specific arrangements of discourses, objects, practices, and subject positions "made perceptible specific qualities, capacities, and possibilities for buildings and bodies." Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty* (Durham: Duke University Press, 2006), 12.

nature."[466] After clear-cutting, the Hubbard Brook Ecosystem team found an increase in erosion and in streamwater concentration for all of the nutrients they studied, including calcium, magnesium, and nitrogen. This experiment to test "the homeostatic capacity of the ecosystem to adjust to the cutting of vegetation" suggested that human-caused disturbance dramatically changed the flow of water, nutrients, and energy at Hubbard Brook.[467]

For decades ecologists had thought of ecological communities as self-repairing. Restoration, therefore, had not meant helping the ecological community to repair itself. Rather, the emphasis had been on abating the damaging process, since nature would then heal itself. As Clements wrote in 1935:

> From the very nature of climax and succession, development is immediately resumed when the disturbing cause ceases, and in this fact lies the basic principle of all restoration or rehabilitation.[468]

But during the Cold War the idea emerged that there was a threshold of damage past which ecosystems could not repair themselves. In 1965, Woodwell wrote:

> Most natural ecosystems of temperate zones retain their capacity for regenerating the climax after a wide range of types and degrees of damage. Forests are usually self-

---

[466] "Man's Impact on Nature and Himself Studied," *The Science News*-Letter 84 (1963): 211; F. H. Bormann and G. E. Likens, "Nutrient Cycling," *Science* 155 (1967): 424-429; F. H. Bormann, G. E. Likens, D. W. Fisher, and R. S. Pierce, "Nutrient Loss Accelerated by Clear-Cutting of a Forest Ecosystem," *Science* 159 (1968): 882-884; Gene E. Likens, F. H. Bormann, and Noye M. Johnson, "Nitrification: Importance to Nutrient Losses from a Cutover Forested Ecosystem," *Science* 163 (1969): 1205-1206; Gene E. Likens, F. Herbert Bormann, Noye M. Johnson, D. W. Fisher, Robert S. Pierce, "Effects of Forest Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-Ecosystem," *Ecological Monographs* 40 (1970): 23-47; G. E. Likens, F. H. Bormann, R. S. Pierce, and W. A. Reiners, "Recovery of a Deforested Ecosystem," *Science* 199 (1978): 492-496.

[467] Gene E. Likens, F. Herbert Bormann, Noye M. Johnson, D. W. Fisher, Robert S. Pierce, "Effects of Forest Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-Ecosystem," *Ecological Monographs* 40 (1970): 23-47.

[468] Frederic E. Clements, "Experimental Ecology in the Public Service," *Ecology* 16 (1935): 342-363.

> regenerating units, even after clear cutting; abandoned fields revert to stable native vegetations through a series of developmental stages. […]
>
> Destruction of the ecosystem, however, may reduce the potential of the site for supporting life for long periods, possibly for scores of years […] Very intense exposures of ecological systems to ionizing radiation might damage them sufficiently to reduce the capacity of the site for supporting life, slowing the succession greatly or diverting toward a new, less complex climax.[469]

Thus Woodwell contended that the ecosystem was a real, physical biological entity that could be destroyed by human action. And the scale of human action was now, as Woodwell and other ecologists contended, enough to obliterate local ecosystems:

> Destruction of vegetation over areas as large as tens or hundreds of square miles might slow recovery by isolating devastated areas by distance alone from sources of recolonization. The probability that destruction could be that severe after a heavy attack is real enough.[470]

Thus ecologists began conceptualizing ionizing radiation, persistent pesticides, deforestation, and eutrophication as causing similar types of damage to ecological communities and to ecosystem "functions" like productivity and decomposition. They drew parallels between the effects of these human actions and those of extreme natural forces. For example, the subtitle of Woodwell's 1970 paper in *Science*, "Effects of Pollution on the Structure and Physiology of Ecosystems," read: "Changes in natural ecosystems caused by many different types of disturbances are similar and predictable."[471] In this paper Woodwell argued that pollutants have effects that "are chronic and may be cumulative in contrast to the effects of short-lived disturbances that are repaired by succession." Woodwell then explained that while there were

---

[469] G. M. Woodwell and A. H. Sparrow, "Effects of Ionizing Radiation on Ecological Systems," in G. M. Woodwell (ed.), *Ecological Effects of Nuclear War* (Upton: Brookhaven National Laboratory, 1965).
[470] G. M. Woodwell and A. H. Sparrow, "Effects of Ionizing Radiation on Ecological Systems."
[471] G. M. Woodwell, "Effects of Pollution on the Structure and Physiology of Ecosystems," *Science* 168 (1970): 429-433.

very few studies of the effects of chemical pollutants on ecosystems, ecologists could make inferences from studies of ionizing radiation, which suggested that human-caused and natural-caused disturbances were similar in their effects: "The ecological effects of radiation follow patterns that are known from other types of disturbances" such as exposure to high winds or severe drought.[472]

Woodwell then summarized the results from Brookhaven's "Irradiated Forest Experiment." He reported that in areas of highest radiation levels –the "central devastated zone" – only sedges, sweet ferns, lichens, and wild raspberries survived. These were species commonly found in "disturbed places" like roadsides, gravel banks, and areas with nutrient-deficient soil. He then noted that ecologists at the Savannah River Laboratory, working in abandoned agricultural fields, not deciduous forests, had similarly found that the most "radiation-resistant" and "fire-resistant" species were weedy forbs "characteristic of disturbed places." Likewise, ecologists studying plant communities around smelters in Ontario had found "a striking reduction in the number of species of higher plants" close to the smelters. And the problem with a reduction in species diversity, Woodwell concluded, was that there would be a concomitant decrease in the ability of the ecosystem to retain nutrients within the system: "Any chronic pollution that affects the structure of ecosystems, especially the plant community, starts leaks and reduces the potential of the site for recovery." If humans continued on their current trajectory, then, Woodwell predicted a move

> away from a world that runs itself through a self-augmentive, slowly moving evolution, to one that requires constant tinkering to patch it up, a tinkering that is malignant in that each act of repair generates a need for further repairs to avert problems generated at compound interest.[473]

---

[472] G. M. Woodwell, "Effects of Pollution on the Structure and Physiology of Ecosystems."
[473] G. M. Woodwell, "Effects of Pollution on the Structure and Physiology of Ecosystems."

Fig. 1. The effects of chronic gamma radiation from a 9500-curie ^{137}Cs source on a Long Island oak-pine forest nearly 8 years after start of chronic irradiation. The pattern of change in the structure of the forest is similar to that observed along many other gradients, including gradients of moisture availability and of exposure to wind, salt spray, and pollutants such as sulfur dioxide. The five zones are explained in the text. The few successional species that have invaded the zones closest to the source appear most conspicuously as a ring at the inner edge of zone 2. These are species characteristic of disturbed areas such as the fire weed, *Erechtites hieracifolia,* and the sweet fern, *Comptonia peregrina*, among several others. [The successional changes over 7 years are shown by comparison with a similar photograph that appeared as a cover of *Science* (*16*)].

Figure 54. Figure from G. M. Woodwell, "Effects of Pollution on the Structure and Physiology of Ecosystems," *Science* 168 (1970): 429-433.

In a paper in *Science* in 1969, Eugene Odum posed the question: "Is variety only the spice of life, or is it a necessity for the long life of the total ecosystem comprising man and nature?" Until recently, he continued, humans had "more or less taken for granted" water purification, nutrient cycling, and other "functions of self-maintaining ecosystems" because human environmental manipulations had not been of a scale to "affect regional and global balances." Now, however, the "stresses introduced by man" were "too sudden, too violent, or too arrhythmic" for an ecosystem to recover.[474]

Restoring Ecosystem Function

It was in this context that President Lyndon B. Johnson delivered a "Special Message to the Congress on Conservation and Restoration of Natural Beauty" in February 1965, stating that in "the storm of modern change,"

> We must not only protect the countryside and save it from destruction, we must restore what has been destroyed and salvage the beauty and charm of our cities. Our conservation must be not just the classic conservation of protection and development, but a creative conservation of restoration and innovation.

That same year, the President's Science Advisory Committee published a 1965 report, "Restoring the Quality of Our Environment," claiming that the very same technologies that had made the United States a "nation of affluence" had also made vast quantities of waste that polluted the environment.[475] It defined pollution as unfavorable human-caused changes in

[474] Eugene P. Odum, "The Strategy of Ecosystem Development," *Science* 164 (1969): 262-270.
[475] *On concerns about overpopulation during the Cold War, see Paul Ehrlich, The Population Bomb (New York: Ballantine Books, 1968); R. B. Fuller, Operating Manual for Spaceship Earth (Carbondale: Southern Illinois University Press, 1968); Lynn White, "The Historical Roots of our Ecological Crisis," Science 155 (1967): 1203-1207; Thomas Robertson, The Malthusian Moment: Global Population Growth and the Birth of American Environmentalism (New*

"energy patterns, radiation levels, chemical and physical constitution and abundances of organisms."[476] Members of the Ecological Society of America understood that the Science Advisory Committee report represented a major opportunity to expand their influence. At the time the ESA was seeking funding to participate in an "International Biological Programme" modeled on the 1958 International Geophysical Year. And so the ESA argued that an ecologically guided IBP would fulfill the recommendations on pollution mitigation.[477]

The following year, the House Subcommittee for Science, Research and Development agreed to hear testimony on whether to fund a U.S. branch of the IBP. Ecologist witnesses focused their presentations on possible futures. The Secretary of the Smithsonian Institution argued that humans had "reached the limits of the earth" and were faced with the urgent problem of "achieving homeostasis in natural energy systems with man as a member."[478]

With such rhetoric, ecologists were successful in positioning the IBP as a tool for mitigating pollution, and in 1966 the Subcommittee issued a report in which they called ecology

---

Brunswick: Rutgers University Press, 2012); Paul Sabin, The Bet: Paul Ehrlich, Julian Simon, and Our Gamble over Earth's Future (New Haven: Yale University Press, 2013).

