Wild Rice: the Dynamics of Its Population Cycles and the Debate Over Its Control at the Minnesota Legislature

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

Rachel Elena Durkee Walker

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

John Pastor

July 2008

Acknowledgements

I thank my advisor, Dr. John Pastor, for his timely, consistent, and expert academic guidance throughout the seven years we worked together. I am grateful for his unwavering commitment to our work, my academic progress and his willingness to consider alternative angles to the questions we pursued. I thank him for letters which assisted my garnering critical financial support. I thank Bradley W. Dewey for his unparalleled abilities in experimental design, data collection and critical analysis.

I thank my committee members Dr. Paul Bloom, Dr. Sarah Hobbie and Dr. Brenda Child. Dr. Bloom was one of the most accessible, interested and helpful professors I have had the privilege of knowing. I have rarely met someone as enthusiastic and devoted to the study of wild rice. Dr. Hobbie was exceptionally supportive, responsive, and thorough in her feedback at all steps of the process from preliminary oral and written exams to publishing chapters of my dissertation. Dr. Brenda Child has invaluable and unique personal connections to and perspectives on wild rice. I thank her for asking me important and critical questions throughout my research. I thank the Water Resources Science Program, in particular Ray Newman, Maria Juergens and Bonnie Anderson for their support and assistance.

I am grateful to the Fond du Lac Reservation where I obtained my introduction to this project as a summer intern. I thank Fond du Lac's Business Committee for providing permission for this research. I am particularly indebted to Nancy Schuldt, Reginald DeFoe, Thomas Howes and the much missed Larry Schwarzkopf for their support, guidance and interest in the project.

Additionally at the university providing invaluable feedback were Dr. George Spangler, Dr. Craig Hassel and Karl Lorenz. From the White Earth Indian Reservation I am indebted to Paul Schultz, Joseph LaGarde, Earl and the much missed Kathy Hoagland. I am grateful to Sarah Alexander, Allen Richardson (formerly), Andrea Hanks, Winona LaDuke (currently) of the White Earth Land Recovery Project. I thank Steve Smith of the Minnesota Chippewa Tribe, John Persell of the Leech Lake Department of Resource Management, Peter David of the Great Lakes Indian Fish and Wildlife Commission, Representative Frank Moe of the Minnesota Legislature and Thomas Vennum, Jr. for their insights.

Finally, I thank my family: my husband, Kevin, my father, Phillip, my mother, Evelyn, my son, Leif and my daughter, Sanna. I thank you, Kevin, for your support on every front – the summers of commuting to Duluth and shouldering the bulk of child care, juggling family and work, and editing thesis chapters and funding applications. I thank my father whose legacy I recognize in completion of this degree. I thank my mother whom I can never really thank. And I am grateful for my children who came into the world during this journey, part and parcel of this work.

Dedication

This dissertation is dedicated to my father and mother, George Phillip and Evelyn Mae Durkee. Much of its approach is attributable to them. In reading my father's Ph.D. thesis recently, I was startled to realize how many of our academic interests, never fully articulated, were intertwined. I know he would have enjoyed discussing its development and completion with me had he been able. My mother, with her omnivorous interest in the world, shaped indirectly many of the historical and political questions I posed.

Abstract

Population cycling in plant and animal communities is of interest to Ojibwe band members and ecologists, and Western ecologists. The causes and consequences of wild rice population cycling and its long term viability have both cultural and scientific implications. I examine several Western scholars' research, its strengths and weaknesses, regarding Ojibwe accommodation of wild rice populations. Building on the interest of Ojibwe and Western ecologists in population cycles, and collaborating with Fond du Lac Reservation managers, I present a model which simulates delays from the release of nitrogen in decomposing wild rice straw. The model and experimental work show how these delays may cause population cycles. I planted wild rice seed obtained from the Fond du Lac Reservation over three years in mesocosms. I asked whether wild rice litter accumulation could inhibit plant growth by nitrogen immobilization in fresh litter. The timing of litter nitrogen immobilization and mineralization affected the potential growth of wild rice, seed production and total plant nitrogen. My data reveals that delays in nutrient availability due to deposition of immobilizing litter potentially cause fluctuations. Litter quantity appears to play a central role. Root litter also appears to be the source of the longest delay in nitrogen cycling through slower decay rates and sustained periods of nitrogen immobilization.

Therefore, both Ojibwe cosmological worldviews and my experimental research recognize wild rice population cycles as part of healthy ecosystem functioning. Interest in these cycles is part of a larger interest in wild rice protection, central to the spiritual and cultural integrity of Ojibwe. Due largely to Ojibwe initiatives, legislation passed in Minnesota 2007 requiring submission of an Environmental Impact Statement in the case of a permit to genetically engineer wild rice either within or outside Minnesota. These efforts are part of a long history of Ojibwe attempt to address the cultural implications of Western scientific inquiry, inquiry often made without their consent. In the last chapter of this thesis, I examine the cultural background of this political process, concluding that the historical and political context of scientific investigation is critical to exposing weaknesses in research questions and political processes.

Table of Contents

List of Tables

Chapter 3

Chapter 4

List of Figures

Chapter 2

Chapter 3

Chapter 4

CHAPTER 1

Ecological Knowledge of Wild Rice: An Historical Academic Perspective

> *Research is not an innocent or distant academic exercise but an activity that has something at stake and that occurs in a set of political and social conditions.*
>
> Linda Tuhiwai Smith[1]

> *We cannot understand human history without natural history and we cannot understand natural history without human history. The two have been intertwined for millennia.*
>
> Bruce A. White[2]

> *…In approaching the oral traditions of Indians from a Western perspective: instead of postponing judgment and viewing the anomaly as a prospect for future research, conclusions are drawn prematurely…and the usefulness of the tradition is lost.*
>
> Vine Deloria, Jr.[3]

Discussions at the Minnesota Legislature are not innocent activities. In the 2007 session, a bill was passed to protect native stand wild rice in Minnesota, a wild plant both culturally and spiritually important to Ojibwe.[4] On the House Floor, one legislative opponent asserted: "[This bill] is about politics, emotion, guilt and pride… The guilt comes from people feeling guilty about how they treated Native Americans. There is pride that the Native Americans now feel that they have a more equal footing…The process was pushed… for the purpose of raising the profile of culturalists

[1] Tuhiwai Smith, Linda. 1999. Decolonizing Methodologies. St. Martin's Press: New York.
[2] White, Bruce A. 1998. Fraser River pink salmon catch and exploitation patterns: 1989-1998. Pacific Salmon Commission: Vancouver, B.C.
[3] Deloria, Vine. 1997. Red earth, white lies: Native Americans and the myth of scientific fact. Fulcrum Pub.: Golden, CO**.**
[4] Anishinaabe(g), Ojibwe, Ojibway, Ojibwa and Chippewa are all names for the same group of people. This can cause confusion. According to several scholars, the use of Ojibwe or Anishinaabe(g) is one of personal preference. I use Ojibwe in this paper. Quotations, however, will not be changed. Dr. Brenda Child recommended using Ojibwe as best representing this thesis' tone. Generally, Anishinaabe(g) is used by the people themselves. Chippewa is the official name recognized by the federal government.

on Native American Reservations."[5] While testimony rarely translates directly into law, it is not without consequence. Legislator viewpoints, publicly or privately articulated, often reflect broader constituent attitudes not transparent in a particular piece of legislation.

Academic writing, like bill-making, also is not innocent.[6] Linda Tuhiwai Smith, Associate Professor in Education for Maori and Indigenous Education and Devon A. Mihesuah, Professor of History at Northern Arizona University, assert that native voices are distinctly absent or not adequately represented in Western scholarship.[7, 8, 9] Native voices, in particular, Ojibwe, are lacking in academic literature on wild rice.[10] Given the central role wild rice plays in the spiritual and cultural cosmology and livelihood of Ojibwe, such omission is significant. Unable to redress past omissions, I examine how analysis of past research might assist in preparing for future work. I examine research by three of the most well-known Western scholars in the twentieth century on wild rice and Ojibwe. To date, these works have not been analyzed together. Looking at these scholars, the times in which they lived, their methodologies, and the strengths and weaknesses of their observations, an opportunity emerges to redress some of what is missing from current discussions. These scholars provide perspectives through which to discuss Western research with real-world impacts, one of which is signed legislation.

---

[5] Representative Mahoney, House Floor testimony, May 15, 2006 and personal communication on May 23, 2007.
[6] Smith, ibid, page 36.
[7] Smith, ibid.
[8] Mihesuah, D.A. 1998. Natives and Academics: Researching and Writing about American Indians. University of Nebraska Press: Lincoln, NE.
[9] Smith, L.T., Director of the International Research Institute, the University of Auckland, New Zealand. Mihesua, D., an enrolled member of the Choctaw Nation of Oklahoma.
[10] Personal communication, Paul Schultz, Joe LaGarde, White Earth Reservation, January 2007.

Not only relevant is current research on wild rice, so too are the methods and context of past research.

The scholars are Albert E. Jenks, Frances Densmore and Thomas Vennum, Jr. All three were ethnographers who wrote extensively over the course of their careers about American Indian culture, broadly, and wild rice, to some extent, in the twentieth century. I am interested in what they tell us collectively about scholarship on wild rice and Ojibwe at the beginning of and through its evolution during the last century. I am interested in understanding what we miss from their work, as confirmed broadly by Smith, Mihesuah, Shultz and LaGarde, and what we gain, albeit biased, imperfect and incomplete.

While missing some of their perspectives, the works of Jenks, Densmore and Vennum, are not monolithic or uni-dimensional. Critical differences in approach and methodology between these three scholars are clear. The enterprise of "ethnography" and "anthropology" changed dramatically over the century. Even scholars who lived contemporaneously, such as Jenks and Densmore, shared different perspectives and methods. All three writers' work provide platforms from which to ask critical questions and highlight gaps that address some of what is missing from contemporary discussions, including legislative discussions on wild rice.

Albert E. Jenks

Albert E. Jenks, ethnologist, was one of the earliest Western scholars to write about wild rice.[11] He was born in 1869 and published his Ph.D. thesis as Wild Rice Gatherers of the Upper Great Lakes in the annual Report of the U. S. Bureau of

[11] Jenks, Albert E. 1901. The Wild Rice gatherers of the upper lakes: study in American primitive economics. Government Printing Office: Washington D.C.

American Ethnology. In 1992, Elden Johnson, an anthropologist from the University of Minnesota described this publication as "still stand[ing] as an important contribution to North American ethnology."[12] Jenks played a key role in the inception of the Department of Anthropology at the University of Minnesota [c. 1918]. He wrote, "[T]here is a growing demand for the professional anthropologist in our universities. There seems to be a realization of the value of Anthropology as a culture study, a professional study, and as the foundation work for other sciences…."[13] He later wrote, "The horizon of this coming field for research among present and future man and ethnic groups is seen to extend indefinitely into the future."[14]

Jenks believed, along with his colleagues, that he was breaking new ground. In 1902 at the annual President's Address to the Society of American Folk-Lore, F. Russell stated, "… [a]nthropology, 'the crown and completion' of the sciences, is assuming its rightful place; … its very comprehensiveness is a virtue; … suitable to serve as a framework for all other knowledge..."[15]

With such grandiose language, the "founders" of this new anthropology indicate they believed they had "discovered" a "new" and "critical" approach to research. Not only believing themselves groundbreakers in academic tradition, these researchers knew themselves to be "saving" traditions. Known later as "salvage anthropology," the President at the Second Annual Meeting of the American Folk-Lore Society explained, "Those who had paid attention to the subject would recognize the value, as historical

[12] Johnson, E. 1992. A.E. Jenks and the University of Minnesota Algerian Excavations in Breitborde, L.B., ed. Alonzo Pond and the 1930 Logan Museum Expedition to North Africa: The 1985 Beloit College Symposium. Logan Museum Bulletin, Vol.1, No. 1.
[13] Jenks, A.E. 1907. Anthropologic Miscellanea, American Anthropologist, Vol. 9, No.2, April-June.
[14] Jenks, A.E. 1921. The Relation of Anthropology to Americanization, The Scientific Monthly, March. pages 241-248.
[15] Russell, F. 1902. Know, then, thyself, Journal of American Folk-Lore, Vol. 15, Jan-Mar., pages 1-3.

data, of the stories, legends, and traditions which appear to float through the popular life of all countries… Such persons would see that the largest part of the life of humanity exists only as folk-lore, and that such survival is the only record of literature before letters… rendering possible the history of civilization."[16] It was the job of anthropologists and ethnographers to "save the culture of 'primitive races' and 'extract' missing links in the 'history of civilization.' "[17]

In another volume of the Journal, Otis Mason suggests, "You may be pleased to know that the Bureau of Ethnology in Washington, at infinite pains, is gathering the stories of our Indians. The work is done by men who insist on hearing a narrative over and over again until there is no mistake about accuracy…"[18] "I hope I may be pardoned for repeating that every specialist in anthropology must first go down and sit at the feet of the folk, to be instructed in all the ways of life, and in the proper method of accounting for phenomena."[19] Mason continues, "Folk-lore… means the lore of the folk… The folk are: (1) all savages, (2) the old-fashioned people, (3) the children, and (4) all of us when we are old-fashioned."[20] "Above all, let us not forget that all science, and every human industry, custom, and belief originated with the folk."[21] Folk were "unlettered," "primitive," "tribal," "Indian." The anthropologist was "lettered," "non-

[16] Summary of Second Annual Meeting of the American Folk-Lore Society. 1891.Journal of American Folk-Lore, Vol. 4, January-March, No. 12, page 1.
[17] Discussions of the origin of "salvage anthropology" and "salvage ethnography," Wikipedia definition: Salvage ethnography is a branch of ethnography concerned with the practice of salvaging a record of what was left of a culture before it disappeared. Salvage ethnography is also a branch of anthropology. http://en.wikipedia.org/wiki/Salvage_ethnography; Review of McFealy, E. 2002. The Zuni and the American Imagination. New York: Hill and Wang. http://www.powells.com/cgi-bin/biblio?inkey=1-0809027070-2.
[18] Mason, O. 1891. The Natural History of Folk-Lore. Journal of American Folk-Lore, Vol. 4, April-June, No. 13, pages 97-105.
[19] Ibid, page 104.
[20] Ibid, page 97.
[21] Ibid, page 105.

Indian," entrusted with the task of "sitting at the foot of the folk," preserving civilization.

Part of this work included recording specimens of the "natural world," and Jenks' work falls within this enterprise. In the Journal of American Folk-Lore, Volume 4, Popular American Plant-Names includes an exhaustive list of "common wild and cultivated plants." Such work was apparently modeled after similar work in Great Britain.

Part of "discovery" included learning how plants got their names. The author discusses, "the word *Indian* we find in constant use to distinguish wild species from those tame or more familiar… Now and then, hints and traditions of the use of certain plants in the rude medical practice of our Indians may have resulted in fastening the name Indian to that of these plants, and it is evident enough that the Indian rice, *Zizania aquatica*, owes the first part of its popular name to the great importance which some tribes attached to it as an article of food."[22,23] This plant is now known as wild rice (*Zizania palustris*). Jenks' work in The Wild Rice Gatherers fits well into the goals of this approach to anthropology. He pursued the cultural and historical connections between wild rice and Ojibwe, endeavoring to address larger questions of "development" and "civilization." Large was the task, undaunted however, were its acolytes.

---

[22] Author unspecified. 1892. Popular American plant-names. The Journal of American Folk-Lore. Vol. 5, April-June, No. 13.

[23] Oelke, E. 2006. The Saga of the Grain. Lakeville, MN: Hobar Publications. Some confusion existed in the naming of the species growing naturally in north-central North America. It is now referred to as *Zizania palustris* L. *Zizania aquatica* L. is longer and thinner than *Z. palustris*, shattering easily and not productive as a food source.

Jenks followed the rules: he made exhaustive lists of scientific and popular names for wild rice, described harvesting practices in detail and recorded the division of labor among Ojibwe bands. He desired "to know the culture status of North American Indians."[24] He contrasts different band perspectives: "Menomini Indians refuse to sow wild rice -- their motive is simply that of belief; the Dakota Indians do not sow the grain, but apparently have no myth-founded scruple against it; while among the Ojibwa no such belief seems likely ever to have existed, for they sow the grain from purely economic motive..."[25] What is "culture status?" What are "stages of development?" What was he *discovering*?

Jenks' approach is affected by the thinking and research norms of his discipline during the period in which he lived. In his discussion contrasting his perceptions of differing tribal relationships to wild rice, he does not veil what he believes is a "right" relationship with the plant. Menomini appear to be missing out on a prime economic opportunity, whereas neither the Dakota nor Ojibwe have "mythic scruples" preventing them from gaining wild rice profits. The Ojibwe, however, according to Jenks, are the only ones "taking full advantage" of an economic profit motive…[26] He attempted to construct a hierarchy of civilization. He felt no reservation in asserting his opinions as objective.

Wild rice grows in spite of Jenks' observation that the Indians are its enemy: "[T]he Indian, by his use of the wild-rice seed, is a great enemy of the plant, for it will be shown that the plant, unless it is artificially sown, is gradually being extinguished in

---

[24] Jenks, ibid, page 1019.
[25] Jenks, ibid, page 1019.
[26] Jenks, ibid, page 1019.

such beds as are continually used."[27] Jenks, however, cannot ultimately draw that conclusion. He learns that from lake to lake, wild rice populations flourish and crash in cyclical patterns. "Information from such sources as Chief Pokagon and government farmers at Indian reservations show that [wild rice] fails once in three or four years."[28]

Jenks is at a loss to make sense of a plant that both flourishes and crashes but does not become extinct. He cannot make sense of Indian cultivation techniques, so intricate and detailed, apparently requiring great skill, and yet somehow so "primitive." He describes in clear, laudatory terms the skill necessary to winnow rice:

> [T]hey then grasp both ends of the tray, and by a very simple, yet clever movement gradually empty the chaff. The tray is lifted several inches and carried slightly outward. This upward and outward movement is checked quite suddenly, and the tray, while being drawn toward the body of the laborer is let down again. The light chaff is thus spilled over the outer edge when the tray is at its highest point and just as it is suddenly jerked toward the laborer. However, because of the rapidity with which this shaking is done, the movements appear neither sudden nor jerky, and the chaff falls almost constantly.[29]

His admiration for these skills is diminished by his final conclusion that wild rice is in fact holding back Indians from further progress, "unless, indeed, they left it behind them, for with them [wild rice] was incapable of extensive cultivation."[30] He notes that "one year the gathering of 3 or 4 per cent of the crop gave food for a winter's consumption, another year its failure, which might occur for any one of many reasons, threatened the people with starvation."[31] From his training, it seems that people should

---

[27] Jenks, ibid, page 1026.
[28] Jenks, ibid, page 1095.
[29] Jenks, ibid, page 1071.
[30] Jenks, ibid, page 1113.
[31] Jenks, ibid, page 1113.

not be able to subsist on so unpredictable a crop. But the crop and the people who harvest it defy this "natural law."[32]

> In civilization one class of people at least must have comparative leisure in which to develop short-cut methods of doing old things, of acquiring the traditions of the race, and mastering new thoughts and methods. Such leisure is impossible with a precarious food supply. But, in spite of these facts, for barbaric people during the period of barbarism, the most princely vegetal gift which North America gave her people without toil was wild rice. They could almost defy nature's law that he who will not work shall not eat.[33]

Jenks makes transparent some of the complexities of natural wild rice ecology and wild rice -- human interactions. Neither Ojibwe perspectives, nor insights he may have gleaned from later Western ecologists, however, were available to him. The discipline of ecology was in its infancy. Jenks lived before Nicholson and Bailey (c.1930's), and later May (1970's), had looked more closely at population cycles. Jenks lived before Lotka and Volterra developed a mathematical theory of how population cycles emerge through the interactions of several species.[34] Ojibwe, however, accepted and adapted to wild rice (and other species) population oscillations without the benefit of in-depth understandings of Western Ecology. Ecology, a discipline with its own limitations, may have offered Jenks some insights, but also would not have provided a comprehensive or full understanding of wild rice -- American Indian interaction and survival.

Jenks, eager to know more about the plant which occupied so much of his intellectual attention, was limited in his understanding, perhaps due to the infancy and norms of his disciplinary training and other Western disciplines. Disciplinary

---

[32] Jenks, ibid, page 1113.
[33] Jenks, ibid, page 1113.
[34] Nicholson and Bailey 1935, May 1972.

boundaries may, therefore, have prevented him, in part, from being open to Ojibwe perspectives and knowledge of wild rice.

American Indian-wild rice coexistence seemed a contradiction. “The Indian silently stalks into the labors of rice harvesting when the thrashing begins, and when it is completed he silently stalks out again…”[35] While a contradiction for Jenks, Ojibwe were not hemmed in by such norms or methods of inquiry.[36]

Frances Densmore

In stark contrast, Frances Densmore, ethnomusicologist, does not share Jenks' views of the contradiction between wild rice -- American Indian co-existence. They lived contemporaneously and shared some research methods and approaches to the study of plant ecology. In her book, How Indians Use Wild Plants for Food, Medicine & Crafts, she mimics Jenks in listing “wild” plants, including wild rice, their common, and “native” names. [37] Like Jenks, she is interested in harvesting practices, which include making maple sugar, gathering wild rice, and the brewing of vegetable based “beverages.” Her writing comprises ordered examinations of aspects of the ecology of “wild plants” used by Ojibwe. The similarities end there.

Unlike Jenks, Densmore is not interested in the “culture status of North American Indians.”[38] According to Archabal, “At a time when most Americans were interested in eradicating Indian culture, she labored with a sense of urgency to document their customs and music. Essentially self-taught and with little institutional

[35] Jenks, ibid, page 1070.
[36] Paul Schultz and Joe LaGaarde, January 2007, personal communication.
[37] Densmore, Frances, 1867-1957 : How Indians Use Wild Plants for Food, Medicine & Crafts [1974]. Dover Publications Inc.: New York, page 317.
[38] Jenks, ibid, page 1019.

support, she tirelessly collected and transcribed native music, conducting field studies among tribes from the Pacific Northwest to the Florida Everglades. By the time of her death in 1957, she had made 2500 sound recordings, published more than 20 books and 200 articles and lectured throughout the United States on Indian customs and music."[39]

She also respected Indigenous knowledge of plants and plant usage. She wrote for persons in her fields including: ethnomusicology, ethnobotany and anthropology. She was aware she was translating an oral tradition into a written one. Whether she believed that this work was somehow less significant if not written down, she lived at a time which privileged written documentation over oral. She did not need to draw conclusions about Ojibwe motives in understanding, collecting and using wild plants, nor find Indian -- wild rice relations antagonistic. To the contrary, she desired to share very detailed and sophisticated methods of collecting, preparing and using plants.

While Jenks' topic choices seem unconnected, Densmore's writing is less ambitious and more organized. She links well her previous work on "Chippewa music" to her work on wild herbs: "Herbs were used in the treatment of the sick and in the working of charms, and songs were sung to make the treatment of the charms effective."[40] In this volume, she recounts what she has learned through observation and interviews with Ojibwe regarding plants: as food, as medicine, as dyes, as charms, and as decorative arts.[41] Her questions do not appear disjointed because she is not troubled by, or uncomfortable with, Indian means to live, subsist and thrive.

---

[39] Archabal, Nina Marchetti. 1998. Frances Densmore: Pioneer in the Study of American Indian Music, pages 94-115 in Stuhler, Barbara and Gretchen Kreuter, eds. Women of Minnesota, MHS Press, St. Paul, MN.

[40] Densmore, ibid, page 281.

[41] Densmore, ibid, page 279.

She lived in accordance with the academic research methods of her time. To a reader today, she unnecessarily rationalizes particular Ojibwe practices and beliefs; her language is anachronistic: "knowledge that comes from dreams" may not "make sense" from a Western academic perspective, but [certain plants] "have effective medicinal traits, and are found in the pharmacopoeia of the white race."[42] She was perhaps more skilled than Jenks, however, in her observations and acceptance of certain traditions. She was still trained, however, to believe that the best understanding of medicine was found in Western traditions.

She respected knowledge emerging from different traditions. "It must be conceded that the use of plants by the Indians was based upon experiment and study. The Indians say that they 'received this knowledge in dreams,' but the response of the physical organism was the test of a plant as remedy."[43] She was perceptive in refraining from generalizations regarding plant usage. "The remedies are individual, not general, and an individual when questioned invariably replies, 'I can tell you about my own medicines. I do not know about other peoples, nor their uses of the same plants.' Thus it is frequently found that different people have different names and uses for the same plant."[44] Differing from Jenks who was compelled to devise a theory of "the culture status" of Ojibwe in relation to wild rice, Densmore allowed for the possibility of a less abstract relationship. She did not attempt to construct all-encompassing theoretical paradigms.

---

[42] Densmore, ibid, page 322.
[43] Densmore, ibid, page 322.
[44] Densmore, ibid, page 323.

Densmore, like Jenks, was fascinated by the ecology and harvesting of wild rice. She painstakingly recounts the rice-beating, tying, parching and winnowing. Unlike Jenks, she did not perceive Indians as enemies of wild rice. She accepts as legitimate some ecological processes that she may not have fully understood. "It was not the intention to harvest all the rice, a portion being allowed to fall into the water, or being sowed on the water as seed."[45] Unlike Jenks, she did not judge the activities of dancing and singing during the ricing period as a waste of time preventing Indians from gathering more rice.[46] Rather, she observes, "[r]ice making was an industry essential to the food supply… [with a] pleasant social phase, which was appreciated by old and young…Dogs and little children were running about, and the scene with its background of pines and shining lake was one of pleasure and activity."[47]

Densmore, whether unconcerned with, or more accepting of what she could not know, did not cast aspersions on Ojibwe knowledge or practices. She was not interested in questions about how to change Indian life or in making recommendations commensurate with preconceived notions of right cultural perspective. She was curious and appreciative "that Ojibwe people organize their view of the world with plants and music co-existing in symbiotic partnership."[48]

Densmore's work elicits many questions as it includes Ojibwe perspectives. As Child notes, "her study is not definitive nor does it reflect the sum of Ojibwe

---

[45] Densmore, ibid, page 316.
[46] Jenks, ibid, page 1074.
[47] Densmore, ibid, page 316.
[48] Child, B.J. Introduction in Densmore, Frances. 2005. Strength of the Earth: The Classical Guide to Ojibway Uses of Native Plants. Minnesota Historical Society Press: St. Paul, page vii.

knowledge."[49] Yet, even with its omissions, she makes evident the complexities of wild plant -- human interactions. She allows that there is much she does not understand and yet accepts [wild rice and other plants'] existence as stable and long-lasting, if unpredictable in human terms. From Densmore, readers do not learn how wild rice propagates, coexists with other species, including humans, nor why it grows in abundance some years and not others. And yet, from her, one understands more fundamentally the intrinsic value of wild plant -- human interactions in terms that do not exclusively emerge from traditional Western academic inquiry.

Thomas Vennum, Jr.

Thomas Vennum, Jr., ethnomusicologist, writing almost a century after Jenks and Densmore, observed that in spite of the long time lapse, "few outside Indian culture appreciate [wild rice's] place in Native American tradition or understand the complexity of the growth, harvest, and processing of the crop."[50] He wrote his book on wild rice after eighteen years of field research, eager for a thorough synthesis of past sources as well as the incorporation of "recent verbal recollections of traditional Ojibway elders" on wild rice.[51] Compared to his predecessors, Vennum writes in a very different time period informed by different scholarship. Perhaps because so much time had lapsed since Jenks and Densmore, and so little had been documented about wild rice, he felt compelled to put this volume together even though he identified himself primarily as an ethnomusicologist.

---

[49] Child, B.J. Introduction in Densmore, F. 2005. Strength of the Earth: The Classic Guide to Ojibwe uses of Native Plants. Minnesota Historical Society: St. Paul, MN, page viii.
[50] Vennum, Jr., T. 1988. Wild Rice and the Ojibway People. Minnesota Historical Society Press: St. Paul, page viii.
[51] Vennum, ibid, page ix.

Since Vennum's writing, there has not been as exhaustive or carefully written a treatment of wild rice in terms of its ecology, interpretations of Ojibwe legends, its economic role in Ojibwe life, and the history of Ojibwe harvest and cultivation.

