Tod F. Stuessy

Environmental History of Oceanic Islands

Natural and Human Impacts on the Vegetation of the Juan Fernández (Robinson Crusoe) Archipelago

Springer

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Frontispiece Tree ferns and other endemic vegetation on Alejandro Selkirk Island in the Juan Fernández Archipelago

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No doubt the general appearance of the vegetation is very different now from what it was when the island was first visited.

Henry Moseley (1892: 467)

This book is dedicated to the memory of Professor Clodomiro Marticorena Pairoa (1929–2013) of the Departamento de Botánica, Universidad de Concepción, Chile, who shared a deep interest in the historical aspects of the Juan Fernández Archipelago. He had a vast knowledge of early sea voyagers and their chronology and influence. It is with great sadness that he passed away before this book was conceived and written, but his spirit flows through every one of these pages.

Other Books by Tod F. Stuessy

Cladistics: Perspectives on the reconstruction of evolutionary history (1984). Edited with T. Duncan.

Cladistic Theory and Methodology (1985). Edited with T. Duncan.

Plant Taxonomy: The systematic evaluation of comparative data (1990).

Case Studies in Plant Taxonomy (1994).

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Plant Systematics: A half-century of progress (1950–2000) and future challenges (2001). Edited with E. Hörandl and V. Mayer.

Deep Morphology: Toward a Renaissance of morphology in plant systematics (2003). Edited with V. Mayer and E. Hörandl.

Plant Taxonomy: The systematic evaluation of comparative data, ed. 2 (2009).

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Monographic Plant Systematics: Fundamental assessment of plant biodiversity (2011). Edited with W. Lack.

Plant Systematics: The origin, interpretation, and ordering of plant biodiversity (2014). With D. Crawford, D. Soltis, and P. Soltis.

Plants of Oceanic Islands: Evolution, biogeography, and conservation of the flora of the Juan Fernández (Robinson Crusoe) Archipelago (2018). Edited with D. Crawford, P. López-Sepúlveda, C. Baeza, and E. Ruiz.

Systematics of Hypochaeris *Section* Phanoderis (2019). With 15 co-authors.

Preface

Scientists from the Ohio State University, the University of Vienna, the University of Concepción (Chile), and many other institutions have worked on evolutionary and biogeographic investigations in the Juan Fernández Archipelago for over 35 years. These investigations have resulted in numerous articles in scientific journals during this period, as well as having been synthesized recently in a comprehensive book on the evolution and biogeography of the plants of the archipelago (Stuessy et al. 2018a). On our 12 expeditions to the archipelago from 1980 to 2011, we became aware of the natural and human impacts to the island ecosystem, and these experiences suggested that another story needed to be told in more detail: the historical ecology of the archipelago.

Many natural factors have impacted these isolated islands. The two major islands are four and one million years old, and during this time, much natural change has taken place. Subsidence and erosion by wind and water has shaped the landscape to the form seen today. These modifications have not only impacted the geomorphology of the islands but also their vegetation and flora.

Following four million years of natural changes in the islands, impacts have come from human activities over the past more than 400 years. The archipelago was first discovered in 1574 by the Spanish navigator Juan Fernández, and from this point onward, a series of European visitors arrived in the islands. The archipelago was strategically situated for obtaining food, water, and edible plants, and subsequently also for meat from goats set ashore by the early visitors. Fish and lobster also abounded. This was a true oasis for ships surviving the harrowing voyage around Cape Horn and before sailing further westward into the Pacific for oriental markets. As time progressed, the islands also became a convenient hiding place for English, French, and Dutch ships as they attacked the Spanish colonies along the western coast of South America.

The historical visitors to the Juan Fernández Archipelago often left chronicles of their activities. Captains, pilots, and travelers routinely kept logs of their voyages, sometimes with considerable details. These documents were often published, supplemented at times by drawings and maps, as the European public was thirsty for information about the New World. It is this trove of information that has been digested for the assessments presented in this book.

Historical ecology recognizes the huge roles that humans have played in shaping the landscape of the planet (Bilsky 1980), and oceanic islands have been particularly susceptible to disturbance from human activities (Kirch and Hunt 1997; Keppel et al. 2014; Copsey et al. 2018). People are by nature competitive and greedy, motivated largely by familial and tribal affinities. Because of their beauty, natural resources, and remoteness (and hence often weakly defended), oceanic islands have had their environments substantially modified. These become case studies of human impact on the ecology of the Earth. Because islands are small and surrounded by water, the impacts can often be clearly documented as resulting from specific human activities.

