Present day plant communities as a legacy of Indigenous management over millennia

by

Kalina Hunter
B.Sc., University of Victoria, 2017

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We acknowledge with respect the Lekwungen peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

Supervisory Committee

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Abstract

Human activities have fundamentally shaped ecosystems across the globe. While this is often associated with degradation, cultures with alternative philosophies can leave a different kind of legacy. First Nations in the temperate rainforest of coastal British Columbia, like the Heiltsuk and Wuikinuxv, have inhabited the land for over 14,000 years, leaving behind tangible legacies in the plant communities we see today. From fine-scale effects of enriched plant leaves to landscape-level species distributions, this research investigates the ecological legacies of human land use and management—both past and present. In one chapter, I test if plants growing on ancient, human-modified soils are enriched in nutrients. I find that plants growing on these sites contain more phosphorus and sodium, which generally benefit fruit production and overall growth. This aligns with oral histories that describe fertilized shrubs as having berries that are bigger, healthier, tastier, and more productive. In the following chapter, I create models that predict the distribution of culturally important plants. With the Heiltsuk Integrated Resource Management Department, I develop a framework for habitat suitability modelling that can be used as a tool for aiding their resource management decisions. All models performed well (AUC = 0.9 overall), and offer insight into suitable habitat across a 3,600 km^2 area. Out of five predictor variables, distance to shore, site series (a vegetation index), and human influence contributed the most to model performance. This research contributes a practical tool for resource management and adds to the growing body of interdisciplinary knowledge that uses scientific methods to answer questions of cultural significance. In a time of overlapping environmental crises—like climate change and biodiversity loss—it is important to be aware of the positive influence humans can have on the environment, and how this can offer a hopeful direction for resource management into the future.

Table of Contents

List of Tables

List of Figures

Acknowledgements

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Chapter 1: General Introduction

1.1 Human Land Use

Since before the industrial revolution, the narrative around humans and the environment has often been one associated with degradation (Crutzen, 2006; Dirzo et al., 2014; Tyagi et al., 2014). Land use changes such as habitat destruction and fragmentation, biodiversity loss, and alteration of nutrient cycles are common examples of how humans have transformed the Earth's surface (Foley et al., 2005; Hoekstra et al., 2005; Ellis et al., 2010; Venter et al., 2016; Shackelford et al., 2018). The damaging effects of these activities are widespread, and there are few places left today that are free from some form of human influence (Watson et al., 2018). However, there are alternative narratives to this story—examples of cultures in the past and present that interacted with their landscapes differently. Over thousands of years, Indigenous Peoples have cultivated philosophies, practices, and protocols that not only maintained but benefited their environments (Anderson, 2005; Deur & Turner, 2005; Turner, 2014; Mathews & Turner, 2017). This is evident through the abundance of complex management systems–developed from careful observation, adaptation, and intimate knowledge of the local environment—which are passed down over generations (Berkes, 1999). Cultures like these often leave a footprint that mimics natural processes and patterns, which resulted in the Western world seeing these landscapes as 'untouched' and 'pristine' wilderness for centuries (Denevan, 1992). Indigenous Peoples have been, and continue to be, active stewards and managers of the ecosystems they rely on, and this stewardship has received increased attention from researchers, conservationists, and governments over the past few decades (Bohensky & Maru, 2011). Their alternative systems and approaches are of great significance, particularly now, as collectively we face global crises around biodiversity loss, environmental exploitation, and climate change (Makondo & Thomas, 2018; Reyes-García & Benyei, 2019; Ellis et al., 2021).

1.2 Western Science & Indigenous Knowledge

Much can be learned from the Coastal First Nations of central British Columbia (B.C.), Canada, where thousands of years of continuous occupation has fostered the prosperity of both people and ecosystems (Deur & Turner, 2005). The ecological and cultural richness of this landscape has attracted many researchers, with Western science awakening to the inherent value of Indigenous knowledge (Kimmerer, 2002). Working together, these two systems of knowledge can create complementary insights and directions, often greater than the sum of their parts (Ban et al., 2018; Salomon et al., 2018; Reid et al., 2020). Using science as a tool to answer culturally relevant questions is the cornerstone of this work, which fits into the larger body of research conducted in this area, done in service to and in partnership with First Nations (Adams et al., 2014; Service et al., 2014; Armstrong & Veteto, 2015; Artelle et al., 2018; Salomon et al., 2018; Ban et al., 2018; Beveridge et al., 2020; DeRoy et al., 2021; Kitasoo/Xai'xais Stewardship Authority, 2021). Integrated approaches that weave together multiple knowledge systems emphasize a respectful, ethical, and equitable research process for all parties involved (Kitasoo/Xai'xais Stewardship Authority, 2021). Integrated approaches like this can broaden the capabilities of ecological research and resource management, and it is through this perspective that this thesis work was conducted.

1.3 People of the Central Coast

Delineated by the Pacific Ocean, the Central Coast of B.C. is one of the largest temperate rainforests in the world, characterized by its heavy rainfall and mild temperatures (Pojar et al., 1991; DellaSala et al., 2011). Highly productive and rich in biodiversity, this rugged interface of land and sea is characterised by islands, inlets, forests, mountains, and valleys. The Central Coast is home to four First Nations—the Kitasoo/Xai'Xais, Heiltsuk, Nuxalk, and Wuikinuxv—who have lived here since time immemorial (CCIRA, 2016). Archaeological evidence reveals at least 14,000 years of habitation (Gauvreau & McLaren, 2017; Mackie et al., 2018; McLaren et al., 2018), which translates to roughly 500 generations. It is through this extraordinary depth of time that people have modified the landscape with a variety of innovations and management systems. Inter-generational oral histories and archaeological evidence point to continuous and comprehensive use and modification of the landscape, despite being considered as ‘wild’ and ‘untouched’ by outsiders (Denevan, 1992; Deur, 2002; Mackie et al., 2011). A perceptive and nuanced study of subtle cultural cues reveals archaeological features and physical records of habitation in abundance (Carlson, 1979; Cannon, 2000; Mackie et al., 2011; McLaren et al., 2015, 2018). Places of long-term use and occupation (referred to as habitation sites from here on) often contain material records of shell, bone, charcoal, ash, and organic matter (Ceci, 1984; Roksandic et al., 2014). Other physical features include fish traps, sea gardens, culturally modified trees, pictographs, burial cairns, and stone tools, among others (Deur & Turner, 2005). Signals of human influence can also be found in the vegetation through the organization of berry patches, orchards, and root gardens (Turner et al., 2013).

1.4 Culturally Important Plants

Coastal First Nations in the Pacific Northwest have used more than 300 plant species for food, medicine, and material—hereafter referred to as culturally important plants (Deur & Turner, 2005; Nolan & Turner, 2011; Joseph, 2021). Cultivation practices such as selective harvesting, replanting, digging and tilling, weeding, sowing, transplanting, pruning, and burning are examples of techniques employed by First Nations to modify plant communities (Turner & Cocksedge, 2001; Turner et al., 2013). Throughout this continued occupation, some land use practices have altered biodiversity (Fisher et al., 2019; Armstrong et al., 2021), increased functional trait diversity (Armstrong et al., 2021), and enriched forest productivity (Trant et al., 2016; Hoffman et al., 2017). Based on ecological and cultural criteria, these management techniques were often directed at a specific plant species to encourage their abundance and productivity (Deur & Turner, 2005). This species 'favouritism' has resulted in the persistence of many culturally important species that remain a central focus in coastal First Nations' livelihoods today.

1.5 Thesis Objectives

This research is focused on culturally important plants and their relationship to people—past, present, and future. It intends to illustrate how, traced through the thread of time, ancient Indigenous activities have produced significant present day benefits, affirming how contemporary actions guide and sustain future generations. In the following chapters, I investigate how humans have influenced plants at multiple scales—from leaf tissues to the distribution of species across the landscape.

- In Chapter Two, I investigate if plants are enriched from growing in human-modified soil. I ask the question: *Do understory shrubs on habitation sites have higher leaf nutrient content than control sites?* Through a paired-site study design, I compare the leaf nutrient content of shrubs growing on habitation sites versus paired control sites. I hypothesize that shrubs growing on habitation sites will have higher phosphorus, calcium, and sodium than those growing on control sites. Higher nutrient content in plants generally translates to better growth and higher productivity (Barker & Pilbeam, 2007; Griffith, 2010).
- In Chapter Three, I developed habitat suitability models (HSMs) for culturally important plants as a direct response to management objectives from the Heiltsuk Integrated Resource Management Department (HIRMD). HSMs combine known occurrence data with a suite of environmental variables to predict habitat conditions for a species of interest (Guisan & Zimmermann, 2000; Pearson, 2010). The association between these variables creates a map of suitable habitat, which can help resource managers target their management efforts (Pearson, 2010). For this chapter, I ask a two part question: *Can I develop a user-friendly framework to model habitat suitability of culturally important plants across the Central Coast of BC?* and *What happens when I incorporate a cultural predictor alongside environmental ones?* In service to HIRMD, I developed a habitat suitability modelling framework using ArcGIS and Maxent, which is generalizable and reproducible for their needs. This work can help expand management capacity, particularly when handling resource extraction or development proposals that might overlap with sensitive habitats.

Throughout these chapters, I use nutrient analysis and spatial mapping as tools to answer culturally significant questions. Linking ancient practices with modern tools is a powerful way to manage culturally important plants for present and future generations. Not only is it inherently important that Indigenous Peoples have sovereignty over their territories through the management of cultural resources, but it is also of fundamental importance in facing many of the global crises today.

Chapter 2: Enriched Plant Communities as a Legacy of Long-term Indigenous Land Use

2.1 ABSTRACT

Human activities have fundamentally shaped ecosystems across the globe. While this is often associated with degradation, cultures with alternative philosophies can leave a different kind of legacy. First Nations in the temperate rainforest of coastal British Columbia have inhabited the land for at least 14,000 years, leaving behind tangible legacies from the depth of soils to the tops of trees. Locations of long-term human occupation and use—referred to as habitation sites—contain materials like shells, charcoal, and bones that continue to fertilize the plants we see today. Through a paired-site study design, I tested the hypothesis that understory shrubs on habitation sites will have higher nutrient contents than those on control sites (sites without material records of intense human habitation). Nutrient analysis was conducted on leaf tissues from three common understory shrubs—salal (*Gautheria shallon*), false azalea (*Menziesia ferruginea*) and red huckleberry (*Vaccinium parvifolium*)—all of which were growing on habitation and control sites. I find that plants growing on top of habitation sites contain higher phosphorus and sodium, which can translate to improved fruit production and plant growth. This research reveals that ancient activities can have present-day effects, and exemplifies how land use philosophies continue to benefit the land for future generations.

2.2 INTRODUCTION

We have fundamentally altered ecosystems across the globe (Crutzen, 2006; Dirzo et al., 2014). Human activities like industrialization can lead to degraded landscapes, leaving behind legacies like habitat destruction, pollution, and species declines (Foley, 2005; Hoekstra et al., 2005; Ellis et al., 2010). While this might be the predominant narrative in Western culture, there are alternative philosophies modelled by many Indigenous cultures, both present-day and in the past. Indigenous peoples have developed sophisticated land use practices that also leave a mark on the modern landscape, although they often go unnoticed due to their lack of physical structures or industrialized development (Deur, 2002; Anderson, 2005; Deur & Turner, 2005; Lepofsky & Lertzman, 2008; Turner et al., 2013). Places formerly seen as ‘untouched’ by humans are in fact steeped with human influence. Examples in coastal British Columbia (B.C.) include open oak savannahs maintained by prescribed fires (McCune et al., 2013; Hoffman et al., 2019), rocky beach slopes altered to maximize clam harvest (Groesbeck et al., 2014), and forest gardens planted and pruned to encourage biodiversity (Berkes, 1999; Deur & Turner, 2005; Turner et al., 2013; Armstrong et al., 2021). These human activities often leave a footprint that mimics ‘natural’ processes and patterns, which resulted in the Western world seeing these landscapes as ‘untouched’ and ‘pristine’ wilderness for centuries (Denevan, 1992).

These alternative philosophies and their legacies permeate the Central Coast of B.C., a remote region known for rugged temperate rainforests, waterways, and wildlife—far from industrial development. Ancient oral histories combined with an emerging body of literature demonstrate that these seemingly ‘wild’ landscapes are in fact embedded with human influence (Deur & Turner, 2005; Lepofsky et al., 2015; Trant et al., 2016; Hoffman et al., 2017; Fisher et al., 2019). First Nations here have inhabited the land for at least 14,000 years (Gauvreau & McLaren, 2017; Mackie et al., 2018; McLaren et al., 2018), leaving tangible legacies from the depth of soils to the tops of trees. Throughout this continued occupation, some land use practices have altered biodiversity (Fisher et al., 2019; Armstrong et al., 2021), increased functional trait diversity (Armstrong et al., 2021), and enriched forest productivity (Trant et al., 2016; Hoffman et al., 2017). Cultivation practices like selective harvesting, fertilization, tilling, transplanting, pruning, and burning are examples of techniques employed by First Nations to modify plant communities (Turner & Cocksedge, 2001; Turner et al., 2013). Fertilization was a common practice to promote plant productivity. Harnessing natural decomposition processes, people would intentionally discard waste products at the base of plants, incorporating seaweed, rotting wood, ash, clamshells, and animal remains into the soil (Deur & Turner, 2005). Controlled burning at mixed-severities was a common tool for modifying plant communities and successional stages, which has been employed across this landscape for at least 700 years (Hoffman et al., 2016, 2017). Practices like these are passed down over generations through oral histories and lived experiences, and continue to this day (Berkes, 1999). This rich history of stewardship has imprinted the modern landscapes we see today, particularly in plant communities, since they can act as indicators of site conditions and past use (Lepofsky & Lertzman, 2008).

Sites with a history of long-term habitation (referred to as ‘habitation sites’) often have material records left behind from years of seasonal or annual occupation (Ceci, 1984; Cook-Patton et al., 2014; Trant et al., 2016). Material records like shell, charcoal, ash, rock, bone, artefacts, organic matter, and other anthropogenic inputs are common constituents of habitation sites in the Central Coast (Ceci, 1984; Roksandic et al., 2014; McLaren, 2015, 2016). Most habitation sites are located along the shoreline for ease of access and proximity to both marine and terrestrial resources (e.g. root and clam gardens, shellfish and fish) (Waselkov, 1987). Shellfish are a significant component of coastal people's diets, which results in the repeated consumption and deposition of shells in the terrestrial environment (Cook-Patton et al., 2014). These shell deposits can be seen today as a physical record in the soil, referred to as *shell middens* (Cribb et al., 1988; Roksandic et al., 2014; Vanderplank et al., 2014). The term *midden* translates to 'refuse heap', implying that intentionally managed sites were haphazard accidents (Blukis-Onat, 1985; Balbo et al., 2011). This outdated term fails to recognize people as active agents of change, however it is used intentionally in this work to define the shell-filled extent of habitation sites. Also associated with habitation sites is the cultural use of fire, varying in scale from localized hearths to site-level burning for clearing (Lyons & Orchard, 2007; Hoffman et al., 2016). Other anthropogenic additions come from human refuse and waste, burials, products of animal husbandry, and intentional fertilization (Holliday, 2004). Each of these inputs can have enduring effects on soil, although the residence time may vary by material. For example, small ash particles might reside on annual time scales, whereas solid pieces of charcoal or shell can persist on decadal to millennial timescales (Demeyer et al., 2001). The combination of all of these materials can fundamentally alter the soil chemistry of these sites. These human modified and created soils are also known as anthropogenic soils, or *anthrosols*, when their original state has been significantly transformed by human activity (Eidt, 1977).

Habitation sites differ from their surrounding matrix for many reasons. Past use and material additions considerably alter local topography, nutrient concentrations, soil pH, and drainage potential (Smith & McGrath, 2011; Roksandic et al., 2014; Vanderplank et al., 2014; Trant et al., 2016). Central to this work is pH, which is a measure of hydrogen ions in the soil solution, ranging from acidic to neutral to basic (Mclean, 1983). Soil pH affects the availability of other ions, thereby influencing oxidation state, solubility, and important biological processes (Lambers et al., 2008). Notably, a pH closer to neutral allows nutrients to become more biologically available, which is favourable for plant growth (Mclean, 1983). The slow decomposition of shells allows for the persistent release of calcium (from $CaCO_3$), which can mitigate soil salinity and increase soil pH (Brady & Weil, 2002; Roksandic et al., 2014; Vanderplank et al., 2014). The historical use of fire leaves behind charcoal and ash, both of which increase soil pH, modify nutrient availability (especially of phosphorous), and enhance biological activities (Demeyer et al., 2001; Glaser et al., 2002). Sites with a higher pH and greater nutrient availability can offer pockets of favourable habitat for plants across the landscape (Sawbridge & Bell, 1972; Cook-Patton et al., 2014). Enriched soils that contain charcoal and higher levels of nitrogen and phosphorus are known to significantly increase plant growth and nutrition (Lehmann et al., 2003; Lambers et al., 2008). These conditions offer plants a refuge from the water-logged and nutrient-poor soils indicative of coastal temperate rainforests.

Habitation sites offer a unique opportunity to test hypotheses regarding human-nutrient inputs over long time scales and how this might be reflected in plant communities. At this eco-cultural intersection, a growing body of evidence suggests that long-term human activity alters plant communities (Cook-Patton et al., 2014; Vanderplank et al., 2014; Trant et al., 2016; Fisher et al., 2019). This study builds on work that focused on plant communities on habitation sites in the Central Coast of B.C. (Trant et al., 2016; Fisher et al., 2019). Both studies found that habitation site soils had higher pH (mean of 5.5 compared to 3.5 on control sites), nutrient content (specifically B, Ca, Mn, Na, P, Zn, inorganic C), cation exchange capacity, C:N ratio, and organic matter. Habitation sites tend to host plant communities with greater cultural importance and higher nutrient requirements (Fisher et al., 2019), while supporting taller and wider trees with higher wood calcium (Trant et al., 2016). These sites have been without intense occupation for at least 125 years, so it is notable that ancient human activities have present-day effects. This study aims to deepen this work by investigating the fertilization effect of habitation sites, specifically at the understory level. Through a paired-site study design, I compare habitation sites with control sites (nearby sites without a history of intense human occupation). I tested the hypothesis that understory shrubs on habitation sites will have higher nutrient contents than those on control sites. Phosphorus, sodium, calcium, and nitrogen are the main nutrients targeted for this analysis, since their origins in habitation sites are clear. Specific predictions are as follows:

- **P**: Plants on habitation sites will have higher P content than those on control sites. Excess P comes from anthropogenic inputs (waste, refuse, burials), wood ash, and soil organic matter (Holliday & Gartner, 2007; Carter & Cannon, 2018). Soil retention of P is long-lasting over geological time scales (Holliday & Gartner, 2007). Trant et al. (2016) and Fisher et al. (2019) found that soils on habitation sites had significantly higher P than control sites.
- **Na**: Plants on habitation sites will have higher Na content than those on control sites. Higher Na is associated with past human activities around food preparation and consumption (Wells, 2004; Holliday & Gartner, 2007). Higher cation exchange capacities of habitation sites suggests greater soil retention of Na (Brady & Weil, 2002). Trant et al.

(2016) and Fisher et al. (2019) found that soils on habitation sites had significantly higher Na than control sites.

- **Ca**: Plants on habitation sites will have higher Ca content than those on control sites. Excess Ca comes from discarded shells in the soil matrix. Slow decomposition of shells suggests a long-lasting input of Ca (Cox et al., 2020). Trant et al. (2016) and Fisher et al. (2019) found that soils on habitation sites had significantly higher Ca than control sites. Trant et al. (2016) also found that trees on habitation sites contained higher wood Ca than control sites.
- **N:** There will be no difference in N plant content between site types. Excess N comes from soil organic matter and marine-derived inputs like shells and fish carcasses. Soil retention of N is fleeting (Johnson, 1992). Trant et al. (2016) and Fisher et al. (2019) did not find a significant difference with N between site types.

If these nutrients are present in the soil and trees on habitation sites, this signal may also be measurable in understory vegetation. This research improves our understanding of the mechanisms behind nutrient inputs to plants, and reveals an ancient example of human land use enriching the landscape. This interdisciplinary work was enhanced by looking at a question through many different lenses, synthesizing ideas from ecological, archaeological, and cultural perspectives. An interdisciplinary approach is necessary for work done in cultural landscapes, which are more prevalent than people may realize—especially where industrial logging activities have not removed them from the landscape.

2.3 METHODS

2.3.1 Study Region

The study region is situated within the traditional territories of the Heiltsuk and Wuikinuxv First Nations on the outer coast of central British Columbia (B.C.), Canada (Figure 1). Located in the Hakai Lúxvbálís Conservancy, it lies within the largest protected area on B.C.'s coast. The study region is classified as a temperate rainforest ecosystem, specifically within the very wet hypermaritime subzone—the central variant of the Coastal Western Hemlock biogeoclimatic zone (CWHvh2; Meidinger & Pojar, 1991). The CWHvh2 receives some of the highest annual rainfall in B.C. (up to 4,000mm annually) and has a moderate climate with annual average temperature of 8^{o}C (Pojar et al., 1991). Excess water governs this hypermaritime environment, with cascading effects on soil and vegetation a driving force in shaping ecosystem function (Banner et al., 2005). These climatic conditions combined with local bedrock geology give rise to soils that are acidic, nutrient-deprived, and poorly drained (Banner et al., 2005). Quartz diorite/granodiorite is the dominant bedrock. It weathers slowly and contains few available nutrients. Soils in these forests are poorly drained podzols (B horizon mainly Al, Fe, and/or C) and folisols (thick organic materials) (Banner et al., 2005). All study sites were located in forests in the nearshore environment. Tree canopies are characterized by western red cedar *(Thuja plicata)*, western hemlock *(Tsuga heterophylla)*, yellow cedar *(Cupressus nootkatensis*), Sitka spruce *(Picea sitchensis*), and shore pine (*Pinus contorta*). Common understorey species include salal *(Gaultheria shallon)*, deer fern, *(Blechnum spicant)*, false azalea *(Menziesia ferruginea)*, lanky moss *(Rhytidiadelphus loreus)* and step moss *(Hylocomium splendens)* (Green & Klinka, 1994). Notably for this study, salal and false azalea are considered dominant shrubs, whereas red huckleberry is common but sparser.

2.3.2 Study Design

2.3.2.1 Site Selection

I conducted a paired-site study of habitation and control sites (eight each), sampling predetermined sites from Fisher et al. (2019) and Trant et al. (2016; Figure 1). The habitation sites exhibit a long history of human occupation as documented by archaeological records, and are defined by two main material characteristics: shell middens (>50 cm in depth) and signs of past fire (charcoal in soil, burn scars on trees; Trant et al., 2016; Hoffman et al., 2016, 2017). The control sites were selected on the basis of having similar productivity levels, forest structure, and site characteristics (slope, substrate, aspect, proximity to shore), but lacked shell middens and signs of fire (Trant et al., 2016). Each habitation site was paired with an analogous control site in proximity. As this place is a cultural landscape, and human use is not spatially discrete, it is not assumed that control sites were never used, but rather they were not used with the same intensity of habitation sites (i.e. having no material record of shell or fire, which was confirmed with archaeological surveys). That being said, it is also important to acknowledge the difference between plant cultivation sites (e.g. berry patches) and habitation sites (Deur & Turner, 2005). These likely existed in proximity to each other, however this is difficult to confirm. From an archaeological standpoint, cultivation sites are very difficult to detect because any physical clues or materials left behind are either ephemeral or patchy (D. Mathews, personal communication, July 8, 2021). Berry patches would likely contain small pockets of crush shell, ash, and elevated phosphorus, however this is marginal compared to the large footprint of habitation sites. So it is possible that the control sites could have overlapped with past cultivation sites, however, they still do not have a comparable intensity of use and remnant materials as the habitation sites.

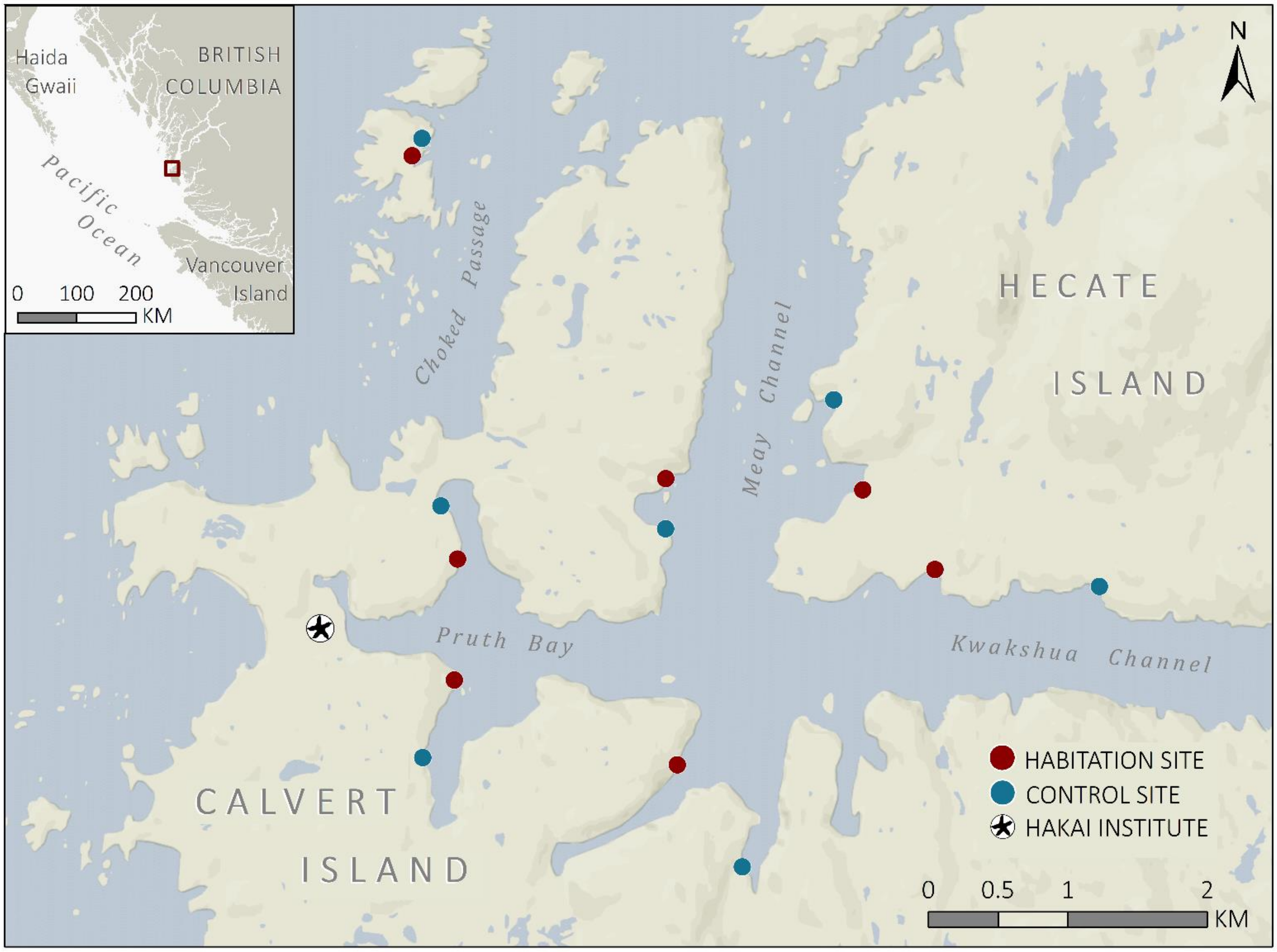

Figure 1. Map of the study region showing the locations of habitation (red) and control (blue) sites. Field work was based out of the Hakai Institute.

2.3.2.2 Species Selection

For leaf collection, three culturally important shrubs were targeted: salal (*Gautheria shallon*; nk̓vas in Haíłzaqv; nk̓ʷàs in Oowekyala), false azalea (*Menziesia ferruginea*; ƛ̓ṇ́q̓ʷás in Haíłzaqv; ƛ̓ṇq̓ʷas in Oowekyala), and red huckleberry (*Vaccinium parvifolium;* ǧvádṃ in Haíłzaqv; ǧʷàt̓as in Oowekyala). These species were selected because they are culturally important and ubiquitous across habitation and control sites. Salal and red huckleberry have high cultural importance, particularly for their berries (Turner, 1995). While false azalea's fruit is an inedible capsule with little cultural significance, it often hosts a prized fungus (*Exobasidium sp. affin. vaccinia*; p̓sp̓iy̓ú yis l̲u̯áł in Haíłzaqv). Mimicking 'berries', *Exobasidium* is an edible, culturally important associate of false azalea (Compton, 1995; Pojar & MacKinnon, 2004). All three plants occur on nitrogen-poor, acidic soils (Klinka et al., 1989; Pojar & MacKinnon, 2004). Despite these requirements, salal is an excellent competitor and generalist due its extensive horizontal root system, often establishing dense thickets across a range of conditions (Weetman et al., 1989; Pojar & MacKinnon, 2004). False azalea and red huckleberry have sparser distributions and occur more obviously as individual shrubs. A main difference between these species is their plant type—salal is evergreen, false azalea is deciduous, and red huckleberry is 'mostly' deciduous as it can have evergreen young leaves (Pojar & MacKinnon, 2004). These species also have different fruiting phenologies (false azalea 'fruits', July – August; red huckleberry, July – September; salal, June – September), which may result in different foliar nutrient signals between species (Lepofsky et al., 1985; Chapin & Van Cleve, 2000). Comparisons will be made within the same species across treatments, so different fruiting times should not confound the results.

2.3.2.3 Sampling Design & Data Collection

Habitation and control sites were delineated prior to field sampling in ArcGIS. Since each habitation site differs in extent (width along the shoreline, length into the forest), polygons predefined by archaeology surveys were used to measure the extent of the shell middens (British Columbia Archaeology Branch, 2019). A matching extent was then assigned to the respective paired control site. For leaf collection, a plotless line intercept technique was implemented

(Coulloudon et al., 1999). This involved running three transects perpendicular to the shoreline, spaced at random intervals and buffered 5m into the forest to reduce any edge effect. Transect length varied according to shell midden length, where the largest site spanned 30m into the forest and the smallest site spanned 15m. Each transect had two plotless sampling points at predetermined random intervals. At each sampling point, the three focal shrub species were searched for within a 5m radius, moving in a clockwise fashion. 10g of leaves from the most recent growing season were collected (as per Van Den Driessche, 1974) and placed in coin envelopes surrounded by desiccant to reduce moisture. Leaf collection followed cultural protocols (i.e. never taking more than half; Brown & Brown, 2009) to be as non-destructive as possible. Samples were dried at 60^{o}C in a drying oven and sent to the British Columbia Provincial Analytical Laboratory for macronutrient analysis, which included combustion for total C, N, and S, and microwave digestion (ICP-MS) for all standard metals (Al, B, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, P, S, Zn).

2.3.3 Statistical Analysis

I used linear mixed effects models to evaluate intraspecies nutrient differences between paired habitation and control sites. All statistical analyses were performed using the R statistical software (R Core Team, 2017). Using the lme4 package (Bates et al., 2015), twelve models were created for each plant paired with each nutrient of interest (P, Na, Ca, N). Plant species were modelled separately, since their physiological response to nutrients are unique. All response variables were log-transformed to meet linear model assumptions, which was checked by analyzing residual plots. One outlier was removed because it contained uncharacteristically high nitrogen content, which was assumed to be a false reading. Following Trant et al. (2016) and

Fisher et al., (2019), I included random effects and nested individual site within site pair (habitation and control sites within close proximity). This is to account for any unexplained variability between sites, which is important since habitation sites differ in duration, intensity, and seasonality of use. The rest of the nutrients were explored for differences between site types, though these were a lower priority, since there were not concrete hypotheses for each.

2.4 RESULTS

Plants on habitation sites had higher phosphorus and sodium leaf content than control sites. There was no site effect for calcium and nitrogen (Figure 2).

Table 1. Summary of log-transformed model coefficients. A linear mixed effects model was computed for each species and nutrient, resulting in twelve models. Significant p values denoted by '*' if value < 0.05. Estimates associated with '*site type: habitation'* indicate effect size. Following Cohen (1988), effect sizes are deemed 'small' if >0.2, 'medium' if >0.5, and 'large if >0.8.

PHOSPHORUS (%)				
Species	***Fixed effects***	***Estimate***	***SE***	***p-Value***
Salal	Intercept (Control)	-1.98109	0.05377	**0.03 ***
	Site type: Habitation	0.18974	0.07604	
False Azalea	Intercept (Control)	-2.12207	0.06082	**0.01 ***
	Site type: Habitation	0.25699	0.08633	
Red Huckleberry	Intercept (Control)	-2.07783	0.04319	0.27
	Site type: Habitation	0.07082	0.06108	
SODIUM (mg/kg)				
Species	***Fixed effects***	***Estimate***	***SE***	***p-Value***
Salal	Intercept (Control)	6.3124	0.1084	**0.02 ***
	Site type: Habitation	0.4191	0.1533	

False Azalea	Intercept (Control)	7.5350	0.1265	**0.003 ***
	Site type: Habitation	0.6558	0.1795	
Red Huckleberry	Intercept (Control)	5.2611	0.1829	**0.01 ***
	Site type: Habitation	0.7686	0.2587	
CALCIUM (%)				
Species	***Fixed effects***	***Estimate***	***SE***	***p-Value***
Salal	Intercept (Control)	-0.72135	0.04409	0.21
	Site type: Habitation	0.08331	0.06235	
False Azalea	Intercept (Control)	-0.27002	0.05044	0.24
	Site type: Habitation	0.08835	0.07175	
Red Huckleberry	Intercept (Control)	-0.01512	0.05419	0.30
	Site type: Habitation	0.08230	0.07663	
NITROGEN (%)				
Species	***Fixed effects***	***Estimate***	***SE***	***p-Value***
Salal	Intercept (Control)	0.07223	0.05042	0.81
	Site type: Habitation	0.01741	0.07130	
False Azalea	Intercept (Control)	0.248368	0.037415	0.90
	Site type: Habitation	-0.006923	0.053104	
Red Huckleberry	Intercept (Control)	0.491065	0.066433	0.96
	Site type: Habitation	-0.004634	0.093950	

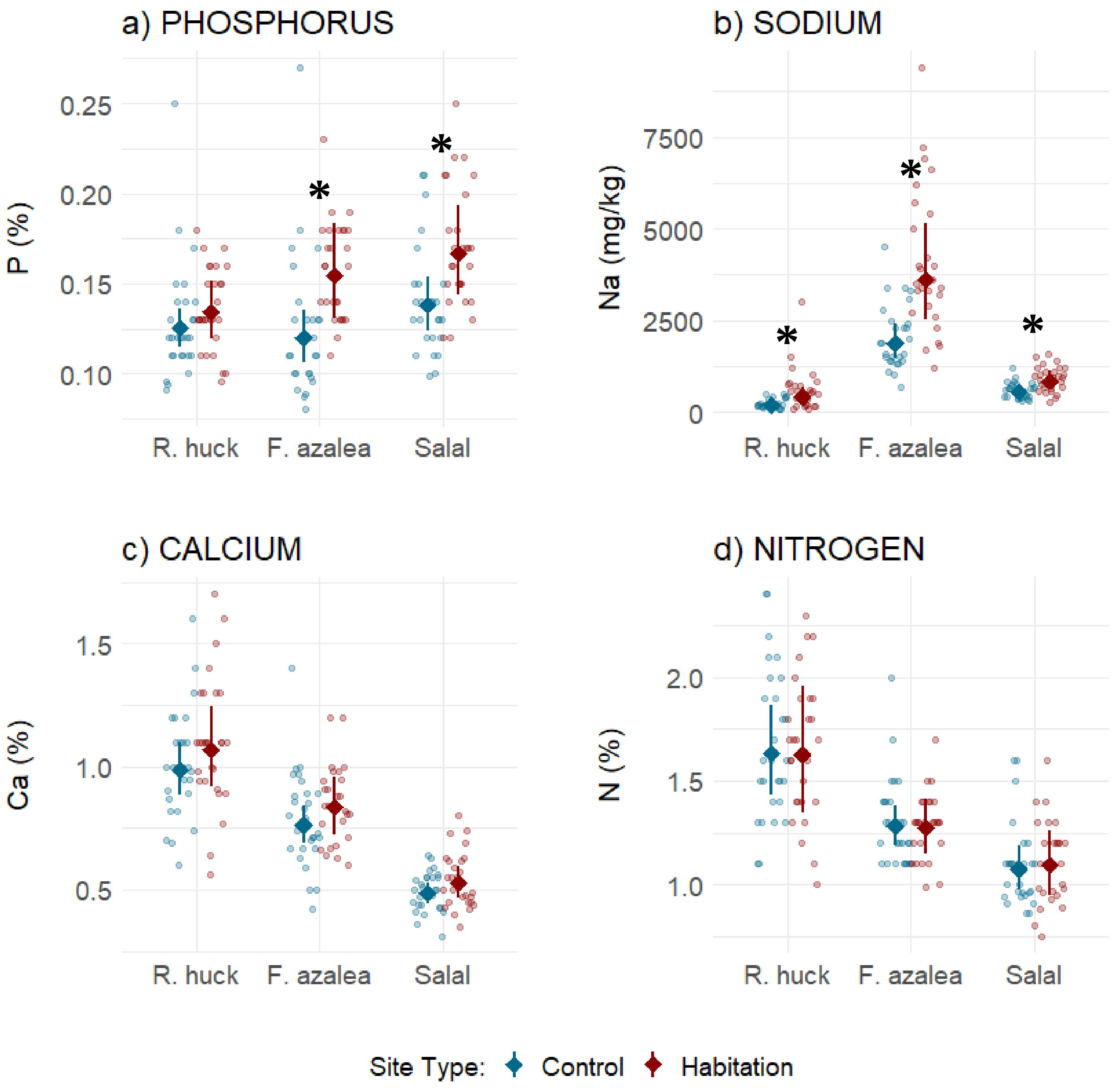

Figure 2. Modelled relationships between leaf nutrient content, species, and site type (control = blue, habitation = red). Habitation sites had (a) significantly higher phosphorus for false azalea and salal and (b) significantly higher sodium for all three species. There were no significant differences for (c) calcium and (d) nitrogen. Significantly different values are denoted by '*'. Diamonds are mean values and error bars represent 95% confidence intervals.

2.4.1 Nutrient Results

Phosphorus content was significantly higher on habitation sites for two of the three plant species (Figure 2a). The results reveal a significant difference ($p < 0.05$) between site types for salal and false azalea with small effect sizes (Table 1). There was no significant difference between site types for red huckleberry ($p = 0.27$), although the habitation site mean is modelled slightly higher (Figure 2a). Sodium content was significantly higher on habitation sites for all three plant species (Figure 2b). The results reveal a significant difference ($p < 0.05$) between site types for all three species, with effect sizes ranging from small (salal) to medium (false azalea and red huckleberry; Table 1). There were no significant differences for calcium or nitrogen content between site types for all species (Figure 2c/d). Although there is a trend of higher values on habitation sites for calcium, it is not significant (Table 1).

2.5 DISCUSSION

The tragic history of colonization and dispossession in this region has led to these habitation sites being without intense human occupation for over 125 years. Despite this, human habitation has left a legacy of beneficial soil conditions and, consequently, higher nutrient content in plants. Despite over a century since material inputs, there was a significant fertilization effect of nutrients on several important plants species, notably by phosphorus and sodium. I examine each of these nutrients in turn.

2.5.1 Phosphorus

Phosphorus content of plant leaves is higher on habitation sites for two of the three species sampled, which aligns with results from Trant et al. (2016) and Fisher et al. (2019). P is widely known as an important indicator of anthrosols, and its persistence in the soil over long time scales can be used to delineate archaeological sites (e.g. the P-spot test; Schlezinger & Howes, 2000). Anthropogenic inputs of waste, refuse, burials, animal husbandry, and intentional enrichment from fertilizers contribute to high soil P (Holliday, 2004; Holliday & Gartner, 2007). In plants, P is critical for photosynthesis, respiration, cell division, and cell growth—all functions that are essential for fruiting and overall plant development (Barker & Pilbeam, 2007; Griffith, 2010). Recognizing that every species responds uniquely to fertilization, there are a variety of growth factors associated with high P in plants: stimulated root development, improved stalk and stem strength, better flower formation and seed production, earlier plant maturity, increased resistance to disease, and improved development throughout life cycle (Griffith, 2010). Most relevant to humans is the fertilization effect on fruit. Berry shrubs have been intentionally managed (fertilized, pruned, burned) for millennia to increase berry quality and quantity (Deur & Turner, 2005). Oral histories reveal that intentional fertilization of shrubs produced berries that were bigger, healthier, more productive, and tastier than those left untended (Deur & Turner, 2005). While fruit measurements were not collected in this study, higher P content is known to improve quality and quantity of fruit for some species. Osman et al., (2014) found that peach trees (*Prunus persica L.*) fertilized with P had higher fruit and leaf nutrient content, which translated to increased vegetative growth, fruit yield, and fruiting measurements. Another study found that Cape gooseberry (*Physalis peruviana*) responded to N/P fertilization with increased fruit quantity, weight, and volume (Deepti et al., 2018). While people used to intentionally fertilize and cultivate plants on these sites, the patterns seen here are likely from ancient land use (both active and passive) and its associated inputs, which have not been intensely altered in 125+ years.

Phosphorous leaf content was higher in salal and false azalea on habitation sites, however there was no difference in red huckleberry P content between sites. All three species are from the heather family (Ericaceae) and share similar traits—they are generally shade-tolerant, associated with nitrogen-poor and acidic soils, characteristic of compacted (Mor) humus, co-occur with ericoid mycorrhizae, and commonly grow in coniferous forests, often on decaying wood (Klinka et al., 1989; Pojar & MacKinnon, 2004). Although there is no clear explanation for this difference among species, red huckleberry has some traits that may lend itself to lack of P uptake. Primarily, *Vaccinium* species are not known as strong competitors among ericaceous shrubs (BC Forest Practices Branch, 1997). Red huckleberry often grows on nutrient-poor nurse logs, so it is likely that its roots do not access the midden soil (Kennedy & Quinn, 2001; Pojar & MacKinnon, 2004). Phenological traits can also influence the timing of nutrient storage (Chao et al., 2015). Red huckleberry is 'partially' deciduous and its leaf nutrient content tends to peak at the beginning of the growing season (Tirmenstein, 1990). This could offer an explanation for its lack of high P content, since sampling may have taken place after this peak. Age structure, root morphology, and fruiting time of shrubs were explored to explain differences between species, however no reasonable explanations were found in the literature.

2.5.2 Sodium

Sodium content of leaf tissues is higher on habitation sites for all species, following soil Na results from Fisher et al. (2019). High Na is associated with past human activity, although its direct source is sometimes unclear (Holliday & Gartner, 2007; Schmidt et al., 2014). In a tropical rainforest context, Wells (2004) found anthrosols with higher Na and suggested it was related to food preparation and consumption. More specifically, Na has been associated with wood ash in hearths (Middleton & Price, 1996). Na could also be coming from the shell matrix, since clams, mussels, and cockles contain trace amounts of sodium oxide (Na_2O; Mohammad et al., 2017). Habitation sites have a higher cation exchange capacity (Fisher et al., 2019), which influences the soil's ability to retain nutrients—particularly cations like Na. Because of this, Na is less likely to be leached from the soil, which might explain its lasting signal in the soil and plants alike (Brady & Weil, 2002). As plants growing in a coastal environment with heavy salt spray, they have likely adapted a salt tolerance. Unlike the essential nutrients included in this analysis, Na is nonessential for most plants in growth, development, or reproduction (Barker & Pilbeam, 2007). While excess Na can be toxic to plants, small amounts in moderation can be beneficial (Maathuis, 2014). For some species, Na is also associated with improved plant growth (i.e greater root and shoot biomass; Kronzucker et al., 2013). In some cases, Na can compensate for potassium (K) deficiency. Na can functionally replace K for certain enzymatic processes, since they share similar physical and chemical structures (Kronzucker et al., 2013). Notably, Trant et al., (2016) and Fisher et al., (2019) found significantly lower soil K at habitation sites, which could explain the heightened Na content in plants if they are trying to compensate for K deficiency.

2.5.3 Calcium

There is no difference in calcium leaf content between habitation and control sites across all species, which differs from Trant et al., (2016) who found higher levels of wood Ca in trees on habitation sites. Heightened Ca is expected from discarded shells in the soil matrix that slowly release calcium carbonate ($CaCO_3$) over long time scales (Cox et al., 2020). Ca has multiple roles in plant functioning, most notable are aiding with nutrient absorption, disease resistance, and growth and stability of stems (Littke & Zabowski, 2007; Fromm, 2010; El Habbasha & Ibrahim, 2015). Similar to how humans require Ca to develop strong bones, plants require Ca to strengthen cell walls (Hirschi, 2004). Considering the importance of Ca for wood formation and structure, it is possible any enhanced signal was missed by targeting leaf tissues rather than stems. It is also possible that the sample size was not large enough to capture this signal for Ca. While leaf tissues did not have heightened Ca, Ca still seems to play an important role as a facilitator of other nutrients (i.e. its presence can enhance the availability of others). In the soil, Ca raises the pH which improves bioavailability of nutrients in general (Brady & Weil, 2002). Similarly within plants, Ca facilitates the absorption of other nutrients, potentially aiding in the heightened P and Na signals discussed above (El Habbasha & Ibrahim, 2015).

2.5.4 Nitrogen

There is no difference in nitrogen leaf content between habitation and control sites across all species. Trant et al., (2016) and Fisher et al., (2019) also found similar N patterns. This was expected because N has a rapid turnover time in the soil, so without continual inputs, any enhanced signal is likely fleeting (Johnson, 1992). Any additional N inputs would come from elevated soil organic matter associated with habitation sites, accumulated from past human activities like waste disposal or intentional fertilization (Miller & Gleason, 1994; Stein & Farrand, 2001). Additionally, marine-derived N is found in plant tissues when there are vectors transporting marine materials across this interface. For instance, when bears and wolves drag salmon carcasses inland, creating a seasonal N pulse (Mathewson et al., 2003; Hocking & Reynolds, 2011; Reimchen & Fox, 2013). Compared to the slow leaching of calcium from shells or the persistent signal of phosphorus, N moves through its cycle over shorter time scales and is lost when there is no continuous input (Johnson, 1992).

2.6 CONCLUSION

Habitation sites offer a unique example of human-modified soils that are nutrient-rich and benefit the plant communities above (Cook-Patton et al., 2014; Vanderplank et al., 2014). Anthropogenic additions to the soil like shell, charcoal, ash, bone, and other organic wastes all contribute to soil with a higher pH and nutrients. This excess of nutrients is expressed in the plant communities above, specifically through greater phosphorus and sodium content in certain shrubs. Phosphorus, and sodium to some degree, are generally beneficial for fruit production and plant growth (Barker & Pilbeam, 2007; Griffith, 2010). Intentional fertilization of plants has been practiced by people for millennia, producing berries that were bigger, healthier, more productive, and tastier than those unfertilized (Deur & Turner, 2005). While these sites have not been intensely managed or fertilized for the last 125 years, the longstanding land use legacies remain.

Plants are an expression of long-term site conditions, distinct enough to be the basis for many indicator plant classification regimes (e.g. site series in BC’s Biogeoclimatic Ecosystem Classification; BC MFLNRORD, 2017). Ecological work like this focuses primarily on moisture and nutrient regimes, however it cannot always capture the complexity of cultural landscapes. A deep understanding of site history is imperative to any ecological work, since ancient activities can have contemporary effects. This work adds to the body of knowledge, both oral and written, that plants can be important indicators of ancient human activities, and that long-term human use of sites has an important impact on biodiversity patterns we see today. Through repeated occupation of at least 14,000 years (Gauvreau & McLaren, 2017; Mackie et al., 2018; McLaren et al., 2018), it is evident that coastal First Nations have developed land use practices that enriched nutrient-limited ecosystems. Habitation sites like this occur along coastlines globally, so this research may have generalizable implications about enriched nutrient signals in plants from long-term human occupation.

Chapter 3: Habitat Suitability Modelling of Culturally Important Plants on BC's Central Coast

3.1 ABSTRACT

Habitat suitability models have evolved to become useful tools for resource managers to predict species distributions. Nevertheless, many models fail to incorporate human influence, and if they do, it is often associated with disturbance or industrialization. However, there are alternative models of human influence that might alter a species distribution. For millennia, Indigenous peoples have developed sophisticated land use practices that leave a mark on the modern landscape, although they often go unnoticed due to their lack of physical structures or industrialized development. This is evident in the long-standing management techniques of the Heiltsuk First Nation in the Central Coast of British Columbia, Canada. In collaboration with the Heiltsuk Integrated Resource Management Department (HIRMD), I develop habitat suitability models to predict the distribution of culturally important plants. Using a combination of environmental and cultural variables, I create models for five culturally important plants. All models performed well (AUC = 0.9 overall) and offer insight for suitable habitats across a 3,600 km^2 area. For most models, distance to shore and site series (a vegetation index) were the most informative predictors for model performance. Human influence ranked third in all models, indicating that it is more important than other topographic variables commonly included in habitat suitability modelling (e.g. elevation and slope). These habitat suitability models are offered as a practical tool to expand management capacity and aid decision-making processes around cultural resources.

3.2 INTRODUCTION

Over the last two decades, habitat suitability models (HSMs) have been developed to predict species distributions across space and time, which can be a useful tool in resource management (Guisan & Zimmermann, 2000; Guisan & Thuiller, 2005; Pearson, 2010; Guisan et al., 2017). Based on niche theory (Hutchinson, 1957), the main goal of habitat suitability modelling is to outline the potential distribution of a species using climatic and ecological variables (Araújo & Guisan, 2006; Hirzel et al., 2006). HSMs combine known occurrence data with a suite of environmental variables to predict habitat conditions for a species of interest (Guisan & Zimmermann, 2000; Pearson, 2010). The association between these variables creates a map of suitable habitat, which can help resource managers target their management efforts (Pearson, 2010). The information provided by a HSM can help expand management capacity and add an additional layer to aid decision-making processes (Guisan et al., 2013).

HSMs continue to evolve with their increasing popularity in resource management, but their application has been largely focused on the natural sciences (i.e. climatic, topographic, and ecological predictors) and tend to overlook human influence (Pearson, 2010; Franklin, 2010, 2013; Guisan et al., 2013). Considering the extent to which humans have transformed the environment and altered species distributions (Ellis et al., 2010; Seddon, 2010; Ellis et al., 2021), human influence should not be overlooked. Unfortunately, when human influence is incorporated, it is often associated with disturbance, industrialization, or degradation (Guisan & Thuiller, 2005; Márquez et al., 2011; Molinos et al., 2018; Ellis et al., 2021). However, there are alternative models of human influence that might alter a species distribution—cultures with reciprocal relationships to the environment that have been co-evolving for thousands of years

(Smith, 2011). Indigenous Peoples have developed sophisticated land use practices that also leave a mark on the modern landscape, although they often go unnoticed due to their lack of physical structures or industrialized development (Deur, 2002; Anderson, 2005; Deur & Turner, 2005; Lepofsky & Lertzman, 2008; Turner et al., 2013). Ancient oral histories combined with an emerging body of literature demonstrate that these seemingly ‘wild’ landscapes are in fact embedded with human influence (Deur & Turner, 2005; Lepofsky et al., 2015; Trant et al., 2016; Hoffman et al., 2017; Fisher et al., 2019).

This is true on the Central Coast of British Columbia, a remote region known for rugged temperate rainforests, waterways, and wildlife—far from industrial development. First Nations have a deep history of inhabiting these landscapes for at least 14,000 years (Gauvreau & McLaren, 2017; Mackie et al., 2018; McLaren et al., 2018), developing sophisticated land use practices that modify their environment. Throughout this continued occupation, some land use practices have altered biodiversity (Fisher et al., 2019; Armstrong et al., 2021), increased functional trait diversity (Armstrong et al., 2021), and enriched forest productivity (Trant et al., 2016; Hoffman et al., 2017). Cultivation practices like selective harvesting, fertilization, tilling, transplanting, pruning, and burning are examples of techniques employed by First Nations to modify plant communities (Turner & Cocksedge, 2001; Turner et al., 2013). These practices contribute to habitat enhancement (e.g. weeding and tending existing root gardens) and habitat expansion (e.g. transplanting of crabapple trees)—both of which modify the ‘natural’ distribution of plants (Deur, 2002; Lepofsky & Lertzman, 2008). This species favouritism has resulted in the persistence of many culturally important plants—those used for food, medicine, and material—

that remain a central focus in coastal First Nations' livelihoods today (Deur & Turner, 2005; Nolan & Turner, 2011; Joseph, 2021).

The development of sophisticated land use practices and protocols over thousands of years is evident in the long-standing management techniques of the Heiltsuk First Nation. The Heiltsuk Integrated Resource Management Department (HIRMD) represents the stewardship branch of the Heiltsuk Nation located in Wágḷísla (Bella Bella), British Columbia. HIRMD manages the land, water, and resources within Heiltsuk Territory using an integrated Ecosystem-Based Management approach, which seeks to balance ecological, economic, and cultural values (HIRMD, n.d.). HIRMD has identified under their Strategic Plan (2013-2016) that they wish to expand their natural resource management and planning capacity, specifically with culturally important plants (W. Housty, K. Starr, & L. Reid, personal communication, September 17, 2018). Habitat suitability models offer a practical solution for expanding management capacity, particularly when managing resource extraction or development proposals (e.g. logging, dock licensing) that might overlap with sensitive habitats.

There are numerous methods, frameworks, and software for habitat suitability modeling, so the selection of software was done mindfully to accommodate HIRMD's goals. I use a combination of ArcGIS and Maximum Entropy (Maxent) software for data preparation and suitability modelling. Given the local context and specificity of this target, this project was driven by the following goals:

1. **Minimizing barriers** – I prioritized software that HIRMD is already familiar with (ArcGIS) and sought out new software that is open-source and user-friendly with easy to understand outputs (Maxent).
2. **Encouraging future use** – The habitat suitability model framework was designed with future use in mind. The step by step data preparation using ModelBuilder in ArcGIS can be easily mimicked with other datasets. While the data for this project are limited to outer island groups, Maxent has the ability to map beyond the study area, which was a priority for HIRMD.

I create multiple models of culturally important species and incorporate a human influence predictor as a proxy for management of plants. I also compare two model evaluation methods—data partitioning and independent data collection—to see how outputs differ. Ultimately, this project seeks to provide a foundation for HIRMD to build upon and use for their management objectives. Suitability modelling has largely developed through a natural sciences lens (Elith & Leathwick, 2009; Franklin, 2010; Antoine Guisan et al., 2013), but as this field evolves, interdisciplinary approaches are emerging. There are a growing number studies that incorporate cultural predictors or model culturally important species (Gaikwad et al., 2011; Yang et al., 2013; Baumflek et al., 2015; Benner et al., 2019; Prevéy et al., 2020; DeRoy et al., 2021), and this work fits into this body of literature. Humans are a part of ecosystems, therefore habitat suitability modelling should acknowledge and incorporate these human dimensions.

3.3 METHODS

3.3.1 Study Region

The study region spans the traditional territories of the Heiltsuk, Wuikinuxv, and Kitasoo/Xais'xais First Nations on the outer coast of central British Columbia (B.C.), Canada (Figure 3). It is located within the Great Bear Rainforest, which is one of the largest undeveloped tracts of coastal temperate rainforest with a unique Ecosystem-Based Management (EBM) regime (Price et al., 2009). EBM is a framework that seeks to balance human well-being and stewardship, ecosystem protection, and resource extraction, while giving more negotiating power to local First Nations (Great Bear Rainforest Order, 2016). The Great Bear Rainforest lies within the Coastal Western Hemlock (CWH) Zone as designated by the Biogeoclimatic Ecosystem Classification (BEC) system, and this study was restricted to the central variant of the very wet hyper maritime subzone (CWHvh2; Meidinger & Pojar, 1991). This zone is characterized by high levels of precipitation, a mild mesothermal climate, and in coastal areas and along waterways, large rainforest tree species like western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Sitka spruce (*Picea sitchensis*; Pojar et al., 1991).

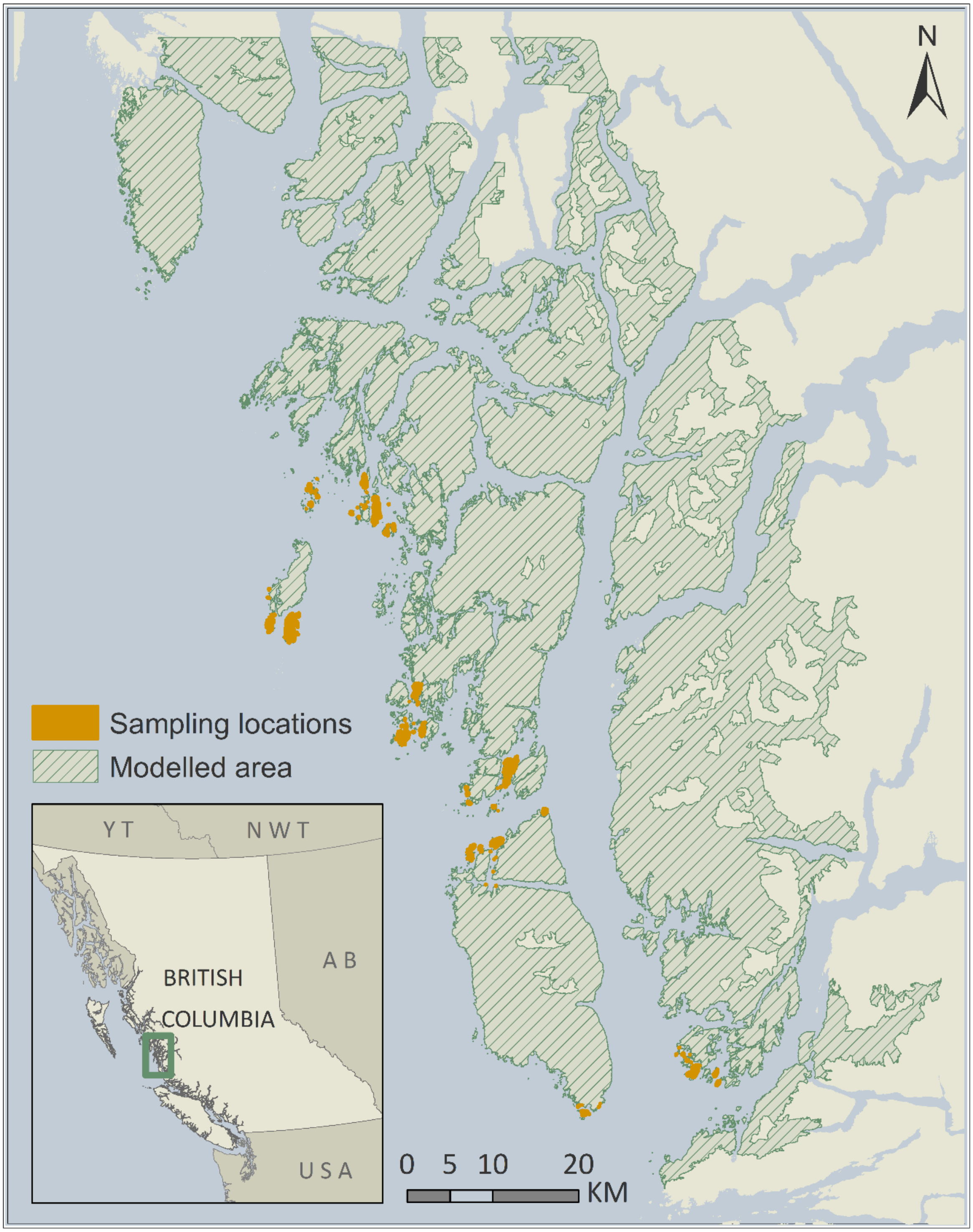

Figure 3. Map of the study area, located on the outer coast of central British Columbia, Canada. The study area was restricted to the central very wet hyper maritime subzone (CWHvh2) of the Coastal Western Hemlock biogeoclimatic zone (green striped area). This is because the sampling locations (orange) were limited to this zone, so modelling predictions beyond this zone would be inappropriate.

3.3.2 Software Selection

Habitat suitability modelling can be implemented in many different ways, so I purposefully selected software that would best accommodate HIRMD’s goals. ArcGIS (ModelBuilder) and Maxent were most suitable for this task, as outlined below.

3.3.2.1 ModelBuilder

ModelBuilder is an application in ArcGIS that helps create, edit, and manage models. As a visual programing language, it can be used to chain together sequences of processes and tools in a diagram (ESRI, n.d.). ModelBuilder was intentionally selected because the workflow is easy to follow, mimic, and share for HIRMD’s future use, and ArcGIS Desktop is their software of choice. Maxent has specific format requirements for data input, so ModelBuilder was used to prepare the predictor variables in ArcGIS. Each predictor was clipped to the same extent and converted to a 25m resolution raster file in the BC Albers projection. The ModelBuilder workflow is one of the deliverables for HIRMD, acting as a blueprint for future data preparation when they want to include other predictors.

3.3.2.2 Maxent

Maxent (short for ‘Maximum Entropy’), is a machine learning program that estimates habitat suitability based on presence records and randomly generated background points (Phillips et al., 2006; Phillips & Dudík, 2008). The maximum entropy principle posits that the best approximation of an unknown probability distribution is the one with the greatest entropy, i.e. the one that best reproduces the data (Phillips et al., 2006). Therefore the maximum entropy method calculates a probability distribution that best represents the data (species presences), as constrained by the environmental predictors. A species model is determined from a set of spatially explicit and overlapping environmental predictors, combined with sample locations where the species has been observed. The model then calculates the suitability of each pixel as a function of the environmental predictors at that location. As a presence-only method with no absence points, Maxent generates background points as an alternative. Background points are a collection of randomly sampled pixels within the study area grid that represent the full scope of environmental conditions within the data. The final output is a continuous raster grid with values from 0 to 1 representing habitat suitability, where each pixel represents a suitability value within that range (Phillips et al., 2006; Phillips & Dudík, 2008).

What once was a black box procedure, Maxent's settings have become increasingly customizable and accessible since its conception in 2004 (Phillips et al., 2017). Ultimately, Maxent was deemed the most appropriate software for this analysis due to its balance of accessibility (open-source and user-friendly) and scientific robustness. It only requires presence data, integrates continuous and categorical data, and offers robust results for small sample sizes compared to other modelling methods (Hernandez et al., 2006; Phillips et al., 2006; Elith et al., 2011). Parameters were customized before running the models, but the settings were consistent across all six models. Five out of the six models were partitioned using 70% of the presences as training data and 30% as testing data, while the last model used the independently collected data (which I explain in further detail in the following sections). Since some species had a small sample size and each point contained valuable data, the settings were adjusted to use samples with some missing data (the coarseness of the site series data skipped some presence points).

Auto features were kept as default, since Maxent will adjust feature types based on the number of training samples, which differed across models (e.g. linear, quadratic and hinge features are used for sample sizes of 15 to 79). The default number of background points (10,000) was kept and ‘write background predictions’ was included so that the model produced customizable output files (see Figure 4). The ‘cloglog’ output was applied because it offers the simplest estimate of occurrence probability, expressed as habitat suitability on a 0-1 scale. The remaining settings were kept as default.

Maxent produces a range of metrics to evaluate how well the models performed (i.e. predictive accuracy). To evaluate and compare models, I examined model performance (area under the curve: AUC), species response functions, and predictor variable contributions. AUC is a measure of predictive accuracy that describes the model’s sensitivity (correct positive predictions) and specificity (proportion of correctly predicted absences) (Merow et al., 2013). On a scale of 0 to 1, a value of 0.5 indicates the model is no better than random, and values increasing towards 1 indicate better model performance (Mandrekar, 2010). The species response functions plot the predicted value (i.e. the estimation of species presence) against each predictor. Predictor variable contributions reveal which predictors are most important for the model and their percent contribution.

3.3.3 Data Collection & Preparation

3.3.3.1 Plant Presence Data

The plant presence data used in this study were collected by researchers as part of the 100 Islands Project—a three year biodiversity survey that sampled 100 small islands in the Central

Coast of B.C. (Fitzpatrick, 2018; Miller, 2019; Obrist et al., 2020). Sampling was focused on the coastal margin of an island (from shoreline to 40m into the forest), but also included one or more interior plots depending on island size. This sampling effort resulted in a database of 91 plant species. Five species were selected for modelling due to their high cultural importance, relatively specialized niches, and enough presences (>30) for an appropriate sample size (Table 2). These include northern rice root (*Fritillaria camschatcensis*; xvúk̓vás in Haíłzaqv; xʷùk̓ʷas in Oowekyala), salmonberry (*Rubus spectabilis*; ğúl̓ás in Haíłzaqv; ğùl̓as in Oowekyala), devil’s club (*Oplopanax horridus*; wíq̓ás in Haíłzaqv; wìq̓as in Oowekyala), Pacific crabapple (*Malus fusca*; łṇ́x̌ in Haíłzaqv; łṇ́ṇ́x̌ in Oowekyala), and western yew (*Taxus brevifolia*; λ̓ṃ́q̓ás in Haíłzaqv; λ̓ṃ́q̓as in Oowekyala). One species was used to illustrate how the model would perform with a small sample size (devil’s club, n = 17). To control for pseudoreplication, all presence points were resampled to ensure only one occurred per 25m pixel.

3.3.3.2 Predictor Variables

Five predictor variables were included in the habitat suitability models (Table 3). Starting broadly, there are five main categories of environmental variable to include for plant modeling: topography, climate, substrate, vegetation cover, and disturbance (Ferrier et al., 2002). The environmental predictors were further specified based on habitat conditions of the study species (Klinka et al., 1989; Haeussler et al., 1990; Pojar & MacKinnon, 2004). For modelling over a regional scale (~3,600 km^2 with a 25m resolution), it was appropriate to use fine scale predictors (e.g. slope, site series), as opposed to large scale climate trends normally used in global models. The list of predictors were further narrowed by removing covariates and variables of low importance. To incorporate human influence, I used ‘distance to archaeological site’ as a proxy. I acknowledge it is an imperfect attempt to capture the role humans have played in shaping the distribution of plants. It oversimplifies the context and intentionality behind each of these culturally important sites, reducing each to a dot on a map. However, it was the best spatially explicit option available and still contains valuable information.

Table 2. Description of the five culturally important plants selected for this analysis. Ecological and cultural information are provided to contextualize their habitats (from Turner, 1995; Turner et al., 2013; Pojar & MacKinnon, 2004).

Species	**Life form**	**Cultural use**	**Ecological habitat**	**Cultivation practices *(that may influence distribution)***	**Number of presences in dataset**
Northern rice root	Herb	Food	Moist open sites, along shorelines and in meadows, estuaries, salt marshes, and tide flats	Enhanced by periodic burning, replanting, weeding, tilling, transplanting; patches owned by families/individuals.	48 (100 islands); 85 (GBIF)
Salmonberry	Shrub	Food	Moist/wet sites, along streams and on disturbed sites (e.g. logged areas)	Enhanced by periodic burning, pruning, fertilizing, selective harvesting; patches owned by families/individuals.	58
Devil's club	Shrub	Medicine, material	Moist forested sites, particularly in seepage areas and along streams	Enhanced by pruning, transplanting	17
Pacific crabapple	Tree	Food, medicine	Moist forests, swamps, along streams and ponds, beaches, and estuaries	Enhanced by pruning and coppicing; trees pegged to indicate ownership.	91
Western yew	Tree	Medicine, material	Sporadic in moist forests, along streams and wet slopes	Selective harvesting, transplanting	68

Table 3. Description of predictor variables included in the habitat suitability models.

Predictor name	Source	Description
Elevation	TRIM[1]	Elevation (m) is a continuous variable derived from a 25m resolution Digital Elevation Model (DEM), with values ranging from 0 – 1,000m in the study area.
Slope	TRIM	Slope (^{o}) is a continuous variable derived from a 25m resolution DEM, with values ranging from 0 – 90^{o}.
Site Series	MFLNRORD[2]	Site series is a categorical variable (50 classes) that classifies forested ecosystems and indicates sites capable of producing the same climax vegetation. These assessments are based on soil moisture and nutrient regimes, and are derived from a combination of field surveys and modelled predictive ecosystem mapping. It also contains classes that indicate anthropogenic or natural non-forested units (e.g. rocky outcrop).
Distance to shore	MFLNRORD	Distance to shore (m) is a continuous variable that measures Euclidean (straight line) distance, and was derived in GIS using a coastline polygon. This predictor is a proxy for microclimate.
Human influence	RAAD[3]	Human influence is quantified as distance to archaeological site (m), which is a continuous variable derived in GIS from point locations. This is a proxy for the intensity of management practices that influence plants (i.e. tending, fertilization, transplanting) that are assumed to be higher closer to archaeological sites. Sites included in the analysis are middens, culturally modified trees, clam gardens, fish features, cultural depressions, canoe skids, habitation features, and food harvesting sites.

[1] Terrain Resource Information Management
[2] Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
[3] Remote Access to Archaeological Data
All data are sourced from the Province of British Columbia.

3.3.4 Model Evaluation

Model evaluation can be carried out in two main ways: data partitioning and gathering independent data (Guisan et al., 2017). Data partitioning involves building the model with a randomly selected portion of the data (e.g. 70%) and testing it with the remaining portion (e.g.

30%). Five out of the six models were created using the 70/30 data partitioning method. The other option of gathering independent data is generally preferred for reducing sampling bias, however this can be expensive and time consuming if collected additionally (Newbold et al., 2010), and I did not have this option since the data were already collected as part of the 100 Islands Project. I include an additional model to demonstrate the independent data validation method using northern rice root data from the Global Biodiversity Information Facility (GBIF, 2021). GBIF offers a robust and accessible way for citizen science data to be incorporated into analyses like this. After cleaning the data, 85 reliable occurrences of northern rice root were compiled for model testing. Similarly to the training data, pixels were resampled to account for one presence per 25m pixel.

3.4 RESULTS

All six models performed well (AUC = 0.9 overall) and generated informative maps indicating where the most suitable habitat is for each species (Figures 5-9). Five models were created for five species that used the data partition method, and one additional model was created to compare model evaluation techniques. For northern rice root, the independent validation did not perform as well as the data partition method.

3.4.1 Model Performance (AUC)

All models produced predictions that were much better than random (i.e. AUC > 0.5). Despite subtle variation between models, all models generated AUCs around 0.9 (Table 4), which is considered excellent performance (Mandrekar, 2010). The higher the AUC, the better the model can reliably distinguish between suitable and unsuitable habitats (Mandrekar, 2010). The training AUCs are all higher than the testing AUCs, which is expected since models will fit best with the data they are calibrated with. Out of the partitioned models, the model with the best performance is salmonberry (AUC = 0.990). When comparing the partitioned method with the independently validated method for northern rice root, the former model performs best (AUC of 0.984 compared to 0.908).

3.4.2 Relationships Between Species & Predictors

All five partitioned models show similar responses to the predictor variables, since they share similar habitats (Figure 4). Generally, these results reveal that all five species are typically found at low elevations (less than 50m) and on moderate slopes (0^o to ~30^o). Considering the distance variables, all five species generally occur near the shoreline and in relative proximity to archaeological sites. Finally, most species are associated with a small proportion of site series vegetation classes. Most species are expected to occur with shoreline-associated classes, either vegetation communities associated with Sitka spruce or non-forested rocky outcrops. For five out of the six models, distance to shore and site series contributed the most to model performance (Table 4). Human influence ranked third in all models, although to a smaller degree contributing from 4.4 to 8.3%. With the exception of the devil’s club model, slope and elevation consistently contributed the least to model performance, with each contributing less than 3% (Table 4).

Table 4. Outputs for six models, which includes five species models using the data partition method, and one model (northern rice root) using the independent validation method for comparison. AUC values for both training and testing datasets are reported to indicate model performance, although the testing AUC is the most discerning.

Model	**AUC (training)**	**AUC (testing)**	**Variable contributions**
Northern rice root *(data partition)*	0.991	**0.984**	Distance to shore: 46.8% Site series: 45.6% Human influence: 5.6% Elevation: 1.6% Slope: 0.4%
Northern rice root *(independent validation)*	0.988	**0.908**	Distance to shore: 53.1% Site series: 40.4% Human influence: 4.4% Elevation: 1.1% Slope: 1%
Salmonberry *(data partition)*	0.991	**0.990**	Distance to shore: 49.2% Site series: 40.9% Human influence: 8.3% Elevation: 1.6% Slope: 0%
Devil's club *(data partition)*	0.996	**0.989**	Site series: 67.7% Elevation: 18.2% Human influence: 7.4% Distance to shore: 5.6% Slope: 1%
Pacific crab apple *(data partition)*	0.991	**0.985**	Distance to shore: 54.5% Site series: 35.9% Human influence: 6.7% Elevation: 2.9% Slope: 0%
Western yew *(data partition)*	0.989	**0.989**	Distance to shore: 51.5% Site series: 40.4% Human influence: 5.6% Elevation: 1.3% Slope: 1.2%

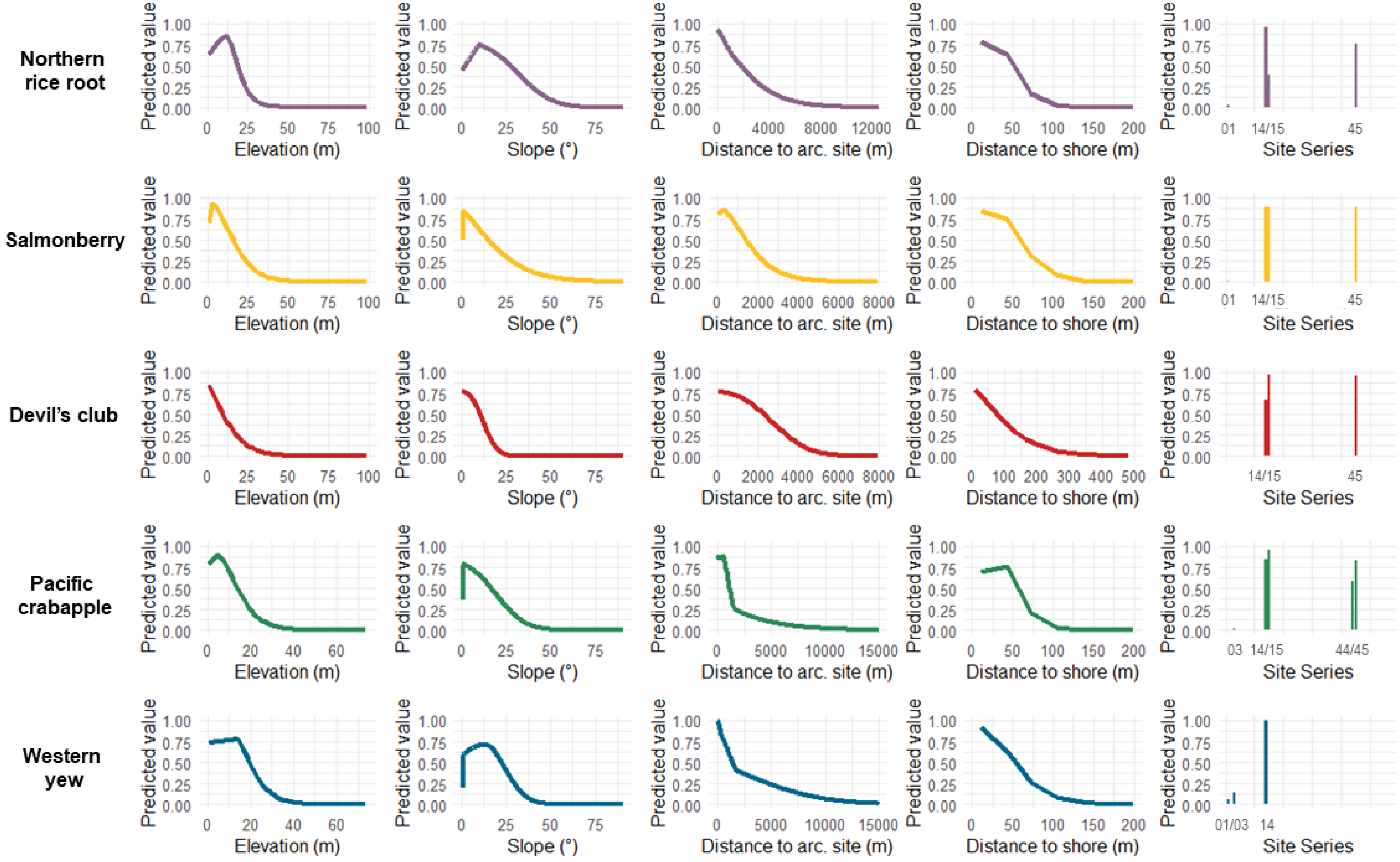

Figure 4. Response curves for the five partitioned models: (a) northern rice root, (b) salmonberry, (c) devil's club, (d) Pacific crabapple, and (e) western yew. Higher values on the y-axis indicate a higher habitat suitability for the corresponding variable on the x-axis. Note the x-axis values vary across species. All continuous variables are plotted as lines (elevation, slope, distance to archaeological site/human influence, and distance to shore). Site series is categorical and plotted as a bar chart, where vegetation classes are coded numerically (see Appendix for list of classes). Note the x-axis values vary across species

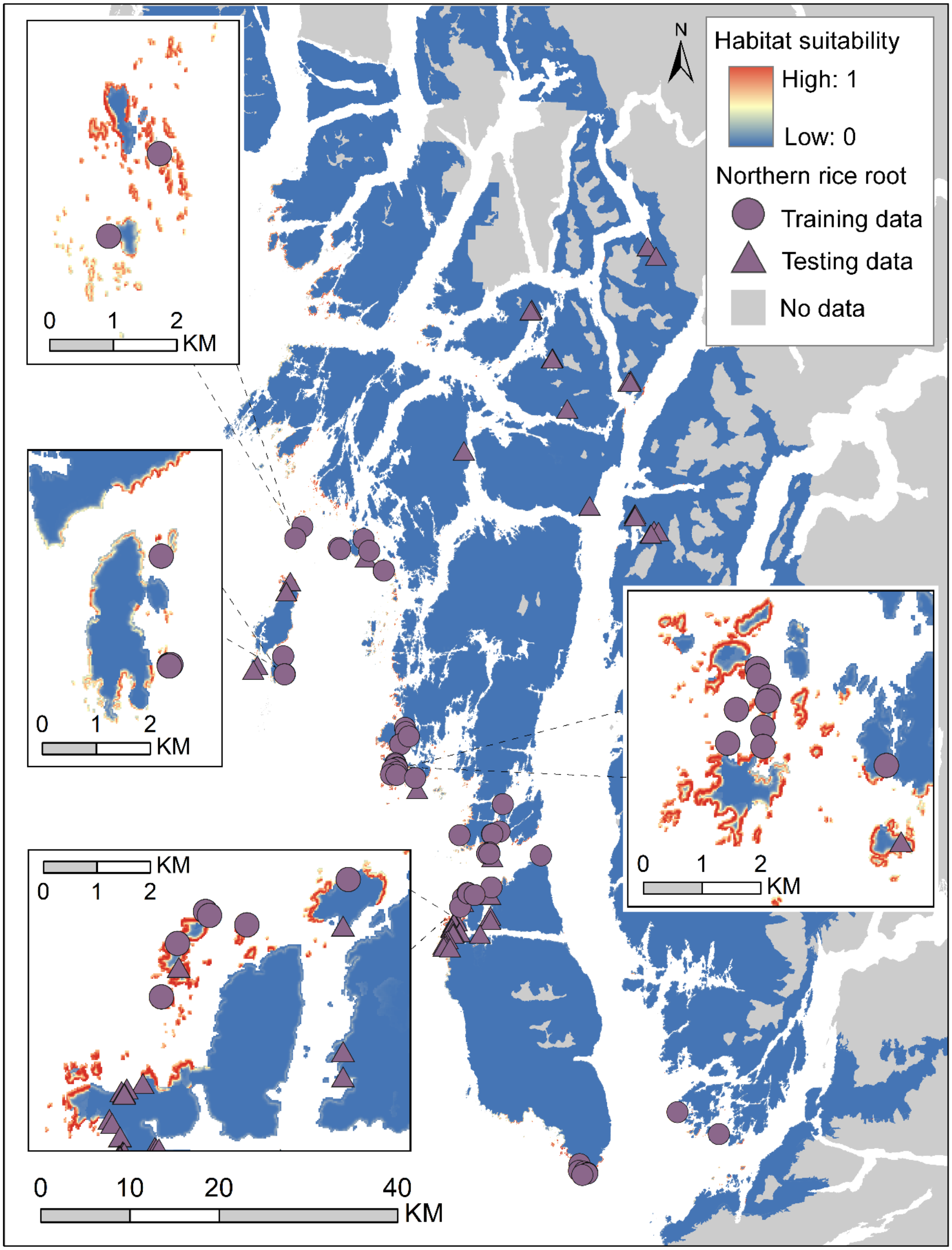

Figure 5. Predicted output for northern rice root across the study area, ranging from highly suitable (red) to non-suitable (blue). Purple circles are known presences of northern rice root from the 100 Islands survey data and purple triangles are independently collected presences from GBIF.

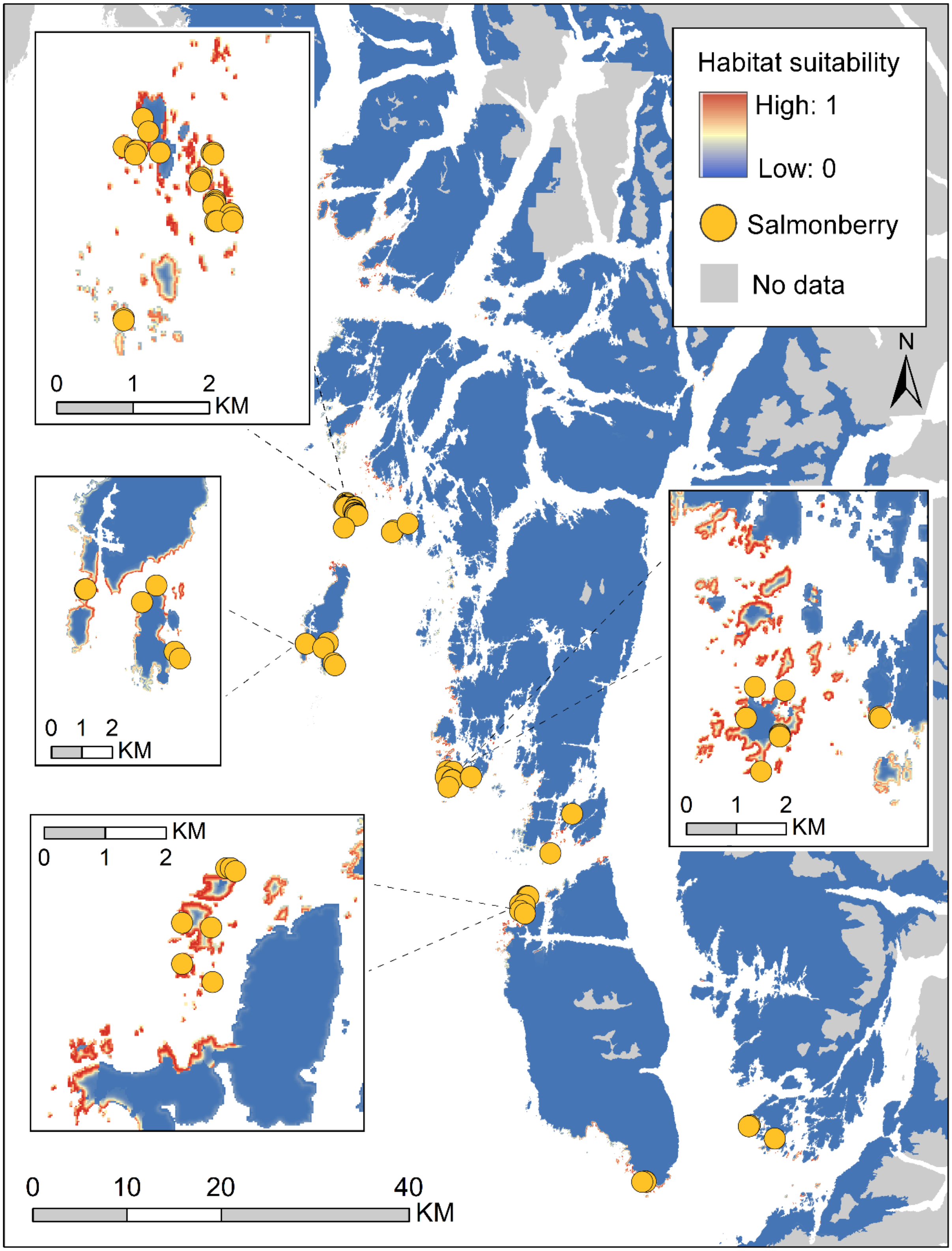

Figure 6. Predicted output for salmonberry across the study area, ranging from highly suitable (red) to non-suitable (blue). Yellow circles are known presences of salmonberry from the 100 Islands survey data.

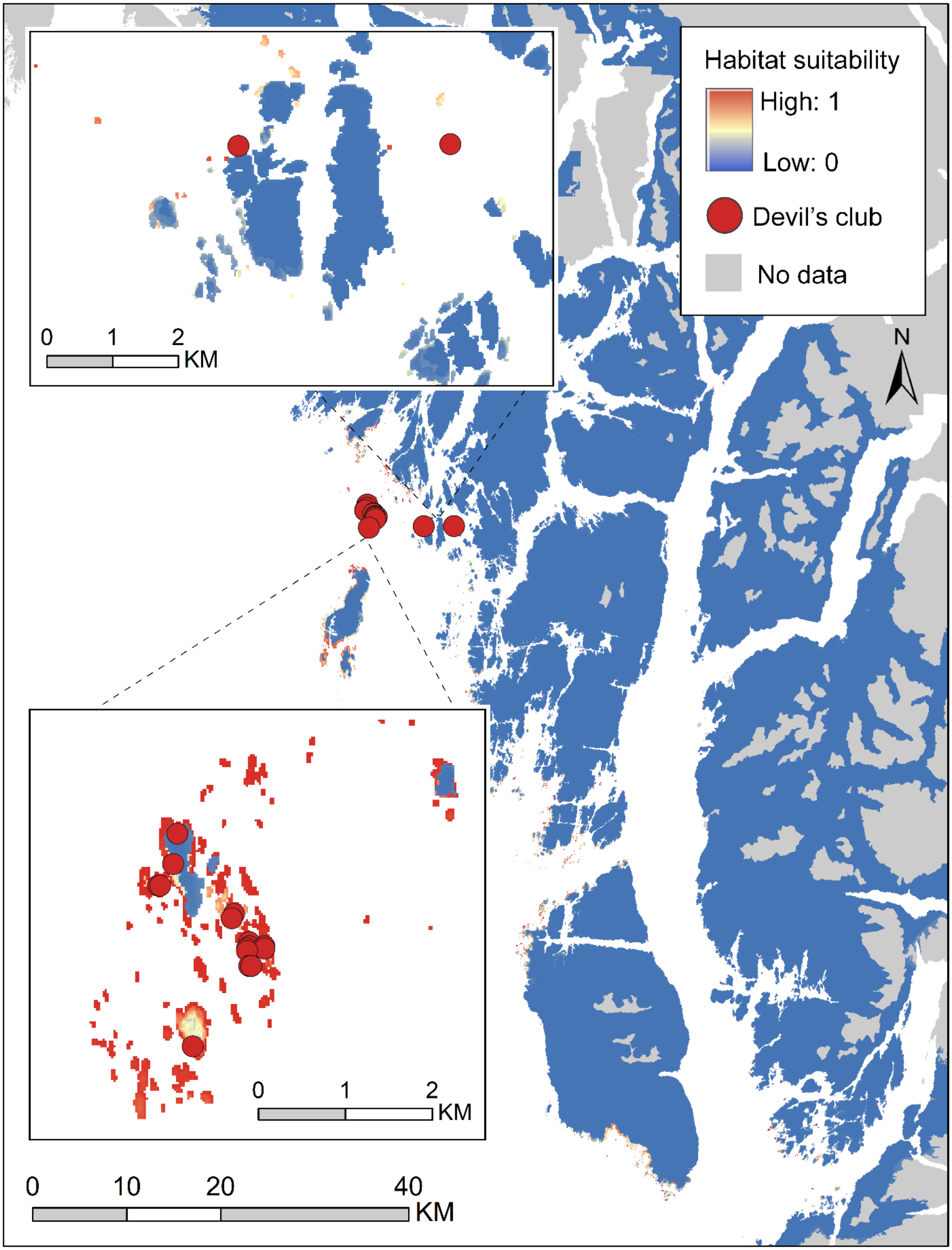

Figure 7. Predicted output for devil's club across the study area, ranging from highly suitable (red) to non-suitable (blue). Red circles are known presences of devil's club from the 100 Islands survey data.

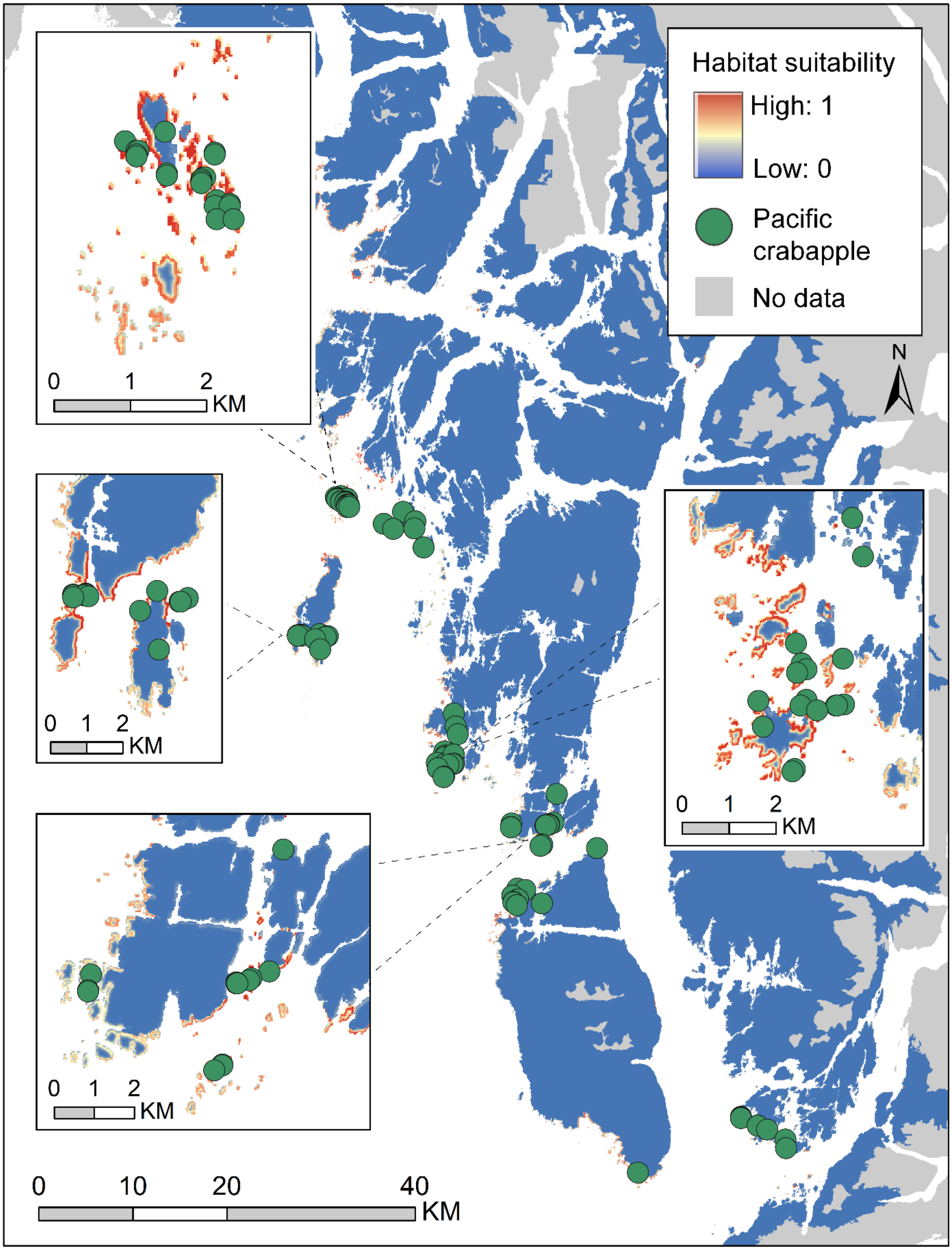

Figure 8. Predicted output for Pacific crabapple across the study area, ranging from highly suitable (red) to non-suitable (blue). Green circles are known presences of Pacific crabapple from the 100 Islands survey data.

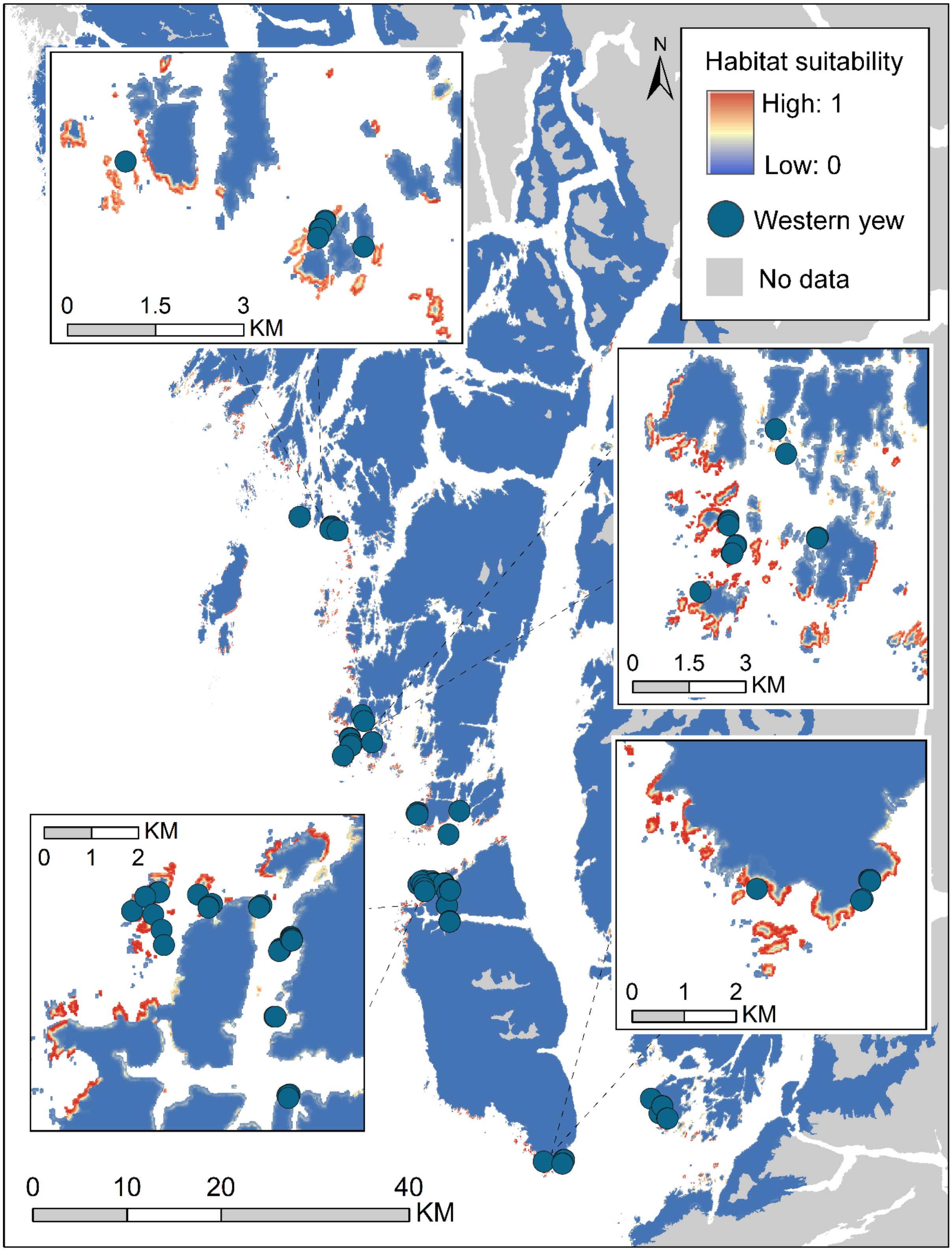

Figure 9. Predicted output for western yew across the study area, ranging from highly suitable (red) to non-suitable (blue). Blue circles are known presences of western yew from the 100 Islands survey data.

3.5 DISCUSSION

Overall, each model performed well (AUC = 0.9 overall) and offers insight into which variables best predict the habitat of culturally important plants. For most models, distance to shore, site series, and human influence contributed the most to model performance. All five species share similar habitats with some subtle differences, which is evident in the suitability maps produced across a 3,600 km^2 area. Navigating to islands in this remote coastal landscape is time-consuming, expensive, and individual islands are often difficult to access. These maps can be a useful tool for preliminary exploration and narrowing in on areas of interest before ground truthing.

3.5.1 Assessing Model Performance

Maxent is a presence-only modelling platform, and therefore has different assumptions compared to presence-absence methods (Phillips et al., 2006). Maxent has strong assumptions regarding sampling design of presence data—notably that sampling is random or representative of a landscape and that detection probability is constant across sites (Yackulic et al., 2013). The 100 Islands survey data used in this study generally meet the assumptions as they are robust, systematically sampled, and collected by knowledgeable experts. While not random, systematic sampling is expected to be representative of the study area (remote outer island groups). It is important to note that this study focused on the coastal margin of islands, and while there were still island interior plots, sampling is likely more representative of shoreline habitat. This is important to consider, since distance to shoreline was consistently the top predictor for most models. For instance, northern rice root commonly occurs in rocky outcrop habitats as well as estuarine marshes, which exhibit different characteristics. Since the input data were heavily focused on rocky outcrop habitat, this habitat type is likely more represented in the model output than the marsh habitat, as evident from the site series results. While all models were considered to have excellent performance, previous field experience or future ground truthing can aid judgement when interpreting results.

Sample size is also an important consideration when modelling, and a general rule of thumb is to have at least 30 samples (Guisan et al., 2017). Generally, larger sample sizes are better for more accurate results (Hernandez et al., 2006). Despite this, the devil's club model maintained high performance (AUC = 0.989) with a sample size of 17. Maxent is well-known for producing robust results with small sample sizes (Hernandez et al., 2006), so this is to be expected. However, the devil's club samples were restricted to a small geographic area, so confidence in the model predictions naturally decreases with distance from these inputs. Conversely, Pacific crabapple had the largest sample size (n = 91) and presence points spanned the entire study area. This combined with its high AUC gives us greater confidence in the model outputs.

3.5.2 Comparing Model Evaluation Methods

I tested two model evaluation methods—data partitioning and independent collection—to compare how well they perform with the same dataset. I used northern rice root as a test species to compare the different methods, and the partitioned model performed better than independent validation. This is expected, since independently collected data will be inherently different when compared to a subsampled dataset, so it should be interpreted with caution. Additionally, the

GBIF data extended beyond the study area of the training data. It was also more representative of northern rice root's estuarine and marsh habitat, compared to the rocky outcrop bias discussed above. The independent data validation still performed very well, and suggests that GBIF offers a useful, open source resource for test data.

3.5.3 Modelling Species Across a Cultural Landscape

It is important to consider site history when modelling across landscapes, moving beyond a strictly natural sciences approach and considering cultural influences. Human influence consistently ranked third in variable contributions for all models, signifying its importance in predicting habitat for culturally important plants. While it did not contribute the same magnitude of an effect as distance to shore or site series, it contributed more than slope and elevation—topographic variables commonly included in habitat suitability modelling (Ferrier et al., 2002; Guisan et al., 2017). Human influence was quantified as 'distance to archaeological site' as a proxy for past human management of plants, potentially altering their distribution patterns. I acknowledge that it is a broad predictor, since archaeological sites vary in intensity, type, and duration of use. However, it is the best spatially explicit option available and little is known about patterns and relationships between site types. For instance, food harvesting sites could seem more relevant to culturally important plants than fish features. However, human use of the landscape is not spatially discrete and management activities were often intertwined (Turner et al., 2013). If other measures of human use are suspected to be better, this modeling framework makes it easy to include them as predictors in updated models. A notable cultivation practice that would alter the 'natural' distribution of species is the transplantation of roots or propagules to another location (Lepofsky & Lertzman, 2008). This practice is well documented with plants like northern rice root, Pacific crabapple, stinging nettle, hazelnut, and cattail (Turner et al., 2013; Armstrong, 2017). Because of this, many culturally important plants are often indicators of old village sites (Turner et al., 2013; Fisher et al., 2019). In fact, many of the species included in this study are expected to be transplanted.

Another important caveat to consider is that the 100 Islands sampling protocol was designed to not disturb archaeological sites, out of respect for cultural protocols. Because of this, sampling did not take place directly on top of archaeological sites (to the best of our knowledge), might may introduce some bias within the human influence predictor. Despite this, archaeological sites are abundant across these island groups, and were likely adjacent to some of the sampling locations. A resolution of 25m is coarse enough that this should not influence results drastically.

3.5.4 Predicting Beyond the Study Area

Much of the study area lies within the Hakai Conservancy, so it has been mostly unaffected by industrial development or resource extraction. Activities like this can erase signs of past human influence and dramatically alter site conditions permanently (Goudie, 2018). Beyond the conservancy, much of the Central Coast falls under an Ecosystem-Based Management regime, which allows for resource extraction to occur. HIRMD plans to model habitat suitability throughout their territory, which is why it is important the models can be generalized beyond the study area. While Maxent creates a prediction for the entire area inputted to the model, confidence with model predictions is highest within the range of the testing dataset.

It is preferable to use data near the area of interest whenever possible, and the workflow created for this project makes it easy for additional presence data to be incorporated. The models will likely not have accurate predictions where intensive logging has already occurred, since site conditions can be significantly altered.

3.6 CONCLUSION

Areas under Indigenous management are among the most biodiverse in the world (Garnett et al., 2018; O'Bryan et al., 2020; Ellis et al., 2021), therefore Indigenous-led management may often be the most effective and ethical way forward for conservation (Artelle et al., 2018; Ban et al., 2018; Schang et al., 2020). The Heiltsuk First Nation has developed sophisticated land use and management practices over thousands of years, and this is represented today through the Heiltsuk Integrated Resource Management Department (HIRMD). Linking ancient principles and protocols with modern day tools can be a powerful strategy for managing culturally important resources. Habitat suitability models are offered here as a practical tool for predicting and mapping habitats of culturally important plants. Particularly in remote islands groups that are difficult to access, predictive models can aid the search effort. I designed a habitat suitability modelling workflow that can be mimicked and fine-tuned by HIRMD for future use. Using ArcGIS and Maxent software, I created a workflow that is user-friendly, open-source, generalizable, and offers robust results. I combined environmental and cultural predictors and used biodiversity survey data and open-source GBIF data to exhibit the diversity of datasets that can utilized. These models can be further enhanced through ground truthing, as well as increasing sample sizes and spatial coverage. This work can help expand management capacity, particularly when handling resource extraction or development proposals that might overlap with sensitive areas. Ultimately, habitat suitability models will allow HIRMD to better assess the current and potential distributions of culturally important plants in their territory.

Chapter 4: General Conclusion

4.1 Overview of Results

This research emphasizes the importance of considering human influence and past land use when interpreting the ecology of a site. These results highlight the ecological legacies that exist from previous use and occupation of the landscape, from enriched plant leaves to landscape-level species distributions. Through continuous occupation of the Central Coast of British Columbia for at least 14,000 years (Gauvreau & McLaren, 2017; Mackie et al., 2018; McLaren et al., 2018), First Nations have developed land use practices that enriched nutrient-limited ecosystems. The distribution of culturally important plants is associated with generations of cultivation and stewardship, which can be carefully mapped and managed for the subsistence of future generations.

In Chapter Two, I investigated the nutrient legacies on sites of intense human habitation, which contain unique materials that continue to change and improve soil conditions. Material additions like shell, charcoal, ash, rock, bone, artefacts, organic matter, and other inputs create unique site conditions, altering local topography, drainage potential, pH, and nutrient availability (Ceci, 1984; Cook-Patton et al., 2014; Roksandic et al., 2014; Vanderplank et al., 2014). Previous studies in this area found that habitation sites had higher pH (mean of 5.5 compared to 3.5 on control sites), nutrient content (specifically B, Ca, Mn, Na, P, Zn, inorganic C), cation exchange capacity, C:H ratio, and organic matter (Trant et al., 2016; Fisher et al., 2019). As a result, I found that plants growing on these sites had higher nutrient content than control sites, notably with phosphorus and sodium. Generally, these nutrients can enhance fruit production and overall plant growth (Barker & Pilbeam, 2007; Griffith, 2010). This research deepens work done by Trant et al. (2016) and Fisher et al. (2019), adding details regarding nutrient inputs at the understory level. First Nations have intentionally fertilized plants for millennia, knowing that it improves growth and productivity (Deur & Turner, 2005). This work offers finer detail regarding which nutrients continue to be elevated in plant tissues, despite more than a century without inputs.

In Chapter Three, I developed habitat suitability models for culturally important plants on remote islands across the Central Coast of British Columbia. Using a combination of ArcGIS ModelBuilder and Maxent software, I created models for five culturally important species using multiple evaluation methods to illustrate the breadth of modelling capabilities. Overall, each model performed well (AUC = 0.9 overall) and offers insight into suitable habitats across a 3,600 km^2 area. All five species share similar habitats, but the results reveal subtle differences in their potential distributions and predictor importance. Out of the five environmental and cultural predictors, distance to shore, site series (a vegetation index), and human influence contributed the most to model performance. For most models, human influence outranked slope and elevation—topographic variables commonly included in habitat suitability models (Ferrier et al., 2002; Guisan et al., 2017). I used repeatable methods, and developed a framework for the Heiltsuk Integrated Resource Management Department (HIRMD) to follow and modify for future use. Habitat suitability models are offered as a tool for managing cultural resources, particularly when HIRMD is managing development proposals near sensitive habitats. This project directly addresses HIRMD's desire for expanding management capacity around culturally important plants.

4.2 Methodological Limitations & Future Directions

For Chapter Two, one of the biggest limitations was the delineation of midden boundaries. