Unraveling Korea's Mysterious Ulleung Island:

Human Impacts on the Forest Understory of a Temperate Island in the Sea of Japan

by

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ABSTRACT

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Oceanic islands are biologically important for their unique assemblages of species and high levels of endemism. These ecosystems are also sensitive to environmental change because of their isolation and small species source pools. Habitat destruction caused by human landscape development is generally accepted as the main cause of extinction on islands, with exotic species invasion a secondary cause of extinction, especially on tropical islands. However, secondary impacts of human development (e.g. general degradation through resource use and exotic species introduction) are understudied on temperate islands. This thesis serves as a case study of forested ecosystems on a temperate island, Ulleung Island, in the Sea of Japan, to determine secondary impacts of human development on the understory vegetation community, a proxy for ecosystem health. Diversity and percent cover of introduced, native, and endemic species were tested against proximity to developed areas and trail usage using parametric and nonparametric methods. The overall finding was that these secondary effects from human activities do impact the understory vegetation community, but only slightly. Additionally, there are no apparent locally invasive plant species on the island at the time of this study. The findings indicate that while there are some human-caused secondary effects on the forest understory, these effects do not pose an immediate threat to these ecosystems. Costly restoration is likely not necessary for forests on Ulleung Island—and possibly analogous temperate islands—however, conservation efforts should focus on reducing habitat destruction from development and educating tourists visiting the island.

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Introduction

Human colonization and landscape development of oceanic islands has caused a loss of global biodiversity through habitat loss and competition with and predation by exotic, introduced species. This loss of biodiversity is due to the extinction of endemic species, or species that are found across a limited geographic range. Because of the isolation inherent to islands, these species have small or nonexistent source pools and limited ability to migrate when their habitat becomes inhospitable. The fragility of island ecosystems and their species is important to research in order to understand the underlying processes of human-caused extinction and to better inform management decisions to preserve at-risk species.

The primary goal of this thesis will be to examine indirect and direct human influence on a temperate forest island ecosystem through a case study of Ulleung Island, South Korea, in the Sea of Japan. The thesis will begin with a review of the literature, then continue on to study area and methods, and conclude with results and in-depth analysis and implications of those results, with suggestions for future research and management.

Literature on islands and island ecology

Literature on oceanic islands and their importance in biological research is abundant and ranges from general theory (MacArthur and Wilson, 1964; Carlquist, 1974) to case studies of species and ecosystems (Vitousek et al., 1995) to discussions of threats to conservation (Denslow, 2003; Sax and Gaines, 2003; Sax and Gaines, 2008). Island ecosystem processes and species assemblages are often more simplified than those found in analogous continental ecosystems, which makes them ideal areas for ecological study (Vitousek et al., 1995; Wardle, 2002; Vitousek, 2002). Because of their isolation, they are also prone to having higher percentages of endemic species than mainland areas and often have unique assemblages, making them biologically important as well as scientifically important (Adsersen, 1995; Eliasson, 1995).

Although there is consensus within the literature on island biology that habitat destruction caused by human development is a leading cause of biodiversity and species loss, opinions on the effect of secondary impacts are more varied. These secondary impacts of human colonization include predation by and competition with introduced exotic species, degradation from use of resources in the proximity of human development, increased edge effects caused by habitat fragmentation, and range shifts and limitations caused by climate change. While habitat loss caused by development has been determined the primary cause of species and diversity loss, invasion and fragmentation likely influence diversity and species as well, and are thus relevant to this thesis.

The research presented in this thesis will examine secondary impacts of human development, with a focus on the introduced species and degradation from proximity to human activity, and will briefly cover edge effects. Further, this study focuses on a temperate forest understory as a proxy for community composition and ecosystem health.

Study Area: Ulleung Island

The study area, Ulleung Island, South Korea, located in the Sea of Japan, is excellent for a case study of the secondary impacts of human activities on a temperate forest island ecosystem. It hosts a high diversity of vascular plants—up to 685 taxa (Jung et al., 2013)—and a high number of endemic vascular plants—up to 33 taxa (Yang et al., 2015). For the purposes of this thesis, 'taxa' will refer to the lowest level of classification of an organism (e.g. species, subspecies, form, etc.). The island has also been subjected to varying levels of development by humans in different areas, which creates a gradient of human impact on the island's ecosystems.

Although studies have been conducted on distributions of native and introduced plant species on Ulleung Island, there has not been a study focused on the impacts of introduced species and degradation through human proximity on the native and endemic species of the island. This thesis study will examine these impacts on Ulleung Island, and in doing so will contribute to the literature on temperate island ecology and conservation.

Hypotheses and Expectations

The primary goal of this thesis research is to determine the impacts of human land development on native vegetation communities on a temperate island, using Ulleung Island as a case study. The expectation is that there are differences in the vascular plant communities across the island, based on proximity to and magnitude of human development. Therefore, the objective of this thesis is to determine the existence and extent of these impacts on the forest understory plant community on Ulleung Island. The main hypotheses are threefold.

First, the site factors ‘Distance to Development,’ ‘Distance to Town,’ and ‘Trail Usage’ will impact the site diversity and percent cover of introduced, native, and endemic species. This would mean that one or more of these factors would be included in the selected model for predicting site diversity and percent cover of each plant group. The reasoning for this prediction is that areas closer to development are exposed to exotic species from human activities, and these areas are more likely to be cleared for agricultural or other purposes. Invasive introduced species are often opportunistic and crowd out native species where sunlight is plentiful, so open areas may be more susceptible to invasion by exotic species. Native and endemic species as well as diversity would be impacted negatively by proximity to development, towns, and trail usage due to general degradation from human activities. The null hypothesis is that none of the selected site factors—‘Distance to Development,’ ‘Distance to Town,’ and ‘Trail Usage’—are included in any model for diversity or percent cover of introduced, native, or endemic species, or that there is no significant model for the dependent variables.

Second, native and endemic cover and biodiversity will decrease as introduced species cover increases. If there is a correlation between these factors, it is likely that the introduced species are impacting native communities, meaning some form of control is needed. The null hypothesis is that there is no correlation between introduced species and diversity and native/endemic species cover.

Third, community composition will be affected by one or more of the selected site factors—'Distance to Development,' 'Distance to Town,' 'Trail Usage.' Human activities may cause alterations or significant shifts in community composition. The null hypothesis is that no site factor will predict community composition.

Overview of methods

The methods used in this thesis study are predominantly quantitative, with limited qualitative observations used in discussion of the results. More specifically, these methods include vegetation sampling of the forest understory, use of GIS software to map island vegetation and data points, and statistical analyses of habitat features and community structures. Data was collected on Ulleung Island in the summer of 2016 at 90 field sites with a total of 270 1-meter squared sample plots.

Independent factors included habitat parameters and distance to development for each site, and introduced species cover per plot. Dependent factors included plant diversity and introduced, native, and endemic species cover per site, and plant diversity and native and endemic species cover per plot. The expectation is that distance to development will have a relationship with diversity and introduced, native, and endemic cover site-to-site, while introduced species cover will have a relationship with diversity and native and endemic cover within individual plots. The statistical importance and effect of each site factor will be determined through ordinary least squares regression, and different candidate models will be evaluate using a model selection approach.

Implications of the study

General findings from this thesis include the following. First, factors associated with human development—including distance to development, distance to town, and trail usage—are included in each of the best supported models, indicating some level of influence on the understory community. Second, introduced cover has an inverse correlation with distance to development, meaning that the highest concentrations of introduced species are close to developed areas. Third, species diversity correlates negatively with four of six tested native and introduced species. This includes the Black locust tree (*Robinia pseudoacaia*) which may have the potential to become invasive. Fourth, while human development did not have any effect on community composition, two of ten community types had introduced species as indicator species. Lastly, introduced species cover did not have any correlation with either plot diversity or endemic species cover. All results indicate that there are no locally invasive plant species on Ulleung Island at the time of the study.

These results indicate that secondary impacts of human activity may have some effect on the species and diversity of Ulleung Island forest ecosystems. Some of the statistical weakness of these results may be attributed to the random nature of community ecology, but it is likely that secondary human impacts are not yet degrading these ecosystems, even those close to development. If this is the case, habitats and their reliant species on Ulleung Island could be easily preserved by limiting development and complete habitat destruction. Costly restoration efforts could therefore be avoided altogether without degrading ecosystem function or causing the extinction of endemic species.

Ultimately, the long-term goal of this study is to determine changes over time of the vegetational community on Ulleung Island. Tracking changes due to further development and climate change can provide insight into these factors' effects on community ecology, and as an extension, ecological health. This initial research will serve as a baseline study for future research and will provide methods for ecosystem study specific to rare endemic species on the island.

Literature Review

Islands have long been recognized for their importance in ecological and evolutionary research. By studying islands, scientists and naturalists have made strides in understanding processes that shape ecosystems and create new species. As important as they are for studying and understanding ecological functions, islands are equally important as biological and genetic resources. Isolation and subsequent evolution of island species often leads to high percentages of endemic species, especially on islands that are highly isolated (Adsersen, 1995; Eliasson, 1995). Because of this isolation and lack of regional species source pools, island ecosystems can be more susceptible to environmental change and stochastic events which can cause species extinction and affect ecosystem equilibrium. This is becoming especially relevant with increased human influence on natural ecosystems, in terms of both direct and indirect influence. Direct influence may include habitat loss through human development, while indirect influence includes gradual ecosystem change or stochastic events brought on by human induced factors such as exotic species introduction, increased edge effects, or climate change.

One long-term goal of the research presented in this thesis is to provide a baseline for measuring possible effects of anthropogenic climate change on vegetational communities. This thesis will be predominantly focused on 1) indirect human influence, specifically on exotic species and ecosystem alteration caused by human presence and development and 2) oceanic islands, rather than islands created by fragmentation or other insular ecosystems such as streams or caves.

This review of the literature will examine the importance of island ecosystems for ecological research, direct human influence on islands in terms of development, and invasion ecology with a focus on islands. It will conclude with an argument for the importance of research on the selected study ecosystem on Ulleung Island and a justification for studying the herbaceous layer of the forest understory.

Importance of islands and their ecological study

Islands are scientifically and ecologically important for a variety of reasons. For scientific study, islands can serve as model ecosystems where ecological and evolutionary processes are easier to observe because they are often simpler than on continental ecosystems (Vitousek et al., 1995; Wardle, 2002; Vitousek, 2002). Islands are also important as biological resources because they support high levels of endemism, biodiversity, and genetic diversity.

In ecological research, islands have been used as model ecosystems to study complex ecological functions. Because of their small size and isolation, island ecosystems usually have fewer species (MacArthur & Wilson, 1964; Vitousek et al., 1995) and are often simpler than comparative ecosystems on continents. Understanding of ecological and evolutionary processes can be used to identify important processes support theory development and test limits of models. (Vitousek et al., 1995). Additionally, using environmental gradients on and between islands can further understanding of these processes (Vitousek, 2002).

Ecologically, the isolation inherent in island ecosystems encourages radiative and anagenetic evolution. Radiative evolution involves two or more species evolving from one parent species, while anagenetic evolution occurs when a single species evolves from the parent species, often resulting in higher genetic diversity (Stuessy et al., 2006). These evolutionary processes result in high percentages of endemic species, so much so that endemism can even be an indicator of an island's isolation (Adsersen, 1995). Island species, particularly endemic island species, generally have small populations, restricted genetic diversity, and narrow ranges (Vitousek, 1988). Because endemic species only occur across a limited geographic range, they are more susceptible to range decline and extinction from anthropogenic influence (Vitousek, 2002). Furthermore, rareness on the landscape is far more frequent in endemics than in other native species. Thus, rare endemics are "three times more vulnerable" than natives to range decrease and extinction from anthropogenically introduced plants and animals (Adsersen, 1995). With human alterations and destruction of the landscape reducing already-limited critical habitat, it is crucial to understand environmental factors and processes affecting the survival of rare endemic species in order to conserve them.

Depending on location, climate, size, and isolation of the island, islands can accumulate unique assemblages of species that differ from those on continents, often very substantially. Island ecosystems are also more vulnerable to environmental change and stochastic events than are continental ecosystems (Vitousek, 1988; Vitousek, 2002; Denslow, 2003) and so striving to understand and preserve them is crucial. This review of the literature will further explore the invisibility of islands and the potential threats of exotic species.

Human influence and invasion ecology on islands

Habitat destruction caused by human development has been a primary cause of species extinctions around the world, and this effect is disproportionally greater on islands (Vitousek et al., 1995; Sax and Gaines, 2008). The main causes of extinctions on islands include habitat destruction by deforestation and fire, introduced grazing mammals, cultivation of crops, and introduced exotic plant species (Heywood, 1979; Vitousek, 1988). Furthermore, anthropogenic alteration of the landscape can lead to fragmentation of the native ecosystem, which creates further detriment to native species and their habitats.

Much of the literature on island invasion ecology contends that islands are more invasible than comparative continental ecosystems, for plants at least (Lonsdale, 1999; Vitousek, 1988; Denslow, 2003). For the purposes of this thesis, invasibility will be defined as the susceptibility of an ecosystem to significant alteration by exotic, invasive species. Island ecosystems may be more invasible than continents because of low native diversity, missing functional groups, communities that have yet to reach equilibrium, and low existing pressures for competition (Denslow, 2003).