The fact that so little research came before or has subsequently emerged is a tribute to Vennum's careful study. It may also say something about larger issues that include wild rice and research. The fact that Vennum spent *eighteen* years conducting research before writing on this subject suggests that ethnographies of wild rice -- Ojibwe relations and the complexity of wild rice ecology are not easily taken on. In contrast, Jenks completed his research in a year. It is unclear exactly how much time Densmore spent researching Native plants and their relationship to Ojibwe, but the duration of her study was likely much less than Vennum's. It may also be that pleas for more native perspectives by writers such as Deloria, Smith, Mihesuah and Ojibwe were emerging during Vennum's research. His work includes quotations from numerous interviews with Ojibwe. He does not claim these views tell a complete story. And he does not speak in place of his interviewees.[52]

In the latter twentieth century and now early twenty-first, for whom does Vennum write? While making contributions in their own right, previous works do not offer complete insights into the subject of wild rice -- Ojibwe relations and the ecology of wild rice. At the end of the twentieth century, many voices in American Indian studies changed the course of discussion and writings on American Indian culture, history and relationships to natural resources. The full spectrum of this knowledge is so

[52] Tuhiwai Smith, ibid, page 3; Mihesuah, ibid, page1.

recently acknowledged, but no less urgently called for: "there is a great and rich store of information still locked in the hearts and minds of Indians all over the nation."[53]

Vennum's work is nothing less than a *tour de force*. But he appears to piece together a still largely unarticulated story. He draws on historical works of other researchers for his information and information from interviews with Ojibwe elders. Formidable is the task to grasp well an ecological understanding of wild rice from a tradition that is oral and translated into written form, from historical sources missing American Indian voices, and from a broad range of disciplines. Nabokov writes that "from a good ethnological monograph, one can obtain a 'feel' for a native group… viewed from within a native community."[54] Vennum is extremely sensitive and respectful of Ojibwe perspectives and oral history. Based on Nabokov's criteria and given the reviews of his work from native communities, Vennum's monograph is a successful ethnography.

Yet his main goal, documenting "recent verbal recollections of traditional Ojibway elders," is not a significant enough part of his book. Too much can be attributed to the broad headings of "the Law," "the Economics," and "the Future" of wild rice around which the book is organized. And thus much is omitted.[55] Each of these headings could be a book and yet he appears to try to make amends for many years passing without much attention paid ricing and the Ojibwe.

Vennum, as with Jenks and Densmore, meticulously observed rice harvests, its habitat, camp traditions, wild rice legends and ceremonies, and its changing role in the

---

[53] Mihesuah, ibid, page 2.
[54] Nabakov, P. 2002. A Forest of Time: American Indian Ways of History, Cambridge University Press: Cambridge, U.K, page 237.
[55] Mihesuah, ibid, page 4.

lives of the Ojibwe. From beginning to end, this is his book's strength. While covering much in one volume, he asks important questions: "What role can the Ojibway expect wild rice to play in their future? What are the "long-needed Indian perspectives" on wild rice?

The book ends with conclusions that "Ojibway who remember the past are generally critical of changes in the harvest and processing of wild rice. Most say that earlier people knew how 'to take care of the rice.'"[56] In this section, Vennum does a laudable job of what Mihesuah endorses: "scholars can strive for accuracy by scrutinizing all available written data, by incorporating the accounts and interpretations of the participants and descendants of the participants… into their analyses…"[57] With foreboding, he reflects the views of elders that the grain itself may be changing in irreversible ways. He cites Norma Smith of Mole Lake:

> We have a deep feeling of satisfaction and gratitude as we sack up the rice again toward evening. We do not feel the ache in our arms as we anticipate the gain. If the rice is light, we will sell it for seed. If it is heavy, we will take it home to cure for eating. And tomorrow we will be back again for another day of picking… I often wonder what my children will do when the rice is gone forever. What will take its place when this last tradition is gone?[58]

Vennum comes a long way from Jenks. In particular, he carries forward some of the richness of Densmore's work. He does not restrict his views and methodology; he does not attempt a hierarchy of culture. He is not interested in the "culture status" of Ojibwe and includes many of their voices in his work. While likely privy to intimate details of tribal life, he appears to use discretion when writing in order not to reveal

---

[56] Vennum, ibid, page 296.
[57] Mihesuah, ibid, page 5.
[58] Vennum, ibid, page 299.

information deemed private or sacred.[59] One observes that his treatment of "Ojibway knowledge of wild rice" is not "unitary" in that he includes a large number of voices from many age groups, gender and band affiliations. With this approach one can observe the "cultural ambiguity common among Indians…"[60] While Vennum is trained in Western academic traditions, his sensitive orientation rewards all of us with greater understanding of wild rice and the Ojibwe than anything recorded to date in Western scholarship. Filling in some of the glaring gaps, Vennum's research, however, by no means makes the picture complete.

Benefiting from broader perspectives of a larger number of community members, additional pathways of ecological research may be forthcoming. While Champagne does not believe that Indian scholars have a monopoly on Indian studies, he concedes that "Indian scholars may have the advantage of direct access."[61] Smith observes: "Indigenous peoples want to tell our own stories, write our own versions, in our own ways, for our own purposes. It is not simply about giving an oral account or a genealogical naming of the land and the events which raged over it, but a very powerful need…to bring back into existence a world fragmented and dying."[62] She defines this pathway more clearly, the pathway of defining approaches to making manifest ecological knowledge:

> I have become skeptical of the mystical, misty-eyed discourse that is sometimes employed by indigenous people to describe our relationships with the land… I believe that our survival as peoples has come from our knowledge of our contexts, our environment, not from some active beneficence of our Earth Mother. We had to know how to survive. We

[59] Mihesuah, ibid, page 4.
[60] Mihesuah, ibid, page 38.
[61] Champagne, ibid, page 182.
[62] Tuhiwai Smith, ibid, page 28.

> had to work out ways of knowing, we had to predict, to learn and reflect, we had to preserve and protect, we had to defend and attack, we had to be mobile, we had to have social systems which enabled us to do these things. We still have to do these things.[63]

Summary

Jenks learned that wild rice populations fluctuate over the course of several years. While he did not understand the reason for these fluctuations or Indian people's ability to rely on a seemingly unreliable crop, he documented their existence. These observations, however, and the fact of his interest in questions of wild rice, might have led to potentially more "informative" interactions for his research purposes, for his specific and inferred audiences. In hindsight, his goal to know the "culture status" of "the wild rice gatherers" was the wrong one, preventing him from gleaning ecological knowledge from within native communities.

Densmore, less interested in economic or cultural trajectories, learned much about wild plant propagation and their human uses. She observed the co-existence of wild rice and humans as stable and long-lasting. While all aspects of such propagation and usage were unclear to her, she was not troubled with describing, in detail, how and why humans and wild rice co-existed. Her work was a sensitive inquiry, but remains just a small part of the ecological story of wild rice.

Vennum benefited from his tenure working with American Indian communities and also from sensitive ethnographies such as those carried out by Densmore. He desired to include more native voices in drawing out perspectives on wild rice. Yet, he may have unnecessarily circumscribed his work, taking on too much and confusing his audience with broad headlines of "the law, folkore, and economics of wild rice."

[63] Tuhiwai Smith, ibid, page 10.

Have we come full circle? Hardly. The evolution in scholarship is ongoing, as it is in legislative discussions and individual households. Clear now are the gaps in Western research as outlined in the paper. First, the practices and *attitudes* of the early part of the last century have not disappeared. Native voices are still absent from mainstream universities and research, as they are from legislative halls and mainstream culture.

> Without the opportunity for Indian peoples to tell their historical experiences in their many different ways, and without the burden upon non-Indian American [scholars] to somehow weave Native ways… into the research and methodologies of their accounts, the fullness of the North American experience will remain unwitnessed and alternative visions for its future unrevealed.[64]

Second, the formal rules of scholarship even inhibit scholars who were not blinded by disciplinary dogma. Densmore and Vennum, in trying to follow "approaches and methodologies" taught them in Western academies, seemed unduly constrained. Densmore felt she needed to insist on a Western "rational" use of plants for medicinal purposes. Insisting that such knowledge came from dreams rather than experiments could not be "correct." Yet, she aligned her conclusions with paradigmatic views: "the response of the physical organism is the test of the plant as remedy." That may have been the case, but "denies the validity of indigenous cultural knowledge and systems for living within our environments."[65] And Smith insists, "More traditional, indigenous points of view are criticized because they do not make sense…"[66]

Now, over a century later, Smith asserts, "It galls us that Western researchers and intellectuals can assume to know all that is possible to know of us, on the basis of

---

[64] Nabokov, ibid, page 239.
[65] Smith, ibid, page 3.
[66] Smith, ibid, page 14.

their brief encounters with some of us. It appalls us that the West can desire, extract and claim ownership of our ways of knowing."[67] Mihesuah adds, "Many scholars write as if they and other members of their profession have the monopoly on truth." And Deloria points to the main tension, I argue, surfacing in Jenks' work: "Indeed, many authors of comfortable fictions sit in positions of power, setting the standards for how we should write about Indians."[68]

Fast-forwarding to current discussions about Ojibwe culture and natural resources which occurred in the 2007 Minnesota Legislature, "indigenous communities have quite valid fears about further loss of their cultural knowledges" and protection of rights accrued through treaty negotiation.[69] White Earth elder, Paul Schultz, explains,

> The lives and spiritual well-being of Anishinaabeg are inextricably tied to wild rice, in a way that science cannot explain or comprehend… Our concern is that Western development and Western science, in their quest for doing whatever they have designated is important, would operate with total disregard for that truth. That's what they miss. This isn't about owning the rice. It's about rice and the Creator, being the symbol that we are meant to be. If the rice were to disappear…our people would be in great confusion and despair…[70]

While many decision-makers have not necessarily read relevant academic literature, they are still influenced by many of the same ideas and norms that prevailed a century ago. Smith explains, "It angers us when practices linked to the last century are still employed to deny the validity of indigenous peoples' claim to land, territories, ...,

[67] Smith, ibid, page 3.
[68] Mihesuah, ibid, page 5.
[69] Smith, ibid, page 5.
[70] Schultz, P. White Earth Band of Anishinaabeg elder in Clancy, F and M. Adamek, "Chapter Seven: Teaching as Public Scholarship" in Peters, S.J. et al., eds. 2005. Engaging Campus and Community: the practice of public scholarship in the American land-grant university system. Kettering Foundation: Dayton, OH, pages 242-243.

natural resources,… and systems for living within our environments."[71] Jenks' work, in particular, but also that of Densmore and Vennum, their methodologies and conclusions, are not often enough screened in terms of what remains valid and what is anachronistic. Without that kind of scrutiny, outdated views prevail as was seen in the 2007 Legislature. Academic works in the past, as well as today, are not innocent. Future research relies on perceiving the gaps in order to fill them. Such practices need to include: many more native voices, more nuanced and alternative understandings of "acceptable research protocols," and a realization that these issues matter beyond narrow disciplinary boundaries.

---

[71] Smith, ibid, page 3.

References

Archabal, Nina Marchetti. 1998. "Frances Densmore: Pioneer in the Study of American Indian Music, pages 94-115 in Stuhler, Barbara and Gretchen Kreuter, eds. Women of Minnesota, Minnesota Historical Society Press, St. Paul, MN.

Champagne, Duane. 1998. Natives and Academics: Researching and Writing about American Indians. University of Nebraska Press: Lincoln, NE.

Child, Brenda in Densmore, Frances. 2005. Strength of the Earth: The Classical Guide to Ojibway Uses of Native Plants. Minnesota Historical Society Press: St. Paul.

Deloria Jr., Vine. 1997. Red earth, white lies: Native Americans and the myth of scientific fact, Fulcrum Pub., Golden, CO**.**

Densmore, Frances. 1974. How Indians Use Wild Plants for Food, Medicine & Crafts, Dover Publications Inc.: New York.

Jenks, Albert E. 1901. The Wild Rice gatherers of the upper lakes: study in American primitive economics, Government Printing Office: Washington D.C.

Jenks, Albert E. 1907. "Anthropologic Miscellanea," *American Anthropologist*, Vol. 9, No.2, April-June.

Jenks, Albert E. 1921. "The Relation of Anthropology to Americanization," The Scientific Monthly, March.

Johnson, Eldon. 1992. "A.E. Jenks and the University of Minnesota Algerian Excavations," in Breitborde, L.B., ed. "Alonzo Pond and the 1930 Logan Museum Expedition to North Africa: The 1985 Beloit College Symposium." Logan Museum Bulletin, Vol.1, No. 1.

Popular American plant-names. 1892. The Journal of American Folk-Lore, Vol. 5, April-June, No. 13.

LaGarde, Joseph. 2007. White Earth Reservation elder, personal communication.

Mahoney, Timothy. House Floor testimony, May 15, 2006, and personal communication on May 23, 2007.

Mason, Otis. 1891. The Natural History of Folk-Lore. Journal of American Folk-Lore, Vol. 4, April-June, No. 13.

May, Richard M. 1972. Time-delay versus stability in population models with two and three trophic levels. Ecology 54.

Mihesuah, Devon A. 1998. Natives and Academics: Researching and Writing about American Indians. University of Nebraska Press: Lincoln, NE.

Nicholson, A. J. and Bailey, V. A. 1935. The balance of animal populations. Proc. Zool. Soc. London 1935.

Nabakov, Peter. 2002. A Forest of Time: American Indian Ways of History, Cambridge University Press: Cambridge, U.K.

Oelke, Ervin. 2006. The Saga of the Grain. Lakeville, MN: Hobar Publications.

Russell, F. 1902. Know, then, thyself. Journal of American Folk-Lore. Vol. 15, Jan-Mar.

Schultz, Paul. 2007. White Earth Reservation elder, personal communication.

Schultz, P. White Earth Reservation elder in Clancy, F and M. Adamek. Chapter Seven: Teaching as Public Scholarship in Peters, S.J. et al., eds. 2005. Engaging Campus and Community: the practice of public scholarship in the American land-grant university system, Kettering Foundation: Dayton, OH.

Summary of Second Annual Meeting of the American Folk-Lore Society. 1891. Journal of American Folk-Lore. Vol. 4, January-March, No. 12.

Tuhiwai Smith, Linda. 1999. Decolonizing Methodologies. St. Martin's Press: New York.

Vennum, Jr., Thomas. 1988. Wild Rice and the Ojibway People. Minnesota Historical Society Press: St. Paul.

White, Bruce A. 1998. Fraser River pink salmon catch and exploitation patterns: 1989-1995. Pacific Salmon Commission: Vancouver, B.C.

CHAPTER 2

Delays in Nutrient Cycling and Plant Population Oscillations

Published: **Pastor, J., and Walker, R.D. (2006) Delays in nutrient cycling and plant population oscillations. Oikos, 112, (3): 698-705.**

Abstract

It is well known that delay-differential and delay-difference equations can produce plausible simulations of population oscillations, but many of these equations lack a specific mechanism responsible for the delay. We suggest that delays in release of nitrogen from decomposing litter, caused by microbial uptake, could produce oscillations in populations when the delay in the release of nitrogen is longer than the characteristic time scale of nitrogen uptake. We present a model which bifurcates from fixed point equilibria, to apparently bounded periodic orbits (oscillations), and finally to extinction of the plant population as the parameter controlling microbial uptake of nitrogen during litter decay increases. We suggest that such a mechanism may be especially important for annual plants which do not store nitrogen in perennial tissues to buffer delays. Natural populations of wild rice (*Zizania palustris*), an annual plant, oscillate with approximately four-year periods. Our model qualitatively mimics the period and shape of population oscillations in wild rice with parameter values in the range of those determined by experiments. The model therefore demonstrates a logical and experimentally plausible link between plant population dynamics and the ecosystem

processes delaying the cycling of limiting nutrients.

Introduction

Since the pioneering studies of Nicholson and Bailey (1935) and Elton and Nicholson (1942), ecologists have been fascinated with the causes and consequences of population fluctuations. More recently, time series analyses show that natural populations exhibit complex dynamics, including oscillations of one or more periods and possibly chaotic dynamics (Witteman et al. 1990, Tilman and Wedin 1991, Turchin and Taylor 1992, Ellner and Turchin 1995, Lindstrom et al. 1997).

Uncovering what causes population oscillations is a difficult theoretical and experimental issue. It is well known that time delays in differential and difference equations of population growth cause their solutions to oscillate (Hutchinson 1948, Wangersky and Cunningham 1957, Jones 1962, May 1972, 1974). Although such delays have been suggested as one possible cause for oscillations in real-world populations, these theoretical studies have not explicitly included a biological mechanism that accounts for the delays.

We are particularly interested in whether time delays in nutrient cycles caused by slow decay and accumulation of litter cause oscillations in plant populations. Several experimental studies have reported that litter accumulation appears to inhibit growth of plant populations (Al Mufti et al. 1977, Sydes and Grime 1981, de Jong and Klinkhamer 1985, Knapp and Seastedt 1986, Bergelson 1990, Carson and Peterson 1990, Tilman and Wedin 1991). In some cases, litter accumulation appears to suppress seed emergence and survival the following year (Bergelson 1990, Carson and Peterson

1990). Knapp and Seastedt (1986) suggest that litter accumulation depresses temperature and moisture, which in turn slows decay rates and depresses productivity by decreasing nutrient availability. de Jong and Klinkhamer (1985) suggested that uptake of nutrients by microbes decomposing fresh litter depresses nutrient availability, and hence plant production, during the following growing season. But of all these studies, only one (Tilman and Wedin 1991) has proposed a model and presented some observations that suggest litter accumulation might not simply reduce productivity but also cause oscillations. However, the mechanism for suppression of productivity by the litter was not specified in this model.

We suggest that microbial uptake of nitrogen, the nutrient often the most limiting in terrestrial ecosystems (Vitousek and Howarth 1991), could cause delays in its availability that could in turn cause oscillations in productivity. This delay in the release of nitrogen happens because the C/N ratio of a fresh cohort of litter (20 to 70) is greater than that of the microbes decomposing it (10 or less). Therefore, for every unit of C taken up by microbes from the litter, there is insufficient nitrogen to be taken up along with it to make one unit of microbial biomass (Berg and McClaugherty 2003). To support the growth of their populations, microbes must compete for and import nitrogen from the inorganic nitrogen pool to make up this deficiency, a process known as immobilization (Berg and McClaugherty 2003). Therefore, in the initial stages of litter decay, the litter-microbe complex temporarily accumulates nitrogen as microbial biomass grows. Eventually, because nitrogen is imported while carbon is respired off as CO_2, the C/N ratio of the litter-microbe complex approaches that of the microbes. At the same time, the growth of microbial biomass slows as the supplies of easily decomposable carbon compounds, such as sugars, are depleted. Net nitrogen immobilization then ends and the litter enters a subsequent phase of net nitrogen mineralization in which there is a net release of NH_4 or NO_3 through microbial metabolic waste or death. These inorganic forms can be taken up across root membranes. Inorganic nitrogen availability to plants is therefore determined by the net balance of the rates of nitrogen immobilization and mineralization. Net nitrogen availability to plants therefore depends on the relative proportions of litter cohorts in immobilizing and mineralizing stages of decay.

The period of nitrogen immobilization may last for several months for species producing nitrogen-rich, rapidly decomposing litters or several years for species producing nitrogen-poor, slowly decomposing litters (Berg and McClaugherty 2003). The period of immobilization, therefore, can result in a substantial time delay in the cycling of nutrients through an ecosystem. Numerous litterbag studies demonstrate these dynamics, which are not necessarily restricted to nitrogen but can also apply to phosphorus or any nutrient for which the carbon to nutrient ratio in litter is much greater than in microbes (Berg and McClaugherty 2003).

Nitrogen cycling and population oscillations in wild rice, an annual plant

In this paper, we are interested in the mechanism of delays in nutrient availability and their effect on plant population dynamics, questions which have previously been unaddressed in the literature. Wild rice (*Zizania palustris*), an annual plant, may be a good candidate for examining that question. The productivity of almost all wild rice ecosystems cycles with periods of 3-5 years; highly productive years are often followed by unproductive years, which are in turn followed by a gradual recovery

(Jenks 1899, Moyle 1944, Grava and Raisanen 1978, Atkins 1986, Lee 1986, Aiken et al. 1988, Keenan and Lee 1988, Archibold et al. 1989). Although wild rice growth is correlated with rice density, alkalinity, and water temperature and depth (Lee and Stewart 1983), applications of nitrogen usually increase wild rice productivity (Grava and Raisanen 1978, Grava 1982). Keenan and Lee (1988) observed a marked decline in wild rice production five years after a lake in Ontario was seeded. Of all nutrients in the sediments, available inorganic nitrogen showed the greatest decline coincident with the decline in productivity (Keenan and Lee 1988).

Because it is an annual, wild rice does not store nutrients in rhizomes over winter and it must therefore meet its nutrient requirements by uptake from inorganic nitrogen in sediments and the water column each year (Grava and Raisanen 1978). Fifty percent of the annual uptake of nitrogen occurs during a 10-day period 1.5-2 months after emergence early in spring and much of the rest occurs shortly thereafter during seed set (Grava and Raisanen 1978, Grava 1982). Thus any asynchrony or delay in the supply of nutrients with respect to the timing of uptake can reduce productivity directly via limitations to growth or indirectly through limitations on seed production.

There is some evidence that nitrogen immobilization in decaying fresh litter may cause this delay. Sain (1983) shows that the litter from the previous year immobilizes nitrogen from the surrounding sediments and water column during periods of most rapid uptake by the following year’s crop. Sain (1983) also found that net nitrogen mineralization from fresh litter does not begin until the end of the following growing season, or even the second year. Therefore, the nitrogen in an annual cohort of litter may not be available for the following year’s wild rice crop because the timing of net nitrogen release from decomposing litter is asynchronous with the timing of the uptake by the following year's rice plants (Sain 1984, Keenan and Lee 1988). The asynchrony in uptake and release of nitrogen from decomposing litter delaying nitrogen supply to plants may cause oscillations in productivity.

Several alternative causes of population oscillations can be discounted in wild rice ecosystems. First, because wild rice often forms nearly monotypic stands, competitive interactions with other plant species cannot lead to stable limit cycles (oscillations). Second, oscillations do not appear to be caused by broad-scale sunspot, climate, weather, or hydrologic cycles because populations in adjacent lakes or in different parts of the same lake often fluctuate out of phase (Lee 1986). Third, interactions of wild rice with higher trophic levels or diseases do not appear strong enough to cause and sustain oscillations. Bacterial, fungal, and viral diseases may afflict wild rice, but epidemic outbreaks of these diseases are uncommon in natural stands (Aiken et al. 1988). The predominant insect pests (Peterson et al. 1981) of wild rice are riceworm (*Apamea apamiformis*) and the rice stalk borer (*Chilo plejadellus*). While riceworm populations in Manitoba were reported to go through extreme highs and lows between 1957 and 1963, there was no evidence these extremes in the insect population influenced or were affected by oscillations in wild rice populations (Peterson et al. 1981). Although rice stalk borers are found throughout natural wild rice stands in Minnesota, only 5.1 – 9.2% of the grain was lost from infested stands compared with non-infested stands for three different sites. No stems were lost due to infestations (Peterson et al. 1981). In high density, managed wild rice paddies in Minnesota, blackbirds occasionally reduce the amount of wild rice grain by up to 52% (Aiken et al.

1988), but such high consumption rates are most likely stochastic and there is no evidence that such reductions result in limit cycles between blackbirds and rice. Ducks and muskrats occasionally eat young wild rice stems and shoots, but their populations are rarely large enough to significantly affect wild rice stands (Aiken et al. 1988). Genetic factors that delay seed germination for more than one year may result in oscillations. This phenomenon, however, is not discussed in the literature. Our own attempts to germinate wild rice seeds have proven very unsuccessful when seeds have been stored in water and sediments for more than one year.

We ask whether delays in the recycling of limiting nutrients through microbial uptake of nitrogen into decomposing litter could contribute to oscillations in wild rice populations.

Model Description

To examine more precisely how immobilization of nitrogen in decomposing litter causes a time delay in the cycling of limiting nutrients in natural stand wild rice ecosystems and consequently annual oscillations in productivity, we constructed a simple model of nitrogen cycling through a wild rice system (Fig. 1). The purpose of such a simple model is to capture the salient features of the hypothesis to see whether the major predictions (in this case oscillations in the plant pool) follow logically from the premises (in this case immobilization of nitrogen by microbial uptake into the first year cohort of litter followed by subsequent mineralization by an older cohort and sediment organic matter). The model contains two cohorts of litter. The first, *L1*, contains the nitrogen in plant production from the previous year (*P*) plus an additional fraction (*a*) of nitrogen in plants (*aP*) required by microbes to satisfy their demand (nitrogen immobilization) obtained from the available nitrogen pool (*N*) . The total amount of nitrogen in *L1* is then transferred to the second cohort of litter, *L2*, the following year. *L2* mineralizes a fraction k_1 of its nitrogen and the remaining fraction (1 - k_1) is transferred to the sediment nitrogen pool, *S*. The sediment nitrogen pool also mineralizes a smaller fraction of its nitrogen (k_2). A fraction, *e*, of inputs (*I*) and the mineralized nitrogen from *L2* and *S* are exported from the system via leaching or transport. The remaining fractions (1 - *e*) of inputs and mineralization from *S* and *L2* are transferred to *N*. Plants (*P*) take up all available nitrogen after the mass balance transfers of immobilization, mineralization and inputs through *N* are satisfied. Plants live for one year and then transfer their nitrogen to *L1*. This is a linear model which is described by the following set of difference equations:

$$\begin{aligned} S_{t+1} &= (1-k_2)S_t + (1-k_1)L2_t \\ N_{t+1} &= (1-e)I + (1-e)k_1 L2_t + (1-e)k_2 S_t - aP_t \\ P_{t+1} &= N_{t+1} \\ L1_{t+1} &= P_t + aP_t \\ L2_{t+1} &= L1_t \end{aligned} \tag{1}$$

The delay in supplying nitrogen to plants arises because there is a finite probability that some of the available nitrogen will be recirculated in the loop *N-L1-L2-N* rather than enter the plant pool through the paths *L2-N-P* and *L2-S-N-P*. Thus, the higher the fractional immobilization rate, *a*, or the higher the litter inputs into *L1* from *P*, the greater the probability that a given atom of nitrogen will remain in this loop. This decreases the nitrogen available for uptake into *P* the following year.

We parameterize the model with the following parameter values, which are reasonable values from the literature for wild rice or similar graminoid wetland plants

(Grava and Raisanen 1978, Sain 1983, Azam et al. 1991, Adachi et al. 1997, Bridgham et al. 1998): k_1 = 0.45 yr^{-1}, k_2 = 0.06 yr^{-1}, e = 0.0001 yr^{-1}. I = 0.00001 g m^{-2} yr^{-1}, $S(0)$ = 10 g m^{-2} (midway between minimum and maximum values as reported in Lee 1986), initial values for all other components = 0. We varied the fractional nitrogen immobilization rate (a, yr^{-1}) and examined the response of the plant N pool (P), which we use as a surrogate for net primary productivity.

Eq. (1) can be stated more compactly in matrix form:

(2)

$$\begin{bmatrix} P \\ L1 \\ L2 \\ S \\ N \end{bmatrix}_{t+1} = \begin{bmatrix} -a & 0 & k_1(1-e) & k_2(1-e) & 0 \\ 1+a & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1-k_1 & 1-k_2 & 0 \\ -a & 0 & k_1(1-e) & k_2(1-e) & 0 \end{bmatrix} \begin{bmatrix} P \\ L1 \\ L2 \\ S \\ N \end{bmatrix}_{t} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ I \end{bmatrix}$$

The advantage of this matrix form is that we can examine how the different values of a affect its eigenvalues (λ_i), and therefore the nature and onset of possible oscillations (Strogatz 1994). Eigenvalues can be real numbers or complex conjugate pairs. Real eigenvalues in the range ($-1 < \lambda_i < 1$) cause perturbations near equilibrium to decay to a fixed point with ($-1 < \lambda_i < 0$) or without ($0 < \lambda_i < 1$) oscillations. Eigenvalues can also be complex conjugate pairs, which can also generate oscillations. For a linearized difference equation model, when the modulus of complex conjugates is less than 1, solutions remain within the unit circle in the complex plane and oscillations are damped to a fixed point equilibrium. But when the modulus is greater than 1, the fixed point equilibrium is unstable and trajectories spiral away from it either to a periodic orbit or to unstable growth (Strogatz 1994). We searched for values of *a* for which the modulus of complex conjugate eigenvalues exceeded 1.

Results

Different immobilization rates, *a*, cause the plant nitrogen pool to oscillate in different ways (Fig. 2). Low immobilization rates (a = c. 0.4 yr^{-1}; Fig. 2a) yield small delays in the cycling of nitrogen through litter and sediments and oscillations of plant nitrogen are dampened as the system settles on a stable, positive-valued fixed point equilibrium. Although these oscillations are dampened, they remain quite large for several decades. The size of the equilibrium plant nitrogen pool is within the range of calculations using measurements of wild rice biomass growth in typical organic sediments (Day and Lee 1990) and measured values of nitrogen concentration in the plants at the end of the growing season (Grava and Raisanen 1979).