The Juan Fernández Archipelago is an instructive case study of human impact on the vegetation of an oceanic island. There never were indigenous peoples in this archipelago (Haberle 2003), and therefore, from the moment in 1574 when the islands were discovered, human impact began. Over the subsequent 400 plus years, the detailed reports from officers and travelers on visiting ships serve as an accurate picture of human activities. Because ecological sensitivities were virtually unknown until the second half of the twentieth century, nearly all of the human impacts on the islands have been negative. It is somewhat sad to present negative perspectives, but it hopefully serves as a reminder of what can happen to the entire planet if we do not care for it properly. The Anthropocene (Steffen et al. 2011) may be remembered as a remarkable period of invention by a single species on earth, or it may signal the end of the natural ecosystem upon which we and all other life forms depend.

Columbus, USA/Vienna, Austria Tod F. Stuessy
2020

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Every book reaches completion because of support from numerous individuals and institutions. This book is no exception. During research in the archipelago, our group has been aided by the administrators and guides of the Robinson Crusoe Islands National Park. This park is one of many in Chile that is managed by the Corporación National Forestal (CONAF), charged with oversight of the natural resources of the country. As one of Chile's national parks, all collecting and scientific study now is carefully regulated. Supporting our work have been the park chiefs, Bernardo Ackermann, Gastón González, and Ivan Leiva. The guides and associates were especially helpful, and these included: Alfonso Andauer, Jorge Angulo, Guillermo Araya, Danilo Arredondo, Danilo Arredondo, Jr., Oscar Chamorro, Esteban Charpentier, Miguel García, Alvis González, Claudio González, Guillermo González, José González, Michael González, Bernardo López, Guillermo López, José López, Eduardo Paredes, Aldo Recabarren, Teodoro Rivadeneira, and Ramón Schiller. Work in the islands would have been impossible without the support of these outstanding professionals and friends.

Time away from normal duties to work in the Juan Fernández Archipelago was generously granted by the Ohio State University, the Los Angeles Museum of Natural History, and the University of Vienna. Because of the complex logistics involved with research in the islands, especially on the remote Alejandro Selkirk Island, where no supplies exist, considerable time was needed for the expeditions, normally lasting four to six weeks. The Departamento de Botánica of the Universidad de Concepción, Chile, served as a site for many pre- and post-organizational aspects of the expeditions, as well as their personnel joining as full collaborators on all trips and research publications.

This book would never have been written without the encouragement and support from colleagues on so many expeditions and cooperative laboratory studies from 1980 to the present. These include: Gregory Anderson, Pedro Aqueveque, Jorge Arriagada, Carlos M. Baeza, Gabriel Bernardello, Daniel J. Crawford, Michael Doyle, Leonardo Gaete, Alejandro Gatica, Fidelina González, Josef Greimler, Ana María Humaña, Gabriele Kottirsch, Thomas Lammers, Alejandro Landero, Luis Letelier, Patricio López-Sepúlveda, Oscar Matthei, Johannes Novak, Patricio Novoa, Patricia Pacheco, Oscar Parra, Patricio Peñailillo, Roberto Rodríguez, Richard Roederer, Mauricio Rondanelli, Eduardo Ruiz, Roger Sanders, Jaime Sepúlveda, Mario Silva, José Soto, Alan Stuessy, Patricia Stuessy, Ulf Swenson, Koji Takayama, Eric Tepe, Karin Tremetsberger, Eduardo Ugarte, Hugo Valdebenito, and Delbert Wiens. These colleagues come from Argentina, Austria, Chile, Ecuador, Japan, Mexico, Sweden, and USA.

Most of the historical information for this book was obtained from the primary literature, but some additional data were acquired from institutions and individuals. Visits to the Royal Geographic Society, London, UK, and the Archivo de las Indias, Sevilla, Spain, resulted in copies of important historical maps. James Flatness of the Map Division of the US Library of Congress, Washington, DC, also sent me copies of old maps of the archipelago. Books were consulted at the library of the British Museum. Lyndon Wester and John Francis kindly shared copies of older texts already acquired during their previous researches on the archipelago. Carlos M. Baeza provided scientific identifications of some plants mentioned as vernacular names in the historical documentation. The excellent history of the Juan Fernández Archipelago by Ralph Woodward (1969), frequently cited in this book, was most helpful for information on the cultural side of island development. Ann-Mari Skottsberg graciously translated into English the diary of her mother, Inga, written in Swedish on their expedition to the archipelago in 1954–1955.

Maps, drawings, and photographs have been reproduced with permission from several sources: *Pacific Science* (Figs. 2.2, 6.1, 6.2); Josef Greimler (Figs. 4.1a, b, 6.1, 6.2); National Portrait Gallery, London (Figs. 7.5, 7.9, 9.1); Oscar Matthei (Fig. 9.4); Botanical Research Institute of Texas Press (Fig. 9.5); Piero Delprete (Fig. 9.5); Royal Botanic Gardens, Kew (Fig. 10.1b); Departamento de Botánica, Universidad de Concepción (Fig. 10.4); Rüdi Looser (Fig. 12.3); University of California Botanic Garden (Fig. 12.6); Mary Anne Kunkel and Alfonso Susanna (Fig. 12.10); Otto Solbrig (Figs. 13.1, 13.11a); *Nordic Journal of Botany* (Figs. 14.1, 14.2); and Cambridge University Press (Fig. 15.1).

