Portland State University

PDXScholar

Dissertations and Theses

Dissertations and Theses

1-1-2011

Deforestation, Drought and Humans: New Discoveries of the Late Quaternary Paleoenvironment of Rapa Nui (Easter Island)

Candace Lynn Gossen
Portland State University

Follow this and additional works at: https://pdxscholar.library.pdx.edu/open_access_etds

Let us know how access to this document benefits you.

Recommended Citation

Gossen, Candace Lynn, "Deforestation, Drought and Humans: New Discoveries of the Late Quaternary Paleoenvironment of Rapa Nui (Easter Island)" (2011). *Dissertations and Theses*. Paper 782.
<https://doi.org/10.15760/etd.782>

This Dissertation is brought to you for free and open access. It has been accepted for inclusion in Dissertations and Theses by an authorized administrator of PDXScholar. Please contact us if we can make this document more accessible: pdxscholar@pdx.edu.

Deforestation, Drought and Humans:
New Discoveries of the Late Quaternary Paleoenvironment of Rapa Nui (Easter Island)

by
Candace Lynn Gossen

A dissertation submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy
in
Environmental Sciences and Resources

Dissertation Committee:
Mohammed Aslam Khan Khalil, Chair
Robert Dunbar
Dan Johnson
Gil Latz
Peter Schoonmaker
Dean Atkinson

Portland State University
©2011

ABSTRACT

The mystery of the trees of Rapa Nui (Easter Island) is a complex problem within a dynamic ecosystem. With new physical cores from the volcanic crater lake Rano Kao, this dissertation uncovers a detailed 15,000 year ecological history of Easter Island and its climatic variability. New radiocarbon dating methods establish a more precise chronology which shows that the island before human habitation was very different than what we know today. It had a simple but prolific ecology that transitioned into a barren grassland. What factors caused the transition are unclear but are likely to be human related. As the forests slowly disappeared, it could have triggered changes in regional and local climate, particularly rainfall, which generally leads to a rapid loss of ecosystems. With virtually stable climate conditions over the last 2,000 years, Easter Island has lost 33 species of plants including the giant palms, and still has not recovered today.

This research challenges the previously accepted theory that humans deforested the island for the sole purpose of moving the Moai around, and focuses rather on uncovering the role of climate change that may have altered the ecosystem. New cores were obtained in 2005 from Rano Kao that were radiocarbon dated using scirpus seeds. The nine meters of core were sampled for oxygen isotope analysis of the lake water changes, a new science to the island. Detailed palynological studies of pollen and non-pollen palynomorphs uncovered changing vegetation patterns that aligned with a 700 year drought cycle. Conclusions support a cool-dry event that occurred 545 years ago, at which time the giant palms disappeared. While it was not the focus of this study, evidence confirms human occupation for more than 500 years before the disappearance of the trees.

To my son
Kijika
“he who walks quietly with a brave heart”

ACKNOWLEDGEMENTS

To the casual observer, a doctoral dissertation may appear to be solitary work. However, to complete a project of this magnitude requires a network of support and I am grateful to many people. I owe my deepest gratitude to my advisor Aslam Khalil for allowing me the freedom to find my way through this journey and never failing to support all of my lunatic ideas with amazing grace. From the first day that I knocked on his office door with a grandiose idea of saving the world, he honored the simpleness that was really all about saving me. Thank you.

Thanks to my committee members: Rob Dunbar, Gil Latz, Dan Johnson, Peter Schoonmaker and Dean Atkinson for their interest, curiosity and support for this very diverse and complex research. I am so very thankful for your inspiration and friendship all of these years.

I am eternally grateful to Rob Dunbar for his friendship, guidance and support. He and his Stanford crew saved my coring expedition in 2005, believing every time a door was closed that I would find a new way to complete my task. He had great faith in telling me to rent my own gear, show up and we would make it happen!

John Flenley has tremendous generosity. First by allowing me to build upon his work on Rapa Nui and second by teaching me about coring the lakes on the island even if it meant floating out in a little dingy, tethered to the floating totora mats in a windstorm at Rano Raraku! I thank him for a very gracious invitation to work in his lab at Massey University in order to process the pollen samples for the core KAO3. John has offered endless emails and encouragement throughout all of these years. A special thanks also to David

Meek and Xun Li who without this teamwork none of this would have been possible.

In one of those moments along the way when things seemed to be at a dead end in this project, Ed Cushing opened an invitation for me to work in his ecology lab at the University of Minnesota. Ed became my mentor for nearly a year teaching me all that I have learned about plants, pollen, microscopy and Rano Kao. All of the long hours we spent in the lab extracting every detail, watching as I conjured up strange findings in the slides, he was always good at reminding me he was from the “Show Me State” of Missouri which taught me to become a meticulous sleuth. Thanks Ed.

I am thankful to Amy Myrbo, Anders Noran and the staff of the LRC for their assistance with the core analysis and for countless hours of lab space, help and guidance. Amy had great faith in renting the coring equipment to me in 2005, and if it had not been for this service my expedition would not have been possible. Eternally grateful for the friendship and archive of these priceless cores that made this work possible.

Tom Guilderson and the staff at the Lawrence Livermore AMS Labs were instrumental in obtaining the radiocarbon dates for the Rano Kao cores. Tom offered the option for me to work in the labs processing my own radiocarbon dates so that I could learn, and be an integral part to this significant change that this chronology has brought to the understanding of Rapa Nui. I am warmly thankful to the friendship created through this creative dialogue.

The oxygen isotope portion of my research was a completely new experiment for Brent Wolfe and the Wilfrid Laurier University graduate students. The outcome was an amazing addition to the unknown science of Rapa Nui. Thanks Brent for the years of trudging thru

trial and error and for the faith in strong working professional relationships and friendship that has evolved.

Funding my own dissertation research was always a challenge over all these years, and I am deeply appreciative for the Easter Island Foundation supporters and Chris Stevenson who accepted my grant proposals to help fund the radiocarbon dates for my work. Chris steered me to the idea of coring the lakes on Rapa Nui, when I had never thought of such before. Thank you Chris, for expanding my horizons and changing the direction of my path.

If it had not been for the country of Chile, CONAF, the mayor and governor of Rapa Nui, and the people of the island that welcomed my team and me so openly, none of this would have been possible. There was always a care and concern each time we hiked down to the lake from those working up at Orongo, making sure that we were safe, that none of us fell and disappeared into the quagmire, and for their ongoing curiosity to know more. To the people of Rapa Nui, may this be the beginning of a lifelong friendship that this work will bring more healing in so many ways. A personal thank you to Yan, Francisco, Alejandro, Roseanne, Michael and Ki who mucked into the water and mud of the lake helping to core. To Nico Haoa for providing all the needed support in equipment, transport, and a great place to camp out. To Selma Tuki, my other mother who took care of us with a forever welcome into her home and big heart. Iorana and Maururu.

I am forever ecstatic that my son, Kijika was able to be part of my second expedition to Rapa Nui. To be able to share this amazing journey with him reminded me of reading about Thor and his son and the stories in Aku Aku. Ki and I shared many strange adventures on this small spit of land that have changed us both. Thank you Kijika for always being my biggest supporter and believer. I love you.

To the leader of the band, my grandfather Kenneth D. Long, I thank you for your genuine curiosity and belief in my wanderlust. Some grow up without knowing their elders, but I proudly remember riding my first roller coaster at age 12 when you were just 65. Thank you for teaching me to grow food from the earth, for listening to the creatures of the bayou, for teaching me that music lived in my soul and that love had no conditions. I am grateful that you were able to share the beginnings of this research with me. I still feel your grand smile nudging me on to the finish line.

It is impossible to thank everyone that has supported me and this work over the last 6 years, to all that have fed me, housed me, dried my tears, cheered, healed me and never faltered being there for me, THANK YOU!

I am grateful for Simon Haberle, of the Australian National University for inviting me to Australia for two months in 2010 to add my Easter Island pollen information to the Australasian Pollen and Spore Atlas. This atlas is crucial and important to the world. As a free online resource, it offers access to the largest collection of pollen and spore information in the Australasian region. With Simon's help, all of my Easter island pollen information is now accessible to the world.

Thanks to Denise Lee Long, the amazing illustrator who took my plant images and turned them into beautiful ink and thank you to Holly Sigler for editing the thousands of photographs that I took with my little digital camera by lens of my microscope and turned them into Appendix A.

When it came time to finally put things on paper, I am grateful to two amazing women

who helped my voice find grace. Sharlene and the brown paper workshop was the ice breaking moment to jump in and get this done. Thank you. Jackie, you are an amazing editor and without your help I would still be struggling with the one-button mouse! Thank you for your wonderful talent as an editor and hearing my voice in my writings.

Thanks to my talented graphic artist friends Jon and Cindy who teeth-grittingly brought all the software quirks and anomalies into check by merging hundreds of pages of text, illustrations, and photographs into one final piece of art that you read before you.

Sometimes when we begin to be grateful for all that have helped on a journey, it goes way back in time. My friend and mentor, Malcolm Wells, taught me to look at things sideways and upside down, in a different perspective. It was through the lens of a seeker that I could see what others were blind to. Mac you are missed and are always in my heart. Thank you for the years of beautiful letters and drawings that brought light to my path.

Merci beaucoup! to my cajun friend and teacher Jon “Doc” Gibson who gave me my first job as an archaeologist counting Poverty Point Objects. Little did you know that when I rolled my fingers into the grooves of those 5,000 year old clay balls, that I could feel the hands of the makers. My soul was transported to that muddy river where red jasper was traded and bird mounds and ball courts were created. Thank you for introducing me to the mystical world of the red fox and for supporting me all of these many, many years on this journey.

To the healers, doctors, shaman, and yogis that held my body together and my spirit strong, Aho!

TABLE OF CONTENTS

Abstract.....	i
Dedication.....	ii
Acknowledgements.....	iii
List of Figures.....	xi
Preface.....	xiii
 Chapter 1 Introduction.....	 1
1.1 Research Overview.....	3
1.2 Climate Trend Discoveries – LGM to Holocene History of Rapa Nui	7
1.3 Fifteen-thousand-year Ecology of Rano Kao and the Island’s Plant Evolution. .	9
1.4 New Evidence for Human Arrival on Rapa Nui.....	11
 Chapter 2 Natural History of Rano Kao, Rapa Nui.....	 14
2.1 Geology and Island Formation.....	14
2.2 Weather and Climate	16
2.3 Observations from the Resolution and Adventure 1774	19
2.4 Natural History Studies by Skottsberg.....	23
2.5 Diamond’s Collapse Theory.....	25
 Chapter 3 The Trees on Rapa Nui	 38
3.1 Introduction	38
3.2 Why Are We Interested in the Ancient Forests of Rapa Nui?	39
3.3 Extinction of Palm Trees on Pacific Islands of Oceania	43
3.4 Unique New Discoveries and the Amazing Life of the Palm.....	49
3.5 Possible Causal Scenarios Attributed to the Disappearance of the Palms	53
 Chapter 4 Coring of the lake Rano Kao.....	 62
4.1 Introduction	62
4.2 Coring the Crater Lakes	65
4.2.1 KAO3 Core	67
4.2.2 KAO4 Core	69
4.2.3 KAO5 Core	69
4.2.4 KAO6 Core	70
4.2.5 Rano Raraku - RKU05 Core	71
4.3 Rano Kao Expedition 2008 - RKE08 Core	72
4.4 Testing, Methods and Findings KAO3.....	78
4.4.1 Magnetic Susceptibility	79
4.4.2 Whole Core Low Resolution KAO3	80
4.4.3 Split Core High Resolution KAO3	82
4.4.4 Digital Linescan Camera Imaging.....	84
4.4.5 Sampling and Sub-sampling of the cores.....	86

Chapter 5 Radiocarbon dating and the Stratigraphy of Rano Kao	100
5.1 The Heated Debate of Radiocarbon Dating on Easter Island	100
5.2 Scirpus Seeds – A New Linear Chronology	103
5.3 Dating of KAO3	105
5.4 Core Chronology	106
5.5 Discussion	107
5.6 Comparing KAO3 to Flenley’s KAO1 and KAO2 Cores	113
Chapter 6 Oxygen Isotopes – Evidence of Climate Change	120
6.1 Introduction to Cellulose Isotope Studies	120
6.2 Lake Evaporation	123
6.3 Processing Samples for Oxygen Isotopes	125
6.4 Analysis of Oxygen Isotopes of Rano Kao	126
6.5 Lake Level Changes Over the Past 15,000 Years at Rano Kao	127
6.6 ENSO and Lack of Long-term Climate Records	129
6.7 Climatic Events	132
6.8 Intervals Between Events	136
6.9 Trend Lines	137
6.10 Carbon Cycling in the Lake	138
6.11 Plant Indicators of Rainfall and Drought	139
6.12 Deforestation Not Caused by Climate Change	141
Chapter 7 Palynology and Ecological Change	153
7.1 Pollen	153
7.2 Processing Sediment for Pollen at Massey University, New Zealand	154
7.3 Identifying and Creating Reference Collection	155
7.4 Pollen Diagrams	156
7.5 Plants as Climate Indicators	157
7.6 Non-pollen Palynomorphs and Macrofossils	158
7.7 New Discoveries	159
7.7.1 Palm types	159
7.7.2 Polygonum and totora – plant allies	160
7.7.3 Exotics	160
7.7.4 Fungi and other plant allies	162
7.7.5 Algae, cyanobacteria and others	162
7.7.6 Resin and lignin	163
7.7.7 Chitin and insects	163
7.8 Pollen Summary	164

Chapter 8 Human Appearance on Rapa Nui	193
8.1 Introduction	193
8.2 Theories about Migration and Human Occupation	194
8.2.1 Polynesian Migration theory	194
8.2.2 Thor Heyerdahl's South American theory	197
8.2.3 1421 the Year China Discovered America	198
8.2.4 The 535 AD Event	200
8.3 Methods to Determine Human Activity in the Past	202
8.4 Archaeology and Charcoal (Determining Natural vs. Human)	203
8.5 New Discoveries in the KAO3 Core Related to Humans	204
8.6 Discussion	206
Bibliography	216
Appendices	
A. Fossil Pollen, Spores and Non-pollen Palynormorphs	225
B. Core Diagrams	341
C. Pollen Diagrams	351
D. Plant Illustrations	369
E. Reference Pollen	407
F. Pollen Count Sheets	426
G. "The Mystery Lies in the Scirpus"	431
H. Rapa Nui Natives Taxonomy List	438
I. Water Quality Testing Data 2005 and 2008	440
J. Flenley Pollen Diagram Rano Kao	442
K. Core ICD Sheets	444
L. Statistics Correlation	453
M. Magnetic Susceptibility Charts	458

LIST OF FIGURES

Chapter 1

1. Map of Rapa Nui 13

Chapter 2

2. View of island from the summit of Rano Kao 31
3. The three crater lakes of Easter Island 32
4. Google Maps of Rano Kao coring points. 33
5. Ocean current circulation map of Easter Island and the South Pacific 34
6. Easter Island Rainfall History 1941 – 2008 35
7. Daylight and Humidity Factors for Easter Island. 36
8. Rain-Wind-Temp Averages for Easter Island 1941-2008. 37

Chapter 3

9. A Simplified Sketch of the *Jubaea* like *Paschalococos disperta*. 60
10. Photo of palm forest, Chile 61

Chapter 4

11. Satellite image of Rano Kao 2006 87
12. Map of Rano Kao with topographic elevation and ocean depth (meters) 88
13. Boreholes March 2005. Rano Kao, Rapa Nui 89
14. Sketch of Rano Kao with 2005 coring locations 90
15. Stratigraphic sketch of the core KAO3 with C14 RC dates 91
- 16a. KAO3 Core photographs with Magnetic Susceptibility graphs (1L-3L) 92
- 16b. KAO3 Core photographs with Magnetic Susceptibility graphs (4L-6L) 93
- 16c. KAO3 Core photographs with Magnetic Susceptibility graphs (7L-9L) 94
17. KAO3 core photos with RC dates 95
18. Low resolution chart with RC dates. 96
19. Rano Kao lake profile sketch 97
20. Lake Profile KAO3 and KAO6 98
21. Sediment profile sketch 99

Chapter 5

22. KAO3 Radiocarbon graph 115
23. KAO3 RC graph, seeds and pollen 116
24. Comparative RC Dating at Rano Kao (1982-2009) 117
25. KAO3 calibrated RC dates. 118
26. KAO3 calibrated RC dates with error bars 119

Chapter 6

27. Rano Kao 2002-2008 photographs	143
28. Easter Island MWL and LEL	144
29. Rano Kao CN data analysis	145
30. Oxygen Isotope graph with trend lines	146
31. Oxygen Isotope graph with events	147
32. $\delta^{18}O$ scatterplot	148
33. Isotope summary with pollen data	149
34a. Climate change profile (zones 15-10)	150
34b. Climate change profile (zones 9-6)	151
34c. Climate change profile (zones 5-1)	152

Chapter 7

35a. Ecological profiles (zones 15-10)	167
35b. Ecological profiles (zones 9-7)	168
35c. Ecological profiles (zones 6-4)	169
35d. Ecological profiles (zones 3-1)	170
36a. Pollen Diagrams – All Pollen	171
36b. Pollen Diagrams – Trees	172
36c. Pollen Diagrams – Palms	173
36d. Pollen Diagrams – Aquatics	174
36e. Pollen Diagrams – Grass and Ferns	175
36f. Pollen Diagrams – Charcoal	176
36g. Pollen Diagrams – Non-Pollen Palynomorphs	177
36h. Pollen Diagrams – Lycopodium	178
36i. Pollen Diagrams – Deposition Time	179
36j. Pollen Diagrams – Total Pollen	180
36k. Pollen Diagrams – Pollen Concentration	181
36l. Pollen Diagrams – Pollen Influx	182
36m. Pollen Diagrams – Pollen Mat	183
36n. Pollen Diagrams – Pollen Mat, ferns and grass	184
36o. Pollen Diagrams – Pollen Mat, ferns	185
36p. Pollen Diagrams – Pollen Concentration Mat	186
36q. Pollen Diagrams – Total Pollen Mat	187
37a. Pollen Count Sheets (1L-3L)	188
37b. Pollen Count Sheets (3L-5L)	189
37c. Pollen Count Sheets (5L-7L)	190
37d. Pollen Count Sheets (7L-9L)	191
38. Pollen Summary	192

Chapter 8

39. Island Profile Sketch	215
-------------------------------------	-----

PREFACE

I grew up in the bayous of Louisiana where there were more things that could bite you, sting you or eat you than any other place I have lived in this world. Everything here was used, nothing was wasted, and living on the land was respected for its tremendous power and changes. Growing up in the wet, wooded marshes, brought great life to my adventures and adventure to my life. Trees, lightning bugs, crickets, cicadas, mudbugs, all had cycles and seasons. Even amazing phenomenon of biological synchronicity, to group, flash, move all based on diet and social interaction impressed my early ages to know that all things are connected.

Everything changed and was honored. Even hurricane season brought preparedness. It was a resourceful life growing up poor, where proper nutrition was scarce, but I found my peace in the vacant lots full of grass, birds, bugs, and trees to climb. The smells and sounds and feelings are all still with me in my heart. I can be in another part of the world and a smell will bring me back to the age of riding my bike in those grassy fields. Being able to sense the humidity on my skin, I became aware and awake like a walking barometer, knowing when storms would come. We were living with nature.

This life with the trees became more real with an even stranger awareness and respect for nature when I found myself in an architecture degree focusing on ecology and then a masters of science studying solar. But my real education came from the elders, the old adoberos that taught me the ancient way of the Anasazi, of living with the land, their use of passive solar, earth and nature. Creating a home that honored and utilized these systems became my responsibility, as Buckminster Fuller stated “you just see what needs

to be done and you do it.” Most importantly to give back more than I took so that there would be great and wonderful things for my son to grow up with.

Continuing on as a teacher of this knowledge I found my way searching for scientific methods to show what I intuitively felt, that the loss of forests was also connected to climate change, loss of biodiversity, death of ecosystems and an old wisdom that was being destroyed. It was Dr. Irving Friedman, who was very helpful in steering me to his observations at Marajo Island, off the coast of Brazil. He noticed by flying over the island in an airplane that half of island’s forests had been cut. Through direct observation, he noted that the half with the forest received up to $\frac{2}{3}$ ’s more rainfall than the side that had been cut. Clearly it was the forest ecosystem that was the direct link to this moisture change.

In his testing methods, Dr. Friedman looked at obsidian glass as a time capsule. When obsidian is formed during a volcanic eruption, the glass captures oxygen and hydrogen isotopes, which can be used scientifically to determine a climate signature. In simple terms, this glass can tell us whether the climate, at the time of explosion, was hot or cold or perhaps dry or wet. Intriguingly, humans also use obsidian as artifacts. This set the course on my journey to find evidence between human impact and climate change through the obsidian.

Following this journey I found myself in 2002 joining an Earthwatch adventure to Easter Island in order to find Chris Stevenson. Chris, operates an obsidian hydration-dating lab as well as conducting human impact studies on the island that are linked to deforestation. In the following year we conducted pilot tests on obsidian to determine if the climate signature in the obsidian changed over time. Although there were weak signals, they were not significant enough to determine climate change using the obsidian alone. Chris,

on his way to Belgium to meet with Dumont, the scientist who had cored Rano Raraku, then suggested that I also should core the crater lakes!

Coring the lakes on Rapa Nui is a fairly new adventure having first being conducted by Thor Heyerdahl's research expedition in 1958, and then followed by John Flenley in the late 1980s. I would be the second person to core the larger crater, Rano Kao and the first female to ever core any lake here. I was intrigued. These lakes were repositories for pollen and other airborne evidence such as ash from burning forests that could also retain a climate signature via the rainfall in the lake. This was all new to me and to the island, and my adventure began.

Coring the lake Rano Kao was an amazing adventure of this unique ecosystem. It was March 2005 by the time I had collected enough funds, rented the proper gear, and found a partner to begin this research. Originally set up to join John Flenley and his assistant David Meek, the expedition was cancelled due to a conflict with Dr. Flenley's Japanese benefactor. All but canceling the entire PhD, I was introduced to Rob Dunbar with Stanford University, who was also going to the island in March to core coral, and we collaborated to join together to get the coring completed. I am very grateful to Rob for so many saves that he offered along this path.

Rano Kao is a difficult, challenging and very large crater, that stretches nearly one kilometer wide with a mat of floating plants growing across it. The crater walls are very steep, and it is difficult to get into the lake having to carry all gear by hand, and walking across the mat with and not drop into the holes between. The challenge keeps most out, and I am grateful to that as well. With the help of the Stanford team both in 2005 and again from one of Rob's students in 2008, I have been able to successfully core both the

lake sediments and the mat floating on the surface.

The importance now of this research is to provide more color, more information and new exciting things unknown until now. The ecology of the last fifteen thousand years on the island, how things changed as a result of climate events, and what happened to the trees will all be documented in the following chapters within this dissertation.

Going back to the original journey, to find an artifact that would link human impact with deforestation and drought, the past 6 years of analyzing Rano Kao have provided more than I could ever have expected. Not only is there evidence of a changing forest system, I have discovered at least 4 new palm species unidentified, tephra from volcanic events that show activity as late as 2,000 years ago, very strange events that occurred some 3,500 years ago and 1450AD, as well as first signs of human arrival that are much older than the normal paradigm would like to accept and the disappearance of the forests after human arrival that they are not entirely directly responsible for.

In a classical dissertation sense, just like classical mechanics, once sufficient data was received, it searched for yes or no answers for all further questions. But I also took a more exciting quantum mechanics leap and simply have left unanswered questions in the theory to be answered by the experiences. So for this dissertation I will give the facts pertaining to the cores and the science introduced by this research, and will leave the stories about a palm tree that breathes like an animal, an AKU that made its presence after following me home, a phantom fungi unlocked from its dormant state in 15,000 year old mud, meeting the lady of the brown murky waters of Rano Kao, and umu ceremonies with taro and white chickens for another time.

The final gate in this journey opened to a new beginning, which is much more than just science. Life also happened along the way and during this whole adventure I have survived divorce, lost dreams, losing my house, my teaching job, a phantom illness Indiana Jones style and found a greater truth in myself.

Along this path I have been taught the importance of what happens with this knowledge. It must not sit on a shelf as a theoretical exercise, but yet become real in helping to heal this little island, that is beholden to one of the greatest mysteries of humanity on this planet. While some still argue the place where these humans came from, when they arrived, why they built the huge Moai, I will be focusing on the plants, the trees and the healing.

My hope is to provide a book of native plants that once existed on the island that I have found in the fossil pollen record of Rano Kao. These 33 plants with at least 20 of them now extinct from the island, have important medicinal value. It is wisdom in the plants, in the trees that will heal the land and the people. The women are holders of this wisdom and I hope to return all of this knowledge so that it can become real and viable and alive again to heal this very injured place. If the world sees Easter Island as the microcosm of planet Earth, to our ability as humans to destroy our forests and cause demise, then we can also rewrite the story as a means to regrow and heal.

Chapter 1 Introduction

Rapa Nui, the island we know as *Easter Island*, was also called in ancient times *Te Pito O Te Henua*, meaning “the navel of the world.” While Rapa Nui may have been the center of the world for the ancients, today, even with modern technology, traveling there is an adventure entailing long flights between continents and over thousands of kilometers of ocean. It is the most remote inhabited island on Earth, uniquely identified with more than a thousand stone statues called Moai on its perimeters.

Rapa Nui is known as one of humanities unrequited mysteries. The sheer labor involved with building and erecting stone Moai implies a hierarchal society, but how these people were able to move the statues around still remains an ecological mystery. Until Thor Heyerdahl and his group of scientists arrived on the island in the 1950s, no one knew that this small and barren island once had a flourishing forest of trees. With the first lake sediment cores that came from Rano Raraku, Heyerdahl uncovered palm pollen similar to the Chilean wine palm known as *Jubaea chilensis*.

This palm, endemic now to Chile, grows up to 2 meters in diameter and more than 20 meters tall. It is famous for creating wine from its sugary sap, sometimes as much as 100 gallons per tree. The common practice for obtaining the sap is to cut the tree down. Since the first observations by Heyerdahl’s expedition, the work of Meith and Bork (2002) attempted to determine just how many palms of this giant nature existed on the island. Their conclusion was that a lush sub-tropical forest with millions of trees was once covering Rapa Nui.

What happened to these trees? This question has raised theories about the trees being

cut down to transport the moai around the island or to clear the land to grow food. This dissertation research however adds new physical evidence to a previously unknown climate history that sheds light on the ecological changes of the forests of Rapa Nui as well as a glimpse of early human influence.

The island of Rapa Nui consists of a variable ecosystem created by three major volcanoes and the remnants that form crater lakes. The largest of the craters, called Rano Kao, is the focus of this research. Rano Kao is situated in the southwest corner of the triangular shaped island where it has been mostly undisturbed for over a million years. It was here that the last native tree *Sophora toromiro* was seen alive by Thor Heyerdahl who collected its last remaining seeds. Throughout its existence, the open basin of the crater has been accumulating airborne pollen, charcoal and volcanic ash, and decomposing plants. Sensitive and responsive to moisture changes, the lake that once appeared to be open and full of algae now carries a floating mat of *titora* (*Schoenoplectus californicus*) and *Polygonum acuminatum* that formed nearly 3,500 years ago during a long period of drought.

Three types of analysis were conducted on the evidence collected during this study:

1. Observation and identification of 90 pollen samples from nine meters of core collected from the lake sediment and 2 meters of the floating mat. The fossil pollen identified 33 plant types that grew on the island over the last 15,000 years, showed how they changed over time, and introduced four previously unknown palm types.
2. Radiocarbon dating of *scirpus* seeds found throughout the entire core.
Carbon dating of *scirpus* seeds established a clear chronology of the lake's ecological history.
3. Aquatic cellulose oxygen isotope analysis of plant material found in the lake

sediments. The oxygen isotope analysis disclosed long-term changes in water level fluctuations and climate.

These data, along with the observation and analysis of macrofossils and non-pollen palynomorph materials contained in the cores, give a new understanding of the ecological transformations of Rano Kao and the island of Rapa Nui.

1.1 Research Overview

This thesis focuses on the coring of lake sediments from Rano Kao in the southwest corner of the island Rapa Nui. This steep closed basin is nearly one kilometer across at the lake's surface and 1.5 km rim to rim at the top of the crater. On the surface of the lake is a floating mat of aquatic plants, ranging between 2 to 4 meters in depth. The water column between the floating mat and the lake sediments varies but averaged twelve and a half meters in 2008. The deposits below hold a record of an abundant and diverse forest of trees that included the palms that have now become extinct. How things changed over time and particularly when these trees disappeared can be identified in the pollen record.

This research allowed me to establish a linear chronology of climate change events with noted flourishing and changing plant species, including at least four species of palm trees that persevered even in the worst droughts. The biodiversity uncovered from the lake sediments allows us now to compare what the natural world was like before and after humans arrived. Furthering a more realistic picture, the fossil pollen allows an illustrated and defined plant index to be used as an informative ecological key describing their environmental preference particularly of hot and dry or cool and wet conditions.

Since the ongoing theory of what happened to the trees postulates that human cutting caused deforestation. I asked if there were conditions other than human presence, perhaps climate, that might have caused their disappearance. What other indicators besides the pollen and non-pollen palynomorphs, could help describe the changes we were looking for? In a very diverse and thorough study, all parts of the core were used including charcoal, fungi, insects, minerals, and starch, and reflected a changing ecosystem caused by something other than humans.

To obtain evidence of biodiversity, I retrieved a 9-meter core, labeled as KAO3, 400 meters from the edge of the lake Rano Kao in March of 2005. Working at the Lacustrine Research Center at the University of Minnesota in Minneapolis, the core was scanned for magnetic susceptibility to uncover significant geomagnetic trends that helped identify volcanic events, geologic events and erosion from deforestation and human impact. Further sampling at 10cm intervals provided pollen and non-palynomorph identification, and equal matching samples were used for aquatic cellulose oxygen isotope analysis to determine ecological changes in the lake water evaporation, rainfall or drought trends and plant adaptation. Most importantly a new radiocarbon chronology from 15,000 BP to present time was established using *scirpus* seeds.

Beginning with the natural history of Rapa Nui, Chapter 2 explains the geology and formation of the island. Its remoteness also limits what has been documented about weather and climate. Data began to be collected more consistently approximately 60 years ago when the airport was built on the island. Previously what was known about the natural history came from collections of notes from various voyages, expeditions and missions. Carl Skottsberg conducted the first botanical works on the island in 1920, which established the foundation upon which the more recent palynological studies have been

conducted. The final part of chapter 2 discusses the more modern and popularized collapse theory written by Jared Diamond to set up what has been proselytized as the collapse of the culture of Rapa Nui due to their own destruction of their environment.

In Chapter 3, I attempt to answer the question of what happened to the trees from a scientific standpoint first addressing why we are interested in the ancient forests of Rapa Nui that until now we have only known through palm pollen found in lake sediment that was discovered some 60 years ago. The next issue explored involves more studies across Oceania to see if there was a trend occurring, human or climate that may have affected Rapa Nui as well. This leads to unique discoveries about the life of palms, the extinction of palms and possible casual scenarios to their disappearance.

My actual research is described in Chapter 4 beginning with the coring of the lakes on Rapa Nui. Two expeditions, one in 2005 and another in 2008 complete the study of Rano Kao and the core KAO3, which is used for the methods contained and described in this chapter. The actual coring and initial core work at the Lacustrine Research Center at the University of Minnesota completes this chapter.

Significant tests and methods begin in Chapter 5 with radiocarbon dating. The heated debate of radiocarbon dating on the island set up a need to establish a clear linear chronology which I found by using *scirpus* seeds from the KAO3 core. Discussion of the core chronology as well as how KAO3 fills in Flenley's previous KAO1 and KAO2 cores adds greater detail to the natural history record of the island.

The unique research I have added to the studies of Rapa Nui is a long-term climate history. Although the lakes have been cored for soil and palynological studies, previous to this

research oxygen isotope analyses have never been conducted on the lakes. Rano Kao was a good test subject in that it is mostly undisturbed, was never irrigated, and is a steep closed basin with its own microclimate which shows signs of human occupation. The isotopes disclose long-term climate trends, drought cycles, and the adaptive vegetation changes that followed. Aquatic plant cellulose trapped in the lake sediments is useful in reconstructing lake water changes that infer rainfall events.

Supporting the evidence of rainfall and drought cycles, Chapter 7 introduces the palynological analysis simultaneously sampled at the same locations as the isotopes. These 90 samples create a new pollen record uncovering 33 identified plant species and how they changed along with the climate cycles over the last 15,000 years. Pollen diagrams take the numerical and identification data and create a visual understanding through thousands of photographs that document a long-term study of adaptation. Adding in new evidence from the non-pollen types including fungi, algae, resin, chitin and other plant allies a chronological summary brings together a rich ecological profile.

In Chapter 8, I review evidence of human arrival and occupation in light of new discoveries seen in the core samples. Although not the focus of this research, the appearance of human evidence in the core is important to include in this study. This chapter begins by introducing four very different and distinct theories regarding human arrival on Rapa Nui and its impact. The first and most accepted theory is the Polynesian story. Thor Heyerdahl's expedition uncovered evidence for his South American theory as well. A more obscure story comes from the research of Gavin Menzies and the idea of Chinese visitations to the island. Finally, MacIntyre's 535 AD event includes thoughts of a global migration due to a meteor impact. The chapter comes back to the facts collected from the core data and how it relates to the original question, what happened to the trees, and closes

with a final discussion. The final summaries are presented in hopes that we can learn from the fossil record about how biodiversity is impacted by humans with Rapa Nui as an example.

1.2 Climate Trend Discoveries – Last Glacial Maximum (LGM) to Holocene History of Rapa Nui

What little is known about Rapa Nui is mostly related to the late stages of human occupation in the last few hundred years. Late stage refers to the Moai building period, but what is missing are the details of the natural world and what the island was like before humans arrived. In order to understand the significance of this research project, we will place it in the context of what is already known about the Rapa Nui environment.

Prior to Thor Heyerdhal's Norwegian Expedition of 1955, which discovered ancient palm pollen in the sediments of Rano Raraku, the island was thought to be treeless. Over time, through sediment studies and pollen analysis, researchers discovered that the island had been covered with a sub-tropical forest. John Flenley (1984, 1991) published his research on sediment coring in the three crater lakes Rano Kao, Rano Aroi and Rano Raraku, and proposed that Easter Island was formerly forested with trees of varying species and size including *Sophora toromiro* and *Triumfetta semitriloba*.

In following Flenley's work, I am the second person to successfully core this lake and conduct palynological analysis to construct a long-term natural history of the island. This research project expands Flenley's research by adding previously unknown climate data using oxygen isotope analysis. The core KAO3, taken 400 meters from the edge of the lake and very near to center, is comprised mostly of detritus (plant remains). This core reveals

how these plants changed with rainfall patterns reflected through the lake water changes. Included in these plants remains are four new palm species and tree/shrubs introduced for the first time to the islands known history.

A new scientific method was needed for this project, something to determine what changes we might see in the landscape that reflect climate change differentiated from human intervention, particularly the disappearance of the trees. A recent introduction in science and new to the island is the analysis which I conducted of the aquatic plant cellulose in the lake sediments. The cellulose found in the core samples records rainfall and drought patterns as well as carbon and nitrogen levels of the lake. This evidence further informs us how the island was responding to climate change over the last 15,000 years. Important results of this analysis included notable 700-year cycles of drought and wet periods. Once established this long-term climate profile is used as the foundation for identifying human presence as revealed through evidence of charcoal, changing sedimentation rates, and introduced species found in the core.

My initial research previous to my work on Rapa Nui began with a conversation with Irving Friedman (1997) regarding his observation of Marajo Island, off the coast of Brazil. He observed that when half of the island's forest had been cut the rainfall patterns also change appreciably. The cut side only received one-third of its previous rainfall while the forested side received two-thirds of its precipitation through evapotranspiration. The ecology changed drastically through a trickle effect. Perhaps these discoveries on Marajo Island are similar to what occurred on Rapa Nui. Cumulatively we look at the noted climate events, the changes in ecology and lake response, and make deductions about what can be determined regarding the early human impact on the island.

1.3 Fifteen-thousand-year Ecology of Rano Kao and the Island's Plant Evolution

Previous coring attempts have had problems with bulk dating to achieve accurate radiocarbon dates of the lake Rano Kao. Pollen is scarce on the island and this makes Accelerated Mass Spectrometry (AMS) dating with pollen also problematic due to low content of carbon with low pollen volume. Therefore, the first and most important step in this research was to determine a dependable chronological profile. By selecting *scirpus* seeds from core samples, a reliable radiocarbon-dated profile set the foundation for all of the studies in this research and those that follow. Both pollen samples and seeds were run simultaneously and are discussed in the Rapa Nui Journal (Gossen, 2007) found in Appendix G.

The first reports of the paleoecology of Rano Kao were based on the cores KAO1 and KAO2 collected by John Flenley (1991). In his unique reconstruction of the Rapa Nui landscape over the last 35,000 years, he applied a method derived from Birks and Birks (1980) to use *intuitive methods* with a well defined narrow ecological tolerance rather than counting modern pollen rain alone. Flenley used indicator species with ecological preferences to compare cool/warm, moist/dry, and mesic/stressed. Once the pollen from KAO3 was counted and identified, Flenley's ecological indicators were useful to help broaden the climate data obtained from the oxygen isotope analysis.

It has been discovered that *scirpus* is present in the core for at least 15,000 years. *Scirpus* became dominant when there was heavy rainfall. When conditions became dry and water levels fell, the plant retreated to the lake edges and *polygonum* became dominant. It is *polygonum* that first landed on the island around 3500 BP when the lake was desiccated. When rains returned the *polygonum* grew across the bog and sometime between 1800 BP

and 1200 BP lifted from the lake-bed and became the floating mat as we know it today.

Non-pollen palynomorphs and macrofossils as well as non-plant materials such as minerals also give supporting information to the pollen records. These allies showed when minerals wash into the lake through erosion or if algae are present fixing nitrogen. A particular pattern was noticed between the presence of chitin and a dominant plant in samples, which uncovered a symbiotic relationship between the plants and insects in a particular environment. Other factors such as starch are now being discussed as a means to identify human cultivation of crop plants. In this case starch was present in the whole core record but changed both in quantity and form with environmental shifts such as increasing with drought. This starch is directly related to plant growth and likely related to the *totorā* plant. *Scirpus* seeds in this case confirmed that this plant did in fact exist on the island for the entire 15,000 year record, but notable differences of species variation have been discovered; a new more modern variety came into the pollen record as confirmed by DNA testing of modern day plants collected by me in March of 2008 and analyzed at the University of California at Davis through joint collaboration.

The finding of an extinct achatenelid (land snail) in the soils by Kirch and Christensen (1991) is an important indirect indicator of a forest presence as these organisms depended on woody growth for their survival. By analyzing the raw sediment samples from the core, certain macrofossils such as snails, beetles and mites, were utilized in understanding plant allies that are also sensitive to moisture changes and indicative of environmental change. Counting and identifying the presence of allies, both macrofossils and non-pollen palynomorphs, was established by the work of Bas van Geel (2001) who was also helpful in many discussions on samples from the KAO3 core. A new colorful and changing ecosystem emerged from the data, supporting the proposition that a lush environment

existed previous to what is now mostly barren grassland.

1.4 New Evidence for Human Arrival on Rapa Nui

The timing of humans arriving on the island is a disputed subject. Some scientists refer to archaeology to make a claim as to when settlements were established on Rapa Nui. Hunt and Lipo (2007) set an arrival date of 1200AD based on their archaeological investigation of Anakana Beach. Flenley (1991) established human appearance through palynology with the presence of charcoal and introduced plants as early as 300AD and with evidence of deforestation as early as 800AD.

Many have studied DNA of bones in burial sites and blood from people currently residing on the island. Others have collected artifacts and records. Still the argument is not settled. What science can do is collect and test evidence. With enough evidence, a strong case can be made but still nothing is as conclusive as living in that moment. Scientific conclusions, based on evidence of the past, particularly with human behavior, are not very clear.

This research takes into account myths and theories that have been told or written, such as the arrival of Hotu Matu'a as the first King to settle the island. The migration theory of Ferren MacIntyre suggests a natural catastrophe such as a meteor or volcano that could have triggered an oceanic migration as people fled inhabitable conditions or traveled with the purpose of finding a new home. Thor Heyerdahl's Kon-Tiki exploration offered the possibility of South American migration to Rapa Nui possibly more than once. To the Polynesian people the island is known as Rapa Nui, as in the 1860's it reminded them of *Rapa* - a small island in French Polynesia (now commonly referred to as *Rapa Iti*). Before 1863, the name was unknown on the island (Fischer, 1993).

What this research adds to the discussion is palynological evidence regarding the environmental conditions preceding and after human habitation. Through pollen analysis, oxygen isotope analysis and radiocarbon dating, it is now clearer with compelling evidence to determine climate versus human occupation changes. It does not go without comment that there are suspicious, interesting and mysterious new things found in the KAO3 core that will again challenge and change what has been known about Easter Island.

Figure 1 - Map of Rapa Nui

Chapter 2 Natural History of Rano Kao, Rapa Nui

2.1 Geology and Island Formation

Rapa Nui is centered at 27° 10' S latitude and 109° 26' W longitude on the Nazca plate gradually moving eastward towards continental South America. Having an area of approximately 173 sq. km with the longest apex of nearly 22 km and the greatest width of 11km, this little triangular island was formed by three major volcanoes of varying spatial orientations and geologic periods of activity. Poike, the oldest volcanic cone 370 meters tall, is situated on the eastern edge of the island and was formed approximately three million years ago. It is now void of a crater having been filled in with erosion long ago.

The second cone, which formed nearly a million years ago, was a volcano that is now known as Rano Kao. Currently there is a crater lake situated within its imploded rim. The lake sits at 110 meters above sea level with the rim of the crater reaching 305 meters skyward. Terevaka, the tallest peak on the island at 510 meters above sea level, is the youngest volcano having formed some 300,000 years ago. Its main crater is called Rano Aroi, a lagoon turned swamp and irrigated during human settlement. Clouds often cling to the upper heights of Terevaka while the nearby town of Hanga Roa is dry and hot. The wind moves across the ocean picking up moisture and bringing deluges of rain as it slowly edges over the crater rim of Rano Kao.

P.E. Baker (1967) led an investigation into the geology of the island's lava flows and parasitic cones, numbering over 70 and scattered throughout the island. Baker writes that the lava flows of the island are relatively young as the blocky surfaces and lava tubes are still visible without soil layers on the exposed rock. He estimates that these flows are

unlikely to be more than about two or three thousand years old and could possibly be younger. This information is further supported with the tephra found in the soil cores of KAO3 discussed in the following chapters.

In order to better understand the type of rock that formed the volcanoes and craters, particularly in the case of Rano Kao, I have cited the following from Baker, who conducted the geologic studies of the island. Baker states, “although there is a considerable range of rock types exposed on Easter Island, extremely basic lava such as picrite basalts and ankaramites are apparently absent. From previous petrological studies it would seem that the Easter Island rocks belong to the alkali-basalt-trachyte-soda rhyolite series, but that even the most basic rocks are slightly oversaturated with silica” (1967, p. 121).

Poike is the oldest strato-volcano. It has been eroding as deforestation exposed its red soils where very little vegetation grows now. This volcano sits on a Pliocene age oceanic crust, which is different than the other two volcanoes with their contributions of inflow of basalt minerals into the lake waters. Rano Raraku is composed of tapilli tuft, from which the giant moai are carved. On Terevaka, Rano Aroi lies in a porphyritic lava with Hawalite being observed in the upper reaches of the summit. At Rano Kao the exposed lava flows are of “benmoreite composition with some (resorbed plagioclase phenocrysts and doleritic xenoliths set in devitrified glassy matrix) and tuff/agglomerate containing fragments of obsidian.” (Flenley, 1991)

From a traveler’s view upon arriving via airplane from continental South America or from Tahiti, the plane circles, dipping to reveal the sheer cliffs of the ancient volcanoes that have been eroding for millions of years. Even Motu Nui and Moto Iti off the coast of Rano Kao are remnants of this once broad-based volcano that has slowly eroded away.

The south face of Rano Kao is now nearly a knife-edge barrier between the ocean and the lake that lies within. Antarctic swells receive no resistance until they meet the sheer outer walls of Rano Kao and the south coast of the island. Scattered across the grasslands, parasitic cones that make up the landscape are of all shapes and sizes in hues of reds, yellows and greens.

Baker's geology findings state that the most recent lava flows on the island may be as young as two to three thousand years old (1967). This is consistent with our findings in the cores of KAO3 showing that volcanic activity occurred as recently as 1300BP.

2.2 Weather and Climate

Historical documentation of weather is very recent at Rapa Nui. It wasn't until the 1950's that regular intervals of observed temperature were recorded. Even more sparse are collected rainfall data. Carl Skottsberg (1920) noted in his report of the vegetation of Easter Island that there were three weather stations placed at Mataverí (the current location of the modern weather station near the airport), another at Otu on Terevaka and a smaller one on the rim of Rano Kao. A summary during the year 1911 – 1912 reports that the temperatures between the three are relatively similar, "but it is the rainfall differences that are to take notice of." At Mataverí, Skottsberg recorded 1268.7mm (49.9 inches), at Rano Kao 1235.8mm (48.6) and at Otu, only 50m higher than Rano Kao, he recorded 2056.9mm (80.9 inches) (1920). Higher elevations and mountains generally are expected to have higher rainfall amounts and in this case more at Terevaka, but at Rano Kao rainfall was unexpectedly lower in comparison, and Skottsberg likens it to the south rim of the crater which is like a razor sharp edge of a cliff between the lake and the ocean. This crater wall will likely be breached by erosion in the near future but it is very

important in catching rainfall as the wind carries the moisture rising from Terevaka and drifts in a southwesterly direction landing inside of crater, while some continues out into the ocean. In 1920 Skottsberg noticed what we see today, that some rainfall is lost as it travels across the lake and continues out over the ocean moving with the wind currents.

Skottsberg's observations of temperature follow:

Temperatures noted for the years of 1912 – 13

MED.	MED./MAX	MED/MIN	ABS./MAX	ABS./MIN
19.7	23.3	17.2	29.5	10.4

Precipitation for the years of 1912 – 13 (208days)

RAINFALL.	HUMIDITY	EVAPORATION	RAINFALL EVAP
1416.8 mm	84 %	963.9	1.47 mm

**Heavier precipitation is noted for fall and winter and a drier spring.*

There are very wet and very dry years. Just as there are dry years, there are also dry spells during each year, but no prolonged periods of drought.

As a rule, the rain descends in light showers, but heavy downpours are by no means rare and may occur at any season. (Skottsberg 1920)

Precipitation data observed over the last 60 years (see Figure 6) show no distinct wet season and no significant correlation when compared to the difference in oxygen isotope (δO^{18}) record or with any of the Sea Surface Temperatures (SST) or air temperature data sets. Rainfall average from 1974 – 1998 was approximately 1105 mm/year (Mucciarone and Dunbar 2003). Nearly 100 years after Skottsberg, a comparison with the original

observations of Knoche, as quoted in Skottsberg, show that the annual rainfall has decreased by 300 mm annually.

Heavy rains come down on the island with a tropical force, but they quickly disappear beneath the surface through the porous volcanic soils. Dew is commonly formed during the night, allowing grazing animals to find moisture. The only known collection sites for water are in caves, on the hills and in the crater lakes. There is also an underground spring that emerges just below the ocean surface creating a brine water site that was used for drinking water in the ancient past. Skottsberg (1920) noted that “hydrographic features are remarkable. While other volcanic South Sea Islands exhibit signs of a very substantial erosion, with deep ravines and narrow ridges, there is not a single valley or ravine in Easter Island with exception of the grooves on the steep crater rims” (1920). The lack of surface water features is a critical factor in the difficulty of obtaining fresh water on this island because rainfall immediately either vaporizes or soaks into the soils without leaving a trace.

A rainfall graph was generated using data collected from the NOAA Global Historical Climate Network V2 from 1941 to 2008 (see Figure 6). The chart shows that the largest rainfall amount in the last 100 years on Rapa Nui was in the year 1979 with almost 200cm. There are noted patterns in the data that show peak-wet years between 17 and 22-year intervals and drought or minimum moisture totals with 7-10 year intervals. The driest year in the record was 2004 with approximately 50 cm of total rainfall, which is an extreme difference from the wettest year just 25 years earlier.

Wind on the island is nearly constant at 15km/hour, increasing with storms during the wet seasons. Calm days are rare. Trade winds from the southeast are common during the

May to September months, whereas more frequently the winds follow from the West and North. The hottest months are January through April, which are the summer months for the island. The wet season falls April through September (see Figure 8). More daylight hours and higher humidity also coincide with the summer months and the hottest days of the year on the island. Humidity is nearly constant year round at close to 80% (see Figure 7).

Historical sea surface temperature (SST) recordings are rare due to the infrequency of ship travel through the Southern Ocean in the location of Easter Island. The Scientific Expedition of Easter Island in 1998 led by John Loret conducted by Mucciarone and Dunbar established a mean annual SST chronology around Easter using cores of the coral called *Porites lobata*.

Reviewing an ocean current map of the area (see Figure 5) the ocean and circulation patterns of winds seem to vortex into what some call a neutral zone with little to no effect from El Nino events. “The most likely influence of mean temperature on ENSO is to change the frequency and perhaps duration of El Niños, rather than the area affected. Since El Niño events seem to have little effect on Rapa Nui, climate events similar to the Little Ice Age—noted in the Northern Hemisphere—might not be detected, even by a climatologist on Rapa Nui” (MacIntyre, 2001). My research does in fact show a distinct cool and dry period that occurred in 545BP that will be discussed in Chapter 6, supporting Patrick Nunn’s description of a 13th century event, which he noted as disrupting societies across tropical Polynesia.

2.3 Observations from the Resolution and Adventure 1774

Some of the earliest recorded descriptions of the island’s natural history come from

the notes of the ships HMS Resolution and HMS Adventure under the leadership of Captain James Cook in 1774. Cook was taken ill by the “Billious colick” and never set foot on Rapa Nui (Cook, 1774), but based on his crews’ observations, he reported that on Tuesday the 8th of March, 1774, the winds were out of the east when they saw many birds, “...such as Tropick, Men of War and Egg Birds of two sorts, grey and white, many sheer-waters or Petrels of two or three sorts...”. These birds led the ships to the island and they anchored on Saturday the 12th. Cook writes, “I made no doubt but was David Land or Easter Island, ...we expected to have seen the low Sandy Isle Davis fell in with, but in this we were disappointed.” Easter Island was not Davis Land, but at 27° 20’S they found a low, sandy island. Twelve leagues to the west they saw a range of high land and “there came hence great flocks of fowls.” (p. 337).

On Sunday the thirteenth, Cook writes that in “stretching in for the land we discovered people and those Monuments or Idols mentioned by the Authors of Roggeveen’s voyage which left no room to doubt but it was Easter Island.” Upon anchoring in thirty-six fathoms of water, a boat was sent ashore and the men exchanged gifts of medals and other trifles for sweet potatoes, plantains and some sugar cane. Cook records that “after having found a small spring or rather well made by the natives, of very brackish water, I returned on board and anchored the ship in 32 fm water” (p. 339).

Notes from Captain Cook’s journal describe the land as “a most desert barren country full of rocks and only three or four bushes not 5 feet high” and “the country appeared barren and without wood, there were nevertheless several plantations of potatoes, plantains and sugar cane; we also saw some fowls and found a well of brackish water”. Leading from the beach back onto the grassland they noted several large tracts of plantings of potatoes and some plantains toward the south end of the island, “but they

saw no fruit on any of the trees". There was fine red earth which bore a longer grass and was not covered with stones as in the other parts, but here they saw neither house nor plantation. Walking another three miles they commented on the barren land with some places being stripped of all soil to a bare rock that likened to iron ore. Beyond this they came to the most fertile part of the island interspersed with large plantations of potatoes, sugar cane and plantain trees without the encumbrance of stones around the bases as they had seen before. The water that was brought to them at this point was brackish and stinking and made them very sick (p.345).

Towards the eastern end of the island they met with a well whose water was perfectly fresh, being considerably higher than the level of the sea, but it was also a place where the native people bathed as they drank. On the following day they visited the mountain to the west (Terevaka) where they found another well where the water was very strong in mineral and had a thick green scum on the top and stunk intolerably. As with the day before this, ... "soon made them so sick they threw it up the same way it went down" (p.347).

In all of their excursions it is noted that they only saw two or three shrubs, and identified one of the native plants called Torromdedo, footnoted as Toro-miro otherwise known as *Sophora toromiro*. They were cautioned not to eat the seeds as they were thought to be poisonous by the natives. Cook writes,

The wood was a pretty hard of redish colour and rather heavy but crooked, small and short, not exceeding six or seven feet high. At the sw corner of the island they found another shrub whose leafe was not much unlike that of ash. The wood was white and brittle and in some measure resembling that of the asp (poplar, *Populus tremula*). They also saw in several places the Otaheite Cloth Plant but it was poor and weak and not

above two and one-half feet at most. They saw not an animal and very few birds, or indeed any thing, which can induce ships, that are not in the utmost distress to touch at this island. (p. 347)

It is noted that had they found fresh water on the island, they were going to continue looking for the low sandy isle mentioned by as Davis land. Cook writes,

No Nation will ever contend for the honour of the discovery of Easter Island as there is hardly an island in this sea which affords less refreshments and conveniences for Shipping than it does. Nature has hardly provided it with any thing fit for man to eat or drink, and as the Natives are but few and may be supposed to plant no more than sufficient for themselves, they cannot have much to spare to new comers. The produce is Potatoes, Yams, Taro or Eddy root, Plantains and Sugar Cane..... Gourds and the same sort of Cloth Plant as at the other isles but not much Cocks and Hens like ours which are small and but few of them and these are the only domestick Animals we saw among them, nor did we see any quadrupeds, but rattts which I believe they eat as I saw a man with some in his hand which he seem'd unwilling to part with. Land Birds we saw hardly any and Sea Birds but a few. The Sea seems barren of fish for we could not catch any although we try'd in several places with hook and line and it was very little we saw among the Natives" (Cook, p. 349).

In his footnotes for the publication of Cook's journal, Forster writes, "Cook's guess at population does not seem to be a particularly good one, and the estimates of all early visitors seem to be unreliable. But when La Perouse landed at Hanga-roa in 1786, he was faced there by a crowd of 800 and thought the total population was about 2000. Metraux, after considering the available evidence (Ethnology, p. 20-22) puts the population c.1840

at between three and four thousand; so whether La Perouse under-estimated or not, Cook certainly did. Metraux adds, “As Cook suggested, the natives were undoubtedly frightened by the arrival of foreigners and hid their women in inland caves as was done in wartime” (Forster, p. 351).

2.4 Natural History Studies by Skottsberg

The first naturalists to come after Katherine Routledge and her lengthy study of the people of Easter Island in 1919 were Carl Skottsberg and Carl Christensen in 1920 authors of *The Natural History of Juan Fernandez and Easter Island*. This volume provides a detailed study of the vegetation of the island, as well as insects, fish, birds, and invertebrates.

Skottsberg’s first observation of the island states, “Easter Island scenery is very monotonous. The Island is a low, undulating basaltic plateau of practically the same geological structure everywhere and covered by the same kind of vegetation” He states that Terevaka, which is the highest peak on the island at 530 meters “is not sufficiently elevated to call forth any distinct vertical regions.” His greater interest was the crater lakes, particularly the crater of Rano Kao, which was “deep enough (200m) to act as a secluded valley and to offer better conditions for arboreous vegetation” (1920, p.487).

When reviewing the soil Skottsberg finds that the lava plains are stony and shallow with bare rock exposed in many places. Cracks and accumulated boulders seem to have more lush vegetation. The soil colors vary according to the mother rock from deep browns to a red or yellow color. In some places there is loose volcanic sand. In places where there was sufficient soil of good quality and fertility, prehistoric plantations were noted to

have supported several thousand people in cultivating crops. He notes that the “injurious effects” of the strong winds were lessened by enclosures built around the plants that are called manavai today. Insect life was noted as very poor. Earthworms were found but only as introduced species (1920).

Skottsberg writes that “indigenous trees and shrubs are almost wanting”. A scanty growth of small trees was noted inside of Rano Kao. On the interior of the island *Broussonetia papyrifera* trees were also located and noted as more than likely an early native introduction. The only other trees that were noted were those growing below the cliffs of the eastern headland, but Skottsberg was not able to identify what they were. Native tradition told that trees were brought by the first immigrants, but which kind of trees is unknown. *Sophora toromiro* was observed to be growing and noted as endemic, easily distinguished from other members of *Edwardsia*. Skottsberg observes:

There is no *Edwardsia* in Melanesia or in the part of Polynesia from where the Easter Islanders are supposed to have come” (p. 491). Some small groves of *Sophora* must have existed upon the island as late as 1886, when the U.S. Mohican visited the place. Both Thomson 1891 and Cook 1899, state that there were some groups of trees on the hills but that nearly all were dead and decaying, having been stripped of their bark by sheep and cattle which had been introduced some time previously (p.491).

Skottsberg adds, “Unfortunately, it is a common experience that devastation follows the white man, and many Pacific islands have been badly ravaged” (p. 492). He continues to describe Easter Island as having no sheltered valleys, rivers, streams, or running water. Even with the porousness of the soil and rock, the intense solar radiation and rainfall, Skottsberg theorizes that the island should have supported the growth of trees such as the

leeward sides of the Hawaiian Islands have done.

Skottsberg writes, “I have been led to believe that some kind of forest once existed on Easter Island, formed by *Sophora* and other species, exterminated long ago” (p. 492). No native tradition tells us anything about these forests. My own inquiry into the Spanish and Rapa Nui language about the native plants shows that there is no native name for the palm trees that we now know existed in the millions on the island (Meith and Bork, 2010). This absence suggests that generations of islanders existed without these forests.

The *toromiro* is a small tree that was once plentiful, in the thousands, but gradually became exhausted. Apparently cultivated fields eventually overtook the indigenous vegetation. In Skottsberg’s considerations of what might have happened, he hypothesizes that when first settlers arrived the island was some kind of savanna forest, a park like formation with scattered, stunted *sophora* trees and a grass cover. He continues to say that the flat, rocky plains may have been devoid of trees, which were confined to the hillsides with more rainfall. With the porosity of the soil, the strong sunshine and winds, the water supply should be expected to be sufficient to permit trees to grow just as on the lee sides of the Hawaiian Islands where precipitation is much less. Skottsberg concludes with a concise statement about Easter Island: “The climate is not a grassland climate” (p.492).

2.5 Diamond’s Collapse Theory

Jared Diamond’s book, *Collapse* (2005) is sensationalized, with intention to arouse strong curiosity in its readers, as was Thor Heyerdahl’s introduction of *Aku Aku* to the world. The island Rapa Nui, otherwise known as Easter Island, Isla de Pascua and Te Pito O Te Henua, is the subject of both of these writings. Both speak about the demise

or cultural collapse that occurred on the island due to unknown causes. In reaching into planetary human history, the Collapse Theory has been well defined from documentation of civilizations both past and present. What is unique about Diamond's work is that it systematically created a risk factor of the natural environment absent of humans. He suggests that understanding the risk of place before introducing a dynamic, unpredictable creature such as a human may provide a better understanding as to what may have happened on Rapa Nui. In discussing Rapa Nui specifically, Diamond writes of "the most extreme example of forest destruction in the Pacific, and among the most extreme in the world: the whole forest gone, and all of its tree species extinct" (p. 170).

Reconsider the fragile physical nature of Rapa Nui. The climate is mild, there are fertile soils from volcanic activity as recent as 2,000 years ago, and the island at 27 deg S latitude is cool rather than a lush humid tropical island. The average temperatures measure 22C (72F) most of the time. There are 127 species of fish found around the island, as compared to thousands of species on Fiji. Rainfall averages 1,270mm (50in) a year that drains quickly through porous soils. There are three locations on the island where rainfall collects into basins. These are the lakes Rano Kao, Rano Raraku and Rano Aroi, all of which are now swampy, boggy marshes. There are over forty identified cultivated crop plants that were brought by voyagers and settlers including bananas, taro, sweet potato, sugarcane, and paper mulberry along with chickens, rats and foreign insects. The native flora and fauna were the first to be changed and exterminated (Diamond, 2005).

Flocks of migrating birds and land nesting birds were eventually driven into non-existence (Steadman, 1995). Steadman states that "Easter Island was once the home of at least 25 species of seabirds, of which 8 to 10 no longer breed on the island, and 13 to

16 no longer breed on any of the offshore islets. The entire prehistoric seabird fauna of Easter Island probably exceeded 30 breeding species, more than are known from any other single Polynesian island. Of these only *Phaethon rubricauda* still nests on Easter Island itself.” With the deforestation of the island nearly 550 years BP many indigenous insects, land snails and land birds also disappeared.