The fixed point equilibrium becomes unstable and apparently periodic orbits or bounded oscillations of plant nitrogen of 3-4 year periods begin to appear as higher immobilization rates ($a >$ c. 0.6 yr^{-1}) increase the delay in the cycling of nitrogen through litter (Fig. 2b). We qualify the appearance of these trajectories as "apparently periodic or bounded" because we have not excluded very slow divergence to infinity, even with model runs of a thousand years. Therefore, in an ecological, if not strictly mathematical, sense we (cautiously) conclude that they are bounded. Further increases caused multiple oscillations of different periods with increasing amplitudes until finally at even higher values (a = 0.8; Fig. 2c) pulses of immobilization and subsequent mineralization led to extinction of the plants.

When *a* is greater than the critical value of c. 0.6 yr^{-1}, a productive year produces a large cohort of litter which then causes a large pulse of microbial uptake (*aP*) into *L1* the following year. This large pulse of microbial uptake in turn decreases nitrogen availability and hence productivity. During the next two years, this large litter cohort moves through the mineralizing phases, *L2* and then *S*, releasing the nitrogen it carries with it into the available nitrogen pool and allowing a gradual recovery of plant production.

That oscillations appear once *a* exceeds a critical value is confirmed by calculation of the five eigenvalues of the matrix in Eq. (2). One of the eigenvalues is 1.0 because in Eq. (1) P_{t+1} and N_{t+1} are equal and therefore mathematically redundant (although biologically we think it is important to keep them distinguished from one another). This eigenvalue does not contribute oscillations. Two of the other eigenvalues are real and in the range (-1,1) and are therefore responsible for damping to a fixed point equilibrium. The two remaining eigenvalues form a complex conjugate pair. The modulus of the complex conjugate pair exceeds 1 when $0.66 < a < 0.67$ and a periodic orbit away from the fixed point equilibrium emerges, followe by extinction of the plant population at even higher values.. Thus, microbial immobilization of nitrogen is a bifurcation parameter in this model. Below the critical value of $a = 0.66$, solutions have damped oscillations to a fixed point equilibrium, but above this value the trajectory spirals away from a fixed point to a periodic orbit and eventually to extinction of the plant population.

Discussion

The model demonstrates that population oscillations could logically arise from delays in nitrogen cycling caused by microbial uptake into fresh litter to satisfy microbial demands. Because microbes must take up nitrogen from the available nitrogen pool, they decrease the proportion of this pool available to plants, especially in the year following a productive year when litter inputs to *L1* are high. As this large litter cohort begins to mineralize in subsequent years, nitrogen availability increases making plant recovery possible. The cycle then begins again with production of a new large litter cohort. To our knowledge, population oscillations have not previously been attributed to delays in nutrient cycles.

Our model runs were made with reasonably realistic parameter values, especially for the immobilization rate, *a* (Sain 1983, Berg and McClaugherty 2003) and initial sediment nitrogen pool (Lee 1986), resulting in estimates of the plant nitrogen pool within reported ranges, using biomass data from Day and Lee (1990) and nitrogen concentrations from Grava and Raisanen (1978). Further experiments are needed to refine our estimates of other parameter values, but the approximate correspondence of the results with measured values is encouraging.

We observed a bifurcation when microbial uptake incorporated an additional 66% of the original amount of nitrogen in plant litter into the first-year litter cohort. With microbial uptake rates less than this amount, oscillations are damped, but microbial uptake rates slightly greater than this amount result in apparently bounded oscillations. Experimental tests are needed to confirm these critical parameter values. However, preliminary litterbag experiments that we have been conducting with ^{15}N

labeled wild rice straw indicate an approximate microbial uptake of an additional 60% of the original nitrogen within the first several weeks of decay in late spring-early summer. Approximate correspondence of this measured value of microbial uptake rate with the critical value (0.66) of this parameter (a) producing a bifurcation in the model behavior to an apparently periodic orbit or bounded oscillations is encouraging. Whether or not this is asynchronous with nitrogen uptake by the growing plants remains to be determined experimentally.

The sequence of damped oscillations, to apparently bounded oscillations, to extinction of the plant population as a increases is reminiscent of the behavior of the discrete version of the logistic equation when r increases (May 1974, 1975, May and Oster 1976). In our model, the oscillations arise not because of a critical value of intrinsic population growth, but because of a critical value of microbial uptake which controls nutrient availability to the plant population.

Population oscillations have been reported for a few other annual plant species (Symonides et al. 1986, Thrall et al. 1989, Silvertown 1991, but see Rees and Crawley (1991) for an alternative interpretation), but there are very few long-term studies over many generations required to detect oscillations in annual plants (Silvertown 1991). Perhaps investigators find the juxtaposition of the terms “annual plant” and “long-term studies” oxymoronic. Although there is some evidence for density-dependent overcompensation of seed production at low densities in annual plants (Symonides et al. 1986, Symonides 1988, Thrall et al. 1989), others dispute whether this is a common mechanism for oscillations in annual plant populations (Crawley and May 1987). Although thinning of wild rice stands increases seed production (Aiken et al. 1988), we know of no studies that quantitatively demonstrate whether density-dependent seed production is strong enough to cause oscillations in wild rice populations.

Because annual plants do not have perennial tissues which can store nitrogen and thereby buffer annual variability in nitrogen supply from soils or sediments, delays in nutrient availability longer than a year may be an additional or alternative mechanism to density-dependent seed production that could also cause their populations to oscillate. The microbial delay in releasing nutrients to available form has to be longer than the characteristic turnover time of the plant nutrient pool, in this case 1 year, for oscillations to begin. In support of this idea, Rao and Mikkelsen (1976), Azam et al. (1991), and Verma and Bhagat (1992) found that incorporation of large amounts of fresh straw from white rice (*Oryza sativa*) depress productivity the following year, but this depression can be alleviated by adding fertilizer nitrogen (Azam et al. 1991) or by allowing the straw to partly decompose and begin to mineralize nitrogen before seeding the next year's crop (Rao and Mikkelsen 1976, also Adachi et al. 1997). Like wild rice, white rice is also an annual wetland graminoid species. These experiments with managed white rice systems lend credence to our proposed mechanism of litter-induced delays in nutrient availability in wild rice systems.

In contrast to annual plant species, perennial species store nutrients in roots, rhizomes, twigs, and bark. These species could mobilize these stored pools to mitigate environmental fluctuations in nutrient availability. But if the characteristic time scale of microbial uptake delay is longer than the plant nutrient pool turnover rate, such populations could also oscillate for the same reasons we describe for annual populations. Very long microbial delays are possible for very low quality litter, such as litter from conifer species (Berg and McClaugherty 2003). There is some limited field and modelling evidence that very long delays in nitrogen mineralization could cause wave-form dieback in coniferous ecosystems followed by recovery (Matson and Boone 1984, Pastor et al. 1987).

More recently, Tilman and Wedin (1991) have observed oscillations in a population of *Agrostis scabra*, a perennial grass. They have also constructed a two-compartment difference equation model of plant and litter biomass which exhibits oscillations and chaos, a model which was further analyzed by Bascompte and Rodriguez (2000). In their model, changes in plant biomass are a function of the product of litter accumulation (which includes the previous year's biomass production) and total soil nitrogen (a parameter which is held constant). In contrast to our model, litter accumulation does not affect total soil nitrogen in their model. The model predicts that the population oscillates when large amounts of accumulated litter inhibit plant growth the following year, but it does not specify a mechanism for that inhibition.

In contrast, our model describes a specific mechanism for how litter accumulation causes oscillations by affecting the net balance of nitrogen flux through the available N pool. In our model, this net flux is determined partly by microbial immobilization which diverts inorganic nitrogen from plant uptake when either the previous year's production (and therefore the new litter cohort) or the fractional immobilization rate, a, is large.

Models which incorporate specific mechanisms can be subject to strong experimental tests which manipulate the hypothesized mechanism. In our case, an experiment test of our hypothesis could consist of growing plants and adding either immobilizing litter (*L1*) or mineralizing litter (*L2*). Plants grown with mineralizing litter should have greater production the first year compared with plants grown with immobilizing litter. In subsequent years, the plant populations receiving different treatments should exhibit oscillations that are out of phase with one another.

Although their model does not explicitly describe a mechanism, Tilman and Wedin (1991) suggest that the underlying mechanism inducing oscillations might be delays in seedling emergence caused by the physical accumulation of litter mulch. This is an alternative, but not mutually exclusive, mechanism to our immobilization hypothesis; litter accumulation can delay both nutrient recycling and seedling emergence simultaneously. Experiments which control for the state of litter decay, as described above, and stage of seedling emergence are required to determine the relative contribution of each mechanism to population oscillations.

Our model simulations and analyses are not meant to conclude that oscillations observed in natural wild rice or any graminoid system are necessarily caused by delays in nutrient recycling to plant uptake. It is clear, however, that oscillations in wild rice as well as other plant populations have been commonly observed. Our model simulations strongly suggest that the delay in release of nitrogen from microbial immobilization during at least the first year of litter decay can potentially cause plant population oscillations. Plant species may induce their own population oscillations through life history characteristics such as litter quality which affects the cycling of nutrients through the ecosystem.

Acknowledgements

This research was supported by a grant from the National Science Foundation. We are grateful to the Fond du Lac Band of Lake Superior Chippewa for their critical logistic, labor, and material support of this project. We particularly thank Nancy Schuldt and Larry Schwarzkopf for their interest in, time and commitment to this project. Thanks to Brad Dewey for graphic assistance and to him and Bruce Peckham for comments on the manuscript.

References

Adachi, K., Chaitep, W. and Senboku, T. 1997. Promotive and inhibitive effects of rice straw and cellulose application on rice plant growth in pot and field experiments. - Soil Sci. Plant Nutr. 43: 369-386.

Aiken, S. G., Lee, P. F., Punter, D. et al. 1988. Wild rice in Canada. NC Press Limited.

Al Mufti, M. M., Sydes, C. L., Furness, S. B. et al. 1977. A quantitative analysis of shoot productivity and dominance in herbaceous vegetation. J. Ecol. 65: 759-791.

Atkins, T. 1986. The life history and ecology of wild rice. In: Wild rice, the natural crop Conference May 13-15. Lakehead University, Minaki, Ontario.

Archibold, O. W., Good, A. G. and Sutherland, J. M. 1989. Annual variation in wild rice growth. Can. J. Plant Sci. 69: 653-655.

Azam, F., Lodhi, A. and Ashraf, M. 1991. Availability of soil and fertilizer nitrogen to wetland rice following wheat straw amendment. Biol. Fertil. Soils 11: 97-100.

Bascompte, J. and Rodríguez, M. A. 2000. Self-disturbance as a source of spatiotemporal heterogeneity: the case of the tallgrass prairie. J. Theor. Biol. 204: 153-164.

Berg, B. and McClaugherty, C. A. 2003. Plant litter: decomposition, humus formation, carbon sequestration. Springer-Verlag.

Bergelson, J. 1990. Life after death: site pre-emption by the remains of *Poa annua*. Ecology 71: 2157-2165.

Bridgham, S. D., Updegraff, K. and Pastor, J. 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. Ecology 79: 1545-1561.

Carson, W. P. and Peterson, C. J. 1990. The role of litter in an old-field community: impact of litter quantity in different seasons on plant species richness and abundance. Oecologia 85: 8-13.

Crawley, M. J. and May, R. M. 1987. Population dynamics and plant community structure: competition between annuals and perennials. J. Theor. Biol. 125: 475-489.

deJong, T. J. and Klinkhamer, P. G. I. 1985. The negative effects of litter of parent plants of *Cirsium vulgare* on their offspring: autotoxicity or immobilization? Oecologia 65: 153-160.

Ellner, S. and Turchin, P. 1995. Chaos in a noisy world: new methods and evidence from time-series analysis. Am. Nat. 145: 343-375.

Elton, C. and Nicholson, M. 1942. The ten year cycle in numbers of lynx in Canada. J. Animal Ecol. 11: 215-244.

Grava, J. 1982. Wild rice production in Minnesota. Univ. of Minnesota Extension Bulletin 484: 18-21.

Grava, J. and Raisanen, K. A. 1978. Growth and nutrient accumulation and distribution in wild rice. Agron J. 70: 1077-81.

Hutchinson, G. E. 1948. Circular causal systems in ecology. Ann. N.Y. Acad. Sci. 50: 221-226.

Jenks, A. E. 1899. The wild rice gatherers of the Upper Great Lakes. PhD dissertation, Dept. of Anthropology, Univ. of Wisconsin, Madison.

Jones, G. S. 1962. The existence of periodic solutions of $f(x) = -\alpha f(x-1)[1+f(x)]$. J. Math. Annal. Appl. 5: 435-450.

Keenan, T. J. and Lee, P. F. 1988. Ecological relationships of wild rice, *Zizania aquatica.* 7. Sediment nutrient depletion following introduction of wild rice to a shallow boreal lake. Can. J. Bot. 66: 236-241.

Knapp, A. K. and Seastedt, T. R. 1986. Detritus accumulation limits productivity of tallgrass prairie. BioScience 36: 662-668.

Lee, P. F. 1986. Ecological relationships of wild rice, *Zizania aquatica.*4. Environmental regions within a wild rice lake. Can. J. Bot. 64: 2037-2044.

Lee, P. F. and Stewart, J. M. 1983. Ecological relationships of wild rice, *Zizania aquatica.* 2. Sediment-plant tissue nutrient concentrations. Can. J. Bot. 61: 1775-1784.

Lindstrom, J., Kokko, H. and Ranta, E. 1997. Detecting periodicity in short and noisy time series data. Oikos 78: 406-410.

Matson, P. A. and Boone, R. D. 1984. Natural disturbance and nitrogen mineralization in wave-form dieback of mountain hemlock in the Oregon Cascades. Ecology 65: 1511-1516.

May, R. M. 1972. Time-delay versus stability in population models with two and three trophic levels. Ecology 54: 315-325.

May, R. M. 1974. Biological populations with nonoverlapping generations: stable points, stable cycles, and chaos. Science 186: 645-47.

May, R. M. 1975. Biological populations obeying difference equations: stable points, stable cycles, and chaos. J. Theor. Biol. 49: 511-524.

May, R. M. and Oster, G. F. 1976. Bifurcations and dynamic complexity in simple ecological models. Am. Nat. 110: 573-599.

Moyle, J. B. 1944. Wild rice in Minnesota. J Wildl. Manage. 8: 177-184.

Nicholson, A. J. and Bailey, V. A. 1935. The balance of animal populations. Proc. Zool. Soc. London 1935: 551-598.

Pastor, J., Gardner, R. H., Dale, V. H. et al. 1987. Successional changes in soil nitrogen availability as a potential factor contributing to spruce dieback in boreal North America. Can. J. For. Res. 17: 1394-1400.

Peterson, A. G., Noctzel, D. M., Sargent, J. E. et al. 1981. Insects of wild rice in Minnesota. Univ. Minnesota. Agricultural Experiment Station Misc. Rep. 157, St. Paul, MN.

Rao, D. N. and Mikkelsen, D. S. 1976. Effect of rice straw incorporation on rice plant growth and nutrition. Agron. J. 68: 752-755.

Rees, M. and Crawley, M. J. 1991. Do plant populations cycle? Funct. Ecol. 5: 580-582.

Sain, P. 1983. Decomposition of wild rice (*Zizania aquatica*) straw in two natural lakes of northwestern Ontario. Can. J. Bot. 62: 1352-1356.

Silvertown, J. 1991. Modularity, reproductive thresholds and plant population dynamics. Funct. Ecol. 5: 577-580.

Strogatz, S. H. 1994. Nonlinear Dynamics and Chaos. Perseus Books.

Sydes, C. and Grime, J. P. 1981. Effects of tree leaf litter on herbaceous vegetation in deciduous woodland. II. An experimental investigation. J. Ecol. 69: 249-262.

Symonides, E. 1988. Population dynamics of annual plants. In: Davy, A. J., Hutchings, M. J., and Watkinson, A. R. (eds.), Plant Population Ecology. Blackwell, pp. 221-248.

Symonides, E., Silvertown, J. and Andreason, V. 1986. Population cycles caused by overcompensating density-dependence in an annual plant. Oecologia 71: 156-158.

Thrall, P. H., Pacala, S. W. and Silander, J. A., Jr. 1989. Oscillatory dynamics in populations of annual weed species, *Abutilon theophrasti*. J. Ecol. 77: 1135-1149.

Tilman, D. and Wedin, D. 1991. Oscillations and chaos in the dynamics of a perennial grass. Nature 353: 653-655.

Turchin, P. and Taylor, A. 1992. Complex dynamics in ecological time series. Ecology 73: 289-305.

Verma, T. and Bhagat, R. M. 1992. Impact of rice straw management practices on yield, nitrogen uptake and soil properties in a wheat-rice rotation in northern India. Fert. Res. 33: 97-106.

Vitousek, P. M. and Howarth, R. W. 1991. Nitrogen limitation on land and in the sea - how can it occur? Biogeochemistry 13: 87-115.

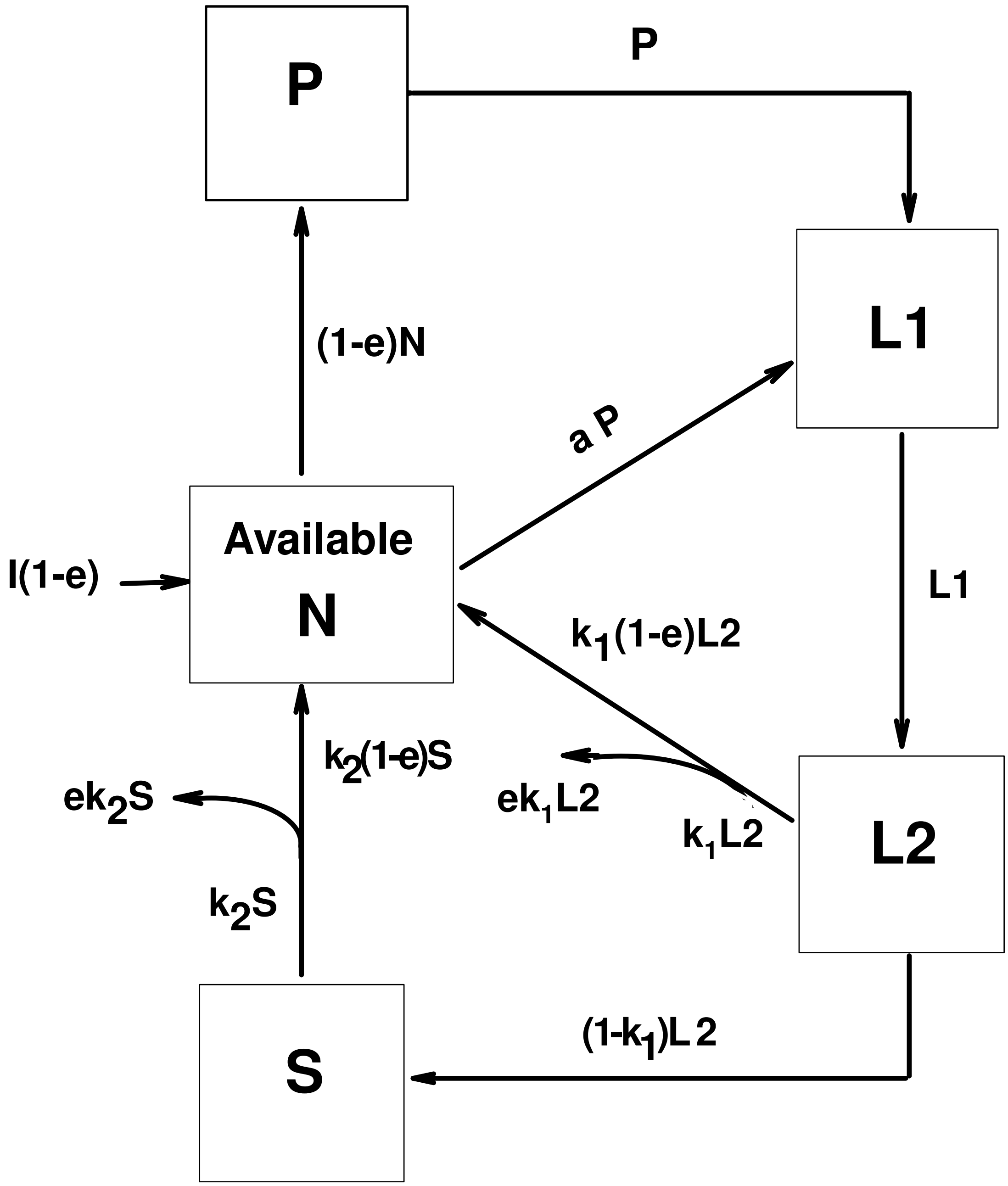
Wangersky, P. J. and Cunningham. W. J. 1957. Time lag in prey-predator population models. Ecology 38: 136-139.

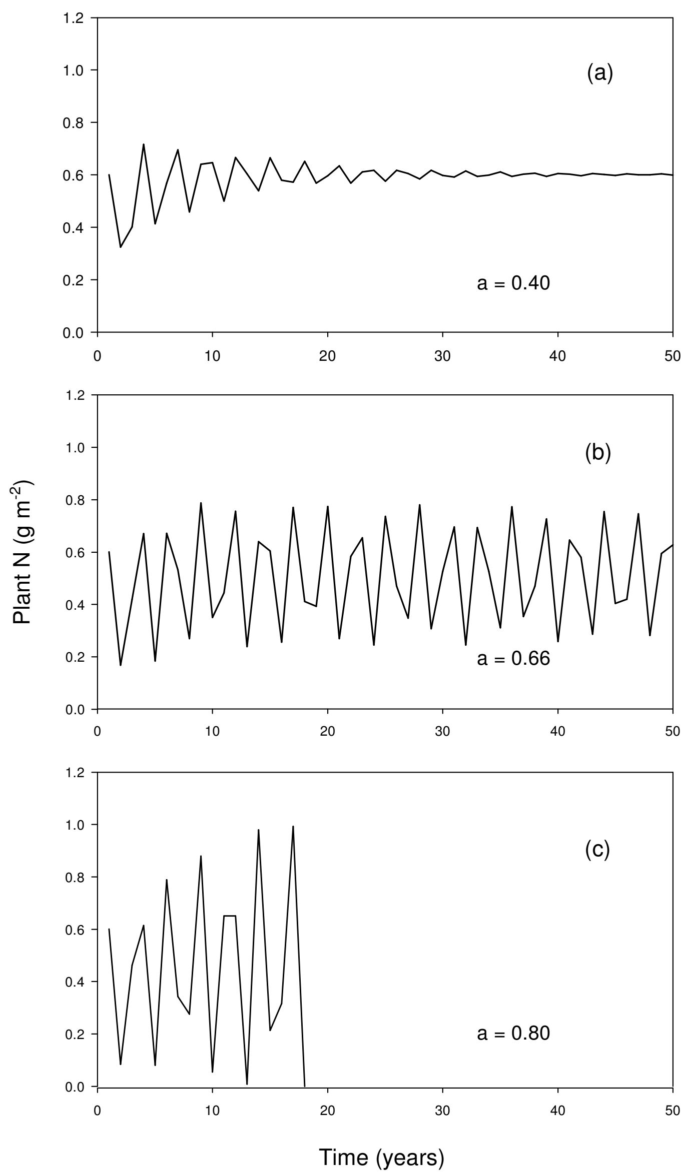
Witteman, G., Redfern, A. and Pimm, S. 1990. The extent of complex population changes in nature. Evol. Ecol. 4: 173-190.

Figure Captions

Fig. 1. A simplified model of nutrient cycling in wild rice ecosystems. Nitrogen in litter is transferred annually to the first-year litter cohort, *L,* from the plant pool, *P,* along with an additional fraction, *a*, immobilized from the available nitrogen pool, *N*. The litter cohort is then transferred to a second-year cohort, *L2,* from which it mineralizes at a fractional rate, *k1,* which transfers nitrogen into the available nitrogen pool after a fraction *e* is lost via leaching. The remaining amount is transferred into the sediment nitrogen pool, *S*, from which it mineralizes at a fractional rate, *k2*, transferring nitrogen into *N* after *e* is lost via leaching. Nitrogen enters the available nitrogen pool via exogeneous inputs *I* and the fraction *e* of inputs leaches from the standing pool of available nitrogen. The remaining amount is taken up into the plant nitrogen pool, *P*.

Fig. 2. Increasing nitrogen immobilization rate by microbes decomposing fresh litter, a yr^{-1} , causes the dynamics of the plant nutrient pool to go from damped oscillations to a stable fixed point equilibrium (Fig. 2a), to apparently periodic orbits or bounded oscillations (Fig. 2b), and finally to extinction (Fig. 2c). Parameter and initial values are: $k_1 = 0.45$ yr^{-1}, $k_2 = 0.06$ yr^{-1}, $e = 0.0001$ yr^{-1}, $I = 0.00001$ g m^{-2} yr^{-1}, $S(0) = 10$ g m^{-2}, initial values for all other components = 0.


P
P
L1
(1-e)N
a P
Available
N
I(1-e)
L1
k_1(1-e)L2
k_2(1-e)S
ek_2S
ek_1L2
k_1L2
L2
k_2S
S
(1-k_1)L 2


(a)
a = 0.40
(b)
a = 0.66
(c)
a = 0.80
Plant N (g m-2)
Time (years)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50

CHAPTER 3

Effects of Wild Rice (*Zizania palustris* L.) Straw on Biomass and Seed Production in Northern Minnesota

Published: **Walker, R.D., Pastor, J., Dewey, B.W. (2006) Effects of wild rice (Zizania palustris L.) straw on biomass and seed production in northern Minnesota. Canadian Journal of Botany, 84 (6): 1019-1024.**

Abstract

Wild rice (*Zizania Palustris* L.) litter accumulation may inhibit plant growth and production both by physically suppressing seedling emergence and by nitrogen immobilization in fresh litter. This latter mechanism could reduce nitrogen availability to plants early in the growing season at a period when more than half of the annual uptake occurs. To test the importance of these mechanisms, we planted wild rice in mesocosms. Half the tanks were planted with seeds sown below the litter and half with seedlings grown to a height taller than litter thickness. One third of the tanks were treated with fresh (nitrogen immobilizing) litter, one third with litter which had been incubated for 26 days and was mineralizing nitrogen, and one third did not receive litter. These treatments resulted in a fully crossed factorial design, with nine replicates for each treatment combination, totaling 54 tanks. We measured plant growth, vegetative, root, and seed biomass, total plant N, and available N at 2.5 cm sediment depth. The presence of litter and its stage of decay caused plant, root and seed biomass, and seed and total plant nitrogen content to increase. We found no physical inhibition of litter on

the potential growth of plants started as seeds. Therefore, the timing of litter nitrogen immobilization or mineralization affects the potential growth of wild rice.

Introduction

Many studies report that litter accumulation may suppress plant populations in subsequent years (Boyd 1970; Al Mufti et al. 1977; Sydes and Grime 1981; Sain 1984; de Jong and Klinkhamer 1985; Knapp and Seastedt 1986; Tilman and Wedin 1991). Some studies reveal that litter accumulation suppresses seedling emergence the following year (Bergelson 1990; Carson and Peterson 1990). Others suggest that litter accumulation depresses temperature and moisture and slows litter decay rates and nutrient availability (Sain and Broadbent 1977; Knapp and Seastedt 1986). de Jong and Klinkhamer (1985) hypothesized that microbes in decomposing litter take up nutrients and create a lag in nutrient availability to plants. In freshwater lake ecosystems, litter may be exported by flushing tides, wind or the flotation of small particles and impact the spatial distribution of nutrients (Odum and Heywood 1978; Davis and Van der Valk 1978).

We chose to test two hypotheses regarding the impacts of litter decay on an unmanaged annual plant, wild rice, *Zizania palustris* L. Litter could suppress plant growth by physically preventing or inhibiting the emergence of seedlings, as proposed for an upland grass species (Tilman and Wedin 1998). Alternatively, fresh litter could suppress plant growth because the microbes decomposing the litter immobilize large amounts of nitrogen early in the growing season (Sain 1984), a period in which wild rice takes up more than half its annual supply of nitrogen (Grava and Raisanen 1978;

Grava 1982). Reduced nitrogen uptake, in turn, could cause reduced seed production and reduced nitrogen concentration in seeds, both of which could affect the density and survivorship of seeds for next year's population growth.