[476] President's Science Advisory Committee, *Restoring the Quality of our Environment* (Washington D.C.: The White House, 1965).

[477] The idea of assembling an international biological program was first articulated in Europe in the late 1950s. In 1963 the Ecological Society of America established its own IBP committee, chaired by Eugene Odum, to lobby committee the National Academy of Sciences for a leadership role in the program. The ESA was particularly interested in the potentially prominent project. Chunglin Kwa argues that the metaphor of the "self-governing machine" fulfilled an "intermediary role between ecologists and politicians" in the establishment of the IBP in "Representations of Nature Mediating between Ecology and Science Policy: the Case of the International Biological Programme," *Social Studies of Science* 17 (1987): 413-442. See also "Draft IBP/PF-UNESCO Symposium on Results of PF Research," 12-18 September 1972, Reading UK, Folder 23, Box 17, W. T. Edmondson Papers (Acc. No. 2024-006), The University of Washington Special Collections, Seattle, Washington.

[478] See R. Lilienfeld, *The Rise of Systems Theory: An Ideological Analysis* (New York: Wiley, 1978); D. Edge, "Technological Metaphor and Social Control," *New Literary History* 6 (1974): 135-147.

"the science which covers most of the technical aspects of pollution." As Chunglin Kwa points out, it was not self-evident that ecology should be the science of pollution, rather than physics, medicine, or another discipline.[479] In August 1970 the Senate passed a law, signed by President Nixon, dedicating $40 million to large-scale ecological projects, and over the next five years the IBP coordinated and funded ecological fieldwork at sites across the United States. An ecosystem was defined by the IBP as the smallest unit to which environmental management could be applied if problems were "to be solved rather than moved."[480]

The stated purposes of the biome studies were two-fold. First, representative ecosystems could be preserved as "natural laboratories" against which to compare areas undergoing "chronic, insidious changes," including soil erosion and eutrophication. Second, biomes could be non-invasively studied to characterize the "operations of ecological systems" that were "interlocked in unexpected ways," so that "the visible effect appears in one part of the system while the cause lies in another."[481] Thus by the 1970s ecologists were promoting both preservation and restoration in parallel. Ecological scientists presented themselves as poised to answer important questions about environmental management, ready, even, to guide the restoration of ecosystems. But they also had to preserve designated areas for study, because it would be important to know how a "normal," undisturbed ecosystem functioned. In 1973, Robert Jenkins, the vice president for science of the newly revitalized The Nature Conservancy (TNC),

---

[479] See Kwa, "Representations of Nature Mediating between Ecology and Science Policy." Public Law No. 91-438.
[480] "Man's survival in a changing world," Folder 28, Box 14, Lauren R. Donaldson Papers, University of Washington Special Collections, Seattle, Washington. Jumping off of the IBP, the UNESCO Man and the Biosphere Programme ran from 1971-1974. See also Michel Batisse, "Man and the Biosphere: An International Research Programme," *Biological Conservation* 4(1971): 1-6.
[481] "Man's survival in a changing world," Folder 28, Box 14, Lauren R. Donaldson Papers, University of Washington Special Collections, Seattle, Washington.

and former student of E. O. Wilson, wrote that “man-engendered environmental changes” might be “of such magnitude and so rapid” as to “disrupt the internal cohesion” of an ecosystem.[482] Some environmental modifications might even “become irreversible after passing an unknown threshold point.” Ecologists, therefore, needed to study unmodified communities in order to establish “baselines” against which human-caused changes “could be perceived and measured”:

> We have become uncomfortably aware that we do not even know how undisturbed ecosystems function, and that insight must be gained in this area before we can appreciate the true effects of ecosystem modification. Such effects can only be perceived and measured if we have environmental baselines with which conditions on altered areas can be compared. A serviceable definition of the baseline might be: ‘an accurate description of the status and workings of an ecosystem in the absence of artificial human disruptions.’

To do this, TNC contended, it would be necessary to develop a global, “comprehensive system to protect” examples of “every extant biotic community.”

> Even very modest libraries have card indices, and any museum collection has specimen catalogues for the retrieval of information; but the worldwide complex of natural areas, representing the largest and most prolific storehouse of information we are ever likely to see, has nothing of the kind. […] Without such a system, entire biotic types or

[482] After WWII, the Ecological Society of America, like many scientific organizations, reified the distinction between “objective” science and “subjective” politics and voted to disband the Committee on the Preservation of Natural Conditions. In response, ESA members formed The Ecologists Union, “devoted to the preservation of natural biotic communities for scientific use.” By its third annual meeting in 1947, the Ecologists Union had 191 members and $425 in its treasury. By 1949 there were 300 members. See Victor Shelford, “Twenty-five-Year Effort at Saving Nature for Scientific Purposes,” *Science* 98 (1943): 280; Tjossem, *Preservation of Nature and Academic Respectability*; Abby J. Kinchy, “On the Borders of Post-war Ecology: Struggles Over the Ecological Society of America’s Preservation Committee, 1917-1946,” *Science as Culture* 15 (2006): 23-44. The Nature Conservancy remained a small organization from its incorporation in 1951 until the 1960s. By 1960 TNC had preserved only about 4000 acres and had an operating deficit. Then, in 1960, Alexander B. Adams, an ex-FBI agent and former vice president of the Mellon National Bank and Trust Company, became president of TNC. He reoriented the organization under the motto “land preservation through private action” and worked on building alliances with major businesses. From 1960 to 1969, TNC’s assets rose from $750,000 to $20 million. On the organizational history of The Nature Conservancy, see Bill Birchard, *Nature’s Keepers: The Remarkable Story of How The Nature Conservancy Became the Largest Environmental Organization in the World* (San Francisco: Jossey-Bass, 2005).

> communities may be totally lost, and some undoubtedly already are. We thereby lose not only vital tools to guide environmental management decisions, but species and relationships which represent opportunity costs of unknown magnitude.[483]

But while many ecologists, faced with the prospect of WWIII, emphasized the irreplaceability of the Earth and its resident organisms, others argued that technological progress offered unprecedented opportunities for restoration. A 1969 Ecological Society of America pamphlet captures both of these positions:

> Extensive tracts of land that once supported balanced communities of many wild species have been given over to unbalanced artificial communities: chiefly single-crop farms, maintained by gasoline, pesticides and constant trouble-shooting. […] In extreme cases, extensive soil erosion by wind and water has made damage that is irreparable, or slow and expensive to mend. […]
>
> But not all of man's activities have been destructive. […] Past ecological research already has begun paying dividends in recognition of problems, in halting abusive practices, and in restoring a natural balance through habitat restoration.[484]

Indeed, some of the first discussions about restoring ecological communities came out of WWIII planning. The 1962 RAND Corporation report on "Ecological Problems and Post-War Recuperation" noted that ecologists had produced "a wealth of information" that would be "pertinent to the problems of post-war recovery of devastated biotic environments." These included previous studies of "the reclamation of deserts, reconstitution of forests after fires, range-management problems, and dust-bowl recovery." It was also possible to "assist natural processes in the recovery effort," the RAND report continued, citing a 1950 paper by a Bureau of

---

[483] Robert Jenkins and W. Brian Bedford, "The Use of Natural Areas to Establish Environmental Baselines," *Biological Conservation* 5 (1973): 168-174. See also Stephen H. Spurr, "The Natural Resource Ecosystem," in George van Dyne (ed.), *The Ecosystem Concept in Natural Resources Management* (New York: Academic press, 1969); MIT, *Man's Impact on the Global Environment: Assessment and Recommendations for Action* (Cambridge: MIT Press, 1970).

[484] "Careers in Ecology: A Vocational Guidance Bulletin," Ecological Society of America pamphlet, circa 1969. Box 57, Folder 1.4, Archives of the Ecological Society of America (UGA 97.061), Hargrett Rare Book & Manuscript Library, University of Georgia, Athens, Georgia.

Land Management conservationist, "Reseeding the Range by Airplane." The airplane was useful not only for crop dusting, predator control, and fire suppression, Killough contended, but also for the re-vegetation of "depleted" and "denuded" rangelands.[485] Nevertheless, the report concluded, it was "possible to allow destructive processes to proceed to a 'point of no return' unless one envisages Herculean attempts at reconstruction," a point at which conditions "have become too hostile for even artificial reconstruction," at which ecosystems would no longer be "self-reconstructing."[486]

One of the first examples of the type of restoration we today recognize as "ecological restoration" – a mode of restoration concerned with constructing a "natural" community – was undertaken by The Nature Conservancy. In 1972, at the Third Midwest Prairie Conference, held at Kansas State University, Robert Jenkins described TNC's new ecosystem restoration program. The Conservancy had acquired more than 800 acres in the last 20 years in its effort to "preserve all of the U.S. ecosystem types" as "benchmarks of naturalness against which we can measure the effects of our pervasive experiments in environmental alteration," Jenkins began. But it had become "increasingly evident that some efforts at manipulation and restoration" would be necessary:

> Initially, our theory of action was that the Conservancy would save undisturbed tracts such as virgin forests and protect these in perpetuity. This concept has evolved as fewer and fewer undisturbed areas were to be found. […] What then do you do when pristine habitats are no longer available and the job of saving representative ecosystems is far

[485] J. R. Killough, "Reseeding the Range by Airplane," *Journal of Range Management* 3 (1950): 33; R. M. Love, D.C. Sumner, V.P. Osterli, and B. J. Jones, "Improving California Brush Ranges.," California Agricultural Experiment Station Circular 371 (1952); W. C. Lowdermilk, "The Reclamation of Man-made Desert," *Scientific American* 202 (1960): 55.
[486] H. H. Mitchell, *Ecological Problems and Post-War Recuperation: A Preliminary Survey from the Civil Defense Viewpoint*, RM-2801 (Santa Monica: The Rand Corporation, 1962).