Human population estimates are generally based on models of projection from small example collections, but rarely has knowledge about the natural history been used to estimate the population or suggest what people may have eaten on this apparently barren land. The first palynology attempt by O. H. Selling (1958), who worked on Heyerdahl’s lake sediment cores of Rano Raraku, discovered a palm species likened to *Pritchardia*. This palm species was known to exist on other islands but no longer on Rapa Nui. This was the first evidence that the island was once quite different from what is now mostly a barren landscape. In 1977 and 1983 Flenley followed Heyerdahl’s attempt at coring the three crater lakes Rano Kao, Rano Raraku and Rano Aroi. With his pollen work he disclosed that there were many species of trees no longer in existence on the island. Palm endocarps were found in a lava cave providing a clue to the type of palm that once existed but is now extinct on the island. This discovery showed that the extinct Rapa Nui palm was similar to if not the same as *Jubaea chilensis*, the largest palm in the world. A living version of this tree is known as the now endangered Chilean wine palm. Not only has the existence of palm pollen been found in great abundance, but also the sheer size of the tree and the idea of the island being covered in a diversity of trees has changed our understanding of Rapa Nui’s history.

Investigation into other tree species continued with Orliac and Orliac (2000) in their work on wood fragments found in umus (earth ovens). In these archaeological sites the

charcoal was analyzed and identified to particular trees and shrubs that may have existed and thrived on this island or were transported here. Meanwhile Flenley concluded with his KAO2 core that twenty-one plant species were once part of the flora but are now absent (Butler, 2001). In my KAO3 core there are even more species identified than previously known with another twenty species no longer present on Rapa Nui.

Diamond asks if we can specify more closely when, between the dates of 900 and 1722 the trees vanish. I suggest through my findings that, yes, the radiocarbon dates can show convincingly the periods associated with the disappearance of the tree pollen. A reliable sequence of radiocarbon dates have been secured, and there is no question when the trees began to disappear. Evidence in the KAO3 core shows heavy charcoal burning in 1176BP with a disappearance of the palm pollen occurring in 545BP.

Diamond writes about the possibility that deforestation may have been caused by natural climate changes such as droughts or El Nino. He makes the statement “It would not surprise me at all if a contributing role of climate change does eventually emerge for Easter” (2005, p. 113). In a second reference to climate he states “at present, we lack information about climate changes on Easter in the relevant period of AD 900-1700: we don’t know whether the climate got drier and stormier and less favorable to forest survival or less stormy and more favorable to forest survival” (p. 114). In his final statement he says “there seems to me to be compelling evidence against climate change by itself having caused the deforestation and bird extinctions” (p. 114). My findings suggest that even though there was a climate event in 545BP it was minor compared to many of the climate events shown in the 15,000-year record obtained from Rano Kao. There is strong evidence that the 545BP event did affect the environment in creating a cool and dry time period of unknown duration. However, if the landscape had changed

significantly due to human occupation, then the ecosystem may not have been able to withstand a minor change such as the 545BP event.

What Diamond defines as “risk” in the fragile island environments of the Pacific, and how climate change could have affected them, are explicated in *Collapse* where he address his specific question: “*What Affects Deforestation on Pacific Islands?*”:

Deforestation is more severe on:
 dry islands than wet islands
 cold high-latitude islands than warm equatorial islands;
 old volcanic islands than young volcanic islands
 islands without aerial ash fallout than islands with it;
 islands far from Central Asia’s dust plume than islands near it;
 islands without makatea than islands with it;
 low islands than high islands;
 remote islands than islands with near neighbors; and
 small islands than big islands” (2005, p. 116)

Diamond’s findings disclosed that these nine physical variables contributed to the condition of the islands outcome. The most important finding was the variations in rainfall and latitude. Those islands that were dryer and cooler, which correlated to distance from the equator and at higher latitude, ended up more deforested than did the wetter equatorial islands: The rate of plant growth and of seedling establishment increases with rainfall and with warmer temperatures.

Eighty-one islands were compared with all of these descriptors above, and the statistical

model predicted “Easter Island, Nihoa and Necker would be the most deforested Pacific Islands. The actual results in real time left Nihoa and Nicker with no human habitation and only one tree species standing (Nihoa’s palm) while Easter ended up with no tree species standing and about 90% of its former population gone.” (2005, p. 118).

This dissertation provides information not available to Diamond when he wrote about Easter Island, information collected in the oxygen isotopes captured in the lake sediments. Specifically, rainfall and drought patterns, vegetation changes and the ecological shifts noted in the climate variability profile covering the last 15,000 years from the KAO3 lake sediment cores. Further support of palynology has also identified more tree and plant types and created a new understanding of how these dynamic systems work together.

Figure 2 - View of island from the summit of Rano Kao

Figure 3 - The three crater lakes of Easter Island

Coring points
2005 and 2008

RKE08 expedition crew

Figure 4 - Google Maps of Rano Kao coring points

Figure 5 - Ocean current circulation map of Easter Island and the South Pacific

(Ref: NOAA Global Historical Network V2)

Figure 6 - Easter Island Rainfall History 1941 - 2008

Figure 7 - Daylight and Humidity Factors for Easter Island 27.16S, 109.43W

Figure 8 - Rain-Wind-Temp Averages for Easter Island 1941-2008

Chapter 3 The Trees on Rapa Nui

A great tree, extinct on Rapa Nui. More than 16 million of these amazing palms with a vascular system like an animal. Imagine this enormous forest, with root fingers linked together, breathing a community of life. An essence drawing moisture from the earth and breathing it out with the sun, keeping the single cells that lived beneath the canopy alive and well.

3.1 Introduction

There are both theories and myths about what happened to the trees on Rapa Nui (Easter Island). A popular idea in scientific and non-scientific writing is that the inhabitants of the island, over time, cut all of the trees down to the last one standing in the crater of Rano Kao. According to this theory, whether deforestation occurred to support moving the *moai* (stone statues) around the island or to clear land to plant taro crops, humans decimated the island creating a barren landscape. But what if there was another cause of deforestation? Climate change, insects, disease, or loss of biodiversity and soil fertility could be factors. It is also possible that the trees on the island were a long-term flowering species similar to the self-destructing Madagascar palm, which flowers once every hundred years then dies. The four new palms I found are not yet identified and could be of a similar reproductive pattern. In considering possible causes of deforestation, it is important to look at the broader context of a widespread extinction of palm forests among other Pacific islands.

One non-human cause of deforestation is climate change. Prior to this research it was unknown whether there were any significant climate shifts noted on this island. Did the climate patterns change enough to cause deforestation, a prolonged drought that drove the forest ecosystem into extinction, for example. The evidence I collected, in both the pollen count and oxygen isotope analysis, suggests such a condition.

For thousands of years deforestation has been documented around the world. Whether the loss of the world's trees is due to fires, floods, drought, or clearing of the landscape to build cities and grow food, these are not new scenarios. Therefore, it was important that this research focus not on the causes of deforestation as a whole but rather on what the palynologic and oxygen isotope records reveal about the changes in lake level, moisture, and vegetation on Rapa Nui over time. This chapter begins with the earliest evidence of an ancient palm tree and other vegetation that no longer exist on the island and then adds new species uncovered in this research. It provides further explanation as to why these trees are important in the island's natural history, shifting our view of Easter Island from a barren landscape devoid of life to a place of great diversity with a magnificent palm forest as the keystone species to the ecosystem. To place the disappearance of these palm trees in a larger context, I discuss the recent studies of their possible mass extinction in Oceania. In conclusion, the chapter discloses unique discoveries of this research regarding possible shifts in a fragile ecology that may have directly or indirectly caused the disappearance of a great palm forest on Rapa Nui.

3.2 Why Are We Interested in the Ancient Forests of Rapa Nui?

Easter Island has been described as a treeless barren landscape that supported an unknown number of people who managed to collectively construct huge statues out of a crater quarry and move them around the island for miles without any visible means to do so. Early visitors to the island, such as Jacob Roggeveen in 1722 and Captain Cook in 1774, and the many unnamed whalers, slave hunters, and conquistadors, barely stayed long enough to ponder the mystery. Their reports have commonly presented the island as having always been a barren landscape with sun-drenched and baked soils that provided hardly any food, plants, or fresh water. These observations on Rapa Nui were not unlike those made by Charles Darwin when he first landed in the Galapagos Islands in the early

1800s and called them “Hell on planet Earth” (1839). But then he began to observe the changes around him and realized how alive the islands really were and how things had been adapting for a long time. In the case of Easter Island, it did not make sense that the obvious monumental labor that built the stone platforms and moai did not have any evidence of plant matter to support the population that created them.

Beyond the adventurers and traders, there were formal expeditions that came with the intent to document what plants did exist on these islands in the South Pacific. Agassiz and his comrades during the Albatross Expedition in 1904 made a small collection of ferns on Easter Island, while G. Forester on Cook’s second voyage produced the *Florulae insularum australium prodromus* in 1786. Francisco Fuentes, from the Museo Nacional de Historia Natural in Santiago, gathered the most complete enumeration of the flowering plants of Easter Island, and called his publication the *Resena botanica sobre la Isla de Pascua* in 1913 (Skottsberg, 1920). The most comprehensive and inclusive study came from the naturalists Carl Christensen and Carl Skottsberg called *The Natural History of Juan Fernandez and Easter Island* printed in 1920. Assisted by a Swedish expedition to the Pacific during 1916-1917, they landed on Easter Island (Isla de Pascua) in June 1917 to conduct the first survey of all living things found on this island including plants, animals, birds, sea creatures, and insects.

In the writings of Skottsberg, there are 30 listed flowering plants thought to be indigenous to the island. Of these, only three are considered trees. Skottsberg also made a list of plants occurring in the wild or in a semi-wild state and thought to have been intentionally introduced by the first immigrants. This list is inclusive of six trees or shrubs. Georg Zizka (1991) followed up on Skottsberg’s study and documented that, of the 30 original native plants, four species remain today one of which is a single tree *Sophora*

toromiro, found in the gardens of CONAF (observation of Gossen, March 2008). Zizka's summation added 141 species of immigrant plants to Skottsberg's list, of which 67 are established today and 74 have only been seen once or twice.

The findings of Christensen and Skottsberg showed only the remnants of a landscape that had survived hundreds of years of disrupted human habitation: societal collapse, civil war, slave stealing, and the annexation of the island by Chile in 1888 for the purpose of sheep farming. What was left living set the foundation for the work of Skottsberg. His extremely important volume provided the most comprehensive information upon which John Flenley expanded his paleo-ecological findings in 1980, using such methods as lake sediment coring and palynology.

Before Flenley, Thor Heyerdahl's expedition in 1958 was the first to attempt to find fossil pollen in the sediment cores from the crater lakes. The art of palynology, or the hunting of fossil pollen in soil and preferably in deposits of wet lake sediments, is a useful tool for discovering flowering plants of the past. Heyerdahl had no idea that he might find a fossil of extinct ancient palm pollen, but with Heyerdahl's core from Rano Raraku, O. H. Selling identified a palm similar to that of *Pritchardia*, an endemic palm now isolated to the islands of Hawaii but never before identified on Easter Island. This work by Selling was never completed and 20 years passed before Flenley discovered an abundance of an extinct palm pollen fossil similar to *Jubaea chilensis* now renamed as *Paschalococos disperta* (Dransfield & al., 1984).

With Heyerdahl's expedition in 1958 and Flenley's palynology in the 1980s, new discoveries were unearthed. Buried in the lake sediment are the fossils of extinct trees that were not available to scientists who, like Skottsberg, observed the living landscape.

As the fossil record that presented this extinct palm tree could not identify how many trees this pollen represented, Meith and Bork in 2003 began their scientific excavations of palm root casts. They determined that it was quite possible that more than 16 million palm trees existed on this little island. The calculations followed this analysis:

(38 palms per 100m = 1400 trees per hectare. With 70% of the island covered in trees, 11,600 hectares x 1,400 trees = approximately 16 million trees)

Flenley took the quest one step further and dated the presence of charcoal in the lake sediment cores as an initial burning of trees around 800AD with the final disappearance of the palm pollen around 1550AD; the latter was based on the radiocarbon date of a palm nut (Flenley, 1991). Given the estimated 16 million palm trees of Meith and Bork, cleared over a period of 800 years according to Flenley, that would equate to approximately 20,000 trees cleared in a year, or 55 per day every day for 800 years, a highly unlikely accomplishment. The calculation argues against deforestation due to humans cutting the trees.

The wide-ranging descriptions offered by explorers and scientist triggered my curiosity and focused my attention on what might yet be learned from the palynologic record. Given the pauperized state of plants on the island now, and the findings of a more diverse ecology uncovered in fossil form, what happened between now and then is still a mystery. Only 30 years ago the fossil of an ancient palm was discovered. This palm is similar to the Chilean wine palm *Jubaea chilensis*, which is the largest palm tree in the world, growing some 30 meters tall and more than a meter across. With Meith and Bork's estimation that millions of palms were alive on this island prior to human arrival, we must wonder what happened to them. Is the story of humans cutting all of these trees

supported by evidence? To date, there is no evidence of humans cutting trees; there is only evidence of the presence and then disappearance of palm pollen along with the root casts indicating the enormity and the quantity of palms, but why they disappeared is unknown.

In this research, I have focused on expanding the palynological science of Flenley. The KAO3 core, taken from Rano Kao, shows a diverse presence of palms over the last 15,000 years (*see Figure 36*). Additionally I have discovered four new types of palm pollen (yet to be identified) that are not *Jubaea* or *Cocos* (*see Appendix E*). These new findings suggest a diverse and majestic palm forest that changed over time. In order to determine why the abundance of pollen changed, I incorporated the first climate analysis conducted on Rano Kao using oxygen isotopes from the lake. This climate analysis brings support in understanding the changes in the trees specifically but also other vegetation. Among the palm pollens, I have also identified 17 native tree species, which broadens both Skottsberg's and Flenley's inventory.

3.3 Extinction of Palm Trees on Pacific Islands of Oceania

Matthew Prebble with the Department of Archaeology and Natural History at the Australasian National University in Canberra, Australia, wrote in the *Quaternary Science Reviews* in 2008 about a "Late Quaternary Decline and Extinction of Palms on Oceanic Pacific Islands." He quoted Steadman (2006) that there has been a close association between faunal extinctions, particularly birds and land snails, with human colonization. "Despite the severe reduction of faunal diversity coincidental with human colonization of these previously uninhabited islands, relatively few plant extinctions have been recorded" (2008). Prebble also cited Flenley et al. (1991), Parkes (1997), McGlone and Wilmhurst (1999), Stevenson et al. (2001), Athens et al. (2002), Haberle (2003), Fall (2005), Mann et al. (2008), and Wilmhurst et al. (2008), who were all in agreement with the evidence

of a decline in native vegetation as a result of human impact. He continued with the commonly accepted argument that Easter Island is the most “convincing case” of humans causing complete decimation of their natural environment immediately after arrival.

In the case of Easter Island, it was the *Jubaea* type palm, now known as *Paschalococos dispersa* (Dransfield, 1984), that was the main target of the decimation. The evidence found in my study of the core KAO3 supports the extinction of 20 native plants, the *Jubaea*-type palm and the four newly unidentified palms occurring at a time when humans were already viable on the island. Palm endocarps found in various caves on the island have given further argument by Hunt in 2007 that rats arriving with humans may have compounded the advent of tree death by not allowing regrowth.

Working in the South Pacific, Prebble, et al, (2008) began to notice a trend in the sedimentary deposits of the lakes and swamps as they were analyzing cores with deposits from the years between human impact and palm decline. Using palynological proxies, these changes represented the losses of ecologically diverse palm forests, sometimes to complete decimation. But it was obvious in these studies that the tree loss was usually quick and occurring immediately after the signs of human arrival. Below is a summary of this 2008 publication with selected statements chosen from Prebble and Dowe’s conclusions (*italics*) with each statement followed by my own research findings from KAO3:

1. “*We have examined the available fossil records and more recent historic evidence showing declines, extirpation or extinction of palms from the oceanic Pacific islands*” (p. 2563).

Gossen: In the KAO3 core from Rano Kao, there are 17 native trees noted beginning with a *Triumfetta* forest 15,000 years BP that gradually became a fully diverse

palm forest of *Jubaea* and other palm species as the island became warmer around 9,250 BP. *Sophora toromiro* was present in abundance over this time period as well. Eventual decline of the *palmae* into extinction occurred at 545 BP, with all native tree species except for *Sophora* disappearing from the pollen record within 100 years (see Appendix C).

2. *“There is no evidence to suggest that palms approached extinction following abrupt regional climate change events recorded from a range of climate proxies elsewhere in the Pacific”*(p. 2563).

Gossen: I added a new element to this research that had not been conducted on this lake before. The aquatic cellulose in the lake sediments was analyzed into oxygen isotope ratios. The climate events that were discovered were correlated with the pollen record. The results agreed with Prebble in that even in the worst drought and cool periods, the palms never disappeared from the pollen record although variances in abundance are noticed as climate shifted and cycled. (see Figure 31)

3. *“Prior to human impact, changing island insularity associated with geological activity and fluctuating sea-levels are the most likely causes of abrupt palm decline or extirpation”*(p. 2563).

Gossen: On Easter Island there was volcanic activity until as recent as 2000 years BP (Baker, 1967). In the core KAO3, there were noticed samples with tephra in them as noted on Figure 31. Based on the evidence of my research, the biggest factor affecting the trees has been temperature changes on the landscape independent of sea-level changes and geologic activity.

4. *“In most records a close correspondence exists between evidence for rapid forest clearance indicated by charcoal particles and declines in pollen of forest taxa, including palms” (p. 2563).*

Gossen: Charcoal particles were counted and grouped according to classic archaeological categories of Class 1-IV. A charcoal chart for both the lake sediment and mat cores shows highest total charcoal particle at 345 BP, 1173 BP, and 3500BP including particles sizes from larger than 200 microns, which refer to localized burning in the lake, to as small as 25 microns, which is airborne ash. In the case of the 345 BP event, this followed the last palm pollen by 200 years, but shortly after a high pollen influx showing a high growing period followed by a high burning period. The event at 1173 BP is high in all classes of charcoal types along with oxidized plant material. At 3500 BP, the lake appears to have been completely devoid of water, with some strange anomalies occurring. Specifically, the arrival of polygonum, the discovery of a mite, many exotic grass pollen greater than 40 microns, obsidian found in this sample only, large wood pieces found in samples along with desiccated soil balls.

5. *“Some records also reveal the rapid invasion of introduced weed species, further indication of human-mediated habitat modification” (p. 2563).*

Gossen: The pollen record for KAO3 includes 33 species of native plants from 15,000 to 1200 BP, then diminishes to six pollen types thereafter, including the introduction of large grass pollen >40 micron, indicative of introduced grasses approximately 2000 BP, with native grasses <40microns coming into the pollen record at 1376 BP.

6. *“Palm extinctions or extirpations on Rapanui, Rapa, Rimatara and the Hawaiian islands were a result of human impact” (p. 2563).*

Gossen: I do not agree with this statement for Rapa Nui. Clearly the last palm pollen is

noted hundreds of years after humans arrived on the island according to the evidence in the lake sediments of KAO3. There is also a climate event that occurred in 545 BP, which although not as significant as other events in the past did not cause extinction of the palms. There may have been some climate change event (*see Chapter 5*) that the trees could not tolerate.

7. *“The decline of the lowland and coastal palm genus, Metroxylon, on large islands of Fiji, may represent the combined effects of changing coastlines following mid-late Holocene sea-level fluctuations that left coastal palm populations more vulnerable to initial human impact at around 3500 yr cal BP” (p. 2564).*

Gossen: There is a noted event in the KAO3 core that supports a complete desiccation of the lake Rano Kao at 3500 BP, also a newly arrived species *Polygonum acuminatum* to the lake. Obsidian pieces also occur in this sample that occur nowhere else in the core. A large charred wood piece, marked as a macrofossil and dated to 6000 BP, was located between two *scirpus* seed findings dated at 3500 BP. An adjacent core nearer to lake edge, which is missing the top five meters of sediment, dates to 3500 BP at the top of the core matching the same level in the KAO3 core. A grass pollen similar to, if not identified as, sugar cane appears at this time at Rano Kao.

8. *“Such effects include seed predation, disruption of pollination and seed dispersal and direct damage from herbivores” (p. 2564).*

Gossen: Many factors correlated with the loss of trees, such as increased solar radiation and evaporation of soil moisture, the loss of soil fungi and fertility. The loss of 25 species of birds as noted by Steadman (cited in Prebble, 2008) and introduction of rats that came with humans are also factors that affected seed predation, pollination, and dispersal.

The direct damage by herbivores affected the remaining shrubs and *Sophora* trees, but herbivores did not affect the palm extinction as they did not appear on the island until 400 years after the palms disappear from the pollen record.

9. *“The diversity of palm lineages in the oceanic Pacific islands drops with the increasing remoteness of islands” (p. 2564).*

Gossen: Rapa Nui is considered the most remote of the South Pacific islands from any large landmass that may have influence on species reaching the island. It has been found through this KAO3 core that there was a diverse palm forest, perhaps more so than any other island in the South Pacific. Direct influence is most likely from South America which holds the closest relation to the Rapa Nui palm species. My findings from the KAO3 do not support Prebble’s statement as applied to Rapa Nui.

10. *“Palm species now absent on oceanic Pacific islands were widespread and locally abundant. In addition, palms may have been predisposed to extinction given their size (<10m in height) and slow reproductive rates” (p. 2564).*

Gossen: *Jubaea chilensis* is the largest palm in the world growing some 30 meters tall and more than 1 m in diameter. The palm reaches its fixed growth early and from evidence of the trees in the wild in Chile, productivity is plentiful except when temperatures are so low as to cause the trees’ death (Gurley & Liller, 1997).

11. *“Palms often dominate environments with high humidity, high rainfall and fertile soils, but on remote oceanic islands these areas were preferred for crop cultivation at initial human colonization suggesting that palms were predisposed to human-mediated extinction” (p. 2564).*

Gossen: “In summary, palms exist in a complete range of hydroseres but are virtually

excluded from environments with freezing temperatures...In wet habitats they occur in mangroves, freshwater swamps and in seasonally inundated forests (varzea). They occur at all levels in lowland tropical rain forests, from understory treelets to emergent climbing palms. In tropical montaine regions they may be the most conspicuous growth form and are also outstanding in dry forests, savannah and at desert oases” (Tomlinson, 2006).

12. “Long-term ecological data of islands only recently colonized by humans suggests that the loss of seed dispersers and pollinators following human colonization has also contributed to palm decline and extinction” (p. 2564).

Gossen: *Jubaea chilensis* is monoecious and thought to be anemophilous, although lacking from the standard reference under the tribe Cocoseae section in Henderson (1986). I think that one has to separate the pollination mechanism from the simpler question: does this palm produce lots of pollen? Many palms produce lots of pollen, which might fall and be blown about, but that doesn't mean they are wind-pollinated (though they might be so in part). Generally, palms were traditionally viewed as wind-pollinated, but the reality is that wind-pollination has only rarely been demonstrated. Nevertheless, many palms still shed their pollen in quantity (personal correspondence, William Baker, Kew Royal Botanical, November 14, 2007).

3.4 Unique New Discoveries and the Amazing Life of the Palm

When I first read P. Barry Tomlinson's report in the *Botanical Journal of the Linnean Society*, entitled “The Uniqueness of Palms,” (2006), I did not know yet what I would find in the KAO3 core taken from Rano Kao in March of 2005. I was searching for signs of trees in the lake sediments through various proxies including palynology, plant macrofossils, starch and other micro-sized particles to piece together more of the puzzle

of the extinct palm tree that found its way to Easter Island and then disappeared.

In reading Tomlinson's report (2006), it became obvious that this was not going to be another study in deforestation. Palm trees, monocotyledons, are different from any other tree on the planet. They are the "world's longest lived trees because stem cells of several kinds remain active in differentiated tissues throughout the life of the palm." And then Tomlinson stated a most amazing fact about these palm trees, one that had bearing on my research: "The palm behaves, in a sense, more like an organism with unitary (animal-like) construction rather than a plant-like modular construction." Tomlinson was saying that the palm was animal-like and not unlike humans. If we lose an arm, we cannot regenerate a new one. Palm trees have the same limitation; if one part is lost or injured, it is gone forever.

A comparison with the ancient Bristlecone pine forest located in the Eastern Sierra Mountains of California elucidates the qualities that are unique in the palm. The Bristlecone pines are thought to be the oldest living trees on this planet with some dated to over 4,000 years of age. The Bristlecone pine being dicotyledonous has a common structure to most trees, a stem and branches and leaves that diverge from the vascular system in two dimensions. On the other hand, "the vascular system of a palm is clearly three-dimensional and at any level, continuously functional" (Tomlinson, 2006). What we see in the Bristlecone pine is mostly dead wood that continues to branch into new sections of living matter. The palm in comparison is a "self-regulated organism" ... "a closed (unitary) growth similar to that of most animals rather than open (modular) growth of most plants. The units are fixed but repeated continually" (Tomlinson, 2006). Dendrochronology, a form of science used to age a tree by taking wood borings, is fixed by the rings of growth, whereas it is impossible to age a palm tree through a boring as it is continually alive.

Tomlinson also states: “From an evolutionary perspective, all groups of organisms are genetically unique as independent lineages” (2006). This statement supports Dransfield’s reclassification of the extinct Easter Island palm as *Paschalococos disperta* (1984) to honor it as genetically unique. Each palm can survive in its unique way, adapting to habitats in all ranges of hydrospheres, with only one limiting factor: it cannot tolerate dormant periods caused by freezing temperatures. If the palms were to undergo freezing temperatures long enough to cause the vascular system to slow, cavitation of the tracheary elements would occur (Tomlinson, 2006).

Palm tree morphology is useful information when considering the possible causes of the disappearance of the palms on Easter Island and perhaps other islands of the South Pacific. The largest palm in the world is the *Jubaea chilensis* (Molina) Baill, which has the widest stem (over 1 m) built by primary growth. Its survival advantage is to increase its height by photosynthesis like most plants and to increase the dispersal range of its pollen and seeds. Being monoecious, having both male and female flowers, wind is the most useful dispersal mechanism to ensure the palm’s survival. Storm and wind damage is minimized as is resistance to fire and pathogens due to its lack of a peripheral secondary vascular system, which means its primary vascular system is continuously active from the root to the crown. There is no heartwood, no conducting tissue in palms, which enables this fibrous stem to hold massive amounts of water. An average *Jubaea chilensis* has been estimated to hold more than 100 gallons of sugary sap within its stem (Gibbons, 1993). “Once the crown size becomes fixed at the end of establishment growth, transport capacity becomes fixed” (Tomlinson, 2006).

When considering why any forest dies, a more common problem is with ground fertility and the loss of moisture in the soil. Palms have continuous cell changes throughout the

stem, the oldest at the base, which is dependent on a lignified ground tissue. “The palm stem is mechanically efficient, and by establishment growth and continued primary thickening growth, together with gradual lignification of fibrous and parenchymatous tissue, the tree habit can be realized” (Tomlinson, 2006). An interesting find in the KAO3 core was a similar lignin resin that was observed, analyzed, and counted among the non-pollen palynomorphs. It is of unknown origin but it does correlate with dry conditions, which also show an increase in palm pollen during these periods. What I may be seeing in the slides is lignified ground tissue in fossilized form from the palm trees at Rano Kao.

Another non-pollen palynomorph observation was starch. I did an extensive study on the starch found in this KAO3 core in an attempt to identify its origin and understand ecologically why it changed in abundance. Using modern-day totora and tubers for starch identification, it matched none distinctly but most closely the monocots such as totora. More of this information follows in Chapter 6 in the plant ecology discussion. There is a known connection between palms and starch. The ground parenchyma cells of the palm hold the starch that forms the energy needed for final reproduction (Tomlinson, 2006). The changing abundance levels of starch found in the lake sediments is inconclusive as to what plant these belong to, but there is a correlation between high abundance and drought conditions. Perhaps under stressed conditions, starch is more abundant in the palms to produce the energy needed to ensure its continuing growth.

Let’s consider the strengths and weaknesses of the palm. We know it is unique, with an animal-like unitary construction, which allows gigantism among the species. It can thrive in a complete range of hydrosere and is self-regulated. Due to its lack of superficial meristematic cambium, it is not vulnerable to fire, pathogens, and trauma. Its weakness is temperature; it cannot undergo dormancy during a time of freezing. The palm stores

massive amounts of water but cannot be tapped to retrieve it. The water does not leak when the stem is cut; the whole tree must be cut down. Since the crown fixes the growth, if the stem is cut, the crown wilts, and if the crown is not fixed, the vascular system of the palm does not function and the tree dies. Therefore, the two obvious factors of palm death are freezing temperature or injury to the stem or crown, something like cutting a head or arm off and stopping circulation.

3.5 Possible Causal Scenarios Attributed to the Disappearance of the Palms

The most widely accepted thought on the cause of death to the Easter Island palms is the use of trees as rollers for the moai. Gurley and Liller (1997) reported on the testing by Killmann in 1988 of the density of the *Cocos nucifera* trees as possible sources of wood. They stated, “A 60-year old *Cocos* palm will have, on average, a stem varying in diameter from 15 to 30 cm and a height of about 20 meters.” The outer section of the tree has a density likened to hardwood trees such as oak and with the hardness of ivory or bone capable of supporting six tons each. The interior of this tree also has a softer tissue that is comparable to white pine although the *Jubaea* palm is comparably larger and more fibrous than dense. There would be no doubt that the Rapa Nui natives would find use for these trees as rollers and as construction materials in all forms.

Beyond the use of the trees for rollers and construction of shelters, food is another motivator. A universal trade of palm oil, evident today, may also have been valuable long ago. The copra (dried kernel) is used to obtain the oils for cooking, making soap, and much more. But when the *Cocos* palm reaches 60 years of age, the copra yield declines (Liller, 1997). Other parts of the tree are useful for making ropes, baskets, and clothes. The *Jubaea chilensis* palm produce a sugary sap used by the Chileans for a sweet syrup

and wine, but it must be cut down in order to produce these sweets. The *Jubaea* is now an endangered species and protected by CONAF, the Corporacion Nacional Forestal de Chile.

There are other important scenarios to consider about why the trees disappeared:

- ***Damage to the palm crown when obtaining palm hearts.*** The palms were suspected to be a valuable source of food. Palm hearts, perhaps an important delicacy as they are today, are found in the crown of the tree. The importance, however, of the crown is in keeping the tree alive; if damaged, the tree can die. “The crown of a rattan wilts rapidly when its stem is cut. However, a paradoxical observation is that the vascular system is strangely disconnected” (Tomlinson, 2006).

- ***Damage to the palm crown via palm weevils and other larvae.*** Perhaps the red palm weevil (*Rhynchophorus ferrugineus*) or something similar was introduced to the island. Originating in tropical Asia and spreading through Africa, Europe, and most tropical geographic regions today, this weevil was distributed primarily through human intervention. It usually infests palms younger than twelve years, with the mortality of the tree caused by the larvae. The life cycle of this weevil is completed in four months but by the time signs of crown wilt and leaf death are visible, it is already too late. The larvae can be found in any place within the palm, even in the very base of the trunk where the roots emerge, although adult weevils will not move to another palm if there is food to be found in the tree they occupy. This weevil also attacks *Agave* and *Saccharum officinarum*, otherwise known as sugarcane (Gomez & Ferry, 1998). In the KAO3 core, there is a distinct period of time around 1332 BP where I have identified sugarcane pollen in Rano Kao. Also in my macrofossils studies, there has been chitin of various unidentified insects that may have played a part in this.

- **Habitat loss for birds.** With the arrival of man and the clearing of trees to grow food, habitat for birds was diminished. Birds may have been critical pollinators for these palm trees. Notes taken from David Steadman in his article entitled “Prehistoric Extinctions of Pacific Island Birds: Biodiversity Meets Zooarchaeology” (1995) include this quote:

On isolated Easter Island, bones from the Ahu Naunau site date from 900 to 650 BP, the fauna is different from the last 500 years, where native birds are much more common. The entire seabird fauna of Easter Island probably exceeded 30 breeding species, more than any known from any other single Polynesian island. Only one still nests on the Island itself. Deforestation of Easter Island was virtually complete along with land birds, insects and land snails by 550 years BP.

This last statement is in agreement with the last palm pollen that I found in the KAO3, which dated to 545 BP.

- **Self-destructing palm.** Perhaps the extinct palms on Easter Island are similar to the newly discovered palm species on Madagascar named *Tahina spectabilis*. The tree has a strange lifecycle in that after growing for as long as fifty years and to an immense height, the stem tip develops a giant inflorescence and bursts into branches with hundreds of tiny flowers. Each flower is capable of being pollinated and developing into fruit and drips with nectar attracting swarms of insects and birds. But the effort of the colorful display and the production of fruit is so taxing that the nutrient reserves of the palm run dry as soon as it fruits and the entire tree collapses and dies (Dransfield, 2008).

- ***Loss of soil moisture and fertility.*** In a spiral effect, with the death of trees the forest canopy opens to solar radiation. A loss of soil moisture and the inability to capture evapotranspiration in the forest canopy could then lower soil fertility with the decline in nutrients and supportive fungi. The changes could have also caused a loss of the insects necessary for many of the other species of plants as well as the palms. Irving Friedman wrote a Letter to the Editor of *Science* in 1977 about Marajo Island off the coast of the Amazon Basin, saying:

The removal of the Amazon jungle can be expected to produce extreme climatic effects, including transforming the basin into a dry savannah, where areas of rich agricultural land would likely to also be affected...

The remainder of the 2 to 5 meters of annual precipitation is derived from recycled transpired moisture. The jungle trees with their deep roots act like giant pumps taking water from the water table—often more than 2 meters below the ground surface—and transferring it into the air from which it falls again as rain (p. 7).

Rapa Nui, an island of great rainfall, barely sees any of it on the surface as it quickly dissipates into the volcanic soils, traveling underground. The depth of the root casts that Meith and Bork (2002) uncovered show deep tap roots, which in fact proves that roots seek out moisture to whatever depths are necessary. The voids that represent the ancient tap roots confirm the existence of a sub-tropical forest rather than the barren savannah that exists today.

- ***A climate cooling event.*** Another consideration is a climate cooling event. Noticed in the KAO3 core was a decline in the O^{16}/O^{18} ratio around 545 BP, which may have triggered a decline in the trees.

Palms are unique biological objects. However, these unique metabolic stem properties seemingly cannot be sustained in cold climates. As highly integrated organisms with all stem cell types physiologically active, palms cannot undergo dormancy; in this characteristic they are indeed the icons of the tropics. (Tomlinson, 2006, p. 13)

- ***Severe drought and a search for water.*** Palm trees are highly adaptable in the hydrosere. Therefore, drought is unlikely as a cause of death to the palms. As stated above, temperatures near freezing can cause death to the trees, and usually in a cooling event the natural environment becomes drier, locking moisture into the surface rather than in evaporation. Cultivated crops and humans do despair in times of drought. Lacking a source of water to grow food, or when rainfall was scarce, people may have turned to the only storage devices of clean water on the island, the trees. The lake sources are full of tannins and fungi, which may have not been potable.
- ***And then there are the rats.*** Many have speculated on the introduction of the rat, both the native Polynesian version and the Norwegian rat that followed, as being an important cause in the death of the palm trees. When the fruit is collected by humans, or falls to the ground naturally, inside is a viable seed for re-germination. In 1983, 30 endocarps were found in a cave on the cliffs of the Poike peninsula, thought to be the first area of deforestation on the island. The endocarps were dated to 820 BP ranging somewhere between 1040 to 1280 AD. All of these endocarps had marks on them accepted as gnaw marks from rats, but it was Dransfield (1984) who reported in a personal communication from A. J. Stewart:

It is probably that this species (*Rattus concolor*), the Polynesian rat, gnawed the endocarps found in the cave, although the toothmarks are

rather small to be those of rats. The same excavations produced numerous fragments of palm endocarps similar to those under discussion, suggesting that the fruits were also part of the human diet (p. 751).

Leaving 30 endocarps in a cave where they might be found by rats is not unusual, neither are fragments of broken endocarps already consumed by humans then found by rats and gnawed upon. So did the rats actually get to the endocarps first, thwarting the re-germination of new trees, or were they scavengers of refuse left by the humans. And if Stewart observed that the gnaw marks are too small for a rat, then what was it that was making marks on these leftovers? The cause of the trees' destruction is unknown.

The discovery in this research with the most impact was the loss of not only one palm species but of at least four palm types. Four palm pollen types existed throughout the 15,000 year history of the island, and they had all disappeared from the pollen record by the year 545 BP. The disappearance of the palm trees and the appearance of human evidence coincide during this time period along with a climate event that brought cooler temperatures. The exact cause of death for the palm forests is unknown. We do know when they disappeared, that they were significant and abundant, and that they coexisted within a very diverse environment that changed and adapted over time.

What is actually discovered is that the way we have been looking at nature is no longer comprehensive enough to explain all that we can observe, and we are asked to form a more inclusive view.

It is time to step out of explaining observations of the everyday world in Newtonian views, and into the understanding of quantum mechanics that predict probabilities of

phenomena. Particularly the loss of the essence of the forests, the vital life force of these breathing palms that behaved like animals. Their significance in holding this islands ecosystem together including the humans that have objectified them as cultural resources, cannot yet explain why the natural world of Rapa Nui has not yet been able to be reclaimed since the demise of the forests.

Figure 9 - A simplified sketch of the Jubaea like *Paschalococos disperta*

Jubaea chilensis forest at La Campana National Park located in the Cordillera de la Costa, Quillota Province, in the Valparaíso Region of Chile. La Campana National Park and the Vizcachas Mountains lie northwest of Santiago. This national park is home to one of the last palm forests of *Jubaea chilensis*. In 1834 Charles Darwin climbed Cerro La Campana, during The Voyage of the Beagle.

Figure 10 - Photo of palm forest, Chile

Chapter 4 Coring the Crater Lakes of Rapa Nui

4.1 Introduction

Rano Kao is a crater lake formed some 300,000 years ago on an island that stood isolated for a million years. What remains some have called a quagmire, ancient, mysterious and beautiful.

When we descended by the only possible path down the crater wall, there was not a single foot of solid flat ground to be found. Stretched out before us was a vast oozing quagmire which lay like green spinach at the bottom of a giant caldron with walls rising steeply into the sky on every side. (Heyerdahl, 1960, p. 167)

It is difficult to describe the adventure it requires to core this lake. The rim stands more than 250 meters above the lake surface and as Heyerdahl noted, there is hardly anything flat between the two. One hikes down the steep slopes, carrying all the required gear, and stumbles into an acacia forest of spiked trees that shade a fern valley. Keeping your feet secure on the ground, while not grabbing onto the spikes is a challenge. But finally through the small spit of a forest that remains on the northwest eroded slope you enter into a whole new adventure, a dense maze of *totor*a plants. The *totor*a, a sedge that stands three to four meters tall, stretches out in front of you. You feel as if you are a bug crawling through a forest of grass.

Quickly you realize that the mat viewed from the top of the mirador is a patchwork of vegetation and dark tea-colored water. The jungle of *totor*a is rooted in a mud bank intertwined with horizontal branches of the *polygonum* that formed this floating bog

thousands of years before.

Walking on water, or falling into the lake with no bottom (Heyerdahl, 1960, p. 169), is the most potent impression. Trudging into waist-deep water, slipping and sliding onto folded plants, you try to hold gear above your head, pulling and thrashing your way through until finally the ferns give a secure stiffness under foot and you arrive at a more stable surface – a bouncy carpet of vegetation. The horizon opens to a field of ferns, *totorā*, *polygonum*, *cyperus*, brown patchy masses, dried dead reeds, gold and green moss, and holes of dark water. The humidity of this plant forest clings to your skin, the smell transporting you back to a time before humans.

What is very clear as you sink into the ankle-deep water on these spongy masses is that the path that you mapped out from above is no longer visible. Pushing through the *totorā* leads to a hole that you cannot jump. Neither can you use your gear to construct a bridge for crossing. So you turn in a new direction forging until the next hole of water begs you to turn back or sideways or perhaps plunge down only to scramble back up to the oozing decomposing mat.

Finally you arrive at a suitable coring spot close to center, or so you believe. Questions you ask along the way include these: Why are those dead patches turned over and why are they dead? Could it be that ancient gas trapped in the sediment below is releasing and killing the vegetation above? Could it be the life end of that patch or a plight of insects? Could there have been settlements here on this mat long ago?

While wandering through the jungle of *totorā* on this mat of floating *polygonum*, you realize that this is in itself an ecosystem different from anything else in Rano Kao. What

is happening in the mat is like the upper canopy ecosystems of the Pacific Northwest rainforests. Sometimes insects only venture a few centimeters their whole lives; perhaps there are things in this mat that are the same. This ecosystem is isolated from the rest of the island and the winds that ravage the land do not come down to the lake surface as gusts but as gentle breezes carrying clouds that gather overhead and settle slowly into the basin.

As fast as the wind brings the clouds, the rain follows drenching the lake in a deluge. There is no shelter here; only if you can make it back to the small stand of acacia trees can you have some reprieve. Instead you become one with the water beneath your feet, drenching your clothes and pounding your head. You are now part of Rano Kao.

We found no suitable places for boring. If we put the bore in, it went straight through the turf and down into open water. Often the turf was ten or twelve feet thick and consisted of a tangled mass of dead reeds. If we sounded in the water holes, we recorded the most varying depths, and we never got down to the bottom of the crater lake, for there was always some underwater tangle in the way. ...Everything was in motion down in the witches' caldron. (Heyerdahl, 1960, p. 170)

My first coring adventure on the lake in March of 2005 was during the dry season. For this expedition, there were five of us including John Flenley, David Meek, Rob Dunbar, Yan Araki and myself. That year there was very little rain; the drought had left dry patches with easy accessibility to the 400-meter mark from the edge of the lake where we chose to core. The mat was brown and there was very little *titora* forest on the mat except for the margins of the lake where it retreats to the muddy bogs. We ended up near the center of the lake for KAO3

core and within close proximity of where Flenley cored KAO2.

During this coring adventure of 2005, KAO 3, 4, 5, and 6 were retrieved from various locations on the lake. Because of the difficulty in getting down and up the steep crater slopes, carrying a hand corer was the only option. Carrying two types of corers was also necessary because the mat required a peat bog corer similar to the Russian D-Section corer, and the lake sediment required a Livingstone corer. The maximum vertical limit of the Livingstone is 21.5 meters. We carried two meter steel rods, both helpful in crossing the smaller pools of water but also very heavy. And to keep the corer straight, a coring tube was required. Maneuvering two 9-meter sections of plastic pipe around the sections of the acacia trees seemed to be the bigger challenge.

Meter by meter, the lake sediment was retrieved until we hit 21.5 meters down and reached the limit of the equipment. Each meter came up oozing with detritus, watery or firm, smelling of decomposing plants and was set aside to await analysis upon return (*see Appendix B*).

4.2 Coring the Crater Lakes

Rano Kao is the largest of the crater lakes on the island. It is one kilometer in diameter at the lake level and nearly two kilometers at rim level. This lake has never been irrigated and is the last area where many species of trees were seen before going extinct. The environment within the crater is temperate and has a very stable microclimate that contributes greatly to plant growth. It is not affected by wind surges like Rano Raraku, but, downwind of the island, it is a good depository for airborne pollen and charcoal.

There is considerable evidence of erosion into this lake that continues today. Three hundred meters elevation at the rim and approximate 100 meters at lake level, the bowl of the crater is quite steep. More than 90% of the surface of Rano Kao is *titora* (*Scirpus californicus*) and *Polygonum* species varying from 1 to 3 meters in depth. An ecosounder was used to verify depth ranges along the way. At the time of coring, we found water depths from 9 meters to 20 meters. A GPS reading of 110 meters elevation was taken at the surface of the *titora* mat at the KAO3 borehole; it was 552 meters horizontally from the mirador, 400 meters from the north edge of the lake in the due north direction, and 350-400 meters in the west direction to the edge of lake (latitude 27.11.37 South, and longitude 109.26.40 West).

On the Chilean Hydrological and Oceanographic Map of the Armada de Chile of 1967, updated by aerial photography in 1992, the lake level reads at 104 meters. In Flenley's report (1991) he also stated the elevation of the *titora* mat at 104 meters. Our reading indicated a lake level 6 meters higher than that shown in Flenley's core taking in 1981.

In March 2005, our collaborative expedition was comprised of John Flenley and David Meek from Massey University, New Zealand; Rob Dunbar from Stanford University; Candace Gossen, and local Rapa Nui men Francisco Rapu and Yan Araki. We attempted 4 borings at Rano Kao, successfully obtaining 3 coring depths with a total of 14 meters of sediment cores from Rano Kao. The lake depths were recorded at KAO3 as 9 meters of water. At KAO4 there was 14 meters of water, at KAO5 the water depth was beyond our 19 meters of rods, and at KAO6 there was 14 meters of water. On a side note, a Rapa Nui man who worked at Rano Kao for 17 years swore that the lake had never had more than 5 meters of water. Flenley reported 8 meters of water in the 1980s, and now we had two indicators that the water depth had increased by 6 meters, measured both in the increased

elevation reading from the *titora* mat at 110 meters, and in the depth of sediment in the coring attempts at 14 meters of water. It is unknown whether there is ground source water input into the lake.

4.2.1 KAO3 Core

In March 2005, our collaborative expedition began the first of four cores, KAO3, located 400 meters from the north edge of the lake, near to the center of the lake. This core began with 2 meters of floating mat on the surface then 12.5 meters of water before reaching the top of the sediment. Nine meters of detritus and lake mud was obtained before the Livingstone corer reached its limit. The range of dates for this core was 1000 BP to 15,000 BP. The mat dated from modern age at the top to 1000BP at the bottom of the mat.

The first day of coring at Rano Kao, the team consisted of Rob Dunbar, Yan Araki, John Flenley, David Meek and Candace Gossen. Flenley and Meek were available to core. John Flenley had cored the same lake 25 years earlier, and I was very interested in his expertise and the opportunity to compare his earlier findings with what we would discover now.

The objective for the first coring site was to come somewhere between KAO1 and KAO2, the two boreholes that Flenley had obtained in the 1980s thereby giving a better profile of the bottom of the lake. Also we wanted to be out of the vicinity of where the Japanese team had cored just days before. We walked approximately 400 meters from the south and east towards the center of the lake. We found a patch of newly growing vegetation and a water depth of approximately 9 meters.

Using a D-Section corer, we cored the first 3 meters of the floating mat. These were obtained in 1-meter sections and placed into the channel tubes that Flenley brought with him. The mat was not difficult to core and presented a dense fibrous material with sediment mixed in.

Once the D-Section hit the water beneath, we inserted a 110mm x 12m long PVC pipe for stability with the corer. We switched to the Livingstone corer, and at about 9.5 to 10 meters of water depth we begin to hit sediment. Because the sediment was too fine to stay in the piston corer, we came up with nothing until the 12.5-13.5 meter section, which was soupy with a large organic plug of *totora* with roots at the end of 13.5 meters. Again the next meter was soupy and mostly water with a *totora* plug at the bottom of 14.5 meters. At 14.5-15.5 meters the fibrous cores became more consistent. 15.5-16.5 meters had good consistency, watery on top but still not full 40mm rounded cores. 16.5-19.5 meters were well formed, consistent, mixed fibrous and detritus. At the depth of 19.5-20.5 meters, we had a natural separation angle at about 20 meters that showed the incline of the lake to be approximately a 12-degree angle.

We were limited to 20 meters of rods, for a total length with corer of 21.5 meters. It was this last meter that showed very fine layering, which we thought might be clay but turned out to be pollen and algae layers at about 21 meters. We were very happy to have found a full core down to this layer which might provide material for dating.

The cores contained mostly dense to medium detritus. Some had mild to moderate smells and were mostly watery at the top few meters. The Livingstone corer was very important in this extraction for if it had not been for the piston creating a nice seal, we would have lost many meters of sediment.

4.2.2 KAO4 Core

The second day of coring at Rano Kao, the team included Yan Araki, Francisco Rapu, and Gossen. The objective of KAO4 was to find a continuous sediment core, one that was not broken between the floating mat and the sediment beneath. We walked down the approach from the northwest and headed south. The *totorā* around the perimeter of the lake was 7-8 feet in height. By poking with the rods, we were able to find floating mat almost to the edge of the lake. We attempted one core about 75 meters from the edge of the lake where we expected continuous sediment, but at 3 meters hit water that continued to 14 meters. We moved and attempted a second spot approximately 100 meters from a small patch of sugarcane growing on the side of the crater wall on the west side of the lake. The mat where we cored was one of the anomalous patches of dead *totorā*, cause unknown. We began coring KAO4, reaching sediment after 14 meters of water. The first meter of sediment was the consistency of grey-green clay with some organic material mixed in. It had no laminations and no smell. At 60 centimeters, the core fractured, making it difficult to go deeper. We gave it a second attempt and at the 15-16 meter level we pulled up 15cm of brown to light grey fibrous and grey clay with volcanic rock at the end indicating that we were at basalt rock and unable to go further.

4.2.3 KAO5 Core

For KAO5, we attempted to walk from the KAO4 borehole to a site near the center of the lake, but a large water hole prevented our going forward. One difficulty in coring this lake is that from the crater rim you can see how all of the floating mats fit together and thereby plan your movement, but once in the *totorā* the pathway is obscured. Maneuvering across the patches sometimes required using the rods as a bridge between

the mats. Often we plunged in through the mat to our knees or waist.

We traveled around the mat to a location more northeast and decided to core next to an open area of water. The ecosounder at this area showed 14 meters of water. Over the full 20 meters of rods, we were not able to bring up any recoverable sediment, and finally we determined that the water depth was greater than 14 meters. What did come up was too fine for the piston corer to keep. KAO5 has no sediment cores.

4.2.4 KAO6 Core

From KAO5, we traveled north to about 200 to 250 meters from the north side of the lake. At this borehole we reached 16 meters of water. The first sediment we obtained was 17-18 meters in depth. The color of the fibrous, coarse detritus was a deep chocolate brown with a reddish hue from the *totorá* roots. The sediment expanded when released from the chamber due to gases in the sediment. The core had noticeable fibers and was not totally consolidated; the last 5cm was round but not firm. There was no smell. At 18-19 meters the color became darker chocolate brown with the top 20cm alternating from firm to watery; the bottom 5cm was firm. At 19-20 meters the color was chocolate with grey-yellow material mixed in at the end of 20 meters. This core was consolidated well.

At this depth it was difficult to keep the corer from bouncing back out of the hole. When we did get it to stick at the depth we wanted, we noticed a buzzing sound coming out of the rods. It appeared that there was gas being released from our corer up through the rods. There was no smell and no attempt was made to ignite the gas. At 20 meters, we could not go further; the resistance in the hole was too great.

This was the last attempted boring on Rano Kao. We had obtained a total of 14 meters

from 3 boreholes in the lake, all of which were at varying levels and each had its own independent features as noted above. (See Appendix B for photographs and Appendix K for ICD core sheets.)

4.2.5 Rano Raraku - RKU05 Core

Rano Raraku is an asymmetrical volcanic crater lake of complex geological origin. It is famous for the moai sculptures that face the south and southeast rims of the cliff tuff that forms the crater rims. Both the inner and outer walls were quarried which left behind much lithic debris that has been washed into the lake. The asymmetry of the lake suggests a large amount of filling-in of the quarry walls with this same debris that continues to wash into the lake with soil erosion.

The first day of coring at Rano Raraku included Flenley, Meek and Gossen. Meek had constructed a small platform in the lake at Rano Raraku and we were able to get to the platform via a 2-person inflatable boat. The platform was moved to the center of the lake, tied off from the available *titora*, and anchored in the 3 meters of water.

We began coring in the middle of the day, and as always the winds, which were mainly calm on the lake in the morning hours, were strong in the afternoon. For most of the coring time, we were challenged with a “drifting platform” due to the strong wind gusts. Consequently the cord that I brought was not truly static but stretched.

Using a Russian D-Section corer, we were able to obtain 5 meters of core at the center of lake. The total water depth at the center of the lake was 10.7 feet noted with the scuba ecosounder and 3.1 meters with tape measure. The ecosounder also located an underwater

horizontal distance of 226 feet (68.9 meters) from the south bank of *totor*a as well as 160 feet (48.8 meters) to the east *totor*a edge.

The D-Section corer worked well with the densely fibrous sediment as it was able to cut and turn into the sections at each meter. It was also very easy to push into the sediment by hand and was able to penetrate a meter at a time as rods were added. The sediments were mostly fibrous and had very little decomposition. The half-meter sections were very watery and some fine sediment was lost through the equipment.

The core dimension was 40mm halves, and we placed them into the PVC halves that were brought from the Limnological Research Center (LRC). A sheet of heavy plastic wrap was placed first into the PVC and then the core wrapped well for transport back to the van. Once the 5 meters were obtained, we pulled ourselves back to the *totor*a and back to the edge of the lake, deconstructed the platform, and carried everything out over the quarry's rim.

Upon initial inspection the cores were reddish brown in color, showing the heavy roots and fibers of the *totor*a reeds. The cores were densely fibrous and not very cohesive. They contained by weight at least 50% water, which later in the lab at the LRC was mostly evaporated. The cores varied in consistency as the tops of the cores were wetter than the bottoms due to the effects of the coring device. We called this core RKU1.

4.3 Rano Kao Expedition 2008 - RKE08 Core

After core analysis was begun on KAO3, the radiocarbon dating showed that the top of the sediment core dated to 1000 BP. We expected that the mat would contain the last

1000 years—a period of human impact and the disappearance of all trees. The 3-meter mat collected above the KAO3 core had been radiocarbon dated with three reliable dates along with correlated pollen and isotope samples. But the core was small in diameter and each sample took up the entire section of core. In order to conduct further analysis for the last 1000 years, more mat cores were needed.

A new expedition was conducted including Ki Istre from Seattle, Washington; Rosanne Hawarden, from Christchurch, New Zealand; Michael Osborne from Stanford, California, and Candace Gossen.

We began by surveying the lake and taking water samples in preparation for our first day of coring. From the rim to the lake surface, it was 250 meters through the acacia and avocado trees on a steep incline of some 60 degrees. At the lake surface, the *totorá* was over 4 meters tall. On the day of coring we walked for about twenty meters on matted roots of *polygonum* and through the stands of *totorá* arriving onto a hardened mat surface of ferns. Within another ten meters we passed three trees that had firmly rooted themselves about 30 meters from the lake edge in the in-washed sediment and water. Two were unidentified, and a third was *Sapindus saponaria*. We proceeded through the *totorá*, towards the center of the lake taking waypoints and depth readings whenever we could

The ferns were much more abundant than we saw in the very dry mat three years before. We obtained 5 waypoints noted on the GPS, and took depth readings with a sonar depth reader (fish finder) that also told air and water temperature. We stopped for the water samples at Waypoint 5 near a 12-meter hole in the mat (*see Figure 13*).

The water sampler allowed for samples at varying vertical depths. The chemical analysis

was conducted partially while at the lake and then completed back at camp. Here are field notes from those results:

Waypoint Information:

Stop 1 27.18218 S lat., 109.43793 W long. NE edge of Lake. *Totora* is very tall at over three meters and it is thick and triangulated. Culms are on top but are not sure of maturity of seed within. In November, the culms are too young with immature seeds. We will find out at camp what these contain. (*Mature seeds were found in abundance). Walking through acacia, fern and avocado trees. Lots of ants on the trees that climb onto you instantly but don't seem to bite. But the thorns on the trees coming were down like daggers of up to one inch long. Mosquito fish were abundant in the lake, many on the edges that were minnow-size of five centimeters long. The slopes in the forest had many ferns and long grasses that draped over the side like hair. A few snail shells were found along with obsidian pieces on the paths.

Stop 2 27.18253 S lat., 109.43795 W long. Approximately thirty meters from the NE edge of the lake. From the edge of the lake approximately thirty meters to the south of the entry point from path. Tall *totora* on the lake edge measuring four meters tall and thick triangulation of five to six centimeters. Deep water, more than a meter to the top of the root surface is noted until the mat surface about 20 meters out. Distinctly different from the edge of the lake, which had *polygonum* and other plants to be identified growing in the shallow waters. This is approximately where the three trees are growing.

Stop 3 27.18343 S lat., 109.43866 W long. First open water probe. Water Temp: 25C; Depth: 5.2 m (sonar); Rope: 7m (weight rope); Black clear water with no smell. *Polygonum* is taking over a dead patch on the mat surface.

Stop 4 27.18432 S lat., 109.43815 W long. Water Temp: 25C; Water Depth: 1.5m; Rope: 1.5m; Black clear water with a smell of sulfur and strong odor. It seems some of the water pools that we saw from above are really shallow water collecting on top of the mat from the very wet winter. Therefore the 1.5 meters of water we are measuring is the rainfall for the winter that has collected on top of the floating mat. Collected sample here of dead matter from mat surface.

Stop 4b 27.18437 S lat., 109.43812 W long. Water Temp: 25.5C; Water Depth: 7.9m; Rope: 8.2m; Black clear water with no smell.

Stop 5 27.18465 S lat., 109.43820 W long., Water Temp: 25C; Water Depth: 12.2m; Rope: 12.4m try one, 12.4 try two, 13.2 try three (rope tends to slide down slope which may add additional length as we discovered the mats have shallow shelves as they slowly decompose into the water).

Water Quality Testing: Location: Stop 5 27.18465 S lat., 109.43820 long.

LOCATION	DEPTH	WATER TEMP	PH	NITRATE	PHOSPHATE	DO	TURBIDITY	BOD (5DAYS)
Surface	surface	26C	6.0 good	<5ppm excellent	0.5ppm (excellent)	3ppm (26C/4ppm = 49% poor)	0JTU	3ppm (excellent) dO=0C
Mid	6m	24.5C	6.0 good	<5ppm good	0.5ppm (excellent)	4ppm (24.5C/4ppm = 48% poor)	0JTU	2ppm (excellent) dO=2C
Bottom	12.2m	23.5C	6.0 good	<5ppm good	0.5ppm (excellent)	4ppm (23.5C/4ppm = 47% poor)	0JTU	1ppm (excellent) dO=2.5C

* No fecal coliform test conducted, as did not want to contaminate water or island with foreign bacteria to test.

Water tests were collected on site in water sampler and then placed into three different-colored nalgene lexan bottles for further testing that was conducted within 2 hours of retrieval.

Testing procedures:

1. pH tested with dissolved tabs
2. Phosphates tested with dissolved tabs
3. Dissolved oxygen tested with dissolved tabs
4. BOD water in tube, wrapped in alum foil for 5 days, then tested the same as for dissolved oxygen with dissolved tabs
5. Nitrates tested with dissolved tabs
6. Temperature in field measured with fish finder in collection tube (1.5 liter)
7. When all tests were completed, remaining water was poured into white container with turbidity secchi disk.

Weather and Climate Information: When we got to the island in March 2008, we discovered that there had been a drought for the past five months resulting in noticeable consequences for the trees and plants; insects were devouring the leaf matter in the trees at the top of the rim and in town in search of fluids. In the water in Rano Kao, however, I saw no insects such as I had seen on the trees in the town. In contrast, the winter previous to this drought was reported to have been exceptionally wet, which accounted for the small pools of water one and a half meters thick on the floating mat of the lake. I realized that these were not open water holes between the mats, but collected water on the top. The captured water allowed the *totorā* to flourish and covered the entire lake surface. What had been an open middle in 2005 was now covered with thick ferns and *totorā* growing to the middle of the lake. We found new rhizomes of *totorā* that were

just branching outward with their typical two-finger thickness and running seven to ten stems per rhizome ranging from tall to new emergent. The rhizomes were about 20cm below the surface in a wet brown mossy-like matter, a perfect peat. On the edges of the lake, the *totor*a was taller than previously seen, and while the *polygonum* grew vertical at the edges, it was also spreading horizontal into the open pools with its suspended roots reaching into the open water. The polygonum was taking advantage of the dying patches by invading and using the nutrients while expanding its thick roots outward and interlocking to branch across the lake forming the mat. Seeing this process provided more understanding into the first formation of the floating mat when the polygonum arrived some 3500 years ago.

Core 1 27.18442 S lat., 109.43832 W. long Water Depth: 12m; Located 200 meters from edge of lake. Length: 2.5 m

The objective for this core was to start off in the direction of the water sample from Stop 5 but focusing more inward to the center of the lake. The *totor*a was tall, the water high, and we stopped at core spot 1 that was firm on a bed of ferns in a *totor*a patch. We began taking 50cm sections, and ended with a total length of 4 meters. This was unexpected as the KAO3 mat core had only 2 meters and Flenley's mat cores were also 2 meters.

This mat core was fibrous and 2 meters long with few gaps. I archived the cores, scanned for magnetic susceptibility, and described the sections. As noted in the smear slides for this core there was charcoal in all of the sections, as well as what appears to be tephra, and glass particles in the bottom section at meter four.