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Contents

Chapter 1
Introduction

1.1 The Importance of an Historical Perspective

There is nothing more important for the interpretation of reality than understanding history. History is the area of knowledge that deals with examination, documentation, and interpretation of events over time. In context of this broad definition, nearly all aspects of our world are in some measure historical, including the origin and evolution of our entire planet (and universe). As long as there is time and structure in our existence, there must be history.

We often think of history as being more focused on human events, and in this context, one of the first Western historians was the Greek writer Herodotus (c. 425 BCE), who traveled extensively throughout the Mediterranean (Classical) world and chronicled information from these experiences. He was somewhat uncritical in his reports, documenting nearly everything he learned, including fanciful or exaggerated claims. Another Greek author, Thucydides, wrote (431 BCE) with much more objectivity about the Peloponnesian War between Sparta and Athens.

From these beginnings, the writing of history has become an important part of the human experience. Because our own life span is limited to a very short slice of time, we find it fascinating to learn more about what has happened previous to our own existence. Whether learning about the past really prevents us from repeating negative consequences in the present or future (Santayana 1905) is debatable, simply because no world situation is exactly the same at any point in time. Hence, what seemed bad policy a thousand years ago may not be bad today or tomorrow due to changing conditions. Nonetheless, studies of previous events of human history are of great interest to most persons, who read history with the hope of understanding better the workings of human society. The most dramatic (or calamitous) events obviously tend to attract the most interest. The challenge is not only to chronicle events of the past but also to try to understand reasons for the occurrence of the events, i.e., seeking causes (Diamond and Robinson 2010).

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History is particularly significant for understanding biological patterns and processes. Although one may not usually view biology in context of historical events, all processes in the biological world are essentially historical. They have a beginning, a transition, and an end. This would include daily cellular processes, such as photosynthesis and respiration, plus energy transformations and development. Reproductive behavior is also historical. The end results from biological processes are patterns, such as cell structures, which represent snapshots in any one particular point in time.

Particularly historical are studies of systematics and evolution. Here we seek patterns in the natural world and then attempt to understand the processes that produced the patterns. Systematics is the study of the kinds and diversity of life and relationships among them (Simpson 1961), or more simply, the study of biodiversity in its broadest sense. The systematist seeks order in nature, and usually arranges the entities so discovered into a structure of information, or classification. If done effectively, such a structure contains much data about organisms to serve as a useful information-retrieval system as well as allowing for predictive insights on qualities not yet observed or chronicled. The revealed patterns then allow search for processes to explain their origins. Evolution is obviously the general explanation for the origin of biodiversity, and two broad approaches have been developed. Microevolutionary investigations focus on understanding the processes active at the populational level, generally dealing with concepts of genetic diversity, isolating mechanisms, and eventual speciation. Macroevolutionary studies deal with understanding the long-term evolutionary transitions leading to the patterns among organisms seen today. Fossil evidence can be of great value here, because fossils provide evidence of morphological features that existed at particular time periods in the past. They are similar to archaeological finds in human historical investigations, but here occurring over millions rather than only thousands of years. Modern phylogenetic analyses using nucleotide data are now fundamental for these phylogenetic reconstructions at all levels of the taxonomic hierarchy (Baum and Smith 2013).

History is also fundamental for ecology, which can be regarded as the affinities of organisms to each another and in relation to their physical surroundings. The role of systematics here is obvious, as one cannot very effectively understand the relationship of organisms to the environment if the entities themselves are not clearly circumscribed, either informally or in a more scientifically meaningful way. As with systematics, ecology first attempts to document the patterns in nature, such as vegetation types, life forms, elements of an ecosystem, etc. After patterns have been revealed, the challenge turns toward explaining the processes of change within the ecosystems. This is immensely difficult, because so many variables exist. Most ecosystems are unbelievably complex, including not only the most conspicuous organisms, such as trees, shrubs, or even herbs, but then come the herbivores, the predators on the herbivores and their own parasites. Not easily observed but extremely important are the below-ground organisms, such as the fungi, arthropods, annelids, and bacteria and viruses in huge quantities. Attempting to understand such complex organismic systems and in relation to environmental factors is what makes ecology intriguing as well as difficult.

1.2 Historical Ecology

Out of this general purview that ecology has strong historical dimensions has developed the scholarly area called historical ecology. The origins of this term are somewhat diffuse, but Crumley (1998) suggests that it was first used in a doctoral thesis by Don Rice (1976). He attributed it to the anthropologist Edward Deevey, who in the early 1970s directed the Historical Ecology Project at the University of Florida. More visibility came with the volume edited by Lester Bilsky (1980) entitled *Historical Ecology: Essays on Environment and Social Change*. Subsequent volumes appeared with historical ecology in their titles (e.g., Crumley 1994; Kirch and Hunt 1997; Balée 1998a), and new reviews have recently appeared (McClenachan et al. 2015; Szabo 2015; Beller et al. 2017).