> from completed? The answer, I think, is that you work on improvement and restoration of disturbed areas to assist in the recreation of disappearing and vanished habitat types.[487]

This approach, Jenkins continued, was not widely appreciated or practiced. Despite "considerable agitation and activity in the environmental quality field," governmental bodies and academics seemed to "show relatively little concern with environmental naturalness":

> Efforts at soil conservation, reforestation, reclamation, air and water quality improvement are, for the most part, simply efforts to improve and extend manipulative controls and in many cases cause additional artificialization of the environments they treat. […] In contradistinction to the above, the restoration effort with which we are involved is a part of the larger preservation effort attempting to maintain the diversity of our biological capital as a long-term contribution to ecological stability and function.[488]

Ecosystem restoration would provide habitat for the continued existence of species *and* ecosystem functioning, Jenkins continued. If an ecological community no longer existed, Jenkins explained, as was the case in the eastern United States, where "what remains hardly measures up to the descriptions of the early explorers," TNC would "attempt the recreation of such communities through the reassembly of their scattered components" in order to restore "sound ecological function to badly damaged landscapes" before "we are compelled to do our experimentation under a state of emergency."[489]

The Nature Conservancy envisioned ecosystem restoration as a process in which humans facilitated restoration, rather than dictating it: "For the most part, ecosystems must restore themselves and our role should be to subsidize more than to guide," Jenkins explained. First, humans could remove "the disturbance" – the "obvious barriers to natural ecological recovery" such as agriculture or pavement – in order to "hasten natural succession processes." Next, they

---

[487] Robert Jenkins, "Ecosystem Restoration," Third Midwest Prairie Conference Proceedings, Kansas State University, Manhattan, Sept 22-23, 1972. Clipping in Folder 24, Box 11, George R. Cooley Papers, New York State Library, Albany, New York.
[488] Robert Jenkins, "Ecosystem Restoration."
[489] Robert Jenkins, "Ecosystem Restoration."

could "correct the damage that the disturbance effected in the physical environment," by re-digging a pond, for example. Finally, humans could reassemble the ecological community. If populations of native species were too far away from the site to recolonize it naturally, this would involve transporting species from locations where they still exist. If exotic species had colonized the site, this would involve eliminating them. "Some remarkable community reassembly jobs have been done, particularly with prairies," Jenkins explained.[490]

Such restoration might involve "the possible necessity of continuous intervention," Jenkins continued. For example, the tall grass prairie ecosystem was adapted to the "periodic redisturbance" of fire. If managers wanted to restore this ecosystem, they would also need to restore a fire regime. "Since our reference is diversity, stability, and function," Jenkins concluded, "I would say that the ecosystem is restored to the extent that human intervention can assist such restoration when these qualities have been restored."[491]

In October 1971 The Nature Conservancy initiated an "ecosystem restoration" program – the Center for Applied Research in Environmental Sciences (CARES) – under the direction of Edgar Garbisch, a former chemistry professor at the University of Minnesota. The CARES's first project would be salt marsh restoration in the Chesapeake Bay. They then planned to expand to prairie, forest, and inland aquatic sites. "So far as I know," Jenkins concluded, "it is the only such center wholly devoted to ecosystem restoration in existence anywhere, though hopefully it will not be the last."[492]

The CARES chose as its first project salt marshes because they were "floristically undiverse" and "one of the most underappreciated, abused and yet important ecosystems in the

---

[490] Robert Jenkins, "Ecosystem Restoration."
[491] Robert Jenkins, "Ecosystem Restoration."
[492] Robert Jenkins, "Ecosystem Restoration."

country." In 1971, six staff members collected seeds of *Spartina*, *Juncus*, *Phragmites*, *Typha*, *Scirpus*, and germinated them in growth chambers. They then planted them into substrate that had been transported and graded.[493] An article in *Sports Illustrated* explained that "the man who makes marshes" had resigned from his previous position in 1970, having come to see "his work on molecules as a kind of empty intellectual chess." That year he moved to Maryland and happened to read *Life and Death of a Salt Marsh* by Mildred and John Teal – who, like Eugene Odum, had studied Georgia's salt marshes and envisioned them as "free sewage treatment plants" that absorbed and purified storm water and served as a buffer against shore erosion. "Can a former professor of chemistry at the University of Minnesota create in half a year what it takes nature 1,000 years to accomplish?" an article in *Sports Illustrated* asked. "Yes, at least in the case of Dr. Edgar W. Garbisch Jr. of St. Michaels, Md., who can in six months establish a coastal salt marsh of up to 500 acres."[494]

---

[493] Robert Jenkins, "Ecosystem Restoration."
[494] Robert H. Boyle, "The Man Who Makes Marshes," *Sports Illustrated*, 20 October 1975. In 1972 Garbisch left CARES to found Environmental Concern, Inc. One of its first projects, backed by the Maryland Department of Natural Resources, was to plant a small marsh at the mouth of the Susquehanna River in order to stabilize the silt there.

(Figures 1-6).

Figure 1. Building graded tidal flat by barging in new substrate.

Figure 2. Collecting seeds of marsh plants for use in restoration.

Figure 4. Grasses being transplanted to graded tidal flat.

Figure 55. Photos from Robert Jenkins (Vice President for Science, The Nature Conservancy), "Ecosystem Restoration," Third Midwest Prairie Conference Proceedings, Kansas State University, Manhattan, Sept 22-23, 1972. Clipping in Folder 24, Box 11, George R. Cooley Papers, New York State Library, Albany, New York.

Conclusion

Since the 1960s, ecosystem science has informed American conservation policy and management, and ecologists have been increasingly empowered to provide information to natural resources managers.[495] The U.S. Endangered Species Act of 1973, for example, aimed to conserve "the ecosystems upon which endangered species and threatened species depend."[496] Similarly, The Nature Conservancy today "provides tools that help decision-makers protect biodiversity and secure full benefits from ecosystems."[497] Thus, the materialization of ecosystems has significantly shaped many environmental policies and, therefore, landscapes themselves.

The history of 1960s radioecology reveals the co-construction of ecological restoration with concepts of large-scale ecological destruction. It also reveals deeper roots for both ecosystem theory and contemporary ecological restoration practice than have usually been discussed, since restoration is often framed as a new endeavor, one that began with the establishment of the Society for Ecological Restoration (SER) in 1987. Those histories that do extend earlier than the 1980s cite Aldo Leopold, former Forest Service employee and author of

---

[495] Stephen Bocking writes: "Most people see it as self-evident that scientific knowledge is relevant to environmental affairs...And yet, never has the relation of science to environmental politics been as actively debated as it is today." Stephen Bocking, *Nature's Experts: Science, Politics, and the Environment* (Piscataway: Rutgers University Press, 2004) p. xi

[496] 16 USC § 1531. Recent literature on the history of endangered species management is also relevant to the history of ecological restoration. See: David Takacs, *The Idea of Biodiversity* (Baltimore: Johns Hopkins University Press, 1996); Jerry C. Towle, Authored Ecosystems: Livingston Stone and the Transformation of California Fisheries," Environmental History 5(1) (2000): 54-74; Christopher J. Manganiello, "From a howling wilderness to howling safaris: Science, policy, and red wolves in the American South," *Journal of the History of Biology* 42 (2009): 325-359. Robert M Wilson, *Seeking Refuge: Birds and Landscapes of the Pacific Flyway* (Seattle: University of Washington, 2010); Peter S. Alagona, *After the Grizzly: Endangered Species and the Politics of Place in California* (Berkeley: University of California Press, 2013).

[497] The Nature Conservancy. 2013 "Our science," accessed January 1, 2013, http://www.nature.org/ourscience/ecosystem-services.xml

the 1949 collection of essays, *Sand County Almanac*, as the "father" of restoration ecology. William Jordan III and George Lubick, for example, described the history of ecological restoration as a case of "arrested development" in which Leopold's ideas were lost for half a century – "a lull during which Americans concluded a war, embarked on a cold war, moved to the suburbs, and went shopping" – before they were taken up again by the founders of the SER.[498] Yet, during the Cold War, the AEC's interests in nuclear waste-containment, ecologists' interests in community metabolism, and the specter of WWIII formed a network of people, forces, and objects that were crucial to the development and popularization of ecological restoration.[499]

The ecosystem idea simultaneously pointed to fragility and to resilience. On the one hand, ecosystems were constructed as so intricate and complex that ecologists could imagine them damaged beyond their capacity to self-repair. On the other hand, ecosystems had universal,

---

498 William R. Jordan III and George M. Lubick, *Making Nature Whole: A History of Ecological Restoration* (Washington DC: Island Press, 2011), 105. Aldo Leopold, *A Sand County Almanac and Sketches Here and There* (New York: Oxford University Press, 1949). For similar histories, see .T. A. Pickett and V. Thomas Parker, "Avoiding the Old Pitfalls: Opportunities in a New Discipline," *Restoration Ecology* 2 (1994): 75-79; William R. Jordan III, *The Sunflower Forest: Ecological Restoration and the New Communion with Nature* (Berkeley: University of California Press, 2003).