Both mechanisms may not simply suppress growth, but could also be responsible for commonly observed regular oscillations (approximately every four years) in which a productive year results in a large amount of straw litter the following year (Jenks 1899; Moyle 1944; Grava and Raisanen 1978; Stevenson and Lee 1987; Atkins 1986; Aiken et al. 1988). This large straw cohort could physically suppress seedling emergence the following year, resulting in a population crash (Tilman and Wedin 1991). In addition, a high but temporary sequestration of limiting nitrogen by microbes during the initial stages of litter decay, a process known as nitrogen immobilization (Berg and McClaugherty 2003), may reduce production the following year by temporarily reducing nitrogen availability. Production recovers during the latter stages of litter decay when there is a net release of nitrogen. Using a model of nitrogen cycling in wild rice ecosystems, parameterized with data from the literature, we show that nitrogen immobilization followed by mineralization could cause oscillations in production of the period commonly observed in natural wild rice ecosystems (Pastor and Walker 2006). Both hypotheses, while not the only explanations, may explain why wild rice populations recover slowly following a year where the population crashes preceded by a very productive year.

Several studies provide some circumstantial evidence for the nitrogen immobilization mechanism. In a seeded lake in Ontario, Keenan and Lee (1988) observed a marked decline in production after five years coincident with a decline in available nitrogen. Being an annual plant, wild rice does not store nutrients in rhizomes over winter and must meet its nutrient requirements by uptake each year (Grava and Raisanen 1978). Fifty percent of the annual uptake of nitrogen occurs during a 10-day period 1.5-2 months after emergence early in spring. Much of the rest of nitrogen uptake occurs during seed set (Grava and Raisanen 1978; Grava 1982), the time when nitrogen immobilization in wild rice straw is often greatest (Sain 1984). Therefore, the nitrogen in an annual cohort of litter may not be available for the following year's wild rice crop because the timing of net nitrogen release from decomposing litter is asynchronous with the timing of the uptake by the following year's rice plants (Sain 1984; Keenan and Lee 1988). Delays in nitrogen supply during microbial immobilization may, therefore, reduce wild rice seed and plant production.

Methods

Experiments were performed at the University of Minnesota Duluth Research and Field Studies Station in Duluth, MN. Polyethylene stock tanks (Rubbermaid #4242), (378 L capacity, 132 cm long x 79 cm wide x 63 cm deep) were fitted with overflow pipes, buried to ground level, and connected to 20 L overflow buckets. The tanks were partly filled with 10 cm of clean washed sand covered with10 cm of surface sediment. Water tables were set at 23 cm above the sediment surface. The sediments were collected from natural wild rice beds from two lakes on the Fond du Lac Ojibwe Reservation in Carlton County, Minnesota. The sediments were mixed in a large stock tank prior to distribution. Analysis of three grab samples taken during the process indicate a homogenous material (%C = 12.18 ± s.d. 1.00, %N = 1.07 ± s.d. 0.02).

The tanks were immediately filled with water after sediment additions to prevent the sediment from drying. Water was added cautiously from a garden hose to prevent sediment suspension or uneven sediment distribution. Water levels were maintained by removing overflow through a drain pipe set at 20 cm above the sediment surface or by weekly additions of water to drain pipe heights. Water used to fill and supplement tank levels was obtained from the U.S. EPA Mid Continent Lab in Duluth, MN, which maintains a research water supply collected from Lake Superior. Rainfall nitrogen concentrations as NO_3-N and NH_4-N ranged from 0.2 ug · mL^{-1} to 1.99ug · mL^{-1} while the supplemental water concentrations were always < 0.1ug · mL^{-1}.

The Fond du Lac band also supplied fresh straw litter from a lake on the Reservation collected 29 April, 2003, seven days after ice out. Half the litter was saved frozen for application as fresh litter. The other half was frozen, thawed, then incubated submerged in lake sediment at 25 ° C for 32 days in tanks in a greenhouse. The sediments comprised an inoculation source for microbes and a nitrogen source for any immobilization. The time period was adequate for transition from the immobilizing to the mineralizing phase (Sain 1984). Mass loss for the incubated plant litter was approximately 35%. During this mass loss, nitrogen content increased from 1.24% to 1.60%, and C/N ratios decreased from 35.9 to 28.9. This is at or near the critical C/N ratio for most litter to begin to mineralize nitrogen (Berg and McClaugherty 2003). Litter was distributed to the tanks based on total nitrogen content: an equivalent of 1.44 g of litter nitrogen was applied as immobilizing litter (90.0 g) or as mineralizing litter (69.8 g). This resulted in litter application of total N within the range of N in litter production for highly productive natural wild rice stands (Day and Lee 1990).

To test whether litter affects production by physically inhibiting seedling emergence, we planted half the tanks with seeds and half with transplanted seedlings grown to a height taller than the litter thickness. Wild rice populations for the seedlings were established in stock tanks in a greenhouse from seed obtained from one population at Fond du Lac Reservation. The seeds were cold stratified (submerged for six months at 2-4 ^{o}C) to break dormancy before sowing. Seedlings were grown to 18-25 cm, which was well above the average litter depth (1-4 cm with approximately 50% surface coverage), and beyond the point of being exceedingly fragile. Seedlings were planted at a density of 30 plants per tank (equivalent to a rate of 40 plants $\cdot$ m^{-2}, the optimal density for production according to Lee and Stewart (1984)) in a random selection of half the tanks. The remaining tanks were planted with 30 seeds sown below the litter. After the plants grown from seeds reached the floating leaf stage, any additional plants that germinated from seeds naturally embedded in the sediments were removed. All tanks were thinned to 30 plants per tank.

We therefore had two levels of regeneration treatment (seed vs. emerged seedlings) fully crossed with three stages of litter decay (no litter, immobilizing litter, and mineralizing litter) with nine replicates for each combination of treatments totaling 54 tanks. We determined statistical differences for all parameters using two-way ANOVAs. We also used the Bonferroni significant difference test to determine significant pairwise comparisons.

We measured plant height of five randomly selected plants from each tank weekly. At the end of the growing season, these plants, along with their roots, were harvested, dried at 60 ^{o} C, and weighed. We also counted and weighed seeds from these five plants. Before weighing the roots, we thoroughly washed them with deionized water and dried them. We harvested all plants and roots from all tanks and dried and weighed them according to the methods above.

Ion exchange resin bags were used as a relative measure of available N in the sediments (Bridgham et al. 2001; Binkley 1984). Three bags, each containing 10 g Rexyn® 300 (Fisher Chemical, Fairlawn, New Jersey, USA) were positioned uniformly in all tanks, approximately 60 cm equi-distant apart, and were inserted into the sediment occupying an area from 0 to 5 cm deep. Resin bags were inserted prior to litter application and were collected at the end of the growing season with plant and root samples. Resin bags were washed with deionized water and dried at 60 ^{o}C. The resins were composited by tank. Ammonium and nitrate were extracted from a 3 g sub-sample with 100 mL of 1 mol · L^{-1} KCl. Reported available nitrogen is the sum of NO_3-N and NH_4-N, but in all cases ammonium nitrogen accounted for more than 97% of the total.

Total N and C were determined on a LECO® 800 elemental analyzer (Leco Corporation, St. Joseph, MI, USA). The five sub-sampled plants were composited and ground up to pass a 40 mesh screen. Sediments were finely ground with mortar and pestle. In all cases replicate samples were run until the difference between determined values varied less than 10% from the mean. Ammonium and nitrate concentration in resin extracts and water samples were determined by standard methods on a Lachat automated ion analyzer (Lachat Instruments, Loveland, CO, USA).

Results

The stage of litter decay significantly affected seed biomass, total tank biomass, root biomass, plant height, sediment N, seed, stem and leaf, root and total plant N uptake (Table 1, Figs. 1 - 4). In a pairwise comparison of litter type, plants in tanks with mineralizing litter had significantly greater seed biomass, tank biomass, greater sediment N, and total plant N uptake compared with plants grown without litter. Plants in tanks with mineralizing litter also had greater seed biomass, tank biomass, sediment N, and seed and total plant N uptake than plants in tanks with immmobilizing litter (Figs. 1 - 4), but those differences were not statistically significant.

Whether plants began as seeds below the litter or as seedlings above the litter had no effect on these measurements at the end of the growing season. There was no significant interaction effect between litter type and planting method for any of the parameters we measured. Plants begun as seeds, however, had less root biomass at the end of the growing season than plants begun as seedlings. Plants grown as seedlings may have maintained their advantage in root biomass even though the final biomass of plants begun as seedlings was not significantly different from that of plants begun as seeds.

Discussion

Regeneration treatment (seed vs. emerged seedlings) did not affect seed biomass, total tank biomass, plant height, sediment N, or tissue N uptake. Therefore, it does not appear that physical suppression of seedling emergence by litter affects end-of-season population characteristics critical to the following year's growth and production.

Presence and stage of litter decay had the greatest effect on plant growth, sediment N, plant N uptake, and seed production. It is possible that plants grown in the presence of partly decomposed litter mineralizing nitrogen had a head start in growth early in the growing season. Plants in tanks with mineralizing litter therefore may have had an advantage over plants in tanks with immobilizing litter.

The short-term effect of nutrient supply from litter on plant growth found in our experiment may have longer term implications for wild rice population growth, especially the origin of population oscillations. As discussed, natural stand and paddy wild rice populations oscillate approximately every four years. After a productive year, commensurate with its requirements, litter microbes immobilize a large amount of nitrogen during the initial stages of decomposition and reduce production. In subsequent years, litter microbes begin to mineralize nitrogen and production recovers. Using a model with parameter values from the literature, Pastor and Walker (2006) showed that changing the immobilization rate results in changes in the oscillatory dynamics of wild rice. The results reported here lend some support to that model.

The likelihood that delays in nutrient availability through microbial immobilization cause population oscillations may be highest in annual plants such as wild rice. For white rice, *Oryza sativa* L., the addition of large amounts of fresh white rice litter which immobilizes nitrogen can depress productivity in the following year (Rao and Mikkelsen 1976; Azam et al. 1991; Verma and Bhagat 1992). Allowing the rice straw to partly decompose and enter the mineralizing phase before seeding the next year's crop may mitigate declines in production (Rao and Mikkelsen 1976; Adachi et al. 1997). Wild and white rice share the same subfamily, *Oryzoideae*. Research suggests these species share many genomic similarities (Kennard et al. 1999). Previous research on productivity and nutrient dynamics in both white and wild rice together with our findings present some evidence that stages of litter decay may affect wild rice plant and seed production from one year to the next and possibly contribute to long-term fluctuations.

Oscillating dynamics in natural populations may occur for reasons other than delays in nutrient availability, such as serial correlations in annual temperature (Counts and Lee 1990; Cohen and Pastor 1991), fluctuations in water depth (Rogosin 1958; Weber and Simpson 1967; Atkins 1983; Stevenson and Lee 1987; Wilcox and Meeker 1991), demographic factors (May 1974) and trophic interactions between a pair of species, such as predator-prey interactions that lead to stable limit cycles (May 1973). Tilman and Wedin (1991) suggest that physical suppression of seedling emergence may cause oscillations in *Agrostis*, an upland prairie grass. Some of these explanations do not seem plausible for wild rice. Others, however, may be important and are worth greater consideration. First, the explanations that do not appear plausible include age-dependendent explanations, trophic interactions, and physical suppression of seedling emergence. Competitive interactions seem unlikely as wild rice forms nearly monotypic stands (Moyle 1944; Lee and Stewart 1984; Aiken et al. 1988). Age-dependent explanations for population oscillations do not seem plausible because wild rice is an annual emergent wetland plant species. Physical suppression of seedling emergence does not appear to affect growth and seed production, as our experimental results demonstrate.

Second, other explanations may be worth exploring in more detail. Counts and Lee (1990) conclude that study of indigenous wild rice populations support a continuum in morphometric characteristics of Ontario wild rice correlated with climatic severity. Water depth also appears to correlate with wild rice growth. Water depth could affect wild rice growth, especially in extremely wet or dry years. To cause oscillatory dynamics coincident with wild rice production, water levels would need to oscillate at a period equal to or an integral multiple of the 4 year period. Such results, however, have not been reported. Studies linking changes in water level or climatic severity and its possible coincidence with wild rice oscillations would be a useful contribution to studies of wild rice population dynamics.

We also did not examine the effects of litter transport within a lake by currents. Accumulation or diminution of litter by transport could still affect local wild rice growth through the mechanism of nitrogen immobilization and mineralization reported here. The transport of litter would simply exacerbate or reduce nitrogen limitations, depending on the amount and decay stage of the transported litter. This hypothesis was not testable given the small size of our stock tanks. Changes in the spatial dynamics of litter accumulation, however, would be an important question for future research. Given the scope and limits of this project, we decided to focus on the question of the relationship between nutrient availability and wild rice production recognizing that we are not exhausting all possible hypotheses.

Differences in production may arise from delays in nutrient availability caused by immobilization-mineralization dynamics of decomposing litter. Litter decay not only impacts plant production, but also life history characteristics such as seed production, which in turn determines the following year's plant population. The stage of litter decay appears to have a direct impact on several important plant regeneration characteristics. Although we do not conclude that oscillations necessarily result from delays in nutrients due to microbial activities in wild rice litter, our results suggest that delays of nutrient supply due to stage of litter decay may be a possible explanation.

Acknowledgments

This research was supported by a grant from the National Science Foundation. We are grateful to the Fond du Lac Band of Lake Superior Chippewa for their critical logistic, labor, and material support of this project. We particularly thank Nancy Schuldt and the much missed Larry Schwarzkopf for their interest in, time and commitment to this research.

References

Adachi, K., Chaitep, W., and Senboku, T. 1997. Promotive and inhibitive effects of rice straw and cellulose application on rice plant growth in pot and field experiments. Soil Sci. Plant Nutr. 43: 369-386.

Aiken, S.G., Lee, P.F., Punter, D., and Stewart, J.M. 1988. Wild Rice in Canada. NC Press Ltd., Toronto.

Al Mufti, M.M., Sydes, C.L., Furness, S.B., Grime, J.P., and Band, S.R. 1977. A quantitative analysis of shoot productivity and dominance in herbaceous vegetation. J. Ecol. 65: 759-791.

Atkins, T.A. 1983. An investigation of the seasonal trends and relationships of wild rice growth and its physio-chemical environment at Lake of the Woods. *In* The aquaculture of wild rice. Progress year 2. Lakehead University, Thunder Bay, Ont.

Atkins, T.A. 1986. Ecology and early life history tactics of wild rice: seed bank dynamics, germination, and submerged leaf phenophase growth. Ph.D. dissertation, Department of Botany, The University of Manitoba, Winnipeg, Manitoba.

Azam, F., Lodhi, A., and Ashraf, M. 1991. Availability of soil and fertilizer nitrogen to wetland rice following wheat straw amendment. Biol. Fertil. Soils, 11: 97-100.

Berg, B., and McClaugherty, C.A. 2003. Plant Litter: Decomposition, Humus Formation, Carbon Sequestration. Springer-Verlag, Heidelberg.

Bergelson, J. 1990. Life after death: site pre-emption by the remains of *Poa annua*. Ecology, 71: 2157-2165.

Binkley, D. 1984. Ion exchange resin bags: factors affecting estimates of nitrogen availability. Soil Sci. Soc. Am. J. 48: 1181-84.

Boyd, C.D. 1970. Losses of mineral nutrients during decomposition of *Typha latifolia.* Arch. Hydrobiol. 66: 511-517.

Bridgham, S. D., Updegraff, K., and Pastor, J. 2001. A comparison of nutrient availability indices along an ombrotrophic-minerotrophic gradient in Minnesota wetlands. Soil Sci. Soc. Am. J. 65: 259-269.

Carson, W.P., and Peterson, C.J. 1990. The role of litter in an old-field community: impact of litter quantity in different seasons on plant species richness and abundance. Oecologia, 85: 8-13.

Cohen, Y., and J. Pastor. 1991. The responses of a forest model to serial correlations of global warming. Ecology, 72: 1161-1165.

Counts, R.L., and Lee, P.F. 1990. Patterns of variation in Ontario wild rice (*Zizania aquatica* L.) 4. Influence of regional and local environmental factors on variation within and among field populations. Aquat. Bot. 36: 193-205.

Davis, D.B., and Van der Valk, A.G. 1978. Litter decomposition in prairie glacial marshes. *In* Freshwater wetlands: ecological processes and management potential. *Edited by* R.E. Good, D.F. Wingham, and R.L. Simpson. Academic Press, New York, pp. 99-113.

Day, W.R., and Lee, P.F. 1990. Ecological relationships of wild rice, *Zizania aquatica.* 9. Production in organic-flocculent sediments. Can. J. Bot. 68: 1542-1548.

de Jong, T.J., and Klinkhamer, P.G.I. 1985. The negative effects of litter of parent plants of *Cirsian vulgare* on their offspring: autotoxicity or immobilization? Oecologia, 65: 153-160.

Grava, J., and Raisanen, K.A. 1978. Growth and nutrient accumulation and distribution in wild rice. Agron. J. 70: 1077-81.

Grava, J. 1982. Wild rice production in Minnesota. Univ. Minn. Ext. Bull. 484: 18-21.

Jenks, A.E. 1899. The wild rice gatherers of the Upper Great Lakes. Ph.D. dissertation, Department of Anthropology, University of Wisconsin, Madison.

Keenan, T.J., and Lee, P.F. 1988. Ecological relationships of wild rice, *Zizania aquatica.* 7. Sediment nutrient depletion following introduction of wild rice to a shallow boreal lake. Can. J. Bot. 66: 236-241.

Kennard, W., Phillips, R., Porter, R., and Grombacher, A. A comparative map of wild rice (*Zizania palustris* L. 2n=2x=30). Theor. Appl. Genet. 99: 793-799.

Knapp A.K., and Seastedt, T.R. 1986. Detritus accumulation limits productivity of tallgrass prairie. BioScience, 36: 662-668.

Lee, P.F., and Stewart, J.M. 1984. Ecological relationships of wild rice, *Zizania aquatica* L. 2. Sediment-plant tissue nutrient concentrations. Can. J. Bot. 61:1775-1784.

May, R.M. 1973. Stability and Complexity in Model Ecosystems. Princeton University Press, Princeton.

May, R.M. 1974. Biological populations with nonoverlapping generations: stable points, stable cycles, and chaos. Science, 186:645-47.

Moyle, J.B. 1944. Wild rice in Minnesota. J Wildl. Manage. 8: 177-184.

Odum, W.E., and M.A. Heywood. 1978. Decomposition of intertidal freshwater marsh plants. *In* Freshwater wetlands: ecological processes and management potential. *Edited by* R.E. Good, D.F. Wingham, and R.L. Simpson. Academic Press, New York, pp. 89-97.

Pastor, J., and Walker, R.E. 2006. Delays in nutrient cycling and population oscillations. Oikos. 112**:** 698-705.

Rao, D.N., and Mikkelsen, D.S. 1976. Effect of rice straw incorporation on rice plant growth and nutrition. Agron. J. 68: 752-755.

Rogosin, A. 1958. Experimental growth of wild rice in relation to water levels, seeding densities and fertilizer application. Proc. Minn. Acad. Sci. 25-26: 95-97.

Sain, P., and Broadbent, F.E. 1975. Moisture absorption, mold growth, and decomposition of rice straw at different relative humidities. Agron. J. 67: Nov.-Dec.

Sain, P. 1984. Decomposition of wild rice (*Zizania aquatica*) straw in two natural lakes of northwestern Ontario. Can. J. Bot. 62: 1352-1356.

Stevenson, S.C., and Lee, P.F. 1987. Ecological relationships of wild rice, *Zizania aquatica.* 6. The effects of increases in water depth on vegetative and reproductive production. Can J. Bot. 65:2128-2132.

Sydes, C., and Grime, J.P. 1981. Effects of tree litter on herbaceous vegetation in deciduous woodland. II. An experimental investigation. J. Ecol. 69: 249-262.

Tilman, D., and Wedin, D. 1991. Oscillations and chaos in the dynamics of a perennial grass. Nature, 353: 653-655.

Verma, T., and Bhagat, R.M. 1992. Impact of rice straw management practices on yield, nitrogen uptake and soil properties in a wheat-rice rotation in northern India. Fert. Res. 33: 97-106.

Weber, R.P., and Simpson, G.M. 1967. Influence of water on wild rice (*Zizania aquatica* L.) grown in a prairie soil. Can. J. Plant Sci. 47: 657-663.

Wilcox, E.A., and Meeker, J.E. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. Can. J. Bot. 69: 1542-1551.

Table 3.1 *P* values from two-way ANOVA for wild rice mesocosm production parameters according to treatment.

	Litter type	Planting method	Litter x planting method
Seed biomass	0.0183	0.3559	0.2152
Tank biomass (roots and shoots)	0.0532	0.7791	0.838
Tank above ground plant weight	0.0737	0.4867	0.8796
Tank root weight	0.0354	0.0168	0.5601
Final plant height (9/11/03)	0.0704	0.3258	0.5310
Root N uptake	0.0936	0.3819	0.1761
Stem and Leaf N uptake	0.0494	0.3131	0.5585
Seed N uptake	3.790e-05	0.1027	0.0823
Total plant N uptake	0.0026	0.3846	0.1643
Sediment Resin Total N	0.0007	0.0343	0.5121

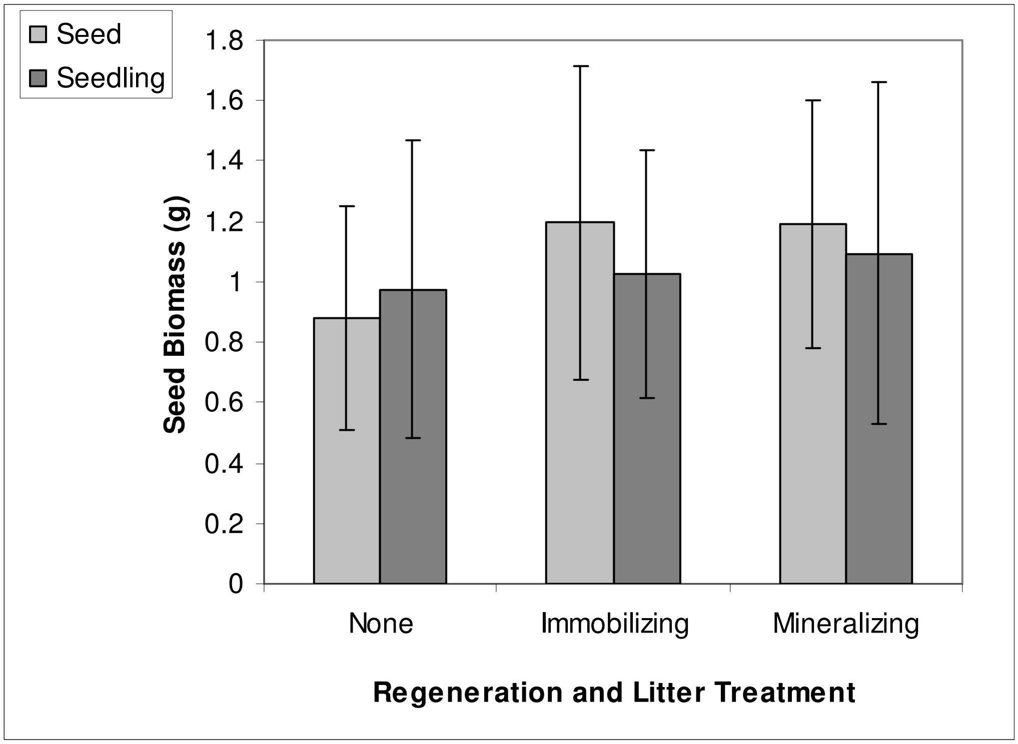


Figure 3.1 Wild rice (*Zizania palustris* L.) seed biomass from summer 2003 for five plants per tank according to stage of litter decay and regeneration status. Error bars are one standard deviation.

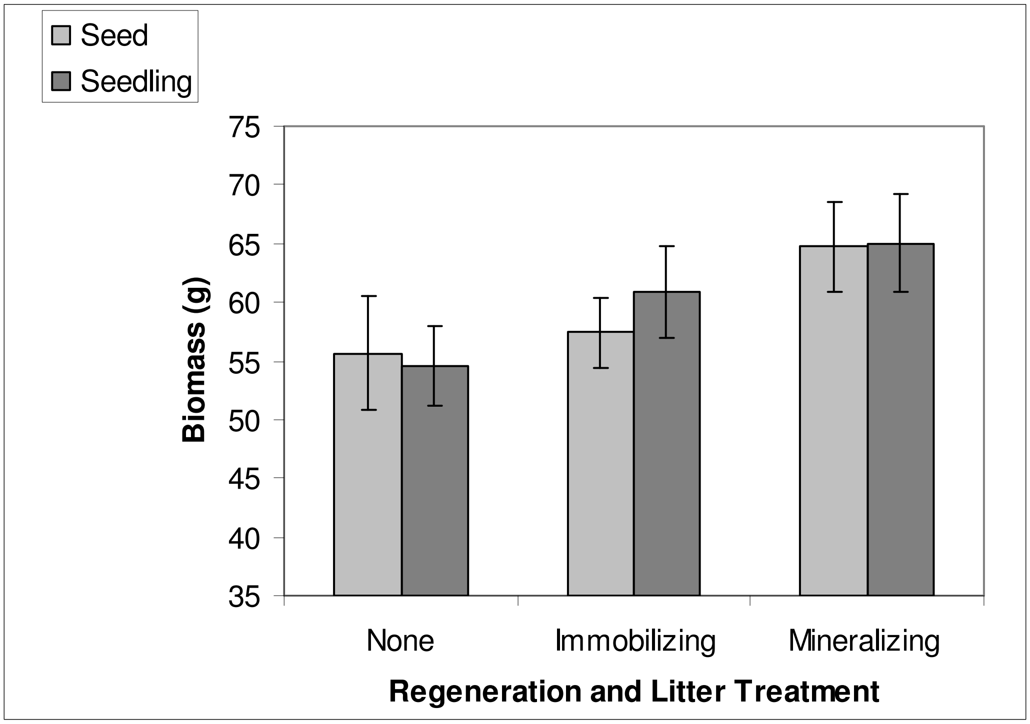


Figure 3.2 Wild rice (*Zizania palustris* L.) total tank above and below ground biomass from summer 2003 according to stage of litter decay and regeneration status. Error bars are one standard deviation.

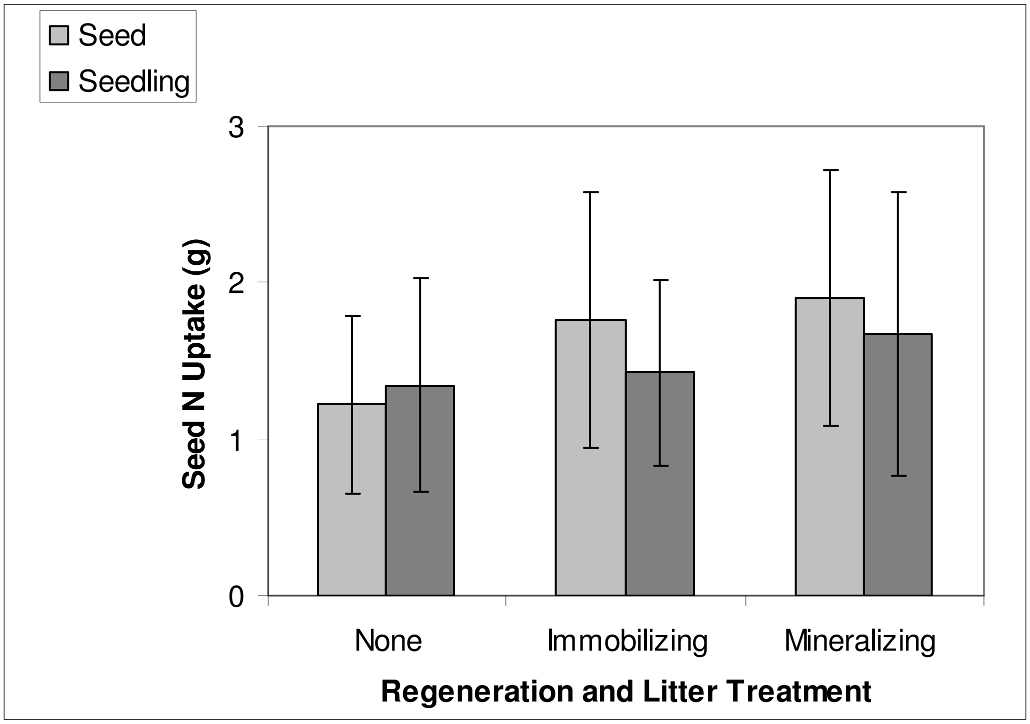


Figure 3.3 Wild rice (*Zizania palustris* L.) seed N uptake (calculated for five sub-sampled plants) for summer 2003 according to stage of litter decay and regeneration status. Error bars are one standard deviation.