Vitousek et al. (1995) states that “the contention that islands inherently have low biotic resistance to invasion has not been well tested.” Although island biodiversity is well-understood within the scientific community, human impacts on island plant species are understudied. Particularly, invasion by exotic species is a gap in existing research (Sax and Gaines, 2008). The effects of plant species saturation and replacement of native species by non-native species are also understudied. The proposed project will fill this knowledge gap by determining how plant species diversity responds to human influence by focusing on disturbance and invasion by exotic species.

Most research aimed at understanding human effects on islands are related to habitat loss and invasion by exotic animals and their subsequent impact on the island ecosystem. This is demonstrated by Vitousek et al. (1995). The 1995 book is an excellent overview of island biology with case studies, however many of the referenced case studies focus on animal species on islands. Exotic animals can impact island communities by outcompeting or predating native island animals, or changing vegetation communities through feeding habits. However, it is also important to study the effects of exotic plant species because they can alter vegetation communities by outcompeting native plant species, which decreases biodiversity. Exotic plant species can also alter habitat quality, including soil chemistry, which can cause changes in community structure. This can lead to reduced habitat for native plant and animal species, especially those that are highly specialized, and reduces ecosystem resilience to recover from stochastic events.

Some research is aimed at understanding the impact of invasive species on native species in tropical island ecosystems (Denslow, 2003; Rejmanek, 1996; Simberloff, 2000; Mack et al., 2000). A notable review of this impact in tropical islands by Denslow (2003) relates that tropical islands in particular are extremely susceptible to invasion by exotic plant species, especially with the added effect of human-related disturbance. Although this article is an excellent review of the invasibility of *tropical* island ecosystems, there are few if any studies that specifically address *temperate* islands and their invasibility by exotic vegetation.

A broader understanding of human impacts on temperate island ecosystems is important because they are biologically diverse ecosystems that have restricted gene and species flow and are therefore more susceptible to endemic species extinctions and ecosystem change than mainland sites. Nevertheless, the effects of human influence on these sensitive ecosystems are understudied. Accordingly, this study will contribute to the knowledge of other ecologically diverse temperate island ecosystems by looking at biodiversity and composition of the understory plant community on the study island.

How big of a deal is invasion by exotic plants?

Although some sources argue that invasion by exotic species is detrimental to native species (Adsersen, 1995; Ricciardi, 2004; Vitousek, 1988), others claim that competition from introduced exotic species does not significantly affect the diversity of the native community (Denslow, 2003; Sax et al., 2002; Sax and Gaines, 2008). In theory, competition and alteration of the native ecosystem by an exotic plant species could cause harm to native species and communities. However, case studies of island diversity have not indicated any change in local species richness at least. This section will further explore both sides of this argument and identify a crucial gap in the methodology for the conclusion that introduced species do not significantly alter species diversity.

Competition is an important interaction to consider in the field of community ecology. Species compete for resources, which drives evolutionary processes. When non-native species are introduced to an area, they often compete with native species. In some cases, especially with opportunistic exotic species and poorly competitive native species, the introduced species can outcompete native species for resources. High resource availability on islands and poor ability of native species to take advantage of those resources are the biggest contributors to plant invasion on islands (Denslow, 2003). This can lead to a population reduction of the native species, or even extinction of those species. This becomes especially important on islands, where there can be high percentages of endemic species and restricted access to a species source pool (Vitousek, 1988). Indeed, a main ideology for community ecology is to preserve island ecosystems by allowing as few exotic species to naturalize as possible, as any alien species might be considered a contaminant to the native community (Adsersen, 1995).

There is abundant literature on invasion ecology on islands, largely focused on birds and other megafauna, documenting species extinctions proceeding human—specifically European—colonization (Vitousek et al., 1995; Drake et al., 2002). However, the effects of introduced plant species on native plant species and communities have been understudied because extinctions of plants species on islands have gone largely undocumented, and there is no noticeable trend in extinction for these species (Sax et al., 2002). To determine the effects of exotic species introduction on native island floras, Sax and Gaines (2008) examined data from the International Union for Conservation of Nature (IUCN) database. They found that there is little evidence for competition-based extinction in plants, and that on local scales, richness has increased for many islands. Indeed, many studies have found that invasion increases local diversity, while decreasing global diversity (Rosenzweig, 2001). Although invasive species may cause extinction to native species through competition, this loss in richness is outweighed, at least locally, by the addition of new exotic species to local communities (Sax et al., 2002; Vitousek, 1988).

Sax and Gaines' (2008) reasoning for the lack of large-scale plant species extinction is that species saturation may be unimportant for plant species, or may be unimportant at the current levels of diversity on islands. They argue that if saturation rates are in fact being approached on islands, the rates of naturalization (and subsequently invasion) should decrease, allowing native species to persist. However, they warn that if extinction just takes a long time for plant species, then many endemic and native species could be going extinct in the future.

It is important to note that many of the cited studies of species assemblages on islands only look at species richness (i.e. the number of species) and do not consider species diversity (i.e. biodiversity) (Sax et al., 2002; Sax and Gaines, 2008; Vitousek et al., 1995). Species diversity is a measure of number of species as well as abundance of each species in a community. Although richness data is easier to obtain and quantify than diversity, richness does not provide information on the rareness of species or the overabundance of others. An overabundance of introduced species on the landscape may not register as a loss in species richness if native species are still present but have had their populations severely truncated. Measuring biodiversity solves this problem by measuring abundance as well as number of species to more accurately determine impacts of overabundant species on rarer species. In this way, diversity is a better measure of ecosystem quality and community structure, and thus will be a main variable in this thesis.

Intention of this thesis within the study of island ecology

This thesis will examine the impacts of human proximity on biodiversity, native versus introduced species, and community composition. It will also seek to determine what effect, if any, the introduced species have on the native plant community. The proposed study is unique in that a similar study has not yet been conducted on Ulleungdo and will further contribute to ecological knowledge of this biologically important island.

Ulleung Island as a study area for ecological research

Ulleung Island, Gyeongsanbukdo, South Korea, is a small, isolated volcanic island located in the Sea of Japan. Ulleung Island, also known as Ulleungdo, is approximately 73 sq km in area (Yoon et al., 2013) and hosts 685 plant taxa, including 41 taxa of rare plants and 30 taxa of endemic plants (Jung et al., 2013). The high species richness (and presumed biodiversity) of the island makes it an excellent candidate for ecological study. In particular, studying human proximity impacts on biodiversity on Ulleung Island can illuminate the influence of anthropogenic activity on ecologically diverse temperate island ecosystems. Currently, there are 89 taxa of naturalized, or introduced, plants on the island (Jung et al., 2013), but their effect on the ecosystem has not been studied, so it is unknown whether any of the naturalized taxa could be considered invasive. Interestingly, there is one species that is controlled by cutting on Ulleung Island, Japanese knotweed (*Fallopia sachalinensis*), which is native (Andersen, 2015). However, the control for the species, predominantly in altered streams near towns, appears to be more for anthropogenic gain than for preserving biodiversity and ecosystem function.

Yang et al. (2015) provides a study of the presence and distribution of naturalized plant species on Ulleung Island. This article indicates problem areas of naturalized species (introduced species that have become integrated into the native plant community) around towns, which supports the hypothesis that human influence is a driver of the success of these species. However, this acts more as a species inventory rather than a controlled study of biodiversity, and therefore a more in depth study is needed to understand the community dynamics of naturalized, native, and endemic species.

From the review of the literature, there appears to be no or minimal vascular plant species loss on Ulleung Island (Jung et al., 2013; Nakai, 1919; Oh, 1978; Yang et al., 2015; Yoon et al., 2013). Currently, there are 9 taxa (or unique species/subspecies/forms) of ‘Critically Endangered’ plants, 6 taxa of ‘Endangered’ plants, and 12 taxa of ‘Vulnerable’ plants, as designated by the IUCN on Ulleung Island (Yang et al., 2015). However, it is unclear whether these taxa are designated because their populations were limited prior to human colonization and development or if their populations have been reduced primarily due to human activity. Further, the role of secondary impacts of development (competition with introduced species, habitat degradation, edge effects) on these taxa are unknown for Ulleung Island.

Importance of the understory and justification in this study

The research used in this thesis is focused on the understory plant community, so it is important to understand the significance of this layer in ecology, and on Ulleungdo specifically. Understory plant species provide a proxy indicator for ecosystem health, which is notoriously difficult to quantify in ecological study, and they are a resource for other organisms.

Gilliam (2007) addressed the importance of the herbaceous layer in temperate forest ecosystems. He analyzed the use of the concept in ecological studies and described the importance of this layer within temperate forest ecosystems. Gilliam argues that the herbaceous layer contains the majority of the plant biodiversity and plays a large role in ecosystem function. Furthermore, the response of the understory is an indicator for ecosystem response to disturbance, which includes both gradual environmental change and stochastic events. This response is also extended to what Gilliam describes as "chronic disturbances," which include but are not limited to introduction of exotic species. He further describes forests with closed canopies as generally resistant to plant species invasion, although he does write that "once exotic plants become established in the herb layer of a forest, they can rapidly become the dominant species, not only altering the species composition of the herb layer but also decreasing biodiversity."

Because forests on Ulleungdo fall within the category Gilliam presented (temperate forests), and because exotic versus native species are of particular research interest on the island, the previous statement by Gilliam forms the basis for the focus on the understory used in this thesis. One goal of this thesis research is to determine whether there are any species that can be considered invasive on the island, and if so, what can be done about them.

Study Area

The data used in this thesis was collected on Ulleung Island in South Korea, and as such, it is important to understand the ecological background and natural history of the island. The island's rich ecology and the impact of human development on its ecosystems make it an interesting case study and an excellent study area for research on human impacts on islands.

Background

Ulleung Island, Geyongsangbuk-do, is a small volcanic island off the east coast of South Korea in the Sea of Japan, or the East Sea as it is known in Korea (Figure 1). Lying 130km east of mainland South Korea, Ulleung Island has an area of 73 square kilometers and a human population of just over 10,000 as of 2015 (Ulleung-gun, 2017; Yang et al., 2015). There are 10 larger towns and numerous villages on the island, mostly concentrated around the coastline, as the interior of the island is very mountainous. One of the main industries on Ulleung Island is tourism. The focus of tourist visits to Ulleung Island is the nearby island of Dokdo, which is highly contested due to claims on the island by both the Japanese and Korean governments. Because of the intense nationalism present in Korean culture, this means that Dokdo and Ulleung Island (as the only access point to Dokdo) receive thousands of visitors per year, with most of these being native Koreans.

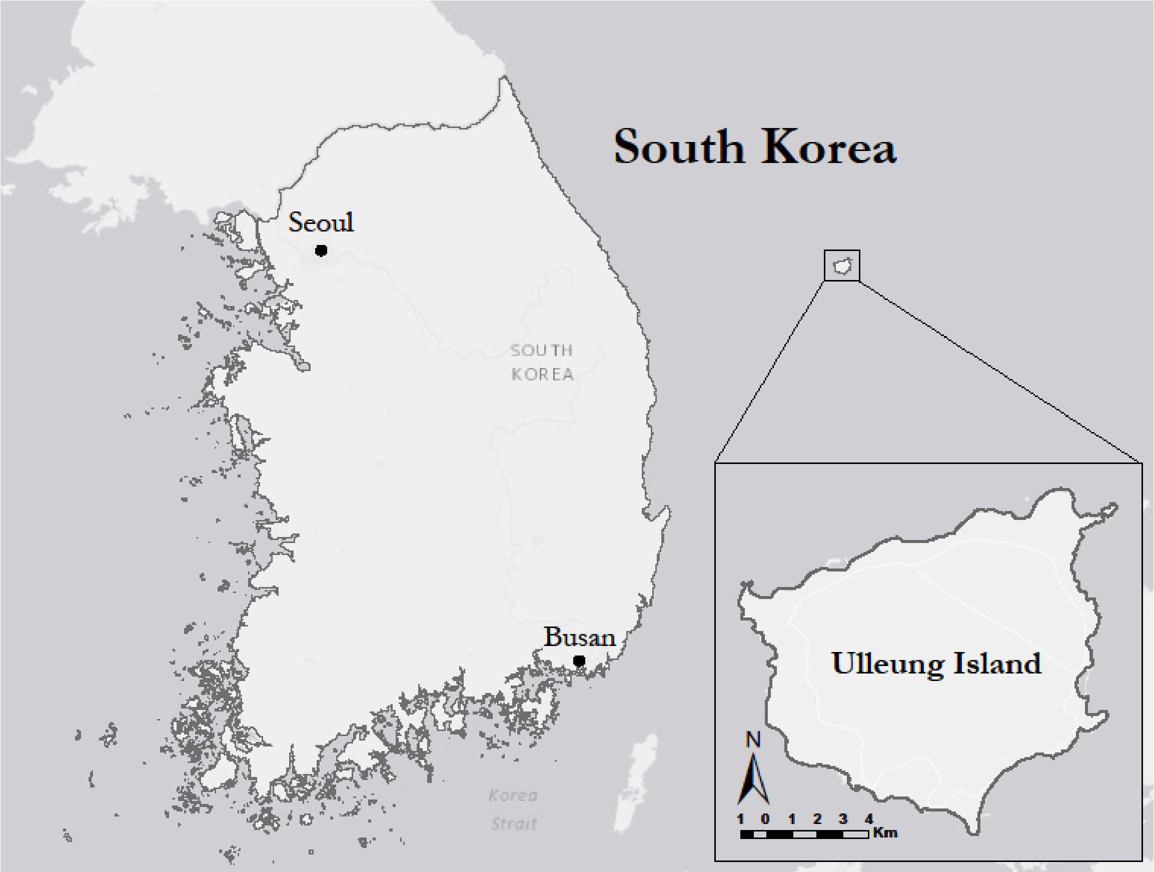

Figure 1: Ulleung Island in relation to the Korean peninsula

The island itself is an erupted caldera, with the highest point being Seonginbong (984 meters) and the only flat area being Nari basin in the center (Jung et al., 2013; Yoon et al., 2013). The island has an oceanic climate that is slightly subtropical below 400 meters and more temperate above 400 meters. Forests make up the majority of the terrestrial ecosystem on Ulleung Island, while sparsely vegetated sea cliffs fringe the edges.