499 Kevin Dann and Gregg Mitman have noted that "America has continually had to reinvent the business of 'ecological restoration'; seemingly something brand new, it is instead an activity with a history." Kevin Dann and Gregg Mitman, "Essay Review: Exploring the Borders of Environmental History and the History of Ecology," Journal of the History of Biology 30 (1997): 296. Historians of horticulture have looked earlier than 1949 for the roots of restoration: See Marcus Hall, *Earth Repair: A Transatlantic History of Environmental Restoration* (Charlottesville: University of Virginia Press, 2005), 9-10. Ian Tyrrell, *True Gardens of the Gods: California-Australian Environmental Reform, 1860-1930* (Berkeley: University of California Press, 1999); Philip J. Pauly, Fruits and Plains: The Horticultural Transformation of America (Cambridge: Harvard University Press, 2007); Marcus Hall, ed. *Restoration and History: The Search for a Usable Environmental Past* (New York: Routledge, 2009); Helen Anne Curry, "Radiation and Restoration: Or, How Best to Make a Blight-resistant Chestnut Tree," *Environmental History* 19 (2014): 1-22.

generalizable functions. The idea of irreversible change pushed conservation practice in multiple directions: it made ecosystem *functioning* the target of some restoration, especially when it was difficult or impossible to restore particular assemblages of species. Yet, the notion of irreversible change also drove efforts to protect ecosystems that were recognizably close to their "natural" functioning. Ideas of ecological destruction and ecological restoration in the Cold War were mutually promoting and mutually critiquing, and, by the 1970s, many ecologists were practicing ecosystem restoration, if reluctantly. As Francis Fosberg, an ecologist who had also worked at the Pacific Proving Grounds, wrote, the natural world was "a system in dynamic equilibrium, damaged but healing its wounds" – or so it was until recently, when "the first organism […] appeared on earth that has achieved the capacity to destroy the entire living component of the system, including itself."[500] With such language, ecologists established the ecosystem in its present position, at the center of ecological management.

[500] F. R. Fosberg, "The Illness of the World-Ecosystem," *Ecology* 45 (1964): 201-202. The paper is a review of Raymond F. Dasmann, *The Last Horizon* (New York: Macmillan, 1963).

CHAPTER 9

CONCLUSION

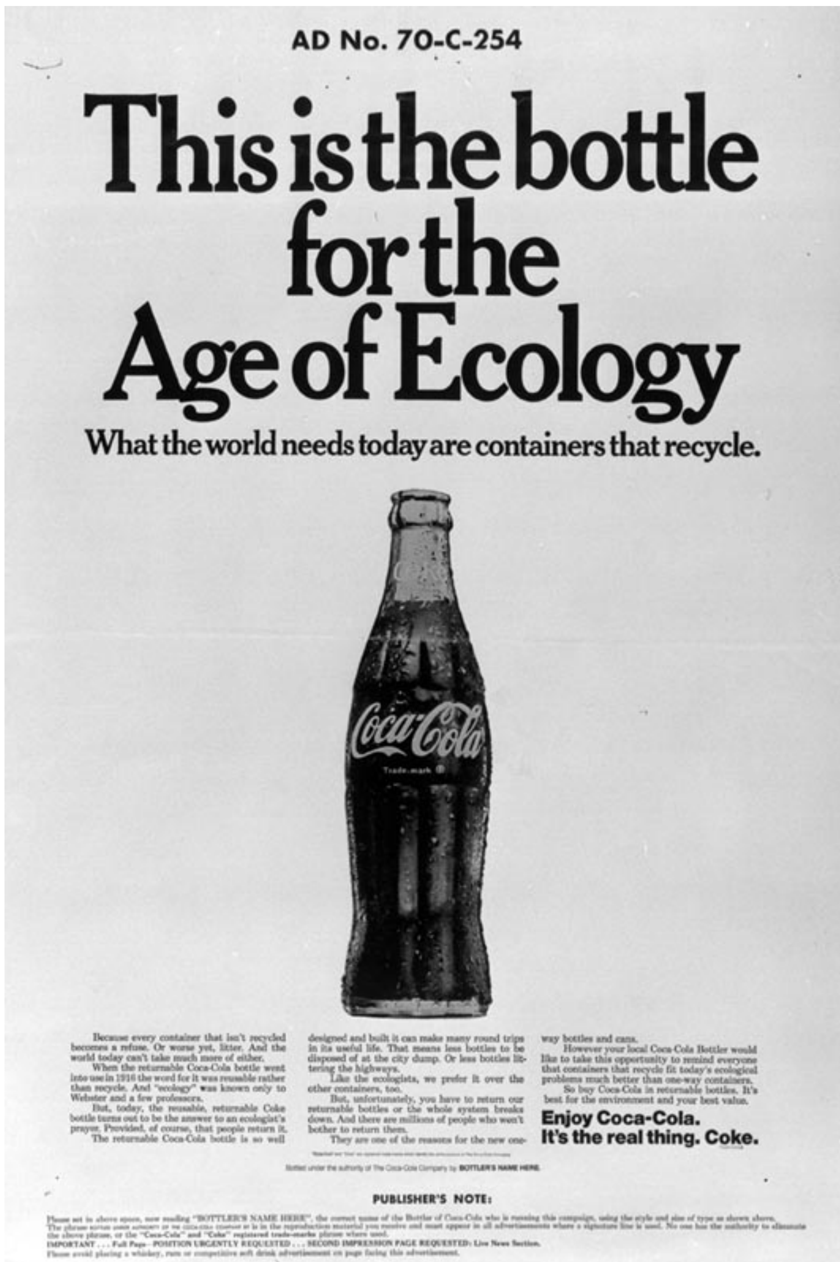


Figure 56. "This is the bottle for the Age of Ecology," Coca-Cola Ad No. 70-C-254. 1970.

Ecology and Restoration into the 1970s

"This is the bottle for the Age of Ecology," proclaimed a 1970 ad for Coca-Cola in reusable glass bottles, "[…] the answer to an ecologist's prayer."[501] That April, over twenty million people participated in the first Earth Day, and the U.S. Congress considered a suite of environmental legislation on topics ranging from urban pollution to species extinction.[502] Ecologist Barry Commoner wrote of the environment as "a huge enormously complex living machine" emphasizing that "every human activity depends on the integrity and proper functioning of that machine."[503] Activist environmentalism and scientific ecology had combined, it would seem, into what magazine articles, politicians, and the Coca-Cola ad heralded as the Age of Ecology.

That same year, as part of the same campaign as the "Age of Ecology" advertisement, Coca-Cola produced and distributed a board game, "Make Your Own World," to 4,000 elementary schools nationwide. The two-round game was developed in collaboration with ecologists at the University of Georgia, including Eugene Odum. In the first round, students divided into eleven interest groups, including "farmers," "jobless workers," "real estate developers," "forests," and "deer." They then had to decide – through debate and democratic vote – whether to allow a series of development projects read out by the teacher.[504]

In the second round, students divided into astronauts and ground-control crews. Two

---

[501] "This is the bottle for the Age of Ecology," Coca-Cola Ad No. 70-C-254. 1970.
[502] The Endangered Species Conservation Act (P.L. 91-135) passed in 1969, amending the Endangered Species Preservation Act of 1966 and granting the U.S. Fish and Wildlife Service the ability to list species in danger of "worldwide extinction." Other legislation includes the establishment of the International Biological Program (1968) and the National Environmental Policy Act (1970).
[503] Barry Commoner, "Can We Survive?," 13. The article was introduced to the Congressional Record (CR-1969-1217 pp. 39741-39744).
[504] The real thing," Time, 14 December 1970. Time, 0040781X, 12/14/1970, Vol. 96, Issue 24

spaceships were on a mission to Mars. But once they reached Mars, one spaceship broke down. The students then had to figure out how to bring all the astronauts safely back in "the closed ecological system of a single cramped spaceship." The game was meant to teach students that the Earth's natural resources were limited, just like a spaceship's, and that only (democratic) planning could avert disaster. As Coca-Cola put it: "the game re-creates the real thing."[505]

Coca-Cola was not alone in employing the spaceship metaphor. In an interview with CBS after the first Earth Day, Eugene Odum explained: "Perhaps the experience of Apollo 13 is symbolic – one has to turn back in order to survive when the spacecraft is overextended and running out of air. The earth spacecraft can become overextended if present trends are not reversed; it might then not survive a major breakdown in some one of its natural regenerating systems."[506] With the spaceship metaphor, Odum and other ecologists conveyed three messages. First, humans were dependent upon Earth's life support systems, just as astronauts were dependent upon their craft's life support systems. Second, Earth's resources were limited, just as a spaceship's were. Third, environmental destruction – whether nuclear holocaust, soil erosion, or water pollution – was akin to mechanical systems breakdown on a lunar mission. The *Sierra Club Handbook for Environment Activists* urged its readers to "remember that we are not concerned here merely with the aesthetics of open space […] The issue is survival."[507] Oceanographer Roger Revelle spoke of a "hidden war,"

---

[505] The real thing," Time, 14 December 1970. Time, 0040781X, 12/14/1970, Vol. 96, Issue 24

[506] E.P. Odum, "Questions and Answers CBS News, New York for Earth Day Tape, 22 April 1970" Hargrett MS3257 Series I Box 104 Folder 27. In 1967, architect R. Buckminster Fuller had delivered a talk to the American Planners Association in which he argued that "we are all astronauts." The talk was published the following year as *Operating Manual for Spaceship Earth*. It would later serve as the inspiration for Walt Disney World's iconic "Spaceship Earth" – the 18 story geodesic sphere of Epcot.