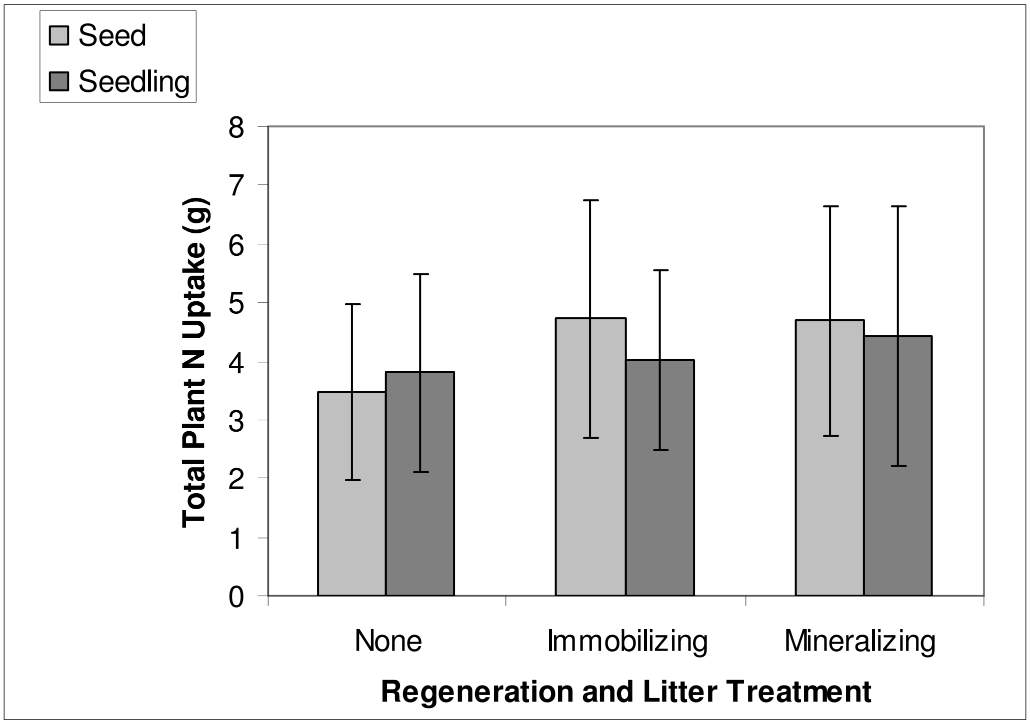


Figure 3.4 Wild rice (*Zizania palustris* L.) total plant (includes seeds, stems, leaves and roots) N uptake (calculated for five sub-sampled plants) for summer 2003 according to stage of litter decay and regeneration status. Error bars are one standard deviation.

CHAPTER 4

The Effects of Litter Quantity and Stage of Decay on Wild Rice (*Zizania palustris* L.) Population Dynamics in Northern Minnesota

Abstract

Delays in nutrient availability to natural stand wild rice (*Zizania palustris* L.) due to microbial uptake (immobilization) of N in litter from the previous year's production may cause population oscillations over a four-year cycle (Pastor and Durkee Walker 2005). Our previous work (Durkee Walker et al. 2006) demonstrated that the proportion of net immobilizing and mineralizing litter affects total production and the number and weight of seeds. In addition to stage of litter decay, we hypothesize that quantity of immobilizing litter and tissue chemistry also affects population fluctuations. In this paper, we tested the effects of each year's shoot and root litter quantity and seed number on the following year's production over two consecutive years with natural stand wild rice planted in mesocosms. Half the tanks were planted holding seedling density constant (tanks thinned to 30 plants per tank); seedlings in the remaining tanks were left unthinned, allowing plant density to fluctuate *ad libitum*. The stage of litter decay and plant density treatments resulted in a fully crossed factorial design with nine replicates for each treatment combination, totaling 54 tanks. During the first year, one third of the tanks were treated with N immobilizing shoot litter, one third with N mineralizing shoot litter, and one third left as control with no shoot litter. In subsequent years, we allowed productivity of each tank to fluctuate *ad libitum*. We measured above ground tank biomass, seed number, seed weight, and release of N and P from fresh

shoot or root litter in litterbags. Production in a given year was most strongly related to the amount of immobilizing litter produced the previous year. Tanks which were productive one year (producing large amounts of immobilizing litter) were less productive the following year. Tanks which were unproductive (producing small amounts of immobilizing litter) were more productive the following year. Wild rice population cycles, therefore, depend on the previous year's litter production. Furthermore, production in tanks with shoot + root litter (immobilizing and mineralizing) did not fluctuate more than tanks with only root litter (no litter). Composed of more recalcitrant C compounds, root, compared to shoot litter sustains longer periods of N immobilization. Root litter may therefore be primarily responsible for the delays in N availability that result in population fluctuations. Although plants in thinned tanks were larger and produced more seeds than plants in unthinned tanks, thinning did not affect overall seed production across the entire population. Unthinned tanks compensated for fewer seeds per plant by producing denser stands. Consequently, both wild rice litter quantity and plant tissue chemistry, not seed production, play central roles in population dynamics of natural wild rice stands.

Introduction

Within the last several decades, time series analyses have shown that natural populations exhibit complex dynamics including oscillations of one or more periods, and possibly chaotic dynamics (Witteman et al. 1990, Tilman and Wedin 1991, Turchin and Taylor 1992, Ellner and Turchin 1995). Most studies of population oscillations focus on animals; plant populations, however, also oscillate (Harper 1977, Thrall et al.

1989, Pacala and Silander 1990). Understanding the mechanisms that explain these dynamics requires a better understanding of how species' characteristics affect ecosystem processes such as carbon and nutrient cycles (Tilman and Wedin 1991, Pastor and Durkee Walker 2006, Vandermeer 2006).

Litter accumulation may influence plant population dynamics by physically inhibiting seedling emergence, thereby delaying growth and causing oscillations in primary productivity (Tilman and Wedin 1991, Hastwell and Facelli 2000, Dos Santos and Valio 2002, Osem et al. 2006). Few researchers, however, have explored the relationship between litter accumulation, decay, changes in soil nutrient availability, and population oscillations (Al Mufti et al. 1977, Sydes and Grime 1981, Bergelson 1990).

Litter deposition can depress nutrient availability because the litter C/N ratio of a fresh litter cohort (30 to 70) is much higher than of the microbes decomposing it (10 or less) (Berg and McClaugherty 2003). For every unit of C taken up by microbes, insufficient N remains in the litter to produce one corresponding unit of microbial biomass. Consequently, microbes import N from their environment to eliminate that deficit, a process termed immobilization (Berg and McClaugherty 2003). Over time, the C/N ratio declines within the litter-microbe complex, and eventually net N immobilization ceases and the litter enters a subsequent phase known as net N mineralization. In contrast to immobilization, net mineralization occurs later when litter C/N approaches that of the microbes and when easily decomposable carbon compounds are depleted. The microbial population declines. The lower C/N together with fewer microbes results in net N release. N immobilization may last for several months for N-rich rapidly decomposing litters, or for several years for some N-poor slowly decomposing litter (Berg and McClaugherty 2003). If the period of immobilization is long enough, delays in release of available N to plants may occur. We were interested to know whether the delays in N availability for plant growth caused by N immobilization in plant stands producing high quantities of litter in one year induce population oscillations in plants, by reducing growth of plants the following year.

Because wild rice (*Zizania palustris* L.) is an annual plant, its nutritional requirements must be met during a given growing season by uptake from the sediment. Fresh wild rice shoot litter immobilizes N until the middle of the next growing season, thus introducing a delay in the release of N from the sediments (Sain 1984). Wild rice populations appear to oscillate in response to immobilization-induced delays which are in part affected by the quantity of proximate wild rice litter (previous years' growth) (Pastor and Durkee Walker 2006, Walker et al. 2006). A model we developed (Pastor and Durkee Walker 2006) mimics the period and amplitude of natural population oscillations in wild rice when using N immobilization rates in the range of those determined by previous experiments (Pastor and Durkee Walker 2006).

In an experiment designed to test the model as well as enumerate more precise parameter values, we found that a large cohort of immobilizing litter did not physically suppress seedling emergence the following year (Walker et al. 2006), as suggested by Tilman and Wedin (1991), Dos Santos and Valio (2002), and Osem et al. (2006). We found that the stage of litter decay (immobilizing versus mineralizing) influenced seed and plant biomass as well as total plant N (Walker et al. 2006). Plants grown with mineralizing shoot litter had greater aboveground, root, and seed production the following year than plants grown with immobilizing or no shoot litter. Plants grown with mineralizing shoot litter also had heavier seeds. Heavier seeds with higher N content generally have greater germination success and seedling survival (Harper 1977). Therefore, sediment and litter N availability might cause population oscillations affecting total production, seed production, and viability.

The experiment's first year (2003) was not sufficiently long to determine whether delays in nutrient availability due to deposition of immobilizing litter cause population oscillations. The experiment was also not long enough to determine the relative importance of changes in seed production and viability versus nutrient deficiencies influencing the following year's growth. Here we report on several years' data illustrating the relative importance of litter accumulation and stage of decay versus seed production and viability in producing population oscillations in wild rice.

Methods

Experimental - Experiments were performed at the University of Minnesota Duluth Research and Field Studies Station in Duluth, MN. Polyethylene stock tanks (Rubbermaid #4242, 378 L capacity, 132 cm long x 79 cm wide x 63 cm deep) were fitted with overflow pipes, buried to ground level, and connected to 20 L overflow buckets. The tanks were partly filled with 10 cm of clean washed sand covered with 10 cm of surface sediment. Water tables were set at 23 cm above the sediment surface. The sediments were collected from natural wild rice beds from two lakes on the Fond du Lac Band of Lake Superior Chippewa Reservation in Carlton County, Minnesota in 2003 (Walker et al. 2006). The sediments were mixed in a large stock tank prior to distribution. Analysis of three grab samples taken during the process indicate a homogenous material (% C = 12.18 ± s.d. 1.00, % N = 1.07 ± s.d. 0.02).

The tanks were immediately filled with water after sediment additions to prevent the sediment from drying. Water was added cautiously from a garden hose to prevent sediment suspension or uneven sediment distribution. During the growing season, water levels were maintained by removing overflow through the drain pipe set at 20 cm above the sediment surface or by weekly additions of water to drain pipe heights. Water used to fill and supplement tank levels was obtained from a nearby wellpoint. Rainfall N concentrations as NO_3-N and NH_4-N ranged from 0.2 – 1.99 $\mu g \cdot mL^{-1}$ while the NO_3-N and NH_4-N concentrations in the well water were always < 0.1 $\mu g \cdot mL^{-1}$. The sediments comprised an inoculation source for microbes and a N source for immobilization. Sediments were sampled and finely ground with mortar and pestle for analysis of total C and N with LECO CHN analyzer.

To test whether the amount of immobilizing shoot litter produced in one year's growth affects production the following year, we initiated the experiment with three shoot litter treatments: a no-shoot litter control, fresh immobilizing shoot litter, and mineralizing shoot litter. Mineralizing litter was produced by incubating shoot litter submerged in water in stock tanks in a greenhouse before application to the tanks. Mass loss for the incubated plant litter was approximately 35%. During this mass loss, N content increased from 1.24% to 1.60%, and C/N ratios decreased from 35.9 to 28.9. This is at or near the critical C/N ratio for most litter to begin to mineralize N (Berg and McClaugherty 2003). The time period was adequate for transition from the immobilizing to mineralizing phase (Sain 1984). Litter was distributed to the tanks based on total N content: an equivalent of 1.44 g of litter N was applied as immobilizing litter (90.0 g) or as mineralizing litter (69.8 g). Total N application (g N/m^2) was within the range of litter N for highly productive natural wild rice stands (Day and Lee 1990). The effect of the different stages of litter decay on the first year's growth was reported in Walker et al. (2006). Thereafter, we allowed each tank with litter to produce new biomass *ad libitum* and documented the differences in total biomass from year to year. Here, we report the effects of different litter quantities on production over the course of two growing seasons.

All tanks retained their root litter; in the "removed shoot litter" treatment, we removed all shoot, but not root biomass to keep sediments intact. Comparison of the results of the "removed shoot litter" tanks with the "intact shoot litter" tanks allowed us to partially separate the effects of root from shoot litter on biomass production the following season.

At the end of the first season, 2003, I found that tanks with mineralizing litter (larger amounts of available N) enhanced seed production (Walker et al. 2006). I was interested to know whether greater seed production (resulting from greater nutrient levels) and/or immobilizing litter influences biomass and seed production the following year. According to Lee and Stewart (1984), maximum wild rice density yielding the greatest production is approximately 40 plants·m^2 (30 plants per our 132 cm long x 79 cm wide tanks). Therefore, in 2004, a treatment in which seedling density was either held constant (tanks thinned to 30 plants per tank) or allowed to fluctuate *ad libitum* (tanks left unthinned) was carried out.

The thinned tanks essentially mimic a “treatment” in which only 30 viable seeds are produced and germinate each year, yielding optimum density for seed production from each plant. The thinned treatment interrupts the feedback between N availability and seed production. By holding density constant, the thinned treatment also interrupts the feedback between density and production the following year. In the unthinned tanks, feedbacks between N availability and seed production in one year and plant density and production the following year were not interrupted.

The experiment had two levels of plant density with 27 replicate tanks for thinned and unthinned treatments, respectively. Thinning continued over two years (2004-2005 and 2005-2006). Thinning occurred early in the season (June) when the plants were still submerged beneath the water surface. Two levels of plant density (thinned versus unthinned tanks) were fully crossed with three initial stages of shoot litter decay (immobilizing, mineralizing, and no litter) with nine replicates for each combination of treatments, totaling 54 tanks.

We measured plant height of either five or eight randomly selected plants from each tank weekly (five from thinned tanks, eight from unthinned tanks). At the end of the growing season, these plants, along with their roots, were harvested, dried at 60 º C, and weighed. We also counted and weighed seeds from these five and eight plants per tank. Before weighing the roots, we thoroughly washed them with deionized water and dried them. Total plant N and C were determined on a LECO® 800 elemental analyzer (Leco Corporation, St. Joseph, MI, USA) after being composited by tanks and ground up to pass a 40 mesh screen.

Although we recognized that some nutrients are lost each year through the harvest of these plants, we decided against adding back lost nutrients. Tantamount to fertilization, we did not add inorganic NH_4 or NO_3. We decided not to add back sediments as the amount needed to replace lost nutrients would be a small fraction of the total amount of N in the tank sediments.

At the end of each growing season (September), we harvested all aboveground shoot material from the tanks and weighed it. A small subsample of approximately five g was dried as above to make wet-dry mass conversions. After weighing, all shoot material was returned to its original tank, except for the tanks designated as "removed shoot litter." We left the roots in all tanks intact.

Total tank seed production was calculated by multiplying the average per plant seed mass (from the five or eight completely harvested plants per tank) by the number of plants in the tank. Plants were counted at the time of harvest (all plants produced seed heads). Total tank root production was calculated by multiplying the aboveground shoot production estimates for the entire tank by the root/shoot ratios of the five (thinned) or eight (unthinned) sample plants.

Litter decay and release of N and P from shoot (leaf and stem) and root material were measured using litterbags collected over several growing seasons. Approximately five g of air-dried, post-senescent shoot litter or 1.5 g of roots were placed in 10 cm x 10 cm sealed bags made from vinyl-coated fiberglass screen with 1mm mesh size. Shoot litterbags were placed on the sediment surface while root litterbags were placed horizontally in the sediment to simulate root distribution. Three replicates were retrieved on days 0, 7, 14, 32, 55, 111, 347 and 427 for the shoot samples and on days 0, 7, 15, 42, 80, 356, 400 and 462 for the root samples. After washing the plant material with de-ionized water followed by drying at 60° C, we weighed the samples to determine mass loss or gain.

The samples were then milled to pass a 40 mesh screen and analyzed for total N, P and C fractions. Total C and N concentrations were determined on a LECO 800 CHN Analyzer. Litter P concentrations were determined after H_2SO_4-H_2O_2 digestion at 350°C (Harmon and Lajtha 1999), with NIST plant standard 1571 used to calculate P recovery. The digested samples were analyzed for PO_4-P using a molybdate-antimony-ascorbic acid method on a Lachat Autoanalyzer (Lachate Instruments method 13-115-01-1-B). C fractions were determined by sequential extraction in: methylene chloride (oils and waxes), hot water (simple sugars) and 70% sulfuric acid (cellulose and starch) with the remaining residue defined as lignin-like material (Ryan et al. 1990).

Hypothesis Testing – I was interested to see whether a previous season's litter affects changes in biomass the following year. Therefore, I determined statistical differences in productivity in each year using one-way ANCOVAs with plant density (thinned or unthinned) as the main effect and litter production from the previous year as the covariate separately in 2004-2005, in 2005-2006 and in both years combined.

To test whether large quantities of litter production one year resulted in decreased productivity the following year, and vice versa, I performed regression analyses of change in biomass (t to t+1) versus biomass (t). I calculated these regressions for thinned and unthinned tanks, and also for tanks with intact shoot litter compared to those with removed shoot litter over two years. I was particularly interested in the slopes of these regressions. A negative slope indicates that high productivity decreases production the following year and years of low production are followed by more productive years. This essentially constitutes a population oscillation. Furthermore, the slopes of these regressions are analogous to the eigenvalue of a discrete time logistic model of population biomass growth from one year to the next. An eigenvalue of -1 is critical for the first period doubling bifurcation in the discrete time logistic model (Strogatz 1994). Therefore, those treatments with regressions whose slope is -1 demonstrate a high propensity for sustained oscillations, similar to a period doubling in a discrete logistic model.

Finally, I was interested to determine whether thinning affects overall tank production on an individual plant or per square meter basis. I therefore performed regression analyses of individual plant measurements against tank production. For 2005, I regressed mean plant weight against plant density separately for the no shoot, immobilizing, and mineralizing litter treatments. I regressed mean seed weight against plant density in 2005. And I regressed mean seed weight against above-ground biomass produced the previous year, 2004.

Results

Production in each tank fluctuated from year to year. Tanks which were productive in 2004 or 2005 were less productive in 2005 or 2006. Conversely, unproductive tanks in 2004 or 2005 were more productive in 2005 or 2006 (Fig.'s 4.1 and 4.3). The effect of litter production on changes in production from one year to the next was tested with analyses of covariance assigning as covariate the previous year's litter production. The effect of the previous year's litter production on biomass production was highly significant in each year ($P < 6.8 \times 10^{-5}$ between 2004 to 2005, and $P < 9.7 \times 10^{-8}$ between 2005 to 2006; Table 4.1). High production in a year yields large amounts of immobilizing litter the following year. Tanks with high productivity in 2004 to 2005 produced large amounts of litter which immobilized N in 2005 to 2006. In these tanks, N was less available for production in 2005 to 2006, and resulted in less plant biomass.

The slopes of regressions of changes in biomass (t to $t + 1$) versus biomass (t) were not significantly different from -1 for tanks with removed shoot litter (Table 2). The slopes of the regressions of changes in biomass (t to $t + 1$) versus biomass (t), however, were significantly less than -1 for tanks with intact shoot litter. Therefore, the amount of root litter appears to have the largest effect on population dynamics.

Root litter may influence population oscillations because it decays more slowly and sustains longer periods of N immobilization compared to shoot litter (Fig. 4.2). Shoot litter immobilized N in a rapid spike early each summer followed by mineralization in mid-summer. Root litter, however, decayed more slowly and immobilized N throughout the summer 2004, beginning mineralization in the summer 2005 (Fig. 4.2). Neither root nor shoot litter immobilized P. Shoot and root litter may influence N immobilization differently due to the relative proportions of different C compounds. Shoot litter had higher concentrations of water soluble compounds (21%) compared to root litter (8.2%, $P < 0.001$). Root litter had significantly higher lignin (8.5%) and cellulose (75%) content, whereas shoot litter is composed of 5.5% lignin and 65% cellulose ($P < 0.001$).

Controlling the number of seedlings in a tank (thinned versus unthinned) had a weaker effect on production within each year than did the amount of litter produced the previous year (Table 4.1). At the end of 2005, tanks thinned to 30 plants produced slightly more biomass (above ground) compared to tanks left unthinned (Table 4.1: $P < 0.0008$). In contrast, at the end of 2004, thinning had less effect on biomass (Table 4.1: $P < 0.0038$).

As for the litter treatments, highly productive tanks lost productivity the following year while unproductive tanks gained productivity the following year regardless of thinning treatment (Fig. 4.3). However, the slopes of the regressions of changes in biomass (t to $t + 1$) versus biomass (t) were not significantly different than -1 for unthinned tanks but were for thinned tanks (Fig. 4.3, Table 4.2). Apparently thinning decreases the propensity for sustained oscillations, whereas tanks left unthinned had a greater propensity for sustained oscillations.

Thinning plants affects individual plant weight (Fig. 4.4) but not seed production on a per square meter basis (according to measures at the tank level) (Fig. 4.5). Although individual plants in unthinned tanks produced less biomass and fewer seeds, greater plant density generally compensated for less production (in terms of biomass and seeds). Hence, plant density does not affect biomass or seed production on a per square meter basis.

Discussion

Tissue chemistry, growth allocation to roots or shoots and the relative production of root and shoot litter appear to cause population oscillations. The stage of litter decay (immobilizing vs. mineralizing) strongly influenced the amount of seed and biomass production in year one (2003) (Walker et al. 2006). The amount of fresh litter produced in one year (and hence the amount of N immobilized) also appeared to affect population dynamics in subsequent years. Tanks producing large amounts of litter one year immobilized larger amounts of N the following year; consequently biomass production decreased the following year. Conversely, tanks producing less litter one year immobilized a smaller amount of N the following year; consequently, biomass production increased the following year. Root litter immobilized more N for longer periods than shoot litter and appears to be responsible for these delays in N supply.

Population dynamics of wild rice therefore result from growth allocation to roots or shoots and N cycling influenced by litter decay. Our previous theoretical studies provide initial evidence that stages of litter decay influence oscillatory behavior in wild rice (Pastor and Durkee Walker 2006). After a three year experiment, it appears that immobilization/mineralization kinetics and litter tissue chemistry, especially root litter chemistry, play an important role in population oscillations of natural wild rice stands.

While N availability -- seed production feedback may affect wild rice population fluctuations (Fig. 3), investigation of its influence on biomass would require additional years of research. Our results indicate that this feedback influences wild rice population dynamics less than the N immobilization -- litter production feedback (Fig. 3, Table 1). Seed production one year intermittently influences biomass the following year. N availability, on the other hand, more consistently influences biomass over time.

Differences in N dynamics of shoot and root litter suggest the relative importance of each in controlling population dynamics. Shoot litter in litterbags immobilized N in a rapid spike early each summer followed by N mineralization in mid-summer. Root litter in litterbags, however, immobilized N more slowly than shoot litter and immobilized N throughout the summer 2004. Mineralization began in summer 2005.

In both wild and white rice shoot litter, N immobilization rates were greatest during the seedling stage of crops and decreased throughout crop maturity (Sain 1984, Kushwaha et al. 2000). Greater N uptake by microbes in early summer may result from significantly higher concentrations of water soluble compounds in shoot litter (21%) compared to root litter (8.2%, $P < 0.001$). Such studies also stress the importance of separately considering plant parts when studying plant decomposition (Abiven et al. 2005).

Root litter's significantly higher lignin (8.5%) and cellulose (75%) content may explain its longer period of N immobilization compared to shoot litter. In contrast, shoot litter is composed of 5.5% lignin and 65% cellulose (differences in concentrations between the two litter types are significant at $P < 0.01$). If root litter decayed more slowly and immobilized N for a longer period than shoot litter, it may be a plausible mechanism for population oscillations. Changes in production from one year to the next in tanks receiving both shoot and root litter were not significantly different from those in tanks receiving only root litter (the "removed shoot litter" tanks, Fig. 4.1 and Table 4.1). If shoot litter contributes to delays in N recycling, one would expect the regressions of changes in biomass versus the previous year's biomass (Fig. 4.1 and Table 4.1) to have different slopes and intercepts, but they do not. Therefore, adding shoot litter back to tanks did not change production dynamics compared to tanks with only root litter.

It is also possible that differences in oxidation -- reduction potential or temperature between the sediments' surface, where shoot litter decays, and the upper 10 cm of sediment, where root litter decays, explain differences in periods of decay and immobilization between roots and shoots. Knapp and Seastedt (1986) reported that litter accumulation depressed temperature and moisture. Depression of these variables slowed decay rates and nutrient availability which depressed productivity. Litter accumulation may increase anaerobic conditions resulting in increased N availability to plants (Acharya 1935, Eagle et al. 2001). We saw no differences, however, in sediment or water temperatures and no evidence that sediments were anaerobic.

In summary, three years of experimental data (this paper and Walker et al. 2006) as well as our model of N cycling in wild rice ecosystems (Pastor and Durkee Walker 2006) suggest that delays in nutrient availability due to deposition of immobilizing litter cause population oscillations over a cycle potentially four years in length. Litter quantity appears to play a central role. Root litter may also cause delays in N cycling. Further studies are warranted, however, to verify this hypothesis.

References

Adachi, K., Chaitep, W., and Senboku, T. 1997. Promotive and inhibitive effects of rice straw and cellulose application on rice plant growth in pot and field experiments. - Soil Sci. Plant Nutr. 43: 369-386.

Aiken, S.G., Lee, P.F., Punter, D., and Stewart, J.M. 1988. Wild Rice in Canada. NC Press Ltd., Toronto.

Al Mufti, M.M., Sydes, C.L., Furness, S.B., Grime, J.P., and Band, S.R. 1977. A quantitative analysis of shoot productivity and dominance in herbaceous vegetation. J. Ecol. 65: 759-791.

Atkins, T.A. 1983. An investigation of the seasonal trends and relationships of wild rice growth and its physio-chemical environment at Lake of the Woods. *In* The aquaculture of wild rice. Progress year 2. Lakehead University, Thunder Bay, Ont.

Atkins, T.A. 1986. Ecology and early life history tactics of wild rice: seed bank dynamics, germination, and submerged leaf phenophase growth. Ph.D. dissertation, Department of Botany, The University of Manitoba, Winnipeg, Manitoba.

Azam, F., Lodhi, A., and Ashraf, M. 1991. Availability of soil and fertilizer N to wetland rice following wheat straw amendment. Biol. Fertil. Soils, 11: 97-100.

Berg, B., and McClaugherty, C.A. 2003. Plant Litter: Decomposition, Humus Formation, C Sequestration. Springer-Verlag, Heidelberg.

Bergelson, J. 1990. Life after death: site pre-emption by the remains of *Poa annua*. Ecology. 71: 2157-2165.

Binkley, D. 1984. Ion exchange resin bags: factors affecting estimates of N availability. Soil Sci. Soc. Am. J. 48: 1181-84.

Boyd, C.D. 1970. Losses of mineral nutrients during decomposition of *Typha latifolia.* Arch. Hydrobiol. 66: 511-517.

Bridgham, S. D., Updegraff, K., and Pastor, J. 2001. A comparison of nutrient availability indices along an ombrotrophic-minerotrophic gradient in Minnesota wetlands. Soil Sci. Soc. Am. J. 65: 259-269.

Carson, W.P., and Peterson, C.J. 1990. The role of litter in an old-field community: impact of litter quantity in different seasons on plant species richness and abundance. Oecologia. 85: 8-13.

Cohen, Y., and J. Pastor. 1991. The responses of a forest model to serial correlations of global warming. Ecology. 72: 1161-1165.

Counts, R.L., and Lee, P.F. 1990. Patterns of variation in Ontario wild rice (*Zizania aquatica* L.) 4. Influence of regional and local environmental factors on variation within and among field populations. Aquat. Bot. 36: 193-205.

Davis, D.B., and Van der Valk, A.G. 1978. Litter decomposition in prairie glacial marshes. In Freshwater wetlands: ecological processes and management potential. Edited by R.E. Good, D.F. Wingham, and R.L. Simpson. Academic Press, New York, pp. 99-113.

Day, W.R., and Lee, P.F. 1990. Ecological relationships of wild rice, *Zizania aquatica.* 9. Production in organic-flocculent sediments. Can. J. Bot. 68: 1542-1548.

de Jong, T.J., and Klinkhamer, P.G.I. 1985. The negative effects of litter of parent plants of *Cirsian vulgare* on their offspring: autotoxicity or immobilization? Oecologia. 65: 153-160.

Dos Santos, S. L. and Valio, I. F. M. 2002. Litter accumulation and its effect on seedling recruitment in a Southeast Brazilian Tropical Forest. Revista Brasileira de Botanica. 25(1): 89-92.