Human history and impacts on Ulleung Island

Humans have inhabited Ulleung Island since about 1000 BC, with the first record of the island as a Korean territory being 512 AD during the Silla dynasty (Ulleung-gun, 2017). Throughout the island's history, its residents were forced to migrate to mainland Korea due to invasions and conflict between Korea and Japan. Around the time of Japanese occupation in Korea (1910), there were reports of Japanese colonization on the previously sparsely populated island ("Special Report Ulleungdo Situation," 1899). These colonists increased the rate of deforestation, after which the forests either reestablished naturally or were replanted, mostly with Japanese cedar (*Cryptomeria japonica*) or Japanese cypress (*Chamaecyparis obtusa*). Although these plantations do not cover a large portion of the island—they are only found in the southeast and central north coastal areas—it is important to note that vegetation under these stands is sparse and diversity is somewhat low (Andersen, 2015).

Currently, with a population of around 10,000, Ulleung Island has varying degrees of human encroachment into the natural forested ecosystems. The majority of the population resides on the margins of the island, and particularly in the southeastern portion in the town of Dodong. Apparent from a map showing forested and bare areas of the island (Figure 2) are varying levels of deforestation and fragmentation in different regions of the island. These variations make the island an excellent study area for research on human impacts on island ecosystems, especially since the residents of the island still rely on timber and non-timber forest products for food and other resources.

In addition to landscape alteration by the island's residents, heavy tourism and consequential use of trails create another aspect of human influence. For example, high-use trails are often highly maintained and have a degree of litter along them, while low-use trails are often overgrown and more representative of unaltered forest.

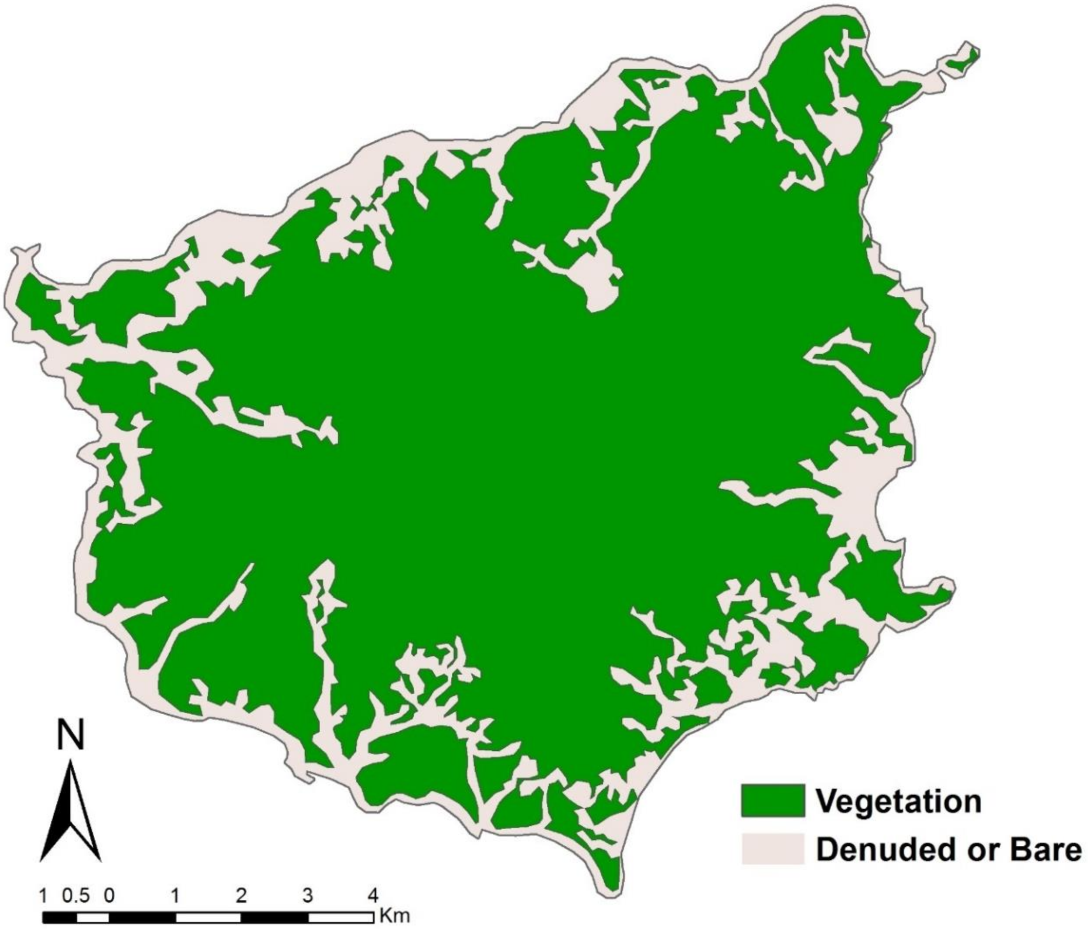

Figure 2: Forested and bare areas on Ulleung Island. Varying levels of development and undeveloped forest make Ulleung Island an excellent area to study human impacts on forested islands. This map was created by digitizing NVDI calculations of Landsat raster datasets from 2012.

Natural History of Ulleung Island

Ulleung Island has diverse forests with species native to both Korea and Japan. Although the island is highly isolated from both Korea and Japan, plant species diversity is very high, and there is a high level of endemism. There are 685 taxa of vascular plants that have been recorded on the island (9.384 taxa/km sq) and 30 taxa of endemic plants (0.411 taxa/km sq; Jung et al., 2013). For reference, the Korean island of Jeju has 1990 total taxa (1.077 taxa/km sq) and 90 endemic taxa (0.049 taxa/km sq; Kim, 2009), while the Galapagos islands have 550 total taxa (0.069 taxa/km sq) and 179 endemic taxa (0.022 taxa/km sq; Mauchamp, 1997). The high numbers of these species make Ulleung Island an important biological resource that has great potential for biodiversity research.

Most of Ulleung Island is forested with rocky cliffs bordering the whole island and human settlements along the edges where streams have carved land suitable for development. Some of the land closer to the towns has been cleared for agriculture and livestock. Within the forests, there are three loosely identifiable ecosystem types differentiated by canopy. Community analysis shows no strong correlation between canopy type and community composition, so these differences are mostly aesthetic (Andersen, 2015). The following natural history descriptions are partially based on *Nature Guide to Ulleungdo* (Andersen, 2015) and on other observations by the author while conducting research on the island during the summers of 2013 and 2016.

Forested Ecosystems

The lower elevation coastal forests of Ulleung Island (<200 meters) have canopies largely dominated by conifers and broadleaf evergreens (Figure A1). The most common canopy forming species is the Japanese Red Pine (*Pinus densiflora*). The plant community under these forests can be very thick with vines, shrubs, and bamboos. Where the canopy is thick or where larger shrubs create a subcanopy, a layer of needles and the lack of sunlight can create very sparse understories. Several plantation forests of Japanese cedar and Japanese cypress on the island have almost bare understories possibly due to the homogenous canopy and densely replanted trees.

Between 200 and 600 meters, the forest canopy tends to be mixed to deciduous and the understory is usually dense with herbaceous plants (Figure A2). The climate here cools slightly, and overall the canopy and understory are not as thick as the coastal forests. Several later succession conifer species can be found in these forests in both the canopy and understory. Some stands with species—which include yew (*Taxus baccata* var. *latifolia*), white pine (*Pinus parviflora*), and hemlock (*Tsuga sieboldii*)—have natural monument designations. It is also in these forests that the canopy is most diverse, with the possibility of both conifer and broadleaf tree species forming the canopy.

The highest elevation forests above 600 meters often have few broadleaf deciduous species forming the canopy, and dense, low-lying understories (Figure A3). Many of the canopy-forming species here—beech (*Fagus multinervus*), maple (A*cer okamotoanum* and *A. takeshimense*), and linden (*Tilia insularis*)—are considered endemic to Ulleung Island. The understory is sometimes dominated by large swaths of a single species, including the fern species *Rumohra standishii* and *Polystichum retrosopaleaceum*. Shrubs are sparse in these forests, and several endemic herbaceous species – including *Lilium hansonii* – are prevalent.

Vascular Plants

Of Ulleung Island's 685 recorded vascular plant taxa, 30 are considered endemic while 26 are listed as critically endangered, endangered, or vulnerable by the IUCN. Many studies focus on genetic lineages of Ulleung Island plant species to determine how genetically different the endemic species on the island are from the mainland progenitor species (Gil et al., 2011; Gil & Kim, 2016; Ku et al., 2004; Oh et al., 2016; Oh et al., 2010; Sun et al., 2011). There is special concern for rare endemic species—particularly *Scrophularia takesimensis* (Figure A5) and *Bupleurum latissimum*—and some studies focus on documenting their populations and ecological requirements (Ahn & Lee, 2007; Ahn, 2005; Choi et al., 2012). Although these two species are well-documented, there is almost no literature or study on status and ecological requirements of some of the other critically endangered endemic taxa such as *Cotoneaster wilsonii* (Figure A6), *Abelia coreana* var. *insularis*, *Corydalis filistipes*, and *Spiraea insularis*. Other endemic species and lower taxa of plants on Ulleung Island include *Poa takesimana* (Figure A4), *Veronica nakaiana* (Figure A7), *Syringa patula* var. *venosa* (Figure A8), *Phytolacca insularis* (Figure A10), and *Lilium hansonii* (Figure A11).

Some notable native plants on Ulleung Island include *Schizophragma hydrangeoides* (Figure A12), *Gymnadenia camtchatica* (Figure A13), *Taxus baccata* var.

latifolia (Figure A14), *Thymus quinquecostatus* (Figure A15), and *Phellodendron amurense* (Figure A9).

In addition to the numerous native taxa, Ulleung Island also has 89 taxa of naturalized plants (Jung et al., 2013). Many of these have become integrated into the natural ecosystems of the island and are even common in some lowland regions (Andersen, 2015). Some naturalized taxa were introduced accidentally whereas others have escaped from cultivation. Although there are no obviously invasive plants among the naturalized taxa, some of them may have the potential to become invasive or at least to alter the island's ecosystems or plant communities. Examples of these introduced species are *Amorpha fruticosa* (Figure A16), *Sonchus oleraceus* (Figure A17), *Boehmeria nivea* (Figure A18), *Erigeron annuum* (Figure A19), *Robinia pseudoacacia* (Figure A20), *Fallopia dumetorum* (Figure A21), *Houttuynia cordata* (Figure A22), *Ipomoea purpurea* (Figure A23), and *Phytolacca americana* (Figure A24).

For example, the tree *Robinia pseudoacacia* (Figure A20) has become incorporated into lowland forests (Andersen, 2015). This may pose a problem because as a leguminous tree, *R. pseudoacacia* can add nitrogen to the soil through nitrogen fixation in the roots. Currently the only other forest species that do this on Ulleung Island are *Alnus sibirica* and *Alnus maximowiczii*. The shrub species *Amorpha fruticosa* (Figure A16) similarly contributes nitrogen to the soil, but it is usually only found in open lowland areas. Alternatively, the herbaceous species *Phytolacca americana* grows along streams, and although it is still sparse on Ulleung Island, *P. americana* has the ability to propagate rapidly and alter stream ecosystems.

Animals

Although the plant community on Ulleung Island is incredibly diverse, it is also important to note the animals that inhabit the island, birds in particular. As of 2013, there have been a total of 112 bird species recorded on and around the island (Yu et al., 2013).