[507] J. G. Mitchell and C. L. Stallings, eds., *Ecotactics: The Sierra Club Handbook for Environment Activists* (New York: Simon and Schulster 1970).

> the complexities and effects of which may be of a magnitude to dwarf any military war yet fought on earth and of a scope to reduce any conventional type of combat to relative unimportance. […] man, through his cunning and acquisitiveness, his desire for comfort and security—and through the technology he has developed to help meet these ends—has engendered the capability to telescope nature; to alter it, to foreshorten it, to accelerate its natural cycles—and very possibly to destroy many of its life-supporting characteristics.[508]

Today it seems obvious that ecological science should inform environmental policy.[509] Hundreds of public and private environmental organizations execute "scientific environmental management." Ecologists' professional societies have active lobbying presences, and ecologists serve on national research boards and international panels on climate change. But in the 1960s, ecologists were still working to establish themselves as experts on environmental management. For instance, in a 1964 report, the Ecological Society of America determined that it should establish mechanisms through which to "place crusading ecologists in positions of authority both within government and within the scientific community." The report explained:

> Technologically almost anything in the way of resource substitution, upgrading, re-utilization, avoidance of waste, multiple use, preservation, or even restoration of resources is possible.[510]

And in 1973, nineteen years after the Odums' Eniwetok study, ecologist Orie Loucks published a guide on how to deliver expert testimony as an ecologist. After reviewing recent hearings concerning the environmental effects of DDT in Wisconsin and the flooding of river basins in Florida, he wrote:

> The systems ecologist may know very well the quality of interconnections that couple air, land, and water systems, and man's long-range impacts on them; but the court has to be

---

[508] The International Biological Program: Its Meaning and Needs. Report of the subcommittee on science, research, and development of the committee on science and astronautics, US House of Representatives, Ninetieth Congress, Second Session, US GPO 1968. 97-061 box 15
[509] Stephen Bocking, *Nature's Experts: Science, Politics, and the Environment* (New Brunswick: Rutgers University Press, 2004).
[510] "Report of the Applied Ecology Committee," Bulletin of the Ecological Society of America, Vol. 45, No. 1 (Mar., 1964), pp. 13-17.

> satisfied that the testimony is both relevant to the case at issue and based on sufficient experience and familiarity with the case to warrant the witness being accepted as an expert.[511]

Louck's caveat suggests that as of 1973, ecosystem was not yet a household word, and ecologists' authority to attest to knowledge of ecosystems was still unstable.

How is it, then, that in the 1970s, ecologists became the official spokespeople for nature?[512] One common narrative is that as U.S. citizens noticed the degrading effects of technologies such as DDT and nuclear bombs, they subsequently called upon ecologists to provide environmental data.[513] Donald Worster writes that "one of the glaring paradoxes of the Age of Ecology was that the public began to follow, even idealize, one small group of scientists in order to fight the ills brought on by science in general."[514] Sharon Kingsland similarly argues that ecology became "a subversive science, whose role was partly to critique modern

---

[511] Orie L. Loucks, "Systems Methods in Environmental Court Actions." In *Systems Analysis and Simulation in Ecology Vol. II.* (Bernard C. Patten, ed.) (New York and London: Academic Press, 1972). Pages 419-472. Quote page 424. See also Yannacone, V.J. (1970) Plaintiffs' Brief in the Project Rulison Case. Cornell Law Review 55, 761-807.

[512] Latour Politics of Nature

[513] In *Beauty, Health, and Permanence*, Samuel Hays divides postwar environmental activism into three stages. From the mid-1950s to the early 1960s, outdoor recreation and wilderness preservation dominated environmental discourse. Then from the mid-1960s to the early 1970s pollution gained attention. Finally environmentalists turned to endangered species, energy conservation, and other diverse interests. But Hays does not focus on the transitions between these periods. Other histories that describe postwar environmentalism as a rise in awareness of the negative effects of modern technologies are Thomas R. Dunlap, *DDT: Scientists, Citizens, and Public Policy*, Thomas Raymond Wellock, *Critical Masses: Opposition to Nuclear Power in California, 1958-1978;* William McGucken, *Biodegradable: Detergents and the Environment.* Adam Rome's *The Bulldozer in the Countryside* represents an intervention in this historiography. Rome argues that an environmental critique of suburban homebuilding from 1945 to 1970 was formative to postwar environmentalism. Unlike Dunlap, Wellock, and McGucken, who compare citizen action to government unresponsiveness, Rome highlights that some federal agencies were instrumental in putting environment on the public agenda.

[514] Worster, *Nature's Economy*, 359-360. Worster suggests that postwar ecologists' "task was to educate citizens about the vital world of nature and explain what we were doing to it." Worster, *Nature's Economy*, 360.

assumptions about technological fixes and economic growth, rather than to promote rational management, as had been the case in the early twentieth century."[515] Ecology from 1930-1970 is thus portrayed as having been corrupted by its allegiance with a strand of environmental utilitarianism that had its roots in Progressive Era conservation, even as the ecological ideas of interdependence, community, and contingency are taken to be antidotes to technological imperialism, individualism, and determinism.

One of the limitations of this narrative is that it portrays ecology as an isolated source of expertise that was poised to respond to the questions of a concerned public and state. It implies a neat division between science and politics – between the objective knowledge generated by ecologists and the humanized applications of that knowledge to questions of environmental stewardship.[516] As this dissertation suggests, however, such a division is impossible. American

---

[515] Kingsland, *The Evolution of American Ecology,* 6. Similarly, Frank Golley writes that "expressions of global and local concern about environmental deterioration engendered a public demand for action that led to a variety of institutional mechanism to study and manage the environment. Ecology was one of the sciences called upon to provide a scientific basis for environmental management." Golley, *A History of the Ecosystem Concept in Ecology*, 69.

[516] This assumed split is at play in ecologists' debates over whether their professional societies and departments should emphasize "pure ecology" or "applied ecology." For a recent example, see Kaiser, "Ecologists on a Mission to Save the World." And it is at play in histories that ask when ecology became political. Many histories of ecology treat ecological research and society as distinct spheres – spheres that interface at their peripheries to exchange data or funding. In *Reassembling the Social*, Bruno Latour argues that the meaning of "social" has shrunk over time, so that now it problematically refers to "a kind of stuff" limited to "what is left *after* politics, biology, economics, law, psychology, management, technology, etc., have taken their own parts of the associations." (Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network Theory* [Oxford: Oxford University Press, 2007]*,* 6.) I would contend some environmental histories use "social" in the "thing" sense – as a vehicle or medium through which ideas become concrete – rather than as a process. Society is thus described as *an environment*, one that determines certain human behaviors. In *Nature's Economy*, for example, Donald Worster analogizes society and scientific ideas to soil and plants, arguing that ecological ideas "are suited to and rooted in their times," "are rooted in their cultural subsoil," and "grow out of specific cultural conditions." (Worster, *Nature's Economy*, 425 and xi.) In another example, writing about California fisheries, Arthur McEvoy describes forms of property and other legal

ecologists had been working to influence environmental management since the early twentieth century, and ecology was never isolated, either intellectually or material, from questions of governance and technology. By 1970, ecologists had largely achieved a position of expertise and influence that they still hold in 2015. As Jon Margolis wrote in *Esquire* in 1970: "The new Conservationist quotes not poets, but scientists such as Paul Ehrlich, Eugene P. Odum, and Barry Commoner."[517] In the first issue of the professional journal *Conservation Biology* in 1987, Archie Carr III wrote, "I think a new era for humanity is possible. It will be an era in which the ecologist stands alongside the economist and the military general to advise government."[518]

Ecological restoration was one of many ideas and practices to emerge from ecologists' efforts to influence national environmental policy. Into the 1970s, the model of diverse, self-regulating, stable, bounded, and measurable ecosystems was inscribed in U.S. conservation projects at home and abroad. Ecologists increasingly emphasized that ecosystems were threatened by nuclear fallout, pollution, and population growth, whose effects ecologists newly imagined as permanent. A desire to mitigate seemingly unavoidable global change motivated the 1971 UNESCO Man and the Biosphere Programme and the projects of The Nature Conservancy.

---

institutions as "creatures of history, evolving to their social and natural environments." (Arthur McEvoy, *The Fisherman's Problem: Ecology and Law in the California Fisheries, 1850-1980* (New York: Cambridge University Press, 1990), 13.) Two authors that push on such an ecology/society divide are Peter Taylor and Matthew Klingle. In "Technocratic Optimism," Peter Taylor suggests ecologist Howard Thomas (H.T. or Tom) Odum's ecosystem research was influenced by a technocratic desire to reduce the complexity of social and ecological relations "to a single energy dial for the social engineers to adjust" – an example of the way that "scientists can build their experience of social relations and social action into their science." Matt Klingle explores the material history of Lauren Donaldson's Fern Lake ecosystem studies, confronting histories of ecology that argue "better science equals better management," the role of non-human actors such as species and atomic technologies in science, and the stability of the divide between "basic" and "applied" ecologists.