Ellner, S. and Turchin, P. 1995. Chaos in a noisy world: new methods and evidence from time-series analysis. Am. Nat. 145: 343-375.

Ghosh, P. and A.K. Kashyap. 2003. Effect of rice cultivars on rate of N-mineralization, nitrification and nitrifier population size in an irrigated rice ecosystem. Applied soil ecology: a section of agriculture, ecosystems & environment. 24(1): 27-41.

Grava, J., and Raisanen, K.A. 1978. Growth and nutrient accumulation and distribution in wild rice. Agron. J. 70: 1077-81.

Grava, J. 1982. Wild rice production in Minnesota. Univ. Minn. Ext. Bull. 484: 18-21.

Harmon, M.E., and Lajtha, K. 1999. Analysis of detritus and organic horizons for mineral and organic constituents. *In* Standard Soil Methods for Long-Term Ecological Research. *Edited by* G.P. Robertson, D.C. Coleman, C.S. Bledsoe, and P. Sollins. Oxford University Press, New York, pp. 143-165.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, NY.

Hastwell, Graeme T. and Facelli, Jose M. 2000. Effects of leaf litter on woody seedlings in xeric successional communities. Plant Ecology. 148 (2): 225-231.

Jenks, A.E. 1899. The wild rice gatherers of the Upper Great Lakes. Ph.D. dissertation, Department of Anthropology, University of Wisconsin, Madison.

Keenan, T.J., and Lee, P.F. 1988. Ecological relationships of wild rice, *Zizania aquatica.* 7. Sediment nutrient depletion following introduction of wild rice to a shallow boreal lake. Can. J. Bot. 66: 236-241.

Kennard, W., Phillips, R., Porter, R., and Grombacher, A. A comparative map of wild rice (*Zizania palustris* L. 2n=2x=30). Theor. Appl. Genet. 99: 793-799.

Knapp A.K., and Seastedt, T.R. 1986. Detritus accumulation limits productivity of tallgrass prairie. BioScience. 36: 662-668.

Kushwaha, C.P., S.K. Tripathi, and K.P. Singh. 2000. Variations in soil microbial biomass and N availability due to residue and tillage management in a dryland rice agroecosystem. Soil & tillage research. 56(3-4): 153-166.

Lee, P.F., and Stewart, J.M. 1984. Ecological relationships of wild rice, *Zizania aquatica* L. 2. Sediment-plant tissue nutrient concentrations. Can. J. Bot. 61: 1775-1784.

Linquist, B.A., S.M. Brouder, and J.E. Hill. 2006. Winter straw and water management effects on soil N dynamics in California rice systems. Agron. J. 98(4): 1050-1059.

May, R.M. 1973. Stability and Complexity in Model Ecosystems. Princeton University Press, Princeton.

May, R.M. 1974. Biological populations with nonoverlapping generations: stable points, stable cycles, and chaos. Science 186: 645-47.

Moyle, J.B. 1944. Wild rice in Minnesota. J Wildl. Manage. 8: 177-184.

Odum, W.E., and M.A. Heywood. 1978. Decomposition of intertidal freshwater marsh plants. *In* Freshwater wetlands: ecological processes and management potential.

Edited by R.E. Good, D.F. Wingham, and R.L. Simpson. Academic Press, New York, pp. 89-97.

Osem, Y., Perevolotsky, A. and Kigel, J. 2006. Similarity between seed bank and vegetation in a semi-arid annual plant community: The role of productivity and grazing. Journal of Vegetation Science. 17(1): 29-36.

Pacala, S.W. and J.A. Silander, Jr. 1990. Field tests of neighborhood population dynamic models of two annual wee species. Ecol. Monogr. 60: 113-134.

Pastor, J., and R.E. Durkee Walker. 2006. Delays in nutrient cycling and population oscillations. Oikos. 112: 698-705.

Rao, D.N., and Mikkelsen, D.S. 1976. Effect of rice straw incorporation on rice plant growth and nutrition. Agron. J. 68: 752-755.

Rogosin, A. 1958. Experimental growth of wild rice in relation to water levels, seeding densities and fertilizer application. Proc. Minn. Acad. Sci. 25-26: 95-97.

Ryan, M.G., J.M. Melillo, and A.Ricca. 1990. A comparison of methods for determing proximate C fractions of forest litter. Can. J. For. Res. 20: 166-171.

Sain, P., and Broadbent, F.E. 1975. Moisture absorption, mold growth, and decomposition of rice straw at different relative humidities. Agron. J. 67: Nov.-Dec.

Sain, P. 1984. Decomposition of wild rice (*Zizania aquatica*) straw in two natural lakes of northwestern Ontario. Can. J. Bot. 62: 1352-1356.

Stevenson, S.C., and Lee, P.F. 1987. Ecological relationships of wild rice, *Zizania aquatica.* 6. The effects of increases in water depth on vegetative and reproductive production. Can J. Bot. 65: 2128-2132.

Strogatz, S. H. 1994. Nonlinear Dynamics and Chaos. Perseus Books.

Sydes, C., and Grime, J.P. 1981. Effects of tree litter on herbaceous vegetation in deciduous woodland. II. An experimental investigation. J. Ecol. 69: 249-262.

Thrall, P.H. Pacala, S.W. Silander, J.A. Jr. 1989. Oscillatory dynamics in populations of an annual weed species *Abutilon theophrasti*. J. Ecol. 77 (4): 1135-1149.

Tilman, D., and Wedin, D. 1991. Oscillations and chaos in the dynamics of a perennial grass. Nature 353: 653-655.

Turchin, P. and Taylor, A. 1992. Complex dynamics in ecological time series. Ecology 73: 289-305.

Vandermeer, J. 2006. Oscillating populations and biodiversity maintenance. Bioscience. 56(12): 967-975.

Verma, T., and Bhagat, R.M. 1992. Impact of rice straw management practices on yield, N uptake and soil properties in a wheat-rice rotation in northern India. Fert. Res. 33: 97-106.

Walker, R.D., Pastor, J., Dewey, B.W. (2006) Effects of wild rice (Zizania palustris L.) straw on biomass and seed production in northern Minnesota. Canadian Journal of Botany, 84 (6): 1019-1024.

Table 4.1 *P* values from one-way ANCOVA for wild rice mesocosm biomass for years 2004 and 2005 with litter biomass from the previous year as covariate.

		Plant density	**Covariate**
Change in Biomass (2004-2005)		0.0008	6.8612e-05
Change in Biomass (2005-2006)		0.0038	9.7223e-08
Change in Biomass (2004-2006)		6.306e-05	1.226e-08

Table 4.2 *P* values of regression analyses for slopes of change in biomass (*t* to *t*+1) vs biomass (*t*)

Treatment	**Year**	**r**	**slope**	**S.E. of slope**	***P***
Overall	Summers '04 and '05	0.3960	-0.5710	0.1280	2.00e-05
Thinned	Summer '04	0.3550	-0.4870	0.2560	0.0690
Unthinned	Summer '05	0.6330	-1.230	0.2770	16.00e-05
Thinned	Summer '04	0.7900	-0.9870	0.1530	9.5e-07
Unthinned	Summer '05	0.5050	-0.5960	0.2000	0.0072
w/o outlier	Summer '05	0.4680	-0.8460	0.3260	0.0160
Roots alone	Summers '04 and '05	0.6100	-0.9500	0.2040	7.85e-05
Roots & shoots	Summers '04 and '05	0.2730	-0.3800	0.1600	0.0200

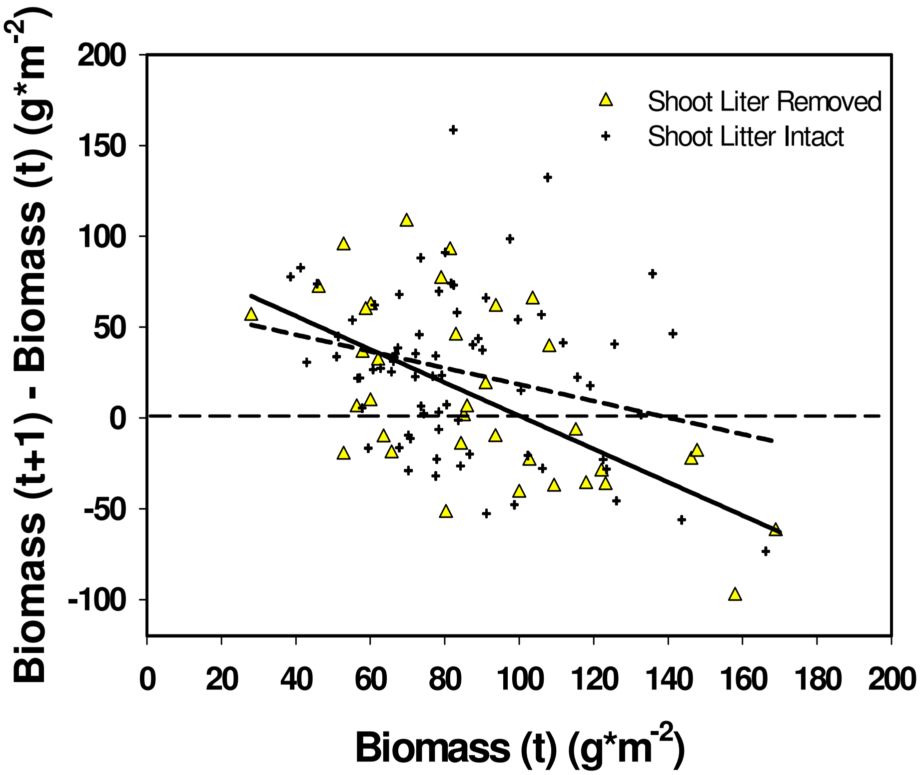


Figure 4.1 Changes in biomass from t to t + 1 for tanks with intact shoot and root litter (crosses and dashed lines) and removed shoot litter but intact roots (triangles and solid lines). Higher biomass in year t causes decreases in biomass the following year, while low biomass in year t causes increased biomass the following year. Both regressions are significant at $P < 0.02$. The slope of the line for tanks with removed shoot litter is not significantly different than -1.

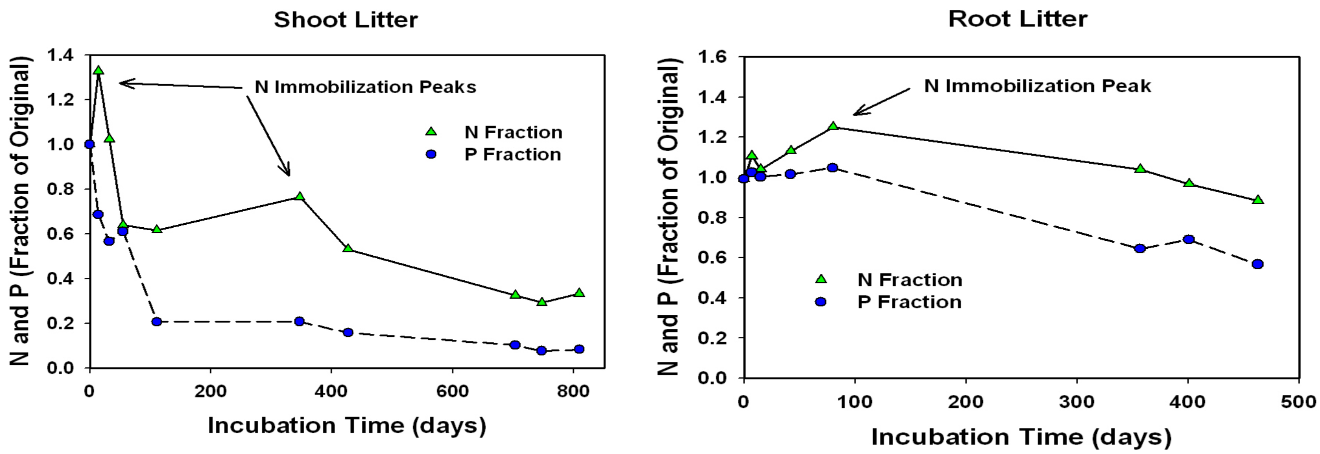


Figure 4.2 Fraction of original N and P for shoot litter over three years and root litter over two years.

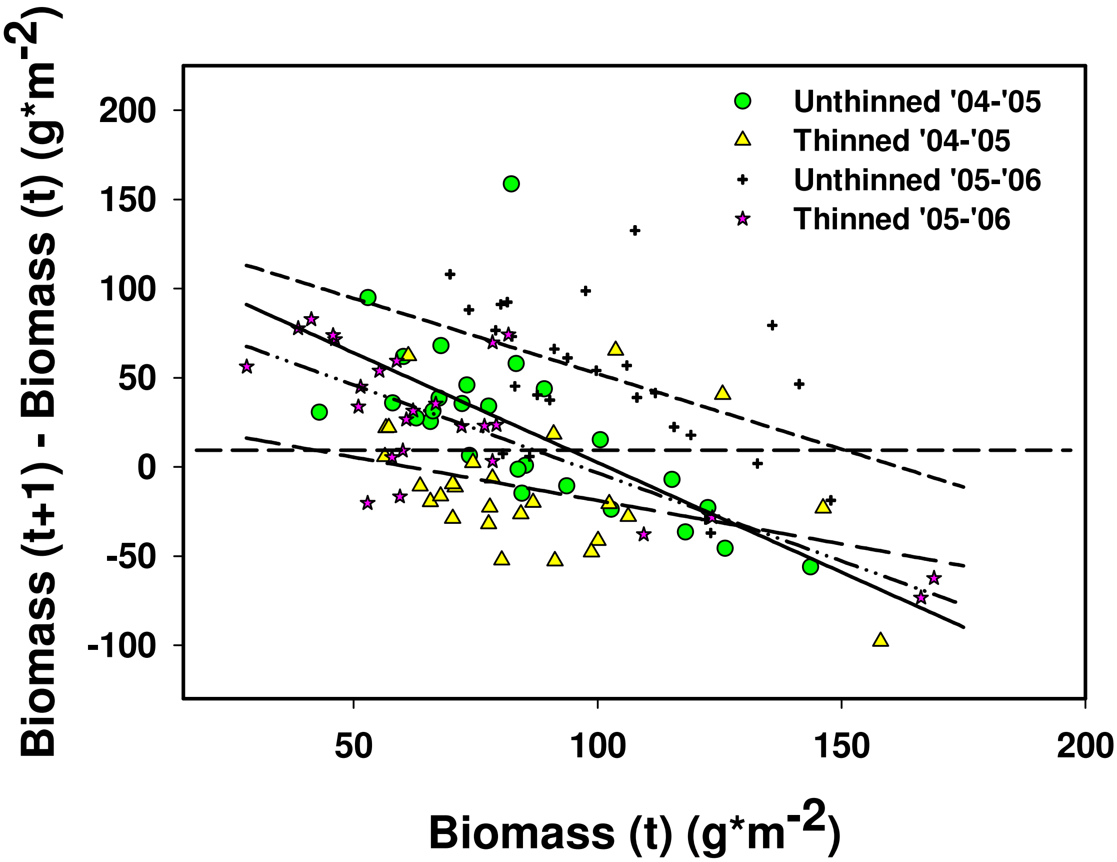


Figure 4.3 Changes in biomass from *t* to *t* + 1 for unthinned and thinned tanks. Regression lines for unthinned tanks are solid (2004-2005) and short-dash (2005-2006). Regression lines for thinned tanks are long-dash (2004-2005) and dash-dot (2005-2006). Greater biomass in year *t* resulted in less biomass the following year, while less biomass in year *t* resulted in more biomass the following year. All regressions are significant at $P < 0.02$. The slopes of the lines for unthinned tanks are not significantly different than -1.

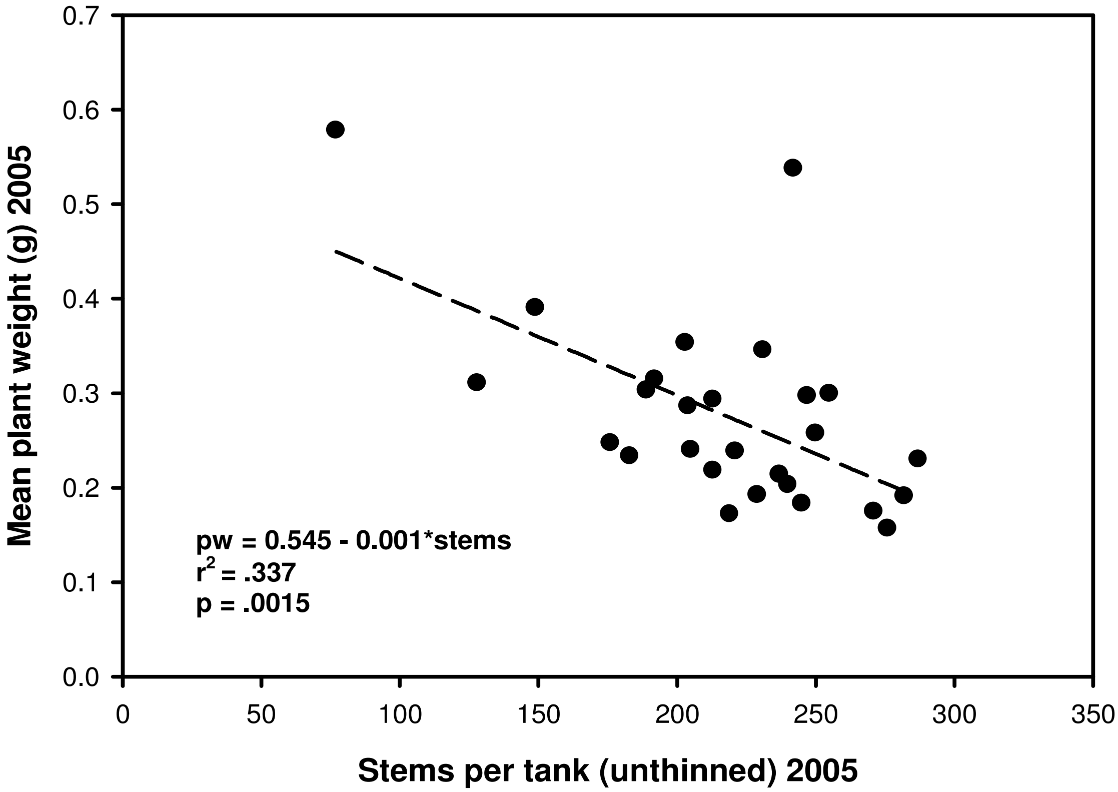


Figure 4.4 Mean plant weight per tank decreased with increasing plant density in 2005.

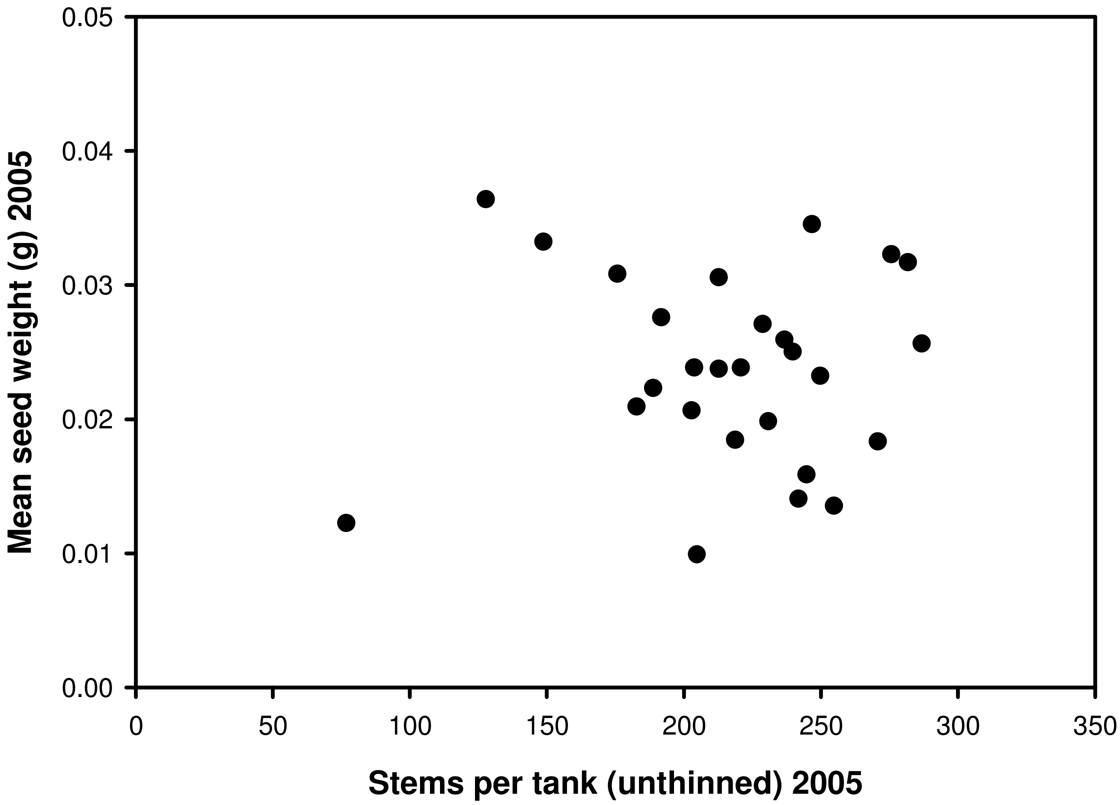


Figure 4.5.a. Mean seed weight per plant per tank decreased slightly with increased plant density in 2005.

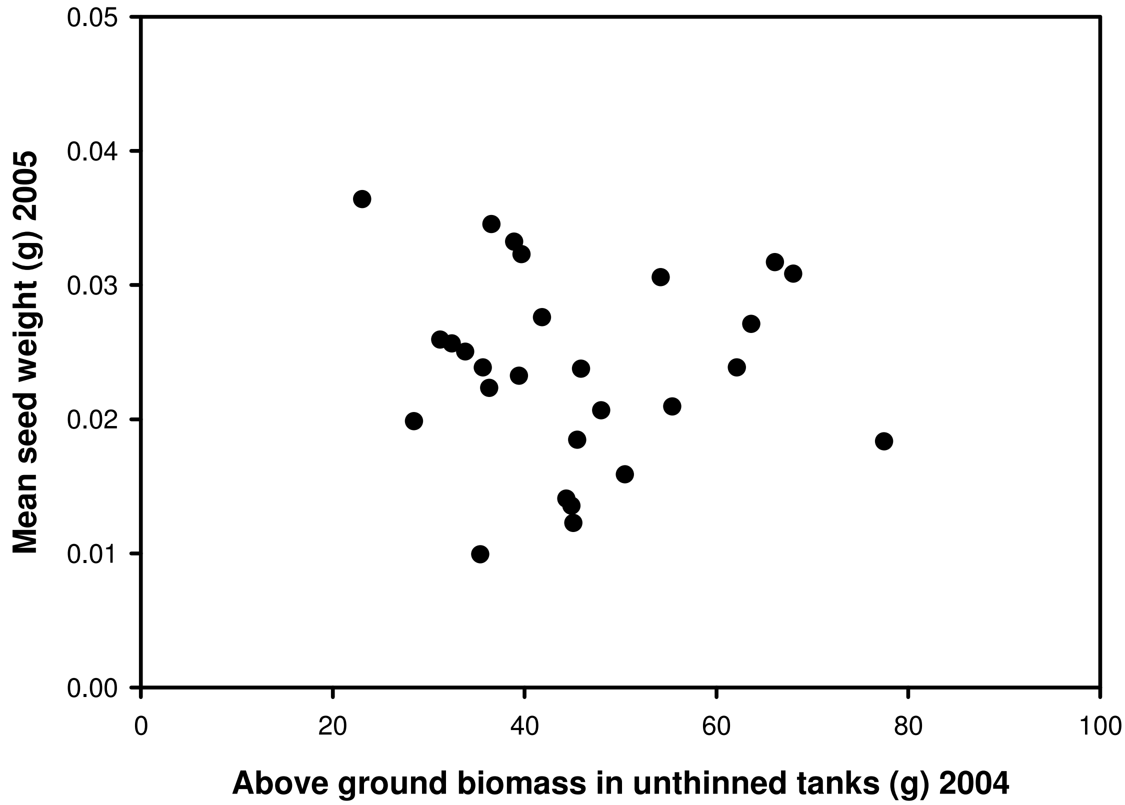


Figure 4.5.b. Mean seed weight per plant per tank in 2005 increased slightly with increased above ground biomass in unthinned tanks produced the previous year, 2004.

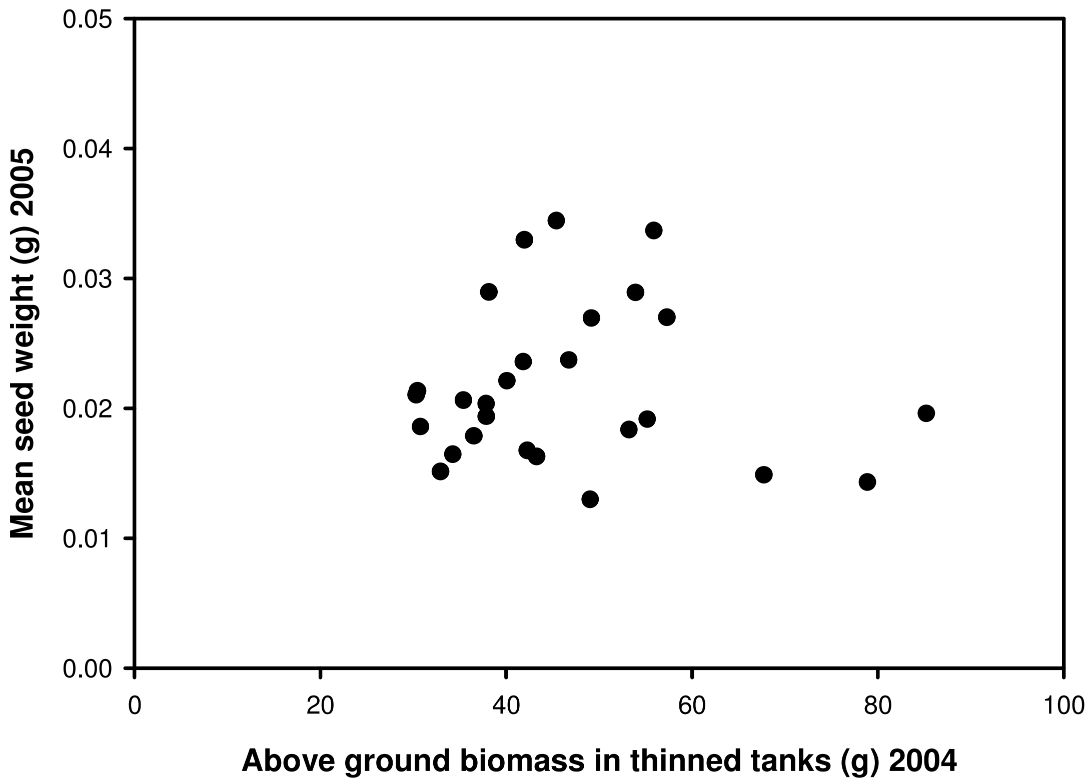


Figure 4.5.c. Mean seed weight per plant per tank in 2005 increased slightly with increased above ground biomass in thinned tanks produced the previous year, 2004.

CHAPTER 5

Wild Rice: The Minnesota Legislature, a Distinctive Crop, GMOs, and Ojibwe Perspectives

> I am proud to represent Monsanto. We have a billion acres of GMO crops and there has not been a single adverse incident in ten years. Monsanto has never thought about engineering wild rice. It is a unique product and so makes no economic sense [to genetically engineer it]. We have federal and state regulations. How much more process can you get? Minnesota has spent a ton of time and money to nurture the biotechnology industry. If this legislation passes, make no mistake, the national organic websites will have its results up all over the country…
>
> Sarah Janacek, lobbyist for Monsanto[72]

Genetically engineered seeds and crops abound in U.S. agriculture. Proponents of this technology cite the promise of genetic engineering to feed a hungry world, reduce pesticide use and provide crop-based energy alternatives.[73] Opponents cite concerns regarding the safety of these technologies to the environment and humans and the capability of federal regulatory agencies to keep genetically and non-genetically engineered crops separate. A few critics are concerned about the respect of Indigenous populations for whom particular food resources are culturally sacred and protected by treaty. The Minnesota Legislature weighed in on this debate, passing legislation in

---

[72] From testimony, HF 3915, March 28, 2006, House Committee of Agriculture and Rural Development, Minnesota Legislature.