The idea of historical ecology is to encourage collaboration between different social science areas, such as anthropology and geography, or between different aspects represented by hybrid fields such as environmental history or landscape ecology (Crumley 1998; Bürgi and Gimmi 2007). The basic concept is to document changes in the environment over time, particularly as events impact the landscape (Balée 1998b). Many factors can and have influenced the landscape of the Earth over different time scales. Two types of basic impacts can be characterized: those that have occurred naturally; and those that are due to human activities (Rhemtulla and Mladenoff 2007).

Very dramatic impacts on the landscape have occurred from natural earth events such as continental drift or Pleistocene glaciations (Lowe and Walker 1997). These are long-term events that have indeed been responsible for major reshaping of large portions of the planet, concurrent with effecting changes in the environment and the organisms contained within it. Other natural impacts have taken place within much shorter time frames, such as volcanic explosions, severe drought, natural fire, pestilence (such as fungal invasions or migrating locust hordes), tidal waves, or meteor impacts (e.g., at the end of the Cretaceous, 66 mya, resulting in the 180 km wide Chicxulub crater in the Yucatán peninsula of Mexico; Renne et al. 2013).

One can argue that human activity is also a part of the natural cycle of the world, but the impact from people has been so great, especially over the past several centuries as the size of the human population has grown geometrically, that it has occasioned a more acute influence on the landscape than most impacts resulting from natural phenomena. The impact that humans have had on the ecosystems of the planet is unparalleled, such that some workers are now referring to this period of Earth history as the Anthropocene (e.g., Steffen et al. 2011; Helmus et al. 2014; Waters et al. 2016). It is impossible not to notice the continual building of new factories and other businesses, as well as more homes, apartments, roads, shopping centers, airports, sports arenas, and parking lots. To feed and clothe the increasing numbers of new persons on the planet requires increased acreage dedicated to domesticated plants and animals, which involves clearing of original ecosystems. The oceans have also been impacted, due mainly to overfishing and pollution (Halpern et al. 2008). To these human impacts can be added the serious problems of sea level rise, desertification, and extreme weather associated with climate change due to increased CO_2 levels in the atmosphere (Mora et al. 2018).

A very significant role of historical ecology is in the interpretation of landscape change that will have impacted evolutionary processes and patterns. This is particularly important in oceanic islands that can have relatively short life spans. Attempting to infer modes of speciation, for example, is difficult in an island that has already undergone significant geomorphological change over millions of years. Because of subsidence and erosion, the present geographic and ecological contexts of populations may not at all reflect conditions when species originated. Clearly, the best locations for the most robust inferences should come from studies on younger rather than older, islands. Comparison between organisms on islands of different ages and even between those on different archipelagos, must always take the historical context into account (Stuessy, in press).

1.3 Impacts on Oceanic Islands from Native Peoples

Oceanic islands are areas of the world that have been particularly impacted by humans. For centuries these islands, many in tropical or subtropical climates, have provided agreeable homes for numerous human tribes, particularly in the Pacific Ocean. From southeast Asia, peoples of the Pacific have travelled in the past thousand years to islands of Polynesia through remarkable voyages of discovery in simple boats (Wilmshurst et al. 2011; Matisoo-Smith 2015). In many islands, fresh water has made it possible to live comfortably and develop communities. Food has often been abundant from the sea, and sometimes also from available native plants, which were supplemented by produce from rudimentary agriculture.

Indigenous peoples, however, have not always treated their ecosystems in a sustainable fashion (Rolett and Diamond 2004). The birds of oceanic islands have suffered considerably, being consumed as food and use of their feathers for adornments (Steadman 1997, 2006; Culliney 2006). Based on fossil evidence, it has been estimated that two-thirds of the species of endemic birds in the Hawaiian archipelago were extinct (Culliney 2006) by the time of first arrival of European voyagers (Captain Cook in 1778; Ziegler 2002). As native birds have gone extinct, it is probable that some native plants that depended on the birds as pollinators may also have disappeared. Such may be the case in the Hawaiian Islands with the honeycreepers (Drepanidinae) and the lobeliads, although direct evidence for coevolution or coextinction between these groups is still uncertain (Lammers and Freeman 1986).

Perhaps one of the most dramatic examples of impact on the natural ecosystem from indigenous Polynesian inhabitants has occurred in Easter Island (also called Rapa Nui). Now belonging to Chile (acquired in 1888), this small island (63 mi^2) is located in the middle of the Pacific Ocean far removed (3,512 kms west) from the Chilean mainland. The closest inhabited island is Pitcairn, some 2,075 kms to the west. Despite this isolation, people did arrive to Easter Island. A number of theories regarding the time of arrival have been proposed, but Hunt and Lipo (2006) have shown convincingly that colonization occurred about 1200 CE. A stable society was developed, and cultural success allowed time for artisans to construct massive human stone figures (moais) weighing more than ten tons. These were moved on designated pathways toward the sea and placed on stone altars (ahus). What mechanism permitted moving such heavy structures has occasioned several hypotheses, the most recent being that of moving them upright with three attached ropes and a rocking motion (Hunt and Lipo 2011). Although most food was taken from the sea, some agriculture was employed. Native trees were harvested for building of houses as well as boats. Lack of foresight led to the continual destruction of more of the forests, until not enough wood was available for making new fishing boats. Hunt (2007) also stressed negative impacts on the vegetation from invasive rats. These factors led to hunger, civil strife, and war. Contact with Europeans occurred in 1722 with the arrival of the Dutch voyager Jacob Roggeveen, which opened the door to other European visitors. These contacts resulted in disease within the native population due to lack of immunity against Old World pestilences. Peruvian ships in 1862–1863 captured hundreds of the inhabitants of Easter Island to work indentured in the guano mines off the Peruvian coast (Maude 1981; Heyerdahl 1989), which reduced the native population to a dangerously low level, with only 110 individuals remaining by 1877. Descendants from these remaining families have survived, but they are only a remnant of the original population. This is a very instructive case study, because it illustrates how human society can collapse if not enough attention is given toward preservation of the natural resources in the environment.

1.4 Impacts on Island Environments from European Visitors

The age of exploration, fueled mainly by hopes of encountering fame and fortune, plus a curiosity about other parts of the planet, led to ships sailing to different areas of the globe from Portugal, Spain, England, France, and the Netherlands (Crosby 1986; Howse 1990; Pagden 1993; Brockway 2002; Cook 2007). The principal objective was to find routes to the lucrative Spice Islands, sometimes combined with an evangelical motive, and many oceanic islands provided convenient stopping points for these early seafarers. Islands in the Atlantic were very strongly impacted (Duncan 1972; Schiebinger 2004) because these became stepping stones from Europe to Africa and then to the New World.

Over the centuries, oceanic islands have been highly valued for communications, navigation, economic gain, and military and strategic objectives (Duncan 1972). During the age of wars in Europe, especially during the seventeenth and eighteenth centuries, islands became additional places of conflict, as they were essential as places to replenish spent food and water and to provide rest for weary or ill sailors. Pirates found them especially attractive, as often no permanent and fortified settlements existed, which gave them free rein to come and go as they pleased.

With the arrival of European visitors to oceanic islands of the world, impacts on natural ecosystems occurred. If indigenous peoples had already been in the islands, then additional changes in the environment took place; if the islands had always been uninhabited, then human alterations of Nature began from this starting point. The principal impact focused on disturbances to the native vegetation, and this had repercussions for other plants as well as animals. Because ships needed constant repair, wood was harvested from native trees and fashioned into lumber for masts, planking, or other needs. During the age of the steamers in the nineteenth century, wood was also turned into charcoal to fire ships' boilers. As trees were cut from these areas, usually as close as possible to the harbors, erosion ensued.

The second most severe impact on the natural vegetation of oceanic islands has come from the introduction of invasive species of animals. Some species were deliberately introduced, such as goats or rabbits. The idea was to allow them to reproduce naturally and develop larger populations, such that hunting them on future visits would provide a source of meat for the sailors. Unsurprisingly, these animals did become successful, but they also ate anything necessary for survival, which included many indigenous species of plants. Goats were especially menacing because due to their sure-footedness, they foraged on nearly all parts of islands.

A third major impact has resulted from damage caused by introduced plants. Usually introduced inadvertently along with packaging or other materials, seeds of aggressive European weeds were transported very successfully to distant islands. Once established, they often flourished in absence of homeland predators. All islands have had their share of such invaders, and with more modern tourism, it is becoming a very high conservation priority to try to halt these new and harmful immigrants. As permanent settlements became established in islands, cultivated plants were also brought for gardens, both for produce and for ornament. Some of the latter sometimes escaped and also became aggressive competitors with the native plant species.

1.5 The Importance of Documenting Human Impact on Natural Vegetation of Oceanic Islands

Human impact on Pacific oceanic islands from European contacts has been going on for many centuries, starting with the sixteenth century. The negative consequences of most of these contacts has been chronicled by numerous scholars, especially during the latter part of the twentieth century. The reader may wonder what the point is to once again document negative consequences of human intervention into island landscapes. Isn't the message abundantly clear without having to beat the drum once more? An appropriate answer might be that we can never emphasize enough the devastation that humans have caused on the natural environment. This is hardly a trivial matter, as our own survival requires that we understand our own impacts on a global scale and carry out remedial actions to mitigate this harm. There can hardly be anything more important than this.

Because trying to deal with all factors causing damage to the environment of the entire Earth is a major undertaking, a focus on a smaller land mass, an island, becomes more tractable. This hopefully serves as a more concrete and envisionable example of the importance of understanding our environment and the role that humans play within it. For example, today many persons find it comfortable to deny global warming, despite the hard data showing temperature increases over the past decades (Hansen et al. 2010). The problem is too vast and the reasons for such an increase in temperature are too multifaceted to be convincing to some persons. An island, however, is much easier to visualize and contemplate. This is also a reason why many scientists find islands as suitable laboratories in which to examine patterns and processes of evolution in preference to continental regions.

Part I
The Archipelago

To appreciate the historical impacts on the ecology of the Juan Fernández Archipelago that will be presented in Chaps. 7–15, we first need to have an orientation to their present condition. This means knowing about the geography, geology and soils, climate and weather, flora, vegetation, and human settlements. These aspects provide a picture of what the islands are like physically, as well as of the plants and vegetation that now grow there, plus the human residents. Chapter 2 presents an overview of this information.

In addition to sketching conditions within the Juan Fernández Islands, it is also important to highlight their political, ecological, and evolutionary significances. This archipelago has long been strategically valuable for Spain and later Chile, and there have been struggles for its political control. As for ecology, the vegetation of the island has been modified over the millions of years of its existence, and to understand the present ecological patterns requires investigating changes due to both natural and human factors. From an evolutionary perspective, the islands harbor many endemic species of plants, which have evolved within the archipelago and whose origins require explanations. This is the natural island laboratory so often mentioned by evolutionary and biogeographic biologists. Chapter 3 provides discussions of these important concepts, which sets the stage for more detailed information on the flora and vegetation in Part II of this book.

Chapter 2
The Island Setting

Most all oceanic islands are very attractive. The blue water, green vegetation, and bright beaches combine to beguile the visitor. That tourism is one of the major pillars of the economy of many island nations, such as Hawaii or Tahiti, attests to the continuing lure of oceanic islands. One can imagine the anticipation of sailors, after barely surviving a hazardous voyage around Cape Horn, to suddenly be viewing a tranquil green and beige landscape with a protected harbor. Although the Juan Fernández Archipelago has very little to offer in the way of accessible sandy beaches, the islands are still undeniably appealing (Fig. 2.1).

The Juan Fernández Archipelago is located in the SE Pacific Ocean at 33°S latitude (Fig. 2.2). There are two major islands, Robinson Crusoe Island, which lies 667 km west from the Chilean coast and Alejandro Selkirk Island, 181 km further west. Off the SW coast of Robinson Crusoe Island, about 1 km, lies the smaller Santa Clara Island, which was likely connected to the former during initial volcanic formation as well as possibly during lowering of sea level during the Pleistocene (Sanders et al. 1987). These islands are small, with Alejandro Selkirk Island being the largest at 50 km^2, Robinson Crusoe Island 48 km^2 and Santa Clara Island only 2.2 km^2. As for elevation, these same islands reach to 1,319 m, 915 m and 350 m, respectively (Stuessy 1995).

The names of these islands have changed over the years, and a short explanation is in order. The discoverer of the easternmost island, Juan Fernández, called it Santa Cecilia after the name of the saint on the day of discovery (22 November 1574; Medina 1974). Other voyagers, however, soon referred to the entire archipelago as the Juan Fernández Islands, and this has been the historical label most used until the second half of the twentieth century. The easternmost island was called descriptively Más a Tierra (often written Masatierra; "closer to the land [continent]") and the one westward Más a Fuera (or Masafuera; "further away"). The Chilean government officially renamed the islands the Robinson Crusoe Archipelago in 1962, primarily to stimulate tourism. Masatierra was officially renamed Isla Piloto Robinson Crusoe,

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Fig. 2.1 Robinson Crusoe island in the Juan Fernández Archipelago. Southwesterly view from Cerro Agudo

commonly referred to as Robinson Crusoe Island, and Masafuera was officially designated Isla Marinero Alejandro Selkirk, or Alejandro Selkirk Island.

The renaming of the islands was not as inappropriate as it might seem, because there was a connection with Robinson Crusoe of Daniel Defoe's famous novel of 1719. In February of 1704 a Scottish sailing master, Alexander Selkirk, arrived near the islands aboard the ship *Cinque Ports* under command of Thomas Stradling (Woodward 1969). Selkirk and Stradling got into a dispute, such that Selkirk demanded to be left off the ship and remain on the island, which at that point Stradling was pleased to allow. Although many ships visited the islands in ensuing years, Selkirk was always wary of being picked up by an enemy of Scotland or England and thrown into prison, such that he remained undiscovered until finally on 2 February 1709 he made contact with British ships (Mégroz 1939). Two years later he arrived in England, and because of his fascinating experiences, he was interviewed by many journalists. There is no evidence that Daniel Defoe actually spoke with Selkirk, but in any event, the reports available served as material that led to Defoe's book *Robinson Crusoe* published in 1719, still available in bookshops today.

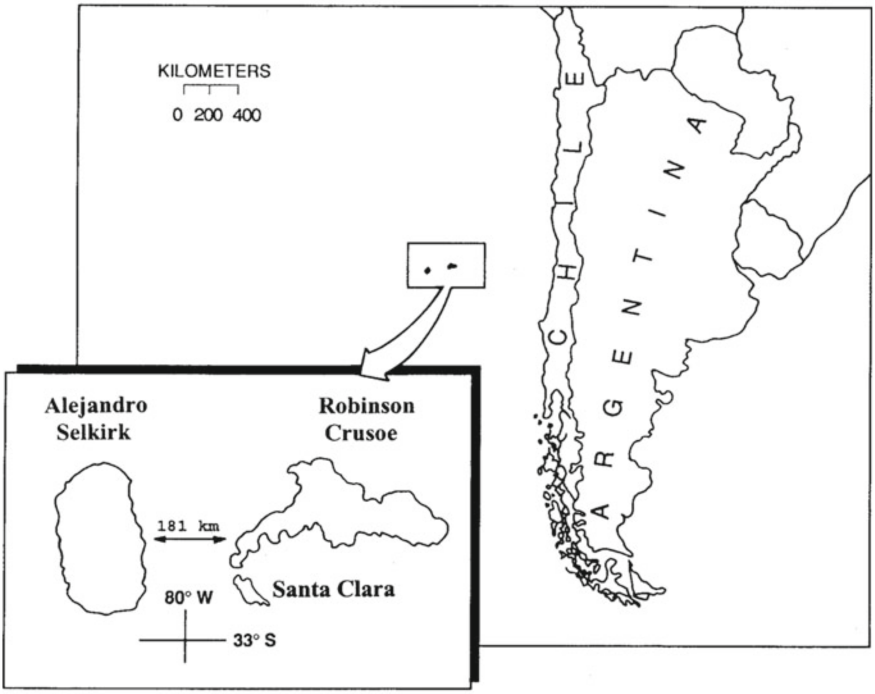

Fig. 2.2 Map of the Juan Fernández Archipelago in the southeastern Pacific showing the three major islands

2.1 Geology and Soils

The Juan Fernández Archipelago is completely volcanic, having originated from a submarine hotspot on the Nazca Plate (Baker et al. 1987; Huene et al. 1997), now located c. 100 km west of Alejandro Selkirk Island. At that spot beneath the ocean is a submarine volcano, called Friday Seamount, which is presumably the present location of the original hotspot that gave rise to the existing archipelago (Devey et al. 2000; Fig. 2.3). Between Alejandro Selkirk Island and Robinson Crusoe Island are additional seamounts, as there are also eastward from Robinson Crusoe Island toward the Chilean continent. Important is that as far as we know, none of these seamounts has ever been above the surface of the ocean. The largest is Guyot (seamount) O'Higgins, 135 km E of Robinson Crusoe Island and now more than 300 m beneath the ocean. Because these seamounts are on the Nazca Plate that inclines downward toward the Chilean coast, and eventually is subducted under it, they get dragged deeper as they travel eastward at c. 6 cm/year (Minster and Jordan 1978). In every oceanic archipelago, it is of interest to learn if ancient seamounts could have served as stepping-stones for the colonization of the flora of the islands. Although it is impossible to exclude such a possibility for the Juan Fernández Archipelago, at present

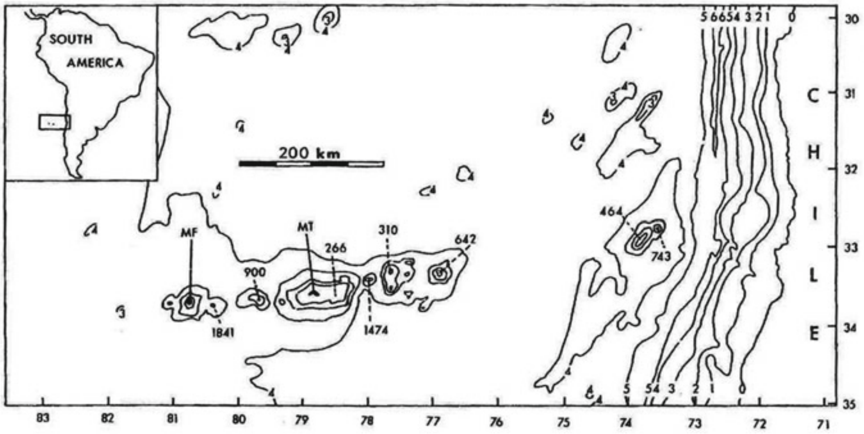

Fig. 2.3 Bathymetry of the southeastern Pacific Ocean, indicating the Juan Fernández Archipelago on the Nazca plate and with submerged seamounts (guyots; numbers indicate depth in meters under the sea to the highest submerged point). MF, Masafuera (= Alejandro Selkirk Island); MT, Masatierra (= Robinson Crusoe Island). Data from Mammerickx and Smith (1978) and Prince et al. (1980); from Stuessy et al. (1984a)

there is no evidence that this occurred. Further, for such a chain of ancient islands to have served as stepping-stones for the present two islands, they would have to have been exposed at the same time. Evidence is again lacking.

The ages of the islands in the Juan Fernández Archipelago were originally believed to be from the Eocene (Brüggen 1950), largely because of the occurrence of Lactoridaceae and Thyrsopteridaceae, ancient families of flowering plants and ferns, respectively. Modern investigations with K-Ar radiometric methods have revealed much younger ages for the two islands, and several laboratories have reached similar conclusions (Table 2.1). Robinson Crusoe Island is approximately 4 million years old and Santa Clara Island is similar, but Alejandro Selkirk Island is much younger at approximately 1 million years.

The older date of 2.4 million years for Alejandro Selkirk Island was reported by Stuessy et al. (1984a) from a rock sample from Chorro Doña María on the SSE

Table 2.1 Radiometric dating (K-Ar) of rocks from islands in the Juan Fernández Archipelago, in millions of years

Reference	Alejandro Selkirk	Robinson Crusoe	Santa Clara
Booker et al. (1967)	0.85–1.3	3.1–3.5	
Ferrara et al. (1969)	0.87–1.3	2.0–3.9	
Stuessy et al. (1984a)	1–2.4	3.8–4.2	5.8 ± 2.1
Baker et al. (1987)		4.0 ± 0.2	
Lara et al. (in prep., cited in Astudillo 2014)	0.93 ± 0.02	3.85 ± 0.15	

coast of the island. The other dates for this younger island range from 0.85-1.3 million years, or an average of 1.1. These data suggest that Alejandro Selkirk Island is most likely about 1 million years old, which corresponds with its geomorphology with deep and narrow valleys (quebradas). Another check on this age comes from considering the distance between the two islands (181 km). At the hypothesized rate of plate movement of 6 cm/year (Minster and Jordan 1978), dividing 181 km by this rate yields approximately 3 million years, or the difference in ages between the two islands. Assuming that the rock sample from Doña María was accurately dated, it may represent volcanic uplifting of an older rock that was laid down from the hotspot prior to the formation of the present island.

From a biogeographic and evolutionary perspective, knowing the geological ages of the present islands is fundamental for the construction of hypotheses. Because Robinson Crusoe Island is the oldest and closest to the South American continent, it would be the likely site of colonization for plant propagules. Because it is the oldest island, more time has existed in which evolutionary processes could have taken place. It is definitely the case that more intra-island speciation has occurred on Robinson Crusoe Island in contrast to Alejandro Selkirk Island. In fact, the largest endemic genera, *Dendroseris* and *Robinsonia*, both of family Asteracaae, have eight and seven species, respectively, on the older island. The largest set of endemic species (five) on Alejandro Selkirk Island occurs in *Erigeron*, also of Asteraceae, but these have not diverged morphologically to such an extent to be designated taxonomically as an endemic genus.

The surface layers of all islands of the Juan Fernández Archipelago consist of volcanic rocks and eroded lava. The backbone of both major islands is made up of basaltic ridges, which are most clearly evident on Robinson Crusoe Island because erosion over a longer period of time has left them more exposed. These areas are resistant to water and wind erosion, but most of the surrounding areas are of ancient lava and ash, both of which degrade more quickly over millions of years. The layers of strata on Robinson Crusoe Island consist of nepheline to alkali basalts, olivine and quartz tholeiites, and hawaiites (Baker and Keyvan-Scocouhi 1982; Gerlach et al. 1986; Farley et al. 1993). The younger Alejandro Selkirk Island contains numerous olivine-rich dikes (Natland 2003), called masafuerite by Johannsen (1937).

The present soils of islands of the archipelago consist of different types, such as dark brown forest soil, gravelly humus soil, weathered basaltic fragments and humus particles mixed together, and yellowish-reddish sand with fragments of rock (Skottsberg 1953a; Quensel 1954). Ortiz R. (1982: 100-134, plus Anexo 1) carried out numerous analyses of soils but only from Robinson Crusoe Island. This survey emphasized the serious soil erosion that has taken place in several places of the island. In fact, only c. 38% of the total surface of Robinson Crusoe Island has no apparent erosion (Ortiz 1982). This is not surprising, because when the vegetational cover is removed, the friable volcanic soil is easily eroded by wind and water. In general, as one goes from sea level to higher elevations on the two major islands, there is more precipitation, the vegetation becomes denser, and the organic layer in the soil increases.