[517] (QUoted in Kwa 1987, fn. 88)

[518] Archie Carr III, "Letter," Conservation Biology 1 (1987).

As national and international organizations preserved ecosystems, ecosystems materialized, not only as an idea, but also a geo-political unit mappable onto real space.

Meanwhile, legislation governing the development of wetlands entailed mitigation practice. The Clean Water Act (1972) required landowners building on wetlands to minimize ecological impacts and mitigate those deemed unavoidable. But it left federal agencies to direct the act's implementation. In consultation with ecologists, the U. S. Fish and Wildlife Service compelled developers to restore on-site or off-site wetlands. Hence a law whose literal content required mitigation became, as interpreted and enforced by the FWS, the first law to compel ecological restoration projects. Because these projects required the direction of experts, the legislation also helped to establish restoration ecology as a distinct subfield. This paved the way, conceptually, for other forms of ecological mitigation that decoupled the site of damage from the site of restoration (e.g. carbon offsets). Thus, the history of restoration in the 1970s contains the history of mitigation, a nexus of ecological ideas and practices of the Cold War era.

Invasion, Conservation, Restoration

In addition to restoration ecology, two other allied sub-disciplines emerged in the 1970s: invasion ecology and conservation biology.[519] Since their inception, these three sub-fields have

---

[519] Although invasive species control is a pervasive practice, its cultural and political dimensions remain largely unexplored. On the history of invasion ecology, see Charles S. Elton, *The Ecology of Invasions by Animals and Plants* (London: Methuen and Co. Ltd., 1958); George Laycock, *The Alien Animals: The Story of Imported Wildlife* (New York: Doubleday, 1966); D. M. Lodge, "Biological Invasions: Lessons from Ecology," *Trends in Ecology and Evolution* 8 (1993): 133-136; Jean Comaroff and John L. Comaroff, "Naturing the Nation: Aliens, Apocalypse, and the Postcolonial State," *Social Identities* 7: 2 (2001), 233-265; Mark A. Davis, "Invasion Biology 1958-2004: The Pursuit of Science and Conservation," in M. W. Cadotte, S. M. McMahon, T. Fukami, eds., *Conceptual Ecology and Invasions Biology: Reciprocal Approaches to Nature* (London: Kluwer Publishers, 2005); Philip Pauly, *Fruits and Plains: The*

greatly overlapped in their memberships. As I continue this project forward, I plan to explore how ideas around ecological restoration, invasion, and conservation mutually shaped one another and, simultaneously, environmental management.

In 1968 the first issue of the journal *Biological Conservation* reported on a range of topics that included "biosphere maintenance," "ecosystem disturbance," "threatened species," and "aliens vs. indigenes."[520] Unlike conservation biologists, it seems, restoration ecologists did not begin considering non-native species as "threats" until the 1980s. For example, in 1976 NATO sponsored a conference in Reykjavik, Iceland, that resulted in the publication of *The Breakdown and Restoration of Ecosystems*.[521] Most of the participants at the Reykjavik conference were European, and most were interested in "rehabilitating" ecosystems rather than trying to restore them to some prior, native condition, as illustrated by the conference proceedings: "from the point of view of nature conservation, rehabilitation should not necessarily mean restoration of the original, often uninteresting, ecosystem."[522]

Horticultural Transformation of America (Cambridge: Harvard University Press, 2007); Peter Coates, *American Perceptions of Immigrant and Invasive Species: Strangers on the Land* (Berkley: University of California Press, 2007); Banu Subramaniam, *Ghost Stories for Darwin: The Science of Variation and the Politics of Diviersity* (Urbana-Champaign: University of Illinois Press, 2014), Chapters 4-6. *Diversity and Distributions* was founded in 1998 (succeeding the journal Biodiversity Letters) with an emphasis on biological invasions. *Biological Invasions* was founded in 1999. Noting how little has been written on the topic, Davis (2005) wrote, "The history of invasion biology would be a dream dissertation topic for some history of science graduate student."

[520] "Editorial Statement," *Biological Conservation* 1 (1968): 1-3.

[521] M. W. Holdgate and M. J. Woodman, eds., *The Breakdown and Restoration of Ecosystems* (New York: Plenum Press, 1978).

[522] Bradshaw 1978. As quoted in Mark A. Davis, "Invasion Biology 1958-2004: The Pursuit of Science and Conservation," in M. W. Cadotte, S. M. McMahon, T. Fukami, eds., *Conceptual Ecology and Invasions Biology: Reciprocal Approaches to Nature* (London: Kluwer Publishers, 2005).

Contrastingly, in his opening editorial of *Restoration and Management Notes* in 1981, William Jordan III stated that the new journal "will deal only with the development and management of communities that are native or at least ecologically appropriate to their site."[523] Two years later, SCOPE (the Scientific Committee on Problems of the Environment, established by the International Union for the Conservation of Nature [IUCN] in the 1970s) convened a scientific advisory committee on the impacts of "biological invasions." The SCOPE invasion program focused on three questions: (1) What factors determine whether a species will be an invader or not? (2) What are the characteristics of an environment that make it vulnerable to or resistant to invasions? (3) How can insights from invasion ecology be used to develop effective management strategies? This work fed into the April 1987 Native Plant Re-vegetation Symposium in San Diego, California, at which William Jordan III, Steve Johnson (TNC), John Rieger (California Department of Transportations), Anne Sands (Riparian Systems), and John Stanley (Harvey & Stanley Associates, Inc.) began to organize what would become the Society for Ecological Restoration and Management (now the Society for Ecological Restoration International, or SER).[524]

The history of ecological restoration from the 1970s forward is thus thoroughly enmeshed with the history of invasion ecology. Today invasive species are at the forefront of international conservation and restoration organizations' concerns. The IUCN states that the impacts of alien species are "immense, insidious, and usually irreversible."[525] The Nature Conservancy cites a

---

[523] William Jordan III , "Restoration and Management Notes: A Beginning," *Restoration and Management Notes* 1 (1981): 1.
[524] William R. Jordan III and George M. Lubick, *Making Nature Whole: A History of Ecological Restoration* (Washington DC: Island Press, 2011),
[525] http://www.iucn.org/about/union/secretariat/offices/iucnmed/iucn_med_programme/species/inva

study that estimates the total economic damage caused by invasions at more than $1.4 trillion dollars, or five percent of the global economy.[526] The Audubon Society's "Stop Invasives Homepage" paints a particularly stark picture: "Imagine aliens —taking the shape of a seemingly harmless plant or small animal—coming into your community and taking over."[527] The total reversal in American attitudes towards non-native species during the twentieth-century is astounding. Federal and state governments, which had systematically killed native predators such as wolves, mountain lions, and bears (and consequentially, many non-targeted species) since the 1800s, passed legislation to protect these species in the 1970s. In the nineteenth-century, too, Anglo-settlers considered non-native species to be improvements to the American landscape, founding acclimatization societies in order to import European species. It was not until the 1980s that ideas about inviolate nature and national borders coalesced into broad public concern over non-native species in natural areas.[528]

---

sive_species/

526 http://tncweeds.ucdavis.edu/

527 http://www.audubon.org/campaign. In a review of 239 articles published in the journal *Invasion Biology*, Gobster found that the word 'threat" was used 331 times in 100 articles. Paul Gobster, "Invasive Species as Ecological Threat: Is Restoration an Alternative to Fear-Based Resource Management?" *Ecological Restoration* 23 (2005): 261- 270. I am interested in the argument that during the 1990s, the rhetoric of conservation shifted from a "balance of power" model to a "terrorist threat" model. Others of invasion biology's central concepts and metaphors – including "evolutionary arms race" and "novel weapons" – reflect restoration's Cold War history.

528 Mark Davis (2005) writes: "It is no coincidence that scientists from South Africa, Australia, New Zealand, and the United States contributed so significantly to the SCOPE initiative. The natural environments in these countries had been experiencing recent and substantial introductions of new species from other regions of the world and considerable conservation concerns were being raised in these countries regarding the impacts of these species." I would like to push this further. Today the countries producing the greatest number of academic articles on invasive species are the United States, Australia, Canada, the United Kingdom, New Zealand, and South Africa. (Laura Martin, unpublished manuscript.) In these countries, discourses about biological authenticity have run in parallel with discourses about national authenticity. The histories of these countries share many differences but also many striking similarities, including:

The period from 1990 to present has been one of institutionalization and privatization. During this time, ecological restoration and national concerns have continued to shape each other. Ecologists increasingly framed their research around the ideas of biodiversity and global change. And the idea and practice of compensatory mitigation "promised a way to have your K-mart and your wetland, too," as Leslie Roberts wrote in *Science* in 1993.[529]

The practice of off-setting ecological damage in one place with ecological care in another location has important political and material consequences. For example, by decoupling the site of ecological impact from the site of its restoration, this off-setting, also called "compensatory mitigation," reconfigures the attitudes of industrialized nations towards developing nations, positioning the latter not only as sources of inexpensive labor or raw materials, but also as field sites or potential "natural" areas. In future work, I am interested in exploring the entwined histories of compensatory mitigation and the preservation of endangered ecosystems. It was during the Cold War that policy-makers conceived the pair of ideas that have driven compensatory mitigation: that of unavoidable ecological damage, necessitating sacrifice zones,

---

(1) overlapping histories of ecological professionalization; (2) a tendency to identify themselves against outsiders and others (culturally, politically, and now biologically); and (3) numerous re-imaginings of national identity. In *Playing Indian*, Philip Deloria describes specific moments in American history when American identity has been refashioned and re-imagined, the same moments when Anglo-Americans have appropriated Native American identity. Deloria focuses on the Revolution, a time when Americans sought to distinguish themselves from England, and modernity, when Americans sought relief from industrial and postindustrial anxieties through the search for an authentic identity rooted in the indigenous. During these same times, the meaning of native and non-native species was also in flux: for example, in the 19th century the buffalo was both systematically killed and co-opted as a national symbol. (Philip Deloria, *Playing Indian* [New Haven: Yale University Press, 1998].) Perhaps globalization in the Information Age can be added as a fourth period in which Americans sought to identify with the "native" and "authentic" – a time in which closer integration of national economies and subsequent international exchange of goods, peoples, and biotas.