The island has particularly important habitat for species that are restricted to oceanic islands. Styan's Grasshopper Warbler, which is classified as vulnerable by the IUCN, breeds exclusively on small islands (Nagata, 1993) and is found in grassy areas and thickets on Ulleung Island. The Japanese Wood Pigeon (Figure A25), is only found in mature forests on oceanic islands in East Asia (Seki et al., 2007). On Ulleung Island, it nests in the Japanese camellia (*Camellia japonica*) and feeds on the fruits of silver magnolia (*Machilus thunbergii*), mountain ash (*Sorbus commixta*), and glory bower (*Clerodendron trichotomum*) (Cha et al., 2010). The Japanese Wood Pigeon, which is a designated natural monument on Ulleung Island, has an estimated population between 30 and 40 individuals. However, during data collection for this thesis, the Japanese Wood Pigeon was observed across the island, sometimes in large flocks of up to two dozen individuals, so the population may have grown or may be larger than previously estimated.

Ulleung Island has no native large mammals but humans have introduced two that historically have been detrimental to island ecosystems (Heywood, 1979). These are the house cat and the goat. House cats are very common on the island—especially in Dodong-ri—and they can even be spotted at the highest peak on the island, Seonginbong (Andersen, 2015). As predatory animals, house cats can devastate native bird populations. Goats can also alter island ecosystems through grazing native vegetation, and there are several free-roaming herds on Ulleung Island that graze around the rocky sea cliffs.

Methods

Site Selection and Mapping Methods

Before data collection, points were randomly selected in QGIS 2.6 Brighton using previously collected trail tracks. Using points along established trails allowed for selection of field sites that were accessible. For the purposes of this thesis, a site is a survey location represented by a single GPS point made up of three 1 meter squared plots, or quadrats.

Field data was collected on Ulleung Island during three weeks in June and July of 2016. Because of Ulleung Island's treacherous terrain, there is little opportunity for off-trail data collection, especially when collecting alone. The terrain also led to the need for modifying or adding survey locations in the field where conditions were unsafe or where trails were closed. When this was the case, new survey locations were chosen at 100, 200, or 300 meters from the nearest established survey location based on the need for extra survey points on a certain trail or under a certain canopy type. This resulted in 30 plots under broadleaf deciduous canopy, 20 plots under evergreen canopy, and 40 plots under mixed canopy (Figure 3). A total of 90 sites were survey, equaling 270 1-meter squared quadrat plots.

Data was not collected above 600 meters as the understory composition changes little beyond that point, which would likely skew the results for higher elevations, distance to development, and deciduous canopy.

Canopy types were mapped previously using QGIS 2.6 Brighton software. Recent (within the last 5 years) Landsat imagery was used in NDVI (normalized difference vegetation index) calculations to create image maps of vegetation on the island. This calculation uses bands 3 and 4 of Landsat imagery (taken from the USGS Earth Explorer website) to measure live green vegetation, and was calculated for summer and winter imagery. Summer imagery provides total cover of vegetation while winter imagery provides cover of evergreen vegetation. These NDVI maps were digitized to create the map below (Figure 3). Although the digitized NDVI map does not account for all the intricacies of canopy across the landscape, it was found to be fairly accurate when compared to canopy type recorded in the field. The resulting canopy type map (Figure 3) was used to select at least 20 sites under each canopy type.

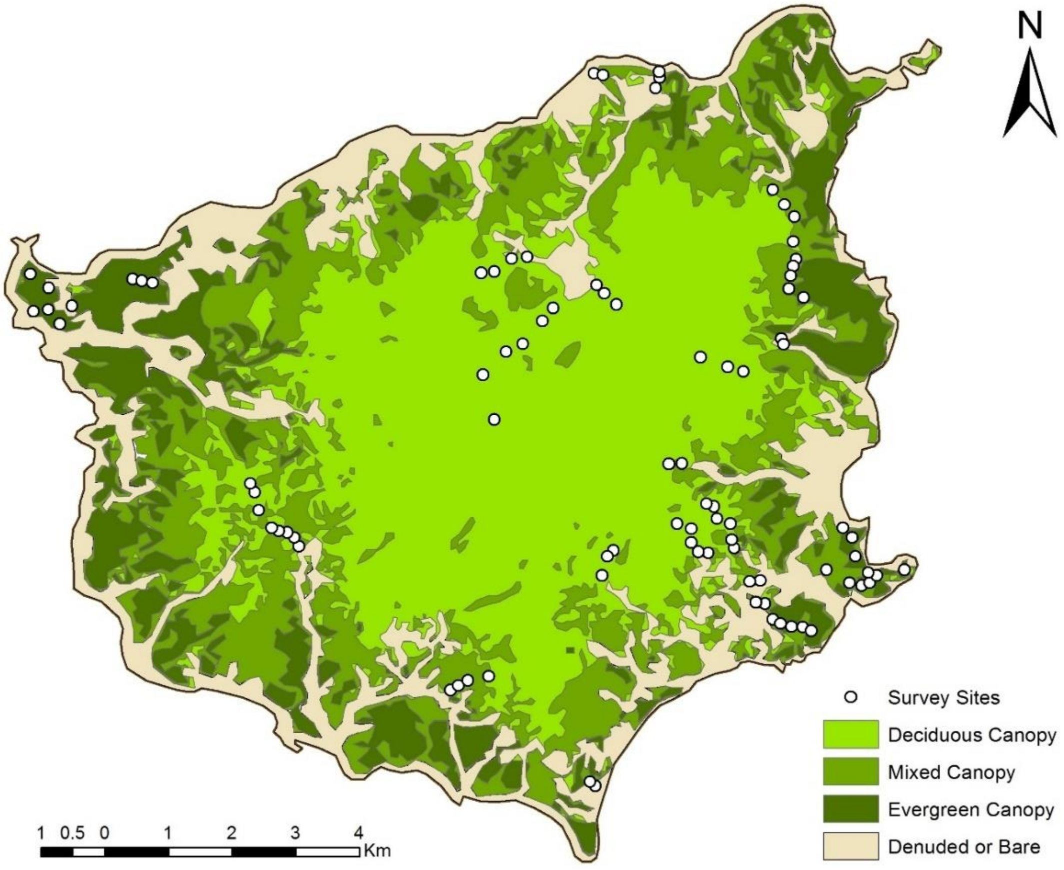

Figure 3: Survey sites, canopy types, and bare areas on Ulleung Island. Created by digitizing recent summer and winter NDVI rasters.

Field Data Collection Methods

At each field site, several types of data were collected. First, the site would be located using a Garmin eTrex 10 GPS. Then, the location of the actual field site would be collected using waypoint averaging for accuracy within 10 meters. Site parameters would then be recorded. These included trail name, elevation (meters), canopy type, canopy composition (species), estimated canopy cover (%), and aspect (slope and direction). Once site parameters were recorded, three 1-meter by 1-meter plot frames were laid down 1 meter off trail at the collected GPS point, and then 5 meters from the initial point along the trail. Within each frame, all vascular species below eye-level were identified, recorded, and estimated for percent cover as a proxy for abundance (Figure A26).

Percent cover was used instead of number of individuals because it is more quickly estimated in the field and because it better indicates the prevalence and influence of the species on the landscape. For example, a single individual of a vine species may take up more space in a plot than multiple individuals of a small herbaceous species – while there are more individuals of the small herbaceous species, the single vine has more influence on the other species in the plot. For this reason, percent cover serves as a proxy for abundance/prevalence/influence within the community.

Several resources were used to identify vascular species in the field and during data analysis. The primary field resource used was *Nature Guide to Ulleungdo* (Andersen, 2015). *Vascular Plants of Dokdo and Ulleungdo Islands* (in Korea; Sun et al., 2014) was used for visual identification of pictures or samples from the field. Any species that could not be identified through these two field guides were compared to species lists from Jung et al. (2013), Yang et al. (2015), and Yoon et al. (2013). *Ferns, Fern-Allies & Seed-bearing Plants of Korea* (Ko & Chon, 2003) was also used for visual identification.

Data and Data Transformations

Human disturbance was measured in three way. First, nearest influence was determined as nearest human altering of the landscape, which may include roads, towns, residences, or agricultural fields, and are indicated as “denuded or bare” areas on the map. This determined the ‘Distance to Development’ factor. Second, nearest town was used as it represents significant alteration of the landscape by humans and greater potential for introduction of non-native species. This determined the ‘Distance to Town’ factor. Third, trails were ranked from 1-3 based on usage (with 1 being lowest and 3 being highest) to determine how human foot traffic alters plant communities within forests. For this, each trail was ranked based on popularity, accessibility, and relative upkeep. These rankings were made from observations and not from quantitative data. This determined the ‘Trail Usage’ factor. Distance from human disturbance and nearest town were measured in GIS after survey points were added to a vegetation map of the island.

To simplify community composition for some analyses, each species was coded as introduced, native, or endemic (Jung et al., 2013), and as a fern, forb, grass, vine, shrub, or tree. For each site, percent coverages of introduced, native, and endemic species were summed and then averaged from the three survey plots for site analysis.

Data transformations included a natural log transformation for introduced and endemic species cover. For introduced and endemic species cover transformations, the equations are as follows:

$$\text{Introduced: } \log(\text{Introduced} + 1)$$

$$\text{Endemic: } \log(\text{Endemic} + 1)$$

*The constant (1) was added to allow the log transformation at sites where introduced or endemic species was zero.

Native species cover was not transformed. An additional reciprocal transformation for introduced species cover was made only for sites where introduced species were present. This transformation was measured against distance to development to establish a possible relationship between the two variables.

To measure biodiversity, Simpson's Biodiversity Index was calculated for each plot and then averaged for each site. The calculation of D' (below) is scaled from 0 to 1, with higher values indicating a higher biodiversity.

Simpson's Biodiversity Index:

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

$$D' = 1 - D$$

*Where n=number (or % cover) of a single species and N=number (or % cover) of all species present

Once all the data was entered and community composition metrics calculated, the data was separated into three main sections. The first was the raw data that includes percent cover of each species for use in community analysis with PC-ORD™ Version 7. The second was the averaged data to determine effects of site parameters on biodiversity and percent cover of introduced, native, and endemic species groups. This included data for the 90 survey sites. The third was the combined vegetation group data for each of the 270 1-meter squared plots. This third section allowed for analyzing the effect of introduced species on native and endemic species within individual plots.

Parametric Analysis Methods

The main variables analyzed were: composition of the understory plant community and the proximity (distance) to human influence (towns, presence of human development), as well as trail usage. Possible confounding site factors included canopy type and cover, elevation, aspect, and distance to the coast. The main parametric methods used to analyze the data were simple linear regression, multiple linear regression, and ANOVA. A model selection approach was used to evaluate different candidate models as described below.

For model selection, global models were created for each of the four response variables: log-transformed introduced cover (Introduced), log-transformed endemic cover (Endemic), native cover (Native), and site diversity (Diversity). These variables will heretofore be referred to as ‘Introduced,’ ‘Endemic,’ ‘Native,’ and ‘Diversity.’ The global model included 6 independent variables: ‘Distance to Development’ (DD), ‘Distance to Town’ (DT), ‘Distance to Coast’ (DC), ‘Trail Usage’ (TU), ‘Elevation’ (E) and ‘Canopy

Cover' (CC). Candidate models were evaluated, and summary statistics were run to determine their significance. Akaike information criterion (AIC) values were then taken for each model where $p<0.05$, and the model with the lowest AIC value was selected as the best fit linear model. For all other models, change in AIC (ΔAIC) was calculated by subtracting the AIC of the selected model from the AIC of the other tested models. Akaike weights were also calculated for each model. The Akaike weight informs the probability of each model being the best representative model, with high Akaike weights indicating the model is more likely to be the best model. Only models with an Akaike weight greater than 0.5 are presented in the results. This value is calculated by:

$$\text{Akaike weight} = \exp(-0.05 * \Delta AIC_{model})$$

To determine the effect of individual species on diversity, simple linear regression was used with individual species as the independent variables and plot diversity as the dependent variable. This resulted in six separate models. The species used in this analysis were three ubiquitous native species—*Maianthemum dilatatum, Hedera rhombea, Pseudosasa japonica*—and three common introduced species—*Robinia pseudoacacia, Erigeron annuum, Ixeris chinensis*—found within the sample plots. The species were chosen based on a calculation of percent cover times number of plots they were present in. For these analyses, only plots where each species was present were used.

In addition to these models, introduced species cover by plot was tested against endemic species cover and plot diversity using simple linear regression to determine what correlation, if any, there was between these two factors and introduced species cover.

ANOVA was used to determine whether canopy type influenced understory diversity or composition.

For parametric methods, significance was determined at a cutoff of $p<0.05$. Parametric analyses were done in JMP® Pro 12.1.0 and RStudio Version 1.0.136.

Community Analysis

In addition to standard parametric analysis methods, community analysis was used to determine any potential impacts of human development and to create a map of community types with indicator species. PC-ORD™ Version 7 was used to analyze the raw plot data containing percent cover for all species. Multi-Response Permutation Procedures (MRPP) analysis was used to determine which – if any – site factors determined community composition.

To map the vegetation communities on the island, the methods used in Khan et al. (2016) were first modified to classify ten community types. In this method, each plot was classified as one of ten community types using cluster analysis. Indicator species analysis was then used to find the three most statistically significant indicator species within each community. When assigning indicator species to communities, the cutoff of $p<0.05$ was not used and instead species were selected for the lowest p-value of each community. A total of 18 species were excluded from this analysis by the statistical program, as they were present in abundance in all community types.