[73] For the purposes of this paper I use the terms genetically engineered foods and genetically modified organisms (GMOs) interchangeably as is often done in the media. I recognize that these terms are technically different but follow the terms' usage as understood by laypersons. I also distinguish between traditional or conventional breeding practices and genetic engineering as defined in molecular biology texts. "Traditionally plants have been improved through selection during many crop cycles" (which can take many generations). Traditional breeding normally involves only individuals of the same species. Genetic engineering is technology that facilitates the successful transfer and expression of genes from one species into another (Pena. 2005. Transgenic plants: methods and protocols. Humana Press, Vol. 286). "[Genetic engineering] is the artificial manipulation of genes and their products. Genes from any source can be manipulated and modified using microorganisms and their enzymes as molecular tools. Now, using genomic techniques, one can search hundreds of genetic blueprints for genes encoding proteins of interest, clone the genes into a suitable host, and then produce the proteins commercially" (Madigan and Martinko. 2006. Brock Biology of Microorganisms, 11th Edition, Pearson Prentice Hall: Upper Saddle River, New Jersey)..

2007 described, in part, as "an act modifying provisions for regulating genetically engineered organisms."[74] The legislation is noteworthy because it specifically addresses concerns regarding some *potential* impacts of genetically engineering a crop sacred to Indigenous bands. Second, the legislation mandates that a state level regulatory body, the Environmental Quality Board, adopt rules requiring an environmental impact statement (EIS) in the case of a permit for the release of genetically engineered wild rice. Finally, the legislation is unique in requiring a study be carried out by the state Minnesota Department of Natural Resources on potential threats to natural stand wild rice, including those from genetically engineered strains.

Opponents of the Minnesota legislation claimed that it "sends a chill through many communities in the state… we [in Minnesota] are circumscribing the ability for people to work in genetic engineering on agricultural crops… and… we [in Minnesota] are opening a door we will be sorry we opened."[75] In this chapter, I examine the history of this legislation, arguments supporting and opposing it, and some legislative procedures facilitating its passage. Minnesota's case is unique because it concerns a plant sacred to sovereign American Indian Nations (Ojibwe) governed by treaty rights specific to wild rice. It is also unique because non-American Indians in Minnesota also claim it as part of their identity (e.g. Minnesota state grain). Non- American Indians, living outside Minnesota but in places where wild rice grows, also view it differently from other cash crops. Wild rice is considered unique to northern North America. Minnesota's situation, however, is not unique to the extent it shares in common with

---

[74] From testimony, HF3915, March 28, 2006, House Committee of Agriculture and Rural Development, Minnesota Legislature.
[75] From testimony, HF2096, April 25, 2007, House Floor, Minnesota Legislature.

other states' discussions stemming from larger debates over the regulation of crop biotechnology.

History of wild rice legislation in Minnesota

In legislative session 2005, a version of the "wild rice bill" prohibited the release and sale of genetically engineered wild rice in Minnesota. The 2005 bill, S.F. 1566, was tabled.[76] The 2006 bill, H.F. 3915, emerged, in part, after discussions between interested parties.[77] H.F. 3915, titled, "A bill for an act relating to agriculture; providing for a wild rice study," was heard in the House Agriculture, Rural Economies and Veterans Affairs Committee. Passing the House, it did not reach the Senate.[78] In 2007, Senate File 2096, an Omnibus Environment, Natural Resources, and Energy Appropriations bill, contained language regulating the release of genetically engineered

---

[76] Posted March 8, 2005 and heard in the senate committee Agriculture, Veterans and Gaming Committee. Principal author: Becky Lourey. "A person may not release, plant, cultivate, harvest, sell, or offer for sale in Minnesota a genetically engineered organism containing or related to wild rice."

[77] Stakeholders including members of several Minnesota Ojibwe bands, members from the Minnesota Cultivated Wild Rice Council, the Department of Natural Resources, academics and interested citizens met in Bemidji, Minnesota on January 17, 2006 to discuss stakeholder concerns regarding revised legislation for Legislative Session 2006. The forum was convened by Paul Swenson, DNR. The forum included discussion but no firm consensus regarding these groups' or individuals' abilities to work together on matters relating to wild rice legislation.

[78] Posted April 6, 2006 and heard in the House Agriculture, Rural Economies and Veterans Affairs Committee. Principal author: Frank Moe. H.F. 3915 Wild Rice Study: "The commissioner of agriculture, in cooperation with the commissioner of natural resources shall review the need for a study of strains of wild rice that are indigenous to Minnesota, sacred to the Ojibwe people, and important both historically and economically to this state. These specific strains are zizania aquatica and zizania palustris. The study would include: (1) evidence of population decline in Minnesota lakes, rivers, and streams and, if such decline is found, an explanation of possible contributing factors; (2) arguments for and against the economic, agronomic, cultural and historical importance of maintaining the integrity of these strains; (3) evaluation of methods available for maintaining the integrity of these strains in Minnesota lakes, rivers, and streams, including scientific, regulatory, and any other reasonable methods the commissioners may identify; and (f) recommendations that address the findings in clauses (1) to (3). Subd. 2 Deadlines…"

wild rice. Passing the House and Senate, the bill was signed by the Governor on May 7, 2007.[79]

This legislation, pertaining to genetically engineered organisms and wild rice, underwent much negotiation over three years. The process by which legislation with little support in 2005 became law in 2007 warrants consideration. The evolution of this bill -- its language, the discussions in and outside committees, and its outcome -- was likely influenced by procedural, economic and political events. For the first time, it is possible to see a series of related discussions over several years on crop biotechnology in a state legislative context.

The case of Minnesota, wild rice and the legislature

One can argue Minnesota's case is unique because of the combination of cultural, political and economic circumstances which led to inclusion of language pertaining to wild rice and genetic engineering in S.F. 2096. Other states are on the cusp of passing or have passed similar legislation reflecting broader changes in national and international discussions. First, I examine some reasons why this legislation may be unique to Minnesota. Second, I discuss the broader context of crop biotechnology and Indigenous rights also of interest to other states and jurisdictions.

> I remember when my grandfather harvested wild rice. I remember climbing a tree when I was too young [to directly participate]. [Harvesting wild rice] is something I've participated in my whole life. I have first hand knowledge [of this practice], the harvesting, hand-parching, and finishing. [This practice] was passed onto me by my [grandparents and parents] and now I am passing it on to my children…

---

[79] In summary, the bill makes the state Environmental Quality Board (EQB) responsible for coordinating state and federal regulatory activities relating to genetically engineered organisms within Minnesota. The board must adopt rules requiring an environmental impact statement (EIS) in the event of a permit application for genetically engineered wild rice. The bill also requires a study by early 2008 estimating, among other factors, potential threats to natural stands, including those from genetically engineered strains.

> The Creator has given us many things. Every time we try to change [what we are given], it messes things up. I'm afraid this will happen to our wild rice beds. To [genetically engineer] wild rice would be disrespectful to the First People who inhabited this land… It would be morally wrong.
>
> Chairman George Goggleye Jr., Leech Lake Band of Ojibwe[80,81]

Although legislation on this issue was heard in the years 2005, 2006, and 2007 at the Minnesota legislature, for approximately a decade prior to these hearings, members from all six bands of Ojibwe in Minnesota expressed views similar to those expressed by Chairman Goggleye in 2007. In 2006, all Minnesota bands passed resolutions in support of state legislation. Ojibwe from Wisconsin, Michigan and parts of Canada also expressed similar concerns during the decade preceding the introduction of Minnesota's legislation. While Ojibwe bands in and outside Minnesota are distinct Sovereign Nations with views differing on many subjects, they unanimously supported various iterations of this bill.

Throughout the course of three years, members opposing or voicing concerns about this legislation made the following comments:

> Is there a problem with wild rice? Did a sportsmen's group come to you or is it one or more of the Sovereigns from up North? Do you have knowledge of what the Sovereigns are doing to address this concern among themselves?
>
> Representative Emmer[82]

---

[80] From testimony of H.F. 1662 and 1663 (precursors to S.F. 2096), House Environment and Natural Resources Committee, March 15, 2007.

[81] The word for wild rice in the Ojibwe language is *manoomin*, often translated as "good berry" (Vennum, Thomas, Jr.,1988, Wild Rice and the Ojibway People, Minnesota Historical Society Press: St. Paul, pages 5-6.) Referring to wild rice as *manoomin* recognizes that this food is traditionally and originally associated with Ojibwe. Wild rice is the English name given *manoomin*. Ojibwe language includes a number of dialects resulting in non-uniform spelling of the word. There are additional challenges with spelling because while the double vowel system is gaining popularity, there is no single standardized orthography for the language. (http://en.wikipedia.org/wiki/Ojibwe_writing_systems#Fiero_Double_Vowel_System)

[82] Representative Emmer, House Floor testimony, addressing Representative Moe, bill's author, May 15, 2006.

> Is the interest in this study about economic benefits just for tribal folks in your area? I was just wondering if it was becoming a "we" vs. "them" sort of debate. Seemed like it was starting to go that way.
>
> Representative Klinzing[83]

> [This bill] is about politics, emotion, guilt and pride. We've had only one instance of white rice being a problem…
>
> Representative Mahoney[84]

> This legislation was all political…It was completely politically driven. This is a Native American plant… The whole process was pushed by Leanna (sic) LaDuke for the purpose of raising the profile of culturalists on Native American reservations. The guilt comes from people feeling guilty about how they treated Native Americans. There is pride that the Native Americans now feel they have a more equal footing..."
>
> Representative Mahoney[85]

In light of these remarks, it seems critical to clarify specific, Constitutional, Sovereign and Treaty rights held by American Indians in this country. Such clarifications were not made during legislative testimony. Ojibwe perspective on wild rice is not just "one more" among other "equally valid" perspectives in Minnesota. Ojibwe are citizens of federally recognized Sovereign Nations guaranteed by a series of Supreme Court judgments from the 1820's and 1830's. Tribal governments voluntarily negotiate with states regarding matters of tribal jurisdiction and resource management guaranteed in negotiated treaties.[86]

In this case, a matter regarding natural stand wild rice growing in large quantities on American Indian Reservations, it is not a question of "we vs. them;" rather, it is one of considering justly the rights guaranteed to Ojibwe in treaty making. It is also a matter of rendering due consideration the lengthy history and integrity of

[83] Representative Klinzing, House Floor testimony, addressing Representative Moe, bill's author, May 15, 2006.
[84] Representative Mahoney, House Floor testimony, May 15, 2006.
[85] Personal communication, Representative Mahoney, May 23, 2007.
[86] Berger,T.R. 1992. A Long, Terrible Shadow: White Values, Native Rights in the Americas, 1492-1992. Seattle: University of Washington Press.

Indigenous environmental law and management that precedes and succeeds settlement. As recognized by Borrows (2002), Kidwell (2002) and Wilkins (2001), from somewhat different angles, "Indigenous or tribal peoples of the world… regulate rights and obligations crucial for maintaining the harmony with nature and the environmental awareness characteristic of the traditional way of life" (Borrows 2002).

Indigenous legal and management approaches to natural resources, broadly speaking, take into consideration the pre-eminence of "natural cycles" (Kidwell 2002). "The cycles of the natural environment oriented native people to the repetition of events… Native worldviews were more often concerned with events that repeated themselves on a regular basis -- the growth and harvest of crops, the mating and migration of animals, the movements of stars and planets. Recognition of… cycles… depends on accumulation of data over extended periods of time, usually greater than those of the lifetime of a single observer, and requires some form of record-keeping." Many Indigenous communities for millennia had sophisticated record-keeping including the Mayans, Aztecs, and Incans to name a few (Kidwell 2002). Communities today continue these traditions.

Kidwell (2002) points out that, "Native systems of knowledge are difficult to describe, for while they often reflect familiar Western processes -- observation, deduction, hypothesis, experimentation -- they also rest upon fundamentally different understandings of the world..." As the Brundtland Commission noted, [some Indigenous people] "have enjoyed substantial and long-term environmental successes" (Borrows 2002). Borrows (2002) continues, "Indigenous inclusion… in existing [legal and government] institutions … facilitates sustainability by suggesting important reconnections of biological relationships with ecosystems." Finally, "Indigeneous legal principles form a system of 'empirical observations and pragmatic knowledge' that has value both in itself and as a tool to demonstrate how people structure information" (Borrows 2002).

Wild rice has enjoyed an Indigenous management history that is unique and precedes modern times (Paul Schultz, Joseph LaGarde, John Persell, personal communication, 2006-2008). Such management is distinct and more developed than other Indigenous resource management (management for deer, for example). Tribal elders and resource managers have historically monitored and managed water levels as part of wild rice management. For example, if a particular beaver appeared to be building a dam that might affect water levels and negatively impact wild rice growth, that beaver "ended up in the pot" (John Persell, personal communication, 2008). In Nett Lake, Bois Forte Band of Chippewa, a boulder the size of a small car protrudes out of the water in front of Spirit Island. Historically, tribal elders determined the time of rice harvest, in part, by gauging when water levels reached a particular point on that rock (John Persell, personal communication, 2008).

While Ojibwe have well-developed wild rice management traditions, elders appreciate both the fragility and resilience of this resource (Paul Schultz, Joseph LaGarde, personal communication, 2006-2007). Historically, if a crop was not robust, damaged by storms or straight line winds, communities traveled to other lakes for harvesting. Ojibwe wild rice managers have acknowledged the complexity of biological relationships and ecosystems (John Persell, personal communication, 2008).

In their remarks at the legislature in 2007, legislators failed to acknowledge critical historical and legal precedents. Minnesota became a state in 1858. Statehood did not eliminate the sovereign status of American Indian nations and management of resources within their jurisdictions, nor did it eliminate prior treaty obligations (McClurken et al. 2003). It also did not eliminate the "Federal Government's obligation to protect tribal trust resources: land, water, hunting and fishing rights, and that sovereign immunity is integral to protection of those resources…" (Wilkins 2001).

In 1837, the United States entered into a treaty with several Bands of Chippewa Indians guaranteeing certain hunting, fishing and gathering rights (among them wild rice) on ceded land. This treaty did not specify that Ojibwe "owned" wild rice, but guaranteed the protection of Ojibwe to harvest and manage native stands. The rights guaranteed in that treaty were recently recognized again in a 1999 Supreme Court decision: Minnesota, et al., Petitioners v. Mille Lacs Band of Chippewa Indians et al.[87] This case was filed in August 1990, by members of the Mille Lacs band of Ojibwe against the State of Minnesota for "interfering with the hunting, fishing and gathering rights that had been guaranteed them in the 1837 treaty with the United States."[88]

Serious consideration of Ojibwe views regarding wild rice is not a matter of considering "another view." It is not optional to overlook the ways treaty rights confer specific responsibilities to American Indians over particular natural resources. In discussions about science, biotechnology and management of natural stand wild rice, it is potentially unlawful for states to ignore treaty-based claims. Legislators need to

---

[87] McClurken, J.M., Cleland, C.E., Lund, T., Nichols, J.D., Tanner, H., White, B. 2000. Fish in the Lakes, Wild Rice, and Game in Abundance. Michigan State University Press: Lansing, MI.
[88] McClurken et al., ibid, p. vii.

consider Constitutional and Supreme Court mandates; abdication of these responsibilities is tantamount to ignoring the rule of law.

Ojibwe and wild rice

Over three years of legislative discussion, proponents argued that wild rice is spiritually and culturally sacred to Ojibwe. Little, if any, discussion clarified that relationship. We take time to include discussion, while not presenting an exhaustive analysis.

Ojibwe band members signing the treaty of 1837 asserted their right to gather wild rice in ceded territories based on reasons of livelihood and spiritual tradition; wild rice is central to Ojibwe survival and identity.[89] The Ojibwe migration story tells of a time when they lived in the East and were instructed by the Creator to follow the *miigis* (cowrie shell) on a westward journey that would end when they reached "the place where the food grows on water."[90,91,92] Wild rice is this food. Ojibwe nations live alongside Minnesota, Wisconsin, Michigan and Canadian lakes and rivers where they encountered rice, perhaps many hundreds of years ago, perhaps longer, where it grows naturally today. Associated with origin stories, wild rice is central to notions of being Ojibwe; managing wild rice in its natural state is a moral obligation.[93]

---

[89] There are many versions of this story. We extrapolate from the most widely recognized among Ojibwe.

[90] The Creator is also commonly called the Great Spirit or Gichi Manitou and is generally understood as the maker and designer of everything.

[91] A miigis is a type of shell that is small, light in color (cream, beige or ecru), oval shaped and has a long, narrow opening on one side. It is known as a cowry (also spelled cowrie) shell in English.

[92] Benton-Banai, E. 1988. The Mishomis Book: The Voice of the Ojibway. Indian Country Communications: Hayward, pages 94-102.
Regguinti, G. 1992. The Sacred Harvest: Ojibway Wild Rice Gathering. Lerner Publications Company: Minneapolis, pages 17-18.

[93] From testimony of H.F. 1662 and 1663 (precursors to S.F. 2096), House Environment and Natural Resources Committee, March 15, 2007, Vennum, page 299.

For Ojibwe, wild rice has medicinal and nutritional value derived from its spiritual significance — a belief reflected in use of wild rice to promote recovery from sickness as well as for ceremonial feasts."[94] Wild rice is served at spiritual ceremonies, pow-wows, family gatherings, other special events, and as a regular part of family meals.

Ojibwe understand their relationship to wild rice through stories known to all members from childhood. The stories depict the advent of specific "heroes" and their connection to humans, animals and plants. "[T]hese legends explain the origin of wild rice."[95] One story describes how Wenabozhoo, the main Ojibwe "culture hero," was introduced to wild rice.[96]

> …One evening [Wenabozhoo] returned from hunting but had no game. . .As he came towards his fire, there was a duck sitting on the edge of his kettle of boiling water. After the duck flew away, he looked into the kettle and found wild rice floating upon the water, but he did not know what it was. He ate his supper from the kettle, and it was the best soup he had ever tasted. Later, he followed in the direction the duck had taken, and came to a lake full of manoomin. He saw all kinds of ducks, geese, mud hens, and all the other water birds eating the grain. After that, when [Wenabozhoo] did not kill a deer, he knew where to find food to eat. . .[97]

Other stories tell how wild rice was a gift to Ojibwe from the Creator to end famine during the late winter when supplies of food often ran low and game was difficult to secure.

---

[94] Vennum, pages 60-71.
[95] Vennum, page 58.
[96] A culture hero is the most important legendary figure of a specific people and is often involved in the creation of the world. A culture hero often discovers significant things like fire, or, as in this case, wild rice. Different Ojibwe communities use a variety of names for the culture hero due to dialect differences in the Ojibwe language. He is known by names including Nanaboozhoo, Nanabush, Nanapush, and Manaboozhoo (Johnston, B. 1976. Ojibway Heritage. McClelland and Stewart: Toronto).
[97] LaDuke, Winona. 1999. The Wild Rice Moon. Whole Earth. Winter, page 78.

> Only the old ones speak of how the people suffered during the hungry-time. It occurred in the late winter or early spring. . .when snow covered the ground and the supply of stored food dwindled. Babies cried desperately for food. Mothers wept in despair, and fathers turned their backs to hide their tears… Soon people found rice growing in many shallow lakes and rivers. The hungry times ended.[98]

Considered perfect in its natural state as depicted in oral tradition, the process of harvesting wild rice is also central to the relationship between Ojibwe and this sacred resource. Many offer a prayer and gift of tobacco before beginning harvest. Owing to its cultural, spiritual and nutritional sustenance, Ojibwe appropriately honor the rice and its Creator.[99]

Harvesting is most often done in teams of two – one person using a forked pole to propel the canoe, and the other using knocking sticks to gently knock the rice into the canoe and into the water.[100] The grains landing back in the water help ensure the harvest for the coming years. It would be nearly impossible for one person to harvest rice using a canoe and knocking sticks; cooperation between the paddler and harvester is essential. Acts of cooperation remind harvesters of their relationship with rice and keep the community strong.

Ojibwe understand themselves, their history, and their relationship to the natural world through these stories. The first story emphasizes the importance of learning from animal siblings. The second illustrates how food is directly connected to survival. Neither story places humans in positions superior to wild rice; rather, culture heroes, the

---

[98] Dunn Anne M., 1995, The Gift of Mahnomen in When Beaver was Very Great: Stories to Live By. Midwest Traditions, Inc.: Mount Horeb, WI, page 126.
[99] A prayer of thanks is offered and then a small amount of tobacco is placed near the shoreline or in the water near the wild rice. Many Ojibwe believe that tobacco is a special plant that feasts spirits so in this case tobacco is offered to both thank and feast the spirit of the rice.
[100] Regguinti's Sacred Harvest gives an excellent modern-day account of the wild rice harvesting process. Vennum, ibid, p. 97-98.

Creator, animals, and plants possess significance that humans cannot fully know. From these stories, Ojibwe understand their mandate to protect and maintain this sacred resource.

Throughout the course of Minnesota's Legislative hearings, it is unclear whether the spiritual and cultural significance of wild rice to Ojibwe affected outcomes. In previous years, the bill did not pass in spite of testimony similar to Chairman Goggleye's in 2007. It is possible, however, that the consistency of these arguments, the increased participation by Ojibwe tribal leaders, along with other arguments, helped in passing "wild rice language" in S.F. 2096. Whatever the full set of reasons, it is inaccurate to claim this legislation was mainly about "non-American Indians feeling guilty" or "American Indians having Native Pride" exercising political muscle. These explanations discount the legal realities of American Indian sovereignty and treaty-secured resource management. They discount the significance of Sovereign Nation rights to preserve Ojibwe identity and livelihood.

Wild rice and Minnesotan identity

> I am supporting this legislation because it is about wild rice and wild rice alone. It is a very unique crop.
>
> Representative Juhnke[101]

> I have frequented for a long time a lake home of my parents near wild rice beds. We have also harvested it. We eat a lot of wild rice… It is an important part of our heritage in Minnesota. It's important to our [Minnesota] heritage to maintain a pure wild rice strain…
>
> Representative Klinzing[102]

> Wild Rice, Minnesota's State Grain, is almost as old as history itself.
>
> C&G Enterprises[103]

---

[101] From testimony in House Committee on Agriculture and Rural Development, April 4, 2006.
[102] From testimony on H.F. 3815, May 15, 2006.
[103] C&G Enterprises, http://www.mnwildrice.com/riceinfo.htm, accessed May 24, 2007.

> We offer you the essence of Northern Minnesota in our products (wild rice).
>
> GRV Gibbs Wild Rice[104]

Many legislators, Democrat and Republican, supported this legislation because, as they stated, "wild rice is unique to Minnesota" and Minnesotan identity. They wanted to clarify that, while perhaps important to American Indians, wild rice was important to non-American Indians as well. Precisely what is "Minnesotan" about wild rice? Answers may vary greatly from person to person. In any case, while such views may have played a significant role in this bill's passage, I look at concrete legislative procedures and political realities that likely came into play. In sum, the most important reasons for this bill's passage in 2007, according to its chief author, were: a Democratic House and Senate majority with sufficient partisan loyalty on some issues and supportive chairs in both the House and Senate Environment Policy and Finance Committees.[105]

Legislative factors contributing to passage of S.F. 2096

When brought to the House Floor, this bill passed as part of an Omnibus Environment bill: 88 to 44. For legislation which in previous years did not make it past the first committee hearing, this vote represents a dramatic shift. In this section, I consider the political make-up of the Minnesota House and Senate, lobbying tactics and the role of outside support in 2007.

In 2006, some of the bill's opponents described it as purely an "Indian bill," meaning bands, band-affiliated, or "American Indian" non-government organizations

---

[104] GRV Gibbs Wild Rice, http://www.gibbswildrice.com/, accessed May 24, 2007.
[105] Frank Moe, personal communication, June 22, 2007.

comprised its primary support. The bill was in fact heavily supported by band members: all six Ojibwe bands from Minnesota passed their own resolutions in support of this legislation. The Leech Lake Band of Ojibway and Red Lake Nation showed strong support, as did the White Earth Land Recovery Project (WELRP). The bill, however, was also supported by the Izaak Walton League of America and closely watched by the Minnesota Center for Environmental Advocacy, Sierra Club, League of Conservation Voters, Audubon Society, Farmers Union, Institute of Agriculture and Trade Policy (IATP), and the Land Stewardship Project.[106]

In 2007, the number of organizations officially supporting the legislation jumped to approximately 51, and also included six mayors, two city councils, and one county board.[107] Among the diverse range of new organizations supporting the bill were the Joint Religious Legislative Coalition and the Minnesota Association of Conservation Professionals, which wrote formal letters to leaders of key committees at the start of 2007. While impossible to determine the influence of particular

[106] Frank Moe, ibid, May 2006.

[107] Joint Religious Legislative Coalition, Minnesota Farmers Union, Institute for Agriculture and Trade Policy, Land Stewardship Project, Minnesota Association of Conservation Professionals, Isaak Walton League Minnesota Division, Mankato Area Environmentalists, NE Minnesotans for Wilderness, League of Women Voters – Minnesota, Sustainable Farming Association of Minnesota, National Environmental Trust, The Alliance for Sustainability, EAGLE (Environmental Association for Great Lakes Education), Kids for Saving Earth, Renewing the Countryside, MN COACT (Citizens Organized Acting Together), Sweetwater Alliance, Institute for a Sustainable Future, Institute for Local Self Reliance, The Wild Institute, Friends of the Boundary Waters Wilderness, Minnesota River Valley Audubon Chapter, Duluth Audubon Society, Saint Paul Audubon Society, American P.I.E. (Public Information on the Environment), Lake Superior Sustainable Farming Association, Round River Farm, Park United Methodist Church, Brainerd Aveda Corporation, The Lutsen Resort, Gunflint Lodge, Chef Lucia Walker, GRV Gibbs Wild Rice, Northern Waters Smokehaus, Fitgers Brewhouse, Bennett's on the Lake, Blue Heron Trading Company, Chester Creek Café, Linden Hills Co-op, Whole Foods Co-op (Duluth), W-Trek Outfitters, Midnight Sun Adventure Company, Duluth Pack, Wilderness Family Naturals, Mississippi Corridor Neighborhood Coalition, North American Water Office, Harbor Friends of Grand Marais, Environmental Justice Advocates of Minnesota, Clean Water Action Alliance of Minnesota, Voyageurs National Park Association, 1000 Friends of Minnesota, Mayor R.T. Rybak (Minneapolis), Mayor Chris Coleman (St. Paul), Mayor Herb Bergson (Duluth), Mayor James Wallin (Brainerd), Mayor Elaine Flemming (Cass Lake), Mayor Larry Buboltz (Detroit Lakes), Mayor Bill Eck (Waubon), Park Rapids City Council, Duluth City Council, St Louis County Board.

organizations, the sizeable jump in support and its widespread political and geographic base are noteworthy.

It is also important to take into account some changes in opponent tactics. In 2006, those publicly testifying against the bill included a Monsanto lobbyist, representatives from biotechnology trade organizations including MNBIO and Medical Alley, officials from the Minnesota Department of Agriculture (Dept. of Ag.), officials from the University of Minnesota, and the Minnesota Cultivated Wild Rice Association. The Minnesota Department of Natural Resources (DNR) took a neutral stance.[108] In both 2006 and 2007, opponents lobbied legislators off the Capitol and Committee floors. In 2007, however, the number of public testimonies against the bill shrank. The DNR supported the legislation, but did not play an active role in its support. Several of the same biotechnology trade organizations from the 2006 session testified. Monsanto, the Minnesota Department of Agriculture and the Minnesota Cultivated Wild Rice Council, however, did not testify. The University of Minnesota took a neutral position.

Concurrent with changes in political support for and against this bill were changes in political leadership in the Legislature. In 2006, the Republicans controlled the House and Governor's seat, but in 2007, the Democrats took control of the House and maintained control of the Senate. While not necessarily a partisan issue -- in fact, many in favor of the bill were Republican and many opposed were Democrat -- votes, however, tended to divide along partisan lines. Even prior to the 2007 session, the bill's authors had adequate numbers of votes in both the House and Senate. The vote in the House was not close: 88 to 44. House proponents voted in favor of wild rice language

---

[108] From testimony in House Committee on Agriculture and Rural Development, March 28, 2006.

and funding in S.F. 2096; House opponents proposed amendments to remove this language on the House Floor, but the amendments were defeated.

The bill's main author, Representative Frank Moe, attributed success to several important factors. Several representatives played particularly active roles. Representative Kent Eken, co-author, was an especially strong supporter throughout the session. Representative Phyllis Kahn's support in the Government Operations Committee was pivotal in keeping the bill moving. Finally, Chair Jean Wagenius, was adamant that this bill not be removed from the Environment Omnibus bill. She met with Speaker Ellen Anderson and Senate Finance Chair Lyndon Carlson to make clear her position.[109]

In addition to the work of particular representatives, other factors played important roles. Prior to Committee hearings, Representative Moe met with seasoned legislator, Senator Rod Skoe (served two terms in the House and currently in his second term in the Senate). Representative Moe consulted Senator Skoe, working with him to draft mutually agreeable language. Senator Skoe is a paddy wild rice farmer and represents many constituents from White Earth and Red Lake Bands. Senator Skoe is also a member of the Minnesota Cultivated Wild Rice Council. In 2006, Senator Skoe's public position on the bill was unclear. He did not openly oppose the bill as it traveled through Committee to the House floor. At one point during a House Agriculture, Rural Economies, and Veterans Affairs Committee hearing, the Minnesota Cultivated Wild Rice Council claimed its members opposed this legislation.[110] Such claim, however,

[109] Personal communication, Representative Frank Moe, June 22, 2007.
[110] From testimony, HF3915, "Wild Rice Study," the House Committee of Agriculture, Rural Economies, and Veterans Affairs, Minnesota Legislature, March 28, 2006.

failed to acknowledge that Council members, Senator Skoe and the Red Lake Nation, did not actively join the bill's opposition. In 2007, understanding that Democrats held the majority in the House and that the "wild rice issue" was not going away, it is possible Senator Skoe consented to work on mutually agreeable language with the bill's authors.[111]

Prior to the 2007 session, as well as ongoing during hearings, Representative Moe and lobbyists met with Legislators who may not have made up their minds regarding the bill. In comparison to 2006, Representative Moe noted proponents simply had more people on the ground. It is also possible that lobbying in 2007 was more effective due to increased tribal leader testimony. Complementing such testimony was the work of lobbyists in 2007, Andrea Hanks and Allen Richardson from the White Earth Land Recovery Project (WELRP), Jamie Edwards of Mille Lacs Band, Henry Erdman and Bob Johnson (former legislators) of Bois Forte Band, Steve Smith of Minnesota Chippewa Tribe, and tribal attorney, Wayne Bohn of Leech Lake Band. Craig Hassel, Professor of Food and Nutrition, University of Minnesota, spoke on behalf of the legislation at several committee hearings as a private citizen.

Lobbyists in 2007 were better informed and more strategic, having benefitted in part from their experiences in 2005 and 2006.[112] Prior to the 2007 session, resolutions for "wild rice" were introduced and passed at the DFL precinct caucuses. These resolutions then went to the county and finally state DFL Conferences. Such resolutions may or may not be taken seriously depending on the legislator. It is worth mentioning the "wild rice" resolution was the only one in the "Agriculture" category

---

[111] Personal communication, Representative Frank Moe, June 22, 2007.
[112] Lobbying efforts were led largely by Winona LaDuke and Sarah Alexander of WELRP.

that made it to the DFL's action agenda for the 2007 session.[113] Perhaps few constituents realize how few items actually become a part of a party's "action agenda," and yet without that level of support, legislation may be weaker. Lobbyists may be effective in many ways. The energy, strategic planning, and competence of some of the most active lobbyists was apparent in the 2007 bill's first hearing in the House Environment and Natural Resources Finance Division Committee. Representative Dennis Ozment, serving for almost 24 years, singled out Richardson saying that during all his time in the Legislature he had never been as well-briefed on a single issue as he was by Allen Richardson of White Earth Land Recovery Project (WELRP).[114]

Finally, the Environment and Natural Resource Committees in the House and Senate, critical to the bill's passage, were controlled by sympathetic Chairs, Representative Jean Wagenius and Senator Sautveer Chaudhary. These Chairs were willing to hear the bill and supported it throughout the session. While the bill had the votes needed to pass the House and Senate, getting through committee is not an insignificant hurdle. The importance of "procedure" can be pivotal, as is seen in the following example.

On March 27, 2007, the House Government Operations, Reform, Technology and Elections Committee heard the bill. After testimony and discussion, most of its members were in favor of sending it to the House Finance Committee. House Government Operations Chair, Gene Pelowski, however, had received a request to hear the bill from Chair Tim Mahoney, House Biosciences and Emerging Technology Committee. The Biosciences Chair and many of its members adamantly opposed the

---

[113] Personal communication, Allen Richardson, WELRP June 28, 2007.
[114] From testimony, House Environment and Natural Resources Finance Division Committee, April 2007.

bill. Sending the bill to Biosciences would most likely have led to its demise. Chair Pelowski, however, desired to follow procedural precedent and respect another chair's request to hear the bill. Representative Pelowski moved to send the bill to Biosciences. In an effort to save it, Representative Phyllis Kahn motioned for an amendment to send the bill to the Finance Committee. Representative Moe and others rallied committee members to their seats. When a quorum was met, Representative Pelowski called for a vote. He voted against sending it to the House Finance Committee. His committee members, however, over-ruled him, and the bill was sent to Finance and not Biosciences.[115]

While this bill had critical support outside the Legislature, and sufficient votes to pass the House and Senate, all bills follow Committee protocol. The controlling caucus and Committee chairs play powerful roles in a bill's fate. While legislative procedure is not unique to Minnesota, the "wild rice bill" relied on legislative process for success. Wild rice, unique in terms of its relationship to Indigenous communities, unique as the state's official grain, was in no way unique when it came to enduring legislative process. No matter how hard its proponents worked, including the bill's authors, without majorities in the House and Senate and without the support of critical Committee chairs, this bill would likely not have passed in 2007.[116]

In terms of garnering the Governor's support, proponents arranged for every tribal chair to call the Governor asking that he not "line item-out" funding for wild rice in S.F. 2096.[117] The Minnesota Chippewa Tribe passed a resolution and sent it directly

[115] Personal communication, Frank Moe, May 2007.
[116] Personal communication, Frank Moe, June 22, 2007.
[117] Personal communication, Frank Moe, May 2007.

to the Governor.[118] The Governor may not have supported this legislation, *per se*, but it is possible that during the 2007 session, when he vetoed a large number of Democrat authored legislation, he needed to prioritize his vetoes.

Impossible as it may be to decipher exactly which factors facilitated passage of wild rice language in S.F. 2096, it is likely that increased levels of constituent support, proponent strategy, and economic factors outside the state, played a role. At this point, we look briefly at the political and economic context of crop biotechnology in 2007 as it relates to this legislation.

Changes in the political landscape of crop biotechnology

Federal oversight: Are the regulators regulating?

Lobbyist Janacek for Monsanto declared in 2006, "We have federal and state regulations. How much more process can you get?" Paul Strandberg, representative from the Agricultural Marketing Services of the Minnesota Department of Agriculture, declared in 2006, "The [GM] germplasm won't escape into natural stands."[119] Then came escaping genetically engineered Liberty Link white rice from Arkansas and escaping bentgrass from Oregon in the summer 2006. [120] Suddenly "adequate federal process" seemed hard to come by, and "inescapable germplasm" somehow capable of escaping.

[118] Personal communication, Allen Richardson, May 2007.
[119] Testimony at Minnesota House Agriculture and Rural Development Committee, March 28, 2006. Strandberg does not cite evidence that germplasm will not excape into natural stands.
[120] Weiss, R, *Washington Post*, Gene-altered profit-killer: A slight taint of biotech rice puts farmers' overseas sales in peril, September 21, 2006; Pollack, *NYT*, Grass created in lab is found in the wild, August 16, 2006.

Warnings about federal oversight and the possibility of genetically engineered strains ending up in undesired locations were longstanding. [121] At the 2006 Minnesota Legislature, Dennis Olson, Institute for Agriculture & Trade Policy (IATP), presented information from the Inspector General of the United States Department of Agriculture (USDA). Olson drew attention to an audit that found the Animal and Plant Health Inspection Service (APHIS), the USDA branch responsible for regulating GM crops, "failed to properly oversee field trials of GE plants."[122] According to the report, APHIS, "lacks basic information about the field-test sites it approves and is responsible for monitoring, including where and how the crops are being grown, and what becomes of them at the end of the field test."[123] The audit cited regulatory weaknesses in the internal management controls, "increasing the risk that genetically engineered organisms will inadvertently persist in the environment before they are deemed safe."[124] It seemed all but a prediction of the August 2006 events.

Whether the Monsanto lobbyist's claim from 2006 testimony that "in a billion acres of [Monsanto] GMO crops, there has not been a single adverse incident in ten years," was accurate, for that company, such claim was false for the industry as a whole after August 2006.[125] It is also important to pay attention to several less well-publicized

---

[121]Quist, D. and Chapela, H. 2001. Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico, *Letters to Nature*, Vol. 414: 541-543, Doering, D. 2004. Designing genes: aiming for safety and sustainability in U.S. agriculture and biotechnology, World Resources Institute, http://pdf.wri.org/designing_genes.pdf, National Academy of Sciences, 2002, "The environmental effects of transgenic plants," Pew Initiative on Food and Biotechnology, 2003, "Have transgenes, will travel: Issues raised by gene flow from GE crops," Kapuscinski, A.R. and Schei, P.J. 2005-6. Environmental risk assessment of genetically modified organisms series, Vols 1 and 2, Smith, J., 2004, *Seeds of deception*, !Yes Books, Fairfield, IA.
[122] USDA, 2005, Report from Inspector General of USDA, December, www.usda.gov, September 2006.
[123] USDA, ibid.
[124] USDA, ibid.
[125] Janacek, ibid.

cases of escaped GE germplasm. Scientists in Canada reported an instance in which genetically herbicide resistant canola appeared to have spread to a wild relative. In Japan, transgenic canola was found growing near some ports and roadsides. Since the crop is not grown commercially in Japan, scientists hypothesized that imported seeds had escaped during transportation to oil-processing facilities (Pollack. New York Times. Grass created in lab is found in the wild. August 16, 2006). Representative Mahoney argued that the Arkansas case was "just one problem" involving white rice. Unfortunately, it was not "just one," and that incident alone is estimated to have cost the U.S. long grain rice industry $1.5 billion.[126]

Implications for wild rice

It seems incumbent on legislators to take seriously warnings from relevant testimony. Mary Hanks, Minnesota Department of Agriculture, answered legislators' questions in 2006 regarding possible contamination of wild rice by a genetically engineered variety. Hanks works with APHIS and oversees all applications for plot approvals in Minnesota. When asked, "Is wild rice adequately protected?" she said, "I am not too familiar with wild rice aside from eating it. I would need to [have information] regarding the biology and agronomy of [wild rice]. Such a study would not take two years. But, honestly, I do not know how long it would take… I would need to know about the movement of pollen and seed from research sites to lakes. It is likely that [some kind of] containment of research sites [would be necessary]. As

[126] Schmidt and Clark Law Firm, pursuing lawsuits on behalf of U.S. rice growers, http://www.schmidtandclark.com/Rice-Growers-Liberty-Link-Lawsuit/, June 16, 2007.

Winona LaDuke pointed out, birds carry seed. [So I can imagine], bird netting might be necessary… I would need to know how far pollen moves."[127]

In fact, Joanna Cregan, Master's student at the University of Minnesota, wrote her thesis, 2004, in part, on pollen travel of wild rice. She concluded after a four year study that "the percent pollination observed at various distances are higher than those in corn pollen studies… small amounts of wild rice pollen can travel and remain viable for at least two miles… The release of wild rice pollen follows patterns similar to those observed for other wild-pollinated species."[128]

This study was out well before the 2006 hearings. While Cregan's is a single study and not published in a peer-reviewed journal, its results are supported by similar studies on other crops.[129] These findings taken together with the distribution of water basins with *Zizania sp.* across Minnesota make clear that viable genetically engineered wild rice test plots (ones that would not contaminate native stands) would be nearly, if not impossible, to locate.[130] The farms on which such test plots would be established are nearly, if not all, too close to native stands.[131]

Specific information regarding pollen travel and wild rice in conjunction with information regarding other crops pens undeniable warnings. While such research and warnings were not heeded in 2006, the cases in Arkansas and Oregon dramatically affected national attitudes towards federal regulatory capability.

---

[127] Hanks, Ph.D., Director of Sustainable Agriculture and Integrated Pest Management, testimony, March 28, 2006.

[128] Master's Thesis, Cregan, 2004, Aspects of seed storage, pollen travel and population dynamics of wild rice (*Zizania palustris*), University of Minnesota, pp. 46-47.

[129] Ellstrand, N. 2001. When transgenes wander, should we worry? *Plant Physiology*, April, Vol. 125, pp. 1543-1545.

[130] Cregan, ibid, p. 7 (Figure 2: Distribution of water basins with *Zizania sp.* across Minnesota.)

[131] Personal communication, Bloom, P., Professor of Soil Science, University of Minnesota, June 29, 2007.

Lost opportunities in biotechnology?

One lobbyist during the 2006 hearings stated, "this bill ignores the positive side of GM crops, that a potato resistant to a particular pest may prove critical to agriculture or alleviate chronic malnutrition. There is a dramatic promise for meeting the greatest challenges of the 21st century."[132] A Monsanto biologist in a different setting, speaking to an author writing about genetically engineered crops, said, "You know we need genetic engineering… to feed the world."[133] Finally, opponents of legislation in 2007 stated, "We [Minnesotans] are not going to be the cheapest box stackers and screw turners…This [legislation] sends a deleterious message to those who want to come here and do this work… We are circumscribing the ability for people to work in genetic engineering on agricultural crops… We are opening a door we will be sorry we opened."[134]

How does one evaluate these claims? Every year, opponents repeated their concern about "the chill" this legislation gives biotechnology companies. They repeated their concern each year that Minnesota would set a precedent regarding a clamp-down on important crop and other biotechnological research. These are potent arguments.

It is critical to make distinctions in the claims of the bill's opponents versus real and potential economic, environmental and health risks such technologies pose. To some extent, such clarification gets at the heart of the issue. How do we balance the promises of science and economic development with the known and unknown

[132] Testimony from Beth Nelson, President of Minnesota Cultivated Wild Rice Council, March 28, 2006.
[133] Smith, ibid, page 250.
[134] From testimony, Representative Michael Beard, May 15, 2007.

consequences? When potential risks of public trust and subsequent economic costs become real, the discussion is no longer theoretical.

Crop biotechnology: safety first, what does that mean?

As Representative Hamilton in 2006 stated, "GM crops have been around a long time and are very safe."[135] GM crops have been around for approximately thirty or so years. We look at some specific cases, to the extent that information is available, in order to determine how the definition and questions of "safety" may be relevant to questions of protecting wild rice.

In answer to Representative Hamilton's claim, it may be most relevant to cite Norman Ellstrand, Professor of Genetics, University of California-Riverside:

> The products of plant improvement are not absolutely safe, and we cannot expect transgenic crops to be absolutely safe either. Recognition of that fact suggests that creating something just because we are now able to do so is an inadequate reason for embracing a new technology. If we have advanced tools for creating novel agricultural products, we should use the advanced knowledge from ecology and population genetics as well as social sciences and humanities to make mindful choices about how to create the products that are best for humans and our environment.[136]

The promises of crop biotechnology are often cited -- from the potential contributions of pest-resistance to solving malnutrition. It seems incumbent upon researchers and lobbyists, working on behalf of biotechnology companies, to specify along with benefits, unanswered questions. No matter their institutional affiliation, researchers must be forthright about what they do not understand regarding new technologies. Given the level of controversy, public concern, and economic mishap, it

---

[135] From testimony, House Agriculture, Rural Economies and Veterans Affairs Committe, March 28, 2006.
[136] Ellstrand, ibid.

appears increasingly clear that companies and researchers will be held to higher standards of accountability; they must gain public trust.

Representative Hamilton, in 2006, cited the example of vitamin A rich rice, "Golden Rice," as an example of the promises of biotechnology. Golden rice is the "poster child" for the potential of genetic engineering. This technology, however, has not been perfected and is not yet ready for sale in the world market. It may prove to be a "miracle food." At this point, however, it is not possible to draw that conclusion. Yet, it is often discussed as nothing less than a "technological break-through …potentially solving an urgent and previously intractable health problem for the poor of the developing world." [137] Marion Nestle, Chair of the Department of Nutrition and Food Studies at New York University, acknowledges, "Food biotechnology… may improve nutrition and health, but at the moment its benefits remain theoretical."[138] Those who developed golden rice do not, however, address Nestle's concern, that this one innovation is not enough to make a difference in any individual's health. "The addition of one, two [or more] nutrients to an existing food does not constitute a food-based approach… The complexity of the physiological, nutritional, and cultural factors that affect vitamin A status suggest that no single nutrient added to food can… effectively remedy… dietary deficiencies."[139,140] Gordon Conway, of the Rockefeller Foundation, stated that [golden rice] is a research product in need of considerable

[137] Potrykus, I., 2001, Golden rice and beyond. *Plant Physiology*, Vol. 125, pages 1157-1161.
[138] Nestle, ibid.
[139] Charles, p. 264, 2001.
[140] Nestle, ibid.

development.[141] It is possible that such development may come, but it is premature to speak of it as a break-through.[142]

As Ellstrand points out, it is critical to ask questions about the actual promises of any crop technology and find its relevance to other crop research. Monsanto's lobbyist in 2006 suggested there must be a good reason why "Minnesota has spent a ton of time and money" to nurture the biotechnology industry.[143] General promises of biotechnology are not in and of themselves problematic. But, as in the case of golden rice, it is not enough for its innovator to say, "Of course, there will be substantial equivalence, toxicology and allergenicity assessments. Careful socioeconomic and environmental impact studies will help avoid any possible risk and make sure the technology reaches the poor."[144] None of this is "of course." Promises of "taking necessary precautions and following regulatory procedures" were also made by the creators of genetically engineered white rice and bentgrass. The economic costs of losing public trust were tremendous.

Potential risks – who will take them?

How much risk will we take? When will we know when safe is safe enough? Representative Hamilton in 2006 noted, "the perception that consumers are being sold an unsafe product and that the government isn't protecting them [can be unnerving and will damage consumer confidence and product sales]… But GM products have been around a long time and they are very safe, everything from cooking oils to papayas."[145]

---

[141] GMWatch.ORG, Profiles: Ingo Potrykus, www.gmwatch.org/profile1.asp, September 20, 2006.
[142] Mayer, J. Golden Rice research update. University of Minnesota. September 2006.
[143] Janacek, ibid.
[144] Potrykus, ibid.
[145] Hamilton, ibid.

Michael Meacher, former UK minister of the environment, wrote that because "genes interact, one gene may trigger other unpredicted and undesired effects… The random position and lack of control of the gene's functions could change any character of the plant and might not be evident immediately." He notes, "While it is often claimed that GMOs have been 'rigorously' tested, all that this testing amounts to is deciding whether a GM crop is similar in terms of its composition to the non GM plant… It wholly misses the point that health concerns are focused, not on known compounds, but on the effects of GM technology which are unpredictable…" A protein chemist working at AgrEvo, Sue MacIntosh, said, "We wish there was a test where you plug in a protein and out pops a yes or no answer [whether it is allergy-producing]. But no such test [exists]… short of giving it to a lot of people and seeing what happens."[146] We do not have proof that GMOs cause allergies. But we also do not have evidence that they do not.

In 2006, the market answered the question of how much risk is enough. Following the revelation of unauthorized Liberty Link in U.S. commercial supplies, rice exports to the E.U. effectively stopped. In December 2006, Russia formally announced a ban on global rice imports, citing the U.S. case as a reason for this decision. On March 19, 2007, the California Rice Commission voted to support a moratorium on field-testing all genetically modified rice cultivars in California for the 2007 crop, and for future crops, until research protocol and safeguards are acceptable to the Commission.[147]

---

[146] Smith, ibid.
[147] Business Wire*,* August 28, 2006, Cohen, Milstein, Hausfeld & Toll announces six state class action filed against Bayer CropScience over rice contamination.; Inside U.S. Trade, Vol. 24, No. 51, December

On March 31, 2007, the U.S. rice industry declared they wanted the federal government to reject a plan to grow genetically modified rice in Kansas, saying the country's growers would suffer "financial devastation" if modified crops contaminate the commercial supply. "If Ventria's pharmaceutical rice were to escape into the commercial rice supply, the financial devastation to the U.S. rice industry would be absolute," the USA Rice Federation declared. "There is no tolerance, either regulatory or in public perception, for a human gene-based pharmaceutical crop to end up in the world's food supply." The National Farmers Union also issued a statement expressing the same concern as USA Rice Federation regarding pharmaceutical rice. Al Montna, Chairman of the USA Rice Federation said in March 2007 that he was "increasingly frustrated with the apparent lack of ability on the part of private companies and federal regulators to control research and maintain accountability of the resulting products. The current approach to research, development and management in the biotechnology industry must be replaced with more conservative technologies."[148]

Summary

> I am supporting this legislation because it is about wild rice and wild rice alone. It is a very unique crop. If this isn't about wild rice, it will be advertised as the camel's nose under the tent, a moratorium on GE crops broadly. If you're going to go after other crops, and say that GMOs aren't good, then you're [the bill's authors and supporters] not helping yourselves with this bill. The FDA will have some oversight and they treat GM products as not substantially different from what is on the shelves. Cutting to the chase, this bill is about the fact that in Beltrami County, [Minnesota], wild rice is unique.

22, 2006, "Russia bans all rice imports, cites U.S. GMO contamination; Western Farm Press Online Exclusive, Prism Insight, March 19, 2007, "California Rice Commission supports GM rice testing moratorium."

[148] Associated Press Worldstream, Business News, March 31, 2007, "Industry opposes plan to grow genetically modified rice in US"; National Farmer's Union, May 21, 2007, "NFU concerned over GMO rice approval."

Representative Juhnke[149]

> The problem is that legislation like this sends a message to the rest of the country. We don't want to be the only state that has legislation like this. We don't want to stick out. We don't have any idea where legislation like this will lead.
>
> Representative Davids[150]

> We have reaped the benefits of GM crops and [we do not want to send a message that suggests we are ignorant of that fact].
>
> Representative Welti[151]

The above testimony heard in 2006 exposes a contradiction. Wild rice is unique as articulated earlier in this paper, particularly for Ojibwe Sovereign Nations, and also for non-American Indian Minnesotans. Yet after summer 2006, its cultural relevance may not matter in the context of the larger debate over public trust and crop biotechnology.

Warnings preceding white rice and bentgrass came for more than a decade prior to 2006, and yet were largely ignored. Other states have attempted to pass legislation placing stricter regulations on genetically engineered crops. In 2006, Vermont introduced legislation, "An act relating to liability resulting from the use of genetically engineered seeds and plant parts." Passing in the House and Senate, it was vetoed by the Governor.[152] In 2007, the University of Hawaii declared that it would not take out patents on taro, a food sacred to Native Hawaiian people. Legislation imposing a 10-year moratorium on developing, testing, propagating, cultivating, growing, and raising

---

[149] From testimony, Representative Al Juhnke, the House Agriculture, Rural Economies and Veterans Affairs Committee, March 28, 2006.
[150] From testimony, Representative Gregory Davids, Chair, the House Agriculture and Rural Development Committee, March 28, 2006 and personal conversation, August 18, 2006.
[151] From testimony, Representative Andy Welti, the House Agriculture and Rural Development Committee, March 28, 2006.
[152] Vermont legislative hearings. 2006.
http://www.leg.state.vt.us/database/status/summary.cfm?Bill=S%2E0018&Session=2006

genetically engineered taro in Hawaii was introduced in 2007. The House Agriculture Chair refused to hear it.[153] Legislation in California and Arkansas, however, passed giving these states the power to prohibit the introduction of GE rice. In Washington, legislation was adopted prohibiting the planting of GE canola in areas near the state's large non-GE seed production.[154] Additional success outside Minnesota may be a matter of time.

Far from being the "camel's nose under the tent," this legislation may result in Minnesota being viewed as exercising caution where caution is warranted. One might argue that legislators should be evaluated in terms of how well they examine warnings. Once warnings turn to irreversible events, the costs are undeniable. It matters not whether Monsanto, another company or scientist, plans to genetically engineer wild rice. The issue is how well legislators analyze relevant information that place Indigenous cultural identity and livelihood, the environment or public at risk. This will not be the last case of its kind. Minnesotans, citizens of the U.S. and citizens of other countries must ask themselves whether they are willing to consider the technological, scientific, cultural, and human questions such problems demand. We do well to begin our deliberation before the next biotechnological mishap for which we are ill-prepared.

---

[153] Hawaii legislative session hearings, 2007, http://www.capitol.hawaii.gov

[154] Center for Food Safety. http://www.centerforfoodsafety.org. Referenced on May 1, 2007. .

References

Associated Press. Industry opposes plan to grow genetically modified rice in US. March 31, 2007 ; National Farmer's Union. NFU concerned over GMO rice approval. May 21, 2007.

Benton-Banai, E. 1988. The Mishomis Book: The Voice of the Ojibway. Indian Country Communications: Hayward.

Berger, T.R. 1992. A Long, Terrible Shadow: White Values, Native Rights in the Americas, 1492-1992. University of Washington Press: Seattle.

Borrows, J. 2002. Recovering Canada: the resurgence of Indigenous law. University of Toronto Press: Toronto, Canada.

Business Wire. Cohen, Milstein, Hausfeld & Toll announces six state class action filed against Bayer CropScience over rice contamination. August 28, 2006.

Charles, D. 2001. Lords of the Harvest: Biotech, big money and the future of food. Perseus Publishing: Cambridge, U.K.

Center for Food Safety. http://www.centerforfoodsafety.org. Referenced May 1, 2007.

Cregan, J. 2004. Aspects of seed storage, pollen travel and population dynamics of wild rice (*Zizania palustris*). University of Minnesota M.S. Thesis.

Doering, D. 2004. Designing genes: aiming for safety and sustainability in U.S. agriculture and biotechnology. World Resources Institute. http://pdf.wri.org/designing_genes.pdf.

Dunn A. M. 1995. "The Gift of Mahnomen." In When Beaver was Very Great: Stories to Live By. Midwest Traditions, Inc.: Mount Horeb, WI.

Ellstrand, N. 2001. When transgenes wander, should we worry? Plant Physiology, April, Vol. 125.

Hawaii legislative session hearings. 2007. http://www.capitol.hawaii.gov.

Kapuscinski, A.R. and Schei, P.J. 2005-2006. Environmental risk assessment of genetically modified organisms series, Vols 1 and 2.

Kidwell, C.S. 2002. "Native American Systems of Knowledge." In Deloria, P.J. and Salisbury, N. eds. A companion to American Indian History. Blackwell Publishers Ltd: Oxford, U.K.

LaDuke, W. 1999. The Wild Rice Moon. Whole Earth, Winter.

LaGarde, Joseph. 2007. White Earth Reservation elder, personal communication.

Minnesota Legislative Hearings and Testimony. 2005-2007. St. Paul, MN.

National Academy of Sciences. 2002. "The environmental effects of transgenic plants."

Madigan and Martinko. 2006. Brock Biology of Microorganisms, 11th Edition, Pearson Prentice Hall: Upper Saddle River, N.J.

McClurken, J.M., Cleland, C.E., Lund, T., Nichols, J.D., Tanner, H., White, B. 2000. Fish in the Lakes, Wild Rice, and Game in Abundance. Michigan State University Press: Lansing, MI.

Nestle, M. 2002. How the Food Industry Influences Nutrition and Health. University of CA Press: CA.

Pena. 2005. Transgenic plants: methods and protocols, Humana Press, Vol. 286.

Persell, John. 2008. Leech Lake Reservation Department of Resource Management, personal communication.

Pew Initiative on Food and Biotechnology. 2003. Have transgenes, will travel: Issues raised by gene flow from GE crops.

Pollack. Grass created in lab is found in the wild. New York Times. August 16, 2006.

Potrykus, I., 2001, Golden rice and beyond. Plant Physiology, Vol. 125.

Quist, D. and Chapela, H. 2001. Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. Letters to Nature, Vol. 414.

Regguinti, G. 1992. The Sacred Harvest: Ojibway Wild Rice Gathering, Lerner Publications Company: Minneapolis, pages 17-18.

Schmidt and Clark Law Firm, pursuing lawsuits on behalf of U.S. rice growers. http://www.schmidtandclark.com/Rice-Growers-Liberty-Link-Lawsuit.. Referenced June 16, 2007.

Schultz, Paul. 2007. White Earth Reservation elder, personal communication.

Smith, J. 2004. Seeds of deception, !Yes Books, Fairfield, IA.

USDA. 2005. Report from Inspector General of USDA. www.usda.gov. Referenced September 2006.

Vennum, Thomas, Jr. 1988. Wild Rice and the Ojibway People, Minnesota Historical Society Press: St. Paul.

Vermont legislative hearings. 2006. http://www.leg.state.vt.us/database/status/summary.cfm?Bill=S%2E0018&Session=2006.

Weiss, R. Gene-altered profit-killer: A slight taint of biotech rice puts farmers' overseas sales in peril. Washington Post. September 21, 2006.

Wilkins, D.E. and Lomawaima, K. Tsianina. 2001. University of Oklahoma Press: OK.