[529] Leslie Roberts, "Wetlands Trading is a Loser's Game, Say Ecologists," *Science* 260 (1993): 1890-1892.

and that of ecosystems as substitutable, making compensatory mitigation possible. This paved the way for other forms of ecological mitigation that decoupled the site of damage from the site of restoration, leading to a "sacrifice zone/ protected zone" duality that underlies wetlands law, carbon off-setting, and other contemporary ecological interventions.

History and Ecology

By 2000, many U.S. ecologists reasoned that ecological restoration projects should strive to replicate pre-colonial ecological conditions, or a "1492 baseline." In 1999, Thomas Swetnam and colleagues reviewed this idea in article titled "Applied Historical Ecology: Using the Past to Manage for the Future." [530] The authors contended that restorationists should analyze both "natural" and "documentary" archives. By documentary archives, they meant written, tabulated, mapped, or photographic records (e.g., diaries, land surveys, maps, plot measurements, weather observations), and by natural archives, they meant those events "recorded by earth-system processes" (e.g., fossil pollen, ice cores, tree rings). Restoration ecologists needed a deep understanding of historical knowledge, the authors concluded, because the past illuminated "causes of change and the historical pathways that brought ecosystems to their current condition."[531]

---

[530] Thomas W. Swetnam, Craig D. Allen, Julio L. Betancourt, "Applied Historical Ecology: Using the Past to Manage for the Future," *Ecological Applications* 9 (1999): 1189-1206. They continued: "As might be expected in the development of a relatively new concept, the early stages have been marked by some confusion and missed opportunities for better communication between scientists and managers."
[531] See also: D. R. Foster, P. K. Schoonmaker, and S. T. A. Pickett, "Insights from Paleoecology to Community Ecology," *Trends in Ecology and Evolution* 5 (1990): 119-122; M. Brenner, T. J. Whitmore, M. S. Flannery, and M. W . Binford, "Paleolimnological Methods for Defining Target Conditions for Lake Restoration: Florida Case Studies," *Lake and Reservoir Management* 7 (1993): 209-217; F. B. Allen, W.W. Covington, and D.Falk, "Supporting Research in Restoration

And yet, within a decade, many ecologists and conservationists were contesting the 1492 baseline. Into the twenty-first-century, an increasing number of ecologists argued that rapid environmental change – including climate change and species invasions – made it impractical or impossible to restore ecological communities to a historical baseline. As Young Choi wrote: "We need to admit our inability to restore an ecosystem to its very original state. We cannot go back to our nostalgic past!"[532] Embracing this critique, proponents of "novel ecosystems" argued that restoration projects should aim to achieve particular ecosystem functions rather than to return to

---

Biology: NSF Workshop Offers Recommendations," *Restoration and Management Notes* 14 (1996): 148-150; N. L. Christensen *et al.*, "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management," *Ecological Applications* 6 (1996): 665- 691; M. L. Hunter, Jr., "Benchmarks for Managing Ecosystems: Are Human Activities Natural?" Conservation Biology 10 (1996): 695-697; P. S. White and J. L. Walker, "Approximating Nature's Variation: Selecting and Using Reference Information in Restoration Ecology," *Restoration Ecology* 5 (1997): 338-349; J. C. Schmidt, R. H. Webb, R. A. Valdez, G. R. Marzolf, and L. E. Stevens, "Science and Values in River Restoration in the Grand Canyon," *BioScience* 48 (1998): 735-747; D. Egan and E. Howell, *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems* (Washington, D.C.: Island Press, 2001).

532 Young D. Choi, "Restoration Ecology to the Future: A Call for New Paradigm," *Restoration Ecology* 15 (2007): 351-353. See also: A. D. Bradshaw, "The Reconstruction of Ecosystems," *Journal of Applied Ecology* 20 (1983): 1–17; Mark A. Davis, ''Restoration''—A Misnomer?" *Science* 287 (2000): 1203; Y. D. Choi, "Theories for Ecological Restoration in Changing Environment: Toward ''Futuristic'' Restoration," *Ecological Research* 19 (2004): 75–81; J. A. Harris, R. J. Hobbs, E. S. Higgs, and J. A. Aronson, "Ecological Restoration and Climate Change," *Restoration Ecology* 14 (2006): 170-176; J. W. Williams and S. T. Jackson, "Novel Climates, No-analog Communities, and Ecological Surprises," *Frontiers in Ecology and the Environment* 5 (2007): 475-482; R. J. Hobbs, E. S. Higgs, and J. A. Harris, "Novel Ecosystems: Implications for Conservation and Restoration," *Trends in Ecology and Evolution* 24 (2009): 599-605; S. T. Jackson and R. J. Hobbs, "Ecological Restoration in Light of Ecological History," *Science* 325 (2009): 567-568; D. A. Norton, "Species Invasions and the Limits to Restoration: Learning from the New Zealand Experience," *Science* 325 (2009): 569–70; Emma Marris, *Rambunctious Garden: Saving Nature in a Post-wild World* (New York: Bloomsbury, 2011); R. J. Hobbs, E. S. Higgs, and C. M. Hall, *Novel Ecosystems: Intervening in the New Ecological World Order* (Oxford: Wiley-Blackwell, 2013); Laura Jane Martin, John E. Quinn, Erle C. Ellis, M. Rebecca Shaw, Monica Dorning, Clifford E. Kraft, Lauren Hallett, Nicole E. Heller, Richard J. Hobbs, Elizabeth Law, Nicole Michel, Michael Perring, Patrick D. Shirey, Ruscena Wiederholt, "Conservation Opportunities Across the World's Anthromes," *Diversity and Distributions* 20 (2014): 745-755.

a historical configuration of species. Relatedly, proponents of "managed relocation" maintained that it was better to move endangered species to new, "non-native" habitats than to let them go extinct.[533]

Separately, yet other ecologists have argued for a new historical baseline: the Pleistocene. In a 1998 paper, Michael Soulé and Reed Noss coined the term "rewilding" to describe the reintroduction of large mammals as "a critical step in restoring self-regulating land communities."[534] In 2005, a dozen ecologists took the concept of rewilding one step further, arguing for the reintroduction of "Pleistocene megafauna" to North America.[535] The authors argued that humans were at least partly responsible for extinctions of American cheetahs, mastodons, and other large vertebrates approximately 11700 years BP, and that ecological functions these species performed could be restored by introducing African cheetahs, Asian elephants, and other "proxy" species to the American West. The authors envisioned a series of small-scale experiments leading up to the creation of one or more "ecological history parks" that would cover "vast areas of economically depressed parts of the Great Plains." Not only would such programs restore historical ecological and evolutionary relationships, but they would help

[533] I review this literature elsewhere. See Martin *et al.* (2014). See also Harris *et al.* (2006); Jackson and Hobbs (2009); Ricciardi and Simberloff (2009); Stone (2010); Marris (2011); Davis *et al.* (2012); Zedler *et al.* (2012);

[534] Michael Soule and Reed Noss, "Rewilding and Biodiversity: Complementary Goals for Continental Conservation," Wild Earth 8 (1998): 19-28.

[535] C. J. Donlan, H. W. Greene, J. Berger, C. E. Bock, J. H. Bock, D. A. Burney, J. A. Estes, D. Foreman, P. S. Martin, G. W. Roemer, F. A. Smith, and M. E. Soulé, " Re-wilding North America," *Nature* 436 (2005): 913-914; C. J. Donlan, J. Berger, C. E. Bock, J. H. Bock, D. A. Burney, J. A. Estes, D. Foreman, P. S. Martin, G. W. Roemer, F. A. Smith, M. E. Soulé, and H. W. Greene, " Pleistocene Rewilding: An Optimistic Agenda for 21st Century Conservation," *American Naturalist* 168 (2006): 660-68.

protect species endangered elsewhere.[536]

Their proposal prompted rebuttals – some ecologists contended that the intentional introduction of large species from their present ranges to North America could lead to ecological catastrophes like disease transmission or food web collapse – but it also garnered support.[537] Indeed, rewilding has become an international movement. In the Netherlands, for example, "de-domesticated" horses and cattle have been introduced to the Oostvaardersplassen with the goal of recreating the ecological conditions that existed at the end of the Pleistocene, when their now-extinct ancestors, Aurochs and Tarpans, would have grazed the land. And recent calls for "de-extinction," "resurrection biology," or "species revivalism" take rewilding even further. Proponents of de-extinction imagine that soon it will be possible to create an organism that is a member of or resembles an extinct species through cloning. "Don't mourn," the Long Now Foundation encourages us. "Organize."[538]

---

[536] Caroline Fraser, *Rewilding the World: Dispatches from the Conservation Revolution* (New York: Henry Holt and Company, 2009); Jozef Keulartz, "Boundary Work in Ecological Resotration," *Environmental Philosophy* 6 (20090: 35-55; Elizabeth Kolbert, "Recall of the Wild," *The New Yorker*, Dec. 24, 2012, p. 50; J. Lorimer and C. Driessen, "Wild Experiments at the Oostvaardersplassen: Rethinking Environmentalism in the Anthropocene," *Transactions of the Institute of British Geographers* 39 (2014): 169–181. Zimmer (2013); Radin (2013). Dolly Jørgensen, "Rethinking Rewilding," *Geoforum*, in press.