After these communities were classified, they were mapped in ArcGIS 10.4 using Kriging interpolation, where frequency of community type at each site was used as the “Z value” field. Kriging was used because it is the only method of interpolation that produced full coverage maps of the island. Separate Kriging maps were created for each community type. The resulting raster maps were then used as the inputs for the “Highest Position” tool, which created a map of the most frequently occurring community types across the island. The “Highest Position” tool creates a classified map of which input layer has the highest value of a selected attribute for a given location across the map area. In this study, the attribute used in this process was frequency of occurrence of each community type per site.

Results

Introduced Model

The selected model for the variable "Introduced" includes the site factors "Elevation," "Canopy Cover," and "Distance to Development." A total of nine models were tested along with the global and null models (Table 1). Model 7 (Table 2) had the lowest AIC value and is therefore considered the "best-supported" model, However, Model 8 had the next lowest AIC and an Akaike weight of 0.828, indicating it is 82.8% likely that Model 8 is the best-supported model to explain the data. Models 5 and 6 also have some support with AIC values within 2 of the best-supported model and Akaike weights > 0.5.

Table 1: AIC table of models for Introduced variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
E,CC,DD*	7	-87.064	4	184.128	0.000	1.000	0.200	0.173
E,CC	8	-88.253	3	184.506	0.378	0.828	0.179	0.160
E,CC,DC,DD	5	-86.644	5	185.288	1.160	0.560	0.208	0.171
TU,E,CC,DD	6	-86.704	5	185.408	1.280	0.527	0.207	0.170

TU="Trail Usage" E="Elevation" CC="Canopy Cover" DC="Distance to Coast" DD="Distance to Development"

*indicates the best supported model

Table 2: Coefficient table for best supported Introduced model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.3644854	0.2079793	6.561	<0.0001
Canopy cover	-0.0092096	0.0036963	-2.492	0.0146
Elevation	-0.0009022	0.0005542	-1.628	0.1072
Distance to Development	-0.0003283	0.0002163	-1.517	0.1328
Notes: N=90, R^2=0.20, p=0.0002				

Native Model

The selected model for the ‘Native’ variable includes the site factors ‘Distance to Development’ and ‘Distance to Town.’ A total of six models were tested for this factor, along with the global and null models (Table 3). Model 5 (Table 4) had the lowest AIC value, with Model 4 having the second lowest AIC. The Akaike weight of Model 4 was 0.879, indicating it has an 87.9% chance of being the best model.

Table 3: AIC table of models for Native variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
DD,DT*	5	-369.584	3	747.167	0.000	1.000	0.106	0.086
E,DD,DT	4	-368.713	4	747.425	0.258	0.879	0.123	0.093
E,CC,DD,DT	3	-368.433	5	748.867	1.700	0.427	0.129	0.088

E=“Elevation” CC=“Canopy Cover” DD=“Distance to Development” DT=“Distance to Town”

*indicates the best supported model

Table 4: Coefficient table for best supported Native model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	72.438843	2.888189	25.081	<0.0001
Distance to Development	0.014063	0.004591	3.063	0.00291
Distance to Town	-0.004956	0.002387	-2.076	0.04087
Notes: N=90, R^2=0.11, p=0.0075				

Endemic Model

The selected model for the 'Endemic' variable includes the site factor 'Trail Usage.' This variable only had one statistically significant model – Model 7 (Table 6) – out of eight models tested (Table 5).

Table 5: AIC table of models for Endemic variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
TU*	7	-112.963	2	231.926	0.000	1.000	0.050	0.039

TU="Trail Usage"

*indicates the best supported model

Table 6: Coefficient table for best supported Endemic model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.1695	0.2380	9.116	<0.0001
Trail Usage	-0.2320	0.1082	-2.143	0.0349
Notes: N=90, R^2=0.05, p=0.0349				

Diversity Model

The selected model for the ‘Diversity’ variable includes the site factors ‘Trail Usage,’ ‘Elevation,’ ‘Canopy Cover,’ ‘Distance to Development,’ and ‘Distance to Town.’ A total of nine models were tested for this variable (Table 7). Model 1 (Table 8) had the lowest AIC value, followed by Model 2. The Akaike weight of Model 2 was 0.844, indicating it has an 84.4% chance of being the best model.

Table 7: AIC table of models for Diversity variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
TU,E,CC,DD,DT*	1	84.919	6	-155.873	0.000	1.000	0.254	0.209
TU,CC,DC,DD,DT	2	84.767	6	-155.534	0.339	0.844	0.251	0.207
TU,E,CC,DC,DD,DT	Global	85.306	7	-154.611	1.262	0.532	0.260	0.207

TU=“Trail Usage” E=“Elevation” CC=“Canopy Cover” DC=“Distance to Coast” DD=“Distance to Development” DT=“Distance to Town”

*indicates the best supported model

Table 8: Coefficient table for best supported Diversity model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.7777	0.04604	16.892	<0.0001
Trail Usage	-0.03568	0.01401	-2.547	0.0127
Elevation	0.0001941	0.00009	2.088	0.0398
Canopy Cover	-0.001160	0.00057	-2.034	0.0451
Distance to Development	-0.000077	0.00004	-2.133	0.0358
Distance to Town	0.0000338	0.00002	1.823	0.0719
Notes: N=90, R^2=0.25, p=0.0001				

Alternative Introduced Model

When only sites where introduced species were present (introduced cover >0) were analyzed, introduced species cover had an inverse relationship with the ‘Distance to Development’ variable (Table 9, Figure 4). Additionally, 87% of plots containing introduced species occur within 500 meters of development and 100% of plots containing introduced species occur within 1 km of development.

Table 9: Coefficient table for alternative Introduced model (simple linear regression)

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.6197585	0.2124900	2.917	0.00555
Distance from Development	0.0023848	0.0006775	3.520	0.00102
Notes: N=46, R^2=0.22, p=0.0010				

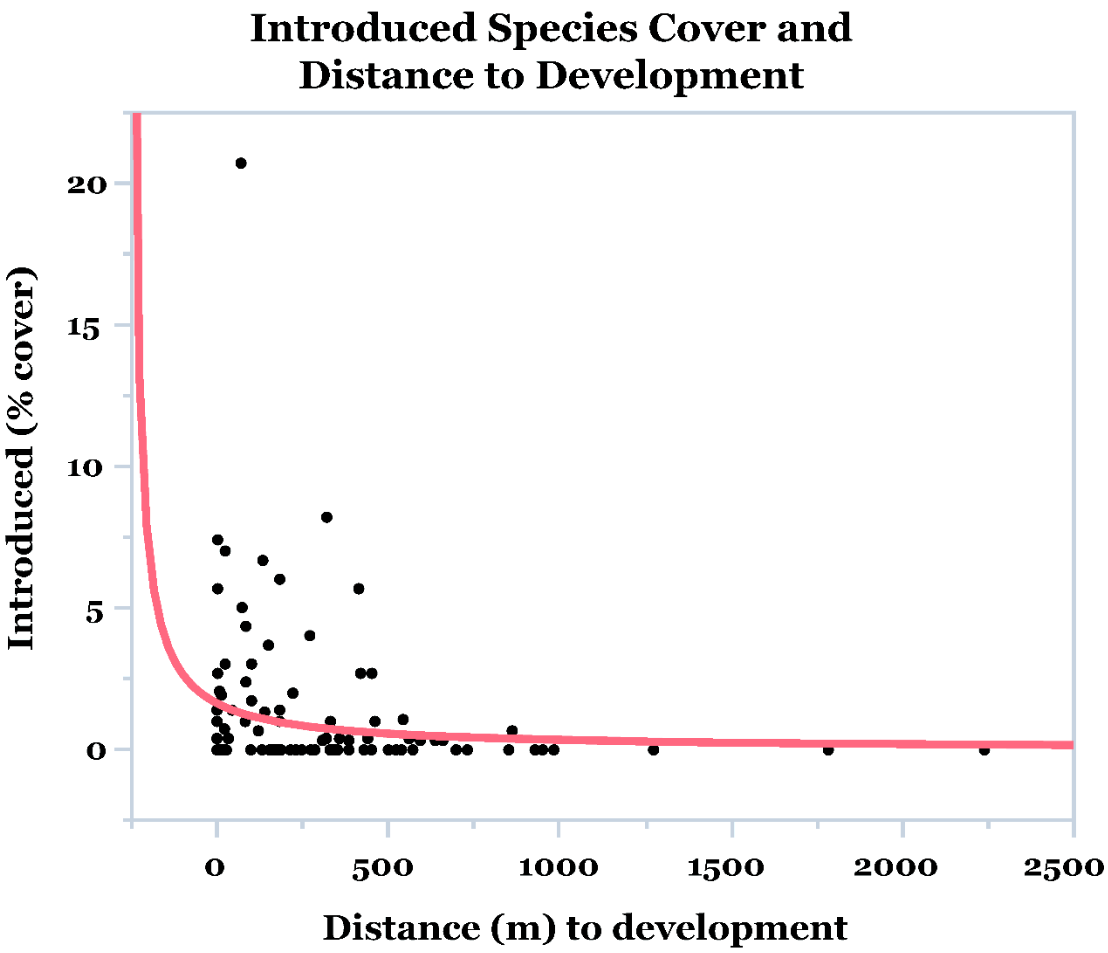

Figure 4: Average introduced plant species percent cover has an inverse relationship with distance to development, meaning that introduced species are more prevalent closer to altered landscapes (specifically within 500 meters of developed areas).

While statistically significant, this model has a low R-square value. However, when viewed geospatially, it is easy to see where the highest concentrations of introduced species are (Figure 5). Particularly, average percent cover is high in areas close to towns in the southeast corner of the island, where the majority of the island's population and tourism occur.

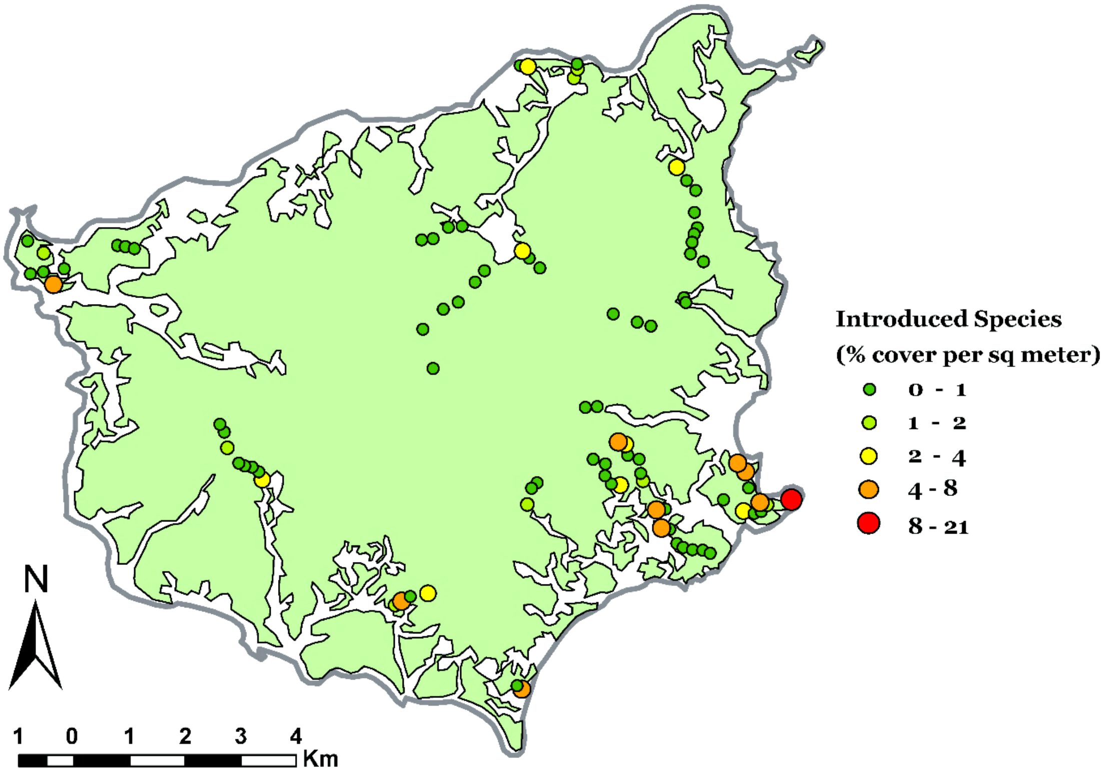

Figure 5: Geospatial representation of introduced species cover (averaged for each site). The light green polygon represents vegetation while the light gray areas represent bare ground (either natural or human-caused).

Species that Impact Diversity

Out of the three ubiquitous native species and three common introduced species, all three native species and two introduced species had correlations with biodiversity (D'). understory diversity (D'). For all three native species found in abundance across the island, a higher percent cover meant a decrease in plot biodiversity. *Hedera rhombea* and *Pseudosasa japonica* both had quadratic fits while *Maianthemum dilatatum* had a linear fit (Figure 6).