Cores 2 and 3 27.18365 S lat., 109.43653 W long. Elevation: 110m; Water Depth: 12.2 m (12.7 with rope); Water Temp: 23.0C

Heading east from our previous starting point, we stopped near a large water hole with 12.7 meters of water but were unable to obtain consistent cores. *Polygonum* was growing on the edges of the hole with ferns. Inside it was dark brown moss. We took core 2 and moved a little farther away for core 3.

Core 4 27.18403 S lat., 109.43675 W long. Elevation: 108.5m; Depth: 12.2m; Water Temp: 23.0C

Moving towards the center of the lake, we secured a full core that continued down to 3.5 meters. The following 50 centimeters was mostly water.

The water in the lake showed a distinct thermocline. It was very warm at the top but dropped significantly after only a meter. We attempted to get a vertical profile of the mat and realized that the mats sink on the edges and provide a shallow ledge as they fold into the lake.

Nearby we noted an ancient pile of obsidian containing large primary and secondary flakes. This site was located on a dead brown patch, not the grey dried up vegetation that we commonly noted as chemical death. Before we departed, Alejandro told us this lake is called the Lago de Antigua, the ancient lake of Agua Dulce, sweet water.

4.4 Testing, Methods, and Findings KAO3

The core KAO3 showed a chronology dating back 15,000 years. The core consisted of 2

meters of floating mat over a column of 10.5 meters of water with 9 meters of sediment below. The analysis that followed the coring successfully reconstructed the ecology of the lake that includes pre-Holocene and inter-glacial climate information. Detailed below is the scientific analysis that followed once the cores arrived at the Limnological Research Center (LRC) in Minneapolis, Minnesota.

At the LRC laboratory, the cores were archived and logged. They were then photographed and scanned in whole meter sections. Smear slides and Initial Core Description (ICD) offered initial observations before the cores were sampled. Sub-sampling then followed at 10cm intervals to process for pollen and isotope analysis. A basal date from the bottom of the core was processed in order to get an idea of age. This information came back with a basal calibrated date of 15,000 years BP. Following below are the initial tests and results that were conducted on the KAO3 core at the LRC:

4.4.1 Magnetic Susceptibility

The Limnological Research Center Core Facility is an open laboratory operating with funds from the National Science Foundation and the University of Minnesota. The mission of the Core Facility is to provide expertise, equipment, and instrumentation in support for the collection and study of lake sediment cores. It serves the University, North American, and international communities.

In 2004, with NSF funding, the LRC acquired a new Geotek Multi-Sensor Core Logger (MSCL), with capabilities for logging and imaging both whole and split cores, and a Geotek XYZ core logger, which automates the measurement of high-resolution magnetic susceptibility by point-sensor, color analysis by spectrophotometry, and detection of

natural gamma emissions.

Analyses completed on the KAO3 Core April 19-22, 2005:

- Whole-core multi-sensor logging
- Core splitting into working and archive halves
- Core surface preparation
- Digital whole-core imaging
- ICD sheet production
- Split core multi-sensor logging
- Macroscopic sediment description
- Microscopic sediment description (smear slides and coarse fractions)
- Cold storage in D-tubes
- Data archiving and curation

4.4.2 Whole Core Low Resolution KAO3

Whole-core logging on the Geotek Multisensor Core Logger (MSCL) track was the first step in analyzing the cores and developing the ICD. Unwrapped cores extruded into PVC tubes in the field were placed into the whole-core logger. Each meter section was scanned and constructed into contiguous low-resolution charts to show the results of the whole core (*see Figure 18*). Analysis and results of these types of scans are conducted before dating is performed on the sediments. The information received as a result can be helpful in targeting specific events that may be visible in the layers of the core, once opened, or targets to date in the future.

These scans help the researcher detect mineral matter that generally comes into a lake

through erosion, in wash, or by air. These are generally indicative of human impact, drought, and volcanic activity. The key when considering the charts is to look for the intensity (amplitude) of the spike, how abrupt it is, and how long it lasts. For KAO3 the low-resolution magnetic susceptibility scans found down-core mineral peaks that are linked to periods of deforestation and the subsequent erosion of mineral soils. The variations in the amplitude in the record were used as a proxy indicator of the intensity of erosion.

The KAO3 core shows an abrupt spike around 14 meters (1.5 meter core depth) with intensity but not much matter and covering a short time period. Applying dates to these results show that this event occurred around 1340 BP with a margin of error in the dating of 35 years. It is the largest spike in the core. The narrow band of the spike indicates that the event was of short duration. Forty centimeters below this event is another from the same period with no signs of mineral activity. Given that the core was taken very near the center of the lake, and the mineral content does not show a large event of erosion, this mineral is indicative of airborne input.

There are four more spikes near the 20.5-meter depth (8-9 meter core depth). These spikes have dates ranging from about 9320 BP to 11,030 BP showing major climate changes both in temperature and volcanic activity. At 9320 BP, the spikes show the highest oxygen isotope evaporation in the sample which correlates with high evaporation and high heat; it indicates one of the hottest events that occurred on this island in the whole history of the 15,000-year-old KAO3 core.

In comparison, the KAO4 chart shows a large in-wash of mineral over a long period of time. The chart has a broad rounded profile rather than a sharp abrupt spike. This KAO4

core was taken 75 meters from the west edge of the lake and below Orongo. The core upon retrieval was very different than KAO3, which was taken at the center of the lake. KAO4 is greenish in color, solidified like clay with large rock particles within.

4.4.3 Split Core High Resolution KAO3

Once the descriptions and smear slides were made, the core was split into halves, rewrapped and placed on the Geotek XYZ core scanner. This scanner is used primarily for measurement of high-resolution point-sensor magnetic susceptibility on split cores. The automated track of the high-resolution scanner features sensors that non-destructively measure sediment density, acoustic wave velocity, electrical resistivity, and loop-sensor magnetic susceptibility at any resolution. In these scans high susceptibility events were noted in greater detail as the intervals were set very close, at 0.5mm settings. The radiocarbon dating that followed was based on the obvious peaks that were noted in these scans (*see Figure 18*).

The high-resolution scanner is slow relative to the low-resolution scanner (~2.5 hours per 1.5 m section), but the XYZ can be loaded with up to nine core sections at a time and left to run unattended, even overnight. When each section finishes, it can be replaced with another section for non-stop continuous logging. Typically the archived half of the core is placed on the XYZ, and the working half is imaged and then placed in a core cradle for visual description.

Sediment description begins without the attempt to identify the environment that created the sediments. The detailed description of the lake basin comes from basic sense perceptions of color, smell, feel, consistency, and observation of layers of geological

types and sediment load between time periods. Lake sediments are highly variable from basin to basin and over time within a basin, so the level of descriptive detail is dictated by the nature of the sediments themselves.

With the cores obtained from Rapa Nui, there were certain noted differences, which altered the settings of the XYZ scanner. The Raraku cores once split only covered the area of 1/4 to 1/2 of the pick tube. They were mostly coarse fibrous matter and had lost most of their water content. We “levelize” the cores using “elephant gut,” a grey rounded stuffing material inserted to the center of the tube, and sometimes using only one wrap of plastic to make sure the scanner was able to get to the appropriate depth. Scanning this type of core was difficult because of the small amount of matter. The laser would often pick up the metal structural beam beneath the core and register a negative number in the graphs.

KAO4 was also different from the other samples in that it consisted of grey-green clays with volcanic rock, which had very high magnetic feedback, and the scanner had to be adjusted accordingly. These two meters of core were run alone while KAO3 and KAO6, which were very similar, were run as a batch. Once the XYZ was finished, each section of core was replaced in its D-tube and stored in the cooler. Over the course of three days, we spent about 8 hours of lab time per day analyzing the 19 meters of core. The cores are permanently archived at the repository at the LRC.

The results from the XYZ scan of KAO3 were similar to what was found in the low-resolution scans but with greater detail. Where there were small rises in the low-resolution scan, one can look at the high-resolution scan and see there is great variation in that same area. A contiguous chart for each core is found at the end of this chapter, while

the charts for each meter of KAO3 are found in Appendix M.

4.4.4 Digital Linescan Camera Imaging

As one-half of each core was put into the XYZ scanner, the other halves were photographed by a Digital Linescan Camera. There are two cameras used at the LRC. One is the DMT CoreScan Colour, a digital linescan camera with a resolution of ten pixels per millimeter. This camera has an orthogonal polarizing filter over the light source and lens for even light filtering. The second is a Geotek Corescan-V, a digital linescan camera with a resolution of twenty pixels per millimeter also using an orthogonal polarizing filter over the light source and lens.

The digital line scanner produces a 50 MB single image per one half-meter core section at a resolution of ten pixels per millimeter (~300 dpi). Polarizers on the light source and the camera lens completely eliminate glare from the core and allow fine details to be seen. A color card in each file allows for color correction after the fact, and the D-tube end cap help in identifying the core. 10 pixels/mm is sufficient for almost all cores; however, in special cases such as microlaminated cores, another camera, mounted on the Geotek MSCL track, collects images at a resolution of 20 pixels/mm. In the case of the Rapa Nui cores, the 10 pixels/mm was sufficient.

Once the cores were scanned and photographed, a semi-automated production of ICD sheets (also called “barrel sheets”) were created to facilitate sediment description. Logger data (typically magnetic susceptibility) and the core image are placed on an electronic standard core description sheet that is printed within minutes of the completion of the digital scan. The core descriptions and notes made on this sheet can then refer to the

logger and image data, and point to, rather than simply describe, particular features.

The cores were moved to a description area whereupon core description was noted by hand on the printed sheets for each meter of core. Characteristics included in the description were depth, description of texture, color, smell, laminations, wet-dry, elasticity, humification, and noted changes or points of interest.

Random and specific smear slides were made at various intervals of each core. A total of 100 slides for the 19 meters of core were created. Smear slides taken at regular intervals and in anomalous layers are used to identify minerals and organic components that make up the sediment, to make an initial estimate of relative abundance of each sedimentary component, and to estimate grain size distribution. Smear slide compositional information is combined with macroscopic structural description to classify and name sedimentary units (Schnurrenberger et al., 2003). The practice of naming sediments in a way that includes compositional information and according to uniform guidelines enables comparison of sediment descriptions between researchers and provides information supplementary to the core image that can be made available through the LRC Vault database.

Random and quick viewing of the smear slides from Rano Kao showed no diatoms. While disappointing, this was considered to be related to the anoxic and anaerobic conditions of the lake as well as the lack of sunlight penetrating beyond the top foot of lake surface onto the secchi disk. Flenley had noted similar findings in his written descriptions of his core findings in the 1980s, although Dumont (1998) found both diatoms and ostracoda at Rano Raraku in the top layers of his cores. These two lakes are very different in their structure, their water quality, and the very important fact that Rano

Kao is mostly covered by a floating vegetation mat, whereas Rano Raraku is an open, shallow lake with vegetation at the margins.

4.4.5 Sampling and Sub-sampling of the cores

KAO3 was selected as the core to analyze for this research project. Once the imaging and core scanning was complete, one half of the split core was placed into D-tubes and archived. The other half of the 9 meters became the working half in which to sub-sample for pollen, isotope, radiocarbon dating, diatoms, macrofossils, and for use in other scientific tests to determine total viability of the core. Ninety-five cubic centimeter samples were taken at 10cm intervals and split to form two matching sets of 2.5cm samples.

One set of these samples was sent to Brent Wolfe at Wilfred Laurier University for carbon/nitrogen ratio and isotope analysis. These fibrous samples would be the first experiment using this method on a tropical South Pacific island. These samples were mostly composed of cellulose from the aquatic plants that grow and thrive in the lake Rano Kao. Meanwhile I began processing the other set of 95 samples for pollen, macrofossil, and ecological assessment at Massey University with John Flenley and later completed the analysis at the University of Minnesota with Ed Cushing.

The results of the sampling of the core KAO3 are discussed in the following chapters on radiocarbon dating, climate analysis, and plant ecology, respectively. The findings have established a connection between rainfall and the changes in the lake water levels, as well as the plants that thrived in this ecosystem. Climate change, particularly drought, plant adaptation, and impact by humans, will also be discussed in the upcoming chapters.

(courtesy of Digital Globe/Google Earth)

Figure 11 - Satellite image of Rano Kao 2006

Figure 12 - Map of Rano Kao with topographic elevation and ocean depth (meters)

Figure 13 - Boreholes March 2005, Rano Kao, Rapa Nui

Figure 14 - Sketch of Rano Kao with 2005 coring locations

Figure 15 - Stratigraphic sketch of the core KAO3 with C14 RC dates

Figure 16a - KAO3 core photographs with Magnetic Susceptibility graphs (1L-3L)

Figure 16b - KAO3 core photographs with Magnetic Susceptibility graphs (4L-6L)

Figure 16c - KAO3 core photographs with Magnetic Susceptibility graphs (7L-9L)

Rano Kao KAO3 cores

March 2005

red indicates dry event, blue indicates wet

Lake sediment cores were hand-extracted using a Livingstone D-Section Corer

Top surface of lake is a floating 2 meter mat of totora and polygonum

with 12.5 meters of water beneath

9 meters of sediment were collected which them maxed out the Livingstone at 21.5 meters

All cores are archived and stored in the repository at the LacCore/Limnological Research Center, Minneapolis, Minnesota

Figure 17 - KAO3 core photos with RC dates

Figure 18 - Low resolution chart with RC dates

Figure 19 - Rano Kao lake profile sketch

Figure 20 - Lake profile KAO3 and KAO6

Figure 21 - Sediment profile sketch

Chapter 5 Radiocarbon Dating and the Stratigraphy of Rano Kao

5.1 The Heated Debate of Radiocarbon Dating on Easter Island

There have been heated debates as to the validity of radiocarbon dating on Easter Island, and especially between archaeologists and paleoecologists. All hope to find a linear chronology along the vertical column of whatever they are digging into. Contamination, erosion, animals, plants, and humans have all changed the landscape of the island over time. Often in radiocarbon dating there are inversions of dates where older organic matter has been turned over on top of younger material creating problems for determining a reliable chronology of events. Finding a method of dating organic matter is generally agreed upon, but where and how one retrieves this organic matter is the general difference among the sciences.

On Easter Island, the consensus between archaeologists is to radiocarbon date organic matter such as bone and wood that have a clear association with human use and agriculture. Their main questions attempt to bring light what humans were doing on the island. In a different direction geologists and paleoecologists attempt to reconstruct a natural history of long term events also using radiocarbon dating of organic matter. Their focus is generally on finding the differences between natural vegetation changes and those that look like human interference and often times the initial evidence of human arrival through the introduction of new vegetation species and extinction of others. The debates are sometimes heated between the sciences especially concerning initial arrival of humans to Easter Island.

Current argument regarding the island is between Hunt and Lipo on one side and Flenley,

Butler, and Bahn on the other. In “Respect versus contempt for evidence: Reply to Hunt and Lipo” printed in the *Rapa Nui Journal* October 2007, Flenley stated:

Hunt and Lipo have criticized the work on core KAO2 from Rano Kau, Rapa Nui, in various ways. They point especially to the anomalous dates obtained from pollen extracts (Butler et al. 2004). These were indeed inexplicable until we discovered that the preparation technique for the samples included the strong possibility of contamination with old carbon (Prior et al. in prep.) These results are therefore now irrelevant. (p. 99)

Hunt and Lipo in 2007 also criticized Flenley’s bulk sediment dates claiming that they were contaminated by in-washed sediments containing older carbon, or by plant roots growing beyond their horizon and into younger or older deposited material. Recently Flenley (2008) has reworked the dates on the KAO2 core and released new information that provides a more linear chronology. The key element in this debate is that once this argument was engaged, it created doubt by focusing purely on the faults of the science rather than the wealth of evidence that Flenley uncovered.

A new chronology created by the core KAO3 expands upon Flenley’s previous work in a methodical, exhaustive manner; see the new radiocarbon dated chronology for KAO3 in figure 22 at the end of this chapter. The radiocarbon results of KAO3 were printed in the *Rapa Nui Journal* in October 2007 (*see Appendix G*). These results present a reliable chronology used for both the climate data and ecological discoveries from KAO3.

Referencing the origins of radiocarbon dating on Easter Island, William Ayres (1971)

wrote of Heyerdahl's expedition in 1956 as being the first major attempt to examine systematically the archaeological remains of the island. The results of their excavations of a variety of sites and 18 radiocarbon dates from archaeological contexts were published in Smith (1961b: 393-6).

Following this expedition, William Mulloy in 1962 added more knowledge of the structure and chronology of the *ahus*, and to this knowledge Ayres (1971) added six more radiocarbon dates to further explain these structures: "Six additional radiocarbon dates are now available to assist in outlining the prehistory of Easter Island. The samples submitted to Gakushuin University were collected by the author during field work on Easter Island in 1968 under the direction of William Mulloy" (p. 497). After collecting the six samples, Ayres made these comments: "An analysis of the true age and significance of these dates in relation to their context is necessary....Conversion of radiocarbon age from radiocarbon years before present (1950) to calendrical years is no longer thought to be a simple one-to-one ratio because of the long-term variation in C¹⁴ level" (p. 498).

Ayres presented his results in "true age" according to Stuiver and Suess (1966), who claimed that a radiocarbon date might correspond to more than one true age. Therefore it should have a time range rather than a discrete date. Continuing, Ayres then applied the suggestions of Polach and Golson (1966) that a standard deviation be equal to 100 years in order to offer a more realistic range rather than an absolute date allowing for small errors that occur in the organic dating procedures.

There are two important findings of Ayres' work. The first is his radiocarbon dating of a set of ruins on the eastern shore of Easter Island known as Tahai 1. The resulting

dates of the ruins ranged from AD 560-820. His findings support those of Smith, from the Norwegian expedition in 1956, who dated the structure as AD 400. “The proposed settlement date of ca A.D. 400 still seems reasonable in light of this new information since Tahai I was a large, complex structure at the early date shown by radiocarbon analysis” (p. 502). The second significant statement of Ayres was in his writings distinguishing three culture periods on Easter Island. The first called the Early Period occurred with unknown human arrival up to AD 1100. This period is characterized by the orientation of stone platforms, or *ahus*, to solar events (Mulloy and Smith both made similar statements (Heyerdahl, 1965). Tahai I is also oriented to the winter solstice. Following the Early period was a Middle Period characterized by the raising of the statues on the *ahus* between AD 1100 and 1310, and the last was a Late Period following AD 1310.

Ayres work is significant to this research because it supports an established human presence on the island by archaeological settlement around the same time period that pollen changes are noted in the paleoecology of Rano Kao found through KAO3. The distinct human time periods that Ayres establishes also support a time frame for the disappearance of the palm trees.

5.2 Scirpus Seeds – A New Linear Chronology

One of the goals of this research was to establish a new linear chronology based on error free radiocarbon dating of similar organic matter. Due to the complications that Flenley had with bulk sediment dating and erosion causing inversions in the dates, I searched for viable seeds that were plentiful, of the same plant, and not likely to drift in the sediments with gravity, or branch like roots. The *scirpus* seeds were found throughout the nine

meters of core, were strong and intact within the sediment, and offered enough carbon with minimum error in the dating process. Therefore for this research *scirpus* seeds established a new chronology with accurate results and a viable history upon which to date the remaining tests.

In order to retrieve the seeds from the nine meters of core, sampling was necessary. Once the cores were archived, scanned, photographed, and identified, one half of the split cores went into deep freeze archive. The other half became the working material for analysis beginning with radiocarbon dating. Sampling every 10 cm, seeds were chosen at equal distance intervals as well as at suspicious or curious spots in the core. Working at Lawrence Livermore Laboratories using the Accelerated Mass Spectrometry (AMS) equipment, I could obtain a reliable radiocarbon date with as little as two *scirpus* seeds per sample.

Even before the first radiocarbon date returned, the significant finding of the *scirpus* seeds established that the plant did in fact live and thrive on the island over the last 15,000 years. Although they were thought by Thor Heyerdahl to have been introduced to the island by humans, my core gave evidence that the *scirpus* existed long before humans arrived. However, the seed structure changed in small but significant details approximately 2,000 years ago. Further evidence to support these findings came from the DNA tests conducted on the living plants collected in 2008 that show the Rano Kao species similar to the coastal Peruvian type, whereas the Rano Raraku species is more likened to what is known as *Scirpus californicus*. More details on this matter can be found in Chapter 7. The seeds changed in size and shape around the top of the third meter of core, which dates to 1581 BP. Appendix B offers a photographic record of each core section that includes a photograph of each *scirpus* seed that was used for radiocarbon dating of KAO3.

The *scirpus* was the key to obtaining proper radiocarbon dates. It is also the same plant that holds clues to the cellulose isotope analysis conducted on this core for climate change discussed in Chapter 6. The radiocarbon dates were eventually secured with the basal date of the core at C¹⁴ 12,900 BP and a top-of-core date at 1000 BP. Additionally the floating mat was dated at C¹⁴ 600BP at the bottom and the top at modern age.

5.3 Dating of KAO3 Core

The first radiocarbon date processed on the KAO3 core was at the Rafter Radiocarbon Laboratory in Wellington, New Zealand. The sample was taken above an algal layer at 8.5 meters into a 9-meter core. The date in the core arrived at a C¹⁴ 11,017 plus or minus 45 years with a calibrated date of a sigma two interval ranging from 12,868 to 13,058 BP. This was the oldest date found for the Rano Kao cores including Flenley's KAO1 and KAO2 cores. The placement of this sample was selected because the layering in the bottom half of the ninth meter resembled clay with a dark humus layer above. This condition in most coring stratigraphy would likely mark a place to find the oldest living date settled upon inorganic matter. But it was discovered later that these yellowish-colored layers were pollen, not clay, ending at the bottom of the core with gyttja, a muck of algal matter. The bottom of the core was later dated at Lawrence Livermore National Laboratories (LLNL) by *scirpus* seeds at 12,930 BP with calibrated dates ranging from 15,014 to 15,560 BP.

For a year and a half I worked with Tom Guilderson at LLNL processing these seeds for radiocarbon dates. They were run one after another in groups as funding was found to do more. Eventually I ended up with 20 seed dates and 20 pollen sample dates. The chart at the end of this chapter shows the results of both.

Running alongside these seed dates for comparison were pollen samples matching the same location from which the seeds were procured (see Figure 23). The pollen sample at about 3550 BP was the only one where we were able to extract carbon (200ug). The other samples were <100ug, which became highly unreliable in dating as we did not know if modern or dead carbon had been added from the chemical processing alone. For the small macros, the *scirpus* seeds, we knew exactly where they came from (good firm sediment, not soupy, located away from any section breaks and edges of the core). An interesting anomaly occurred between a pollen sample and a seed date in that they both matched with confidence at the fifth meter of the core marked at the 5L 54-55cm depth dating to 3600 years BP. This site would later become the most intriguing of the entire core. This was the point where the lake desiccated, where *polygonum* first came into the pollen record, where charcoal was heavy, non-native grass was present, and 100 centimeters of sediment was deposited over a 20-year span in the driest part of the lake's history.

First print of the radiocarbon dates for KAO3 appeared in a peer-reviewed article in the *Rapa Nui Journal*, entitled "The Mystery Lies in the *Scirpus*." (Gossen, 2007).

5.4 Core Chronology

Core chronology is based on 21 accelerator mass spectrometry (AMS) C¹⁴ dates of *scirpus* seeds, and eight C¹⁴ dates of pollen calibrated using CALIB REV 5.0.1 (Stuiver & Reimer, 2005). No reservoir correction was applied as the combination between the floating mat and the lake sediment vertical column contained bomb radiocarbon (Rowe et al., 2002). Mineral matter is low to none in the pollen slides indicating that the carbon from the seeds was growing at the center of the lake surface and depositing as such in a linear chronology, not in-washing from the eroding crater walls. An age model was also

created with CALIB showing the range in error bars for the macrofossil radiocarbon dates.

5.5 Discussion

The whole core scan showed certain magnetic deposits indicating events that were later radiocarbon dated. The radiocarbon dating then helped to determine period of the event and whether it was within the context of human presence on the island. The stratigraphy of the lake then helped to define the sedimentation rate. But nothing of the environment could be determined without the pollen and oxygen isotope data. The interpretations of my findings depend on all of these methods and not only stratigraphy and radiocarbon dating alone.

This discussion begins with the bottom of the core KAO3, which is the oldest sediment, then moves up the vertical column to the top. Core photographs are part of Appendix B and the Initial Core Description sheets (ICD) sheets are in Appendix K. A detailed ecological summary occurs at the end of this chapter comparing all of the findings within each ecological zone. I will follow the same zone intervals in this discussion. Zone intervals are labeled with depth in meter and centimeter. For example 9L95cm as the ninth meter, L being a whole meter length, and 95cm the point of depth below the top of the ninth meter.

1. Zone 1 (9L95cm-9L50cm) begins near the bottom of the ninth meter of the KAO3 core. The sediment is comprised of gyttja, an algal consolidated muck. The seeds that were found in this sample dated to 12,900 BP with a calibrated range between 15,121 and 15,390 BP. Dating within the end of the Last Glacial Maximum, the environment

was cool and dry. The lake Rano Kao was open with the edges of the lake surrounded with *scirpus*, and the island covered in a *Triumfetta* forest. The lake ecology consisted of cyanobacteria fixing nitrogen with testate amoeba and dinoflagellates. Volcanic glass was found at about 12,511 BP. Very distinct pollen and algal layers appear as yellowish green in this part of the core. Sedimentation rate is approximately 28 years per centimeter here.

2. Zone 2 (9L50cm-9L5cm). Beginning half-way down the ninth meter at a dark humus layer and up to the top of this section, the detritus is fine and consolidated well. Palms are plentiful at the top of the section dating to about 9,550 BP. Algal matter is in clumps in the sediment and chytrids are present in the holes found in the pollen. Sediment was deposited at a rate between five and eight years per centimeter.
3. Zone 3 (8L95cm-8L20cm) covers the bottom of the eighth meter to near 20 centimeters at the top of this section. The sediment is medium detritus with no marked features. Volcanic glass was found at 9,345 BP. Palms and ferns along with lignin increased as the hottest event over the lake's 15,000-year history occurred at 9,274 BP. The sedimentation rate is very fast at approximately one year per centimeter for the next 75 years, with most of it from blown-in dust, not erosion, which is evident as the samples lack minerals. The lake was open and evaporating.
4. Zone 4 (8L20cm-7L97cm). The lake remains hot and dry during this period with evaporation declining. The sediment is medium detritus

with no remarkable features. Large woody fragments with leaves and bark were found in the macrofossil analysis. This section is dated between 9,274 and 9,255 BP with sediment depositing at a rate of one year per centimeter. Other tree species such as *Caesalpinia* and *Sophora* became dominant during this period while palms declined.

5. Zone 5 (7L85cm-7L40cm). Ranging from 9,241 to 9,195 BP is the range date of this section. This period was marked by the coolest and driest period in the 15,000-year record of this lake, a very distinct period lasting for only 50 years. This O¹⁸ depletion at this point was also accompanied with tephra in the sediment. It is possible that this period was very cold as a reaction to a volcanic event. This event however was not marked by anything visually significant in the core and included mostly lignin in the pollen slide at 9,225 BP, with high root matter, wood fragments, and chitin in the macrofossils. The sediment is still medium detritus. Sedimentation rate is moving from approximately one year per centimeter to about eight years per centimeter.
6. Zone 6 (7L40cm-5L90cm). Distinguished by the highest sedimentation rate of the core, it begins at the 7L40cm, marked 9,195 BP, with 8 years per centimeter and ends with 60 years per centimeter at 5,443 BP. This period moved between dry to extremely dry. Low pollen counts were sometimes below 50 per slide. Tephra is found in the sample dated to 9,044 BP. Oxidized plant matter and charcoal pieces were found with large dicot fragments. These few thousand years are marked by constantly high evaporation.

7. Zone 7 (5L90cm-5L40cm) 5,443 BP to 3,464 BP. A distinct cooling event, found at 60 centimeters into the fifth meter section, began at 5,443 BP, peaked at 4,170 BP and ended at 3,464 BP. The sediment is still defined as medium detritus with some larger pieces of root matter. All four palm species are abundant in this sample as well as all tree species. This period is marked as cool and wet at 4,170 BP. Tephra is noted in the pollen slide and charcoal fragments in the macrofossils. Beginning around 5L54cm to 5L40cm, I conducted analysis at every centimeter as this area was marked with a noticeable hardened and lightened color of detritus in the core. Pieces of hardened desiccated soil were first thought to be gypsum, but lacking carbonate in this lake, the white balls with dark charcoal flecks turned out to be desiccated soil representing an era of time where the lake was completely devoid of water. Obsidian pieces were found in these samples. This period around 3,500 BP had many noticeable changes including exotic species such as *ephedra* found in the pollen; *polygonum* first appears in the core at this time as well. Many seeds were found in the macrofossil analysis as well as animal chitin. At approximately 3,464 BP there are large charcoal pieces and the introduction of grass pollen greater than 40 microns. Sedimentation rate is 60 years per centimeter.
8. Zone 8 (5L40cm-4L35cm) 3,464 to 3,045 BP. Palms dominate this time period with dry and warm conditions. Around 3,452 BP, polygonal dominates the pollen record as it signifies a growth across the boggy dry lakebed. This is also the slide where a “bug” was found approximately 200 microns in size. Abundance of large charcoal pieces was found. Sedimentation rate is high one year per centimeter.

9. Zone 9 (4L55cm-4L15cm) 3,443 to 2,659 BP. Palm and two types of *triumfetta* were common. A marked cooling event around at 3,045 BP is supported with the finding of tephra in the sample here. A hot dry period followed at about 2,659 BP. The sediment is medium detritus brown in color with no marked features. The sedimentation rate changes to a drier environment with 15 years per centimeter.

10. Zone 10 (4L15cm-3L20cm) 2,659 to 1,698 BP. Beginning with a hot event at 2,659 BP, the environmental conditions fall into another cool and dry event about 2,400 BP and recover around 2,213 BP to more warm and wet conditions. *Scirpus* begins to dominate the lake surface. Sedimentation rate falls back to eight years per centimeter.

11. Zone 11 (3L20cm-2L65cm) 1,698 to 1,376 BP. Three hundred and fifty pollen were found in one slide at 1,698 BP, which is uncommonly high for the KAO3 core. New exotics like *Canavalia* and *Cordyline* are noticed. Charcoal is consistently increasing. At 1,376 BP, the lake surface was thriving with *polygonum* and *scirpus*. Palm and triumphant were abundant. Large abundance of charcoal with a diatom and conifer pollen was found in the pollen slide. A *totoria* root mass was found at the bottom of the second meter of core at 2L65cm.

12. Zone 12 (2L65cm-1L71cm) 1,376 to 1,304 BP. This time period established what is similar to the last 1,700 years. The evaporation rate is similar to today. High presence of human impact is evident in all of these samples including charcoal, introduced species, and grass pollen larger than 40 microns. *Scirpus*

dominates and all palms are present. Sedimentation rate is approximately seven years per centimeter. Tephra was found at 1,332 BP.

13. Zone 13 (1L71cm-1L3cm). This is the top meter of the lake sediment core. It is composed of coarse to medium detritus and has a large *totoria* bulb at the bottom of this core section. The calibrated dates range from 1,173 BP to 1,304 BP. This section has a calibrated radiocarbon range of 1,076 BP to 1,292 BP. The top of the core is characterized by more than 62 pieces of charcoal of all classes, pollen of *vitis* and *quercus*, native grasses, *sophora* and *triumfetta*, and low palm count. Sedimentation rate is about three years per centimeter. The *polygonum* mat that grew across the original dry bed at 3,500 BP gradually filled with water and lifted the mat of plants which begin floating on the lake surface as the lake continues to fill with water over the next thousand years.

14. Zone 14 (Mat 2) 345 to 605 BP. The bottom of the collected mat for KAO3 represents an abundance of palm, *polygonum* and *scirpus*, indicating that conditions were relatively humid and warm. Palm pollen disappears around 545 BP with *triumfetta* disappearing from the pollen record at 445 BP. There is a noted cooling event occurring around 545 BP. The length of time it lasted is unknown due to wide spacing of dates in this mat core. Although at approximately 245 BP the isotope data shows a change from -.030 to current levels at +2.64 evaporation rate. The 545 BP event shows that moisture was locking into the ground surface and not evaporating; it was also cooler. The core is dense, coarse detritus comprised mostly of mat plants of *totoria* and *polygonum* root matter. Sedimentation rate is one meter of plant matter for 250 years.

15. Zone 15 (Mat 1). 345 BP to modern. Conditions are similar to modern day
 Pollen counts drop severely with some charcoal. Coarse root and plant matter,
 dense and more than 50% water once retrieved.

5.6 Comparing KAO3 to Flenley's KAO1 and KAO2 Cores

The radiocarbon dates from both of Flenley's cores (KAO1 and KAO2, 1984) were plotted along with the radiocarbon results of the KAO3 core taken in 2005 (see Figure 24). This plot sets out to compare how these dating attempts and methods match or differ from each other. Responding to the previous arguments that Flenley's dates were contaminated, it was apparent that KAO3 needed to have more reliable chronology. This core has been dated with confidence and therefore sets a foundation upon which to compare the other cores. The chart entitled "Comparative RC Dating at Rano Kao (1982-2009)" includes the macrofossil and pollen samples for KAO3 as well as the bulk dates for KAO1, and the bulk and macrofossil updates for KAO2.

The chart begins with the floating mat on the left side. The KAO3 core has a clear linear progression from modern dates at the top to 605 BP at the bottom of its two-meter floating mat. Flenley's mat core is three meters deep and although having an inversion at the bottom of the first meter, the end of the core adds another 400 years to the KAO3 chronology that fills in the gap between the bottom of the mat and the top of the lake sediment core. To further confirm the overlap, the bulk date at the top of KAO1 matches the same depth and date as the KAO3 core.

Continuing up the line of the KAO3 macrofossils, the bulk dates and new KAO2 samples, although varying off the curve from time to time, are all varying within normal limits

and still moving up the curve. At the end of the core, the pollen samples have insufficient carbon, which resulted in younger dates than the macrofossils as shown on the graph. The KAO3 core continues to follow this curve until the bottom date is reached at 12,930 BP.

Another noticeable artifact on the graph is the beginning depths of the KAO2 (1984) and KAO3 (2005) cores. Both were taken very near to the center of the lake, and the water depths vary by two meters. This variance matches the increase in lake water level due to precipitation input over time that is discussed in further detail in the upcoming climate change chapter.

Sketches of the lake were drawn to show the coring locations, the estimated depth profile of the lake, and its changing water level over time. The profile provides a visual illustration that over time evaporation was occurring more rapidly than rainfall was coming in. Sometime around 3,500 years ago, the basin was completely devoid of water, which left a hardened desiccated surface with marginal plants growing closer to the center of the lake. Filling with water as rainfall increased, the lake expanded higher onto the crater walls. In 1958 Heyerdahl noted a building platform low to the water level on the crater slopes. Today it is not visible and calculations of changes in the lake level support the idea that it would be found underwater. As found in the 1950 coring exploration, the lake water depth was 2.5 meters lower than discovered in 2005. I based these calculations on the slope of the crater, input of rainfall, and lake levels noted between Flenley (1991), Gossen (2005) and the Chilean Armada (1967), who all took lake level readings. There is a calculated sketch that shows how I derived these estimates, which on average show an increasing rate at which the level rises over the last 1200 years, whereas the previous 2000 years mostly maintained an increased rate of one centimeter (1cm) per year input, or one meter (1m) over 100 years.

Figure 22 - KAO3 Radiocarbon graph

Figure 23 - KAO3 RC graph, seeds and pollen

Comparative RC Dating at Rano Kao (1982-2009)

Figure 24 - Comparative RC Dating at Rano Kao (1982-2009)

CAMS #	Sample Name	other ID	$\delta^{13}\text{C}$	fraction Modern	^{14}C age macrofossils	$\pm$	actual depth	sigma 1 calibrated dates	sigma 2 calibrated dates
132962	KA03 0-5cm	N79557	-25	1.1383	45	>Modern	0.005	modern	modern
132963	KA03 85-90	N79558	-25	0.9699	245	40	0.85	278-316	266-332
132964	KA03 120-125	N79559	-25	0.9346	545	35	1.2	525-556	513-564
132965	KA03 195-200	N79560	-25	0.9276	605	30	1.95	586-612	545-653
125890	RNKA05-3A-1L 15-16	N73885	-25	0.8610	1200	35	12.65	1076-1171	1053-1185
123142	1L-1 48-52	N71916	-25	0.8466	1340	35	12.98	1261-1300	1225-1310
123143	1L-1 81-82	N71917	-28.6	0.8484	1320	30	13.31	1257-1292	1225-1298
125893	RNKA05-3A-2L 58-60	N73888	-25	0.8468	1335	30	14.08	1262-1297	1231-1304
123145	3L-1 52-54	N71919	-25	0.7907	1885	35	15.02	1811-1881	1723-1895
125891	RNKA05-3A-4L 36-37	N73886	-25	0.6998	2870	120	15.86	2859-3162	2763-3271
123147	5L-1 54-55	N71921	-25	0.6495	3470	70	17.04	3682-3834	3564-3921
123219	6L-1 31-32	N71922	-25	0.3527	8370	320	17.81	8972-9710	8581-10179
123148	7L-1 42-43	N71923	-25	0.3178	9210	100	18.92	10253-10441	10204-10600
123149	8L-1 77-78	N71924	-25	0.3135	9320	70	20.27	10417-10599	10291-10697
123150	9L-1 22-23	N71925	-25	0.2993	9690	400	20.72	10496-11721	10128-12401
123151	9L-1 27-28	N71926	-25	0.2533	11030	130	20.77	12877-13067	12821-13186
NZA 23878	basal date	NZA 23878	-30.2	0.2520	11017	45	21	12885-12974	12872-13055
136170	KA 0053A 9L 95cm	N82176	-25	0.1999	12930	50	21.5	15121-15390	15014-15560
123153	pollen-1L-1 25-27	N71929	-25	0.7341	2480	60	12.75	2469-2620	2362-2722
123154	pollen-3L-1 52-54	N71930	-25	0.7888	1910	130	15.02	1695-2001	1538-2153
123155	pollen-4L-1 47-48	N71931	-25	0.6977	2890	130	15.97	2871-3171	2768-3347
123156	pollen-5L-1 54-55	N71932	-25	0.6423	3555	35	17.04	3826-3901	3809-3929
123157	pollen-6L-1 30-31	N71933	-25	0.3947	7470	100	17.8	8195-8374	8038-8428
123158	pollen-7 L-1 42-43	N71934	-25	0.3822	7730	210	18.92	8342-8780	8154-9091
123159	pollen-8 L-1 77-78	N71935	-25	0.3571	8270	110	20.27	9127-9415	9010-9482
123160	pollen-9 L-1 22-23	N71936	-25	0.3878	7610	200	20.72	8180-8607	8020-8808
135731	KA005 6A 1L 8-9	N81936	-25	0.8610	3185	40	17.08	3378-3444	3338-3479
135732	KA005 3A 5L 49-50	N81937	-25	0.6998	3440	35	17	3639-3723	3615-3829
135734	KA005 3A 5L 49-50 rep	N81939	-25	0.8227	3435	40	17	3636-3724	3609-3782
135733	KA005 3A 5L 52-53	N81938	-25	0.8468	6385	45	17.02	7266-7330	7248-7424

RC samples processed at Lawrence Livermore National Laboratories except for the sample labelled NZA which was processed at Rafter Laboratories in Wellington, New Zealand

Calibrated dates via *calib501*:

PJ Reimer, MGL Baillie, E Bard, A Bayliss, JW Beck, C Bertrand, PG Blackwell, CE Buck, G Burr, KB Cutler, PE Damon, RL Edwards, RG Fairbanks, M Friedrich, TP Guilderson, KA Hughen, B Kromer, FG McCormac, S Manning, C Bronk Ramsey, RW Reimer, S Remmele, JR Southon, M Stuiver, S Talamo, FW Taylor, J van der Plicht, and CE Weyhenmeyer (2004), Radiocarbon 46: 1029-1058.

Figure 25 - KAO3 calibrated RC dates

Figure 26 - KAO3 calibrated RC dates with error bars

Chapter 6 Oxygen Isotopes – Evidence of Climate Change

After the volcano cratered and formed Rano Kao some 300,000 years ago, this basin began to collect rainfall. Over time a lake began to form and a viable ecosystem of trees, shrubs, ferns, grass, birds, animals, insects, and people thrived here. Rano Kao thrived in its own unique ecosystem separate yet connected to the island; it is a unique microclimate, deep enough to be sheltered from the ravaging winds that frequent the island yet subject to the intense solar radiation. Slowly the lake releases its moisture, evaporating and supporting its thriving plant ecology. After the lake went through its trials of drought and boggiess, a matted cover threaded with roots and stems of *polygonum* and *totoria* slowly lifted from its boggy surface. The floating mat became a floating peat bog also with its own unique ecosystem within the Rano Kao microclimate.

How does an ecologist discover the range of tolerance and environmental preferences between aquatic and terrestrial plants that are both inside and outside of a volcanic crater? That was a special challenge for this research as more than 20 plants discovered as fossil pollen in the core no longer exist on the island. Many of these plants were endemic and are now extinct. Being left with only the remnants and fossils in the lake sediments, they were used nonetheless to date, test, and reflect upon what kind of environment they were living in. The main input of carbon in the oxygen isotope analysis came from the two aquatic plants *polygonum* and *totoria* that grow on the lake surface. The lake changes with rainfall input and evaporation, and captured within the cellulose of these plants are the lake water history.

6.1 Introduction to Cellulose Isotope Studies

Lake sediments are useful in advancing our understanding of ancient environments.

Trapped within the sediment deposits are carbon and oxygen isotopes from the decaying aquatic plants that flourished in a lake system, and consequently the lake sediment cellulose can provide a record of the lake's paleohydrology. More commonly, carbonates have been used in paleolimnological investigations, but sometimes the lake does not have sedimentary carbonates, as is the case of the Rano Kao. Therefore, cellulose is the best option for analyzing the history of such a lake. The main input of carbon in the oxygen isotope analysis came from the two aquatic plants *polygonum* and *totorá* that grow on the lake surface. As the lake changes with rainfall input and evaporation, the lake water history is captured within the cellulose of these plants.

Analyzing carbon and oxygen isotopes in lake sediments is a recent science, first tested by Wolfe, Edwards and McAndrews in 1989 to investigate the Holocene paleohydrology of a lake in southern Ontario, Canada (Wolfe, 2001). For lakes that are carbonate-free in their sedimentary process, such as a volcanic crater lake of basalt, aquatic plants that thrive on the lake water offer another option for analysis of carbon and oxygen isotopes. Wolfe, from Wilfrid Laurier University in Waterloo, Ontario, wrote that "Lake sediment cellulose has been used as an archive of paleoenvironmental information in diverse geographic and ecoclimatic settings" (2001, p. 373). He listed places around the world where cellulose has been used to determine lake paleohydrology, including the Great Lakes of North America, Eastern Africa, the arctic and subarctic, subtropical Andes, and the ancient Glacial Lake Agassiz (2001). Rano Kao was the first lake in the South Pacific where this was attempted, and KAO3 produced excellent results.

With a floating mat of two aquatic plants as well as algae, cyanobacteria, and other nitrogen-fixing organisms, Rano Kao provides suitable materials for this type of analysis. The lake is rich in flora that collect a signature of stable and dynamic isotopes deposited

into the cellulose of their cell walls. This cellulose is primarily found in stalks, stems, trunks, and woody parts of the plant (Ott et al, 1954). In the floating mat of Rano Kao there are two aquatic plants: *totorā*, a sedge with a horizontal rhizome, and *polygonum*, with a segmented hollow channeled root and rhizome plant; both are high in bio-molecules and cellulose. The KAO3 core was comprised mostly of 15,000 years of decomposed detritus from these aquatic plants.

The $d^{18}O$ signal in the lake sediment cellulose reflects changes in climate, particularly rainfall cycles and patterns with distinct events occurring periodically. The signal also reflects a change in temperature, solar conditions and wind. But the isotope analysis alone cannot differentiate cause and effect; the pollen and ecology portion of this research is critical to support the climate data revealed in the isotope analysis. Detailed results for the isotope record for KAO3 are discussed in the upcoming sections. (*For a summary over the last 15k years, see Figure 34*).

The research questions that we wished to answer from the cellulose oxygen isotope study of the lake included the following:

1. How has the water balance of the lake varied during the past?
2. What does the paleohydrologic record suggest about past changes in climatic conditions?
3. What is the relationship between past hydrologic changes and lake or watershed carbon cycling?

Our analysis showed that throughout the record of the lake in all its extremes, palm and other tree species survived in abundance and diversity. Although at times pollen quantities became very sparse, they did not disappear previous to human arrival. Their

only disappearance in the pollen record appears around 550 BP. The climate event that occurred at that time, a cool/dry event that aligns with the Little Ice Age, may have caused a failure of crop plants on the island, but it certainly did not cause the collapse of the trees, as other events over the last 15,000 years were more extreme than this minor cooling episode. There may be an unknown factor correlating the cool/dry event with a lack of germination due to humans, rats, insects, birds, or some other ally that we do not know of yet but that may have made an impact. Nevertheless, it is clear with this isotope record that climate change did not cause the demise of the trees.

6.2 Lake Evaporation

Carbon and oxygen isotope analysis of cellulose in lake sediments can be used to trace lake water changes ($\delta^{18}\text{O}_{\text{lw}}$) by applying a cellulose-water fractionation factor between terrestrial cellulose and leaf water. This isotopic fractionation results in a Meteoric Water Line (MWL) observed between the oxygen isotope ^{18}O and deuterium ^2H . It is the composition of the oxygen and hydrogen isotopes that enter the lake from rainfall that define two linear relations to deuterium ^2H and ^{18}O . When rainfall enters a lake, both a heavier oxygen isotope ^{18}O and a lighter ^{16}O show in the record. It is the change in ^{18}O by which we gauge whether the lake was experiencing increased input due to rainfall or evaporation at a greater rate due to temperature increase. Depletion refers to a lessening of ^{18}O being due to an increase in ^{16}O , or less evaporation due to rainfall input. Enrichment of ^{18}O means that the lighter isotope ^{16}O is evaporating due to temperature increase, more wind, and less rainfall. Both depletion and enrichment of ^{18}O are significant in understanding a changing lake environment. Complete procedures, process, and methods are detailed in an article by Wolfe (2001).

Surface water samples were taken from the lake Rano Kao in March of 2005. Before processing the samples taken from the core KAO3, we needed to test the modern water samples to determine if the lake evaporation could be detected as expected and how the Local Evaporation Line (LEL) compared to the Meteoric Water Line (MWL). It is the composition of the oxygen and hydrogen isotopes that enter the lake from rainfall that define two linear relations to deuterium ^2H and ^{18}O . In Figure 28 the rainfall is plotted on the MWL and the evaporation of the lake is set upon the LEL.

The “delta-delta” plot of the March 2005 water sample showed ($\text{d}^{18}\text{O} = +2.57$ per mil; $\text{d}^2\text{H} = +13.23$ per mil). It is isotopically enriched compared to what would be expected based on the measured precipitation at Easter Island, which averages -1.6 .

The result for the water sample from March 2008 was nearly identical to the March 2005 sample: ($\text{d}^{18}\text{O} = 2.49$; $\text{d}^2\text{H} = 14.06$). Both indicated that evaporation is a major component of the present-day water balance of the lake. These results also lined up well with the inferred values from the cellulose d^{18}O from the KAO3 sediment core.

Therefore, the results of the water samples showed an acceptable confidence level for continuing on to testing the sediment samples.

In March 2008, the Rano Kao Expedition (RKE08) team performed a survey of the lake, analyzing water quality (*see Appendix I*) to support isotopic changes in the lake water. Water quality is imperative to the viability of plant and microbial growth of the lake. Evidence of a very wet winter showed up in the presence of 1.5 meters of rainfall deposited on top of the floating mat and filling shallow wells. Also in response to the rainfall the mat was covered with 3-4-meter tall *totorá* (*Scirpus californicus*), whereas in March 2005 the *totorá* was only on the edges of the lake. We also discovered that the lake

had been accumulating more water every year since Flenley's first coring in the 1980s. At that time his KAO1 and KAO2 cores showed a floating vegetation mat of an average of 2 meters thick, separated with a water column 8 meters in depth, and obtaining 9 meters of sediment before the corer had reached its maximum length. The KAO3 that we retrieved in 2005 also collected a 2-meter floating vegetation mat, but with 10.5 meters of water in the lake, and collected 9 meters of sediment. There were four cores taken during this expedition, all of which supported more rainfall entering the lake than evaporating since 1980. The RKE08 team also took bottom-of-lake depth readings and noted an average water column depth of 12.5 meters, again supporting more accumulation of rainfall than evaporation.

6.3 Processing Samples for Oxygen Isotopes

Methods for lake sediment sample preparation for cellulose carbon and oxygen isotope analyses followed those developed by the University of Waterloo-Environmental Isotope Laboratory (UW-EIL) (Edwards et al., 1997; Elgood et al., 1997; Heemskerk & Diebolt, 1994).

Forty-five samples were taken at 20cm intervals from the 9-meter KAO3 core; the samples were then processed with a preliminary treatment of acid washing and freeze-drying to remove carbonate if any. These samples were heavy in detritus loaded with coarse-grained material, which made sieving almost impossible. The sieving is a very important step in sample preparation as for most lakes it is needed to remove terrestrial sources. The KAO3 core taken near the center of the lake contained coarse detritus from the floating mat. The first test after preliminary processing was to determine if the organic matter was terrestrial or aquatic. The tests revealed that the cellulose derived from the

soil samples was in fact from the aquatic plants, registering with C and N elemental and isotopic compositions of aquatic plants.

The next step was solvent extraction to remove lipids, resins, and tannin which are abundant in Rano Kao. The third step in the process was bleaching for the removal of lignin. Alkaline hydrolysis was the fourth step in the process; it removes xylan, mannan, and other polysaccharides. The fifth and final step in the procedure was to leach oxyhydroxide.

The ending analysis of each sample taken at regular intervals and radiocarbon dated included organic carbon content (% dry weight), nitrogen content (% dry weight), C/N ratio, organic carbon and nitrogen isotope composition, and cellulose oxygen isotope composition.

6.4 Analysis of Oxygen Isotopes of Rano Kao

In the case of Rano Kao, the change from isotope depletion to enriched ^{18}O involves humidity and evaporation. Surrounded by ocean, and located on the edge of the island facing incoming trade winds, the lake is subject to these two important factors in changing moisture conditions. When conditions are dry on the island, solar radiation is intense and winds evaporate moisture at a quicker pace. Without a forest canopy, there is nothing to stop the moisture loss. With intervals of prolonged drought lasting four to five months a year, it was observed that high ratios of ^{18}O also reach a highly evaporative response leaving the lake environment drier as the moisture leaving the lake surface is swept away very quickly. In comparative analysis, depletion of ^{18}O generally means it is cool and dry; enrichment means there is more evaporation than input of

rainfall. Somewhere between these two limits is a rainy, saturated point for Rapa Nui. In numerical values, the rainfall average is measured at -1.6 in the isotope ratio used for this study (see Figure 28).

6.5 Lake Level Changes Over the Past 15,000 Years at Rano Kao

In the early chronology of the KAO3 core, some 15,000 years ago, the lake was calm and the environment cool. Our core data show that the island was covered in a forest of *triumfetta* that dominated the pollen record for a thousand years. These trees shared the island with at least four palm species creating a rich and diverse island that was thriving while the planet was coming out of its last ice age.

The isotope record reflects the lake's response to distinct periods of enriching and depleting isotopes. As the climate warmed on the planet, so did Rano Kao. Over the next thousand years the lake experienced a warming period, culminating in 9345 BP with the hottest and driest event noted in all of the KAO3 record as the pollen became sparse with this global heat wave that was noted in this deep open lake. The climate slowly changed as the isotope record documents a move into wetter conditions. At the same time, the pollen record shows ferns being dominant. A volcanic event interrupted this warm period with a very short 30-year major isotope depletion, indicating a cool dry period, as expected with volcanic ash being emitted into the atmosphere, and with the most extreme isotope depletion in the entire record occurring in 9225 BP.

For some 5,000 years, conditions became very dry on the island, and around 3,500 BP Rano Kao became completely devoid of its water. Hardened soil balls found in the core at 5L 50cm were analyzed and identified as desiccated soil with obsidian flakes. The KAO6

core, which was taken approximately 100 meters from the lake edge curiously had 17 meters of water before lake sediment was reached. The top of this core matched the same period as the 5L50cm section that was desiccated. I dated the top of this core and came up with similar dates as the KAO3 core with five more meters of sediment. The curious question was why would the core in the center of the lake contain more sediment than the one nearer the lake edge? If the steep crater walls were eroding, then the plausible scenario would be to expect more sediment near the lake edges. This curious 3,500 BP time period is discussed further in the upcoming chapters.

Also during this 3500 BP time period, pollen counts were consistently lower than 100, sometimes even with the counting of two slides. The dominant species moved from *scirpus* to fern to palm. Slowly the lake became a bog and the *polygonum* grew across the surface with rainfall aiding its growth. Once it formed the floating mat, *polygonum* began to grow horizontally with strong jointed stems stretching at least two meters across open holes with no support.

Once the *polygonum* surface was secure, it continued to grow until more and more rainfall lifted the mat from its surface around 1500 BP. Fern dominated this time period further supporting a wet environment. A wet and warm environment followed with *totoria* and *polygonum* continuing to grow on the floating mat surface. Currently there is 12.5 meters of water between the floating mat and the top of the lake sediment. In comparison, Flenley's coring in the 1980s noted 10 meters of water. The basin is collecting more rainfall than it is evaporating. It is possible that the mat covering more than 90% of the lake surface also filters or slows the amount of evaporation losses (see Figure 34).

6.6 ENSO and Lack of Long-Term Climate Records

A lack of scientific evidence previous to this research makes the oxygen isotope study critical to shedding light on the conjectured events of El Nino Southern Oscillation (ENSO) and climate change that may have affected Easter Island.

There are only short-term reports of collected weather data on Rapa Nui. The longest running record of temperature with scattered rainfall reports for the island goes from 1941-2000. There have been a few researchers (Hunt and Genz, 2003 and Ferren MacIntyre, 2001) who have attempted to find a connection between ENSO events and the climate of Easter Island, but they have come up with a general lack of evidence to correlate. Most ENSO data have been and continue to be collected in the Northern Hemisphere.

Being thousands of kilometers from South America, Easter Island is also lacking in historically collected sea surface temperatures (SST). Attempting to discover long-term climate trends on the island therefore required a new science. The oxygen isotope analysis conducted on the KAO3 core is now available to compare with known changes to the landscape of the island. This section connects the lake water changes of Rano Kao with its link to the Southern Hemisphere as well as global events.

Outside of the majority of previous theories explaining what happened to the forests on Rapa Nui, there are a few that question whether a climate event had an effect on the landscape as well as on the humans. McCall (1993) stated that climate was a significant factor in cultural change for prehistoric Rapa Nui. Hunter-Anderson (1998) claimed that El Nino Southern Oscillation events occurred on the island resulting in a prolonged

drought. Nunn (2000) found that there was uncommonly heavy precipitation that affected the island, while Orliac and Orliac (2000) claimed drought conditions caused major disturbances, and Macintyre (2001) found that there was no measurable ENSO effect on weather patterns at Rapa Nui.

Macintyre's model (2001) showed Rapa Nui just outside of the climate effects in the eastern South Pacific Gyre. Hunt (2003) also stated that "ENSO records and their teleconnections are presently of no help as a proxy in reconstructing a climate history for the island" (p. 10). However, all these researchers are in collective agreement that rainfall is highly variable and unpredictable

In Chapter 2, a constructed rainfall history chart from NOAA data shows the last 67 years of rainfall patterns on the island. There are apparent patterns that follow 14 to 17 year cycles for high rainfall accounts measuring nearly 200cm (80in). Drought cycles follow an 11-year pattern, with as little rainfall as 52cm (22in) for those years. The variance between the most and least case scenarios are drastically different when considering an island that is on the edge of the South American Gyre, which sometimes appears to reach a stall zone near Easter Island.

Depending on the circulation patterns of the Pacific Ocean, wind is also an important variable affecting the evapotranspiration over the landscape. The island now barren of trees has no means to capture any available moisture, and with certainty this created agricultural problems.

Solar radiation is intense year round and becomes more intense during the hot dry months. Over time with the loss of the forests, soil eroded, dried up, and became

infertile. There is severe erosion noted on the island today evident in aerial photographs and in underwater coastal studies. Whatever moisture landed on the soils through rainfall either evaporated or was filtered through the porous volcanic soils. However, at some time between the loss of the forests and the barren landscape, humans adapted. Through archaeology of the agricultural gardens and observing the shape of the landscape, Stevenson (2002) discovered that humans were adapting to both increased solar radiation and drought. He also states that there are known adaptations on the island using lithic mulch and manavai to shelter plants. Even going beyond sheltering plants, there is evidence to show that the lithic mulch was also used to actively produce moisture for their plants (Gossen, 2005). The connection between the landscape changes and evaporation of the lake are directly related to the shift in ^{18}O depletion and enrichment cycles.

Another consideration related to isotopes stems appears in a paper published in *Nature* by Wilson and Hendy in 1971, which discussed the ability to determine wind strength from isotope studies. Although that analysis was not conducted in this research, it is a plausible idea to pursue because of the strong winds that affect the evaporation rate on the island, particularly the evaporation of Rano Kao. Wilson and Hendy (1971) found that winds also increase with temperature changes and can be detected with both oxygen and hydrogen isotopes either as $^{18}\text{O}/^{16}\text{O}$ ratios or $^2\text{H}/\text{H}$ comparisons. By comparing the delta T (δT) between polar temperatures and equatorial temperatures, they can see patterns during glacial times of more than 25% increase in δT . When it was warmer in tertiary times, the wind was less. Wilson and Hendy observed that the Little Climatic Optimum in the 12th and 13th centuries was the optimum time for Polynesians to be traveling with less storminess in the oceans, thus supporting cultural effects during this time period as well as pollen changes noted in KAO3 core which are also supported in the oxygen isotopes. Then in the 14th century there was a sharp decrease in rainfall into the so-

called Little Ice Age over the 15th, 16th, 17th, and 18th centuries. This is confirmed with the Greenland ice cores from Dansgaard et al (1973). The transition between these two events shows a dT of 1°C or about 2.5% increase in storminess.

Whether it is storminess or cooling as noted by works cited above, there is a notable climate event found in the KAO3 core that occurred sometime around 545 BP. This supports the idea that the Little Ice Age had some effect on Rapa Nui.

6.7 Climatic Events

There are many climate events noted throughout the 15,000-year history of the KAO3 core. This analysis attempts to tease out long-term climate cycles as well as short-term, temporary events along the way.

Marked events (spikes) in the KAO3 isotope record were first thought to be errors in the data as they were sent over from the lab in Waterloo. Upon further inspection of the soil, macrofossils, and pollen, and comparison of these with the isotope record, I realized that these were not errors but indicators of environmental events. Some occurred over short time periods and others were longer lasting. The most drastic shifts were noted as severe isotope depletion (cool/dry/windy). The isotope graph at the end of the chapter presents a visual interpretation of the events discussed below.

Event 1 occurred as the lake was warming and moving out of the Last Glacial Maximum into the Holocene. The core begins with a distinct cold event referred to as the “Huelmo-Mascardi cold/wet event” about 12.0 to 13.4 ka, or possibly a portion of the Antarctic Cold Reversal (ACR). However, in the KAO3 core, the exit out of Event 1 occurred 12.5 ka to 11.9 ka with a very abrupt warming period

that could also be representative of the Younger Dryas Cold Reversal (YDCR). Lake Titicaca, on the Peru-Bolivia border, had several climate events in common with Rano Kao; it was also going through a wet period between 13 ka and 11.5 ka (Baker et al, 2001). McGlone (1983b) suggested that three phases of rapid climatic amelioration occurred for New Zealand at 14.5 ka, 12.5 ka, and 10 ka, rather than a gradual improvement in climate. He suggested both temperature and precipitation increased by indeterminate amounts. Afforestation was also rapid, occurring over a period of only 500 years on the South Island. Subsequent vegetation changes depended upon how rapidly individual taxa were able to take advantage and expand their population. Glacio-eustatic sea level records show that at the height of the last glacial maximum, sea level was probably 140m below present levels, and rose on average a meter per 100 years until about 6,000 BP (Chappell, 1982; McLean, 1980).

Event 2 As the climate was warming around 11.9 ka, there was a steep isotope depletion for approximately 500 years followed by a cool period of approximately 1,500 years during the same noted time as the Younger Dryas event. These same events align with a dry period at Lake Titicaca between 11.5-0 ka. (Baker et al, 2001). What followed this cool event was a drastic upswing to a very hot period that occurred within 300 years. This appears in the isotope record as a highly evaporative period. With intense heat one also expects high levels of charcoal from fires to be present in the core. An interesting human interaction that supports the find during this time period is with the site of Santa Julia on the Chilean semiarid coastline. Human activity was very intense with high amounts of charcoal around 13 ka. Around 10.5 ka in the middle of the Younger Dryas, all evidence of human and charcoal disappeared (Maldonado et al., 2010).