[537] G. Chapron, "Re-wilding: Other Projects Help Carnivores Stay Wild," *Nature* 437 (2005): 318; E. Dinnerstein and W. R. Irvin, "Re-wilding: No Need for Exotics as Natives Return," *Nature* 437 (2005): 476; M. A. Schlaepfer, "Re-wilding: A Bold Plan that Needs Native Megafauna," *Nature* 437 (2005): 951; Dustin R. Rubenstein, Daniel I. Rubenstein, Paul W. Sherman, Thomas A. Gavin, "Pleistocene Park: Does re-wilding North America Represent Sound Conservation for the 21st century?" *Biological Conservation* 132 (2006): 232-238; C. Josh Donlan and Harry W. Greene, "NLIMBY: No Lions in my Backyard," in Marcus Hall, ed. *Restoration and History: The Search for a Usable Environmental Past* (New York: Routledge, 2009); Anthony Ricciardi and Daniel Simberloff, "Assisted Colonization is not a Viable Conservation Strategy," *Trends in Ecology & Evolution* 24 (2009): 248-253.

[538] Quoted in Ben A. Minteer, "When Extinction is a Virtue," in Ben A. Minteer and Stephen J. Pyne, eds., *After Preservation: Saving American Nature in the Age of Humans* (Chicago: University of Chicago Press, 2015), 96-104.

The Society for Ecological Restoration's alterations to their definition of restoration between 1990 and the present captures ecologists' negotiations over the relationship between ecology, management, and the past:[539]

1990	The process of intentionally altering a site to establish a defined, indigenous, historic ecosystem. The goal of the process is to emulate the structure, function, diversity, and dynamics of the specified ecosystem.
1993	The process of re-establishing to the extent possible the structure, function, and integrity of indigenous ecosystems and the sustaining habitats they provide.
1994	The process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems.
1996	The process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices.
2002	The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.

Thus twenty-first-century restoration may end up looking quite different from the University of Wisconsin Arboretum, or Donaldson's salmon farms, or The Nature Conservancy's first wetlands re-plantings.

[539] On recent definitions of ecological restoration, see Eric Higgs, *Nature By Design: People, Natural Process, and Ecological Restoration* (Cambridge: MIT Press, 2003); Sahorta Sarkar, "Habitat Reconstruction: Moving Beyond Historical Fidelity," in Kevin deLaplante, Bryson Brown, and Ken Peacock, *Philosophy of Ecology* (London: New Holland, 2011), 327-363; Stuart K. Allison, *Ecological Restoration and Environmental Change: Renewing Damaged Ecosystems* (New York: Routledge, 2012).

Figure 59. Screen capture from Twitter, 14 April 2015, of a manager sharpening the beak of a Bald Eagle raised in captivity before its release.

Ecological Restoration as Political

Over the past century, ecological restoration has both shaped and been shaped by competing understandings of the ecological past and visions of ecological futures. Understanding the history of ecological restoration in the United States enables closer scrutiny of which historical events restorationists are attempting to undo (e.g., the 1492 "discovery" of the Americas; industrialization; the discovery of atomic fission; globalization) and, accordingly, which cultural practices they implicitly criticize. In addition to the politics of deciding what to undo, one must consider the politics of what to do. Underlying debates about ecological restoration are questions such as: What should nature be?[540] Which species should be permitted to live in a particular area, and which should not? Who gets to decide? Who benefits?

And yet debates over ecological restoration are usually framed as technical ones – as contestations over questions of naturalness and achievability. This is because over the past century all sciences, including ecology, have come to be framed as apolitical. Facts are taken to be the opposite of values. Nature is taken to be the opposite of politics. The "objective" sciences are taken to be the opposite of the "subjective" humanities. In a recent community ecology textbook, for example, Gary Mittelbach wrote "ecologists understand in a deep and fundamental way the factors that regulate populations, and we use this knowledge to manage our natural resources effectively (or at least we try to—politics often gets in the way).[541]

The problem with such configurations is that nature and its facts are not independently "out there" to be discovered. Rather, as Bruno Latour has argued, nature has become "a hidden procedure for apportioning speech and authority," and ecosystem science has "allowed us to dispense with the requirements of discussion and due process in building the common world."[542] It happens often within liberal democracies that governments justify actions on the basis of scientific knowledge. By now it is received wisdom that more and better science equals better environmental management, and to the extent that ecological knowledge is seen as apolitical, it is

---

[540] Michael Pollan makes this point elegantly in "The Idea of a Garden," in *Second Nature: A Gardener's Education* (New York: Grove Press, 1991), 176-204.
[541] Mittelbach, *Community Ecology*, 340.
[542] Latour, 133. Latour writes that scientists have come to be seen as concerned with "the sublime epistemological questions," leaving others to contend with the "lowly political questions" of "values and the difficulty of living together." *Politics of Nature*, 15. On ecological governance see McEvoy (1986), Taylor (1988), Lowood (1990), Palladino (1991), Scott (1999), Mitchell (2002), Allen (2003), Frickel (2004), Latour (2004), Frickel and Moore (2006), Pauly (2007), Pritchard (2011); Kwa (1987), (1994), (2005); Bocking (1995), (1997), (2004), (2007), Harvey (1993). Latour (2004) pp. 131 and 19

not subject to democratic oversight.[543] But as this dissertation documents, what we treat today as received wisdom is the product of decades of interactions between scientific and governmental actors, environments, and technologies. To make sense of present environmental issues, it is essential to understand the nature of ecological expertise and to note that within "scientific governance," expertise and power are mutually reinforcing.[544] When restorationists today conceive of themselves as looking to nature for answers, they may disavow their own roles, and the roles of humans more broadly, in constructing that nature. Best practices in restoration ecology, however, entail the restorationists' acknowledgement of responsibility for the shapes of facts as well as values.

Recently, Eric Higgs and colleagues suggested that "novel ecosystems" and future-oriented restoration has become popular because of urbanization; they write: "as ecosystems change, so too do people's beliefs about the value of those ecosystems."[545] This dissertation argues for more complicated relationship between ideas about nature and how nature is managed. In the Dust Bowl, ecologists argued for kinds of management that would give them the sites they required in order to explore ecological systems further. During the Cold War, enabled by powerfully destructive technologies, ecological scientists created the very thing that was to be perceived as threatened by modernity: the stable and material ecosystem. The rise of ecology to its position of influence was hence a precondition to the perception of environmental decline, and not response to that perception. Ecological concepts like the ecosystem, that seem at first glance stable, often emerge contingently for reasons that are as much cultural, social, political,

---

543 Latour (1993) and (2004), Shapin and Schaffer (1985)
544 Porter (1996), Irwin (2008)
545 Eric Higgs *et al.*, "The Changing Role of History in Restoration Ecology," *Frontiers in Ecology and the Environment* 12 (2014): 499-506.

and economic, as natural.

The purpose of this argument is not to undermine the life work of ecologists, but to untangle the ways in which the contingencies of scientific work shape theory, and how such theory is then applied to policy and the environment as though it were resolved and unchanging. As a pervasive environmental practice, ecological restoration opens up a set of questions whose answers are relevant to environmental studies scholars broadly, as well as to natural resources managers and policy makers. As an institutionalized mode through which Americans have grappled with their past, ecological restoration is a lens through which to examine the interwoven technical, cultural, and political dimensions of environmental management.

During the twentieth century the relationship between ecological science and popular environmentalism was dynamic, and this history of the emergence of new units of ecological analysis – like species, habitats, and ecosystems – sheds light on environmentalists' changing concerns, the changing material landscape, and how changes to the landscape affected the content of ecological theory. The history of Donaldson's research tells a messy story, for example, one in which things we today think of as unrelated – atomic weaponry, ecological restoration, fish farms, Bacon Bits – are thoroughly enmeshed. It is a history that challenges a clean divide between environmentalism and the military-industrial complex, between environmental destruction and environmental restoration.

In some ways, it is the goal of ecological restoration to reverse and to revise human-caused environmental change. But to measure success by such reversal and revision threatens to erase more than the damage in a given landscape: it also threatens to erase history and hence our ability to acknowledge and to analyze the complex ways in which humans have interacted with their environments, not only in the twentieth century, but in the past ten millennia or longer. In taking moral responsibility for damage to environments, might we turn from reversal and erasure to other forms of reparation and memorialization?

In 2000, the Marshall Islands Nuclear Claims Tribunal awarded the people of Eniwetok Atoll $107 million dollars for ecological restoration, the idea and practice of which was importantly shaped by work at the bombed-over island. The continuing story of Eniwetok, then, is a story in which ecological destruction and ecological restoration were never diametrically opposed. This history of restoration ecology offers us the perspective that management practices are constantly changing, as are the scientific ideas with which they are justified and the material landscapes that they shape.

Figure 60. Robert ParkeHarrison and Shana ParkeHarrison, *Reclamation*, 2003. Photogravure, from the series *The Architect's Brother*, 2003