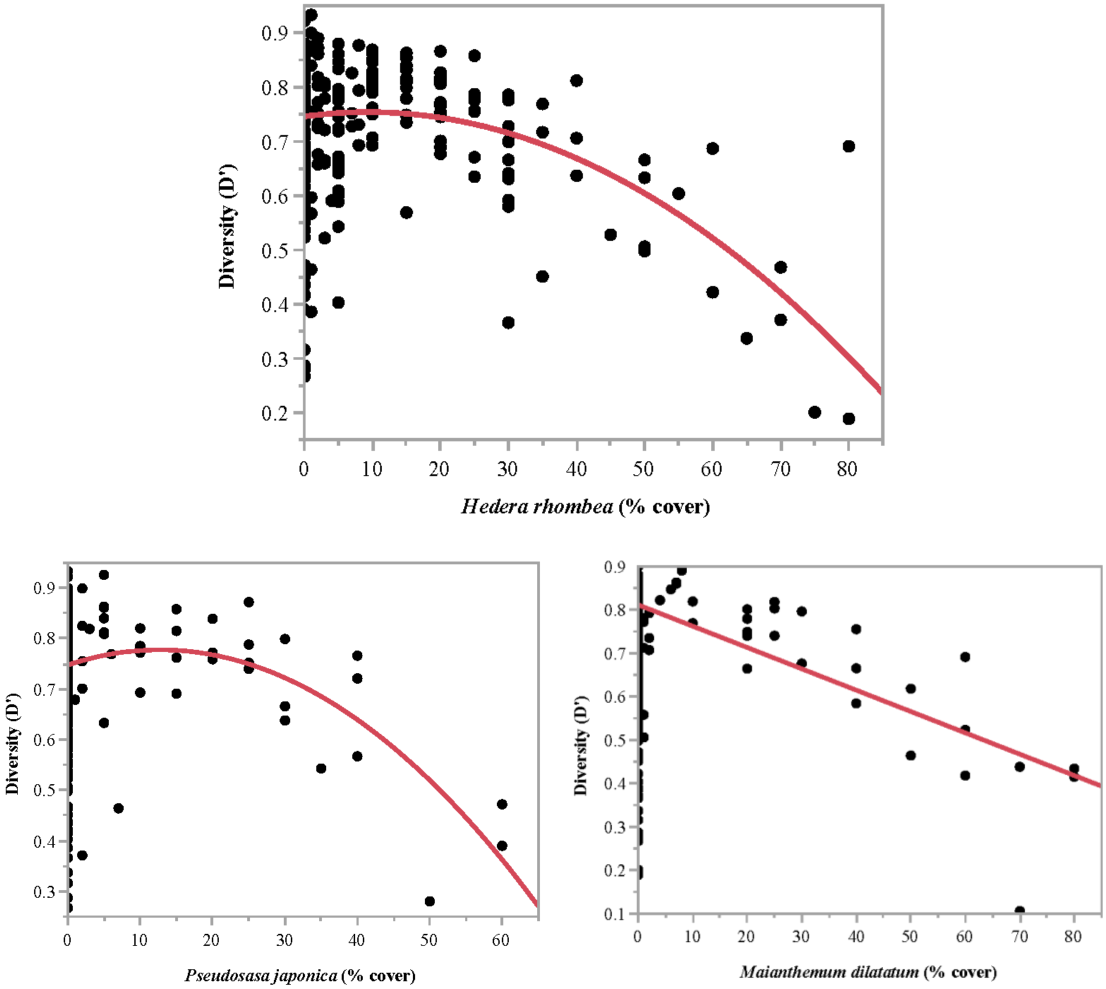

Figure 6: Graphs showing Diversity (D') as the dependent variable of percent cover of *Hedera rhombea* (144 plots), *Pseudosasa japonica* (44 plots), and *Maianthemum dilatatum* (37 plots). For all three species, as percent cover increases, plot diversity decreases in plots where the species are present.

Table 10: Coefficient table for Biodiversity (D') by *Hedera rhombea*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.7741914	0.013561	57.09	<0.0001
Hedera rhombea	-0.001495	0.000816	-1.83	0.0690
(*H. rhombea*-17.5903)^2	-0.0000904	0.000022	-4.12	<0.0001
Notes: N=144, R^2=0.36, p<0.0001				

Table 11: Coefficient table for Biodiversity (D') by *Pseudosasa japonica*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8026173	0.026055	30.81	<0.0001
Pseudosasa japonica	-0.00167	0.001594	-1.05	0.3011
(*P. japonica*-17.2045)^2	-0.000186	0.0000639	-2.92	0.0057
Notes: N=44, R^2*=0.42, p<0.0001*				

Table 12: Coefficient table for Biodiversity (D') by *Maianthemum dilatatum*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8111702	0.028797	28.17	<0.0001
Maianthemum dilatatum	-0.004914	0.000789	-6.23	<0.0001
Notes: N=37, R^2*=0.53, p<0.0001*				

For the three introduced species, only *Robinia pseudoacacia* (Table 8) had an effect on plot diversity (Figure 7). Where it was present in the understory community, plot diversity decreased with higher percentages of this species. There was no correlation between plot diversity and *Erigeron annuum* or *Ixeris chinensis* percent cover.

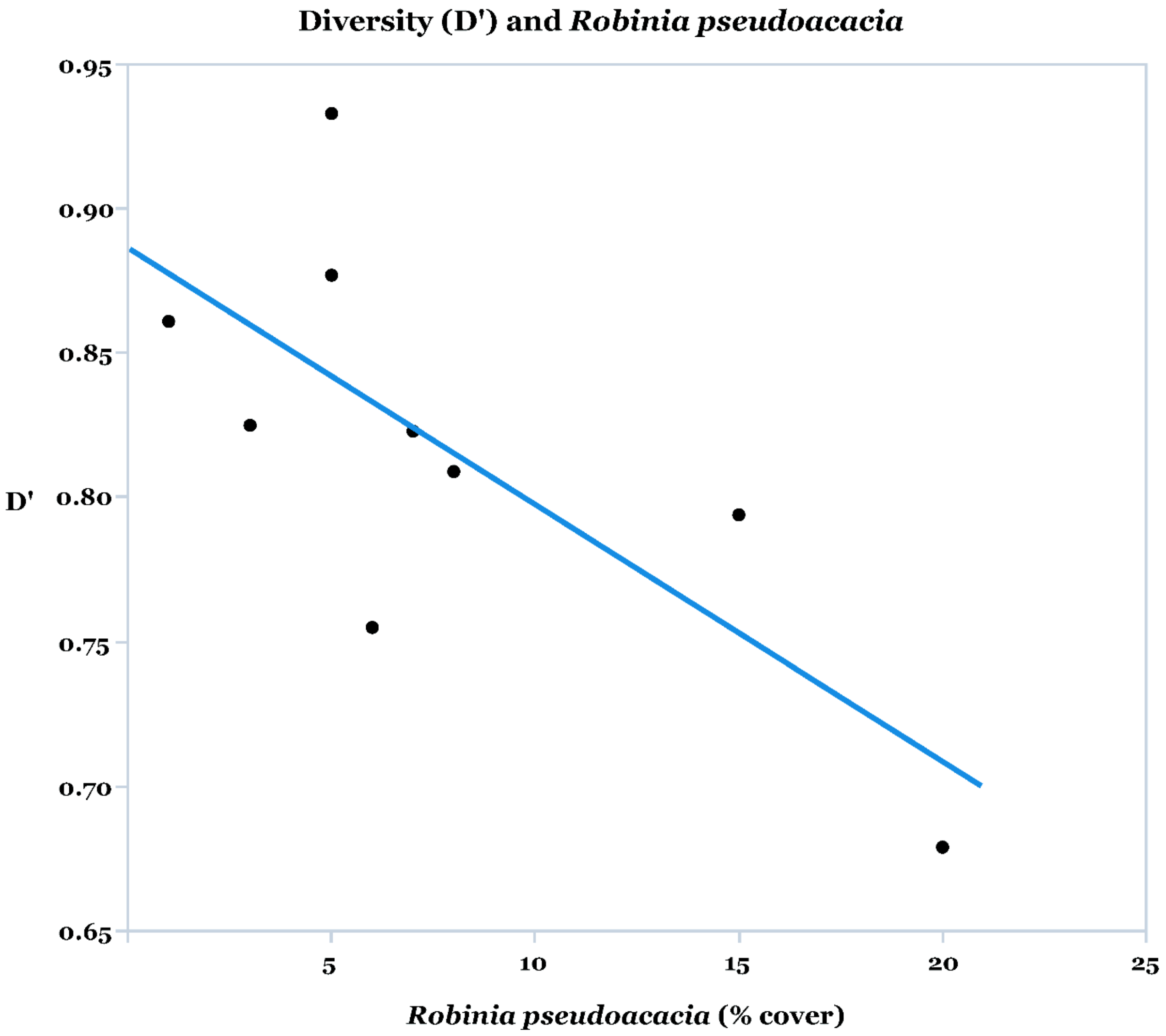

Figure 7: Understory plant species diversity (D') decreases as Black locust (*Robinia pseudoacacia*) percent coverage increases when the plant is present in the plot.

Table 13: Coefficient table for Biodiversity (D') by *Robinia pseudoacacia*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.8864827	0.029999	29.55	<0.0001
Robinia pseudoacacia	-0.008891	0.003116	-2.85	0.0246
Notes: N=9, R^2*=0.54, p<0.0246*				

Community Analysis

The first analysis using MRPP of communities yielded no significant results for any of the site parameters, meaning that no single site factor determined community composition. The method used to classify communities (Khan et al., 2016) resulted in ten different communities (Table 9). Each community was assigned three indicator species. While some of the indicator species are not statistically significant at $p<0.05$, this method follows the method used in Khan et al. (2016).

Mapping using the Kriging interpolation tool created a map of most common/likely community types across the island (Figure 8). All community types are represented in this map except for community 3, which only accounted for 2.6% of plots in the original dataset.

Table 14: Understory vegetation communities. Including frequency of each community in the sampled plots, top three indicator species, and corresponding indicator species p-values. Indicator species are listed from lowest to highest p-value within their community.

Community	Percent of plots	Indicator species	Indicator species p-values
1	23.3%	*Artemisia princeps*	0.0006
		Artemisia japonica	0.0176
		Aster spathulifolius	0.0230
2	17.0%	*Polystichum tripteron*	0.0218
		Athyrium sp.	0.1256
		Fallopia sacchalinensis	0.1326
3	2.6%	*Rumhora standishii*	0.0002
		Chelidonium asiaticum	0.0012
		Polystichum polyblepharum	0.0014
4	16.3%	*Boehmeria nivea*	0.1118
		Rhus trichocarpa	0.3355
		Dryopteris lacera	0.4737
5	4.4%	*Miscanthus sinensis*	0.0002
		Erigeron annuum	0.0014
		Veronica arvense	0.0032
6	8.9%	*Equisetum arvense*	0.0180
		Dioscorea batatas	0.1680
		Viola verecunda	0.1836
7	11.1%	*Pyrola japonica*	0.1540
		Pteridium aquilium	0.2158
		Matteucia orientalis	0.2685
8	5.2%	*Polygonum lapathifolium*	0.0576
		Amorpha fruticosa	0.1546
		Polypodium vulgare	0.1600
9	3.7%	*Prunus takesimensis*	0.1202
		Hepatica maxima	0.1748
		Lilium hansonii	0.1806
10	6.7%	*Neolitsea sericea*	0.0108
		Aucuba japonica	0.1160
		Rhus javanica	0.1582

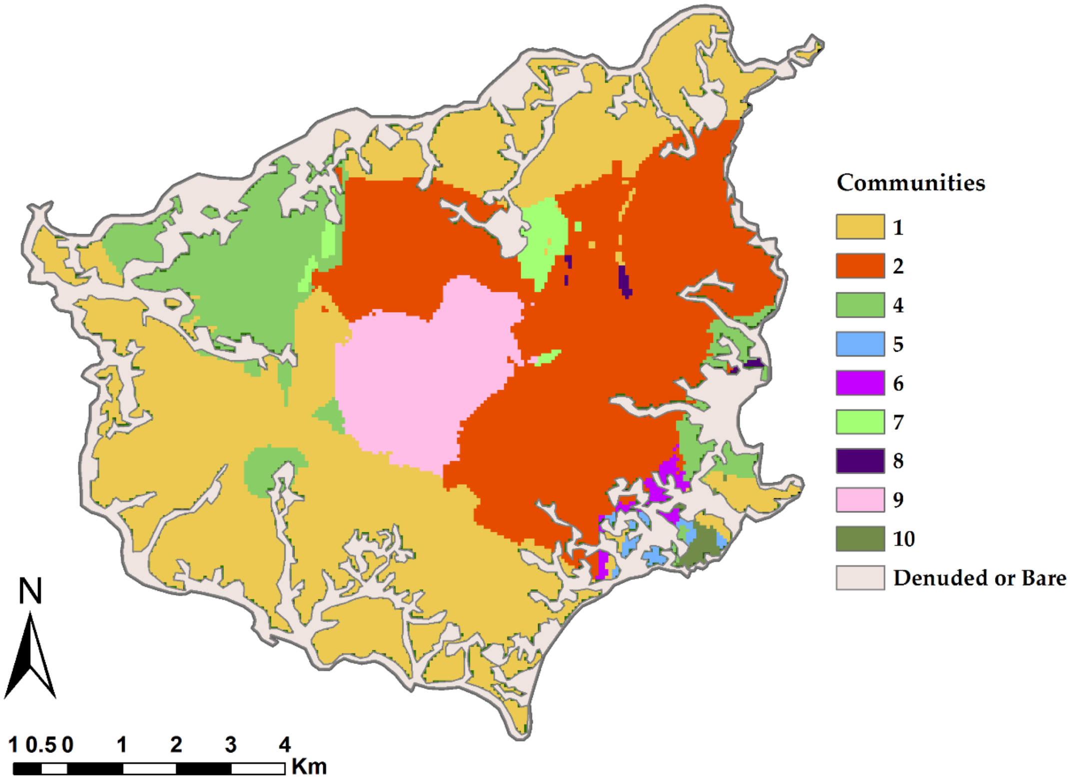

Figure 8: Map of understory vegetation community types. Created using highest position community types for Kriging interpolation maps of ten understory vegetative communities. Community 3 is not present as its frequency is too low to be a dominant community type.

Other Results

Introduced species cover had no correlation with either endemic species cover (p=0.58) or site diversity (p=0.76). ANOVA analyses showed that there was no difference in introduced ($F_{(2,87)}$=0.176,p=0.839), native ($F_{(2,87)}$=0.945,p=0.393), or endemic cover ($F_{(2,87)}$=2.001,p=0.141) among canopy types (evergreen, mixed, deciduous). For biodiversity, variances were unequal among canopy types (Welch's test, p=0.03), so ANOVA was not tested for this variable.

Discussion

Overall, all best supported models were influenced by one or more human-related factors. While their relative influence within each model may have been low, this shows that there are implications of human influence on the forest understory aside from habitat destruction due to development. Additionally, introduced species cover correlates with distance to development. It was also found that several species—including an introduced tree species, *Robinia pseudoacacia*—decrease diversity in plots where they are present. In terms of communities, there was no clear influence of human-related factors on community composition; however, two of ten community types were indicated by introduced species. There were no correlations between introduced species and diversity or endemic species, indicating there are no invasive plant species at the time of this study.

Introduced Model

The model selection results for the "Introduced" variable indicates that canopy cover and elevation are important factors in predicting the percent cover of introduced species: introduced cover declined with more canopy cover and higher elevation. These two variables were included in *all* the supported models (Table 1). In the best-supported model, introduced cover also declined as distance to development increased, but this variable was excluded from the next-best model.

In this model, canopy cover has a higher coefficient and a lower p-value than elevation, indicating that canopy cover has a greater effect on introduced cover than elevation. It makes logical sense canopy cover influences introduced species, as many are opportunists and take advantage of greater light availability. It also makes sense for these species to be mostly found in lower elevations because dispersal uphill takes more environmental energy than dispersal downhill, and most of the towns on Ulleung Island are in low-lying coastal areas. Dispersal of introduced species to higher elevations would likely require dispersal by animals or humans. Although these introduced species are not very common at higher elevations on Ulleung Island, it should be noted that they are present in small amounts even around Seonginbong – the island's highest peak – likely due to hiking traffic along the trail.

Distance to development, which is also included in the selected model, has the lowest effect on the model. Considering the high Akaike weight of the model that does not incorporate this variable, distance to development does explain as much variation in introduced cover compared to canopy cover and elevation.

The inclusion of distance to development in the introduced model supports the first hypothesis that one of the three human-related site factors is important to predicting introduced species cover.

Native Model

Distance to development and distance to town were the two variables that predicted native cover within the selected model. The coefficient of "Distance to Development" is positive in this model, meaning that sites farther from developed areas will have a higher percent cover of native species than sites closer to development. This may be due to an effect of general habitat degradation close to developed areas. Conversely, the coefficient of “Distance to Town” is negative, meaning sites closer to towns have higher percent cover than areas farther from towns. This could be due to regional variations across the island, but it has a small coefficient in the model, and therefore a small effect on native species cover. This model also has a low R-square value (0.11), which means that it explains a very small portion of the variation within the model.

The significance of both distance to development and distance to town in this model support the first hypothesis that humans indirectly influence native species cover.

The model including ‘Elevation’ had a high Akaike weight (0.88), so it is also possible that elevation influences native cover on Ulleung Island.

Endemic Model

In predicting endemic cover, only the model including trail usage was significant, meaning that trail usage has the greatest impact on endemic species cover. Since the coefficient in the model is negative, this means that endemic species cover decreases along trails with heavy traffic. However, this model has the lowest R-square value (0.05) of the models presented in this thesis, so it is likely that some other untested environmental factor is affecting endemic species cover, or that variation in endemic species cover is due to random chance.

This model supports the first hypothesis that humans influence endemic species cover. Additionally, no other model had a low enough AIC value to be considered.

Diversity Model

The selected model for predicting site diversity was the most complex model, including nearly all site factors used in the global model. The one factor not included was ‘Distance to Coast’. Some of the site factors are more significant and have more weight within the model, but the inclusion of all but one of the factors in the best fit model indicates that the factors influencing understory biodiversity are complex and varied.

In the diversity model, the most significant site factor with the greatest absolute t-value was ‘Trail Usage.’ Since the coefficient for this variable is negative, this means that higher trail usage decreases site diversity. This may be due to increased use of forest resources on heavily trafficked trails, or to the tendency of trail users on Ulleung Island to leave garbage strewn along the trails. The second most significant site factor is ‘Distance to Development,’ which also has a negative coefficient, meaning sites closer to developed areas have slightly higher diversity. This is likely due to higher number of introduced species, which increases richness and diversity assuming the introduced species themselves are not dominating the plant community and displacing native species.

Next, diversity increases with elevation. Higher elevations are more difficult to get to and alter on Ulleung Island, so they generally have plant communities that most closely represent “untouched” or “natural” communities. They are also more in the temperate region of the island (whereas lower elevations are considered almost subtropical). This may mean less domination of vine species that are common in the lower elevation, more subtropical areas of the island. As the next significant factor, increased canopy cover decreases diversity slightly. More canopy cover means less light availability, which means potentially lower establishment and abundance of certain species. Finally, ‘Distance to Town’ is the least significant factor in this model, and has a positive effect on diversity. This is likely due to regional variation or is somewhat unimportant to the model, as the ‘Distance to Development’ factor indicates that human activities do in fact influence diversity to a degree.

The model for site diversity supports the first hypothesis that human activities indirectly influence diversity.

Alternative Introduced Model

While the model for the reciprocal of introduced cover only includes a subset of the data and has a low R-square value, it does still show a relationship between introduced cover and distance to development that can be readily seen when mapped (Figure 5). The highest percentages of introduced species will usually be found closer to their sources, which are developed areas where humans have introduced them. Additionally, this model and the lack of significant introduced species cover past 1km from distance to development indicate that there are few if any problem areas of introduced species

Species that Impact Diversity

When individual species were compared with biodiversity within individual plots, it became apparent that ubiquitous native species had a greater influence on diversity than did the three most common introduced species. The decrease in biodiversity for plots with the native species likely had to do with the dense root formations of all of these species, with high percent cover leading to crowding out roots of other species.

The decrease in diversity in plots where *Robinia pseudoacacia* is present may be due to environmental variables affecting the success of *R. pseudoacacia* or to *R. pseudoacacia* altering its environment. However, it is still important to note that only 9 plots out of 270 are represented by this result, and therefore any impact of *R. pseudoacaia* abundance is currently not very great for ecosystems across the island. For the two other introduced species, it is likely that their abundance is so insignificant that those species do not affect the dynamics of the surrounding plant communities.

Community Analysis

The lack of significant results in ordination of communities by site parameters indicates that community composition is not influenced by any single environmental factor. This supports the null hypothesis that ordinated community composition is not affected by human activities.

Alternatively, the grouping and subsequent mapping of understory plant communities on Ulleung Island serves as an interesting study in ecological modeling and gave insight into communities that are largely inaccessible to surveying.

Of the ten community types, two of them (communities 4 and 5) were classified with introduced species as indicator species. Indicator species for community 4 include the introduced species *Boehmeria nivea*. This community makes up 16.3% of survey plots, making it the third most common community surveyed. The indicator species for community 5 include the introduced species *Erigeron annuum* and *Veronica arvense*. This community only makes up 4.4% of surveyed plots, making it the third least common community surveyed. While it is interesting that introduced species indicate for two different community types, it should be noted that introduced species do not themselves impact community composition.

Other Results

Introduced species cover had no correlation with either endemic species cover or plot diversity. This indicates that introduced species are not impacting the understory plant community in any significant way in the context of this study. This result supports the null hypothesis that introduced species have no correlation with or effect on diversity or community composition.

Although qualitative observations of Ulleung Island understory plant communities would indicate that communities differ under canopy types, the lack of difference in community composition under the three canopy types tested indicates that understory plant community composition on Ulleung Island is not impacted by canopy type.

Conclusions

Implications of models on Ulleung Island understory plant communities

The models selected to best represent the vegetation data collected on Ulleung Island indicate that human activities have slight impacts on the understory plant communities of the island. First, human activities somewhat increase the percent cover of introduced species closer to developed areas. Humans likely have little control over spreading of introduced species, with the exception of escaped cultivated species like *Boehmeria nivea*, and introduced species do not appear to negatively impact the native plant communities of the island. This is especially apparent in the lack of influence secondary human activities have on native and endemic species percent cover. Secondary activities in this case primarily include introduction of native species and general degradation that happens with human proximity and use of forested areas.

Although these secondary human activities on Ulleung Island do not impact native and endemic groupings, it is somewhat concerning that understory diversity decreases with increased trail usage. While this may be due to overgrowing along trails that are not kept up, it may indicate poor environmental stewardship of trail users. This could be because of a lack of awareness of ecological and environmental processes. Anecdotally, Koreans tend to be very culturally invested in their forests, but environmental science and ecology are often less important to them. This is apparent in the abundance of trash that is sometimes present along the more popular trails on the island. Degradation along popular trails may be exacerbated by the large amounts of tourists the island sees every year.

Implications for analogous islands

Secondary influences caused by human activities likely do not significantly impact understory plant communities on other temperate islands. While the story may be different on tropical islands or unforested islands, the forest cover, climate, and potentially limited resources on temperate islands make establishment and invasion difficult for exotic plant species. Further, the limited impacts of these exotic species on the native and endemic species of Ulleung Island indicate that there may be little impact on analogous islands.

The exceptions would be islands where one or two particularly invasive species are introduced and spread, or where a non-invasive introduced species displaces a rare endemic species. The latter would be difficult to detect in studies of the whole plant community, and a targeted survey for the at-risk species would have to occur to determine decline and displacement by exotic species. In this case, a time series study of percent cover of introduced species and community ordination in areas where the target species occurs would be appropriate.

To further determine the secondary effects of human landscape development on the understory vegetation communities of Ulleung Island and analogous temperate islands, baseline studies—like the one presented in this thesis—and continued monitoring of these communities is necessary. However, it is likely that declines in richness and diversity are caused by habitat destruction and are, at best, only minimally influenced by secondary human activities.

Methods in community mapping

By building on the community classifying methods used by Khan et al. (2016), this thesis provides a method for mapping plant communities that could potentially be used for other groups of organisms as well. Community classifying and mapping can be useful in ecological study because it can inform on existing or ideal community compositions for species at risk of extinction. Further, it may be useful when comparing communities to different groups of organisms (e.g. plant communities and endangered animal species).

Community ordination provides a tool to determine how communities differ from region to region, or how they respond to environmental factors. In some instances—as in the study used in this thesis—the MRPP method of ordination does not provide any insight into environmental or regional factors that affect community composition. Cluster analysis on the other hand separates communities by similarities in composition and can be effectively mapped using interpolation. The method outlined in this thesis can be used in future research to map communities of both plant and animal species.

Limitations of the study

While this study is a good start to understanding the effects of secondary human activities on understory communities on Ulleung Island and on analogous temperate islands, there were definite limitations and sources for error. This study also does not analyze impacts by introduced animal or impacts on certain endemic species that are at higher risk of extinction.

For limitations, field studies are typically limited in sample sizes. Only 90 sites and 270 plots were surveyed across the island, and three one-meter squared quadrats are not likely to capture all of the community variability within sites. Similarly, 90 sites across the island probably do not capture the variability of communities across the entire 73km^2 island. Additionally, site parameters did not include other environmental conditions, including soil properties, that may impact plant communities more than conditions that are immediately available to observe in the field without using expensive equipment or taking field samples.

Another limitation was that the terrain of the island greatly limited the sites available for surveying. Surveying more remote areas of the island may or may not have allowed for more precise models explaining variations in community data. This would be especially true in ordinating and mapping different community types. The issue of terrain also limited the survey sites to areas along trails, which likely skewed the data because the presence of trails necessitates human influence. It is likely that plant groups and community composition would differ between remote areas and areas along trails. Additionally, areas above 600 meters were not surveyed in this study, but including those areas in future surveys could improve models and community analysis.