Event 3 Approximately 9,274 BP began what was to become the hottest event in the 15,000-year history of Rano Kao. Leading up to this event was the release of the moisture tied up in the Younger Dryas event, culminating in a very wet period. The Santa Julia site saw a wetland expansion between 10.5 and 9.5 ka (Maldonado et al, 2010), while Lake Titicaca was also wet another thousand years into 8.5ka (Erickson, 2000). Rano Kao's warming trend saw a spike around 9,555 BP, then for almost 70 years again it became cooler and drier only to then shift over the next 200 years into a highly evaporative intensely hot event. Hays in 1983 wrote of O. H. Selling's work in Hawaii in 1948 as showing warm-demanding taxa taking over cool-adapted plants. This event coincided with a temperature maximum between 8000 BP and 9000 BP detected by oxygen isotope curves in deep ocean cores.

Event 4 Within 30 years, the hot period dipped into a cooler, less evaporating period. With a short recovery into warming for 20 years, a drastic isotope depletion, the most extreme in the KAO3 core, shows in the record around 9,225 BP. Tephra was noted in the pollen slides, although no ash layer was noticed in the core. This was a very short period lasting only about 50 years for the full oscillation from warm to cool, as indicated by isotope depletion, then back to warm again, as indicated by isotope enrichment. The Santa Julia site also concurs with two dry periods between 11.2-10.5 ka and 9.5-9.0 ka. Lake Titicaca does not see the extreme warming event as that of Rano Kao and that may be due to a difference of latitude. The dry period of Lake Titicaca followed around 8.5 ka.

Event 5 There was a very long dry period with periodic intervals of wet and drought until around 5443 BP. Further supporting the oscillations found in the

Rano Kao core is Hope's (1976) findings from Papua, New Guinea. In these cores he found pollen evidence for expansion of forest above the present tree line between 8600 and 5000 BP, which is attributed to higher temperatures, increased cloudiness, and more rainfall in the highlands (Hope, 1976). The decline from 5443 BP to 4170 BP has been captured in climate history around the world as the 4.2k event with plagues, drought, and floods shown in ice cores, soil cores, and sea bed cores containing Saharan dust. The event at 4170 BP also has tephra noted in its sample. Lake Titicaca shows an extremely dry period from 6-5k and a loss of 250 feet of water (Baker, 2001). This time period overlaps with similar events in Rano Kao. There is tephra noted in the pollen slide matching this isotope sample as well. At the end of this even period, it took nearly 600 years to move into an extreme dry period, which ended up desiccating the lake in 3,500 BP.

Event 6 shows up in a sample with volcanic glass in it. This event appears after a short period in which there was great deposition of soil yet in a period of desiccation of the lake. This is the driest period of the lake, which then slowly begins to fill with water. The isotope depletion associated with this event took 400 years to reach its peak. Over the next 400 years the record shows evidence of movement into another hot event around 2,659 BP. Meanwhile, while Rano Kao is desiccated, Lake Titicaca has already begun a wet period and the lake continues to rise again around 4.5ka.

Event 7 Within the 700-year cycles that have been found between drought events in the KAO3 core, the time period between Event 6 and Event 7 is roughly 650 years. About 2400 BP, a major climate event occurred that was cool and dry with little to no mineral found in the sediment sample at this point. This period occurred around the same time as the Plague of Athens, which was caused by a dry event (MacIntyre, 2002). Another

200 years and the lake began to stabilize to current conditions, becoming wetter and accumulating water. Now the lake has a floating mat surface, which is growing. There were two more noted volcanic events occurring around 1581 BP and 1332 BP.

Event 8 Occurred in the mat samples of KAO3. This single event at 545 BP is the subject of many inquiries into the Little Ice Age. This isotope depletion indicates a cool and likely dry event. How long this event lasted is yet unknown, but conditions restabilized within the next 200 years according to the isotope record. As with Rano Kao, Lake Titicaca collected more rainfall during the last 100 years than it lost in evaporation. Lake Titicaca has varied over 6.5 meters in that time (Baker, 2005) while Rano Kao shows a 6-meter increase in lake water as noted in the first recording of lake water levels in 1967.

An interesting correlation is the climate-forced Bond Events (Bond et al., 1999) of 1400 BP, 2800 BP, 4200 BP, 5900 BP, 8100 BP, 9400 BP, 10300 BP, and 11100 BP. All of the Rano Kao samples for these time periods noted high ^{18}O enrichment, indicating a warm and evaporating lake. “It now is increasingly clear that many (if not all) Bond Events are related to solar variability. However, climate forcing of the latest Bond Event, the Little Ice Age, represented by a strong cooling of the North Atlantic sector (Bond et al., 1999), has been convincingly ascribed largely to volcanic forcing” (Baker, 2005).

6.8 Intervals between Events

I examined the data by averaging the intervals between peaks; this included intervals between hot peaks and cool peaks, as shown by peaks of increased ^{18}O enrichment and

peaks of ^{18}O depletion. The average number of years between peak hot events was about 720. Between the peak cool events, the average was about 637 years. These data support the findings from North America, particularly the United States data for climate change. In 2006, the 10th Annual Paleolimnological Symposium was held in Duluth, Minnesota. Research presented by Antje Schwalb entitled “Modes of Atmospheric Circulation over Midwestern North America during the Past Four Millennia,” showed the discovery of a 700-year drought cycle for North America over the last 4,000 years. The isotope evidence from Rano Kao shows a similar correlation in drought cycles, supporting a general theory that these droughts are part of a long-term global climate pattern.

6.9 Trend Lines

In Figure 30 there are two trend lines that emerged from the KAO3 isotope analysis representing long-term climate changes in Rano Kao. The findings show lake response to global climate events, by recording changes indicative of rainfall and drought affecting the lake water level and oxygen isotope ratios. Trend line 1 begins with the emergence of an open lake in a cool LGM (Last Glacial Maximum) environment then sharply rises from a cool and dry environment with oscillations of wet periods to the hottest event of the 15k-year record at 9274 BP. This trend has a very steep 3,000-year growth towards warmer and wetter into the Holocene.

Trend line 2 (9,274 BP to current) covers a 9000-year time period. This trend line represents a negative slope towards isotope depletion, becoming cooler and drier. Over the last 2,000 years the lake has been relatively stable. The rainfall into the lake has been greater than the evaporation out of the lake, but the isotope ratio, which was +2.5 in 2005, has increased to +2.64 in 2008, numbers indicative of more evaporation and hotter

temperatures within the last few years. The environment oscillates between wet/warm events to cool/dry peaks on average every 700 years. The most extreme depletions have aligned with volcanic events verified with tephra in the pollen slides (*see Figure 31*).

6.10 Carbon Cycling in the Lake

The last of the research questions that we wished to answer from the cellulose oxygen isotope study of the lake concerned the relationship between past hydrologic change and lake carbon cycling. Generally the sensitivity of the lake water levels to rainfall pattern changes is displayed in the results of the cellulose-inferred lake water composition ($^{18}\text{O}_{\text{lw}}$) value; the carbon cycling is evident in the changing cellulose carbon isotope composition ($^{13}\text{C}_{\text{cell}}$) values. Reviewing the oxygen isotope results for Rano Kao, the carbon 13 results have two distinct profiles (*see Figure 29*). The bottom of the core, dating to the end of the LGM, shows an open lake with little carbon input from the lake surface. ^{13}C declines along with each cooling event keeping the lake productivity low. Entering into the Holocene time period there is an abrupt warming period with ^{13}C increasing and lake productivity also increasing.

Lake productivity in other studies often use diatom-inferred dissolved organic carbon as a means to deciphering the organic carbon input, although for Rano Kao there were no diatoms to help in this process. There is a significant noticeable decline in the carbon record, as shown in the KAO3 isotope record around the 3500 BP time period when the lake was devoid of water. A noticeable increase in carbon input occurred around 1325 BP, which may be soil-derived minerals from the floating mat, which was established by this time period. Because the $^{13}\text{O}_{\text{cell}}$ values from Rano Kao register mainly from the aquatic plants, it was necessary to look to the pollen record to give greater detail into environmental changes.

6.11 Plant Indicators of Rainfall and Drought

Over time the lake Rano Kao changed with rainfall input and evaporation. These moisture changes were captured within the cellulose of the aquatic plants and are recorded in the lake water history. Determining the ecological changes based upon the isotope data alone is nearly impossible. The question that remains is what happened to the terrestrial plants? Particularly, did they have the same response as the aquatic plants during drought? These subtle details are therefore indicated in the environmental tolerance of each of the plants and the context in which they were growing.

When understanding the science of reading the isotope record from Rano Kao, we refer to ^{18}O enrichment as when the ambient air is less humid than the lake water and therefore evaporation of ^{16}O occurs. Does this mean, however, that the environment was dry or hot or both? Depletion of isotopes means there is less of the heavier isotope O^{18} while also inferring that the lighter isotope O^{16} is also depleted and suggests a lack of incoming rainfall. Could the environment then be inferred to be dry with no rain or cool with no evaporation or both? Somewhere between the depletion and enrichment of the oxygen isotopes is also a point of saturation, when there is just rainfall. For Rano Kao we only have the last 67 years of weather data to calculate the saturation point for rainfall on the island at (-1.6) , with the known evaporation based upon collected water samples from 2005 and 2008 at $(+2.5)$ and $(+2.64)$ respectively.

In order to associate lake water changes with the ecological preferences of the 33 types of fossil pollen identified in the KAO3 core, each were marked for their moisture preferences (*see Appendix D*). After identifying a temperature and moisture preference for each of the plants, a dominant species for each sample was noted. Matching the isotopic value and the dominant plant of that same time period gave greater detail and support for

varying climate conditions (*see Figure 33*). General correlations were found between isotopic depletion values and low pollen counts, which indicated drought-like conditions. Another correlation was found between the number of pollen counted, the diversity of pollen in the slide, and the number of transects required to count a total of 300 pollen.

Comparing the details a step further, the KAO3 results aligned with Flenley's ecological profiles (1991) based on the moisture preferences of grass (warm/dry) and ferns (cool/wet). Modern observations from my coring expeditions in 2002, 2005, and 2008 also supported the ecological preferences of the aquatic plants as projected from both the isotope and pollen research. In 2002, the mat surface was dry and brown and had been subject to a long drought. In 2005, rainfall had increased and the mat produced more green thriving plants. In March of 2008 was the most significant observation. Walking onto the mat was much more difficult as the boggy part of the lake edges were much higher, at waist height, whereas the previous was at knee level when we got out onto the mat. The *totorā* had also grown across the lake with the mat holding 1.5 meters of rainfall from the wet winter that came before.

Another observation in 2008 was the amazing jungle of *totorā* that had taken advantage of the wetness and grown more than 3 meters tall and across to the center of the lake.

When times are drier, the *totorā* stays near the muddy edges of the lake.

But it is the symbiotic relationship between *totorā* and *polygonum* that allows for the expansion of *totorā*. When rainfall comes, it holds for a while on the top of the mat and allows the rhizomes of the *totorā* to spread and hold onto the threaded *polygonum* plants that weave the floating mat. As the *polygonum* reaches out horizontally across the holes in the mat, the *totorā* continues to follow. Ferns and *totorā* are dominant during wet periods. *Polygonum* is the plant that appeared in the pollen record some 3500 years ago, shortly

after the lake desiccated. When the rains returned, the *polygonum* grew across the surface and dominated the pollen record.

During times of drought, the aquatic and terrestrial plants that dominated during wet environments became passive in the pollen record and the palm pollen became dominant. This signal from the island was that it was dry and more wind-blown pollen arrived into the lake during this time.

Ferns have a preference for cool environments with some species preferring moisture and others able to exist under a forest canopy in a dry duff. In the record collected by Christensen and Skottsberg in 1920 and in Flenley's reference collection, there are at least eight species of ferns that have a very broad collective range of tolerance. It is quite possible that some of these fern spores noted in the pollen slides were tree-like ferns living in Rano Kao.

6.12 Deforestation Not Caused by Climate Change

Ever since palm pollen was discovered in the lake sediment of Rano Raraku by O.H. Selling's palynology work (unpublished), the idea changed that the island was not really always barren and dry at all, but rather once covered with a forest of palms that thrived within a sub-tropical environment. What is known from my isotope analysis for Rano Kao is that over the past 15, 000 years there have been climate events that have been drastic both in isotope depletion (cool/dry) (9200 BP) and enrichment (hot/dry) (9274 BP). There have been noted events in both the isotope and pollen record of volcanoes (9225, 4170, 3045, 1581, 1332 BP), and 6,000 years of droughts between 9195 BP and 3500 BP. The most significant conclusion is that the disappearance of the palm

pollen occurred during an isotopic depletion in 545BP, but that was a minor event when compared to the other eight significant periods of extreme drought.

Rano Kao December 2002 drought

Rano Kao March 2005

Rano Kao March 2008 wet year 1.5 meters of rain

Figure 27 - Rano Kao 2002-2008 photographs

Rapa Nui (Easter Island) 2005 (+2.53) and 2008 (+2.68) water samples

Oxygen and hydrogen isotope compositions of precipitation and surface waters commonly define two linear relations in $\delta^2\text{H}$ and $\delta^{18}\text{O}$. Precipitation plots along a meteoric line (MWL) while surface waters undergoing vapor loss plot on a local evaporation line (LEL).

Figure 28 - Easter Island MWL and LEL

Figure 29 - Rano Kao CN data analysis

Figure 30 - Oxygen Isotope graph with trend lines

Figure 31 - Oxygen Isotope graph with events

KAO3 d18Olw Rano Kao

Figure 32 - d018lw scatterplot

KAOS	Rano Kao Carbon and Nitrogen summary										28/1.028	dominant	# of		# of pollen		
C14 Age	depth	actual depth	core #	Corg	N	C/N ratio	δ ¹³ C	δ ¹⁵ N	δ ¹⁸ Ocell	δ ¹⁸ Olw	pollen	πλάκιν τύπε	πλάκιν	πλάκιν	# of	πρεσποτεροσ επι	πρεσποτεροσ
50	8-12cm	0.08	Mat1	50.96	1.36	37.36	-25.21	2.97	29.96	1.90	fern	186	42	4			
245	88-92cm	0.88	Mat1	48.27	1.54	31.31	-25.21	1.46	30.71	2.64	fern	277	2	139			
545	115-120cm	1.15	Mat2	50.53	0.80	63.45	-25.95	-1.02	27.69	-0.30	scirpus	217	29	7			
1173	0.00	12.50	1L top	51.58	1.18	43.61	-25.99	-1.20	31.12	3.03	scirpus	243	9	27			
1200	0.15	12.65	1L 15cm	52.59	1.58	33.30	-26.87	-0.96	30.59	2.52	scirpus	212	4	53			
1236	0.35	12.85	1L 35 cm	52.11	1.42	36.61	-26.19	-0.47	29.30	1.27	ferns	226	3	75			
1273	0.55	13.05	1L 55cm	53.32	1.89	28.18	-26.92	-1.76	29.44	1.40	scirpus	200	9	22			
1304	0.72	13.22	1L 71cm	52.71	1.21	43.52	-26.26	-0.78	30.88	2.80	palm	207	11	19			
1325	1.06	13.56	2L 6cm	52.22	1.62	32.16	-27.66	-1.83	29.69	1.64	scirpus	203	8	25			
1329	1.25	13.75	2L 25 cm	47.97	1.22	39.33	-27.48	-0.39	30.40	2.33	grass	309	14	22			
1332	1.45	13.95	2L 45cm	52.13	1.19	43.70	-26.80	0.37	30.11	2.05	scirpus	207	11	19			
1376	1.65	14.15	2L 65cm	51.88	1.17	44.51	-27.10	-2.30	30.37	2.30	scirpus	262	19	14			
1581	2.00	14.50	3L top	50.52	1.20	42.19	-27.41	-2.83	29.31	1.28	ferns	218	5	44			
1698	2.20	14.70	3L 20cm	52.69	1.28	41.16	-27.87	-3.30	30.76	2.69	ferns	350	2	175			
1815	2.40	14.90	3L 40cm	52.10	1.58	32.88	-27.30	-2.32	30.46	2.39	palm	257	8	32			
1979	2.60	15.10	3L 60cm	52.39	1.39	37.79	-27.73	-2.76	29.71	1.66	ferns	208	4	52			
2213	2.80	15.30	3L 80cm	56.48	2.20	25.74	-27.06	-2.78	29.57	1.53	ferns	213	3	71			
2401	2.96	15.46	3L 96cm	57.19	2.24	25.52	-26.91	-3.19	25.41	-2.52	ferns	208	16	13			
2471	3.02	15.52	4L 2 cm	55.99	2.12	26.40	-27.04	-3.22	31.25	3.16	ferns	163	17	10			
2659	3.18	15.68	4L 18cm	53.21	2.12	25.08	-28.09	-2.04	31.82	3.71	scirpus	202	9	22			
3045	3.40	15.90	4L 40cm	55.99	1.60	34.99	-28.90	-3.49	28.65	0.63	palm	202	17	12			
3443	3.60	16.10	4L 60cm	56.48	1.12	27.45	-27.61	-3.13	30.69	2.61	scirpus/palm	222	6	37			
3448	3.80	16.30	4L 80cm	56.35	1.74	32.44	-27.85	-2.21	30.83	2.75	palm	219	12	18			
3452	3.98	16.48	4L 98cm	55.73	1.63	34.29	-27.33	-1.98	30.56	2.49	fern	201	19	11			
3454	4.05	16.55	5L 5cm	54.98	1.44	38.32	-27.55	-1.95	31.10	3.02	polygonum	252	18	14			
3459	4.25	16.75	5L 25cm	56.27	1.22	46.18	-27.48	-2.73	31.42	3.32	palm	161	20	8			
3464	4.45	16.95	5L 45cm	55.13	1.15	48.11	-26.72	-1.21	32.12	4.01	palm	216	17	13			
			5L 50cm								polygonum	199	19	10			
4170	4.65	17.15	5L 65cm	57.40	1.32	43.39	-27.66	-0.08	27.50	-0.48	ferns	281	2	141			
5443	4.85	17.35	5L 85cm	54.88	1.05	52.22	-27.99	1.70	31.59	3.49	palm	173	36	5			
6525	5.02	17.52	6L 2cm	55.86	1.30	43.12	-27.51	-0.08	30.21	2.15	fern	121	18	7			
7670	5.20	17.70	6L 20cm	54.46	1.22	44.58	-27.87	0.76	31.25	3.16	palm	47	38	1			
8438	5.40	17.90	6L 40cm	54.91	1.19	46.16	-27.68	-0.60	30.41	2.34	fern	192	18	11			
8589	5.60	18.10	6L 60cm	53.62	0.94	57.30	-27.13	0.92	31.70	3.60	scirpus	223	19	12			
8741	5.80	18.30	6L 80cm	56.07	1.31	42.91	-27.92	-1.97	31.54	3.45	scirpus	99	19	5			
8885	5.99	18.49	6L 99cm	54.22	1.05	51.69	-28.41	-1.37	30.12	2.06	scirpus	245	10	25			
8915	6.03	18.53	7L 3cm	54.54	1.06	51.25	-28.10	-2.09	30.60	2.53	fern	48	20	2			
9044	6.20	18.70	7L 20cm	53.63	1.03	52.34	-28.05	-1.87	30.50	2.43	fern/scirpus	191	32	6			
9195	6.40	18.90	7L 40cm	55.16	0.95	57.99	-27.91	-1.11	31.85	3.74	cyperus	214	27	8			
9225	6.60	19.10	7L 60cm	54.53	1.21	45.10	-27.74	-0.65	17.83	-9.90	scirpus	207	38	5			
9241	6.80	19.30	7L 80cm	56.64	1.52	37.24	-28.54	-2.20	31.42	3.32	fern	194	16	12			
9255	6.97	19.47	7L 97cm	56.46	1.81	31.16	-28.16	-0.99	31.71	3.61	scirpus	166	17	10			
9260	7.03	19.53	8L 3cm	53.77	1.09	49.42	-28.26	-1.11	30.38	2.32	fern	218	18	12			
9274	7.20	19.70	8L 20cm	53.09	0.80	66.11	-28.79	-1.66	33.40	5.26	fern	196	20	10			
9290	7.40	19.90	8L 40cm	53.74	0.88	61.20	-28.53	-1.57	33.05	4.92	fern	210	3	70			
9306	7.60	20.10	8L 60cm	54.87	1.01	54.33	-28.59	-1.46	32.73	4.60	palm	48	18	3			
9345	7.80	20.30	8L 80cm	57.10	1.47	38.72	-28.67	-0.80	31.54	3.45	grass	101	35	3			
9484	7.97	20.47	8L 97cm	60.28	1.84	32.68	-29.21	0.91	25.22	-2.70	fern	201	13	15			
9550	8.05	20.55	9L 5cm	58.96	1.80	32.80	-28.63	0.56	27.61	-0.38	palm	271	12	23			
9674	8.20	20.70	9L 20cm	61.14	2.46	24.83	-22.70	-1.05	21.25	-6.56	palm	227	12	19			
11393	8.40	20.90	9L 40cm	58.82	1.85	31.88	-29.88	0.69	20.76	-7.05	fern	201	5	40			
11952	8.60	21.10	9L 60cm	55.51	1.88	29.47	-28.66	0.55	22.77	-5.09	triumfetta	277	14	20			
12511	8.80	21.30	9L 80cm	50.20	1.92	26.22	-25.44	-0.02	12.57	-15.01	triumfetta	199	3	66			
12930	8.97	21.47	9L 97cm	52.74	2.23	23.69	-23.30	-0.05	15.45	-12.21	triumfetta/palm	175	6	29			

less than 100 pollen

enriched O18 high evap (dry/hot)

depleted O18 low (wet/cool)

wet

dry

less than 100 pollen
 enriched O18 high evap (dry/hot)
 depleted O18 low (wet/cool)
 wet
 dry

Figure 33 - Isotope summary with pollen data

Climate Change Timeline Rano Kao 15,000 yrs BP to Current (2008)				
Zone	C14 yrs BP	O18	Sed Rate	Climate Preference
15	245-50	(+2.64)-(+1.80)	9.8yrs/cm 195 yrs	wet/warm
	545-245 *event 8	(-0.30)-(+2.64)	15yrs/cm 300 years	cool event increasing to modern
14	1173-545	(+3.03)-(-0.30)	unknown 628 yrs	Hot dry to cool event
	1236-1173	(+1.27)-(+3.03)	1.6yrs/cm 63 yrs/40cm	hot/dry
13	1304-1236	(+2.80)-(+1.27)	1.7yr/cm 68 yrs/40cm	humid towards cool
	1376-1304	(+2.30)-(+2.80)	0.9 yrs/cm 72yrs/60cm	wet
12	1698-1376	(+2.69)-(+2.30)	8yrs/cm 322 yrs	similar to modern day but cooler
	2213-1698	(+1.53)-(+2.69)	8.6yrs/cm 515 yrs	wet
11	2401-2213 *event 7	(-2.52)-(+1.53)	9.4yrs/cm 188 yrs/20cm	oscillating back to warm
	2471-2401	(+3.16)-(-2.52)	3.5yrs/cm 70 yrs/20cm	hot/dry to wet/cool
10				

Description:

The last 3 years between 2005 and 2008, water was collected and evaporation rate increased from (+2.53) to (+2.68) with an increasing hot and high evaporation trend.

At 545BP a cool event was noted. Pollen count was below 100 which indicates extremely dry as well. Things became warmer over the next 300 years, but due to sparsity on the samples of this mat it is difficult to determine how long the cool event took to occur and leave. This time period aligns with the Little Ice Age event noted in global climate change. At 245BP conditions were close to modern day conditions at the island.

Between the top of the sediment core at 1173 and the bottom of the mat 605, nothing is known in the core. Although 605 the pollen analysis indicates warm and wet as polygonum and scirpus were plentiful as well as palm pollen. Palm pollen disappears after this time period at 545.

Over these 63 years things became hot and dry again, leaving scirpus as the dominant species in the moisture of the lake.

Becomes more humid trending towards cooler and wet with ferns dominating this time period. Ferns are indicators of the mat being wet as noted in the 2008 expedition discovering 1.5 meters of water holding from the winter rains on top of the mat and the ferns being abundant. There are times when terrestrial ferns under a forest canopy were also abundant in the core during drier times. Nothing these differences determine allies such as trees, and the floating mat conditions.

Between 1376 and 1304 things stay wet and rainfall is collecting in the lake. The mat lifts around this time period. It is noted in the 1332 sample that tephra is present. In 1304 there is a hot peak that returns within 30 years to previous conditions with tephra also noted in this sample.

In 1698 a warm and humid peak is reached and the pollen record is plentiful. In 1581 a sharp decline to (+1.28) recorded at the same time Krakatau erupted in 419 AD, although the 535 AD event also may have had some influence in this depletion. 200 years later the environment is staying consistently in a flux of wet/humid. In the 1332 BP sample tephra is found to correlate with many volcanoes documented to be over 4 VEI which may have had an affect on the island including Vesuvius.

After event 7 becomes more enriched a lull happens for a couple hundred years and then a peak is reached at 1698 (+2.69) with fern as dominant species. This period is warm and evaporating but has a forest canopy to provide the terrestrial ferns flourishing in the humidity.

An oscillation back to warm and humid, but not as hot as today's conditions. Things are mildly wet. Low mineral in the sample at 2401 which is the depletion noted of event 7. Previous to 2401 is a noted 2420 plague of Athens that is precessed with a global warming event at 2460. Things in 2471 humid and warm with ferns being the dominant species. Rainfall is collecting in the lake and is forming what would later become the floating mat of polygonum and totora.

Figure 34a - Climate change profile (zones 15-10)

9	3045-2659 *event 6	(+0.63) - (+3.71)	19yrs/cm 386 yrs/20cm	humid to hot evap	Scirpus becomes dominant species and the lake continues to fill. 2659 reaches a hot/dry peak and enriched 018. It is noted in 3045 as event 6 that has a sharp depletion and oscillation back to hot/dry in 2659 within 400 years. Volcanic glass is also noted in 3045. Previous to the 3045 date its is noted in climate history that the LaMarche tree ring data showed a sharp cold decline in their data about this same time period.
	3443-3045	(+2.61) - (+0.63)	135 yrs/cm 2702 yrs/20cm	dry	Conditions begin around normal and become cooler but remain dry with palm species dominant. The lake is still a bog with scirpus and polygonum.
	3464-3443	(+4.01) - (+2.61)	0.25 yrs/cm 21 years/100cm	dry	Things in 3464 are hot and 018 is enriched. Evaporation is occurring and over 100 cm of deposit is noted during this dry time til the decline in 3443. Although climate is becoming more stable during this time, there are very curious things happening in the lake during this time period. Including the missing 4.5 meters of sediment in KAO6 taken 150 meters from the edge, that date to the same depth in KAO3 at the center of the lake.
7	4170-3464 *event 5	(-0.48) - (+4.01)	35yrs/cm 706 yrs/20cm	cool/dry	Following the cool dry event of 4170 noted as event 5, the world has also noted and called this similar event as the 4.2k climate event, where things were so dry that Saharan dust was found in sea cores. Over the next 700 years things became warmer/wetter to dry and hot again. Polygonum first appears in the core at 3464 and begins to grow across the lake/bog that was dessicated. Polygonum became dominant species in the lake 10 years later. It is also noted during this time period that the only obsidian found in the sediment samples is found during this time at 3464. The flakes were fractured without any eroded corners lending to airborne entry or being carried into the lake by a connected thermal vent perhaps that may be the formation of Maunga Orito the obsidian mound NE of the crater.
	5443-4170	(+3.49) - (-0.48)	64yrs/cm 1273 yrs/20cm	Extremely dry	Sometime around 5000BP the lake became dessicated. Hardened soil was found in the core, with pieces of obsidian. And foliwing is a cool/dry event of 4170. Palm dominant changed to fern dominant and stayed dry. Conditions over time become more humid and raining sporadic as things gete closer to 4170 which also align with global events that note a hot dry peak around 5200 then decline to floods and then a cool/dry event called the 4.2k event. There are many volcanoes around this time period that may have had an affect. Monte Burney in Southern Chile with a VEI of 5, Galunggung in Java, perhaps Long Island NE of New Guinea with a VEI of 6+.
6	9195-5443	(+3.74) - (+3.49)	21 yrs/cm 3752 yrs/180cm	dry	Conditions stay on the dry hot with most samples being less than 100 pollen count during this time period. Lowest isotope unit during this time is (+2.06) which is more humid than current conditions today. The Global event of 8.2k is noted as causing drought and cold temperatures around the world is noticed in Rano Kao nearly 200 years previous to this.

Figure 34b - Climate change profile (zones 9-6)

5	9225-9195 *event 4	(-9.90) - (+3.74)	1.5yrs/cm 30 yrs/20cm	hot dry	Between 9241 and 9225 is a noted volcanic event that last 16 years with cool/dry microclimate on the island. Tephra is noted in the core. The total event from (+3.32) to (-9.90) and back to (+3.74) is 46 years. Change is drastic and returns back to hot dry conditions. In 9195 the dominant species is cyperus which grows like a low grass on the mat when conditions are dry and hot. Volcanic events during this time period include Popocatepetl in Mexico and Karkar NE of New Guinea which are close proximity.
	9241-9225	(+3.32) - (-9.90)	0.8yrs/cm 16 yrs/20cm	hot to cool/dry Most extreme cold/dry event in whole 15k	A sharp depletion during this volcanic event noted at 9225. Changes from hot/dry to wetter, and then cool/extremely dry. Change is drastic.
	9260-9241	(+2.32) - (+3.32)	0.5yrs/cm 19 yrs/40cm	Wet	This get cooler around 9260 with rainfall. Scirpus is dominant. Dry soils erode with rains into the lake.
	9274-9260	(+5.25) - (+2.32)	0.7 yrs/cm 14 yrs/20cm	cool/dry	In 9274 things reach the hottest point in the entire natural history record of Rano Kao in the last 15k years. Fern is dominant species under the forest canopy. Lake is open at this point with no floating mat.
Trendline 2 9274 - current					
4	9274 yrs 840cm	(+5.26) - (+2.53)	9274 yrs 840cm	Hot to cooling and increasing moisture	Beginning with the hottest peak in the last 15k year natural history of Rano Kao til now the trend is towards cooling and wetter.
	9484-9274 *event 3	(-2.70) - (+5.25)	2.6yrs/cm 210 yrs/80cm	cool dry to major warming event	After the LGM ends and is noted in the core around 12511, warming increases with another depletion that notes the Younger Dryas and then continues to warm to the peak hot event of 9274 knows as event 3 in this core.
	9550-9484	(-0.38) - (-2.70)	3.3yrs/cm 66 yrs/20cm	wet warm to cooling event	Beginning around 9550 things decline for a short cool event and the slowly increases over the next few hundred years as things emerge from the end of the Younger Dryas event that is noted in North America is also noted in this core as event 2.
	9674 - 9550	(-6.56) - (-0.38)	6.2yrs/cm 124 yrs/20cm	dry to warmer	
2					
2	11952 - 9674 *event 2	(-5.09) - (-6.56)	57yrs/cm 2278 yrs/40cm	cool/dry	Noted in climate history as the possible Younger Dryas event as the lake is open and cool, a decline occurs for approximately 1500 years til things begin to warm and get wetter.
	12511 - 11952	(-15.01) - (-5.09)	28yrs/cm 559 yrs/20cm	cool/dry	Gradual increase in temperatures. Things continue to be cool and dry with a triumfetta forest with Jubaea and at least 3 other palm species covering the island.
	12930-12511 *event 1	(-12.21) - (-15.01)	21yrs/cm 419 yrs/20cm	becoming drier	The end of the LGM the lake is cool and dry, with a forest of triumfetta covering the crater and possibly the whole island. Climate is warming and the core is showing a sharp and steady increase to warming. In the lake algae and cyanobacteria are fixing nitrogen.
	Trendline 1 12930 - 9274	(-15.01) - (+5.25) Depleted to enriched	3656 years 200cm	cool to dry to wet then hot dry again	3656 years of increasing trend from cool/dry to wet then hot dry. Triumfetta forests prefer a cool environment and as things get warmer triumfetta then becomes less dominant to the more drought resistant broad range of tolerance palm trees that existed on the island for the next 12k years.

Figure 34c - Climate change profile (zones 5-1)

Chapter 7 Palynology and Ecological Change

7.1 Pollen

Hyde and Williams first introduced the term *palynology* in 1944. This new terminology expanded to cover a wider aspect of study, taking into account not only pollen, but other resistant microfossils as well: diatoms, cryptogam spores, and animal remains among others. In 1950 Faegri and Iverson established the basic techniques used today for reconstructing former vegetation by means of the pollen grains that it produced. In the beginning these tests were limited to the study of Quaternary lake and bog deposits with the objective of reconstructing Late-Quaternary changes in vegetation (Faegri, 1950). Today pollen is analyzed from various sources of sediments including oceans, lakes, and soils, with the pollen having been transported by water, wind, birds, animals, insects, and people. The pollen analysis can cover very broad periods of time and provide for inferences regarding diverse environments.

The identification of pollen grains to the lowest possible taxonomic level, usually genus, is a difficult and long process. Pollen sizes range from 10 to 100 microns, and identification is limited only by the microscope being used. Automation counting and scanning are available but do not have the reliability of the subjective and educated analyzer.

Generally all flowering plants have an abundance of pollen, which are affected by environmental conditions. Because of their micro size, pollen grains are more evenly dispersed than macrofossils and have a greater possibility of capture. Counting pollen grains as they are found in deposits is a way to statistically analyze abundance and appearance of plant species. Fossil pollen is very durable, remaining for thousands

of years in lake sediments. Environmental conditions affecting the pollen can also be detected in that certain fungi present, such as chytrids, will eat holes in the pollen as noticed in some of the KAO3 samples. The observation of fungi patterns contributes to a greater understanding of the lake's ecology.

For the KAO3 core, sub-samples were taken at 10cm intervals and processed according to the standards of Faegri and Iverson (1989). These samples, eventually becoming micro slides, were then used to count and identify all pollen, charcoal, starch, minerals, fungi, and other non-pollen palynomorphs found in the core. A standard pollen count for Rapa Nui was generally between 200-300 pollen per sample, which is sparse. Sometimes more than one slide was necessary when all transects were counted and the pollen was still below desired pollen counts. All of these data have been put into summary form in Appendix A, which is a photo catalog of more than 1559 images captured from the 90 samples. Appendix F includes the absolute pollen count sheets.

7.2 Processing Sediment for Pollen at Massey University, New Zealand

In March of 2005 we retrieved 20 meters of sediment from the lake Rano Kao, as described in Chapter 4. The core KAO3 was taken very near the center of the lake and is 9 meters in length including 2 meters of floating mat above the lake sediment. This core is the source of the data in this research. After the scanning and initial core descriptions were conducted, one half of the split core was archived and the other half was sub-sampled at 10cm intervals. In July 2005, I arrived with the 90 samples at Massey University in Palmerston North, New Zealand to work in John Flenley's lab processing the samples for pollen.

Working under Flenley's guidance, the KAO3 samples were chemically processed according to the standards and procedures of Faegri and Iverson (1950). One step in the procedure requires the use of hydrofluoric acid (HF) to dissolve carbonates in the soil samples. The HF step was conducted on a test sample and determined not necessary for the samples from Rano Kao because the sediments contained no carbonates. As HF is a very dangerous and highly corrosive acid, the lack of carbonates in the soil allowed us to leave it out. By omitting the HF process, which generally strips the samples of anything other than pollen, we produced samples that contained non-pollen objects, or *palynomorphs*, including plant parts, resin, lignin, algae, chitin, and starch, that would have otherwise been dissolved. These remnants often make counting pollen difficult but provide a more complete picture of the ecosystem. For process and methods of pollen analyzing, see Faegri and Iverson (1989) *Textbook of Pollen Analysis, IV Edition*.

7.3 Identifying and Creating the Reference Collection

Once the pollen slides were ready to be analyzed, a reference library for the Rapa Nui pollen was the next crucial step. The work then moved to the Department of Ecology at the University of Minnesota. Under the direction of Dr. Edward Cushing, Professor Emeritus in the department, I collected a reference library of pollen from his broad collection including Java and the South Pacific. For any pollen or palynomorph we found in the slides that appeared to be unknown, we methodically worked to determine the species and genus of every pollen, starch, animal, resting sacs, or algae through scholarly correspondence with other scientists, the Australasian Pollen Index, and various herbariums around the world. The herbarium at the university was also very helpful for many plants that still contained pollen and root materials for starch.

In order to answer some of the unknown questions particularly about the palm pollen, first we had to create a reference collection of pollen that was known. Two specimens were gifted to us to process and create reference slides. The first was from Kew Royal Botanical Gardens in Richmond, Surrey, England. Dr. William J. Baker, head of Palm Research, sent flowers from the Temperate House *Jubaea* palm, as no male flowers were found in the Kew herbarium. He also sent along five species of *Pritchardia* since that is the pollen type that O. H. Selling had first identified in the lake sediment cores at Rano Raraku (Heyerdahl, 1965). The second set of flowers was sent by Gloria Rojas Villegas from the Museo Nacional de Historia Natural in Santiago, Chile, from a *Jubaea Chilensis* dated 31 October 1901. Reference slides and photos were made of the pollen variations and are located in the Reference Slides section of Appendix E.

The remaining pollen types were referenced from species documented in the UMN slide library. Starch references were made from modern-day taro, sweet potato, yam, and totora (collected at the lake) to help identify the numerous starch grains observed in the samples of the KAO3 core. New exotic species that had not been identified by Flenley were also researched and included in the reference pollen sheets in Appendix E as well as in the images files of Appendix A.

7.4 Pollen Diagrams

Analyzing pollen requires simultaneous counting and identifying, a laborious task. Once all 45 samples (20cm intervals to match the isotope analysis) were counted using count sheets, notes, and photographs, the data were placed into a spreadsheet. For my diagrams I used Cushing's program *Psidium* 1.0B4, which he wrote and operates on Macintosh. At the end of this chapter are the pollen and spore diagram sheets, which have been

grouped in various stages according to aquatics, trees, shrubs, grasses, and ferns, as well as charcoal and the palynomorphs. The diagrams are in vertical columns with the top of the page representing the top of the core and calibrated in meters following the depth of the core. Across the top margin are the categories and names of species. Quantities are measured in percent of total pollen counted. Some of the diagrams measuring sedimentation rate and pollen influx are absolute counts as noted.

Once these diagrams were completed, this information was then coordinated with the isotope graphs. Matching the pollen data to the isotope analysis gave greater detail to environmental changes for both Rano Kao and the island. The raw sediment was also screened for seeds, plant parts, rhizomorphs, rootlets, algae, fungi, minerals, chitin, and charcoal. The combination of macrofossils, pollen, and isotope data provided a foundation for describing the ecological changes taking place on the island.

7.5 Plants as Climate Indicators

Patterns became evident after analyzing the pollen, macrofossils, and isotope data. Trends seen in plant adaptation offered evidence of climate events including drought and rainfall. Plant allies also helped explain how the ecosystem dynamically responded to dry and wet conditions. For example, the *totorā* and *polygonum* are both aquatic allies. When climatic conditions are wet, the *totorā* grows across the mat, and when it is dry it retreats to the margins and the *polygonum* becomes more dominant. Patterns in the pollen record reflected these changes as abundance and decline of pollen. Grass is indicative of a dry landscape; ferns relate to wetter situations.

Palm pollen also showed noticeable trends in drought and wet periods. As the island

became dry, the palm pollen became relatively more abundant in the core. Two causes are possible: increased wind during drought may have carried more airborne palm pollen into the lake, or the aquatic plants may have become less dominant during drought.

Pollen size was an indicator for identifying native and non-native species as separated according to Flenley's observed results and plant identifications (1991). The total pollen counts as well as types of species and their range of tolerance clearly helped give greater detail for environmental conditions as well as define certain ecosystem changes.

7.6 Non-Pollen Palynomorphs and Macrofossils

van Geel, the world's expert in identifying non-pollen palynomorphs in peat bogs (2001), recognized the value of materials that palynologists typically removed from their pollen samples and began looking at non-pollen palynomorphs as plant allies. This included zygnemataceous spores, cyanobacteria, fungal spores, rotifer eggs, chitin, minerals, and everything else that appeared as unexplored fossils that would be useful as paleoenvironmental indicators.

In KAO3, I followed the form of van Geel to place the morphological descriptions of the "extras" into stratigraphic information aligned with the pollen and macrofossil diagrams. For Rano Kao, there is no established taxonomic or ecological documentation of the non-pollen palynomorphs. My correspondence with van Geel uncovered only one fungi type that he was able to recognize among the hundreds found in the KAO3 core. The palynomorphs for the KAO3 core have been counted and given ordinal numbers of abundance and diversity in the diagrams. Further work on these non-pollen palynomorphs will continue along with the future pollen analysis of Rano Kao (*see Figure 36*).

7.7 New Discoveries

7.7.1 Palm types

When O. H. Selling (1958) discovered the palm pollen *Pritchardia*, it was not known that an even greater palm tree existed on Easter Island. Selling's work introduced a palm species and the idea of a palm forest on the island, which was now extinct. It was Flenley in 1984 who conducted the first study of the palynology of the crater lakes. He discovered a palm similar to *Jubaea chilensis*, now referred to as *Paschalococos disperta*. The finding of these pollen types gave a new understanding about the island trees that existed prior to human arrival. The questions about the palm forests were investigated by Meith and Bork (2010), who uncovered ancient root moulds and calculated that at one time there may have been over 16 million palm trees on the island. This information changed the history of Rapa Nui.

Four distinct palm pollen were revealed in the KAO3 core. The one closest to *Jubaea* is identified here as Type 1, the largest fossil palm pollen found in the core. Type 2a is a rounded palm pollen; Type 3 is much smaller than *Jubaea* without the rounded hooked end; Type 4 is a very distinct pointed-end pollen. None of these are *Cocos nucifera*, which came later with human arrival. (Photos of these pollen types are located in Appendix A and E.)

Since the discovery of the *Jubaea*-like fossil pollen and the endocarps in the lava cave (Flenley 1991), there has been additional research as to whether this tree is actually the *Jubaea chilensis* or a similar but different species. Because it is extinct, we will never know, so it has been given its own name: *Paschalococos disperta* (Dransfield, 1984).

7.7.2 *Polygonum* and *tatora* – plant allies

As noted above, *Polygonum acuminatum* and *tatora* (*Scirpus californicus* now named *Schoenoplectus californicus*) are plant allies. They live and thrive together on the boggy lake margins and take advantage of the changing climate of Rano Kao. *Polygonum*, a dicotyledon, is a very aggressive sun-seeker. It has shallow rootlets and requires an enmeshing within the rhizomes of the *tatora* to gain hold and move across the lake surface. The *tatora* is a water plant that prefers rainy periods and wet saturation of the mat. When rainfall is heavy, the *tatora* will migrate towards the center of the lake. The preferences of these plants provide evidence regarding the changing climate effects on Rano Kao. In the fifth meter of core, dated around 3500 BP, *polygonum* entered the pollen record for the first time. It quickly took advantage of the empty desiccated lake surface and grew across the lake. When rainfall followed, the intertwined root masses of *polygonum* with its shallow footing could not withstand the pressures of increasing water in the lake and lifted from the old hardened surface now covered with water to form the floating mat sometime around 1200-1800 BP as identified in the cores, pollen analysis and radiocarbon dates. This floating mat identifies a time period when the lake surface changed.

7.7.3 Exotics

Exotic unknown pollen types stand out on a micro slide. To the palynologist, it is like discovering a black marble in a pile of white ones. In KAO3 there were many exotic pollen types that may not show up on the pollen diagram as significant. But one or two in a sample compared to 80 palm pollen in that same sample generally infers that there are more of the palm trees. This is not always correct; pollen abundance varies with each vascular plant, and some trees may produce much and some little. Distance from

repository also makes a difference in how many will land in the lake. Perhaps some of the exotic pollen were never on Rapa Nui but traveled across the Pacific Ocean from Asia in dust plumes or arrived in volcanic ash from South America. These possibilities must be considered, but the presence of the exotics cannot be ignored.

The most abundant unidentified pollen type was a tricolpate. This pollen appeared as early as 9000 years BP and kept a presence throughout the pollen record along with an unidentified diporate. Upon conferencing with both Cushing (UMN) and Matthew Prebble from the Australian National University, I determined that this may be another unidentified palm.

Coprosma appeared early in the record, about 11952 BP, and *Xylosma* came in at 9550 BP when the Younger Dryas was gone and warming was occurring. *Caesalpinia* appeared in the 9255 BP sample. *Portulaca*, *Inocarpus*, and *Chenopodium* all appeared in the sample dated 9225 BP; perhaps they came along for the ride on the great volcanic event that caused the lowest depletion in the KAO3 isotope record. *Cordyline* was noted in the sediment at 9040 BP along with large amounts of mineral. *Canavali*, along with *Caesalpinia* and *Coprosma* was noted at 4170 BP, the time of another depletion and volcanic event.

Ephedra is a conifer tree and was noted along with introduced grass, high charcoal, and obsidian in the core about 3460 BP, at the time of the lake desiccation. *Myrsine* appeared at the 4L15cm level, which dates to 2660 BP. *Quercus* pollen, which is in the oak family, appeared around 1170 BP, by which time humans had arrived (see Figure 37).

7.7.4 Fungi and other plant allies

Because fungi were abundant in all sections of the core, I created a taxonomy for the types of fungi and then gave them ordinal abundance and diversity ratings between 0 and 5 (see *Figures 36 & 37*). The most common fungal type was a scabrate gourd-shaped specimen. It is unknown what the ally and connections are to the plants, but there is a correlation between the climate data and the abundance of fungi types; when the climate is warm, fungi become more abundant. Therefore, the fungi were used as an extra measure in this research to quantify cool and warm periods.

7.7.5 Algae, cyanobacteria, and others

Algae were noted in the split core scans. There was a distinct point at the 8.5-meter mark where layers of yellow and light green material resembled what we thought were clay layers. But upon further study, the layers were determined to be algae and pollen dated between 11,000 BP and 15,000 BP. In the samples, these were called “gyttja” or dung mud, which is spongy and very difficult to break apart. There were two types of algae seen in these samples: single-cell algae that were light and reflective and often floated, and algal masses with zygamorphs present. Dinoflagellates were also present in these samples when the lake was cool and without a floating mat; the planet was coming out of an ice age, and the lake was fixing nitrogen. As things warmed, these algae seemed to disappear and eventually changed forms when the vegetation mat grew across the lake surface. Many animal resting sacs were also noted. Therefore, it followed over time that when the climate was cool, algae tended to be more present, and when the atmosphere became warmer, fungi would become dominant.

7.7.6 Resin and lignin

A curious plant matter appeared in the early micro slides and continued to be found throughout the core, sometimes in great abundance. This material was counted in the non-pollen palynomorphs according to abundance and diversity. They are called *resin* here but the chemical composition of these pieces and which plant they came from are unknown. Some palms have also been found to have a lignin present as starchy material in the roots. There is diversity in the shape and color of these pieces. At first, this resin was thought to be phytoliths as some carry the character of a leaf or organic stamp, but others are just formless. Without chemical testing, it cannot be determined what this is other than plant solidifications that trend with warming and drying conditions. They are in great abundance during the driest parts of the core (*see Figure 37 and pollen images for each sample in Appendix A*).

7.7.7 Chitin and insects

Last of the discoveries was a mite in whole form flattened in a pollen slide at 4L 95cm dated to 3450 BP. This is the time period of the lake desiccation, where large charcoal pieces were discovered as well as the obsidian flakes and the large grass pollen. Other chitin and insect parts were also discovered in the raw sediments among the macrofossils. Many parts and shapes and varieties were analyzed, counted, and photographed (*see Appendix A*). Beetles have been used to help determine climate change, and I believe that with more study of these chitins, both types and counts, they too will be useful in helping to understand the ecology of Rano Kao.

7.8 Pollen Summary

The Pollen Summary chart on the following page lists all 45 samples, their radiocarbon dates, oxygen isotope ratio, dominant pollen for that sample, the exotic count in comparison to the total pollen count, the number of transverses for each slide, the number of pollen per transverse, and the total charcoal.

Radiocarbon dates: There were 20 radiocarbon dates conducted on this KAO3 core. Therefore, extrapolations between these dates filled in an approximate date for each sample. The dates are in ^{14}C dates as years before present (BP).

$d^{18}\text{O}_{hw}$: The oxygen isotope ratio from the cellulose inferred lake water samples was processed from one split half of the five cubic centimeter (5cc) raw sediment sub-sample. Therefore one half was used for isotope analysis and the other half for pollen.

Dominant pollen: For each sample that was counted, the pollen type that was most abundant in that sample was noted as the dominant pollen.

Pollen count: The target count per sample was 300 pollen, and generally the first 300 were counted. This method of scanning poses many questions as to whether there may have been missed pollen types that came after the count was completed. Therefore, the entire slide was scanned but only the first 300 pollen, along with everything else along those transects, were included in the final count for that sample. A target count could sometimes not be filled even after scanning three slides. In these cases the total pollen counted is listed in this column.

Lycopodium: A *lycopodium* (fern) exotic marker was placed into the pollen processing procedures. This marker is easily recognizable and does not occur naturally in the samples. The marker is used to compare counted pollen grains to a known standard of exotic pollen grains per 1cc of soil sample. This step in the process, scientifically calculated, is used to determine total pollen influx, deposition time, and pollen concentration, factors that help determine whether the environment was wet or dry. *Lycopodium* spore tablets were used as the exotic markers added into the pollen processing and are from (batch 938934), where $X=10,679$ spores per tablet. One tablet per 1cc sample was used.

Number of transverses and number of pollen per transverse: Each slide used to count pollen was measured with coordinates under the microscope. Each transverse was marked and the mechanical stage was shifted two diameters of the field of vision perpendicularly to the first direction of movement and then returned. Therefore in these columns, it is noted how many transverses were needed to count the total amount of pollen for this sample as well as how many pollen were counted per transverse. In some cases we were able to count 300 pollen types over only 3 transverses, while others took 40 transverses. Factors that affect these differences are drought and a lack of pollen types, high mineral load that displaces less pollen for more minerals in the solution, or high abundance of pollen when conditions are wet and plants are thriving.

Total charcoal: Charcoal is a useful proxy to determine both natural and human causes of plant matter being burned. This column is total charcoal, but in order to determine local from distant sources, the classes of charcoal must be referred to. Class 1 is smaller than 25 microns, class 2 between 25 and 50 microns, class

3 between 50 and 100 microns, and class 4 represents a size greater than 100 microns. High charcoal content represents burning of organic matter, the smaller the charcoal the more ash-like is its source. The larger pieces of charcoal are from local sources.

Ecological Discoveries of Rano Kao by 20cm intervals of KAO3

Zone	Sample	C14 yrs BP	O18	Climate Preference	Description:
15	Mat 1-5cm	Modern	(+1.80)	wet/warm	Scirpus dominant species with polygonum and unid tricolpate and diporate charcoal present.
	Mat 1-35cm				Polygonum, scirpus, solanum and microlepia. Large charcoal >200um.
	Mat 1-85cm	245	(+2.64)	climate similar to modern	
	Mat 1-90cm	345			Low pollen count some scirpus. Large amt. charcoal in slides some >200 um
14	Mat 2-105cm	445		wet or cultivation	High pollen, scirpus with high solanum introduced at this time. Some charcoal
	Mat 2-115cm	545 *event 8	(-0.30)	cool/dry	Last triumfetta pollen in core none found after this time period. Last citing of Palm pollen found in core, none found after this time period. Some charcoal
	Mat 2-155cm	605		wet or cultivation	Palm, polygonum, scirpus all plentiful. Unid diporate and tripcolpate.
13	1L3cm	1173	(+3.63)	Warm/drier	237 pollen 98 lycopodium 9 transverses 62 pieces of charcoal in slide Vitis, round tricolpate, quercus, polygonum variant 30 native grass, scirpus, sophora, triumfetta, asteraceae
	1L10cm	1200	(+2.52)	Modern day warm	225 pollen 52 lycopodium 4 transverses 178 charcoal, 14 > 100 um 26 cynadon pollen, burned plant and wood in pollen slide sophora, scirpus, all palm types
	1L30cm	1236	(+1.27)	cooling	226 pollen 30 lycopodium 3 transverses 5 charcoal, 29 > 40um grass, 28 < 40grass 95 psilate ferns, triumfetta, sophora, 45 starch algae med
	1L55cm	1273	(+1.40)	humid	200 pollen 40 lycopodium 9 transverses Very little plant and algae, lots of transparent vaguely visible 18 cynadon, 9 charcoal, 69 starch, lots of refraction mineral scirpus dominant, Jubaea, triumfetta, sophora, inocarpus fungi diverse, 8 > 40um grass
	1L71cm	1304	(+2.80)	hotter	207 pollen 76 lycopodium 11 transverses 9 charcoal, high algae, 43 starch and no resin lots of plant material, triumfetta, sophora, broussonetia, inocarpus, scirpus and jubaea dominant. Root mass totora at bottom of core.
	2L10cm	1325	(+1.64)	cooler	203 pollen 50 lycopodium 8 transverses 44 starch, green mineral and clear w/ black, fungi diverse scirpus dominant, all palms, sophora, triumfetta, canavellia ferns and broken pollen. 16 > 40 um grass
12	2L30cm	1329	(+2.33)	back to warm/humid but cooler than today	309 pollen 40 lycopodium 14 transverses 132 > 40 um grass dominant, 69 native grass, scirpus high ferns, jubaea, fungi, algae low, 107 starch sophora and triumfetta. 16 charcoal class 1.
	2L50cm	1332	(+2.05)	cool	207 pollen 73 lycopodium 11 transverses scirpus dominant, jubaea heavily scabrate, 7 charcoal 35 starch, algae with fungi, xylosma, broussonetia, sophora triumfetta large, tephra found in slide and resin.
	2L65cm	1376	(+2.30)	warmer	262 pollen 136 lycopodium 19 transverses scirpus dominant, cyperus and polygonum thrive in warm jubaea and palms, triumfetta, sophora, spiny sacs, 180 starch, 44 charcoal, conifer and diatom suspect. Root mass bottom of core.
11	3L5cm	1581	(+1.28)	cooler	218 pollen 53 lycopodium 5 transverses 151 psilate ferns dominant, verrucate, echinate, trilete scirpus, jubaea, triumfetta, sophora, fungi-low, 73 starch woody piece with resin. Mycorrhiza, 7 charcoal, 3 > 40um grass
	3L20cm	1698	(+2.69)	warmer	350 pollen 30 lycopodium 2 transverses 295 psilate fern, verrucate, rugulate, wet, palm, scirpus, 18 charcoal, some sacs, algae low, 4 charcoal, 18 starch triumfetta, canavellia, cordyline? And low fungi
	3L45cm	1815	(+2.39)	warm	257 pollen 96 lycopodium 8 transverses new type 4 palm pollen arrives into core. 102 monolete psilate fern dominant, palm all types seen with jubaea scirpus, 52 starch, flecks of algae, fungi low, high sacs low mineral. 8 charcoal, asteraceae, triumfetta, sm. Triumfetta sophora and unidentified tricolpate.
	3L55cm	1979	(+1.66)	cooler	208 pollen 41 lycopodium 4 transverses 117 monolete psilate, round unidentified pollen, sophora, dicolpate, pteris, fungal sacs, all palms present, scirpus 5 charcoal, 23 starch, fungi low, epidermis of plant in slide possible cordyline?
10	3L 75cm	2213	(+1.53)	wet	213 pollen 37 lycopodium 3 transverses 165 monolete psilate fern, rugulate, echinate, fern clusters fungi diverse, 12 starch, resin and sacs, asteraceae, triumfetta, sophora, triolpates and canavellia. slide full of cell mass and algae
	3L94cm	2401	(-2.52)	cool/dry	208 pollen 115 lycopodium 16 transverses 165 starch, round 30 um grass, 127 monolete psilate ferns dominant, all palms, scirpus with a strange surface texture, 9 charcoal, algae low to med, fungi diverse resin, epidermis, asteraceae, triumfetta, sophora.
	4L5cm	2471	(+3.16)	hot	163 pollen 106 lycopodium 17 transverses 202 starch, scirpus dominant, all palms, monolete psilate rugulate, trilete with perispore, resin, plant parts and sacs triumfetta, sophora, and large grass pollen. 24 charcoal large, fungi med, and algae high.
	4L15cm	2659	(+3.71)	hot/dry	202 pollen 56 lycopodium 9 transverses scirpus dominant, all palms, 66 starch, blackened minerals some large algae, 19 charcoal, 21 > 40 um grass with first introduction of round 30um grass pollen, broussonetia, sophora, sapindis/elceocarpus?, monocolpate unidentified myrsine, coprosma, large plant fragments.

Figure 35a - Ecological profiles (zones 15-10)

9	4L15cm	2659	(+3.71)	hot/dry	202 pollen 56 lycopodium 9 transverses scirpus dominant, all palms, 66 starch, blackened minerals some large algae, 19 charcoal, 21 > 40 um grass with first introduction of round 30um grass pollen, broussenetia, sophora, sapindis/elceocarpus?, monocarpate unidentified myrsine, coprosma, large plant fragments.
	4L35cm	3045	(+0.63)	cool/dry	202 pollen 39 lycopodium 17 transverses lots of plant parts, 141 jubaea dominant, 21 charcoal including plant with charcoal. Some scirpus and polygonum, 249 starch, asteraceae, triumfetta, sophora. Volcanic glass fungi diverse - scabrate large dominant, algae high.
	4L55cm	3443	(+2.61)	dry and warming	222 pollen 43 lycopodium 6 transverses 29 starch, fungi diverse abundant, algae low, scirpus high, cyperus. Some ferns, 6 charcoal large, low mineral, palm high, triumfetta large and small, sophora, tricolpate.
	4L75cm	3448	(+2.75)	drier	219 pollen 171 lycopodium 12 transverses 452 starch, jubaea dominant, all types. Triumfetta, sophora, asteraceae, tricolpate, polygonum, scirpus. 111 charcoal with large pieces. Low fungi, more algae, low mineral clear spiny sacs, large plant epidermis
8	4L95cm	3452	(+2.49)	humid	201 pollen 79 lycopodium 19 transverses (2 slides) monoete psilate fern dominant under forest canopy, jubaea, scirpus, polygonum, fungi diverse, little algae, 804 starch, diverse mineral. Tephra noted. Some resin. 53 charcoal some large pieces. Most interesting find was the "bug" in the slide. The only winged fully intact mite.
	5L10cm	3454	(+3.02)	dry	252 pollen 120 lycopodium 18 transverses Polygonum dominant, palm high, scirpus, diverse fungi little to no algae, diverse mineral, 67 trilete ferns, unknown large triumfetta round pollen, 25 charcoal large pieces, some > 100 um. 1877 starch.
	5L20cm	3459	(+3.32)	dry	161 pollen 134 lycopodium 20 transverses 842 starch, palm dominant with faint color, jubaea high, small type, polygonum 6, scirpus, diverse fungi, specks of algae, 25 pieces of charcoal, clear and spiny sacs.
	5L40cm	3464	(+4.01)	dry/hot	216 pollen 96 lycopodium 17 transverses palms dominant, scirpus/cyperus, 203 starch, blackened mineral, 12 charcoal pieces large with grass pollen larger than 40 um. Polygonum, sophora, ephedra?.
7	5L45cm				nothing remarkable
	5L46cm				woody dicot frag., roots w/ algae, 8 scirpus seeds, 1 lrg unid seed
	5L47cm				rhizomorphs, rootlets, monocots, long slender leaves,
	5L49cm				15 scirpus seeds, 2 cyperus seeds, 1 large blk seed unid
	5L48cm				large polygonum root, blackend woody pieces, long seed unid 5 scirpus seeds, tipped animal chitin, 1 lrg rectangular seed
	5L49cm				large dicot leaves in clumps, small blk rootlets, 1 seed
	5L50cm			dry	199 pollen 156 lycopodium 19 transverses polygonum dominant 84, scirpus, triumfetta, asteraceae 27 charcoal with large pieces, algae stuck in plant parts 115 starch, ephedra?, podocarpus?, epidermis large pieces spiny sacs, fungi diverse,
	5L51cm				dicot dominant, harded wood frag., a lot of charcoal, dicot leaves, white solid balls clumped with dark charcoal flecks 2 large seeds larger than scirpus, 1 obsidian piece
	5L52cm				clumps of hardened dessicated soil, charcoal pieces seed case or animal sac hardened, 1 sm floating seed, 2 obsidian pieces. White mineral with soil
	5L53cm				small wood fragments, some charcoal, wood with blackened charcoal exterior, 1 round seed, sm red chitin
	5L54				wood fragments with charcoal
	5L60cm	4170	(-0.48)	cool wet tree species flourish event	281 pollen 20 lycopodium 2 transverses palm all 4 species dominant, asteraceae, triumfetta, sophora, canavellia, coprosma, caeselpinia, scirpus, polygonum, no algae, 31 starch, tephra noted. In raw sediment charcoal noted.
	5L90cm	5443	(+3.49)	extremely dry	173 pollen 343 lycopodium 36 transverses (2 slides) 399 starch, blackened mineral common, refractive, a lot of transp. Light brown round fungal sacs, terrestrial fungi high moderate algae. Lots of epidermis and transp sacs. 20 charcoal and large piece. Broussenetia, asteraceae, triumfetta. Very fine silica type particles in raw soil similar to 5L70cm.

Figure 35b - Ecological profiles (zones 9-7)

6	5L90cm	5443	(+3.49)	extremely dry	173 pollen 343 lycopodium 36 transverses (2 slides) 399 starch, blackened mineral common, refractive, a lot of transp. Light brown round fungal sacs, terrestrial fungi high moderate algae. Lots of epidermis and transp sacs. 20 charcoal and large piece. Broussonetia, asteraceae, triumfetta. Very fine silica type particles in raw soil similar to 5L70cm.
	6L5cm	6525	(+2.15)	dry	121 pollen 146 lycopodium 18 transverses palm dominant, jubaea and small type, triumfetta, asteraceae, fungi low, plant matter abundant, monoete psilate, trilete. 72 starch, pollen damaged majority of slide "sacs with worms." charcoal 25 with large pieces. Large dicot fragments.
	6L25cm	7670	(+3.16)	extremely dry	133 pollen 91 lycopodium 38 transverses (2 slides) 480 starch, low fungi. Full of mineral, resin mostly sophora, triumfetta, jubaea, scirpus.
	6L45cm	8438	(+2.34)	dry	192 pollen 81 lycopodium 18 transverses Monoete psilate dominant w/ perispore. Broussonetia, triumfetta, palms high, scirpus low, 27 charcoal, 317 starch fungi low, no algae. 5 red seeds with large see pod and red/yellow rootlets in raw sediment. Woody fragments, chitin diverse in 6L55cm.
	6L65cm	8589	(+3.80)	warm/humid	223 pollen 99 lycopodium 19 transverses 177 starch, 18 charcoal. Scirpus dominant, jubaea high triumfetta, plant parts and resin high in slide. Epidermis from unknown plant and animal sacs high. In raw sediment wood fragments and blackened root, chitin.
	6L85cm	8741	(+3.45)	dry	99 pollen 148 lycopodium 19 transverses Scirpus and jubaea high, sophora, broussonetia, unidentified di/tricolpate, triumfetta, fungi diverse. 92 starch, mineral diverse, fern spores, rugulate ferns 12 charcoal.
	6L95cm	8885	(+2.06)	cooling	245 pollen 71 lycopodium 10 transverses Scirpus dominant, some jubaea and small type palms. sophora, coprosma, sacs abundant, plant parts abundant as well as resin in slide. 82 starch, 14 charcoal pieces ferns some with perispore.
	7L5cm	8915	(+2.53)	extremely dry	48 pollen 15 lycopodium 20 transverses 27 pieces of charcoal. Monoete fern dominant, fungi diverse, 1166 starch. Sacs and epidermis in slide. scirpus, jubaea, flecks of algae.
5	7L20cm	9044	(+2.43)	extremely dry	188 pollen 85 lycopodium 32 transverses (2 slides) Volcanic glass, 185 starch, fungi diverse, 25 charcoal pieces plant matter abundant, zygomorphs and algae abundant scirpus dominant, monoete rugulate ferns, jubaea, sophora, triumfetta, cordyline?, sacs high, psilate ferns heavy reticulated, minerals with holes, leaf. Raphides, plant epidermis, resin high.
	7L40cm	9195	(+3.74)	hot/dry	214 pollen 143 lycopodium 27 transverse Cyperus cyperoides dominant. 116 starch, plant matter high resin and minerals high, ferns, triumfetta, palms high. woody fragment, diverse seeds, chitin, leaf fragments in raw sediment.
	7L60cm	9225	(-9.90)	cool/dry	195 pollen 134 lycopodium 38 transverses (2 slides) Tephra noted. Mostly resin, low algae, high fungi diverse, scirpus dominant, palm, 48 starch, resin abundant, unknown tricolpate, sophora. Raw epidermis iridescent roots, black hollow roots, floating wood frag, chitin frag.
4	7L85cm	9241	(+3.32)	dry	194 pollen 132 lycopodium 16 transverse Fern dominant, triumfetta, sophora, jubaea and type 3, scirpus low, 37 starch. Algae low, fungi diverse, 16 charcoal pieces, some resin. Large woody fragment, leaves, bark dark rhizome and seeds in raw sediment.
	7L97cm	9255	(+3.61)	hot/dry	166 pollen 109 lycopodium 17 transverses 175 starch, algae low, Caselpinia, triumfetta, sophora, some palm and unidentified di/tricolpates.
	8L5cm	9260	(+2.32)	cooler/humid	218 pollen 52 lycopodium 18 transverses Heavy ferns, scirpus high, some palm, sophora, triumfetta, 11 charcoal pieces, fungi abundant, resin high, many sacs, unidentified diportate and di/tricolpate.
	8L20cm	9274	(+5.26)	hottest event in 15k year history of Rano Kao	196 pollen 45 lycopodium 20 transverses Psilate fern dominant under forest canopy, Jubaea and scirpus, 5 charcoal pieces, 33 starch, fungi clusters triumfetta and asteraceae.

Figure 35c - Ecological profiles (zones 6-4)

3	8L20cm	9274	(+5.26)	hottest event in 15k year history of Rano Kao	196 pollen 45 lycopodium 20 transverses Psilate fern dominant under forest canopy, Jubaea and scirpus, 5 charcoal pieces, 33 starch, fungi clusters triumphetta and asteraceae.
	8L45cm	9290	(+4.92)	warming to high evap	209 pollen 15 lycopodium 3 transverses Psilate fern dominant under forest canopy humid, 94 starch high algae, little to no charcoal, little palm, some scirpus resin abundant, large scabrate fungi high, plant parts in slide abundant.
	8L60cm	9306	(+4.60)	very dry/warming	48 pollen 162 lycopodium 18 transverses 250 starch grains, palm and ferns abundant, resin abundant, plant parts and sacs high in slides. Fungi diverse.
	8L75cm	9345	(+3.45)	dry	107 pollen 146 lycopodium 35 transverses Pollen/spores sparse, some palm and scirpus, 98 starch Volcanic glass present, resin abundant, plant parts abundant in slide. Sophora and triumphetta.
	8L95cm	9484	(-2.70)	decline to cool/dry	201 pollen 27 lycopodium 13 transverses Fern dominant, psilate, verrucate and echinate. Small triumphetta, palm dark scabrate, dark red sacs, 35 starch heavy fungi, black pyrite, spiny sacs, heavy sacs diverse no algae. Sporopolline chytrids present thru indications of holes in pollen.
2	9L5cm	9550	(-0.38)	cool/dry	271 pollen 71 lycopodium 12 transverses Jubaea plentiful and all other types abundant. Asteraceae some small triumphetta, diversity of ferns, 46 pieces of charcoal, chytrids affecting pollen, heavy algae single cell and masses, fungi diverse.
	9L20cm	9674	(-6.56)	open lake/wet	227 pollen 53 lycopodium 12 transverses Palm type 3 dominant (small), all type of palm present, Coprosma, diverse fungi, high algae clumps, plant parts animal sacs high, some scirpus, 8 starch grains, 11 pieces of charcoal. Raw sediment included woody fragments, no seeds, brown chitin shell, high charcoal.
	9L40cm	11393	(-7.05)	open lake/diverse	201 pollen 37 lycopodium 5 transverses Scirpus plentiful with cyperus. All palm types present, triumphetta, heavy psilate fern, verrucate, reticulate, echinate little to no charcoal, 38 starch grains, fungi scarce, abundant resin, 2 possible eleocarpus, 2 chenopodium, unidentified dicolpate, sacs and chytrids eating fern spores. Raw sediment including pinhole chitin shells, seeds and gyttja type mud/algae mix.
1	9L65cm	11952	(-5.09)	warming/but still cool	277 pollen 65 lycopodium 14 transverses Small triumphetta dominant, Jubaea present, heavy charcoal less algae, large diverse fungi, resting sacs and testae amoeba?, 142 starch grains, diverse but small amount of fern present, some small grass, sophora, high asteraceae algae masses with small charcoal fragments in raw sediment.
	9L75cm	12511	(-15.01)	cool open lake	199 pollen 30 lycopodium 3 transverses Triumphetta forest dominant, palm high. Scirpus, broussonetia, sophora, all fern types, blackened refractive material, volcanic glass, dinoflagellate and spiny sacs, fungi diverse heavy algae masses and single cell, 38 starch grains.
	9L95cm	12930	(-12.21)	cool open lake	205 pollen 34 lycopodium 6 transverses Type 2 (round) palm species dominant with small triumphetta pollen dominant. Very little fern or scirpus. Sophora, asteraceae, fungi diverse, heavy algae in sediment with algal layers noticeable in core. 45 starch grains, large refractive minerals, zygomorphs present. In raw sediment small black shells, algae clumps, wood fragments, leaves charcoal fragments, floating algae leaf like structure, no seeds, clear transparent root or animal.

Figure 35d - Ecological profiles (zones 3-1)

RANO KAO KAO3 CORE EASTER ISLAND 2008

Figure 36b - Pollen Diagrams - Trees

RANO KAO KAO3 CORE EASTER ISLAND 2008

Figure 36c - Pollen Diagrams - Palms

Figure 36d - Pollen Diagrams - Aquatics

Figure 36e - Pollen Diagrams - Grass and Ferns

RANO KAO KAO3 CORE EASTER ISLAND 2008

Figure 36f - Pollen Diagrams - Charcoal

Figure 36g - Pollen Diagrams - Non-Pollen Palynomorphs

RANO KAO KAO3 CORE EASTER ISLAND 2008

Figure 36h - Pollen Diagrams - Lycopodium

RANO KAO KAO3 CORE EASTER ISLAND 2008

Figure 36i - Pollen Diagrams - Deposition Time

Figure 36j - Pollen Diagrams - Total Pollen

RANO KAO KAO3 CORE EASTER ISLAND 2008

Figure 36k - Pollen Diagrams - Pollen Concentration

RANO KAO KAO3 CORE EASTER ISLAND 2008

POLLEN INFLUX

Figure 36l - Pollen Diagrams - Pollen Influx

Figure 36m - Pollen Diagrams - Pollen Mat

Figure 36n - Pollen Diagrams - Pollen Mat, ferns and grass

RANO KAO KAO3 CORE EASTER ISLAND 2008

FERN MAT

Figure 36o - Pollen Diagrams - Pollen Mat, small ferns

RANO KAO KAO3 CORE EASTER ISLAND 2008

POLLEN CONCENTRATION MAT

Figure 36p - Pollen Diagrams - Pollen Concentration Mat

RANO KAO KAO3 CORE EASTER ISLAND 2008

TOTAL POLLEN MAT

Figure 36q - Pollen Diagrams - Total Pollen Mat

Title	Rano Kao	Rapa Nui	Gossen, C. 2005	Pollen Count Sheets 1L - 2L																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
		51																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				</

Figure 37a - Pollen Count Sheets (1L-3L)

Title		Rano Kao	Rapa Nui	Gossen, C. 2005	Pollen Count Sheets 5L50cm - 7L45cm									
		sample identity	5L 50-51cm	5L 60-61cm	5L 90-91cm	6L 5-6cm	6L 25-26cm	6L 45-46cm	6L 65-66cm	6L 85-86cm	6L 95-96cm	7L 5-6cm	7L 25-26cm	7L 45-46cm
Age		actual depth	17.00	17.10	17.40	17.55	17.75	17.95	18.15	18.35	18.45	18.55	18.75	18.95
d018		(+20 to original #)	3470	4170	5443	6525	7670	8438	8589	8741	8885	8915	9044	9210
Scirpus			0.00	19.52	23.49	22.15	23.16	22.34	23.60	23.45	22.06	22.53	22.43	23.74
Cyperus			27	8	47	12	8	15	108	26	174	4	52	29
Polygonum		cyperoides-med	8	1	0	0	0	2	26	0	33	0	14	105
Palmae		polystachyos-sm	16	1	0	0	0	2	5	0	3	0	2	3
Palmae		acuminatum	84	27	0	0	0	0	0	0	0	0	0	0
Palmae		jubaea chilensis	22	78	84	16	12	44	26	25	9	5	30	24
Palmae		type 2	20	12	0	0	7	2	2	1	0	0	5	1
Palmae		type 2 round	0	0	0	0	0	3	0	0	0	0	0	0
Palmae		type 3	10	41	4	15	2	27	20	5	4	0	1	13
Asteraceae		tubuliflorae	7	4	2	1	0	0	1	0	0	0	0	2
Triumfetta		rhomboidae	0	0	0	0	0	0	0	0	0	0	0	0
Triumfetta		semitriloba	1	2	0	0	0	0	0	0	0	0	0	0
Triumfetta		type small	2	1	2	2	1	2	4	4	0	0	2	2
Sophora		toromiro	0	1	0	0	3	1	0	1	4	0	1	0
Broussonetia		papyrifera	0	0	1	0	0	2	0	0	0	0	0	0
Thespesia		populnea	0	0	0	0	0	0	0	0	0	0	0	0
Inocarpus			0	0	0	0	0	0	0	0	0	0	0	0
Portulaca			0	0	0	0	0	0	0	0	0	0	0	0
Myrsine			0	0	0	0	0	0	0	0	0	0	0	0
Chenopodium			0	0	0	0	0	0	0	0	0	0	0	0
Coprosma			0	2	0	0	0	0	0	0	0	0	0	0
canavalia			0	3	0	0	0	0	0	0	0	0	0	0
caesalpinia			0	0	0	0	0	0	0	0	0	0	0	0
xylosma			0	0	0	0	0	0	0	0	0	0	0	0
dicolpate/tricolpate			1	4	0	0	0	1	0	1	0	0	0	4
diporate			0	0	0	0	0	0	0	0	0	0	0	0
Graminae		sm native < 40um	0	0	1	2	1	0	3	0	1	0	0	3
Graminae		>40um	0	0	0	0	0	0	0	0	0	0	0	0
Filices		monolete psilate	1	79	11	26	2	81	6	15	13	30	27	10
Filices		monolete verrucate	1	9	20	2	10	0	0	11	0	0	3	16
Filices		mono ver. W/ perispor	0	0	0	0	0	1	1	0	3	9	0	0
Filices		monolete rugulate	0	0	1	0	1	0	0	0	0	0	53	0
Filices		trilete	0	7	0	10	0	8	3	9	1	0	1	0
Filices		echinate	0	0	0	0	0	0	0	0	0	0	0	2
Total Pollen		x	199	281	173	121	47	192	223	99	245	48	191	214
Lycopodium		a	156	20	343	146	91	81	99	148	71	15	85	143
Lycopodium tablet		V	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679
cm3 of sediment			1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pollen Concentration		yr/cm	9082	100027	3591	5900	3677	16875	16036	4762	24567	22782	15998	10654
Deposition Time		x/(yr/cm)	0.25	63.64	63.64	63.64	63.64	7.57	7.57	7.57	7.57	7.57	7.57	0.81
Pollen Influx		class 1	36327	1372	56	93	58	2229	2118	629	3245	3009	2113	13153
Charcoal		class 2	21	1	14	26	55	25	12	9	13	25	24	8
Starch		class 3	5	0	3	2	5	1	5	3	1	2	0	4
Algae		class 4	1	0	0	4	2	0	1	0	0	0	1	0
Fungi		total	27	1	18	35	63	27	18	12	14	27	25	12
Sac		abundance	115	31	399	72	611	317	177	92	82	1166	222	116
Mineral		abundance	3	0	3	1	0	0	1	0	1	1	3	0
Plant		diversity	4	2	5	4	3	2	3	5	3	2	4	5
Resin		diversity	3	1	4	3	2	1	3	5	5	3	5	4
		abundance	3	1	4	5	3	3	3	5	3	1	5	4
		diversity	2	1	1	5	2	3	5	1	1	3	5	3
		abundance	1	1	3	1	4	5	1	1	1	2	4	5
		diversity	4	1	2	1	4	3	5	3	5	3	4	5
		abundance	2	1	1	5	5	5	5	5	5	2	3	4
		diversity	1	0	1	1	5	5	5	5	5	3	4	4
		abundance	3	0	0	1	5	5	5	5	5	2	5	4
		diversity	0	0	0	1	5	5	5	5	5	2	5	4

Figure 37c - Pollen Count Sheets (5L-7L)

Title	Pollen Count Sheets 7L65cm - 9L95cm																			
	Rano Kao			Rapa Nui			Gossen, C. 2005													
12.5+ (sample depth)	sample identity	7L 65-66cm	7L 85-86cm	7L 95-96cm	8L 5-6cm	8L 25-26cm	8L 45-46cm	8L 65-66cm	8L 75-76cm	8L 95-95cm	9L 3-4cm	9L 25-26cm	9L 45-46cm	9L 65-66cm	9L 75-76cm	9L 95-96cm	c1.4 (+20 to original #)	cyperoides-med polystachyos-sm acuminatum Cyperus Polygnum Palmiae type 2 round type 3 Asteraceae tabuliferae rhombolobea Triumfetta semitrilobea type small toroniro papyrifera populnea bonduc UFO sm native < 40um monolete psilate mono ver. W/ perispor monolete rugulate trilete echinate x Total Pollen a Lycopodium cm3 of sediment Pollen Concentration Deposition Time Pollen Influx Charcoal	yr/cm x/(yr/cm) class 1 class 2 class 3 class 4 total abundance abundance abundance abundance abundance abundance abundance diversity diversity diversity diversity diversity diversity	
	actual depth	9225	9241	9255	9260	9274	9290	9306	9320	9340	9364	9590	11030	11953	11952	12511				12930
		10.10	23.32	23.61	22.32	23.26	23.42	24.60	23.45	23.45	17.30	19.62	13.44	12.95	14.91	4.99				7.79
		69	16	91	55	40	17	2	12	12	11	17	24	23	1	1				0
		3	8	13	11	11	5	0	8	8	3	0	1	12	3	0				0
		2	0	0	0	0	0	0	0	1	0	0	0	0	0	0				0
		21	11	15	11	24	6	15	17	39	61	61	43	29	59	28				45
		3	0	0	0	2	0	6	8	12	6	6	26	2	10	19				50
		3	0	0	0	5	1	0	0	27	50	22	7	6	29	1				0
		2	6	2	1	5	1	5	2	2	10	9	88	18	35	32				13
	0	0	0	0	0	0	2	0	1	2	0	0	0	1	7	0				
	0	0	0	0	0	0	0	1	2	0	0	0	0	0	1	3				
	1	3	3	2	1	0	0	0	6	0	0	12	2	77	61	50				
	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	0	0	0	0	0	0	0	0	0	0	0	0	0	0						

Figure 37d - Pollen Count Sheets (7L-9L)

Pollen Summary Chart										
C14 Age	depth	actual depth	core #	28/1.028 d18Oiw	dominant pollen	pollen ct	Lycopodium	# of transverses	# of pollen per transverse	total Charcoal
50	8-12cm	0.08	Mat1	1.90	fern	186		42	4	med
245	88-92cm	0.88	Mat1	2.64	fern	277		2	139	high
545	115-120cm	1.15	Mat2	-0.30	scirpus	217		29	7	med
1173	0.00	12.50	1L top	3.03	scirpus	243	98	9	27	62
1200	0.15	12.65	1L 15cm	2.52	scirpus	212	52	4	53	178
1236	0.35	12.85	1L 35 cm	1.27	ferns	226	30	3	75	5
1273	0.55	13.05	1L 55cm	1.40	scirpus	200	40	9	22	9
1304	0.72	13.22	1L 71cm	2.80	palm	207	76	11	19	9
1325	1.06	13.56	2L 6cm	1.64	scirpus	203	50	8	25	22
1329	1.25	13.75	2L 25 cm	2.33	grass	309	40	14	22	16
1332	1.45	13.95	2L 45cm	2.05	scirpus	207	73	11	19	7
1376	1.65	14.15	2L 65cm	2.30	scirpus	262	136	19	14	44
1581	2.00	14.50	3L top	1.28	ferns	218	53	5	44	4
1698	2.20	14.70	3L 20cm	2.69	ferns	350	30	2	175	4
1815	2.40	14.90	3L 40cm	2.39	palm	257	96	8	32	8
1879	2.60	15.10	3L 60cm	1.66	ferns	208	41	4	52	5
2213	2.80	15.30	3L 80cm	1.53	ferns	213	37	3	71	10
2401	2.96	15.46	3L 96cm	-2.52	ferns	208	105	16	13	9
2471	3.02	15.52	4L 2 cm	3.16	ferns	163	106	17	10	24
2659	3.18	15.68	4L 18cm	3.71	scirpus	202	56	9	22	20
3045	3.40	15.90	4L 40cm	0.63	palm	202	39	17	12	21
3443	3.60	16.10	4L 60cm	2.61	scirpus/palm	222	43	6	37	6
3448	3.80	16.30	4L 80cm	2.75	palm	219	171	12	18	111
3452	3.98	16.48	4L 98cm	2.49	fern	201	79	19	11	33
3454	4.05	16.55	5L 5cm	3.02	polygonum	252	120	18	14	25
3459	4.25	16.75	5L 25cm	3.32	palm	161	134	20	8	25
3464	4.45	16.95	5L 45cm	4.01	palm	216	96	17	13	15
					polygonum	199	156	19	10	27
4170	4.65	17.15	5L 50cm	-0.48	ferns	281	20	2	141	1
5443	4.85	17.35	5L 85cm	3.49	palm	173	343	36	5	18
6525	5.02	17.52	6L 2cm	2.15	fern	121	146	18	7	35
7670	5.20	17.70	6L 20cm	3.16	palm	47	91	38	1	63
8438	5.40	17.90	6L 40cm	2.34	fern	192	81	18	11	27
8589	5.60	18.10	6L 60cm	3.60	scirpus	223	99	19	12	18
8741	5.80	18.30	6L 80cm	3.45	scirpus	99	148	19	5	12
8885	5.99	18.49	6L 99cm	2.06	scirpus	245	71	10	25	14
8915	6.03	18.53	7L 3cm	2.53	fern	48	15	20	2	27
9044	6.20	18.70	7L 20cm	2.43	fern/scirpus	191	85	32	6	25
9195	6.40	18.90	7L 40cm	3.74	cyperus	214	143	27	8	12
9225	6.60	19.10	7L 60cm	-9.90	scirpus	207	134	38	5	5
9241	6.80	19.30	7L 80cm	3.32	fern	194	132	16	12	29
9255	6.97	19.47	7L 97cm	3.61	scirpus	166	109	17	10	12
9260	7.03	19.53	8L 3cm	2.32	fern	218	52	18	12	11
9274	7.20	19.70	8L 20cm	5.26	fern	196	45	20	10	5
9290	7.40	19.90	8L 40cm	4.92	fern	210	15	3	70	2
9306	7.60	20.10	8L 60cm	4.60	palm	48	162	18	3	20
9345	7.80	20.30	8L 80cm	3.45	grass	101	146	35	3	10
9484	7.97	20.47	8L 97cm	-2.70	fern	201	27	13	15	9
9550	8.05	20.55	9L 5cm	-0.38	palm	271	71	12	23	46
9674	8.20	20.70	9L 20cm	-6.56	palm	227	53	12	19	11
11393	8.40	20.90	9L 40cm	-7.05	fern	201	37	5	40	4
11592	8.60	21.10	9L 60cm	-5.09	triumfetta	277	65	14	20	177
12511	8.80	21.30	9L 80cm	-15.01	triumfetta	199	30	3	66	95
12930	8.97	21.47	9L 97cm	-12.21	triumfetta/palm	175	34	6	29	119

Chapter 8 Human Appearance on Rapa Nui

8.1 Introduction

There are more than three known names for the island, which include Easter Island, Rapa Nui, and Te Pito O Te Henua. and many unanswered questions. The most popular questions are about its people. Who were the people who landed here? Where did they come from? Was there more than one migration to the island? When did the first people arrive? Why did they build the huge moai? And how did they move them around?

My research did not set out to answer any of these questions directly but rather to focus on the natural world and the place of humans in it. The direct research questions were: What was this island like thousands of years before humans arrived? What kinds of plants lived here? Was the island always barren as it is today? How did climate change affect rainfall and plant ecology? Evidence of humans became apparent in the KAO3 core used to analyze climate change and plant ecology. Therefore I chose to include in my results all the evidence found that suggests human arrival and behavior and most importantly that the palm trees and all of the other 17 species of trees disappeared with evidence of human presence.

Finding evidence of human behavior in the lake sediment core relied upon detecting abrupt palynological changes without a known climate cause, local versus long distance factors in the case of charcoal size input, as well as abundance of charcoal and exotic pollen that appear late in the pollen record.

8.2 Theories about Migration and Human Occupation

Many theories have been presented to explain the unanswered questions about human occupation of the island. A few selected well-known and plausible theories are discussed below ending with a final discussion of the unknown and curious events that may reflect human behavior as found in the KAO3 core from the lake Rano Kao.

8.2.1 Polynesian Migration theory

In 1918, Percy Smith and W. Volz came to a conclusion that Polynesians settled Easter Island about 1400 AD (Haddon, 1918), based primarily on information gathered from genealogical data. In 1919 Routledge attempted to date occupation by including a list of 57 successive kings who had all been born on Easter Island.

In endeavoring to arrive at even an approximate date for these immigrations to the island, evidence outside its borders is likely to prove our best guide. Those that followed in her [Routledge's] inquiries have included Jaussen, Lapelin, Roussel, Knoche, Lavachery, Metraux and Englert that have all proposed at least one Polynesian migration, perhaps two, and all arriving between the 11th and 15th centuries (Heyerdahl, 1965).

Genealogical counting was the only way of estimating arrival date using the most well-known person to land on the island, Hotu-Matua and his people although it was Thomson in 1889 wrote about 20 generations succeeding Hotu-Matua, who landed on the island sailing from the east towards the setting sun, and then a new migration of people from the west proceeding to conquer those who already existed there (Heyerdahl, 1965). Smith,

who accompanied Heyerdahl in the 1958 Norwegian Expedition wrote the following:

“We cannot with certainty state how long man had been present on the island prior to this date, and until further carbon samples are found which may carry us still further back in time, the period around A.D. 386 must be considered the earliest proven date for human occupation on Easter Island” (Heyerdahl, 1965).

Archaeological evidence has led all who have worked on the island to recognize the differences between these people and the general population of Polynesians. For example, those that settled on Easter Island were in full cultural bloom in the 13th century. Moreover, there is evidence of non-Polynesian artifacts that were also left behind including Melanesian association with red hair and the red ochre topknots (Balfour, 1917); architectural allusions to mason work in South America and Vinapu (Heyerdahl, 1952); recycling of *ahus* to previous ceremonial centers (Mulloy, 1958); Early Period ceremonial altars or platforms oriented to equinoctial and summer solstice positions of the sun abandoned near the ceremonial center of Orongo long before the Make-Make (Smith, 1958); the South American arrival of the sweet potato (*kumara*) to southeastern Polynesia; and the most interesting cultural observation and the diversity of skin and eye colors, hair types, and body structure differences among the people that the first European settlers noted when they arrived on the island.

The mysteries that lie on this island are gradually being uncovered, and uncovered again, as when faced with limited boundaries people adapt, recycle, and reuse resources and they have done that very well here. *Ahus* were built, reconstructed, pieces of statues were used in other structures; chicken houses were once burial sites. Clearly with the

unearthing of the clues, the lines of distinction are sometimes blurry making cause and effect even more difficult to unravel.

Cited below is the folk-myth of Hotu-Matu'a, the ancient king of Rapa Nui, as it was written down in the Rapa Nui language for the first time by Pua Ara Hoa in 1890 and hidden away from non-Rapa Nui people until 1950 (Fischer, 2005). Fischer also noted in 1994 that Tu'u ko Iho was the Mangarevan founder god Atu Motua (Father Lord).

History of Hotu Matua and the circumstances that motivated the exit from the ancestral land: Hiva.

The old wise people (Maori) foretold that a time would come in which the Earth would sink; the rising waters would destroy many lives and because of this prophesy the following generations constructed canoes to escape off the island.

In the days of the Ariki Matua, Haumaka had a dream in which his spirit flew towards the East in search of a new earth. When arriving at the eighth land, it saw three small, barren islands at the southwest vortex of the island. It saw these islets (Motu Kao Kao, Motu Iti and Motu Nui) as the three children of the Ariki Taanga (father of Matúa) turned to stone. The spirit crossed the island by the south coast, until arriving at the bay that today we know as Anakena. Before returning to Haumaka it named the big island "Te Pito O Te Kainga."

The spirit returned to Hiva and entered into the sleeping body of Haumaka. When he awoke, Hanumaka went to King Hotu Matua and told him what he had seen. The King ordered him to instruct the young people how to construct a great boat, to gather food and all the necessities to undertake the journey towards the new land.

Seven explorers were sent to find the new land that was sighted by the spirit of Haumaka, and to explore the island before returning to Hiva.

Hotu Matua made the trip towards the new earth in two boats, one for himself and the other one for his sister Avareipua, both boats filled with foods and supplies that would be needed in the new land. They disembarked on the beach of Anakena, a place where they would establish the residence of the kings. At the time of disembarking, the wife of the King, Vakai, gave birth to a boy named Tuu Maheke, the first heir of the royal lineage.

Hotu Matúa divided the territories of the island between his children, who became the ancestors of the different tribes: Miru, Koro Orongo, Ngaure, Raa, Hamea, Ko Tuu, Hotu Iti, etc.

Hotu Matúa lived his last days in the sector of Rano Kau. When he felt near his death, he called the leaders together and he designated his older son as successor. He requested that he be taken to the edge of the volcano so that he could look for the last time towards his native land in the northwest. From there he called to four spirits to announce the signal of his passing through the song of the roosters. Then, his children took him back to his house, where he passed away. His body was buried in Akahanga.

Social organization

From the legend of King Hotu Matua a social order headed by the royal family is defined (Ariki Paka), the religious aristocracy that included the wise people (Maori) and priests (ivi atua), military leaders (matador), professors who taught the art of reading (Maori rongo rongo) and common people (huru manu) that constituted the base of the social pyramid.

The legend was translated from a rapanui manuscript written at the beginning of the 20th century as reproduced in the rapanui press.

8.2.2 Thor Heyerdahl's South American theory

Thor Heyerdahl, famous for his Kon-Tiki adventure in 1947, successfully challenged the prevailing idea that it was impossible to travel from South America to the South Pacific in an ancient raft made only from balsa trees and local plant fiber ropes from Peru. Heyerdahl wanted to offer more possibilities for differing waves of migrations, a diversity of cultures, and understanding of the many artifacts on Easter Island that did not have Polynesian origin.

Following the successful voyage of *Kon-Tiki* Heyerdahl came back to the island in 1958 with the Norwegian Scientific Expedition, their main objectives being “to search for facts hitherto not known that would serve as concrete answers to these disputed questions” (Heyerdahl, 1965).

Besides uncovering the first palm pollen grain in the lake sediments, the expedition also discovered buried stone carvings and evidence of a written language on wooden texts, They unburied the moai revealing more than just the heads described by earlier visitors.

Heyerdahl's theory suggests a wave of three phases of cultural prehistory. The Early Period (AD 400?-1100?) included the building of the *ahus* and structure (1a) at Orongo; the Middle Period (AD 1100?-1680) included cultural remains of ceremonial sites, masonry dwellings, and the statue quarry and moai; and the Late Period (AD 1680-1868), which began with the battle at Poike ditch and the legend of the Long Ears and Short Ears. The Late Period included the cessation of the moai building, the movement into cave dwellings, and eventual population decimation by slave raiders.

8.2.3 1421: The Year China Discovered America

In 2002 Gavin Menzies' wrote a book entitled *1421: The Year China Discovered America*. Within the pages there are maps of the world with numbered markers around the Pacific coasts of North and South America and across the South Pacific to Australia and New Zealand. On page 451 there is a marker located on Easter Island. Menzies uncovered notes with great details that are summarized in the book about the Chinese stopping on Easter Island in their exploration quest. He believed there is an extant road on the island used by the Chinese, which now continues into the ocean as a result of rising sea level and erosion. The concluding paragraph of the book states:

I am, now more than ever, convinced that accepted history has been turned upside down, not only in New Zealand and Australia but also in North and South America, across the Pacific and in the Arctic and Antarctic. The great

bulk of the new evidence that has enabled me to make such startling claims has come from readers of my book. It is you, not historians or academics, who have rewritten history (Gavin Menzies, London, May 2003).

The theory behind Menzies' research includes the following:

- Four huge Chinese fleets circumnavigated the world between March 1421 and October 1423. The fleets were comprised of more than 800 vessels and charted the world.
- Sailors and concubines from those great fleets settled in Malaysia, India, Africa, North and South America, Australia, New Zealand, and on islands across the Pacific.
- The first European explorers had maps showing where they were going before they set sail. They met Chinese settlers when they arrived in the New World.
- China, not Europe, discovered and settled the New World. European "discoveries" relied on China leading the way.
- The whole world was chartered by 1428 – by whom?

A new question was posed with migration from Maoris or Polynesians who may have traveled to South America and returned with the plants. Professor Bryan Sykes and his team at Oxford University examined this question. Sykes made this statement: "If we found DNA matches of Polynesians to Chile or Peru, or even in coastal North America, then Heyerdahl was right. If we found them in southeast Asia, he was wrong. I had to be sure that 247, the defining variant of Polynesian mitochondrial DNA, was not abundant in the Americas. No one had ever seen it. Not even once. Heyerdahl was wrong" (Menzies, 2002).

With that result, Menzie stated: “In my view, this leaves only the Chinese as the possible carriers to Australia (seventy-four species) and New Zealand (eight species) of those South American plants found by the first Europeans” (2002).

8.2.4 The 535 AD Event

Historical documents by Zacharias of Mytilene (c. 465), John the Lydian (c 450), Procopius of Caesarea (c 560), and Cassiodorus the Roman talk about the sun losing its light and becoming bluish in color with no shadows and heat that never came. A whole summer without heat with chilling north winds ruined food crops for more than a year. John of Ephesus wrote, “The sun became dark and its darkness lasted for 18 months” (MacIntyre, 2002).

The 535 AD event is recorded in various places on the planet in tree rings, ice cores, and lake varves that show a worldwide cooling event. This cooling also brought changes in rainfall pattern producing droughts and floods, plagues, failed crops, famine, cannibalism and rebellion. The cultural impact was immense (MacIntyre, 2002).

“535 AD saw simultaneous movements of people in different parts of the world-- migrations that were apparently caused by a global climate event.” Ferren MacIntyre, from the Environmental Change Institute at the National University of Ireland, wrote in a paper published in the *Rapa Nui Journal* October 2002 entitled “Simultaneous Settlement of Indo-Pacific Extremes?” The article was mainly about natural causes that either forced or created opportunity for human migration across open oceans. MacIntyre discusses a curious coincidence between Madagascar and Rapa Nui. It is now generally accepted that both of these places were settled circa AD 500 by people originating from Southeast Asia

(MacIntyre, 2002). Evidence shows that there was a group of Malayo-Polynesian people who lived on Madagascar, were displaced by new arrivals around 500AD, and driven into the center of the island. The central forest was not burned until about 1000AD. The Malayo-Polynesians called the Vazimba were also known as the guardians of the forest in folklore. Nothing remains of these people now except their tombs (MacIntyre, 2002).

When studying migrations around the planet, one discovers that there is always exploration before a permanent settlement is created. Models by Levison (1973) and Irwin (1990) show this philosophy within the whole of Polynesia as well.

In the scientific record, there are scattered aerosols usually relating to a major volcanic explosion or a moderate cosmic strike. MacIntyre wrote that if the 535 AD event was a volcanic explosion, it was larger than the well-documented explosions of Krakatoa on August 23, 1883. The Krakatoa explosions were heard 4800 kilometers away. Barometers detected atmospheric shock waves circling the globe three times. The resulting tsunami was 35 meters high, destroyed 300 towns, killed 36,000 people, carried 600-ton coral blocks ashore and sent a Dutch warship 2.5 kilometers inland. The volcanic peak of 425 meters turned to atmospheric dust reaching as high as 80 kilometers and caused complete global darkness for two days. The sunsets for the next 3 years around the world were affected and some were even green (MacIntyre, 2002).

There is little scientific evidence about the 535 AD event. Hammer et al. (1980) however stated that there is a statistical association between volcanic activity and global temperatures over the last millennium. Baille (1994) in his work in Greenland noted that the ice cores showed no volcanic activity in 535 AD and so suggested a cosmic strike. Evidence indicates that there are over 200 possible eroded impact sites seen from

satellites. Mass extinctions have been noted by some of the largest impact sites including the KT event responsible for the demise of the dinosaurs 65 million years ago. The KT impact reflected enough sunlight to reduce the surface temperature of planet earth by 3-10°C for many years (MacIntyre, 2002).

A note of importance to this research on Rapa Nui is that Clube and Napier (1984) suggested that some 20,000 years ago, a large (50-100km) comet entered the system and disintegrated in three major episodes: in 2800 BC, 1000 BC, and 500 AD, which formed many comets, meteor streams, fireball swarms, and even a lunar hit in 1975 (cited in MacIntyre, 2002). The events of 2800 BC, 1000 BC and 500 AD are all visibly noted in the Rano Kao KAO3 isotope record.

So what happened in 535 AD? In the *Javanes Pustaka Raja Purwa* (Book of Ancient Kings), Keys deciphered the following: “At last, the mountain burst into pieces with a tremendous roar and sank into the deepest of the earth. The water of the sea rose and inundated the land. The land became sea and the island of Java/Sumatra divided into two parts” (cited in MacIntyre, 2002). This echoes the mythological accounts of Hotu Matu’a, retelling of the disappearing island of Hiva and the people’s departure for new land.

8.3 Methods to Determine Human Activity in the Past

Evidence of the past? What do humans leave behind? Usually they leave behind things they do not want to take with them like waste, burials, structures, and plants. These all become fossils layered in time Migration paths have been laid out based on these plants. One of which, significant to Easter Island, is the sweet potato (*Ipomoea batatas*).

Could humans have arrived in small groups and not have made significant changes in the pollen and archaeological record for hundreds of years until their population increased and intensified selective choices of plants, shelter and basic living choices? For this research, human behavior is tracked by changes in the plants, as they are represented by the pollen record, changes in erosion and sediment depths, exotic “others” found in the core, and charcoal as it represents burning.

8.4 Archaeology and Charcoal (Determining Natural vs. Human)

Archaeological studies on the island have found charcoal to be useful in recreating the past. Plant materials found in earth ovens (umus) help explain what plants were being grown for food, what was being cooked, what kind of tree or grass roots were used for fuel.

Charcoal found in places such as lakes tell yet a different story, one of fires caused by nature and humans. The amount of burning is determined by the quantity of charcoal. Determining whether the burning occurred due to volcanic activity, drought, or clearing of forestland to grow food is difficult to determine in the observation of charcoal alone. But charcoal in context with plants and climate change data can be very useful.

The size of charcoal particles is a clue to its source. Generally the smaller the particle, the more likely it is to be airborne ash from any organic material, including tree, grass, or wood. The larger the particle, the more likely it is to be from a local rather than distant source. Taxonomy of type, angulations, roundness, darkness, and lightness is also useful to determine differences in species and how the charcoal arrived in the lake. For example, angulated pieces indicate little wear in transport and more of a chance of being airborne without resistance, or broken at the site rather than being transported.

Charcoal in this research was noted for type and counted in the raw sediment as macrofossil, as well as absolute counts in the pollen slides. In the pollen diagrams in Chapter 7, charcoal is counted alongside pollen and spores, algae, resin, plant parts, and minerals.

8.5 New Discoveries in the KAO3 Core Related to Humans

The points listed below are new findings made as part of this research. Many of the important results, including the carbon dating, were based on the analysis of *Scirpus* seeds seen throughout the KAO3 record. The important discoveries deserve more study in the future:

1. *Scirpus* has existed on the island for at least 15, 000 years (15,000 BP). There is variation between the species at Rano Kao and Rano Raraku. Both have been processed at University of California at Davis for DNA. The Rano Kao type's DNA is closely related to the coastal Peruvian species. Heiser (1974) also found similarities to the coastal species on the island.
2. *Scirpus* seeds vary among themselves over time. Over the last 2000 years they have become larger. (This may be due to the environment becoming wetter, species adaptation, or support for the DNA variation in a new introduction.)
3. New radiocarbon chronology from the top of mat to 9 meters of lake sediment was all based on *scirpus* seeds. The new dating and the presence of charcoal determines that humans were present and burning plants in large abundance in 1173 BP although an increase in charcoal occurred at 1376 BP.

4. A dry period from 8000 BP to 3500BP left the lake desiccated. During this same time period grass pollen (>40 microns) appeared as did high total charcoal, obsidian flakes (found in this sample only), a mite, and sugarcane pollen grains.
5. Seeds dated to 3500 corresponded with woody matter dated to 6000 BP. Missing sediment indicated that the lake was desiccated. Large woody pieces were found between two seed dates of 3500 BP. With no water in the lake, this suggests that large woody matter was being burned at the center of the lake.
6. At least four palm species were found in pollen record of KAO3 and *polygonum* appeared in the pollen record at 4170 BP for the first time. It is curious that *polygonum* is a South American plant, considered valuable in medicine, and it does not appear in pollen before this point, then aggressively becomes the dominant plant in the lake and forms the mat.
7. Missing sediment at top of KAO6 dates to the same time period at the same level in KAO3. This is indicative of possible trenching and cultivation of *totorá* in the lake when the water level was low.
8. Rains lifted mat at 1500 BP approximately. Curious dead patches are unexplained.
9. Starch noted, present in all samples; comparison species is unknown but high probability that it is *totorá* and/or palm.
10. Human presence 1581-1376 BP is confirmed with possible earlier evidence.

11. Exotic pollen of tree and shrub species is found. More detail is in the pollen record and Chapter 7. These exotic plants are known on other islands as being valuable to humans.

8.6 Discussion

The first three points of evidence all relate to the *scirpus* or *totor*a plant found in the crater lakes on the island. This plant was significant to the people on the island in the past; today it is not as important but still holds a valued place in tradition. Clarification of *scirpus* is necessary in that there are four species in the *Cyperaceae* family on the island including: *Cyperus vegetus* (*eragrostis*); *Cyperus polystachyus* (*Pycerus polystachyos*); *Cyperus cyperoides*; and *Schoenoplectus californicus* (*Scirpus riparius* and *Scirpus californicus*). Most of these plants were identified by Skottsberg in 1920 and later updated by Zizka in 1991. None of these plants has been analyzed for DNA except for the plant currently called *scirpus* and known as *totor*a. Skottsberg actually called it *scirpus* (*Scirpus riparius*), which has since been renamed to *Scirpus californicus* because *riparius* is not the triangular sedge but more a grass-like plant that grows on the mat from which both specimens were collected in March 2008. For discussion I am going to refer to the plant by its native name *totor*a.

Charles B. Heiser, Jr., conducted a very thorough study of the *totor*a plant in South America and printed the results *Of Plants and People* in 1985. Heiser included a section called “The Totor and Thor,” in which he talked about Heyerdahl claiming that the *totor*a on the island was the same as the American plant that was cultivated under irrigation all along the coast of Peru in prehistoric times. This plant was used to make mats and boats as well as shelter on Easter Island as was common in Peru (Heiser, 1985).

Heyerdahl's pollen record, never published, was the first to core the sediments and it found that the *scirpus* was present in the pollen record before European arrival, but he said that man must have brought it to the island because it only propagates from the shoots in the rhizomes and could not have been carried by wind, ocean, or bird.

Heiser concurred that Heyerdahl was correct in the commonality between the uses of *totorá* between coastal Peru and Easter Island, but he also stated that it does not suggest that ancient Peruvians taught the Easter Islanders to use it in the same way. It could have developed independently. What Heiser confirmed is that the *totorá* on the coast of Peru is the same as the one on Easter Island. DNA studies conducted for this research at the University of California at Davis provide the following confirmations that also support Heiser and Heyerdahl.

1. By our analysis, the two samples appear to be the same between Rano Raraku and Rano Kao. There are subtle differences between the two, but the equipment necessary to measure this is not available for this study
2. Out of 42 sites in South and North America, the *totorá* plants on Easter Island appear to be more closely related to the coastal Peruvian samples.
3. *Schoenoplectus californicus* doesn't grow in Asia but is found on a few Pacific Islands.

Heyerdahl's statement about the growth of *totorá* needing human cultivation is correct in the highlands of Peru, including Lake Titicaca. Heiser found that at high elevations, due to cool temperatures the plant does not produce seed. Therefore it is common practice for the people of Lake Titicaca to grow the *totorá* by planting the shoots of the rhizome. However, on the coast of Peru, the plant is self-pollinating and, as he stated, "if a single

plant were established on the island it could reproduce by seed as well as vegetatively” (Heiser, 1985). Ornithologists have however not been able to come up with a bird that would have transported the seed across the ocean. And with the decimation of at least 25 bird species that lived or visited the island, there are none remaining to test this idea.

Could a rhizome also have made an across-the-ocean voyage between Peru and Easter Island? Heiser stated that he felt it could, for it is a very hearty plant.

Heiser questioned that if the *totorá*, being a very tough plant, could be brought to the island in pots, why didn't the same people bring seed for food plants? Heyerdahl did after all make a statement that people brought another plant called *Polygonum acuminatum*, which was used for medicine (discussed below).

Scirpus has existed on the island for at least 15,000 years. Although there are variants within species between Rano Kao and Rano Raraku, DNA of the collected specimens from both lakes in March 2008 showed they are closely related to the coastal Peruvian species. The finding of *scirpus* pollen in all of the KAO3 samples, throughout the entire 9 meters of core, confirms that *scirpus* is native to the island. In the pollen slides various morphologies of *scirpus* pollen were described and counted using references slides. The pollen of *scirpus* is not very well preserved and the subtle differences between the species cannot be detected. This will have to be fulfilled with DNA studies.

We can state conclusively, based on the seeds found in the core, that *scirpus* has existed on the island for the last 15,000 years. *Scirpus* seeds were also found in all of the soil cores and used for a new reliable linear chronology of the lake. Beginning approximately 2,000 years ago, the seeds changed to a larger more rounded shape. These differences

are not a preservation difference but rather a morphological change. This may be due to environmental changes (perhaps a wet environment), species adaptation, or introduction of a different species to the island. This last statement may be what Thor postulated as people intentionally bringing *totorá* with them from South America for cultivating on the island. In the following paragraphs we will make the association between *totorá* and the findings that relate to intentional cultivation in Rano Kao.

Of the new discoveries made in the core KAO3, items 4 through 7 above all relate to a changing environment in the lake over many thousands of years. Most of this climate information was discussed in Chapter 6, but a point needs to be made here about human evidence found in the stratigraphy of the lake.

Rano Kao is a caldera, produced from a volcano that was formed over a million years ago and exploded around 300,000 BP. Once this crater took shape, water began to collect and rise as rainfall accumulated over time. The oldest part of the KAO3 core dates to the inter-glacial time period where the climate was cool, the lake open (without a growing mat surface) and surrounded by a *triumfetta* forest. Over time the atmosphere became warmer and wetter, until sometime around 8000 BP, the climate began to get dry. This dry period continued until it was noted in the core around 4170 BP that the lake sediment had changed its structure. A hardened soil structure first thought to be gypsum, but then realized as silicate, hardened and was drawn to the muddy surface as the climate got hotter and the lake began to dry up. The muddy surface near the middle where this core was taken, baked, desiccated, and blew away with the winds.

In these few samples dating between 4170 and 3500 BP, the pollen record also changes. Fewer than 100 pollen were counted in the slides and is noted as being sparse, indicating

that there was not much living and producing during this drought. In the raw sediment, there were three small pieces of fractured pieces of obsidian. Their sharp angles indicated that they were either airborne and landed in the middle of the lake, devoid of water at this time, or part of a vent system connected to Maunga Orito dome, signifying an active thermal connection between the bottom of the lake and the obsidian dome. A third theory is that the pieces had been deliberately carried into this place in the lake.

These little samples opened up many ideas of transport. There is a folk myth that the island was seen from the mainland of South America as a glowing fire, which could have signified volcanic activity and the formation of Maunga Orito just northeast of Rano Kao sometime around 3500 BP. This thermal connection may then have sealed and the rains that came thereafter began to fill the lake again.

Another much more interesting detail occurs between the cores themselves. There were four cores retrieved in March of 2005 from Rano Kao. The core KAO3 was used in this research for pollen and isotope studies. There was another core, KAO4, taken on the west side of the lake near to the edge, which consisted of heavy minerals and had high magnetic susceptibility in the three meters retrieved. This area on the same side as Orongo is highly eroded. Another core KAO5 was attempted, but the sediment was deeper than 20 meters at this point, which exhausted the Livingstone corer limit. The last core KAO6 was taken 150 meters from edge of lake on the north side of the crater. This core had a two-meter mat with 17 meters of water above the top of the sediment. Three meters of lake sediment were retrieved at this point. The KAO3 core in comparison had a 2-meter mat on the surface and 12.5 meters of water beneath, and 9 meters of core was retrieved from the lake sediment.

After radiocarbon dating KAO3, and finding the desiccated event, we dated a few more spots around this point at 1cm intervals to find out exactly how long the event lasted. The seed ^{14}C date at 5L 48-50cm came back with 3440 BP +/- 35 years and the 5L 54-55cm seed dated to 3470 +/- 70 years. The wood fragment found in the desiccated soil between dated to 6385 BP +/- 45 years. With study of the pollen, the lake sediment, and the macrofossils, the established radiocarbon dates were accepted as valid.

How did this sample find its way between two seeds both dating a time 3000 years later? Further questions developed in relation to the core of KAO6. Why was it missing 4.5 meters of sediment? It was closest to the edge of the lake, and if the steep sides of the crater were eroding in, the edges of the lake should have a higher slump of sediment and rock. The top of KAO6 was dated at 3185 BP +/- 40 years. It dated to the same time period, at the same stratigraphic level, as the KAO3 core except it was missing the sediment above.

Consideration of the missing sediment led back to the plants that grew on the margins of the bog. If the lake was desiccated at this time period, whatever water remained would be near the edges trapped in the large hollow stems and roots of the sedges. We reflected on the trenches that the coastal Peruvians built for growing *totora*. These trenches, well documented in Heiser's book, "Totora, taxonomy and Thor" showed depressions up to 5 meters in depth formed deliberately to hold and trap moisture to grow these plants for food, fiber, boats, and shelter. Was the missing sediment found between KAO3 and KAO6 a result of deliberate cultivation of *totora*?

We also discovered the plant *polygonum acuminatum* coming into the pollen record around 3500 BP. Not one pollen grain was recorded in the previous 12,000 years.

According to the isotope record, rain came, and within about 20 years, 50cm of sediment was deposited whereas up until then the deposition rate of the lake was about 60 years per centimeter. *Polygonum* now dominated the pollen record and the lake. This plant set the foundation for what would lift with expanding and rising water to become the floating mat sometime around 1500 BP. This plant is native to the South America Andean range and is used primarily for medicine. It is an aggressive grower and a plant ally to *totorá*. They are symbiotically linked, and both were also very important plants to the ancient people of Easter Island. How did *polygonum* arrive on the island to show up suddenly in the pollen record without any previous indications?

It had not gone beyond our notice that a series of events coincided: a low boggy desiccated lake with a trench-like hole near its edge; a newly arrived plant that has medicinal value to humans; and a soil sample dated to 3500 BP has the only deposit of minerals, three pieces of fractured obsidian glass, and appears nowhere else in the core. Other coincidental events are the first grasses at >40 microns appearing as well as a large spike in the charcoal count when the pollen influx is high.

The discovery listed as number ten refers to the starch found in the KAO3 core. Starch has generally been used to identify the presence of starchy food plants used and eaten by humans. Archaeologists have found starch on mortars and in umus, and in this case starch has been found in the pollen slides of Rano Kao. Identifiable starch such as *Ipomoea batatas* (sweet potato) and *Colocasia esculenta* (taro) known to have been sources of food for the people on the island were part of a small reference collection established to determine what kind of starch was being seen in the slides. We made our own collection and slides of varying types of tubers and potatoes, sugar cane, and all known food starches to have existed on the island. The starch in KAO3 resembled many,

and there were sometimes a count of 1,000 starch nodules per pollen slide, counting more than the pollen by threefold in some slides. There was no visible patterns between a dry environment and more or less starch noticed, or to the age of the soils. Fifteen thousand years ago starch was present and continued throughout the entire record beyond human arrival. The starch is similar to *totorá* starch, which I recovered from a root mass in the core as well as new samples from the expedition in March 2008. (Photographs taken of the starch can be seen in *Appendix A*). In this case, starch presence did not identify human presence.

The change in the appearance of charcoal (increased quantities) and changes in pollen in the KAO3 core, show that around 1581 BP there was the presence of human introduced grass pollen with an abrupt increase of charcoal that soon followed in the sample of 1376BP, while rainfall was increasing. Also the pollen record of *Sophora toromiro*, a valuable tree for human resources on the island, shows a consistent small number of pollen in the record, but has the highest pollen count around 1376 BP suggesting some type of disturbance. The record that follows continues to show presence of charcoal in all of the samples drastically increasing at 1200 BP and moving to large size class 4, larger than 200 microns.

The discovery in this research with the most impact was the loss of not only one palm species but of at least four palm types. Four palm pollen types existed throughout the 15,000 year history of the island, and they had all disappeared from the pollen record by the year 545 BP. The disappearance of the palm trees and the appearance of human evidence coincide during this time period along with a climate event that brought cooler temperatures. The exact cause of death for the palm forests is unknown. We do know when they disappeared, that they were significant and abundant, and that they coexisted

within a very diverse environment that changed and adapted over time.

The way we have been looking at nature is no longer comprehensive enough to explain all that we can observe, and we are asked to form a more inclusive view. Einstein wrote:

...”creating a new theory is not like destroying an old barn and erecting a skyscraper in its place. It is rather like climbing a mountain, gaining new and wider views, discovering unexpected connections between our starting point and its rich environment. But the point from which we started out still exists and can be seen, although it appears smaller and forms a tiny part of our broad view gained by the mastery of the obstacles on our adventurous way up.”

It is time to step out of explaining observations of the everyday world in Newtonian views, and into the understanding of quantum mechanics that predict probabilities of phenomena. Particularly the loss of the essence of the forests, the vital life force of these breathing palms that behaved like animals. Their significance in holding this islands ecosystem together including the humans that have objectified them as cultural resources, is still being focused upon as if they were bicycles in the city rather than the phenomena of life that they created. Reproducing experiments to come up with the same results to gain truth is an outdated view of the world, as it yet cannot explain why the natural world of Rapa Nui has not yet been able to be reclaimed since the demise of the forests.

Figure 39 - Island profile sketch

BIBLIOGRAPHY

- Adkins, J.F., McIntyre, K., and Schrag, D.P. 2002. The Salinity, Temperature, and $\delta^{18}O$ of the Glacial Deep Ocean. *Science*, vol. 298, 29 November: 1769-1772.
- Andrus, C.F.T., Crowe, D.E., Sandweiss, D.H., Reitz, E.J., and Romanek, C.S. 2002. Otolith $\delta^{18}O$ Record of Mid-Holocene Sea Surface Temperatures in Peru. *Science*, vol. 295, 22 February: 1508-1514.
- Armada de Chile, Chile Isla De Pascua (Rapa-Nui). Por el Servicio Hidrografico y Oceanografico de la Armada de Chile. Datum Astro 1967. Restitucion Aerofotogrametrica de 1992.
- Ayres, W.S., 1971. Radiocarbon dates from Easter Island. *J. Polyn. Soc.* 80: 497-504.
- Bahn, P. & J. Flenley, 1992. *Easter Island, Earth Island*. Thames & Hudson. London.
- Baker, P.E. 1967. Preliminary account of recent geological investigations on Easter Island. *Geological Magazine*. 104, 116-122.
- Baker, P.A., Seltzer, G.O., Fritz, S.C., Dunbar, R.B., Grove, M.J., Cross, S.L., Tapia, P., Rowe, H.D., and J.P. Broda, 2001. The history of South American tropical climate for the past 25,000 years from the sedimentary record of Lake Titicaca (Bolivia/Peru), *Science*, 291: 640-643.
- Baker, P.A., Fritz, S.C., Garland, J., Ekdahl, E. 2005. Holocene hydrologic variation at Lake Titicaca, Bolivia/Peru, and its relationship to North Atlantic climate variation. *Journal of Quaternary Science* 20:7-8, 655-662.
- Barker, P.A., Street-Perrott, F.A., Leng, M.J., Greenwood, P.B., Swain, D.L., Perrott, R.A., Telford, R.J., and Ficken, K.J. 2001. A 14,000-Year Oxygen Isotope Record from Diatom Silica in Two Alpine Lakes on Mt. Kenya. *Science*, vol. 292, 22 June: 2307-2310.
- Bond, G. et al 1997. A Pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates. *Science* 278 (5341): 1257-1266.
- Bork, H.R., and Meith, A. 2003. The Key Role of Jubaea Palm Trees in the History of Rapa Nui: A Provocative Interpretation. *Rapa Nui Journal*, v.17 (2) October 2003.
- Boyko, C. B., 2003. The endemic marine invertebrates of Easter Island: How many species and for how long? In J. Loret & J.T. Tanacredi (eds). *Easter Island: scientific exploration into the world's environmental problems in microcosm*: 155-175.
- Butler, K. and Flenley, J. 2001. Further Pollen Evidence From Easter Island. *Pacific 2000 Proceedings of the Fifth International Conference on Easter Island and the Pacific*. (eds. Stevenson, C., Lee, G. and Morin, F.J.).
- Butler, K.; Prior, C. and Flenley, J. Anomalous Radiocarbon Dates from Easter Island. 2004 submitted for publication to *Radiocarbon*.

- Christensen C. and Skottsberg, C. 1920. Natural History of Juan Fernandez and Easter Island. v. 2.
- Clark, M.A., 1998. Supernovas and the Polynesian Canoe. *Rapa Nui Journal*, vol. 12 (1) March: 10-12.
- Cocquyt, C., 1991. Diatoms from Easter Island. *Biol. Jrb. Dodonaea* 59: 109-124.
- deMenocal, P. B., 2001. Cultural Responses to climate change during the late Holocene. *Science*, 292: 667-673.
- De Paepe, P. & Vergauwen, I. 1997. New Petrological and Geochemical Data on Easter Island. *Rapa Nui Journal*, vol. 11 (2), June: 85-93.
- Diamond, J. 2005. *Collapse: How Societies Choose To Fail Or Succeed*. Viking. The Penguin Group. New York. New York.
- Dransfield, J., J. R. Flenley, S. M. King, D. D. Harkness & S. Rapu. 1984. A recently extinct palm from Easter Island. *Nature* 312: 750-752.
- Dumont, H. J. & K. Martens, 1996. The freshwater microcrustacea of Easter Island. *Hydrobiologia* 325: 83-99.
- Dumont, H. J. & D. Verschuren, 1991. Atypical ecology of *Pantala flavescens* (Fabricius) on Easter Island (Anisoptera: Libellulidae). *Odonatologica* 20: 45-51.
- Dumont, H., Cocquyt, C., Fontugne, M., Arnold, M., Reyss, J., Bloemendal, J., Oldfield, F., Steenbergen, C. L. M., Korthals, H. J., & Zeeb, B. A. 1998. The end of moai quarrying and its effect on Lake Rano Raraku, Easter Island. *Journal of Paleolimnology* 20: 409-422.
- Edwards TWD, BB Wolfe, JJ Gibson and D Hammarlund. 2004. "Use of water isotope tracers in high-latitude hydrology and paleohydrology." In *Long-Term Environmental Change in Arctic and Antarctic Lakes, Developments in Paleoenvironmental Research, Volume 7* (eds. R Pienitz, M Douglas and JP Smol). Springer, Dordrecht: 187-207.
- Erickson, C.L. 2000 "The Lake Titicaca Basin: A Pre-Columbian Built Landscape." In *Imperfect Balance: Landscape Transformations in the Precolumbian Americas*, (ed David Lentz), Columbia University Press, New York: 311-356.
- Faegri, K. & Iversen, J. 1989. *Textbook of Pollen Analysis*. IV Edition. New Jersey: The Blackburn Press.
- Feldberg, M. J. & A. Mix, 2003. Planktonic foraminifera, sea surface temperatures, and mechanisms of oceanic change in the Peru and south equatorial currents, 0–150 ka BP. *Paleoceanography*, 18: No. 1, 16.

- Feldberg, M. J. & A. Mix, 2002. Sea-surface temperature estimates in the Southeast Pacific based on planktonic foraminiferal species; modern calibration and Last Glacial Maximum. *Marine Micropaleontology* 44: 1-29.
- Ferry, M. & S. Gomez. 1998. The Red Palm Weevil in the Mediterranean Area. *Journal of the International Palm Society*, vol. 46, No. 4, Palms.
- Finney, B., 1994. The Impact of Late Holocene Climate Change on Polynesia. *Rapa Nui Journal*, vol. 8 (1) March: 13-15.
- Fischer, S.R., 1994. Ship's Surgeon R. Guthrie's Account of a Calling at Rapanui aboard H.M.S. *Seringapatam* on 6 March 1830. *Rapa Nui Journal*, vol. 8 (3) Sept: 63-66.
- Flenley, John & P. Bahn, 2003. *Enigmas of Easter Island*. Oxford University Press, Oxford.
- Flenley, J. R. & S. M. King, 1984. Late quaternary pollen records from Easter Island. *Nature* 307: 47-50.
- Flenley, J. R., A.S.M. King, J. Jackson, C. Chew, J. T. Teller & M. E. Prentice, 1991. The late quaternary vegetational and climatic history of Easter Island. *J. Quat. Sci.* 6: 85-115.
- Friedman, I., J. Gleason and A. Warden. 1993. *Climate Change in Continental Isotopic Records. Geophysical Monograph 78*. American Geophysical Union.
- Friedman, I. 1983. Paleoclimatic evidence from stable isotopes, in *Late Quaternary Environments of the United States*. H.E. Wright, ed., v. 1: The Late Pleistocene, S.C. Porter, ed., 1983. University of Minnesota Press, MN., 385-390, 1983.
- Friedman, I. 1997. The Amazon Basin, Another Sahel? *Science* 1 July, 1997. v. 197 #4298.
- Gentz, J. and Hunt, T. L. 2003. El Nino/Southern Oscillation and Rapa Nui Prehistory. *Rapa Nui Journal* 17: 7-11.
- von Grafenstein, U., Erlenkeuser, H., Brauer, A., Jouzel, J. and Johnsen, S.J. 1999. A Mid-European Decadal Isotope-Climate Record from 15,500 to 5000 Years B.P. *Science*, vol. 284, 4 June: 1654-1657.
- Gossen, C. 2007. The Mystery Lies in the Scirpus. *Rapa Nui Journal*. v. 21, Number 2, October 2007: 105-110.
- Gossen, C. and C. Stevenson, 2005. Prehistoric Solar Innovation and Water Management on Rapa Nui. ISES/ASES World Conference August.
- Green, R.C., 2000. Origins for the Rapanui of Easter Island Before European Contact: Solutions from Holistic Anthropology to an Issue no Longer Much of a Mystery. *Rapa Nui Journal*, vol. 14 (3) September: 71-76.

- Gurley, R. & Liller, W., 1997. Palm Trees, Mana, and the Moving of the Moai. *Rapa Nui Journal*, vol. 11 (2) June: 82-84.
- Hanson, R. L. 1991. Evapotranspiration and Droughts in Paulson, R.W., Chase, E.B., Roberts, R.S. and Moody, D.W., Compilers, National Water Summary 1988-89 –Hydrologic Events and Floods and Droughts: U.S. Geologic Survey Water-Supply Paper 2375, p.99-104.
- Heiser, C. B. Jr., 1974. Totorá, taxonomy, and Thor. *Plant Sci. Bull.*: 22-26.
- Heiser, C. B. Jr., 1979. The totora (*Scirpus californicus*) in Ecuador and Peru. *Econ. Bot.* 32: 222-236.
- Hemm, R.A. & M. Mendez, 2003. Aerial surveys of Isle de Paqua: Easter Island and the new birdmen. In J. Loret & J.T. Tanacredi (eds). *Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm*: 187-194.
- Henderson, A. 1986. A Review of Pollination Studies in the Palmae. *Botanical Review* 52: 221-259.
- Henderson, A., Galeano, G. & Bernal, R. 1995. *Field Guide to the Palms of the Americas*. New Jersey: Princeton University Press.
- Heyerdahl, T. 1960 *Aku-Aku. The Secret of Easter Island*. Ruskin House. George Allen & Unwin, Ltd. Museum Street London.
- Heyerdahl, T. 1989. *Easter Island. The Mystery Solved*. Random House, New York.
- Heyerdahl, T. & E. N. Ferdon, Jr. (eds), 1965. Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific. vol. 1 & vol. 2. *Archaeology of Easter Island & Miscellaneous Papers*. Monographs of The School of American Research and the Kon-Tiki Museum. Number 24, Part 1 & Part 2.
- Heyerdahl, T., 1997. A Reappraisal of Alfred Metraux's Search for Extra-Island Parallels to Easter Island Culture Elements. *Rapa Nui Journal*, vol. 11 (1) March: 12-20.
- Hubbard, D. & M. Garcia, 2003. The coral reefs of Easter Island – A preliminary assessment. In J. Loret & J.T. Tanacredi (eds). *Easter Island: scientific exploration into the world's environmental problems in microcosm*: 53-77.
- Hunt, T. and J. Genz, 2003. El Nino/Southern Oscillation and Rapa Nui Prehistory. *Rapa Nui Journal*, v.17 (1) May: 7-11.
- Hunter-Anderson, R., 1997. Human vs Climatic Impacts at Rapa Nui: Did the People Really Cut Down All those Trees? *Proceedings of the Fourth International Conference on Easter Island and East Polynesia*. August 1997: 85-99.
- Korthals, J. J. & C. L. M Steenbergen, 1985. Separation and quantification of pigments from natural phototrophic microbial populations. *F.E.M.S. Microb. Ecol.* 31: 177-185.

- Koutavas, A., Lynch-Stieglitz, J., Marchitto, T.M. and Sachs, J.P. 2002. El Nino-Like Pattern in Ice Age Tropical Pacific Sea Surface Temperature. *Science*, vol. 297, 12 July: 226-229.
- Kuschel, G., 1963. Composition and relationship of the terrestrial faunas of Easter, Juan Hernandez, Desventuradas, and Galapagos Islands. *Occ. Pap. Calif. Acad. Sci.* 44: 79-95.
- Lagerloaf, G. Effects of Tropical Rainfall on upper ocean dynamics, air sea coupling and the hydrologic cycle. NASA Tropical Rainfall Measurement Mission (microform).
- Lamy, F., Ruhlemann, C., Hebbeln, D., & Wefer, G., 2002. High- and low-latitude climate control on the position of the southern Peru-Chile Current during the Holocene. *Paleoceanography*, 17: No. 2, 16-10.
- Langdon, R., 1997. Evidence for Three Prehistoric Migrations to Easter Island. *Rapa Nui Journal*, vol.11 (1) March: 21-23.
- Liller, W. 1995. The Oldest Toromiro in the World. *Rapa Nui Journal*, vol. 9 (3) September: 65-68.
- Linsley, B. K., Messier, R. G. & Dunbar R. G., 1999. Assessing between-colony oxygen isotope variability in the coral porites lobata at Clipperton Atoll. *Coral Reefs* 18: 13-27.
- Linsley, B.K., Wellington, G.M., and Schrag, D.P. 2000. Decadal Sea Surface Temperature Variability in the Subtropical South Pacific from 1726 to 1997 A.D. *Science*, vol. 290, 10 November: 1145-1148.
- MacIntyre, F. 2002. Simultaneous Settlement of Indo Pacific Extremes? *Rapa Nui Journal*, v. 16, No. 2, October: 96-104.
- MacIntyre, F. 2001. ENSO, Climate Variability, and the Rapanui: Part 1. *Rapa Nui Journal* v. 15 (1) p. 17-26. Part 2. v. 15 (2): 83-94.
- Magliulo-Cepriano, L., M. P. Schrieblman & J.T. Tanacredi, 2003. Finfish in the Rano Kau caldera of Easter Island. In J. Loret & J.T. Tanacredi (eds). *Easter Island: scientific exploration into the world's environmental problems in microcosm*: 177-183.
- Maldonado, A., Méndez, C., Ugalde, P., Jackson, D., Seguel, R. and Latorre C. 2010. Early Holocene climate change and human occupation along the semiarid coast of north-central Chile. *J. Quaternary Sci.*, Vol. 25 pp. 985–988. ISSN 0267-8179.
- Mann, D., 2003. Prehistoric destruction of the primeval soils and vegetation of Rapa Nui (Isla De Pascua, Easter Island). In J. Loret & J.T. Tanacredi (eds). *Easter Island: scientific exploration into the world's environmental problems in microcosm*: 133-153.
- Mann, M.E., Bradley, R.E., & Huges, M.K. (2000). Long-term variability in the El Nino/Southern Oscillation and associated teleconnections. In Diaz, H.E. & V Markgraf (eds.) (2000) *El Nino and the Southern Oscillation: Multiscale Variability and its Impacts on Natural Ecosystems and Society*. (Cambridge University Press): 357-412.

- Martens, K. & F. Behren, 1994. A checklist of the recent non-marine ostracods (Crustacea, Ostracoda) from the inland waters of South America and adjacent islands. *Trav. sci. Mus. nat. Hist. nat. Luxembourg* 22: 84.
- Masson, V., Vimeaux, F., Jouzel, J., Morgan, V., Delmotte, M., Ciais, P., Hammer, C., Johnsen, S., Lipenkov, V.Y., Mosley-Thompson, E., Petit, J.R., Stei, E.J., Stievenard, M., Vaikmae, R. (2000) Holocene climate variability in Antarctica based on 11 ice-core isotopic records. *Quaternary Research* 54: 348-358. doi:10.1006/qres.2000.2172
- McCall, G.. 1980. Rapanui: Tradition and Survival on Easter Island. University of Hawai'i Press, Honolulu.
- McCall, G. 1993. Little Ice Age: Some Speculations for Rapa Nui. *Rapa Nui Journal* 7: 65-70.
- Meher-Homji, V. M. 1991. Probable impact of deforestation on hydrological processes. *Climate change* 19: 163-73.
- Meith A, and Bork H-R. 2010. Humans, climate or introduced rats - which is to blame for the woodland destruction on prehistoric Rapa Nui (Easter Island). *Journal of Archaeological Science* 37(2): 417-426.
- Meith, A., Bork, H.R., and Feeser, I. 2002. Prehistoric and Recent Land Use Effects on Poike Peninsula, Easter Island (Rapa Nui). *Rapa Nui Journal*, v.16 (2) October 2002.
- Melillo, J.M., Steudler, P.A., Aber, J.D., Newkirk, K., Lux, H., Bowles, F.P., Catricala, C., Magill, A., Ahrens, T., and Morrisseau, S. 2002. Soil Warming and Carbon-cycle Feedbacks to the Climate System. *Science*, vol. 298, 13 December: 2173-2175.
- Menzies, G. 2002. 1421: The Year China Discovered America. Harper Collins Publishers. 649p.
- Mix, Alan, 2003. Chilled out in the ice-age Atlantic. *Nature* 425: September 4: 32-33.
- Mucciarone, D. & R. Dunbar, 2003. Stable isotope record of El Nino – Southern Oscillation events from Easter Island. In J. Loret & J.T. Tanacredi (eds). *Easter Island: scientific exploration into the world's environmental problems in microcosm*: 113-132.
- Myers, N. 1988. Tropical Deforestation and Climatic Change, Environmental Conservation. Proceedings Conference on Climate and Geoscience, Session on Climate, Environment and International Security. Louvain-la Neuve, Belgium.
- Nunn, P.D. 2001. Ecological Crisis or Marginal Disruptions: the Effects of the First Humans on Pacific Islands. *New Zealand Geographer*, vol. 57 (2): 11-20.
- Nunn, P.D. (1999) *Environmental Change in the Pacific Basin: chronologies, causes, consequences*. Wiley, London.
- Olsson, I. U., 1991. Accuracy and precision in sediment chronology. *Hydrobiologia* 214: 25-34.

- Orliac, C. n.d. New Data on Easter Island's Woody Vegetation. Paper presented at Pacific 2000. The Fifth International Conference on Easter Island and the Pacific. Hawai'i, August, 2000.
- Orliac, C. and Orliac, J. 1998. The disappearance of Easter Island's forest: over-exploitation or climatic catastrophe? pp. 129-134, In: "Easter Island in Pacific Context South Seas Symposium. Proceedings of the Fourth International Conference on Easter Island and East Polynesia". University of New Mexico, Albuquerque, 5-10 August 1997. C.M. Stevenson, G. Lee, and F. J. Morin, Eds. The Easter Island Foundation, Bearsville and Cloud Mountain Press, Los Osos, CA.
- Nunn, P. D. 2000. Environmental catastrophe in the Pacific Islands around A.D. 1300. *Geoarchaeology* 15, 715-740.
- Peteet, D., W. Beck, J. Ortiz, S. O'Connell, D. Kurdyla, and D. Mann, 2003. Rapid vegetational and sediment change from Rano Aroi crater, Easter Island. In J. Loret & J.T. Tanacredi (eds). *Easter Island: scientific exploration into the world's environmental problems in microcosm*: 81-92.
- Prebble, M. and J. Wilmhurst, 2009. Detecting the initial impact of humans and introduced species on island environments in Remote Oceania using paleoecology. *Biol Invasions*, 11:1529-1556.
- Prebble, M. and J.L. Dowe. 2008. The late Quaternary decline and extinction of palms on oceanic Pacific islands. *Quaternary Science Reviews*. 27, 2546-2567.
- Ruddiman, W. F., 2003. The anthropogenic greenhouse era began thousands of years ago. *Climatic Change* 61: 261-293.
- Segers, H. & H. J. Dumont, 1993. Zoogeography of Pacific Ocean islands: a comparison of the rotifer faunas of Easter Island and the Galapagos archipelago. *Hydrobiologia*. 255/256: 475-480.
- Skottsberg, C. 1956. Derivation of the Flora and Fauna of San Juan Fernandez and Easter Island. Vol 1: 438 pp. Almquist & Wiksells, Uppsala.
- Smith, C.S., 1961a. A temporal sequence derived from certain Ahu. In Y. Heyerdahl & N. Ferdon Jr. (eds), q.v.: 118-120.
- Smith, C.S., 1961b. Radiocarbon dates from Easter Island. In T. Heyerdahl & N. Ferdon, Jr. (eds), q.v.: 393-396.
- Steadman, D.W., 1995. Prehistoric extinctions of Pacific Island birds: biodiversity meets zooarchaeology. *Science* 2667: 1123-1131.
- Stevenson, C.M., Wozniak, J., and Haoa, S. 1999. Prehistoric agricultural production on Easter Island (Rapa Nui), Chile. *Antiquity* 73, 801-812.

- Stevenson, C. M., Ladeformed, T. and Haoa, S. 2002. Productive strategies in an uncertain environment: prehistoric agriculture on Easter Island. *Rapa Nui Journal* 16 (I): 17-22.
- Stokstad, E. 2004. Heaven or Hellhole? Islands' Destinies Were Shaped by Geography. *Science*, vol. 305, 24 September: 1889.
- Stute, M., Forster, H., Frischkorn, H., Serejo, A., Clark, J.F., Schlosser, P., Broecker, W.S., Bonani, G. (1995). Cooling of Tropical Brazil (5°C) During the Last Glacial Maximum. *Science* 269: 379-382.
- Stuiver, M. , and Suess, H. E. , *Radiocarbon*, 8, 534 (1966)
- Stuiver, M. and P.J. Reimer, 1993. CALIB Rev 5.0.1. Radiocarbon Calibration Program, *Radiocarbon*, 35, 215-230.
- Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Henderson, K.A., Brecher, H.H., Zagorodnov, V.S., Mashiotta, T.A., Lin, P.N., Mikhailenko, V.N., Hardy, D.R., and Beer, J. 2002. Kilimanjaro Ice Core Records: Evidence of Holocene Climate Change in Tropical Africa. *Science*, vol. 298, 18 October: 598-593.
- Tomlinson, P. Barry. 2006. The uniqueness of palms. *Botanical Journal of the Linnean Society*. 151, 5-14.
- van Geel, Bas. Non-Pollen Palynomorphs. J.P. Smol, H.J.B Birks & W.M. Last (eds) 2001. *Tracking Environmental Change Using Lake Sediments, Volume 3: Terrestrial, Algal and Siliceous indicators*, Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Venzke E, Wunderman RW, McClelland L, Simkin, T, Luhr, J F, Siebert L, Sennert S, and Mayberry G (eds.) (2002-). *Global Volcanism, 1968 to the Present*. Smithsonian Institution, Global Volcanism Program Digital Information Series, GVP-4 (<http://www.volcano.si.edu/reports/>).
- Vitousek, P.M., Ladeformed, T.N., Kirch, P.V., Hartshorn, A.S., Graves, M.W., Hotchkiss, S.C., Tuljapurkar, S., Chadwick, O.A. 2004. Soils, Agriculture, and Society in Precontact Hawai'i. *Science*, vol. 304, 11 June: 1665-1669.
- Vorosmarty, C.J., Green, P., Salisbury, J., and Lammers, R.B. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science*, vol. 289, 14 July: 284-286.
- Wardle, D.A., Yeates, G.W., Barker, G.M., Bellingham, P.J., Bonner, K.I. and Williamson, W.M. 2003. Island Biology and Ecosystem Functioning in Epiphytic Soil Communities. *Science*, vol. 301, 19 September: 1717-1720.
- Wilson, A.T., and Hendy, C.H. 1971. Past Wind Strength from Isotope Studies. *Nature* v. 234, Dec. 10. p. 344 -345

- Wolfe, Brent & K. Beuning. 2001. Carbon and Oxygen Isotope Analysis of Lake Sediment Cellulose: Methods and Applications. W. M. Last & J.P.Smol (eds) 2001. Tracking Environmental Change Using Lake Sediments. Volume 2: Physical and Geochemical methods. p.373-400. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Zhou, W., Head, J., Jull, A.J.T., Burr, G., Lu, X. 2003. Variability of Holocene Climatic Events Recorded in Peat Sediments from the Tibetan Plateau. XVI INQUA Congress. Paper No. 54-9.

Appendix A
Fossil Pollen, Spores and Non-pollen Palynomorphs
KAO3 core of the crater lake Rano Kao
Total length: 9 meters lake sediment
Chronology: 1000BP – 15k BP

While working at the University of Minnesota Ecology Lab in the fall of 2007 and spring of 2008 counting and analyzing pollen, non-pollen palynomorphs, macrofossils and core samples, I took photographs with my digital zoom Nikon 4100 camera in the microscope lens along the way. What you see here are representative images of each pollen slide. In total there are 1559 images taken at approximately 20 cm intervals from 1.5cc sediment samples within the 9-meter core. The images were captured at 40x and 100x magnification on a Leica DMLB, imported into Adobe Photoshop and organized.

All specimens were prepared using standard Faegri & Iverson palynology techniques excepting the use of Hydrofluoric Acid (HF) in the process. Processed at Massey University Pollen Lab, Palmerston North, New Zealand.

Note.

This information has been prepared for students and researchers interested in applying comprehensive palaeoecological techniques. It is open to use by everyone with the provision that its use is cited in any publications, using the URL as the place of publication. Any comments regarding the images and information presented should be addressed to the author at the above contact.

1L 3-4cm

1174 C14 yrs BP

asteraceae

asteraceae 2

bumpy 2

bumpy 3

bumpy 4

bumpy 5

charcoal

charcoal 2

charcoal 3

charcoal 4

charcoal 5

charcoal 6

charcoal ball

1L 3-4cm page 2

1174 C14 yrs BP

1L 3-4cm

page 3

1174 C14 yrs BP

1L 10-11cm

1200 C14 yrs BP

dark fern

trilete fern

fern 2

fern 3

inocarpus

M1

palm

palm 2

phytolith

plant 1

plant 1(2)

plant epidermis

poaceae 30um

resin

slide overall view

1L 10-11cm

page 2

1200 C14 yrs BP

1L 30-31cm

1236 C14 yrs BP

diporate

diporate 2

diporate 3

diporate 4

F1

palm type 1

palm type 3

scirpus

trilete fern

UFO tricolpate

UFO star

sophora

triumfetta

1L 50-51cm

1273 C14 yrs BP

cell mass

cell mass 2

charcoal fragment

egg cell

F1

fern

fern monolete

fern sprout

sophora

fungi sphere

furry sac 2

furry sac under
epidermis

M

M1

M3

1L 50-51cm page 2

1273 C14 yrs BP

mixed 1

mixed (2)

mixed 2

mixed 3

1L 50-51cm page 3

1273 C14 yrs BP

1L 50-51cm page 4

1273 C14 yrs BP

palm 1

palm 2

palm type 1

palm type 2

palm type 3

palm type 3(2)

polygonum

psilate fern

resin

rhizome

rhizomes

rhizome 4

rhizome with stomata

1L 50-51cm page 5

1273 C14 yrs BP

sophora 3

sac

sac 2

sac 3

scirpus 2

scirpus and
palm

scirpus w/
chytrid holes

sophora 4

starch 1

starch 1 polar

starch 2

starch 2 polar

starch 3

starch 3 polar

3 scirpus

transparent plant

two scirpus

1L 50-51cm page 6

1273 C14 yrs BP

UFO pollen

UFO
tricolporate1 UFO
tricolporate2 UFO
tricolporate3 UFO
tricolporate4 UFO
tricolporate5 UFO
tricolporate6

2L 10-12cm

1325 C14 yrs BP

slide overall view

2L 30-32cm

1329 C14 yrs BP

cell mass
with fungi

F1

trilete fern

fern 2

trilete fern 2

fern 4

F2

fern sporangium

M1

M1 polar

P1

P2

palm type 1

poaceae

2L 30-32cm page 2

poaceae types

polygonum

sac 1

scirpus cluster

UFO 1

UFO 1b

2L 50-51cm

1332 C14 yrs BP

epidermal stuff

dicolporate

fern psilate

fern with shoots

epidermis with stomata

fracture 1

fracture 2

fracture 3

fractures 2

fractures 3

fractures 4

fractures 5

fractures 6

fractures 7

fractures 8

fractures 9

2L 50-51cm page 2

1332 C14 yrs BP

fungal mass

fungi 1

fungi 2

fungi 3

fungi 4

fungi 5

mineral

oval starch

lycopodium exotic

palm type 1

palm open

palms

2L 50-51cm page 3

1332 C14 yrs BP

2L 50-51cm page 4

1332 C14 yrs BP

poaceae

poaceae 2

poaceae 3

polygonum

resin

rhizome 1

scirpus

scirpus 2

scirpus

poaceae

epidermis skin
with cell

2L 50-51cm

page 5

1332 C14 yrs BP

starch 1

starch 1 polar

starch 2

starch 2 polar

starch 3

starch 3 polar

starch 4

starch 4 polar

starch 5

starch 5 polar

starch 6

starch 6 polar

starch 7

starch 8

2L 50-51cm page 6

1332 C14 yrs BP

transparent sac

triumfetta

triumfetta 2

fungal mass

UFO tricolporate

UFO tricolporate 2

UFO tricolporate 3

fungi

palmae

lycopodium

coprosma

xylosma

2L 66-69cm

1376 C14 yrs BP

3L 5-7cm

1581 C14 yrs BP

3L 25-26cm

1698 C14 yrs BP

canavallia 1

canavallia 2

fern spores

fungi w/ chytrid holes

palm type 1

plant

resting egg

resting egg 2

scirpus

UFO monocolpate

UFO sac

UFO tricolpate

verrucated fern

overall

3L 55-56cm

1979 C14 yrs BP

3L 55-56cm page 2

1979 C14 yrs BP

starch grain 1

starch grain polarized

starch grain 2

starch grain
polarized starch grain
polarized (2)

transparent sac

transparent sac (2)

3L 75-76cm

2213 C14 yrs BP
canavalia

algal mass

fern

echinate
fern

cell
mass

fern
bladder

M1

M2

M3

M4

overall

3L 75-76cm

page 2

2213 C14 yrx BP

3L 94-96cm

2401 C14 yrs BP

3L 94-96cm

page 2

2401 C14 yrs BP

3L 94-96cm

page 3

2401 C14 yrs BP

sac 1

sac 2

sac 3

sac 4

scirpus
cluster

sophora

starch 1

starch 1 polar

transparent plant

triumfetta

UFO

UFO (2)

UFO 3

UFO pollen 2

palm with tephra

UFO pollen

4L 5-6cm

24/1 C14 yrs BP

4L 15-16cm

2659 C14 yrs BP

4L 15-16cm

page 2

2659 C14 yrs BP

4L 15-16cm

page 3

2659 C14 yrs BP

plant tissue

poaceae

plant with
mineral

fungi

pollen

polygonum

red resin

sac 1

sac 2

sac 3

sac 4

sac 5

4L 15-16cm

page 4

2659 C14 yrs BP

4L 35-36cm

3045 C14 yrs BP

asteraceae 1

F1

asteraceae 2

F3

cell mass

F2

M2 polar

M3 polar

M2

M3

M4

M5

mixed

mixed 4

4L 35-36cm page 2

3045 C14 yrs BP

4L 35-36cm page 3
3045 C14 yrs BP

4L 35-36cm

page 4

3045 C14 yrs BP

4L 55-56cm

3443 C14 yrs BP

broussonetia

coprosma

echinate
fern

fern

overall 2

fern with
perispore

fern with
spores

overall 3

M1

M2

4L 55-56cm

page 2

3443 C14 yrs BP

4L 55-56cm

page 3

3443 C14 yrs BP

sophora

sophora 2

spiny sac

starch

transparent plant
on cluster trilete
fern a trilete
fern b

triumfetta

triumfetta 2

UFO

UFO b

UFO tricolpate

UFO tricolpate 2

xylem

4L 75cm

3448 C14 yrs BP

asteraceae

asteraceae 2

asteraceae 3

asteraceae 4

cell
mass

charcoal

fern

epidermis

flattened
triumfetta

M2

M or P

M with
charcoal

4L 75cm

page 2

3448 C14 yrs BP

overall

P1

P2

overall 2

P3

P4

P5

P6

P6b

4L 75cm

page 3

3448 C14 yrs BP

4L 75cm

page 4

3448 C14 yrs BP

scirpus

starch

starch 2

starch 2 polar

starch 3

starch 3 polar

tricolpate

tricolpate b

tricolpate c

triumfetta 1

triumfetta 2

triumfetta 3

trilete fern

verrucated
fern

4L 95-96cm

3452 C14 yrs BP

4L 95-96cm

page 2

3452 C14 yrs BP

resin 1

starch
clump

UFO 1 w/ fungi

overall slide
view

palmae

fern

small triumphetta

Mineral w/
charcoal

UFO monoclpate

fungi

5L 10cm

3454 C14 yrs BP

blue

epidermis

epidermis b

5L 10cm page 2
3454 C14 yrs BP

5L 20cm

3459 C14 yrs BP

cell mass with fungi

polygonum

scirpus

scirpus anther

scripus b

starch

starch polar

starch in egg

tricolpate

triumfetta

triumfetta round

5L 40-41cm

3464 C14 yrs BP

ephedra type
UFO tricolpate

palm

plant

ephedra (2)

polygonum

polygonum (2)

trilete fern

scirpus

scirpus (2)

scirpus (2)

cyperus

palm pritchardia

5L 50-51cm

3500 C14 yrs BP

3500 C14 yrs BP

5L 60-61cm

4170 C14 yrs BP

asteraceae

asteraceae 2

caesalpinia 1

caesalpinia 2

caesalpinia 3

canavallia 1

canavallia 2

canavallia 3

canavallia 4

canavallia 5

trilete fern

fern 2

fern 3

starch

5L 60-61cm page 2

4170 C14 yrs BP

overall

palms

palm
type 1

palm
type 3

palm
type 3b

polygonum

scirpus

UFO tricolpate

coprosma

coprosma 2

coprosma 3

5L 90cm

5450 C14 yrs BP

asteraceae

fungi

fungi mass

furry
sac

palm

palm
type 3

resting
fungal sac

resting fungal sac (2)

rugulated fern

scabrate
fungi

spiny sac

starch

starch polar

5L 90cm page 2
5450 C14 yrs BP

terra and aquatic fungi

starch

starch polar

triumfetta

UFO

UFO sac

UFO
sac (2)

6L 25-26cm

7670 C14 yrs BP

6L 25-26cm

page 2
7670 C14 yrs BP

6L 25-26cm page 3

7670 C14 yrs BP

6L 25-26cm page 4
7670 C14 yrs BP

6L 25-26cm

page 5

7670 C14 yrs BP

Starch 3

Starch 4

Starch 5

Starch 3 polar

Starch 4 Polar

UFO

UFO
Cell

UFO Cell 2

UFO
cell 3 UFO
Cell 4 Verrucate
Fern Verrucate
Fern 2

6L 45cm

8438 C14 yrs BP

dicolpate

fern

overall

P1

palm type 1

palm type 3

sophora

triumfetta

6L 65cm

8589 C14 yrs BP

asteraceae

F1

P1

P2

P3

palm
type 1

resin

scirpus

triumfetta

starch tri

starch polar

6L 95cm

8885 C14 yrs BP

7L 5cm

8915 C14 yrs BP

7L 25-26cm

9044 C14 yrs BP

7L 25-26cm page 2

9044 C14 yrs BP

7L 25-26cm page 3 9044 C14 yrs BP

Fern

Resin 5

Resin 6

Resin 7

Resin 8

Resin sac

rhizome and stoma

Rhizome

sac

Square Cell

Square plant cell

Starch

Starch 2

Starch 2 polar

Starch 3

Starch 5

7L 25-26cm

page 4

starch 3 polar

starch 4^{9044 C14 yrs BP}

starch 4 polar

starch 5

starch 5 polar

starch 6

starch 7

starch 7 polar

transparent

transparent plant

transparent

sac

transparent 3

starch
and
raphide

7L 25-26cm page 4

⁹⁰⁴⁴ C14 yrs BP

starch 3 polar

starch 4

starch 4 polar

starch 5

starch 5 polar

starch 6

starch 7

starch 7 polar

transparent

transparent plant

transparent

sac

transparent 3

starch
and
raphide

7L 25-26cm page 5

9044 C14 yrs BP

resin sac 2

resin sac

P3

P2

Plant

UFO
Bubbles

UFO
Fern

Xylem

UFO
Fern 2

resin

P4

7L 25-26cm page 6

9044 C14 yrs BP

7L 25-26cm

page 7

9044 C14 yrs BP

Plant

Plant 2

Plant 4

Phytolith 2

Resin

Starch

Starch grains

Stomata

Stomata 2

Mineral

Triumfetta

Triumfetta 2

Transparent plant polar

Unknown

Unknown 2

Unknown 3

7L 25-26cm page 8

9044 C14 yrs BP

Funnel
fungi

pyrite
sac

Transparent plant

Rugulated fern

Rugulated fern

fern spore
with sprout

Vol glass

Verrucate fern 2

Verrucate fern

xylem

7L 45-46cm

9195 C14 yrs BP

7L 60cm

9225 C14 yrs BP
broken fern

aquatic animal

cells 1

cell 2

cell 3

xylem

fern

fern 4

fern

fern with sac

fungal mass

fungi

furry sac

7L 60cm
9225 C14 yrs BP page 2

asteraceae under mass

overall view

P1

P3

P2

P4

plant

poaceae

cell 1

Polygonum

phytolith

phytolith

7L 60cm page 3
9225 C14 yrs BP

7L 65cm

9225 C14 yrs BP page 1

7L 65cm

9225 C14 yrs BP page 2

7L 65cm

9225 C14 yrs BP page 3

sac 7

sac 8

sac 9

sac 9b

Sac 10

UFO

UFO 3

scirpus

UFO 2

UFO pollen b

UFO pollen d

UFO pollen

UFO pollen c

7L 85-86cm

9241 C14 yrs E

7L 85-86cm

9241 C14 yrs BP page 2

palm type 1

palm type 2 with fungi

palm type 4

P1

resin

scirpus

trilete fern

sophora

verrucated
fern

triumfetta

UFO

worm

7L 95-96cm page 1

9255 C14 yrs BP

7L 95-96cm

9255 C14 yrs BP page 2

8L 25-26cm

9274 C14 yrs BP page 1

cell mass
with fungi

M

M polar

charcoal

M2

M2 polar

overall

palm
type 1 palm
type 3 palm
type 3b

8L 25-26cm

9274 C14 yrs BP page 2

8L 45-46cm page 1
 9290 C14 yrs BP

8L 45-46cm

9290 C14 yrs BP page 2

overall 2

8L 45-46cm

9290 C14 yrs BP page 3

8L 65cm

9306 C14 yrs BP

cell mass with fungi

coprosma

echinate fern

overall

fern spore

fern spore 2

M

overall 2

8L 65cm

9306 C14 yrs BP page 2

8L 75-76cm

9345 C14 yrs BP page 1

transparent plant

cell group

cell mass

fungi 1

egg sac

asteraceae

asteraceae polar

fungi scabrate

fungi mass

Irgcell

fungi scabrate 2

fungi mass 2

palm type 3

mineral

mineral polar

monolete fern

palm type 3(2)

8L 75-76cm

9345 C14 yrs BP page 2

phytolith

8L 75-76cm

93445 C14 yrs BP page 3

UFO

UFO (2)

sporangium

UFO (4)

UFO dicolpate

UFO dicolpate (2)

UFO dicolpate (3)

UFO fern

UFO fern (2)

UFO
glass UFO
plant UFO
plant 2

UFO plant 3

UFO
resin UFO
plant 4 verrucate
fern verrucate
fern (2)

9L 3-4cm

9550 C14 yrs BP page 1

asteraceae

asteraceae 2

blackened resin

asteraceae 3

chytrid eating palm

chytrid eating palm 2

F1

coprosma

coprosma 2

coprosma 3

F2

F3

9L 3-4cm

9550 C14 yrs BP page 2

9L 3-4cm

9550 C14 yrs BP page 3

poaceae

resting egg

starch 1

triumfetta 2

triumfetta

starch 1 polar

triumfetta 3

UFO

verrucated
fern

xylosma

9L 25cm

9674 C14 yrs BP page1

algae

asteraceae

coprosma

epidermis

black sac

fern

overall

fern 2

P1

P2

9L 25cm

9674 C14 yrs BP page 2

9L 45-46cm

11393 C14 yrs BP page 1

9L 45-46cm

11393 C14 yrs BP page 2

resin 1

resin 2

sac 1

sac 2

resin 3

sac 3

sac 4 & 5

sac 6

sac 7

sac 9

sac chain

sac 10

sac 11

scirpus

scirpus 2

triumfetta

UFO

UFO pollen

9L 65-66cm

11952 C14 yrs BP page 1

animal

asteraceae

asteraceae 2

charcoal

charcoal 2

echinate fern

F1

F2

F4

F3

fungal mass

M1

M2

M3

M4

9L 65-66cm

11952 C14 yrs BP page 2

overall

overall 2

P1

P2

palm type 1

palm type 2

palm type 2 round

palm type 3

9L 65-66cm

11952 C14 yrs BP page 3

resin

sac 1

sac 2

sac
spiny sac
worm

sophora

spikes

starch

triumfetta

triumfetta 2

triumfetta
rhomboidea triumfetta
rhomboidea 2

sophora

verrucated fern

verrucated fern 2

9L 75-76cm

12511 C14 yrs BP page 1

9L 75-76cm

12511 C14 yrs BP page 2

overall view

overall view 2

palm and starch

palm damaged

9L 75-76cm 12511 C14 yrs BP page 3

9L 95-96cm

12930 C14 yrs BP page 1

asteraceae

asteraceae
and palm

echinate fern

grass imploded

palm
type 2

P1

palms

palm
type 2b palm
type 2c palm
type 3 palm
type 3c

poaceae

poaceae 2

starch 1

9L 95-96cm

12930 C14 yrs BP page 2

triumfetta 1

triumfetta 2

triumfetta 3

triumfetta 4

triumfetta 5

triumfetta 6

triumfetta 7

triumfetta 8

triumfetta 9

triumfetta 10

triumfetta 11

triumfetta 12

type 3 and
type 1
palm

9L 95-96cm page 3

12930 C14 yrs BP

Appendix B Core Diagrams

Each sheet within this appendix corresponds to a meter of core sediment retrieved in the KAO3 core on Rapa Nui in March 2005. They are numbered consecutively with 1L being the top meter and 9L being the bottom of the core. The dates range from 1000BP at the top and 15kBP at the bottom. On each sheet there is a photograph of the meter section scanned and photographed at the Lacustrine Research Center at the University of Minnesota in Minneapolis. The initial core scanning of the whole core was conducted at low resolution and then the core was split and photographed as you see in these diagrams. Slight variations are noted in color but the core was mostly consistent detritus. Initial Core Descriptions (ICD) sheets can be found in Appendix K for further details.

On each sheet there is a graph line located for each isotope sample taken at the 20 cm interval markings. Also at these same intervals pollen samples were analyzed and two symbols are noted at each sample spot.

One being the dominant plant type for that sample which will be either: aquatics, trees, palms, ferns or grasses. The second symbol is an indicator of percent palm pollen counted in that noted sample. Radiocarbon dates are marked along with a photograph of the scirpus seed type that was used for dating this sample at its noted location.. All of the data drawn onto these diagram sheets become a useful visual descriptor of how the collected data merges together to form a complete recreated ecology.

Note.

This information has been prepared for students and researchers interested in applying comprehensive palaeoecological techniques. It is open to use by everyone with the provision that its use is cited in any publications, using the URL as the place of publication. Any comments regarding the images and information presented should be addressed to the author at the above contact.

1L

Appendix C
Pollen Diagrams
KAO3 core both mat and lake sediment

Within this appendix there are 17 pollen diagrams, 12 of which are from the lake sediment samples found beneath the water level in Rano Kao dating from 1000BP – 15kBP, and the other 5 are from the mat surface which is 2-4 meters thick and floating on the surface waters which holds the last 1000 years of ecological history. Each diagram was created using a program called Psidium v.1.0 Beta 4 created by Edward Cushing, Professor Emeritus at the University of Minnesota using Macintosh OS 9. The program is quite efficient and creates diagrams comparable to the more common palynology software being used on DOS operating systems. Each diagram as noted organizes the counted pollen within a chronological stratigraphic context aging with vertical measurement (top being the most recent). The diagram notes the data was evaluated as either percent of total pollen counted or absolute pollen per sample of each pollen type found and identified. Pollen count sheets which contain the raw data can be found in Appendix F. These diagrams are most useful as a visual display in assessing ecological change and deposition of pollen over time. The diagrams are also statistically analyzed according to the pollen concentration, deposition rate, and total pollen influx. Known numbers of exotic pollen were added to each sample in order to compare the changes of native pollen per volume of sediment which further defines change over time.

Note.

This information has been prepared for students and researchers interested in applying comprehensive palaeoecological techniques. It is open to use by everyone with the provision that its use is cited in any publications, using the URL as the place of publication. Any comments regarding the images and information presented should be addressed to the author at the above contact.

RANO KAO KAO3 CORE EASTER ISLAND 2008

AQUATICS

RANO KAO KAO3 CORE EASTER ISLAND 2008

RANO KAO KAO3 CORE EASTER ISLAND 2008

TREES

RANO KAO KAO3 CORE EASTER ISLAND 2008

GRASS AND FERNS

RANO KAO KAO3 CORE EASTER ISLAND 2008

CHARCOAL ABSOLUTE COUNTS

RANO KAO KAO3 CORE EASTER ISLAND 2008

RANO KAO KAO3 CORE EASTER ISLAND 2008

RANO KAO KAO3 CORE EASTER ISLAND 2008

LYCOPODIUM

RANO KAO KAO3 CORE EASTER ISLAND 2008

POLLEN CONCENTRATION

RANO KAO KAO3 CORE EASTER ISLAND 2008

POLLEN INFLUX

Non-pollen Palynomorphs KAO3 Rano Kao

RANO KAO KAO3 CORE EASTER ISLAND 2008

POLLEN MAT

RANO KAO KAO3 CORE EASTER ISLAND 2008

FERNS MAT

RANO KAO KAO3 CORE EASTER ISLAND 2008

FERNS AND GRASS MAT

RANO KAO KAO3 CORE EASTER ISLAND 2008

TOTAL POLLEN MAT

RANO KAO KAO3 CORE EASTER ISLAND 2008

POLLEN CONCENTRATION MAT

Appendix D Plant Illustrations

Thirty-three (33) plant types were identified by their pollen in the KAO3 core samples. Each sheet in this appendix section contains an illustration of the plant, photographs of the fossil pollen, and habitat information for each. Some illustrations were drawn from photographs of the plants that were found during the 2005 and 2008 coring expeditions to Rapa Nui. Although the majority of these are now extinct or no longer found on the Rapa Nui. Useful resources include the herbarium at UMN, internet resources and illustrations from the naturalist Carl Skottsberg. Each sheet contains an illustration drawn in ink on mylar by Denise Long, Art of Heart Awakening. Pollen photos were taken from the pollen slides, and an ecology of each plant including medicinal and human uses of these particular plants are referenced appropriately to the source. The age of each sample, abundance of the pollen, and diversity of the plants can be found in Appendix F. These plants were alive and thrived between 15k BP and 1000 years BP. Graphic design layout by Jonathon Tudor, graphic artist.

Note.

This information has been prepared for students and researchers interested in applying comprehensive palaeoecological techniques. It is open to use by everyone with the provision that its use is cited in any publications, using the URL as the place of publication. Any comments regarding the images and information presented should be addressed to the author at the above contact.

1. <i>Asplenium adiatoides</i>	17. <i>Myrsine</i> spp.
2. <i>Axonopus paschalis</i>	18. <i>Paspalum scrobiculatum</i>
3. <i>Bidens pilosa</i>	19. <i>Polygonum acuminatum</i>
4. <i>Broussonetia papyrifera</i>	20. <i>Polypodium phymatodes</i>
5. <i>Caesalpinia bonduc</i>	21. <i>Portulaca oleracea</i>
6. <i>Canavalia</i> spp.	22. <i>Pritchardia</i> spp.
7. <i>Chenopodium glaucum</i>	23. <i>Pteris</i> spp.
8. <i>Cocos nucifera</i>	24. <i>Sapindus saponaria</i>
9. <i>Coprosma</i> spp.	25. <i>Scirpus californicus</i>
10. <i>Cyperus cyperoides</i>	26. <i>Sophora toromiro</i>
11. <i>Cyperus vegetus</i>	27. <i>Thelypteris interrupta</i>
12. <i>Pycnus polystachyos</i>	28. <i>Thespesia populnea</i>
13. <i>Inocarpus fagifer</i>	29. <i>Triumfetta semitriloba</i>
14. <i>Ipomoea batatas</i>	30. <i>Tropaeolum majus</i> L.
15. <i>Jubaea chilensis</i>	31. <i>Vittaria elongata</i>
16. <i>Microlepis strigosa</i>	32. <i>Xylosma</i> spp.

Asplenium adiantoides L.

Squamulosum

Spleenwort

Spleenwort Family

Aspleniaceae

A. adiantoides (L.)- C. Chr. var. *squamulosum* C. Chr. (Christensen and Skottsberg 1920)

Habitat: In the crater lake of Rano Kao, c. 110 m on the firm moss peat – Fertile.

Distribution: Skottsberg was the first to note *Asplenium* on Easter Island. Occurs in Asia, tropical Australia, New Zealand, Polynesia, east Africa and adjacent islands.

Spores: Monolete. Perispore typically winged, spiny, reticulate, or perforate .

Identification: Plants terrestrial, on rock, or rarely epiphytic. Stems erect or nearly erect, rarely long-creeping, scaly . Steles radially symmetric or dorsiventral (with structurally distinct abaxial and adaxial aspects) dictyosteles. Leaves monomorphic , rarely almost dimorphic with fertile leaves taller and more erect than sterile ones. Petioles with one vascular bundle X-shaped in cross section or with 2 vascular bundles back to back and C-shaped. Blades extremely diverse, simple to 4-pinnate, commonly with tiny glandular hairs and a few linear scales, rarely with spreading hairs. Veins free to anastomosing. Sori borne on

veins, ± lunate to linear. Indusia usually present, shape conforming to sorus and originating along 1 side of sorus. Sporangia with stalk of 1 row of cells, annulus vertical , interrupted by sporangial stalk. Gametophytes surficial, green, cordate.

Roots fibrous, not proliferous or proliferous and producing tiny plantlets (Wagner)

The members of *Asplenium* are popular with plant evolutionists, field naturalists, and fern gardeners, not only because of the interesting morphology of the plants but also because of their remarkable ability to form spectacular hybrids, often combining dramatically different leaf shapes.

Population: Scarce and limited to the crater lake of Rano Kao. Conservation should be requested to note changes.

Native names: Alae, iwa. (Hawaii) wa'iwa

Medicinal and other uses: None known

Axonopus paschalis

Easter Island Carpetgrass

Grass Family

Graminae/Poaceae*

Monocotyledoneae

**A. paschalis* Pilger nov. spec.—Syn. *P. scoparium* Flugge var. nov.
oligostachyum HACK. ex FUENTES, l. c., *P. paschale* Stapf, nomen, ibid.
 Plate 6, fig. 2. (Skottsberg, pg. 63)

Habitat: Endemic to Easter Island. Widespread across the island from the higher and more moist elevation of Maunga Terevaka to Rano Aroi and the summit, slopes and crater lake of Rano Kao on the moss peat. Noted and collected on the mat of Rano Kao March 2008 by Gossen.

Distribution: Endemic to Easter Island.

Pollen: Monoporate, size in the range 25-40 μ m. Not distinguished from other members (except *Zea*) of the family Poaceae, the pollen of which is considered here to be native.

Identification: Perennial; caespitose. Culms erect; 30-100 cm long. Leaf-blades flat or conduplicate; 15-20cm long and 0.5-0.8mm wide. Inflorescence composed of racemes 3-6; digitate; unilat-

eral; 7-14cm long. Rachis angular. Spikelets comprising 1 basal sterile florets; 1 fertile florets; without rachilla extension. Spikelets ovate; dorsally compressed; 2.5-3mm long; falling entire. Glumes one the lower absent or obscure; reaching apex of florets; thinner than fertile lemma. Upper glume ovate; 1 length of spikelet; membranous; without keels. Basal sterile florets barren; without significant palea. 3 Anthers and fruit caryopsis with adherent pericarp. (Zizka 1991).

Population: Plentiful with no current conservation action taken. Advisable to adequately note population changes as this is an endemic species.

Native names: Heriki hare (Zizka 1991).

Medicinal and other uses: None known.

Bidens pilosa

Blackjack, hairy beggarticks

Aster Family

Asteraceae

Dicotyledon

Bidens pilosa L. – Sp. Pl. 832 (1753); FUENTES (1913); SKOTTSBERG (1922); ETIENNE, MICHEA & DIAZ (1982); ZIZKA (1990); FLENLEY & al. (1991).

Habitat: Skottsberg found on hilltop, 60-90 m alt., sparse. (Albatross no. 21) collected specimen in Hanga Ho Orno and found in Mataverí in the gardens. Wetlands, damp lowland fields and wasteland. Shade and dappled light inhibits germination.

Distribution: Bidens are "zoochorous" which means the seeds are spread by animals, like the burdock. Noted by Skottsberg as being inadvertently introduced by humans after 1722. But Gossen 2008 identified in Rano Kao core pre-historical time period. New Zealand, Africa; Bahamas; Brazil; Dominica; Dominican Republic; Ghana; Haiti; Java; Malaysia; Mexico; Newguinea(Dani); Philippines; S Africa; Tanzania; Tonga; Upper Volta; Venezuela; W Africa

Pollen: tricolporate/stephanocolporate. Pore aperture round wider than colpi. Exine structure very thick 2.5 um, echinate 3-3.5um. Echinate/tectate. Spheroidal 22um diam.

Identification: Root exudates alleopathic to lettuce, beans, maize & sorghum in USA. Root grows vertical not horizontal. Annual herb, stems erect, 25 – 100cm long. Leaves opposite, petiolate; petiole 1.5-4cm; Flower heads solitary 1cm across. Receptacular scales present. Fruits (achenes) compressed 0.6-1cm long with 2-3 retrorsely barbed awns, 2-2.5 mm long (Zizka 1991).

Population: Plentiful around the world. Population on Easter Island sparse to extinct tubiflorae.

Native names: Te. matua kamate (Fiji); ki (Hawaiian) ; papunga (Spanish) ; Picao Preto (Africa, Bontoc, English, Australia, Fijian, Filipino, French, Hawaiian, Ibatan, Japanese, Maori, Niuean, Futunan, Pukapukan, Spanish, Tahitian, Taiwan, and Tonga.

Medicinal and other uses: It is a medicinal herb in China known as xian feng cao. Used against diarrhoea in

Burundi. Leaves used for tea, raw or cooked with a resinous flavor. Added to salads or steamed and added to soups and stews, they can also be dried for later use. Young shoot tips are used to make a tea as well.

Alternative; Antifungal; Antiinflammatory; Antirheumatic; Styptic. A juice made from the leaves is used to dress wounds and ulcers. A decoction of the leaves is anti-inflammatory, styptic and alternative. The whole plant is antirheumatic, it is also used in enemas to treat intestinal ailments. Substances isolated from the leaves are bactericidal and fungicidal, they are used in the treatment of thrush and candida (Duke 1985).

As for the medical implications, in 1991 Egyptian researchers documented *Biden pilosa* had antimicrobial activity against a wide array of bacteria including *Salmonella*, *staphylococcus*, *Neisseria gonorrhea*, *Klebsiella pneumonia*, and against tuberculosis. It is also good for malaria, snake bite and has anti-leukemia activity. Research shows it lowers blood sugar and blood pressure, stimulates the immune system and is anti-inflammatory. Its most important quality in Florida is that it is the 3rd most common nectar producer for caterpillars of some Lepidoptera. Flowers are edible. The nutritional composition of the *Biden pilosa* per 100 g edible portion is: water 85 g, calories 43, protein 3.8 g, fat 0.5 g, carbohydrate 8.4 g, fiber 3.9 g, carotene 1800 g (Leung, W.-T.W., Busson, F. & Jardin, C., 1968). These researchers also recommend you don't eat the leaves raw because of a high saponin content.

Known hazards: The roots, leaves and flowers are strongly phototoxic, the achenes weakly so[218]. Substances isolated from the leaves can kill human skin in the presence of sunlight at concentrations as low as 10ppm.

Broussonetia papyrifera

Paper Mulberry

Mulberry Family

Moraceae

Dicotyledon

B. papyrifera (L.) (Vent. Zizka (1991: 52)

Habitat: Crater of Rano Kao, abundant though mostly immature in 1904 (Skottsberg 1922) (Gossen in 2008 noted the species was limited to the NW crater side as small shrubs up to 2 m high). The fast growing Paper Mulberry when introduced to non-native areas can quickly disrupt the native habitat, becoming a highly invasive species and upsetting the natural ecosystem. This has proven true in many places, including parts of Latin America, the United States, and South Asia. The pollen from this tree is the number one cause of allergy problems in Islamabad. Paper Mulberry chokes out native flora because of its very high consumption of water, which leaves less water to sustain the native flora. Because its root system, while extensive, is shallow, it is also prone to being blown down by high winds. (Skottsberg 1922)

Distribution: Native to eastern Asia spread to Polynesia by human cultivation.

Pollen: Triporate 15 μ m. Operculum small. Psilate with thickness of 2.5 μ m. Exine vaguely appears scabrate, may be tectate but columnellae are too small to see.

Identification: A deciduous tree growing to 15 metres tall. The leaves are variable in shape (even on the same branch), unlobed ovate cordate to deeply lobed, with lobed leaves more frequent on

fast-growing young plants; they are 7-20 cm long, with a rough surface above, fuzzy-downy below and a finely serrated margin. The male (staminate) flowers are produced in an oblong inflorescence, and the female (pistillate) flowers in a globular inflorescence. In summer, the pistillate flower matures into a red to orange, sweet, juicy fruit 3-4 cm diameter, which is an important food for wild animals. The fruit is edible and very sweet but is not seen on Easter Island (Zizka 1991).

Native names: Mahute.(Hawaii) wauke. Other names include Halibun, Kalivon, Kozo, and Tapacloth tree.

Medicinal and other uses: The bark is composed of very strong fibres, and can be used for making highquality paper. The tender leaves and twigs can be used to feed animals, and the tree is sometimes nicknamed the "Deer's Tree". Masi is a Fijian term used to describe the paper mulberry tree, which was brought to the Pacific during voyages of migration. Its bark is used to make cloth, also called masi, and is dyed and decorated with traditional patterns. The cloth is

worn during many Fijian ceremonies, including weddings, funerals, as well as after the birth of a new baby. The inhabitants of the Lau Islands are renowned for their masi paintings.

Caesalpinia bonduc

Grey Nickarbean, Sea Pearl

Legume (Pea) Family

Leguminosae/Fabaceae

Dicotyledon

C. bonduc (L.) Roxb, Hort. Bengal.: 32 (1814) and (L.) (Vent. Zizka (1991: 52)

Habitat: Crater of Rano Kao, rare. Intolerant of shade and is usually open-grown or at least grows in broken sunlight. It tolerates salt spray, salty soils, and occasional flooding with seawater. The species grows in all textures of mildly acid to alkaline soil. It grows most frequently on the beach strand, on coastal dunes, and at the better-drained edge of mangroves. Gray nicker bean also grows inland in disturbed areas. It competes well with grass and herbs and may ascend into the crowns of low trees.

Distribution: Tropical Asia, Australia, Polynesia and is established in nearly every tropical shore worldwide, including Florida, Louisiana, Puerto Rico, the U.S. Virgin Islands, Hawaii, Guam, and American Samoa.

Pollen: tricolporate.

Identification: The plant is a spiny, scrambling shrub to 1.5 m in height (unsupported) and 6 m or more in extension, and has stems up to 5 cm in diameter or more. Plants usually have a single stem arising from the ground but often branch low on the stem. Seedlings form taproots and may retain them later; lateral roots are extensive. The stems grow stiffly upright for 0.75 to 1 m before curving into a more horizontal direction. The stems, twigs, and leaf rachises are covered with straight or curved prickles. The 25- to 80-cm-long leaves are bipinnately compound with four to nine pairs of pinnae, each with four to eight pairs of oblong to elliptic leaflets. Racemes of yellow flowers are lateral or terminal. Prickly, inflated legumes

are flattened oval shaped, 5 to 10 cm long, and reddish-brown when dry. Within each pod are one to three (usually two) smooth, hard, 2-cm long seeds that are olive drab in the pods and remain so until exposure to the sun bleaches them to a light gray color (Howard 1988).

Native names: Kakalaioa. The seed has been called Nickar Nut, from a Jamaican word nickar. Nikker is Dutch for boy's baked clay marble. Sanskrit: Putikaranja.

Medicinal and other uses: Bonduc helps protect the soil, and furnishes cover for wildlife. The seeds have been used as jewelry, prayer beads, good luck charms, and worry stones (Rancho Leona 2002). They were anciently used as standards of weight in India and used in the ancient African game of mancala. The species is sometimes planted as a hedge for dune stabilization. Preparations of the seeds and other plant parts are used to treat a large range of ailments: Triterpenoids, fatty acid triglycerides, and sterols isolated from seeds may possibly explain some of the activity. Seed extracts have been shown to lower blood sugar in laboratory animals (Biswas and others 1997, Sharma and others 1997) and effectively suppress or cure infections of several species of round worms. The fat content of gray nicker nut seeds was measured at 34 percent. The semidrying oil extracted would be useful for manufacture of high-quality alkyl resins, polishes, and paint.

Canavalia spp.

Jack beans

Legume family

Fabaceae

Dicotyledon

Canavalia spp* now known as Canavalia DC

Fabaceae Canavali Adans. Families des Plantes 2 1763 (KEW)

Habitat: Full sun Typically found in the intertidal zone at the water's edge at a short distance from sea level.

Distribution: Found in both temperate and tropical environments. Comprise one of the largest families of flowering plants with 630 genera and 18,000 species.

Population: The genus Canavalia includes the tropical high climbing jackbeans, grown for food and forage in Africa and Southeast Asia. Beach bean became an important food for the British explorer, Captain James Cook and his crew during their voyage around the world from 1768 to 1771.

Pollen: Pollinated by insects such as solitary bees and carpenter bees

Identification: Herbs. The leaves are stipulate, nearly always alternate, and range from bipinnately or palmately compound to simple. The petiole base is commonly enlarged into a pulvinus that commonly functions in orientation of the leaves (sometimes very responsively, as in the sensitive plant, *Mimosa pudica*). The flowers are usually bisexual, actinomorphic to zygomorphic, slightly to strongly perigynous, and commonly in racemes, spikes, or heads. The perianth commonly consists of a calyx and corolla of 5 segments each. The androecium consists of commonly 1- many stamens (most commonly

10), distinct or variously united, sometimes some of them reduced to staminodes. The pistil is simple, often stipitate, comprising a single style and stigma, and a superior ovary with one locule containing 2-many marginal ovules. The fruit is usually a legume, sometimes a samara, loment, follicle, indehiscent pod, achene, drupe, or berry. The seeds often have a hard coat with hourglass-shaped cells, and sometimes bear a u-shaped line called a pleurogram. (Wagner 1999)

Native names: Awikiwiki (Hawaii)

Medicinal and other uses: The seeds contained 35.5 and 34.1% crude protein, 52.8 and 50.5% crude carbohydrates, 1.3 and 1.7% crude lipids and 3.1 and 3.5% ash content, respectively. Among the minerals, potassium was the highest followed by phosphorus. Globulins and albumins constituted the major seed proteins of both plants. Most of the essential amino acids were at adequate levels. Although the crude lipids were below 2%, the unsaturated fatty acids were high. Seeds did not contain tannins and trypsin inhibitors. The Common Jack-bean is also known as the plant from which Concanavalin A was described. This lectin is of major commercial importance as a reagent in glycoprotein biochemistry and immunology. (Agricultural Products India)

Chenopodium glaucum

Oak-Leaved Goosefoot

Goosefoot Family

Chenopodiaceae

Dicotyledon

Chenopodium Glaucum

Ch. ambiguum R. Br. – Ch. Glaucum, FORESTER l.c.; var. paschale FUENTES l. c. Comp. J. MURR in Allg. bot. Zeitschr. 12 (1906) p. III

Habitat: On the sea shore. Hanga Ho Orno; rocky beach near Hango Piko; Islet Motu Nui (all collected specimens by Skottsberg in 1920). Possible dispersal by birds. Native to the island.

Distribution: Australia, Tasman., N. Zealand, Easter Island and now Europe to Asia. Occurring also as sea-shore plants in Australia and New Zealand.

Population: Common on the sea shores

Pollen: periporate. Many round pores with costae. Psilate/techtate. Columnellae under ekstexine. Thickness 2um. Spheroidal 21 um.

Identification: Annual herbs, stems prostrate, 9-25 cm long. Leaves alternate, petiolate. Blades lanceolate or elliptic, coarsely lobed or entire, densely mealy below. Flowers are hermaphrodite or female, clustered and variously arranged in spiciform inflorescences which are short and dense (Zizka 1991). Collected by FUENTES as a distinct species C. ambiguum or subspecies of C. glaucum.

Native names: (Hawaii) alaweo

Medicinal and other uses: Edible. However, many of the species in this genus contain saponins, though usually in quantities too small to do any harm. Although toxic,

saponins are poorly absorbed by the body and most pass straight through without any problem. They are also broken down to a large extent in the cooking process. Saponins are found in many foods, such as some beans. Saponins are much more toxic to some creatures, such as fish, and hunting tribes have traditionally put large quantities of them in streams, lakes etc in order to stupefy or kill the fish. The plants also contain some oxalic acid, which in large quantities can lock up some of the nutrients in the food. However, even considering this, they are very nutritious vegetables in reasonable quantities. Cooking the plants will reduce their content of oxalic acid. People with a tendency to rheumatism, arthritis, gout, kidney stones or hyperacidity should take especial caution if including this plant in their diet since it can aggravate their condition. Young leaves and shoot tips - cooked and used like spinach. Seed - cooked. Ground into a powder and used with wheat or other cereals in making bread etc. The seed is very small and fiddly, about 0.75mm in diameter. It should be soaked in water overnight and thoroughly rinsed before it is used in order to remove any saponins (Brown 1995).

Cocos nucifera

Coconut, Narel

Palmae Family

Areaceae

Monocotyledon

Cocos nucifera L., Sp. Pl.: 1188 (1753); FLENLEY & al. (1991): 88).

Habitat: Ranging from Subtropical Dry to Wet through Tropical Very Dry to Wet Forest Life Zones, coconut has been reported from stations with an annual precipitation of 7-42 dm, annual temperature of 21-30°C and pH of 4.3-8.0.

Distribution: Now pantropical, especially along tropical shorelines, where floating coconuts may volunteer, the coconut's origin is shrowded in mysteries, vigorously debated. According to Purselove (1968-1972), the center of origin of cocoid palms most closely related to coconut is in northwestern South America. At the time of the discovery of the New World, coconuts (as we know them today) were confined to limited areas on the Pacific coast of Central America, and absent from the Atlantic shores of the Americas and Africa. Coconuts drifted as far north as Norway are still capable of germination. The wide distribution of coconut has no doubt been aided by man and marine currents as well

Population: Early introduction to Easter, with more recent planting of 7.5 hectares near the beach at Anakena.

Pollen: Monocolpate. Echinat/psilate. Reticulated, perfussulate. Great variation amongst species from long thin to rounder shape. Elongated 25 um wide to 35 um long on average.

Identification: Palm to 27 m or more tall, bearing crown of large pinnate leaves; trunk

stout, 30-45 cm in diameter, straight or slightly curved, rising from a swollen base surrounded by mass of roots; rarely branched, marked with rings of leaf scars; leaves

2-6 m long, pinnatisect, leaflets 0.6-1 m long, narrow, tapering; inflorescence in axil of each leaf as spathe enclosing a

spadix 1.3-2 m long, stout, straw or orange colored, simply branched; female flowers numerous, small, sweet-scented, borne towards top of panicle; fruit ovoid, 3-angled, 15-30 cm long containing single seed; exocarp a thick fibrous, husk, enclosing a hard, bony endocarp or shell.

Adhering inside wall of endocarp is testa with thick albuminous endosperm, the coconut meat; embryo below one of the three pores at end of fruit, cavity of endosperm filled in unripe fruit with watery fluid, the coconut water, and only partially filled when ripe. Flowers and fruit year round in tropics. (Duke 1983)

Native names: Ehi, Niu (Hawaii) .

Medicinal and other uses: Coconut is one of the ten most useful trees in the world, providing food for millions of people, especially in the tropics. At any one time a coconut palm has 12 different crops of nuts on it, from opening flower to ripe nut. At the top of the tree is the growing point, a bundle of tightly packed, yellow-white, cabbage-like leaves, which, if damaged, causes entire tree to die. All parts of the tree are used for charcoal, shoes, caps, clothing, roofing thatch, medicine and hundreds of other food and medicines. According to Hartwell (1967-1971) coconuts are used in folk remedies for tumors. (Duke and Wain 1981) and Hartwell (1967-1971) have extensive reports of medicinal uses.

Coprosma spp.

Forest mirrorplant

Coffee Family

Rubiaceae

Dicotyledon

Coprosma J.R. Forster & J.G.A. Forster, 1775
Coprosma ernodioides A. Gray

Habitat: Open areas, mid-elevation woodland and into subalpine shrubland. Forest margins.

Distribution: Extinct from Rapa Nui. Coprosma is a genus of about 90 species that are found in New Zealand (45 spp), Hawaii (c. 20 spp) and in Borneo, Java, New Guinea, islands of the Pacific Ocean to Australia. These species are sensitive to climate change and drought, while also being habitat for endangered bird species have a direct link to each other. The genus Coprosma represents Hawaii's only wind pollinated dicots.

Population: Neither Skottsberg nor Zizka note Coprosma as being found on the island. Gossen identified coprosma pollen in the Rano Kao KAO3 core and has noted it as Coprosma spp. being unable to identify species but closely resembles Coprosma ernodioides. Flenley in his KAO1 core identified it as Coprosma lucida or Comp comp. in Rano Aroi.

Pollen: Coprosma ernodioides – tricolpate. 3-4 colpi in ectexine and one transverse colpus in endexine. Sculpture is tectate/psilate. Spheroidal shape scabrate surface approx. 37 um.

Identification: Many species are small shrubs with tiny evergreen leaves, but a few are small trees and have much larger leaves. The flowers have insignificant petals and are wind-pollinated, with long anthers and stigmas. Natural hybrids are common. The fruit is a non-poisonous juicy berry, most often bright orange (but can be dark red or even light blue), containing two small seeds. It is said that coffee can be made from the seeds, Coprosma being related to the coffee plants. A notable feature (also found in other genera of the Rubiaceae) is that the leaves contain hollows in the axils of the veins; in these, and on the leaf stipules, nitrogen-fixing bacteria grow (Moore 1970).

Native names: Maori name for sacred plant Coprosma robusta – Karamu. Hawaii – kukaenene.

Medicinal and other uses: The orange fruit of the larger species were eaten by Maori children, and are also popular with birds. Dermatological aid infusion of pounded vines, roots and other plants strained and used as a wash for skin ulcers, and for skin diseases. Tuberculosis remedy. Used for dyes, fiber, food, medicine.

Cyperus cyperoides

Pacific island flatsedge

Sedge Family

Cyperaceae

Monocotyledon

Cyperus cyperoides (L.) O.Kuntze, Zizka (1991:66)

Habitat: North slope of Rano Kao, scattered between Mataveri and the lepra colony (Skottsberg 1922). Common in wet patches. Can be found in woodland and forest cover as well as open grassy slopes and river banks. Uncommon in disturbed places. Common from sea level to 2000m.

Distribution: Madagascar, the Comoro and Mascarene islands, Africa, Australasia/Pacific, Asia.

Pollen: Periporate. Irregular apertures. Tectate/psilate. Exine 1.5 μ m thick ovoid to pear shaped. Lacunae length more than 20 percent of grain. 25 μ m wide by 30 μ m long.

Identification: Perennial herbs, culms erect, 18-50 cm long, triquetrous. Leaves alternate (tristichous), linear, grasslike; blades 8-30 x 0.2 -0.5 cm; lower sheaths reddish brown. Inflorescence subtended by 7-13 involucre bracts up to 22 cm long; composed of 6-11 +/-

cylindrical, pedunculate spikes, each 1-2.5 cm long and densely bearing many spikelets. Spikelets 1-3 flowered, producing 1 (-3) ripe nuts, 2-6 mm long. Stamens 3. Ovary superior, stigmas 3. Fruits (nutlets) trigonous, 1.5-2 mm long (Zizka 1991).

Population: Widely distributed in the tropics and sub-tropics.

Native names: baubau (Kwara'ae); motie pako, pako (Niuean); ta'ata'a, tuise (Samoan); mo'u upo'o taratar (Tahitian); pakopako (Tongan).

Medicinal and other uses: The two common *Cyperus* species used for healing are *C. rotundus* and *C. articulatus*, of which the roots/tubers are most important in nausea, as a sedative, for the stomach and intestines. Antibacterial qualities as well as fungal are part of a long list of Chinese medicine uses.

Cyperus vegetus

Tall Flatsedge, Nutsedge, Umbrella Sedge

Sedge Family

Cyperaceae

Monocotyledoneae

C. vegetus Willd. Moist places, edges of crater lakes, etc.—FUENTES. Enclosure for banana tree (Albatross no. 11) Mt. Vaintu Rova, humid cave; Rano Aroi, vigorous plants in the crater; crater of Rano Kao (no. 1170); scattered patches about edge of marsh, also in wet places about the islands, (Albatross no. 54); west slope of Rano Kao; Rano Raraku (Albatross nos. 31 and 32). (Skottsberg, pg. 69)

Cyperus eragrostis LAMARCK, Tabl. Encycl. 1: 146 (1791); SKOTTSBERG (1956; 406); ZIZKA (1990: 193); FLENLEY ET AL. (1991: 88, 98).

Cyperus eragrostis Lam. (Zizka 1991, p. 66) Syn *Cyperus vegetus* Willd. (Skottsberg 1922 2:69)

Habitat: Moist places in all of the three calderas and in wet places around Easter Island. Prefers wet soil, clay or gravel. Thrives in a disturbed plant community and seasonal creeks.

Distribution: Temperate South America, Juan Fernandez, Easter Island. Considered native to western North American but also found in Canary Islands and southern Europe.

Population: Common. Noted and collected by Gossen on the mat of Rano Kao March 2008.

Pollen: Periporate, not distinguished from the pollen of other members of the family. Wind pollinated and dispersed.

Identification: Perennial herbs, culms erect, 30-80cm long. Stems tall and triangular. Rhizomatous. Leaves

alternate, linear, grasslike blades with reddish-brown sheaths. Inflorescence subtended by 6-10 involucre bracts up to 40cm long. Spikelets strongly laterally compressed, rounded and greenish-yellow, many flowered, 1-2cm long. Stamens 1. Fruits a trigonous nutlet about 1mm long.

Native name: Hikikio'e A name sometimes interchangeable name between *Cyperus eragrostis*, and *Pycerus polystachyos*.

Medicinal plant: Rhizome used for a variety of human diseases. Contains flavonoids, saponins, tannins, terpenes and sugars. Spontaneous motor activity is decreased; used as a sedative in traditional medicine.

Pycreus polystachyos

Manyspike Flatsedge

Sedge Family

Cyperaceae

Monocotyledoneae

C. polystachyus Rottb. Gram. 39, t. 11, f. 1 - Rano Aroi, in the crater, c. 400m, one specimen seen (no. 686) (Skottsberg, pg. 69)

Pycreus polystachyos (ROTTBOELL) BEAUVOIS, Fl. Oware 2:48, pl. 86, fig. 2 (1816); ZIZKA (1990: 193)

Habitat: Common in wet environments and higher elevations of Maunga Terevaka.

Distribution: Subcosmop. trop.-subtrop. Widespread in the tropics and subtropics of Africa, Asia and Australia;

Pollen: Periporate. Psilate, tectate (columnellae under tectum). Shape more or less equidimensional trigonous. Pores nearly round to elongated; pore membrane scabrate 23-25 µm.

Identification: Culm triangular, glabrous, leafy at the base; leaves shorter than the culm, flat and keeled, generally rough on the margins, umbel, with several rays, for the most part contracted; rays branched, corymbiform at

the apex, many-spiked, most frequently abbreviated; involucre 3 to 6-leaved; spikes fascicled corymbiform, linear-lanceolate compressed, 20 to 22-flowered; scales ovate-elliptic, keeled, shortly mucronated; keel 3-nerved and green; stamens 2. (Syn. *C. fascicularis*, Lam. Illustr. I, 144, t. 38, f. 2; *Pycrus polystachyus* and *Tetraphyllus*, Beauv.; *C. paniculatus*, Rottb. Gram. 40).

Population: First time noted and collected on Easter island by Skottsberg in 1917. Indigenous to the island. Also found on Motu Nui and considered dispersed by birds. Noted and collected by Gossen March 2008.

Native name: Hikikio'e

Thelypteris interrupta

Willdenow's maiden fern

Marsh fern Family

*Thelypteridaceae/*Polypodiaceae*

Thelypteris interrupta (Willd.) K. Iwats. –*Dryopteris gongylodes* (Schkuhr) Kunze. (Christensen and Skottsberg 1920:50).

**D.gongylodes* (Schkuhr) Kuntze synonym for *Thelypteris interrupta* (Willd.) K. Iwats. (accepted name) of Thelypteridaceae Family and *Dryopteris gongylodes* (Schkuhr) Kuntze *Cyclosorus interruptus* (Willd.) Members of Thelypteridaceae have historically been associated with Dryopteridaceae (in particular, *Dryopteris*) but in fact have no close relationship with that family . *Thelypteris* and allies differ from *Dryopteris* and allies by their indument of transparent needlelike hairs (versus needlelike hairs absent in Dryopteridaceae) (Alan R. Smith "Thelypteridaceae". in *Flora of North America* Vol. 2. Oxford University Press.)

Habitat: Noted by Skottsberg at Rano Aroi, c. 400 m, edge of the crater lake with *Polygonum acuminatum*, very scarce; Rano Kao, bottom of crater, c. 110 m, in the *Scirpetum*, and among the large boulders a little higher up (no. 678). –Fertile—Not recorded before Skottsberg. Found in marshes, swamps, wet areas. The plant prefers light (sandy), medium (loamy) and heavy (clay) soils. The plant prefers acid and neutral soils and can grow in very acid soil. It can grow in semi-shade (light woodland) or no shade. It requires moist or wet soil.

Distribution: Pantropical. Found in the Caribbean. A variant called *Dryopteris gongylodes* var. *glabra* (Mett) C.Christensen found in the Congo of Central Africa.

Spores: Monolete, symmetry bilateral, heteropolar; plano-convex to concavo-convex in equatorial longitudinal view; perine rugulate-saccate, projections varying from short linear to round, minutely scabrate; equatorial axis ca. 40 μ m, polar axis ca. 27 μ m (abstracted from Large & Braggins 1991).

Identification: A strong, mostly erect, evergreen fern with a long-creeping, cordlike stem and widely spaced

fronds; stem black except for a green tip. Fronds are 0.5 – 2 m tall or taller, to about 30 cm wide, borne 3 – 7 cm apart along the rhizome. Petiole is 20 –125 cm long, 3 – 6 mm in diameter, straw colored to tan above, blackish near the base; without hairs or scales. The Rachis is straw colored to pale purple. The blades are pinnate-pinnatifid, 30 –125 cm tall, widest at the base and tapering to a pinnatifid apex. Pinnae 7 – 30 cm long, 1 – 2 cm wide; shiny green above; lower surface of main axis vested with tan scales, tissue and veins most often lacking hairs, though sometimes with very short (less than 0.3 mm long) needleshaped hairs; pinnules deltate in shape; lowest lateral veins from adjacent pinnules joining together below and leading to the sinus. The sori are round, borne near the margins of the pinnule and appearing to form a single line that is seemingly connected from pinnule to pinnule. (Skottsberg)

Population: Very scarce. Suggested conservation to note changes. Noted and collected on the mat of Rano Kao March 2008 by Gossen.

Native names: Neke (Hawaiian)

Inocarpus fagifer

Tahitian chestnut

Legume Family

Fabaceae

(Leguminosae-Papilionoideae)

Dicotyledon

Inocarpus fagifer (Parkinson ex Zollinger) Fosberg
Inocarpus edulis J. R. Forst. & G. Forst Char. gen. pl. 66, t. 33. 1775

Habitat: Grows at elevations of sea-level to 500 metres. More common near low elevations along shorelines, wet areas, swamps, marshes, mangroves and rivers where there is mean annual rainfall from 1500-4300 mm (60-170 inches). The tree tolerates shallow, saline, and infertile soils. Prolonged drought of more than several months duration may not be tolerated.

Distribution: Melanesia, Micronesia and Polynesia. From Java to the Marquesas. Pollen found in the KAO3 core by Gossen, but no plant was noted by either Skottsberg in 1920 or Zizka in 1990.

Pollen: Tricolpate. Psilate/tectate. Columnellae visible. Exine thickness 1.5 μ m. Three colpi more than three-quarter length of pollen. Colpus defined irregularly. Square to oval shaped structure 18 μ m wide by 23 μ m long.

Identification: A medium sized tree that grows up to 20 meters tall. Fruiting trees have a mature crown of 4-6 meters with a trunk diameter from 7 – 90 cm. The trees have a distinctive, short, thick, irregular, and very fluted bole. Branches have a spirally alternate arrangement. Secondary branching creates a network of branches within the dense canopy. The flowers are fragrant and clustered along a short rachis found at the apex of branches, stems, and twigs. They are about 1 cm (0.4 in) long and have five petals that vary from white to yellow-

ish. The leaves are simple, oblong, alternately arranged, dark green, and leathery to the touch. The tree has a shallow taproot and well formed network of lateral roots that are most prevalent in the topsoil layer. At the base of the trunk are 3-4 thin buttresses that extend up the trunk up to a height of 1 m (3.3 ft) and reach laterally, snake-like, for a long distance. (Pauku 2006)

Native names: aila (Papua New Guinea); chataignier de Tahiti (French); ifi (Samoa, Tonga, Niue, Horne Islands, 'Uvea); ihi (Marquesas); i'i (Cooks); ivi (Fiji); mape (Society Islands); mworopw (Pohnpei); namambe (Vanuatu: Bislama); naqi (Solomon Islands: Nduke); Tahitian chestnut, Polynesian chestnut (English); te ibi (Kiribati)

Medicinal and other uses: Edible nut, and used for wood. Tahitian chestnut is a leguminous, evergreen tree producing a seed that is edible when cooked and is among the most important nut species in the Pacific. The tree is shadetolerant, although heavy shading may decrease its yield. It has a dense canopy, which makes it unsuitable for close planting between light-demanding agricultural crops such as sweetpotato (*Ipomoea batatas*), taro (*Colocasia esculenta*), sugarcane (*Saccharum officinarum*), and corn (*Zea mays*).

Ipomoea batatas

Sweet potato, Camote

Morning Glory Family

Convolvulaceae

Dicotyledon

Ipomoea batatas (L.) Lamarck; Zizka (1991: 40)

Habitat: Broad habitat ranging from cool temperate to wet tropical and wet forest shade. Tolerant of 3.1 to 42.9 dm precipitation, and temperature ranges of 8.4 to 28.5C. The soil fertility ranges from a pH of 4.3 to 8.7. It grows successfully over a wide range of climatic conditions. The plant prefers a stable temperature between night and day. It is drought tolerant and resumes growth when rain returns. Soils must be well drained. Sweet potatoes flower and cross pollinate easily.

Distribution: Native to the South America. Introduced and cultivated as an important food crop in India, China, Philippines and the South Seas.

Pollen: Periporate. Surface echinate-baculate, semireticulate, columnellae conspicuous. 81-95.7 um. Spherical; pore size 3.0-3.8 um.

Identification: Perennial herb with edible tubers, stems trailing, climbing and usually prostrate up to several meters long. Lateral stem-branches arising from the short stem and usually not branched; Leaves alternate, petiolate; petiole 1.5-10.5cm; blades broadly ovate, entire

to deeply 3-5 lobed, 2.5-12.5 x 3.5-11 cm; stipules absent. Flowers 1-rare like common morningglory, perfect, white or pale violet, axillary, funnel-shaped, borne singly or in cymes on short peduncles; pods round; seeds 1-4 per pod, flattened, hard-coated, angular (Zizka 1991).

Population: Was not found by Skottsberg in 1917. Noted and collected by Gossen from the edge of Rano Kao March 2008.

Native names: Kumara, Kumar (So. America). Uala (Hawaiian).

Medicinal and other uses: According to Hartwell (1967-1971), the leaf decoction is used in folk remedies for tumors of the mouth and throat. Reported to be alterative, aphrodisiac, astringent, bactericide, demulcent, fungicide, laxative, and tonic. Sweetpotato is a folk remedy for asthma, bugbites, burns, catarrh, ciguatera, convalescence, diarrhea, dyslactea, fever, nausea, renosis, splenosis, stomach distress, tumors, and whitlows (Duke and Wain, 1981). The root is a source of starch.

Jubaea chilensis

Chilean wine palm

Palmae Family

Arecaceae

Monocotyledon

Jubaea (Kunth);
Jubaea chilensis (Molina) Baillon, Chile; J. spectabilis
Paschalococos dispersa (Dransfield, 1984)

Habitat: Dry Coastal Chile (excluding Paschalococos which was exclusive to Rapa Nui). Andean foothills in dry river valleys or open hillsides in seasonally dry regions with Mediterranean climate, at low elevations. Jubaea prefers mild winters and can tolerate cool summers.

Distribution: The species of Palm found in the lake sediment of Rano Kao include one that is very similar to Jubaea. Since there is no living specimen of Dransfield's description of the Rapa Nui tree called Paschalococos dispersa it is impossible to make the claim that the pollen and endocarps found on Rapa Nui are not the Jubaea with variation due to geography and environment.

The largest species inside of a glasshouse is within the Kew Herbarium planted from a seed in 1846.

Population: There are 55 genera in Arecaceae and only 1 species in Jubaea. Presently widely cultivated but scarce in the wild. In the past they were common most of the country of Chile, but now confined to few small areas, principally La Campana National Park (where Darwin noted their beauty as wonders of the palm world) and near Cocalan (Zizka 1989).

Pollen: Monocolpate. Furl longer than grain wraps around end. Thin sculpture: psilate, microfoveolate, tectate perforate with columnellae under perforated

tectum. Ektectine three times thicker than endexine. Size 31 um wide by 45 um long.

Identification: Stems are massive 8-15m tall and 1 m or more in diameter, solitary, dark gray and are markedly and sometimes irregularly swollen at or near the base and generally taper toward the apex. Leaves are pinnate, 40-50 in number, and form a dense crown. They are borne in a few tight spirals and cleanly fall when dead and do not persist on the stem. Sheaths are open and fibrous. Petioles are also fibrous, but are short and not really distinct from the sheaths. Leaflets arranged along the rachis. Inflorescences are large and pendulous and are branched to one order. One single bract is woody and dense. Flowers are unisexual and are borne in threes of one central female and two lateral related genera in being borne on a short stalk and having up to eighteen stamens. Fruits are one-seeded, irregularly globose, grown and have a thick endocarp with three pores below the equatorial middle. The endosperm is homogeneous and the seedling leaf is narrow and simple.

Native names: Palma chilena, palma de coquitos.

Medicinal uses: Chilean wine palm, coquito, honey-palm – massive bole tapped or felled for sap (up to 300 litres per tree) for treacle (palm honey) so that tree, now rare in the wild, is still cultivated. Nuts are sold locally and honey (miel del palma) is extracted by tapping from the stems. Palm hearts are a common delicacy which causes great demise of these grand trees.

Microlepidia strigosa

Lace fern, Palapalai

Dennstaedtia family

*Dennstaedtiaceae/*Polypodiaceae*

Microlepidia strigosa (Thbg) K. Presl. – (Christensen and Skottsberg 1920:50)

Habitat: Commonly found all over Easter Island, generally amongst rocks and stones. Eastern headland, Vaintu Rova and Tea-tea; plains near Hanga Ho Orno, not rare (no.647); Rano Aroi, fairly common; between Hanga Roa village and Mataveru, scattered; Rano Kao, in the crater, not rare (no. 1125) – Fertile. (Christensen & Skottsberg 1920 : 51). Can tolerate (-3.9 to -6.6C). Hillsides, forests, roadsides, grasslands, mountains, valleys, streamsides. Likes water in growing season but dry in winter. Perennial evergreen, partial shade to shade, wet environments. Typically found at an altitude of 0 to 1,822 meters (0 to 5,978 feet)

Distribution: Chile, China, India, Japan, Indonesia, Fiji, Mexico, South America, North America, Papua New Guinea, Portugal, Spain, Sri Lanka, Taiwan, Thailand, UK, Vietnam.

Spores: Trilete, polar view subangular to semi-lobate;

maximum diameter 40-45 um; laesura ray ca. 0.75 of radius; laesura margo prominent when laesura split open; exine psilate; perine finely echinate-scabrate, but rarely preserved.

Identification: Large evergreen terrestrial fern spreads thru underground rhizomes to form clumps of delicate lacy arching light green fronds. Leaflets (pinnae) of the ovate to triangular fronds are divided into pinnate segments and can be several meters long.

Population: Common and plentiful. Noted covering the mat of Rano Kao March 2008. Specimen collected by Gossen.

Native names: palapalai (Hawaiian)

Medicinal and other uses: Used for adornment and hula altars. Used as a medicine by Native Americans for the treatment of insanity and delirium and commonly called in Hawaii hehena (insanity) illness.

Myrsine spp.

Colicwood

Primrose Family

Myrsinaceae

Dicotyledon

Myrsine - Linnaeus, Sp. Pl. 1: 196. 1753. - Colicwood

Syn—*Rapaneasuttonia* A.Rich. Guiana rapanea and rapanea

Rapanea punctata (Lamarck) Lundell, Wrightia 4: 121. 1969.

Habitat: Coastal areas and a variety of habitats from dry ridges to wetter areas usually near the ocean. Myrsine is found in hammocks, pinelands, and shorelines and can be found from sea level up to 2000 meters. In full sun.

Distribution: Florida and the Keys, West Indies, Mexico, South America. Old World Tropical Tree.

Pollen: Stephanocolporate. Psilate/scabrate with narrow furrows. Exine thin 1.5 um. Weakly defined pore with costae and furrow but absent from pore which is same width as furrow. 12.5 to 25 um range.

Identification: Myrsine has over 1,000 species of tropical trees and shrubs but only two members are found in North America and only in Florida. Myrsine is an evergreen shrub or small tree that occasionally reaches heights of 25'. The narrow, columnar crown is made of slender branches. The narrow leaves are 2" to 4" long and 1" to 2" wide, simple, alternately arranged, and occur near the end of branches. The obovate to elliptic leaves have leathery, shiny, dark green upper surfaces while the surface underneath is paler and somewhat scaly. Both leaf surfaces are covered with tiny dots. The leaf base is wedged and the

leaf tip is rounded with a shallow notch. The leaf margin is smooth, thick and often curled under. The fruit is a round, dark blue or black drupe that is 1/5" wide with thin flesh surrounding one, white seed. The berries are clustered close to the branch for several inches along the length of the branch. The light gray bark is thin and smooth or slightly fissured. Pale yellow flowers. (Gilman 1999)

Native names: Myrsine, from the Greek meaning Myrtle tree. Mapou in New Zealand. Native Americans – white seasoning tree.

Medicinal and other uses: Native Americans in Florida called this tree, the white tobacco-seasoning tree, because they mixed its leaves with their tobacco to make it go further. The fruit is edible but unappealing to people. It is useful to songbirds as a food source. The bark has been used in leather tanning but otherwise myrsine has no commercial value. Identified on Easter Island previously by Orliac thru wood charcoal in archaeology. Provides food for birds. Medicine, fuel, tannin.

Paspalum scrobiculatum

Indian crowngrass, koda millet, ricegrass

Grass Family

Gramineae/Poaceae

Monocotyledon

P. scrobiculatum L. var. *orbiculare* (Forst.) Domin.

Paspalum orbiculare G. Forst., Fl. Ins. Austr. 7. 1786;

Syn - *Cynodon dactylon* (L.) PERSOON- FUENTES; Pl. 1: (1805); ZIZKA 1990

Habitat: In Fiji, abundant at elevations up to 1,300 m in clearings, along roadsides, in pastures, ditches, waste land, etc. In Hawai'i, "common on slopes in poor, thin soil where few other grasses will grow, and in wet, swampy ground, 0-1,070 m (Wagner et al) Propagation from seed. Abundant as weed along roadsides, in lawns, on sandy wastes, along sand dunes, and readily takes possession of any uncultivated area. Unproductive in poor dry soils, it is best adapted to relatively fertile, well-drained soils, pH 6.0-7.0, in humid areas. Plants withstand long periods of drought, as they produce little growth in dry weather.

Distribution: Tropical Asia, Australia, N. Caledonia, New Guinea, Polynesia, Hawaii, southern United States.

Population: The species occurs throughout the tropics and subtropics as common grass, abundant. A species noted on Poike by Zizka in 1990 is likely to be *Cynodon dactylon* a larger diploid form commonly found in India. Located by Fuentes on Moto Nui, Hanga Ho Orno, Mataveri, Rano Kao and collected by the Albatross expedition.

Pollen: Monoporate. Pore aperture round, thickly defined. Exine structure 1um thin. Psilate/reticulate. Spheroidal 25 um.

Identification: Tufted perennial grass up to 120-150 cm

tall.

Native names: Mati. (English) (Fijian : co duru levu, tho ndina, tho nduru levu, tho ni ndina). (French : herbe à épée) (Hawaiian : mau'u laiki) (Kwara'ae : karasi) (Maori (Cook Islands) : mata), (Palauan : desum) (Spanish : mijo koda) (Tahitian : nonoha). (India: dhub, doob. harialli).

Medicinal and other uses: Root and rhizome decoctions prepared in the Philippines as an alternative during and following childbirth. Although a problem for farmers, doob ghas is a valuable herbal medicinal and used as first aid for minor injuries (Oudhia, 1999a,b). Farmers traditionally apply crushed leaves to minor wounds as a styptic to stop bleeding similar to *Tridax procumbens*, *Achyranthes aspera*, and *Blumea iacera*, Oudhia, and Pal, 2000). According to Unani system of medicine, *Cynodon* plant is bitter, sharp hot taste, good odor, laxative, brain and heart tonic, aphrodisiac, alexipharmic, emetic, emmenagogue, expectorant, carminative and useful against gripe in children, and for pains, inflammations, and toothache (Agharkar 1991). Virus-affected discolored leaves of *Cynodon* are used for the treatment of liver complaints. In Homoeopathic systems of medicine, it is used to treat all types of bleeding and skin troubles (Ghosh 1988; Oudhia et al. 1998).

Polygonum acuminatum

Tapertip smartweed

Buckwheat Family

Polygonaceae

Dicotyledon

P. acuminatum H.B.K. (Skottsberg 1922; Plate 8, fig. 1); Zizka (1991: 56)
synonym *Persicaria acuminata* (Kunth) G. Maza 2000

Habitat: Floating aquatic plant found in ponds, lakes, marshes and peat bogs. Common in the three large craters on Easter. Common in the three large craters on Easter Island.

Distribution: Found in South and Central America, Mexico, Columbia, Uruguay but not in Chile and the Caribbean. In South Africa FUENTES noted (an aberrant form?) "Amer. trop. S. de Australia, but Australia must be a misprint for Africa" (Skottsberg 1922).

Pollen: Periporate. Pore round, deep. Semi-tectate/per-reticulate. Columnellae taller under the contiguous murilumina spaced between muri. Spherical; Average diameter 38.5 μ m.

Identification: Perennial herbaceous plant that grows erect and prostrate as well as stretching unsupported 1-2 meters across open water as noted in Rano Kao (Gossen). Rhizomes spread up to 20 meters from the parent plant and at least 2 meters deep. Root and stem fragments as small as 1 cm can form new plant colonies. Hollow stems. Leaves alternate, linear-lanceolate, ocrea (stipules united into a membranous tubular sheath) 1-3cm long and hairy. The stems are reddish with small pink, white or greenish flowers forming in dense cluster from the leaf joint. "I have compared my specimens with the rich material of this highly polymorphic species in Kew; they differ a little from most other plants in the shorter internodes, often completely covered by the vaginae (ochrae), whose marginal bristles or setae are very long; the nut seems to be a trifle larger than in most other specimens. Still, plants from Uruguay collected by E. GILBERT are very like the

insular ones. On the whole, my specimens agree with *Humboldtii* Meisn. Fl. Brasil V: I p. 14 tab. 4 fig 1; only the leaves are more acuminate and the setae of the ochrea considerably longer. (Skottsberg 1922: 71).

Rano Aroi, few and small patches; Rano Kao, abundant along the lake (no. 679; very abundant in marsh, Albatross no. 561); Rano Raraku (also Albatross nos. 35, 36) but noted difference that the specimens differ in that Raraku's plant has narrower leaves). FUENTES remarks l.c.: Aunque difiere un poco de la forma típica sud-americana, respeto la opinion de los eminentes botanicos doctores ENGLER i STAPF sobre su identificacion.

Population: Abundant in Rano Kao mat formation, small patches in Rano Aroi, and marginal in Rano Raraku but leaves of a different shape as compared to Rano Kao.

Native name: Tavari or Tabari. (sanguinaria del agua, catay or catay grande- central, north and northwest Argentina as well as south of Brazil.

Medicinal and other uses: *Polygonum* species are used as food plants by the larvae of some Lepidoptera species. Have been known to be eaten by humans during times of famine and leaves smoked as a tobacco replacement. Used in tea as treatment for asthma also for healing infected wounds. These species are used internally as antihemorrhoidal, astringent and antirheumatic (Martins et al., 1995; Mors et al., 2000) and as antiseptic for topical use (Gupta, 1995).

Polypodium Phymatodes

Monarch fern, licorice fern

Polypody Family

Polypodiaceae

Polypodium phymatodes L. (Christensen and Skottsberg 1920: 51)

Pleopeltis phymatodes, (L.) F. Moore; *Polypodium scolopendria* (Burm. f.) *Phymatodes scolopendria* (Burm. f.) (Ching); *Microsorium scolopendria* (Burm. f.) Copeland; *Phymatosorum scolopendria* (Burm. f.) Pichi Sermolli

Habitat: "Eastern headland, Vaintu Rova and Tea-tea, humid fissures, not rare (no. 654); Rano Aroi, fairly common; Rano Kao, stone-heaps near the lake, c. 125 m (no. 673), but also seen higher up. – Fertile." (Christensen & Skottsberg 1920). Gossen noted and collected specimen on slope of crater at Rano Kao March 2008. Rhizome left with local people as their reverence is very important to regenerate this plant that has great significance to their people.

Distribution: The tropics of the Old World including Australia, Philippines, Africa and Polynesia.

Spores: Monolete; exospore rugulate-verrucate; relief low; equatorial axis 46-63 μ m. (Tryon, A.F. & Lugardon, B. 1991. *Spores of the Pteridophyta*, NY: Springer, 648 p.)

Identification: Size and division varies amongst island

locations; the leaves now being entire, now trifid or pinnatifid with several pairs of segments, which are longer or shorter, acute or obtuse. (Christensen & Skottsberg, 1920) Specimen collected on slope of Rano Kao in the Acacia forest has 8 leaves with scales, grooves in rachis and irregular branching (this is NOT *Polypodium scolopendria* or *Microsorium scolopendria* as these species are limited to 2 or 3 leaves only. Gossen et al 2008.

Population: Common

Native names: Matu'a Pua'a

Medicinal and other uses: Used for curing disease and numerous symptoms and pain. The rhizome gives great hope. (interview with Selma Tuki). Contains a volatile oil) which is used by the South Sea Islanders for flavoring coconut oil.

Portulaca oleracea

Munyeroo, Little hogweed

Purslane Family

Portulacaceae

Dicotyledon

Portulaca oleracea L., Sp. Pl.: 445 (1753); SKOTTSBERG (1922); GUILLAUMIN, CAMUS & TARDIEU-BLOT (1936); ETIENNE, MICHEA & DIAZ (1982).

Habitat: Occurring on sea-shores, waysides and waste places. Not abundant on Rapa Nui. Occurs in rich fertile soils, and dry to moist sandy soils. Once established, is drought tolerant. Cannot grow in shade. Good heat tolerance.

Distribution: Bird and seawater dispersal. Seeds unable to float, remain viable in seawater (Geesink 1969) and branches are reported to float. Located on Motu Nui. It is a Eurasian species, widespread in the tropics and subtropics.

Population: Growing near beach, not abundant (Albatross no. 17); Hanga Ho orno, not uncommon (no. 636); Mataveru (no. 1198). This may equally well be regarded as indigenous; still, GUPPY thinks it has been introduced into several places in the Pacific (Skottsberg p.80). Gossen identified pollen previous to human occupation in the KAO3 core from Rano Kao.

Pollen: Periporate. Many pores in circular radial pattern around grain. Tectate/echinate structure. Exine thickness 3 μ m with spine 1 μ m. Size average 50 μ m by 57.5 μ m.

Identification: Annual glabrous herbs, stems erect to ascending, 5-30 cm long. Common purslane emerges from a heavy taproot, to develop succulent, smooth, fleshy, stems that are usually purple-red and may root at lower nodes. These many branched stems reach up to 24

inches long and grow in a prostrate fashion to form mats. leaves are alternate to sub opposite, oval shaped with the widest point beyond the leaf's middle. Growing up to 1 1/4 inch long, the thick, fleshy leaves are often clustered near the ends of branches. They are smooth and without leaf stalks. The yellow flowers of common purslane are borne individually in the leaf axils or clustered at end of branches. There are five petals. The flowers open in the sunshine. The fruit is a globular capsule. The small, shiny-black edible seeds are wrinkled; they are formed in a tiny pod. (information detracted from TropiLab Inc medicinal plants, herbs & tropical seeds)

Medicinal and other uses:

The flowers are hermaphrodite (male and female organs are on the same plant) and are pollinated by insects; the plant is self-fertile. Purslane is used as a vegetable in Europe, Asia and also in Suriname. The juice is used against dry cough; also inflammation and sores (topical); hemoptysis and hemorrhage. It is beneficial in urinary- and digestive problems. It is also used in the treatment of candida, lupus and fibromyalgia. It contains Omega-3 fatty acids; these phytochemicals can be used to treat bipolar disorders, depression, hyperactivity congenital heart disease and migraines

Pritchardia spp.

Loulu Palm

Palmae Family

Aracaceae

Moncotyledon

palm pritchardia

Pritchardia Seeman & H. Wendl. Palmae

Habitat: The genus *Pritchardia* consists of 25 species of palms native to the tropical Pacific Islands. There are as many as 19 endemic species of *Pritchardia* in the Hawaiian islands including species categorized as either endangered, rare or vulnerable. Each Hawaiian island has at least one distinct *Pritchardia* species with some islands having distinct species or forms restricted to individual valleys or mountains. From wet valleys to windswept coasts elevations of 650 ft. to 2600 ft. Moist to dry conditions.

Distribution: Fiji, Samoa, Tonga, Tuamotus and Hawaii--has only a single group of native palms, medium-sized fanpalms of the genus *Pritchardia*. They are found in moist or dry forests from the coast almost to 4000 ft (1219 m). The genus *Pritchardia*, according to an early monograph (Beccari and Rock 1921), had about 31 named species of fanpalms, nearly all confined to Hawaii except for about 5 in Fiji and other South Pacific islands. An extinct one is recorded from Laysan.

Population: Unknown to Rapa Nui except for in the pollen record identified first as a possible species by O.H. Selling in Heyerdahl's expedition in 1958, and Flenley in 1991. Gossen identified as possible species in the KAO3 core of Rano Kao in 2008.

Pollen: Monocolpate. Pollinated by bees, wasps and other insects. Pollen slide references were created from Kew Herbarium specimens included: *P. hillebrandii*; *P. remota*

(Kuntze); *P. pacifica*; *P. minor*; *P. lowreyana*;

Identification: This genus is characterized by fan-shaped or wedge-shaped leaves, smoothish trunk with horizontal lines, and absence of spines. Trunk straight, unbranched, 13–30 ft (1–9 m), sometimes much taller, mostly stout and about 1 ft (0.3 m) in diameter, smooth, gray, finely fissured, with horizontal lines from leaf scars. Height varies in different species from about 5 ft (1.5 m) to a maximum of 75 ft (23 m) or more. Leaves crowded and spreading at top of trunk, very large, coarse, evergreen, about 15–30, composed of stout, spineless gray green leafstalk about 3 ft (0.9 m) long and fan-shaped or wedge-shaped blade about 3 ft (0.9 m) in diameter, folded and divided toward edges into many narrow, thick and leathery segments, with many fine longitudinal lines of parallel veins.. (detracted from Little & Skolmen 1989).

Native names: Loulu. Hawane.

Medicinal and other uses: The main use of these native Hawaiian palms is as ornamentals. A few species are in cultivation here and elsewhere in the tropics. Formerly, the Hawaiians made hats from the young leaves and used the mature leaves for thatching and fans. The immature soft seeds, which have a taste slightly like coconut, were eaten. Domestic animals and rats feed on the seeds, and wild hogs also dig up and devour young plants. Formerly, the trunks were used to make fences.

Pteris spp

Greek name "pteron" wing or feather

Fern Family

Pteridaceae

PTERIS Linnaeus, Sp. Pl. 1073. 1753.

Habitat: Sub-tropical temperatures. Ferns that grow in dry habitats and cliff faces.

Distribution: 250 species or more exist as a tropical genus. They are found wild in many parts of the world, such as tropical America, tropical Asia, India, China, Japan, West Indies, southern Africa, Australia, New Zealand and Europe

Spores: Trichotomosulcate. Trilete. Reticulate. Pollen identified in KAO3 core of Rano Kao 2008.

Identification: Pteris vary greatly in their sizes and shapes. Some are a few inches tall and some are several feet tall. Most kinds have fronds that are divided deeply into many long, ribbon-like sections. *P. cretica*, the Cretan Brake, is one of the most popular kinds. Growing up to 18 inches high, this fern forms masses of light green,

evergreen or semi-evergreen foliage. The leaves are broadly oval to triangular and divided into finger-like segments. Rhizomes are short-creeping or erect, often stout, rarely with prop roots. *P. cretica albolineata* grows up to 18 inches high and has evergreen or semi-evergreen leaves, up to 8 inches long. These are in forked or linear segments. They are pale green striped down the center with creamy white (Lorence 1997).

Native names: unknown

Medicinal and other uses: Many ferns are used for medicinal uses including the Pteris spleenwort used as medicine for the spleen. Pteris in the Philippines is used for Bacillary dysentery, enteritis, fever, malaria, swelling and painful throat: Urinary tract infection, leucorrhea: Mumps, measles, eczema: apply as poultice.

Sapindus saponaria

Hawaiian soapberry, soapnut

Soapberry Family

Sapindaceae

Dicotyledon

S. saponaria (L.) FORSTER (1786) and (Zizka (1991: 58)

Habitat: Native to South America, Mexico, New Caledonia and Africa. In Hawai'i, *Sapindus saponaria* grows in moist forests on Hualalai, Mauna Loa, and Kilauea on the island of Hawai'i. It occurs naturally at elevations ranging from 2,900 to 4,500 feet. (Wagner 1990). Found in stream banks, rocky hillsides, woody margin. In shallow soils remains a small shrub, in deep soils can become a large tree up more than 25 meters tall. Tolerant of drought, wind, heat, poor soil, air pollution and other city conditions. Not affected by disease or insects.

Distribution: Tropical America. *Sapindus saponaria* is indigenous to Hawai'i and is also native to Mexico, South America, New Caledonia, and Africa.

Population: A tree was noted growing at least 20 meters from the edge of the lake on the mat near the SE corner of Rano Kao. A leaf was collected by Gossen March 2008 in the crater Rano Kao and further confirmed that this tree is in fact a *Sapindus* that is approximately 5 meters tall.

Pollen: Tricolporate. Pore apertures round, equatorial on thin colpi. Exine thin 1um. Psilate-tectum spheroidal. 13um average size.

Identification: Perennial tree with compound pinnate

leaves. *Sapindus saponaria* is a tall deciduous tree, growing over 20 meters in height. It has pale brown bark that falls off in large patches on mature trees. The leaves are made up of 3 to 6 pairs of leaflets. The upper surface of the leaves is shiny green and the lower surface is fuzzy. The flowers are borne in 4 to 8 inch long loose clusters at the ends of the branches. The flowers are unisexual, but both male and female flowers are produced on the same plant. The fleshy fruit of *Sapindus saponaria* is round and 3/4 inch long and both male and female trees produce fruit. The fruits generally ripen in the fall and winter and are brown to black when mature. Each fruit contains 1, occasionally 2 or 3, dark reddish brown to black seeds. The seeds are about 3/8 inch long. (Wagner 1990)

Native names: Marikuru and in Hawaii Manele or A'e.

Medicinal and other uses: Lei (flower or seed). *Sapindus* means Indian soap. Also used as beads in South America. The poisonous fruit, containing the alkaloid saponin, has been used as a soap substitute for washing clothes. Necklaces and buttons are made from the round dark brown seeds, and baskets are made from the wood, which splits easily.

Scirpus californicus

Totora

Sedge Family

Cyperaceae

Monocotyledononeae

Scirpus californicus (C.A. Meyer) STEUDEL (1841); FLENLEY & al. (1991);

subsp *californicus* HEISER (1977); ZIZKA (1990)

Scirpus californicus ssp. *tatora* (HEISER 1985)

Schoenoplectus californicus (C.A. MEYER) J. SOJAK (1972)

S. riparius Presl var. *paschalis* KUKENTHAL (1920); FUENTES (1913 as *S. riparius*); (SKOTTSBERG 1920); ETIENNE, MICHEA & DIAZ (1982); FLENLEY (1991).

Scirpus californicus subsp *californicus* var *paschalis* (KUKENTHAL) BEETLE (1949); KOYAMA (1963)

Habitat: Wet environments particularly edges of lake, marshes, peat bogs, and on Easter Island on the floating mat of Rano Kao. Human cultivation of *Totora* by planting rhizomes in trenches up to 5 meters deep in South America.

Distribution: South America, California to Louisiana across southern United States, Hawaii.

Population: Very abundant in Rano Kao and sensitive to rainfall which promotes growth across the lake mat. Rano Raraku is restricted to the lake edges.

Pollen: Periporate. One polar pore and three equatorial pores poorly formed. Tectate/psilate, Thin exine and elongated 45um.

Identification: Perennial herb with horizontal rhizomes. Culms erect 2-5m long, triquetrous. Leaves reduced to basal sheaths. Inflorescence subtended by involucre bracts, the outer 2-6cm long, erect; clustered spikelets many flowered, cylindrical or conical. Culms 3-4 metralis subteres ad 2 cm crassus, basi vaginis haud reticulatim fissis obtectus. Anthela decomposita ampla spiculis

innumerosis ornate. *S. esp. gigantesca*; en los craters (FUENTES); Rano Aroi, smaller. The largest plants grow in Rano Kao up to 4 meters tall and 10cm wide at the base of the triangular hollow stem. (Skottsberg p. 70)

The plant in Rano Aroi was called *S. riparius* by FUENTES, who regarded the large form from Rano Kao as another species.

Native names: Nga'atu, *Totora*.

Medicinal and other uses: Rhizomes and the bottom of the stems are high in starch and are eaten by humans and animals. The stems are used for making boats, rafts, basketry, thatch, and matting. Charles B. Heiser in 1975 travelled to South America to study the totora. In Lake Titicaca as well as coastal Peru including Huanchaco Peru, he documented people cultivating totora in large trenches some 5 meters deep by 20 meters long. The totora is used for food for animals and humans as well as crafting boats (caballitos), thatch, beds, mats, fences and baskets that are used and sold in market.

Sophora toromiro

Miro

Legume Family

Leguminosae/Fabaceae

Dicotyledon

Sophora Toromiro

Sophora - Linn., Sp.Pl. 373. (Zizka 1991:47)
Edwardsia toromiro R. A. Philippi, Bot. Zeit. (1873) p. 737; FUENTES (1913)--

Habitat: Endemic to Rapa Nui. Last tree alive was at the crater of Rano Kao noted by Skottsberg in 1920 and Heyerdahl in 1958. The tree was located on the slope of the crater growing between boulders which seemed to shelter both moisture and wind for this tree. Perhaps also enough shelter from the sheep as well that seemed to have eaten most of the low shrubs on the island.

Distribution: *Edwardsia toromiro* of PHILIPPI was given its name but no description of the species. It was characterized by having a different wood from the Chilean species which is a *Sophora* genus and species tetraptera. FUENTES did not consider the Rapa Nui plant to be a separate species. *S. microphylla*, a species in New Zealand was reintroduced to the island in the 1960s with all plantings expiring. It appears that some seeds can float and retain their viability in sea water for at least 3 years. Seeds have been found on beaches of Chiloe and Kermadec Islands (Sykes and Godley, 1968). When comparing plants from Gough, Chile and New Zealand, Sykes and Godley (1968) found them to be races of *S. microphylla*.

Pollen: Tricolporate. Large round thick pores with exine thickness of 1.25 μ m. Psilate tectum, columnellae barely visible. Spheroidal average 17.5 μ m.

Identification: Shrub or small tree growing up to 3 m tall. Leaves alternate, 4.5 – 10cm long, shortly petiolate, imparipinnate with 8-12 pairs of leaflets, rhachis and rhachilla as well as the young branches densely hairy; petiole 3-5 mm; leaflets subsessile, elliptic to ovate. Flowers calyx copular with 5 short, broadly triangular lobes, densely hairy; corolla of 5 yellow petals, 2 cm long, 1 suborbicular, 4 +/- equal and +/- oblong. Stamens 10, free, filaments about 2 cm long, anthers 1.2 – 1.3 mm long. Fruits constricted 1-6 seeds ellipsoid to ovoid. This species varies from the Chilean *S. macrocarpa* and New Zealand specimens of *S. tetraptera*. The pubescence is whitish even in the youngest parts, the leaflets are of a yellowish or otherwise bright green colour above, and very thin, papyraceous; they are also less numerous to the midrib. Finally the seeds are smaller, more globose and yellow. All the forms from Juan Fernandez have unwinged pods and larger, oblong obtuse seeds of a dark castaneous colour, very different from those of Rapa Nui species. (Zizka p.47 and Skottsberg p. 74)

Native names: Miro

Medicinal and other uses: Wood used for carvings by the islanders.

Thespesia populnea

Milo, Portia tree

Mallow Family

Malvaceae

Dicotyledon

T. populnea (L.) SOLANDER ex CORREA, Ann. Mus. Natl. Hist. Nat. 9 (1807) and (Zizka, 1991: 50) *Hibiscus populneus* L., Sp. Pl.: 694 (1753) FORSTER (1778-1780 : 487).

Habitat: Tropical and sub-tropical warm found at sea-level to 275 meters. Mean annual rainfall 500-4000 mm (20-160 in.) In very dry areas milo survives by tapping underground water. Can survived 8 months of drought. Mean annual temperature 20-26 C (68-79 F). The tree is valuable as a coastal windbreak because it is highly resistant to wind and salt spray and grows well in sandy, saline soils. It propagates easily and grows rapidly. The tree grows best under full sunlight and tolerates drought conditions. The heartwood is resistant to drywood termites. Milo has many uses including coastal protection, animal fodder, windbreaks, and living fences. METRAUX (1940) observed plants on the inaccessible cliffs of Poike. Currently planted by CONAF on the island.

Distribution: Coastal areas of the Indian and Pacific Oceans throughout Oceania and East Africa and India to mainland Southeast Asia, Indonesia, and the Philippines. In the Pacific it grows from Papua New Guinea and the northern coast of Australia through the Solomons, Vanuatu, and Fiji. Melanania, Micronesia and Polynesia.

Population: FORSTER, Prodr., reports *Hibiscus bacciferus*, which is considered to be identical with *Thespesia populnea*, from Rapa Nui. No later collector ever observed it there, so it may have disappeared from the island (Skottsberg p.78).

Pollen: Periporate. Round pore apertures, well defined with costae. Exine thickness 2.5 um. Tectate/echinate with varied columnellae longer under echina, compressed at pore opening. Shape spheroidal 72.5 – 87.5 um. Aerolate.

Identification: Milo has a short, straight or crooked trunk and a dense crown with crowded lower horizontal branches. Height averages 6–10 m (20–33 ft) with a crown as wide as or wider than the tree is tall. Average size trees have bole diameters of 20–30 cm (8–12 in), but exceptional trees have reached 18 m (60 ft) in height with boles 60 cm (24 in) in diameter. The bark is grey and smooth to highly fissured and dark brown in larger trees. Flowers are a typical hibiscus shape in appearance:

bellshaped, 4–7 cm (1.5–2.5 in) in length, with five overlapping, broad, rounded petals. Color is pale yellow with a maroon spot at the base of each petal and with star-shaped hairs on outer surface. Flower stalks are 1.3–5 cm (0.5–2 in). Flowers open and close on same day, and the yellow flowers turn dark red, purple, or pink as the day progresses. The alternate leaves are glossy green above and paler green below. Leaf blades are heart-shaped, 10–20 cm (4–8 in) long, and 6–13 cm (2.5–5 in) broad. Leaf stalks are long, 5–10 cm (2–4 in). Leaves in the lower crown turn yellow before falling to the ground. Milo fruits are brittle, dry, woody or papery seed capsules, rounded and flattened, containing five cells and several seeds. The brown or gray capsules, about 2.5–5 cm (1–2 in) in diameter and 2 cm (0.8 in) tall, grow on short stalks clustered at the ends of the branches. Mature fruits may usually be found on trees year-round. The brown, hairy seeds are about 1 cm (0.4 in) long and 0.6 cm (0.2 in) broad. Seeds are blown short distances by wind but are more likely to be dispersed by water. (Friday & Okano, 2006)

Native names: Mako'I. (Etieene, Michea & Diaz 1982) Badriit (Palau); banalo (Northern Marianas); bang-beng (Yap); kilulo (Guam); mi'o (Marquesas); milo (Hawai'i, Marshall Islands, Samoa, Tonga); miro (Pitcairn Island); miro, 'amae (Rarotonga, Society Islands); mulomulo (Fiji); panu (Kosrae); polo (Chuuk); pone (Pohnpei); purau (Tahiti); portia tree, seaside mahoe, Pacific rosewood Indian tulip tree, cork tree, umbrella tree (English)

Medicinal and other uses: Milo (*Thespesia populnea*) is one of the most important trees to Pacific Island peoples. The rich, dark wood is carved into beautiful bowls, tools, small canoes, and figures. Ropes are twisted from the bark. The trees provide protection against wind, salt spray, and the hot sun. The seeds, leaves, and bark provide medicine and food. In ancient times the trees were planted around temple sites. Today the tree is more rare than in the past because of overharvesting.

Triumfetta semitriloba

Sacramento burbark, Burweed

Linden Family

Tillaceae

Dicotyledon

T. semitriloba L. JACQUIN, Enum. Syst. Pl.: 22 (1760); and (Zizka 1991:61)

Habitat: Diverse habitat with precipitation ranging from 760 to 2000 mm and found growing in Hawaii from sea-level to 1067 m in elevation. The species seems to do better when disturbed in full or partial sun as small groups or dispersed individual plants.

Distribution: Tropical Asia, Polynesia and Tropical America; Florida and the Caribbean.

Population: "Rano Kao, with Broussonetia, rare. Four individual plants were seen growing in the Rano Kao (Alden 1990) of which one was seen flowering and fruiting in 1991. According to legends, the species was introduced by Hotu Matua, but with Flenley's palynology study of the Rano Kao lake sediment cores showed that the genus *Triumfetta* was native before human occupation. Gossen in the KAO3 core from Rano Kao in 2008 has further provide at least two differing species of *triumfetta* ranging from a plentiful *triumfetta* forest 15,000 years ago, to a dwindling population in more recent times.

Pollen: Tricolporate. Transverse colpi, 3 pores, thin near colpus. Pore larger than colpus. Exine thickness 2.5 μ m. Heavy reticulated. Evenly spaced columnellae, semi-

tectate/ per-reticulate. 30-35 μ m wide by 55-60 μ m long. (*semitriloba* type) Rhoboidea pollen has very thick 3 μ m exine and heavily reticulated. Prominate single round column with single row under muri of evenly space columnellae. Lumina microret < 1 μ m. Size approx. 30 μ m wide by 52 μ m long. A third type of *triumfetta* pollen was noted of smaller nature 17.5 μ m wide by 30 μ m long. All 3 noted and counted as separate groups.

Identification: Shurbs or small trees, 2-3m high, pubescent with stellate, brownish hairs, especially on younger parts. Leaves alternate, petiolate; petiole 7-17 cm; blades +/- trilobed, dentate, 12-25 x 10-20 cm; stipules present, triangular, caduceus, 1.5 x 0.8 cm. fowers pedicellate, 1.5 cm across; pedicels 0.4 – 1cm; sepals 5, free, 1.3 cm long, reflexed in flower; petals 5, white shorter than calyx, 0.9 cm long. Stamens numerous. Ovary superior. Fruit globose, 5mm across, covered with hoked hairs 2-3mm long, with several seeds; seeds ovoid, 3 x 2mm. (ZIZKA 1990).

Native names: jau jau or hau hau.

Medicinal and other Uses: Rope and fibres. This is the jaujau of the islanders, used for making cordage; Specifically on Easter Island as rope for transporting the Moai.

Tropaeolum majus L.

Climbing Nasturtium, Indian cress

Nasturtium Family

Tropaeolaceae

Dicotyledon

Tropaeolum majus L.

Tropaeolaceae A.L. De Jussieu Ex A.p. De Candolle, 1824, Nom. Cons. - Nasturtium Family

Habitat: A genus of one of the aquatic herbs of the family Cruciferae. Also one of several very popular ornamental garden plants. that are self-seeding. Coastal mountains 500-2000 m as well as coastal areas at sea-level. Full sun to partial shade with a range of 400 – 800 mm of rainfall and able to tolerate 3- 5 months of drought.

Distribution: Native to South and Central America. (possible spontaneous hybrid between Peruvian spp. *T. minus* L. & *T. ferreyae* Sparre, in Lima area. Introduced from Peru to Europe in 1684 (prob. the origin of all modern Eur. stock), though after 1845 crossed with *T. peltophorum* & backcrossed with *T. minus* (non-climbing) fast growing cultivated ornamental climbing annual with fibre-capable of being made into delicate lace. (Mabberley, 1987). Etienne, Michea & Dize (1982), Marticorena (1990) and Flenley (1991) cite *Tropaeolum majus* L. for Easter Island, a native of South America. Zizka noted that this species only occurs in cultivation therefore was not considered for his study in 1990. Widely grown in Australia.

Population: common

Pollen: None identified in the KAO3 core of Rano Kao by Gossen 2008, but collected seeds from the culm of a totora plant on the floating mat and seeded.

The totora seeds did not germinate but the Nasturtium grew instead.

The seeds must have been airborne and collected at the top of the totora culm 3 meters above the floating mat surface.

Identification: They have showy, often intensely bright flowers and rounded, peltate (shield-shaped) leaves with the petiole in the center. The flowers have five petals (sometimes more), a three-carpelled ovary, and a funnel-shaped nectar tube in the back. It is a herbaceous annual plant with trailing stems growing to 1 m long or more. The leaves are large, nearly circular, 3-15 cm diameter, green to glaucous green above, paler below; they are peltate, with the 5-30 cm long petiole near the middle of the leaf, with several veins radiating to the smoothly rounded or slightly lobed margin. The flowers are 2.5–6 cm diameter, with five petals, eight stamens, and a 2.5–3 cm long nectar spur at the rear; they vary from yellow to orange to red, frilled and often darker at the base of the petals. The fruit is 2 cm broad, three-segmented, each segment with a single large seed 1–1.5 cm long. (Jepson Flora)

Tropaeolum majus L. (cont.)

Climbing Nasturtium, Indian cress

Nasturtium Family

Tropaeolaceae

Dicotyledon

Native names: Monks cress

Medicinal and other uses: Annual herb. Peppery leaves and edible flowers taste like watercress. The flowers are popular for making a colorful, zesty addition to salads. The leaves may be used raw in salads or stuffed like grape leaves. Young seed pods can be pickled, and the extremely hot seed can be cooked or ground and used as a pepper substitute. *Tropaeolum* species are used as food plants by the larvae of some Lepidoptera species including Dot Moth and Garden Carpet. A very common "pest" found on *Nasturtium* in particular is the caterpillar of the Large White (Cabbage White) Butterfly. The *Nasturtiums* receive their name from the fact that they produce an oil that is similar to that produced by Watercress (*Nasturtium officinale*), from the family Brassicaceae. (Andersson, Lennart and Andersson, Stephan (2000))

All parts of the plant are edible. The flower has most often been consumed.

The unripe seed pods can be harvested.

The

mashua (*T. tuberosum*) produces an edible underground tuber that is a major food source in parts of the Andes.

Nasturtiums repel squash bugs, cucumber beetles, and several caterpillars. They had a similar range of benefits for brassica plants, especially broccoli and cauliflower. They also attract black fly aphids, and are sometimes planted in the hope of saving crops susceptible to them (as a trap crop). They may also attract beneficial, predatory insects.

This plant has many traditional applications. Its foremost use is medicinal, and it is said to have antibiotic and antiseptic effects, and to act as an expectorant and diuretic. It is considered an excellent option for common cold treatment. The most common way to consume it is as an infusion of leaves.

Vittaria elongata

Tape Fern, Shoestring Fern

Fern Family

*Pteridaceae/*Vittariaceae*

Polypodiaceae

**V. elongata* Sw. – Syn. *V. costata* HICKEN Bol. 137, Rev. 96, non Kunze. (1806)
Haplopteris elongata (SWARTZ) E. H. Crane Tender.

Habitat: Tropical and warm. In fissures between blocks, with moss, in the craters of Rano Aroi c. 420m and Rano Kao c. 125m in the slope rock fissures and in the peat moss of the floating mat of Rano Kao. – Fertile. (Skottsberg p. 52)

Distribution: Distributed throughout Nepal on mossy tree trunks and branches in forested areas; also in India, Sri Lanka, southern China, Taiwan, Southeast Asia, the Philippines, Polynesia and tropical Australia and Africa. “This very common Polynesian species is totally different from the American *V. costata* (Kunze), to which HICKEN referred specimens from the island.” (Skottsberg p. 52) Tropical Asia, Polynesia, N.S. Wales. Old World Species are different from New World species.

Spores: Monolete

Identification: The *elongata* species is now classified as *Haplopteris elongata*. Distinguished by sori in a marginal groove, not submarginal as in most other species. Other characteristics include reddish brown to nearly black rhizome scales, to 1cm (0.5 in) long stripes present; blades to 70 cm (28 in.) by 3-10mm (0.1 –0.4 in.) wide, widest in the middle; midribs distinct on the upper blade surfaces; and paraphyses with tips enlarged to an inverted cone-shape. Fronds borne in tufts. Propagated by spores. (detracted from Hoshizaki & Moran p. 530)

Native names: Known none

Medicinal and other uses: In Native American ethnobotany a complex infusion of leaves was taken for chronic conditions.

Xylosma

I

xv

Brush holly, Coronillo

Flacourtiaceae

Flacourtiaceae

Dicotyledon

Xylosma G. Forster, Fl. Ins. Austr. 72. 1786

Xylosma suaveolens (J. R. Forst. & G. Forst.)

Xylosma suaveolens subsp. *pubigerum* Sleumer

Habitat: The genus *Xylosma* has approximately 100 species in tropical and sub-tropical regions rarely extending into warm-temperate regions although there are three species in China.

Distribution: Indigenous to the islands of the Marquesas (Nuku Hiva, Ua Huka, Ua Pou, Hiva Oa, Tahuata, Fatu Hiva). "It is a small tree 2 m to 8 m high that is endemic to East Polynesia; it is found on dry hillsides along with *Sapindus saponaria*. (Florence 1997: 5-19)

Population: rare, endemic

Pollen: The pollen of *Xylosma* has never been identified on Rapa Nui previous to the KAO3 core of Rano Kao by Gossen 2008. Previous study into the charcoal remnants by Catherine Orliac in 2000 introduced fourteen new taxa of which were found in fire pits as charcoal, in which Gossen also identified *Xylosma*, *Elaeocarpus* and *Myrsine* in the fossil pollen previous to human occupation on the island. The pollen of *Xylosma* is Psilate/ scabrate round to oval in shape. Exine is 1.5 to 2 μ m in thickness. Approximately 15 – 22.5 μ m.

Identification: Shrubs or small trees, usually dioecious, rarely polygamous; trunk and branches usually spiny. Leaves alternate, stipulate, usually petiolate; leaf blade pinnate-veined, margin serrate, rarely entire, teeth glandular. Flowers hypogynous, small, in axillary fascicles, short racemes, or panicles, rudiments of

opposite sex usually absent; bracts small, persistent or caducous; pedicels articulate at base. Sepals 4 or 5, imbricate, free or connate at base only. Petals absent. Disk extrastaminal, or in female flowers extragynoecial, comprised of several small closely set or connate glands (usually in staminate flowers) or annular (often in pistillate flowers). Staminate flowers: stamens ca. 10 to many, exserted; filaments free, filiform; anthers small, basifixed, sometimes apiculate by extension of connective. Pistillate flowers: ovary superior, 1-loculed; placentas 2(-6), each with 2 to many ovules; styles 2 or 3(or 4), often very short, joined in lower part only or completely joined to form a single style column, or styles absent; stigmas semilunate to U-shaped. Berry small, ca. 1 cm or less, pericarp thinly leathery, blackish when dried; disk and calyx often persistent at base; styles and/or stigmas persistent at apex. Seeds few. (G.Forst. Publication: Prod. 72.)

Native names: unknown

Medicinal and other uses: Useful in the fabrication of fishing gear, in the construction and cover of houses, in boat building, and medicine.

Plant Illustrations
by Denise Long
©2008*

Pollen and Spore photographs
KAO3 core
Rano Kao, Easter Island
by Candace Gossen
©2008*

*All illustrations and photographs may be used for educational purposes only,
with request that the users display credit by permission of artist.

Grateful thanks to the palynology expertise of:
Edward Cushing, Professor Emeritus
Dept. of Ecology, Evolution and Behavior
University of Minnesota

and

John Flenley, Professor Emeritus
School of People, Environment and Planning
Massey University, NZ

Plant References:

The Ferns and Phanerogams of Easter Island
Natural History of Juan Fernandez and Easter Island
by
Carl Christensen and Carl Skottsberg
1920 v2

Palmarum Hortus Francofurtensis
Palmengarten PHF 3
Flowering Plants of Easter Island
by
Georg Zizka
1991

- Andersson, Lennart and Andersson, Stephan. 2000. A molecular phylogeny of Tropaeolaceae and its systematic implications. *Taxon* 49 (4): 721-736.
- Bown, D. 1995. *Encyclopaedia of Herbs and their Uses*. Dorling Kindersley, London. ISBN 0-7513-020-31
- Duke, James A. 1983. *Handbook of Energy Crops*. unpublished
- Duke, J. A. and Ayensu, E. S. *Medicinal Plants of China* Reference Publications, Inc. 1985 ISBN 0-917256-20-4 Details of over 1,200 medicinal plants of China and brief details of their uses. Often includes an analysis, or at least a list of constituents. Heavy going if you are not into the subject.
- Friday, J.B., and D. Okano. 2006. *Thespesia populnea* (milo), ver. 2.1. In: Elevitch, C.R. (ed.). *Species Profiles for Pacific Island Agroforestry*. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <<http://www.traditionaltree.org>>.
- Gilman, Edward F., professor. 1999. Environmental Horticulture Department, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.
- Henderson, A., Galeano, G., & Bernal, R. 1995. *Field Guide to the Palms of the Americas*. Princeton University Press. Princeton, New Jersey. p. 138-139.
- Hoshizaki, B.J. & Moran, R.C. 2001. *Fern Grower's Manual*. Edition: 2, revised. Published by Timber Press. 604 pages.
- Howard R.A. 1988. *Flora of the Lesser Antilles, Leeward and Windward Islands. Dicotyledoneae, Part 1. Vol. 4*. Arnold Arboretum, Harvard University, Jamaica Plain, MA. 673 p.
- THE JEPSON FLORA PROJECT, Jepson Herbarium. 1001 Valley Life Sciences Building #2465, University of California, Berkeley, California 94720. 415-643-7008
- Kew Royal Botanic Gardens, Richmond Surrey TW9 3AB, UK
- Large, M.F., & Braggins, J.E., 1991. *Spore atlas of New Zealand ferns & fern allies*. New Zealand J. Botany, supplement, 167 p.
- Little, L. Jr. & Skolmen, Roger G. *Agriculture Handbook no. 679*. The Forest Service, U.S. Dept. of Agriculture, 1989. (a reprint version published by the College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, 2003.)
- Lorence, D. H. (editor) 1997. *Botanical results of the 1988 Fahu Hiva Expedition to the Marquesas Islands*. *Allertonia* 7(4): 221–306.
- Mabberley, D. J. 2006. *The Plant-Book: A portable dictionary of the vascular plants*. Second Edition. Cambridge University Press.

- Moore, L.B.; Edgar, E. 1970: Flora of New Zealand. Volume II. Indigenous Tracheophyta - Monocotyledons except Graminae.
- Orliac, C. 2000. The Woody Vegetation of Easter Island Between the Early 14th and the Mid-17th Centuries AD. Easter Island Archaeology: Research on Early Rapanui Culture. Edited by Christopher M. Stevenson and William S. Ayres. Easter Island Foundation 2000.
- Pauku, R.L. 2006. *Inocarpus fagifer* (Tahitian chestnut), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <<http://www.traditionaltree.org>>.
- Smith, Alan R. "Thelypteridaceae". in Flora of North America Vol. 2. Oxford University Press. Online at EFloras.org.
- Stone, Benjamin C. 1970. The flora of Guam. *Micronesica* 6:1-659.
- Wagner, Warren L., Darrel R. Herbst, and S. H. Sohmer. 1990. Manual of the flowering plants of Hawai'i. 2 vols, Bishop Museum Special Publication 83. Honolulu: University of Hawaii Press and Bishop Museum Press. p. 1229.
- Wagner, Warren L./Herbst, Derral R./Sohmer, S. H. 1999. Manual of the flowering plants of Hawaii. Revised edition. Bernice P. Bishop Museum special publication. University of Hawai'i Press/Bishop Museum Press, Honolulu. 1919 pp. (two volumes).
- Wagner, Warren H. Jr., Robbin C. Moran, and Charles R. Werth "Aspleniaceae". in Flora of North America Vol. 2. Oxford University Press. Online at EFloras.org.

Appendix E
Reference Pollen
KAO3 core of Rano Kao

The representative pollen found on these pages have been captured using an Olympus x100/1.40 power photographing microscope at the University of Minnesota Ecology Lab. Each pollen chosen is noted from the sample it was taken in the core depth and photographed in succession from polar to equatorial view at varying depths. There are two sheets included that came from flowers gifted for referencing *Jubaea* and *Pritchardia* pollen from the following: *Jubaea chilensis* flowers donated by William J. Baker, PhD, Royal Botanic Gardens, Kew. Richmond, Surrey, TW9 3AE, UK from the Temperate House 2008 (no male flowers in herbarium). A second set of flowers arrived as a gift from Gloria Rojas Villegas, Botanica-Palinologa, Museo Nacional de Historia Natural Casilla 787, Santiago from a *Jubaea chilensis* tree dated 31 October 1901. *Pritchardia* of 5 different species was also donated by Kew Royal Botanic Gardens which is also found referenced within this appendix as noted.

Note.

This information has been prepared for students and researchers interested in applying comprehensive palaeoecological techniques. It is open to use by everyone with the provision that its use is cited in any publications, using the URL as the place of publication. Any comments regarding the images and information presented should be addressed to the author at the above contact.

RNKA005 3A 9L 95cm 1000 X

algae

cell cluster

lignin

fungi-1 2000 X

fungi-1b

sac-1

sac-3 2000 X

sac-2

sac-4

RNKA005 3A 5L 60-61cma *Canavallia* 1000 X

Flowers donated by:

William J. Baker PhD
 Royal Botanic Gardens, Kew
 Richmond, Surrey, TW9 3AE, UK
 From the Temperate House 2008 (no male flowers
 in herbarium)

And

Gloria Rojas Villegas
 Botanica-Palinologa
 Museo Nacional de Historia Natural
 Casilla 787, Santiago
 From a *Jubaea chilensis* dated 31 October 1901

Jubaea chilensis

RNKA005 3A 5L 60-61cma
Monolete psilate 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma
Monolete verrucate 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma
Totora 2000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Palm 3b* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Palm 4* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma
Asteraceae

1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Triumfetta* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Polygonum* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Palm 1a* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Palm 1b* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cma *Palm 3a* 1000 X

—6 May 2008

RNKA005 3A 5L 60-61cmb

Coprosma 1000 X

—13 May 2008

RNKA005 3A 1L 30-31cma *Sophora* 2000 X

—13 May 2008

RNKA005 3A 5L 60-61cma

Polygonum variant

1000 X

—9 May 2008

RNKA005 3A 5L 60-61cma

Polygonum variant 1000 X

—9 May 2008

RNKA005 3A 1L 30-31cma

Unidentified Diporate

1500 X

—13 May 2008

RNKA005 3A 5L 60-61cmb

unidentified tricolpate

1000 X

—9 May 2008

RNKA005 3A 1L 3-4cma

Vitis 1000 X

—13 May 2008

RNKA005 3A 5L 60-61cma

2000 X

—9 May 2008

RNKA005 3A 1L 3-4cmb

Sophora 2

1000 X

—15 May 2008

RNKA005 3A 1L 3-4cmb

Quercus 1000 X

—15 May 2008

RNKA O5 31 1L 3-4cmb *Poaceae*

—15 May 2008

RNKA005 3A 1L 3-4cmb *Trilete Fern 2* 1000 X

—15 May 2008

Prichardia Hillebrandii ***Prichardia Lowreyana*** ***Prichardia Minor*** ***Prichardia Pacifica*** ***Prichardia Remota***

Flowers donated by:

William J. Baker PhD
 Royal Botanic Gardens, Kew
 Richmond, Surrey, TW9 3AE, UK

425

RNKA005 3A 1L 3-4cmb *unidentified* 1000 X

—15 May 2008

Appendix F
Pollen Count Sheets
KAO3 core of the crater lake Rano Kao

Pollen count sheets are the raw data counts for all pollen, charcoal, and non-pollen palynomorphs, including starch, resin, algae, sacs, fungi and minerals.

[illegible]

KAO3 Pollen Count Sheets		Rano Kao	Rapa Nui	Gossen, C. 2005										
12.5 + (sample depth)		sample identity	4L 5-7cm	4L 15-16cm	4L 35-36cm	4L 55-56cm	4L 75-76cm	4L 95-96cm	5L 10-11cm	5L 20-21cm	5L 40-41cm	5L 50-51cm	5L 60-61cm	5L 90-91cm
Age	d18	actual depth	15.55	15.65	15.85	16.05	16.25	16.45	16.60	16.70	16.90	17.00	17.10	17.40
Scirpus		(+20 to original #)	2471	2659	2870	3443	3448	3452	3454	3459	3464	3470	4170	5443
Cyperus			23.16	23.71	20.63	22.61	22.75	20.49	23.02	23.32	24.01	0.00	19.52	23.49
Cyperus			42	81	7	55	15	20	45	33	14	27	8	47
Polygonum			8	5	18	1	3	4	0	2	5	8	1	0
Palmae			0	1	1	0	3	0	0	3	0	16	1	0
Palmae			4	1	5	17	7	5	96	5	2	84	27	0
Palmae			14	19	141	54	77	54	66	53	86	22	78	84
Palmae			12	17	9	3	12	2	6	9	47	20	12	0
Palmae			4	0	3	11	25	0	1	5	15	0	0	0
Palmae			5	8	4	37	44	6	23	39	34	10	41	4
Asteraceae			0	0	1	0	1	0	0	0	0	7	4	2
Triumfetta			0	0	0	0	0	0	0	0	0	0	0	0
Triumfetta			0	0	5	2	0	0	0	0	3	1	2	0
Triumfetta			4	0	0	6	13	3	0	3	2	2	1	2
Sophora			4	1	6	3	2	0	0	1	1	0	1	0
Broussonetia			0	0	0	0	0	0	0	0	0	0	0	1
Thespesia			0	0	0	0	0	0	0	0	0	0	0	0
Inocarpus			0	0	0	0	0	0	0	0	0	0	0	0
Portulaca			0	0	0	0	0	0	0	0	0	0	0	0
Myrsine			0	1	0	0	0	0	0	0	0	0	0	0
Chenopodium			0	0	0	0	0	0	0	0	0	0	0	0
Coprosma			0	1	0	0	0	0	0	0	0	0	2	0
canavallia			0	0	0	0	0	0	0	0	0	0	2	0
caesalpinia			0	0	0	0	0	0	0	0	0	0	3	0
xylosma			0	0	0	0	0	0	0	0	0	0	0	0
dicolpate/tricolpate			0	0	0	0	0	0	0	0	0	0	0	0
diporate			0	0	0	3	1	1	2	4	1	1	4	0
Graminae			0	2	0	1	1	1	1	0	0	0	0	0
Graminae			3	21	7	2	0	0	0	0	0	0	0	1
Filices			56	39	3	6	4	100	5	0	3	1	79	11
Filices			0	5	5	2	0	0	1	0	1	1	9	20
Filices			2	0	0	0	0	0	0	0	0	0	0	0
Filices			3	0	0	1	2	0	0	0	0	0	0	1
Filices			4	0	0	2	11	5	7	4	2	0	7	0
Filices			0	0	0	0	0	0	0	0	0	0	0	0
Total Pollen			163	202	202	222	219	201	252	161	216	199	281	173
Lycopodium			106	56	39	43	171	79	120	134	96	156	20	343
Lycopodium tablet			10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679
ccm3 of sediment			1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pollen Concentration			10948	25680	36874	36756	9118	18114	14951	8554	16019	9082	100027	3591
Deposition Time			11.73	11.73	11.73	0.25	0.25	0.25	0.25	0.25	0.25	0.25	63.64	63.64
Pollen Influx			933	2189	3144	147023	36471	72455	59802	34215	64074	36327	1572	56
Charcoal			22	19	21	4	105	28	22	23	12	21	1	14
Charcoal			1	1	0	0	4	4	2	2	1	5	0	3
Charcoal			1	0	0	2	0	1	0	0	1	0	0	0
Charcoal			0	20	0	0	2	0	1	0	1	0	0	1
Charcoal			24	20	21	6	111	33	25	25	15	27	1	18
Charcoal			202	66	249	29	452	804	1877	842	203	115	31	399
abundance			4	1	4	2	2	1	1	1	1	3	0	3
abundance			3	5	5	5	5	5	2	5	4	4	2	5
diversity			2	5	4	5	5	4	2	4	2	3	1	2
diversity			3	3	1	1	2	3	1	1	0	3	1	4
diversity			2	2	0	1	1	4	1	1	0	2	1	1
diversity			2	1	1	1	1	3	1	2	1	1	1	3
diversity			2	1	1	1	1	5	2	1	0	1	2	1
diversity			2	2	4	2	4	3	1	2	1	4	1	2
diversity			2	1	2	1	3	2	2	1	1	2	1	1
diversity			0	3	0	1	1	1	1	0	0	1	0	0
diversity			0	2	0	1	1	1	1	0	0	3	0	0

[illegible]

KAO3 Pollen Count Sheets			Rapa Nui		Gossen, C. 2005		sample identity actual depth c14 (+20 to original #)	12.5 + (sample depth) Age d018	8L 5-6cm 19.55 9260 22.32 55	8L 25-26cm 19.75 9274 25.26 40	8L 45-46cm 19.95 9290 24.92 17	8L 65-66cm 20.15 9306 24.60 2	8L 75-76cm 20.25 9320 23.45 12	8L 95-95cm 20.45 9484 17.30 11	9L 3-4cm 20.53 9550 19.62 17	9L 25-26cm 20.75 11030 13.44 24	9L 45-46cm 20.95 11393 12.95 23	9L 65-66cm 21.15 11952 14.91 1	9L 75-76cm 21.25 12511 4.99 1	9L 95-96cm 21.45 12930 7.79 0
Cyperus									11	11	5	0	8	3	0	1	12	0	0	0
Cyperus									1	0	0	0	1	0	0	0	0	0	0	0
Polygonum									0	0	0	0	0	0	0	0	0	0	0	0
Palmae									11	24	6	15	17	39	61	43	29	59	28	45
Palmae									0	0	0	0	0	0	0	0	0	0	0	0
Palmae									0	2	2	6	8	12	22	26	2	10	19	50
Palmae									5	5	1	5	2	27	50	88	18	35	32	13
Asteraceae									1	1	0	0	1	6	10	9	1	24	7	7
Triumfetta									0	0	0	2	0	2	0	0	0	1	0	0
Triumfetta									0	1	0	0	2	1	9	0	0	1	0	3
Triumfetta									2	1	0	0	0	6	0	12	2	77	61	50
Sophora									5	0	0	0	1	0	0	0	0	4	0	0
Broussonetia									0	0	0	0	0	0	0	0	0	0	1	0
Thespesia									0	0	0	0	0	0	0	0	0	0	0	0
Inocarpus									0	0	0	0	0	0	0	0	0	0	0	0
Portulaca									0	0	0	0	0	0	0	0	0	0	0	0
Myrsine									0	0	0	0	0	0	0	0	0	0	0	0
Chenopodium									0	0	0	0	0	0	0	0	0	0	0	0
Coprosma									0	0	0	0	0	0	0	0	0	0	0	0
canavallia									0	0	0	1	0	0	3	1	0	1	0	0
caesalpinia									0	0	0	0	0	0	0	0	0	0	0	0
xylosma									0	0	0	0	0	0	0	0	0	0	0	0
dicolpate/tricolpate									0	0	0	0	0	0	1	0	0	0	0	0
diporate									1	0	0	0	2	0	0	0	2	0	2	0
Graminae									0	0	0	0	0	0	0	0	0	0	0	0
Graminae									0	0	1	0	16	8	7	8	1	11	6	0
Filices									81	110	176	2	24	68	55	26	78	6	17	4
Filices									34	2	0	0	6	18	11	3	5	10	12	3
Filices									0	0	0	0	0	0	2	1	0	1	0	0
Filices									6	0	0	0	1	0	0	0	22	0	8	0
Filices									7	0	2	15	0	0	11	2	0	7	4	0
Filices									0	0	0	0	0	2	0	0	0	1	0	0
Total Pollen									218	196	210	48	101	201	271	227	201	277	199	175
Lycopodium									52	45	15	162	146	27	71	53	37	65	30	34
Lycopodium tablet									10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679	10,679
ccm3 of sediment									1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Pollen Concentration									29846	31009	99671	2109	4925	52999	27174	30492	38675	30339	47225	36644
Deposition Time									0.81	0.81	0.81	0.81	0.81	8.22	8.22	2.68	27.94	27.94	27.94	27.94
Pollen Influx									36847	38282	123050	2604	6080	6448	3306	11378	1384	1086	1690	1312
Charcoal									7	4	1	20	10	2	39	11	4	142	88	91
Charcoal									4	0	1	0	0	0	5	2	0	16	2	17
Charcoal									0	1	0	0	0	0	1	0	0	11	4	8
Charcoal									0	5	0	0	0	0	46	0	0	8	1	3
Starch									11	5	2	20	10	9	70	11	4	177	95	119
Algae									37	33	94	250	98	35	46	8	38	142	38	45
Fungi									1	1	5	3	0	2	5	5	5	3	5	5
Fungi									4	2	5	5	5	5	4	3	2	4	5	1
Sac									4	2	2	5	3	5	3	5	1	5	5	3
Sac									4	1	2	4	2	5	5	4	4	5	5	2
Mineral									2	1	1	3	1	3	5	4	3	5	5	2
Mineral									2	2	3	2	1	2	3	1	1	5	4	0
Plant									1	1	5	5	5	3	2	1	5	5	3	0
Plant									1	1	4	5	3	2	2	3	2	2	2	0
Resin									5	5	4	5	3	3	1	2	3	1	4	0
Resin									5	5	4	5	5	2	1	2	2	1	2	0

Appendix G
“The Mystery Lies in the Scirpus”
© C. Gossen 2007

First publication of radiocarbon data on the KAO3 core was printed in the Rapa Nui Journal v. 21 (2) October 2007 and is attached for reference. Radiocarbon dates at various intervals of the process of working on KAO3 were most graciously funded by the Easter Island Foundation on three separate occasions. Much thanks and appreciation is most abundantly offered to the contributors and donators of funds to the Foundation for such scholarly endeavors for students of Rapa Nui such as myself. Thank you.

Note.

This information has been prepared for students and researchers interested in applying comprehensive palaeoecological techniques. It is open to use by everyone with the provision that its use is cited in any publications, using the URL as the place of publication. Any comments regarding the images and information presented should be addressed to the author at the above contact.

Report: The mystery lies in the Scirpus

Candace Gossen

This report concerns Scirpus, forests, and a quest to find a method for documenting rainfall changes in the ancient past. I begin with the middle.

It was through a conversation with Irving Friedman and we were discussing how obsidian glass captures a moisture signature when it is formed, and then we began to talk about a small island called Marajo, off the coast of Brazil. While flying over the island, Friedman noticed that half of the island was forested while the other half had been clear-cut. He subsequently discovered that two-thirds of the annual precipitation that formerly occurred on the island no longer fell. He was certain that it was due to deforestation, and I agreed. I knew that when I walked through a forest I could feel the respiration of the leaves. I noted this growing up in the bayous of Louisiana, in the forests of the northwest, in the rainforests of Belize and Guatemala, and in my travels around the world. But now science was demanding a method to show proof that this was true.

Truth and science are all about how you ask the questions, and finding the right method is limited to how creative we are. I did not then find the answers in obsidian. But I have begun an adventure that has taken me to coring lakes and, more particularly, the crater lakes on Rapa Nui.

In March 2005, through great effort and serendipity, John Flenley and David Meek of Massey University, and Rob Dunbar of Stanford and his coral-coring team, were all on the island at the same time as I was. All of us were looking for more pieces to the mystery of Rapa Nui, its past climate, and trying to understand the human connection to this island.

My focus was the crater lakes and, more particularly, Rano Kau. It was at this crater where the last tree was seen on the island, and it was also where Thor Heyerdahl and his expedition team in 1955 discovered (through pollen samples) that the island had supported a sub-tropical palm forest. It was the changes in the forest that drew me here, and what I am searching for is a direct method to test moisture variations in the ancient past.

The climate history of the island is mostly unknown and a great deal of speculation about human impact and environmental degradation has been made considering the lack of information. We all would like to know when humans arrived on the island and whether they had sufficient impact on the natural environment to cause culture failure. But are we missing something really important, like climate? Because of Rapa Nui's isolation from a large land mass, the ecosystem is closed and altering one thing

changes everything. In order to understand ecology we must look at all the connections and this type of research requires a multi-disciplinary approach. Deductively, over the last two years, I have tried method after method to obtain as much information as I can.

THE CORE

My subject is called KAO05-3A, located approximately 400 meters from the northwest edge of Rano Kau's lake at 27°11'37" S, 109°26'3" W and 522 meters (as a crow flies) from the mirador at the rim. My first observation was that the floating mat of vegetation showed an elevation of 110 meters, or six meters higher than the noted 104m elevation on the 1992 Armada de Chile map, and two meters more water-depth than John Flenley found in his coring in the late 1980s. The KAO05-3A core includes a 2m core of floating totora¹ (*Scirpus*) and *Polygonum acuminatum*, and nine meters of lake sediment that reached to a clay bottom. Between them are 10.5 meters of water. The grand total of the core was 21.5 meters from the top of mat to clay at the KAO05-3A coring point.

Like most common testing of lake sediment cores, I began with the Initial Core Description (ICD) that consists of nondestructive measurement of bulk sediment properties, division of the core into working and archive halves, imaging of the whole core, and macro- and microscopic identification of sedimentary structures and composition. This process was conducted at the LacCore Limnological Research Center (LRC) at the University of Minnesota in Minneapolis.

The low-resolution magnetic susceptibility scan set up the beginning investigation. It was found that down-core magnetic susceptibility peaks are linked to periods of deforestation and the subsequent erosion of mineral soils. The variations in the amplitude of the magnetic susceptibility record could be used as a proxy indicator of the intensity of erosion.

In this scan, peaks of high susceptibility were noted and further refined with the high-resolution scans that followed at 0.5mm intervals once the core was opened. What we found in the low-resolution scan were five very distinctive peaks (Figure 1). One was isolated at the 1.7 meter point as referenced from the top of the lake sediment core, and the other four were closely distributed between the 7.0 and 8.0 meters of the core. These were not minor events. The peaks were very pronounced and obvious.

This paper has been peer reviewed. Received 4 July 2007; Accepted 11 July 2007; Revised 15 July 2007.

¹ Totora is an introduced South American name for the plant *Scirpus californicus*, in the family Cyperaceae. Its correct Rapa Nui name is ngā'atu.

Figure 1. Low resolution magnetic susceptibility scan of KAO05-3A sediment core with arrows indicating ^{14}C dates BC.

Figure 2. Magnetic susceptibility scan with calibrated radiocarbon dates indicated with arrows..

Overlaying these peaks on the high-resolution scans, I picked 12 points in the core to sample for radiocarbon dating (Figure 2). Something important was happening at these key points and we needed to know their dates. Were the peaks dated to the time that humans were on the island or were they climate anomalies?

RADIOCARBON DATING

The first radiocarbon date processed at the Rafter Radiocarbon Laboratory in Wellington, New Zealand, was sampled above the clay layer for a basal date of ^{14}C $11,017 \pm 45$ years, with a calibrated date of sigma two interval from 13,058 to 12,868 BP. This was the oldest date in the lake found thus far, and a good start. It was really important at this point to pick the correct item to date by radiocarbon. Did this mean bulk sediment, pollen, or macrofossils? Up to this day, many are still arguing that past radiocarbon dates obtained in the lakes are anomalous and unreliable. Therefore, the first and major effort of this core was to obtain accurate dates with a linear chronology, otherwise all the other data and information would not be reliable.

I knew bulk dating had problems. Noting at first glimpse when I opened the cores that whole *Scirpus* bulbs in the core gave way to inversions. The bulbs were heavier and they would drop through the sediment. Therefore bulk

sediment and macrofossils from plant remains would not be reliable. So I began looking for seeds. *Scirpus* seeds. Since the lake was covered with *Scirpus* I wanted to know if there were seeds in each of the twelve samples taken. And yes, we found *Scirpus* in all of them. We only needed two, at minimum, to get an accurate radiocarbon date, as we later found out. The very finding of *Scirpus* seeds in all of the cores and samples supports the evidence that this plant has been growing on the island, at the very least, to the end of the last glacial period.

An email came in June of 2007 and read "Hey Candace, I do hope you are sitting down. Here are the *scirpus* seed results. They are in perfect order with the uppermost sample having bomb- ^{14}C in it." The message came from Tom Guilderson of the AMS Lab, Lawrence Livermore National Laboratory, with whom I had been working for over the past year and a half, processing radiocarbon dates. In spring of 2006 I spent a week at the LLNL lab processing twelve samples of *Scirpus* seeds and, running alongside for comparison, were pollen samples taken from the same sample depths (Figure 3). Of the pollen dates, the only confidence was in 5L-1-54-55 which dated 3555 ^{14}C yrs BP. It was here that enough pollen was extracted to obtain a reasonable sample size (200 μg of carbon). All of the other pollen extracts were below 100 μg . One needs to think seriously when dealing with less than 100 μg of carbon because

Figure 3. Radiocarbon dates KAO05-3A macro and pollen samples.

it is not known what has been left in the samples from the chemical processing, and a small amount of modern and/or dead carbon will make a significant difference in small samples. For the small macros, *Scirpus* seeds, we knew exactly where they came from (good firm sediment, not soupy and located away from any section breaks and/or edges of the core).

The first set of radiocarbon dates were run only on the lake sediment samples. We knew at this point that the basal date was 11,017 BP ^{14}C but we had no idea what the top of the sediment core would date to. The dates came back with a top of core of 1200 ± 35 ^{14}C date with a calibrated sigma one interval of 779 AD to 874 AD (see Figures 1 and 4 for the complete radiocarbon data on both the mat and sediment core for KAO05-3A).

The last set of dates that Tom referred to in his email were for the floating mat. Until now, all previous dating of the mat had always had inversions, that is, younger dates on the bottom of the mat, and older dates on top. Were the floating mats colliding with each other as they were blown across the lake by wind, and folding over each other? Were sections dying and falling as whole units into the depths of the lake? Whatever was happening, until now no one had obtained clear linear chronology in a mat. With the help of Christopher Stevenson and a grant from the Easter Island Foundation, four samples were taken from the floating mat of my core. The youngest of the dates at top had atomic ^{14}C in it, while the bottom of the mat dated to a conventional ^{14}C of 605 ± 30 and a calibrated date of sigma one interval from 1304 AD to 1397 AD. Still, 400 years of information was slowly decomposing and resting between the bottom of the mat and the top of the sediment core. The floating mat is a curious thing.

THE LAKE

The lake also is curious. Seemingly, it is a closed basin with only rainfall adding to its liquid contents. It is the void left-over from a volcanic eruption 1 million years ago and it has slowly been collecting and evaporating its moisture while providing a unique microclimate within the crater walls. The bottom depth of the lake is unknown, but in this KAO05-3A core we hit a clay layer, that was at least very near to center, and it has given us a date as approximately 13K BP.

At some time in the ancient past *Scirpus* began growing on the lake's surface. Was it planted intentionally in a shallow swamp that existed here, or was it a marginal plant that grew on the edges of the lake and then slowly migrated towards the center over time? However it happened, what we find today is a varying thickness of 2 to 3 meters of floating living plant matter that includes two aquatic plants: *Scirpus* and *Polygonum*, both very useful plants to humans. *Scirpus*, a reed-like plant, provided building materials for many things including boats, and the *Polygonum acuminatum*, a freshwater medicinal plant, has been observed in previous pollen cores and is usually with human occupation. The surface of the lake is mostly covered by these floating nitrogen-rich plant mats that slowly are decomposing into the dark water beneath.

In ecology, it has always been the attempt to classify ecosystems by the biota they support. Biological paleolimnology is an extension that further defines these relationships, and it is these studies of the physical, chemical and biological information stored in lake deposits that color a multi-proxy of past environmental change.

This research continues with identifying pollen and charcoal counts, and expanding the ecological assessment

Table 1. Calibrated radiocarbon dates using Calib v5.1 and IntCal04.

CAMS #	Sample Name	Delta ^{13}C	Fraction Modern	^{14}C Age Macrofossils	Actual Depth m	Calibrated Date Sigma 1	Calibrated Date Sigma 2
132962	KA03 0-5cm	-25	1.1383	$45 \pm >\text{modern}$	0.005	modern	modern
132963	KA03 85-90	-25	0.9699	245 ± 40	0.85	1634-1672 AD	1618-1684 AD
132964	KA03 120-125	-25	0.9346	54 ± 35	1.2	1394-1425 AD	1386-1437 AD
132965	KA03 195-200	-25	0.9276	605 ± 30	1.95	1338-1364 AD	1297-1405 AD
125890	RNKA05-3A-1L-1W 15-16	-25	0.8610	1200 ± 35	12.65	779-874 AD	765-897 AD
123142	1L-1 48-52	-25	0.8466	1340 ± 35	12.98	650-689 AD	640-725 AD
123143	1L-1 81-82	-28.6	0.8484	1320 ± 30	13.31	658-693 AD	652-725 AD
125893	RNKA05-3A-2L-1W 58-60	-25	0.8468	1335 ± 30	14.08	653-688 AD	646-719 AD
123145	3L-1 52-54	-25	0.7907	1885 ± 35	15.02	70-138 AD	61-219 AD
125891	RNKA05-3A-4L-1W 36-37	-25	0.6998	2870 ± 120	15.86	1213-910 BC	1322-814 BC
123147	5L-1 54-55	-25	0.6495	3470 ± 70	17.04	1885-1733 BC	1972-1615 BC
123219	6L-1 31-32	-25	0.3527	8370 ± 320	17.81	7761-7023 BC	8230-6632 BC
123148	7L-1 42-43	-25	0.3178	9210 ± 100	18.92	8492-8304 BC	8651-8255 BC
123149	8L-1 77-78	-25	0.3135	9320 ± 70	20.27	8650-8468 BC	8748-8342 BC
123150	9L-1 22-23	-25	0.2993	9690 ± 400	20.72	9772-8547 BC	10452-8179 BC
123151	9L-1 27-28	-25	0.2533	11030 ± 130	20.77	11118-10928 BC	11237-10872 BC
NZA23878	basal date	-30.2	0.2520	11017 ± 45	21	11008-10944 BC	11109-10919 BC

Radiocarbon dates of KAO05-3A

Figure 4. ^{14}C dates of both the mat and lake sediment core KAO05-3A.

that John Flenley began with plant types which prefer climate differences.

Two indicators that we looked for in the lake were calcium carbonates, or *ostracoda* and diatoms; both were sparse to non-existent. The decomposing plants leave a black tea with hardly any carbonate in its waters, leaving only plants as the key.

SCIRPUS

Scirpus was the key to obtaining proper radiocarbon dates, and it also holds the key to understanding the relative humidity of the lake's microclimate, the hydrology and soil development, as well as the exchange with atmospheric CO_2 . In carbonate-deficient lakes like Rano Kau, organic matter and cellulose will prove to be useful archives.

The chemical structure of cellulose contains carbon, hydrogen and oxygen, each a potential collection of isotopic information. While the ratio of carbon, oxygen and carbon-bound hydrogen isotopes is "locked-in" with death of the

cellulose-synthesizing organism, oxygen-bound hydrogen are exchangeable.

The new and exciting portion of my research is the direct testing of moisture. Plants tell us when the climate was cool and moist by producing those plants that thrive in that environment, while a warm and dry climate allows other species to grow. The aquatic plants, *Scirpus* and *Polygonum*, floating on the lake, are the keys that we are looking to for moisture changes, evaporation, transpiration, rainfall, and temperature changes in the lake. These are the vascular systems and provide the cellulose that can be used to trace lake water history.

At present, Brent Wolfe, Associate Professor and NSERC Northern Research Chair in the Dept. of Geography and Environmental Studies at Wilfrid Laurier University, is leading the analysis of the samples of KAO05-3A and soon we will have a paleo-climate profile of Rapa Nui going back to the end of the last glacial period; it will uncover what past climate conditions were like.

Patterns of drought, rainfall, and water balance will enlighten the type of environmental conditions that were changing and impacting the forests, the plants, the lakes and the humans who were living here.

CONCLUSIONS

With the current information we have collected on KAO05-3A, we know that, sometime around the AD 600s, something drastic changed in the island's forests and soil. Sediment in the lake shows that almost two meters of soil eroded quite rapidly, in about 40 years time. Nowhere else in the KAO05-3A core profile has this rate of sedimentation occurred so fast.

Trends over the past 12,000 years show that a common 0.1 cm per year sedimentation rate has occurred in this lake, while between 8370 BP and 3470 BP, it was very dry and had a 0.01cm rate per year. Flenley has been conducting new dating and analysis on his previous KAO 02 core, also taken from this lake, and his dates are aligning to support what I have found thus far in KAO 03. He has profiled more pollen studies and is uncovering more details that show a distinct mark of charcoal increase and change in aquatic plant abundance at around the same time period as the sedimentation rate that I found.

As for the plants, the carbon/nitrogen ratios are good for the lake sediment samples and show evaporation trends. Once the isotope analysis is complete, we can compare the coral cores that Rob Dunbar's group obtained, and compare changes in the ocean isotopes to the lake water isotopes in order to tease out events that happened on the island, and begin to finally correlate moisture changes with forest changes and, perhaps there will be more amazing surprises to come.

Candace Gossen is a PhD candidate in Environmental Science at Portland State University in Portland, Oregon. More information can be found on her webpage at www.solar783.com.

FURTHER READING

- Armada de Chile, Chile Isla De Pascua (Rapa-Nui). Por el Servicio Hidrográfico y Oceanográfico de la Armada de Chile. Datum Astro 1967. Restitución Aerofotogramétrica de 1992.
- Flenley, J. R. and S. M. King. 1984. Late quaternary pollen records from Easter Island. *Nature* 307:47-50.
- Flenley, J. R., S. M. King, J. Jackson, C. Chew, J. T. Teller and M. E. Prentice. 1991. The late quaternary vegetational and climatic history of Easter Island. *J. Quaternary Science* 6:85-115.
- Friedman, I., J. Gleason and A. Warden. 1993. Climate Change in Continental Isotopic Records. *Geophysical Monograph* 78. American Geophysical Union.
- Friedman, I. 1983. Paleoclimatic evidence from stable isotopes in Late Quaternary Environments of the United States. *The Late Pleistocene*, S. C. Porter, ed.:385-390, 1983. Minnesota:University of Minnesota Press.
- Friedman, I. 1997. The Amazon Basin, another Sahel? *Science* 197:4298.
- Heiser, C. B. Jr., 1974. Totorá, taxonomy, and Thor. *Plant Science Bulletin* :22-26.
- Heiser, C. B. Jr., 1979. The totora (*Scirpus californicus*) in Ecuador and Peru. *Econ. Bot.* 32:222-236.
- Heyerdahl, T. and E. N. Ferdon, Jr. eds. 1965. *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific*, Vol. 1 and 2. Santa Fe: The School of American Research and Museum of New Mexico. Number 24, Part 1 and 2.
- Heyerdahl, T., 1997. A reappraisal of Alfred Métraux's search for extra-island parallels to Easter Island culture elements. *Rapa Nui Journal* 11(1):12-20.
- Mucciarone, D. and R. Dunbar. 2003. Stable isotope record of El Niño – Southern Oscillation events from Easter Island. *Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm*. J. Loret and J. T. Tanacredi, eds.:113-132. New York: Kluwer Academic/Plenum Publishers.
- Wolfe, B. and K. Beuning. 2001. Carbon and Oxygen Isotope Analysis of Lake Sediment Cellulose: Methods and Applications. *Tracking Environmental Change Using Lake Sediments. Physical and Geochemical methods*. W. M. Last and J. P. Smol eds.:373-400. Dordrecht: Kluwer Academic Publishers.

Appendix H
Rapa Nui Taxonomy List
KAO3 core of Rano Kao

This list was compiled before the analyzing of the KAO3 pollen slides. What plants had been found by Skottsberg in 1922 set the base of a following study that Zizka continued in 1991. Along with Flenley's 1991 release of pollen types found in the craters of Rapa Nui, I have compiled a list of all known plant types. Some, not all, were noted in the KAO3 core, as many noted by Skottsberg arrived in historical times with humans. arrived. Meanwhile much of the native flora have become extinct and were not noted by Skottsberg upon his arrival in the early 1900s. The completed list that you find here was updated in January 2010 while working on the Australasian Pollen and Spore Atlas at the Australian National University in Canberra, Australia.

Appendix I

Water Quality Testing Data 2005 and 2008

In 2005 water was collected from Rano Kao when the first coring expedition occurred. This water was kept in a cooler at the UMN Limnological Core Repository along with the lake sediments for archiving. Another water sample was collected in 2008 and the same was stored at the LRC. Upon sampling and processing of isotopes both water samples were sent to Wilfred Laurier Isotope Lab in Waterloo, Ontario for further analysis. It was here that an evaporation of the lake water was established that would set the base for the isotope samples. Basic water quality was the processed for Dissolved Inorganic Compounds (DIC) and Dissolved Organic Compounds (DOC) as well as basic water chemistry. The water samples were taken at varying depths of the lake including surface, 6 meters which is mid water level and slightly above top of lake sediment at 12 meters depth. These results are found within this appendix.

Water Quality Testing Including DIC and DOC from 2005

Rano Kao - March 2008

year	location	Depth	Water Temp	pH	nitrate	phosphate	DO	Turbidity	BOD (5 days)	DIC	DIC	DIC
2008	Surface	surface	26C	6.0 (good)	<5ppm (good)	0.5ppm (excellent)	3ppm (poor 26C/4ppm = 49%)	0ITU	3ppm (excellent) dO= 0C	ppm C raw	Dilution correction ppm C	
2008	Mid	6m	24.5C	6.0 (good)	<5ppm (good)	0.5ppm (excellent)	4ppm (24.5C/4ppm = 48% poor)	0ITU	2ppm (excellent) dO= 2C	-0.085	-0.17	-0.18
2008	Bottom	12.2m	23.5C	6.0 (good)	<5ppm (good)	0.5ppm (excellent)	4ppm (23.5C/4ppm = 47% poor)	0ITU	1ppm (excellent) dO= 2.5C	-0.092	-0.18	-0.14
no fecal coliform test conducted, as did not want to contaminate water or island with foreign bacteria to test												
year	location	depth	CHN C (umol/L)	CHN N (umol/L)	POP PP (um/L)	DOC ppm C	DOC ppm N	DOC ppb C	DIC	DIC	DIC	DIC
2008	Surface	surface	340	50	1.08	15.46	0.8573	15458.69	ppm C raw	Dilution correction ppm C		
2008	Surface					15.88	0.8915	15880.00	-0.092	-0.18	-0.14	-0.24
2008	Mid	6m	260	40	0.655	15.43	1.1051	15425.26	-0.07	-0.121	-0.04	-0.07
2008	Mid					15.49	1.0901	15485.44	-0.121	-0.018	-0.04	-0.07
2008	Bottom	12.2m	3290	260	4.263	15.19	1.4043	15191.20	-0.034	-0.089	-0.18	-0.23
2008	Bottom					15.08	1.4237	15077.51	-0.089	-0.117	-0.18	-0.23
2005	surface	surface	430	50	0.879	16.08	1.5182	16080.62				
2005	surface											

Appendix J
Flenley Pollen Diagram Rano Kao

John Flenley was the first to core Rano Kao in the 1980s and in 1991 released the first information that further detailed an island plant ecology that Heyerdahl's expedition had begun in 1958. With Flenley's research and study, more evolution continued with his cores of Rano Raraku, Rano Aroi and Rano Kao. Further study returned to Rano Kao in 1998 and released a new core of pollen data for KAO2 a core taken near to center of lake. KAO3 the core used for this research follows the mentorship of Flenley and his previous work of understanding ecological changes as analyzed from the pollen found in this lake. This appendix is the pollen diagram released with this information.

Appendix K
Core ICD Sheets
(Initial Core Description)

Upon initial archiving of cores at the Limnological Research Center at the University of Minnesota at Minneapolis, these core sheets were the first data obtained on what the core looked like upon opening, smells, any noticeable and remarkable observations of the sediment color, any plant materials noted, minerals, and smear slides were taken before wrapping and storing long-term in the repository until further sampling was needed.

Appendix L

Statistics Correlation

These initial results are included to show the correlation or lack thereof between plant types and isotope data. There are some significant results as noted.

t-Test: Two-Sample Assuming Unequal Variances
d018 to aquatics

	Variable 1	Variable 2
Mean	1.00679245	52.9411765
Variance	17.4849991	2088.93647
Observations	53	51
Hypothesized	0	
df	51	
t Stat	-8.08230929	
P(T<=t) one-t	5.4027E-11	
t Critical one-t	1.67528469	
P(T<=t) two-t	1.0805E-10	
t Critical two-t	2.00758222	

t-Test: Two-Sample Assuming Unequal Variances
d018 to palmae

	Variable 1	Variable 2
Mean	1.00679245	61.627451
Variance	17.4849991	2074.75843
Observations	53	51
Hypothesized	0	
df	51	
t Stat	-9.46603535	
P(T<=t) one-t	4.048E-13	
t Critical one-t	1.67528469	
P(T<=t) two-t	8.0959E-13	
t Critical two-t	2.00758222	

t-Test: Two-Sample Assuming Unequal Variances
d018 to trees/shrubs

	Variable 1	Variable 2
Mean	1.00679245	12.4705882
Variance	17.4849991	341.134118
Observations	53	51
Hypothesized	0	
df	55	
t Stat	-4.32709769	
P(T<=t) one-t	3.2138E-05	
t Critical one-t	1.67303369	
P(T<=t) two-t	6.4276E-05	
t Critical two-t	2.00404429	

t-Test: Two-Sample Assuming Unequal Variances
low grass to high grass

	Variable 1	Variable 2
Mean	6.33333333	5.66666667
Variance	63.4666667	6.66666667
Observations	6	6
Hypothesized	0	
df	6	
t Stat	0.19499439	
P(T<=t) one-t	0.42591634	
t Critical one-t	1.94318091	
P(T<=t) two-t	0.85183269	
t Critical two-t	2.44691364	

t-Test: Two-Sample Assuming Unequal Variances
d018 low event to high event

	Variable 1	Variable 2
Mean	-1.85	3.47714286
Variance	15.6321	1.34645714
Observations	7	7
Hypothesized	0	
df	7	
t Stat	-3.42052661	
P(T<=t) one-t	0.00556372	
t Critical one-t	1.89457751	
P(T<=t) two-t	0.01112745	
t Critical two-t	2.36462256	

t-Test: Two-Sample Assuming Unequal Variances
low aquatic to high aquatic

	Variable 1	Variable 2
Mean	38.8333333	57
Variance	731.766667	2215.6
Observations	6	6
Hypothesized	0	
df	8	
t Stat	-0.81966009	
P(T<=t) one-t	0.21807363	
t Critical one-t	1.85954832	
P(T<=t) two-t	0.43614727	
t Critical two-t	2.30600563	

t-Test: Two-Sample Assuming Unequal Variances
low palmae to high palmae

	Variable 1	Variable 2
Mean	76.5	56.5
Variance	3253.1	3865.9
Observations	6	6
Hypothesized	0	
df	10	
t Stat	0.58062553	
P(T<=t) one-t	0.28717181	
t Critical one-t	1.81246151	
P(T<=t) two-t	0.57434361	
t Critical two-t	2.22813924	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to low grass

	Variable 1	Variable 2
Mean	-1.85	12.5
Variance	15.6321	15.5
Observations	7	6
Hypothesized	0	
df	11	
t Stat	-6.53862677	
P(T<=t) one-t	2.1E-05	
t Critical one-t	1.79588369	
P(T<=t) two-t	4.2001E-05	
t Critical two-t	2.20098627	

t-Test: Two-Sample Assuming Unequal Variances
low 018 to low palmae

	Variable 1	Variable 2
Mean	-1.85	76.5
Variance	15.6321	3253.1
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-3.35794335	
P(T<=t) one-t	0.01007656	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.02015312	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
low 018 to high palmae

	Variable 1	Variable 2
Mean	-1.85	56.5
Variance	15.6321	3865.9
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.29477369	
P(T<=t) one-t	0.03511464	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.07022929	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
high 018 to low palmae

	Variable 1	Variable 2
Mean	3.47714286	76.5
Variance	1.34645714	3253.1
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-3.1355138	
P(T<=t) one-t	0.01289824	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.02579649	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
high 018 to high palmae

	Variable 1	Variable 2
Mean	3.47714286	56.5
Variance	1.34645714	3865.9
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.08856803	
P(T<=t) one-t	0.04553265	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.09106531	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
high 018 to high grass

	Variable 1	Variable 2
Mean	3.47714286	5.66666667
Variance	1.34645714	6.66666667
Observations	7	6
Hypothesized	0	
df	7	
t Stat	-1.91778741	
P(T<=t) one-t	0.04832196	
t Critical one-t	1.89457751	
P(T<=t) two-t	0.09664391	
t Critical two-t	2.36462256	

t-Test: Two-Sample Assuming Unequal Variances
low trees to high trees

	Variable 1	Variable 2
Mean	12.5	5.66666667
Variance	15.5	6.66666667
Observations	6	6
Hypothesized	0	
df	9	
t Stat	3.55515088	
P(T<=t) one-t	0.00308297	
t Critical one-t	1.83311386	
P(T<=t) two-t	0.00616593	
t Critical two-t	2.26215889	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to high trees

	Variable 1	Variable 2
Mean	-1.85	5.66666667
Variance	15.6321	6.66666667
Observations	7	6
Hypothesized	0	
df	10	
t Stat	-4.11031152	
P(T<=t) one-t	0.00105475	
t Critical one-t	1.81246151	
P(T<=t) two-t	0.0021095	
t Critical two-t	2.22813924	

t-Test: Two-Sample Assuming Unequal Variances
low ferns to high ferns

	Variable 1	Variable 2
Mean	86	65.1666667
Variance	1997.2	3936.16667
Observations	6	6
Hypothesized	0	
df	9	
t Stat	0.66249681	
P(T<=t) one-t	0.26212685	
t Critical one-t	1.83311386	
P(T<=t) two-t	0.5242537	
t Critical two-t	2.26215889	

t-Test: Two-Sample Assuming Unequal Variances
high d018 to low ferns

	Variable 1	Variable 2
Mean	3.47714286	86
Variance	1.34645714	1997.2
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-4.52182403	
P(T<=t) one-t	0.00313619	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.00627237	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
low pollen to high pollen

	Variable 1	Variable 2
Mean	219.5	190.333333
Variance	944.3	1976.26667
Observations	6	6
Hypothesized	0	
df	9	
t Stat	1.3219921	
P(T<=t) one-t	0.10939159	
t Critical one-t	1.83311386	
P(T<=t) two-t	0.21878318	
t Critical two-t	2.26215889	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to low trees

	Variable 1	Variable 2
Mean	-1.85	12.5
Variance	15.6321	15.5
Observations	7	6
Hypothesized	0	
df	11	
t Stat	-6.53862677	
P(T<=t) one-t	2.1E-05	
t Critical one-t	1.79588369	
P(T<=t) two-t	4.2001E-05	
t Critical two-t	2.20098627	

t-Test: Two-Sample Assuming Unequal Variances
high d018 to high trees

	Variable 1	Variable 2
Mean	3.47714286	5.66666667
Variance	1.34645714	6.66666667
Observations	7	6
Hypothesized	0	
df	7	
t Stat	-1.91778741	
P(T<=t) one-t	0.04832196	
t Critical one-t	1.89457751	
P(T<=t) two-t	0.09664391	
t Critical two-t	2.36462256	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to low ferns

	Variable 1	Variable 2
Mean	-1.85	86
Variance	15.6321	1997.2
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-4.79904327	
P(T<=t) one-t	0.00244389	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.00488777	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
high d018 to high ferns

	Variable 1	Variable 2
Mean	3.47714286	65.1666667
Variance	1.34645714	3936.16667
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.40816724	
P(T<=t) one-t	0.030501	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.061002	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
low 018 to low pollen

	Variable 1	Variable 2
Mean	-1.85	219.5
Variance	15.6321	944.3
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-17.5202641	
P(T<=t) one-t	5.553E-06	
t Critical one-t	2.01504918	
P(T<=t) two-t	1.1106E-05	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to high grass

	Variable 1	Variable 2
Mean	-1.85	5.66666667
Variance	15.6321	6.66666667
Observations	7	6
Hypothesized	0	
df	10	
t Stat	-4.11031152	
P(T<=t) one-t	0.00105475	
t Critical one-t	1.81246151	
P(T<=t) two-t	0.0021095	
t Critical two-t	2.22813924	

t-Test: Two-Sample Assuming Unequal Variances
low 018 to high ferns

	Variable 1	Variable 2
Mean	-1.85	65.1666667
Variance	15.6321	3936.16667
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.61206381	
P(T<=t) one-t	0.02377556	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.04755111	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
high 018 to high pollen

	Variable 1	Variable 2
Mean	3.47714286	190.333333
Variance	1.34645714	1976.26667
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-10.2928008	
P(T<=t) one-t	7.4415E-05	
t Critical one-t	2.01504918	
P(T<=t) two-t	0.00014883	
t Critical two-t	2.57057764	

t-Test: Two-Sample Assuming Unequal Variances
low 018 to high pollen

	Variable 1	Variable 2
Mean	-1.85	190.3333333
Variance	15.6321	1976.266667
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-10.5536163	
P(T<=t) one-t	6.59738E-05	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.000131948	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances
d018 to total pollen

	Variable 1	Variable 2
Mean	1.006792453	201.6666667
Variance	17.48499913	3429.746667
Observations	53	51
Hypothesized	0	
df	50	
t Stat	-24.4091106	
P(T<=t) one-t	9.72242E-30	
t Critical one-t	1.675905423	
P(T<=t) two-t	1.94448E-29	
t Critical two-t	2.008559932	

t-Test: Two-Sample Assuming Unequal Variances
high d018 to low total charcoal

	Variable 1	Variable 2
Mean	3.477142857	9.333333333
Variance	1.346457143	45.46666667
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.10087922	
P(T<=t) one-t	0.044826585	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.08965317	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances
low charcoal to low class 4 charcoal

	Variable 1	Variable 2
Mean	9.333333333	0
Variance	45.46666667	0
Observations	6	6
Hypothesized	0	
df	5	
t Stat	3.390516358	
P(T<=t) one-t	0.009725195	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.01945039	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances
high 018 to low pollen

	Variable 1	Variable 2
Mean	3.477142857	219.5
Variance	1.346457143	944.3
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-17.208979	
P(T<=t) one-t	6.06615E-06	
t Critical one-t	2.015049176	
P(T<=t) two-t	1.21323E-05	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to low total charcoal

	Variable 1	Variable 2
Mean	-1.85	9.333333333
Variance	15.6321	45.46666667
Observations	7	6
Hypothesized	0	
df	8	
t Stat	-3.57039341	
P(T<=t) one-t	0.003644748	
t Critical one-t	1.85954832	
P(T<=t) two-t	0.007289496	
t Critical two-t	2.306005626	

t-Test: Two-Sample Assuming Unequal Variances
low charcoal to high charcoal

	Variable 1	Variable 2
Mean	9.333333333	12
Variance	45.46666667	26
Observations	6	6
Hypothesized	0	
df	9	
t Stat	-0.77266741	
P(T<=t) one-t	0.229764397	
t Critical one-t	1.833113856	
P(T<=t) two-t	0.459528794	
t Critical two-t	2.262158887	

t-Test: Two-Sample Assuming Unequal Variances
low d018 to high total charcoal

	Variable 1	Variable 2
Mean	-1.85	12
Variance	15.6321	26
Observations	7	6
Hypothesized	0	
df	9	
t Stat	-5.40484339	
P(T<=t) one-t	0.000215136	
t Critical one-t	1.833113856	
P(T<=t) two-t	0.000430273	
t Critical two-t	2.262158887	

t-Test: Two-Sample Assuming Unequal Variances
low charcoal to high class 4 charcoal

	Variable 1	Variable 2
Mean	9.333333333	0.333333333
Variance	45.46666667	0.266666667
Observations	6	6
Hypothesized	0	
df	5	
t Stat	3.259880697	
P(T<=t) one-t	0.011224317	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.022448634	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

high charcoal to high class 4 charcoal

	Variable 1	Variable 2
Mean	12	0.333333333
Variance	26	0.266666667
Observations	6	6
Hypothesized	0	
df	5	
t Stat	5.575963644	
P(T<=t) one-t	0.001278097	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.002556193	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

high charcoal to low class 4 charcoal

	Variable 1	Variable 2
Mean	12	0
Variance	26	0
Observations	6	6
Hypothesized	0	
df	5	
t Stat	5.764613537	
P(T<=t) one-t	0.001103288	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.002206575	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

low charcoal to low class 1 charcoal

	Variable 1	Variable 2
Mean	9.333333333	7.833333333
Variance	45.46666667	48.96666667
Observations	6	6
Hypothesized	0	
df	10	
t Stat	0.378097864	
P(T<=t) one-t	0.356630032	
t Critical one-t	1.812461505	
P(T<=t) two-t	0.713260064	
t Critical two-t	2.228139238	

t-Test: Two-Sample Assuming Unequal Variances

high charcoal to high class 1 charcoal

	Variable 1	Variable 2
Mean	12	10
Variance	26	26.8
Observations	6	6
Hypothesized	0	
df	10	
t Stat	0.6741999	
P(T<=t) one	0.2577331	
t Critical one	1.8124615	
P(T<=t) two	0.5154662	
t Critical two	2.2281392	

t-Test: Two-Sample Assuming Unequal Variances

low charcoal to high class 1 charcoal

	Variable 1	Variable 2
Mean	9.333333333	10
Variance	45.46666667	26.8
Observations	6	6
Hypothesized	0	
df	9	
t Stat	-0.19209469	
P(T<=t) one-t	0.42596618	
t Critical one-t	1.833113856	
P(T<=t) two-t	0.85193236	
t Critical two-t	2.262158887	

t-Test: Two-Sample Assuming Unequal Variances

high charcoal to low class 1 charcoal

	Variable 1	Variable 2
Mean	12	7.833333333
Variance	26	48.96666667
Observations	6	6
Hypothesized	0	
df	9	
t Stat	1.178773281	
P(T<=t) one-t	0.134356226	
t Critical one-t	1.833113856	
P(T<=t) two-t	0.268712452	
t Critical two-t	2.262158887	

t-Test: Two-Sample Assuming Unequal Variances

low 018 to low class 1 charcoal

	Variable 1	Variable 2
Mean	-1.85	7.833333333
Variance	15.6321	48.96666667
Observations	7	6
Hypothesized	0	
df	8	
t Stat	-3.00350197	
P(T<=t) one-t	0.008490408	
t Critical one-t	1.85954832	
P(T<=t) two-t	0.016980817	
t Critical two-t	2.306005626	

t-Test: Two-Sample Assuming Unequal Variances

high 018 to high class 1 charcoal

	Variable 1	Variable 2
Mean	3.477142857	10
Variance	1.346457143	26.8
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-3.02197375	
P(T<=t) one-t	0.014674955	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.02934991	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

low starch to high starch

	Variable 1	Variable 2
Mean	104	88
Variance	7866.8	4678.8
Observations	6	6
Hypothesized	0	
df	9	
t Stat	0.349904791	
P(T<=t) one-t	0.367229431	
t Critical one-t	1.833113856	
P(T<=t) two-t	0.734458863	
t Critical two-t	2.262158887	

t-Test: Two-Sample Assuming Unequal Variances

low 018 to low starch

	Variable 1	Variable 2
Mean	-1.85	104
Variance	15.6321	7866.8
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.92077361	
P(T<=t) one-t	0.016492048	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.032984095	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

high 018 to high starch

	Variable 1	Variable 2
Mean	3.477142857	88
Variance	1.346457143	4678.8
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-3.0264186	
P(T<=t) one-t	0.014600444	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.029200887	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

low 018 to high starch

	Variable 1	Variable 2
Mean	-1.85	88
Variance	15.6321	4678.8
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-3.21296133	
P(T<=t) one-t	0.011825243	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.023650487	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

high 018 to low starch

	Variable 1	Variable 2
Mean	3.477142857	104
Variance	1.346457143	7866.8
Observations	7	6
Hypothesized	0	
df	5	
t Stat	-2.77593658	
P(T<=t) one-t	0.019544792	
t Critical one-t	2.015049176	
P(T<=t) two-t	0.039089585	
t Critical two-t	2.570577635	

t-Test: Two-Sample Assuming Unequal Variances

d018 below 2.53 to above 2.53 (evaporation rate)

	Variable 1	Variable 2
Mean	-0.74129032	3.47
Variance	22.34423161	0.508609524
Observations	31	22
Hypothesized	0	
df	32	
t Stat	-4.88267504	
P(T<=t) one-t	1.39695E-05	
t Critical one-t	1.693888407	
P(T<=t) two-t	2.7939E-05	
t Critical two-t	2.036931619	

Appendix M

Magnetic Susceptibility Charts

In 2004, with NSF funding, the Limnological Research Center (LRC) acquired both a new Geotek Multi-Sensor Core Logger (MSCL) with tremendous capabilities for logging both whole and split cores, and the first Geotek XYZ core logger in the Western Hemisphere, which automates the measurement of high-resolution magnetic susceptibility by point-sensor, color analysis by spectrophotometry, and detection of natural gamma emissions.

Initial scan at the LRC at the UMN core lab in 2005, comprised of a whole-core scan that created a low resolution magnetic susceptibility analysis as noted within the dissertation text. The core was then split and scanned using the XYZ scanner for high resolution magnetic susceptibility. These charts are the individual scans for each meter IL – 9L.