Sources for error primarily arise from the use of estimation to collect the quantitative data of percent cover for understory and canopy. Even with a set method for estimation, there is always a possibility that estimates will vary from day to day. This error is somewhat remedied by all the estimates being made by a single person, which reduces the error that often occurs when different individuals are asked to estimate the same objective.

Another source of error comes from potential misidentification of species. However, considering the author's familiarity with the plant species on the island, there is likely not significant error in vascular plant identification outside of some grass or fern species.

Suggestions for future study

Opportunities to build on this study are plentiful, and future study would add to understanding of human effects, vegetation communities, and effects of climate change. This study can be expanded on Ulleung Island to include more study sites, species, and time series. This study can also be replicated on analogous islands.

In future studies, it would be beneficial to add more study sites to cover more of the island, or to establish permanent study sites for continued monitoring. First, sites above 600 meters can be added to expand understanding of plant communities. Second, more remote areas could be accessed over time to include areas that are relatively untouched by human disturbance. Further study may also include gathering more environmental data and quantifying human use of trails and forest resources across the island. Monitoring should occur periodically to determine the effects of increased tourism and climate change on the island. Warming could push endemic species to higher elevations, eventually removing their habitable area from the island entirely. One example of this is the endemic species *Corydalis filistipes*, which is already very rare and is primarily found in the highest elevations of the island (Andersen, 2015).

Additional future studies could include linking community composition to endemic species genetics and focusing on individual plant species. Phylogenetic studies of endemic plant species on Ulleung Island are increasing, and linking genetics to environmental factors or community composition would provide interesting insight into evolutionary processes on islands. Certain species, including the critically endangered *Scrophularia takesimensis*, would particularly benefit from studies of community composition. Correlations of at-risk species with percent cover of certain species – whether introduced or native – along with community ordination would be particularly relevant to its habitat management and may point to suitable areas for potential relocation.

One additional suggestion for study is the incorporation of animal species to find correlations with plant communities. The island provides important habitat for bird species, including the range-limited Japanese Wood Pigeon, so correlations with certain bird species would contribute to understanding their habitat requirements. Conversely, Ulleung Island has two introduced mammal species—goats and cats—that may have significant impacts on the native plant and animal communities.

Suggestions for conservation

The results of this study can inform future conservation efforts for Ulleung Island and analogous islands. Future efforts, on Ulleung Island specifically, should focus on environmental awareness and on reducing complete habitat destruction.

Because plant groups and communities are affected only slightly or not at all by secondary impacts of human activities, there is little need for costly restoration of existing ecosystems. Instead of spending funds on eradicating exotic invasive species, funds can be spent on reducing the amount of new exotic species introduced. Additional funds can be spent improving education and signage along trails on the island. Currently, there are some signs showing forest succession and the importance of primary forest (Figure A27), as well as signs about ecological processes and endemic species on the island, but there is much to be desired in terms of conservation and reducing the impact of visitors to the island.

Further understanding of the importance of the island's ecosystems and species can also contribute to the designation of ecologically important areas. This study, along with other ecological studies and a number of genetic studies, help solidify the ecological value of the island. A large portion of the island's forest is designated as a Forest Genetic Resources Reserve (FGRR) by the South Korean government (Korea Forest Service, 2007), and there are many "natural monuments" designated on the island, but more and stronger designations could help reduce habitat destruction for development. Even in the three years between the author's initial and data collection visits, there has been significant environmental destruction from development, as interest in Ulleung and Dokdo Islands has increased tourism to both islands. Reducing development by increasing environmental protection will be the most effective way to preserve diversity on Ulleung Island and its species that are at highest risk of extinction.

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Appendix A – Figures

Figure A1: Low elevation and coastal evergreen forest. Occurring below about 200 meters, these forests are dominated by Japanese Red Pine (*Pinus densiflora*) and often have an understory of Camellia (*Camellia japonica*). Where the canopy is very dense, the understory can be sparse with little vegetation, but where light is more available, thickets of vines and bamboo can form.

Figure A2: Mid elevation mixed and deciduous forests. Occurring between 200 and 600 meters, they often have mixed evergreen-deciduous canopies and medium-density understories. In these forests, yew (*Taxus baccata* var. *latifolia*), white pine (*Pinus parviflora*), and hemlock (*Tsuga sieboldii*) are sometimes part of the canopy.

Figure A3: High elevation deciduous forests. These forests occur above 600 meters and are dominated by deciduous trees such as beech (*Fagus multinervus*), maple (A*cer okamotoanum* and *A. takeshimense*), elm (*Ulmus laciniatus*), and linden (*Tilia insularis*), most of which are endemic to Ulleung Island.

Figure A4: *Poa takesimana*. An endemic grass to Ulleung Island found in forests.

Figure A5: *Scrophularia takeshimense*. An endemic herb that is listed as Critically Endangered. This is a coastal species that has its habitat threatened by human development.

Figure A6: *Cotoneaster wilsonii*. A Critically Endangered endemic shrub on Ulleung Island. Found in lowland forests in the southeastern corner of the island.

Figure A7: *Veronica nakaiana*. An endemic herb found in the forests of Ulleung Island. Also known as *Pseudolysimachion nakaianum*.

Figure A8: *Syringa patula* var. *venosa*. This variety is considered endemic to Ulleung Island.

Figure A9: *Phellodendron amurense*. This tree species is sometimes refered to as *Phellodendron insulare*, and may be an endemic species or form to Ulleung Island.

Figure A10: *Phytolacca insularis*. This large herb is endemic to Ulleung Island and is mostly found in lowlands near streams and roads. Although it is currently considered a separate species, it is possible that genetic testing may prove it to be synonymous with *P. esculenta* (or *P. acinosa*).

Figure A11: *Lilium hansonii*. An endemic lily found in the forests of Ulleung Island.

Figure A12: *Schizophragma hydrangeoides*. A common vine species on Ulleung Island.

Figure A13: *Gymnadenia camtchatica*. An endangered orchid found on Ulleung Island.

Figure A14: *Taxus baccata* var. *latifolia*. Needleleaf evergreen tree native to Ulleung Island. Scarce in forests.

Figure A15: *Thymus quinquecostatus*. Vulnerable herb native to Ulleung Island. Found on rocky outcrops.

Figure A16: *Amorpha fruticosa*. Introduced to Ulleung Island, found in open areas along roadsides and near towns.

Figure A17: *Sonchus oleraceus*. Introduced herb common in disturbed areas.

Figure A18: *Boehmeria nivea*. Introduced for food and naturalized in lowland forests.

Figure A19: *Erigeron anuum*. Introduced and naturalized daisy species.

Figure A20: *Robinia pseudoacacia*. Also known as Black locust (pea family), this tree has been introduced and naturalized on Ulleung Island. It is somewhat common in lowland forests, and has the potential to alter soil and plant communities if it becomes too abundant.

Figure A21: *Fallopia dumetorum*. This knotweed species has been introduced to Ulleung Island. It is not very abundant, but it is considered an invasive species in other parts of Korea, so it should be controlled to avoid invasion.

Figure A22: *Houttuynia cordata*. An herb common in lower elevations. Native to parts of Asia, but not to Ulleung Island.

Figure A23: *Ipomoea purpurea*. Introduced vine species common along roadsides and near towns.

Figure A24: *Phytolacca americana*. Related to *P. insularis*, but not native to Ulleung Island or Korea. Grows well along streams and has become invasive in other parts of Korea, but is still relatively scarce on Ulleung Island.

Figure A25: Japanese Wood Pigeon (*Columba janthina*). One of 112 bird species present on Ulleung Island, the Japanese Wood Pigeon only populates oceanic islands in the Sea of Japan, so habitat on Ulleung Island is crucial for this species.

Figure A26: Representative survey plots with PVC quadrat

사람의 간섭이 없어 자연적으로 이루어진 숲을 자연림(=천연림)이라 하며, 자연림 중에서 사람의 손길이 닿지 않아 원형그대로 보전된 숲을 원시림이라고 합니다. 자연림으로 가장 대표적인 곳은 아마존유역입니다.

사람이 나무를 심어 조림한 숲을 말합니다. 자연림보다 종 다양성은 떨어지지만 목재공급 등 생산성은 높습니다.

울릉둘레길 조성사업은 녹색자금(복권기금)지원으로 시행되었습니다.

Figure A27: Environmental education signage on Ulleung Island. Showing the importance of primary forest (left) compared to secondary forest (right)

Appendix B – Full AIC Tables

Table 15: Full AIC table of models for Introduced variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
TU,E,CC,DC,DD,DT	Global	-86.251	7	188.502	4.374	0.112	0.215	0.158
TU,E,CC,DC,DD	1	-86.344	6	186.688	2.560	0.278	0.213	0.166
E,CC,DC,DD,DT	2	-86.481	6	186.962	2.834	0.242	0.211	0.164
TU,E,CC,DD,DT	3	-86.561	6	187.122	2.994	0.224	0.209	0.162
TU,E,CC,DC,DT	4	-87.037	6	188.074	3.946	0.139	0.201	0.153
E,CC,DC,DD	5	-86.644	5	185.288	1.160	0.560	0.208	0.171
TU,E,CC,DD	6	-86.704	5	185.408	1.280	0.527	0.207	0.170
E,CC,DD	7	-87.064	4	184.128	0.000	1.000	0.200	0.173
E,CC	8	-88.253	3	184.506	0.378	0.828	0.179	0.160
CC	9	-92.057	2	190.113	5.985	0.050	0.107	0.096
1	null	-97.129	1	198.258	14.13	0.001	0.000	0.000

Table 16: Full AIC table of models for Native variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
TU,E,CC,DC,DD,DT	Global	-367.827	7	751.653	4.486	0.106	0.141	0.078
E,CC,DC,DD,DT	1	-367.903	6	749.806	2.639	0.267	0.139	0.088
E,CC,DD,DT	3	-368.433	5	748.867	1.700	0.427	0.129	0.088
E,DD,DT	4	-368.713	4	747.425	0.258	0.879	0.123	0.093
DD,DT	5	-369.584	3	747.167	0.000	1.000	0.106	0.086
1	null	-374.642	1	753.283	6.116	0.047	0.000	0.000

Table 17: Full AIC table of models for Endemic variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
TU,E,CC,DC,DD,DT	Global	-111.739	7	239.479	7.553	0.023	0.075	0.008
TU	7	-112.963	2	231.926	0.000	1.000	0.050	0.039
1	null	-115.253	1	234.505	2.579	0.275	0.000	0.000

Table 18: Full AIC table of models for Diversity variable

Model	Model ID	Log-likelihood	Number of parameters	AIC	Delta AIC	Akaike Weight	R^2	R^2 Adj
TU,E,CC,DC,DD,DT	Global	85.306	7	-154.611	1.262	0.532	0.260	0.207
TU,E,CC,DD,DT	1	84.919	6	-155.873	0.000	1.000	0.254	0.209
TU,CC,DC,DD,DT	2	84.767	6	-155.534	0.339	0.844	0.251	0.207
TU,CC,DD,DT	3	82.641	5	-153.282	2.591	0.274	0.215	0.178
TU,CC,DD	4	78.243	4	-146.486	9.387	0.009	0.134	0.104
TU,DD	5	77.694	3	-147.388	8.485	0.014	0.124	0.103
TU,CC	6	78.228	3	-148.456	7.417	0.025	0.134	0.114
TU	8	77.620	2	-149.240	6.633	0.036	0.122	0.112
1	null	71.759	1	-139.518	16.36	0.000	0.000	0.000

Appendix C – Explanation of Terms

Diversity: a combined measure of richness and abundance of all species in a taxonomic group in a given area

Endemic: a species that is found in a restricted geographic region

Exotic: any species that is not native to a region

Forb: an herbaceous vascular plant

Fragmentation: the breaking apart of an ecosystem type into smaller patches

Herbaceous layer/understory: herbs, shrubs, vines, and small trees below eye level

Introduced: a nonnative/exotic species that has been brought to a region through some anthropogenic activity

Invasibility: the susceptibility of an ecosystem to be altered by an exotic species

Invasive: an introduced species that has become incorporated into the native ecosystem and is significantly altering the community composition and functioning of the ecosystem (e.g. limiting resources to native species and therefore reducing native populations)

Native: a species that was present in an ecosystem before human colonization (this can sometimes be difficult to ascertain due to the long history of colonization on islands, but native assemblages can be pieced together based on historical records, fossil records, levels of establishment, and assemblages of nearby islands and continents)

Naturalized: an introduced species that has become incorporated into the native ecosystem but **has not necessarily become invasive**

Progenitor species: a parent species from which a new species evolves

Richness: the number of species in a given area

Species source pool: the originating population from which satellite populations gain individuals

Taxa: (for the purposes of this thesis) the lowest level of an organism’s classification (e.g. species, subspecies, variety, form, etc.)

Vascular plants: plants with a vascular system; including herbs, shrubs, trees, ferns, vines, etc.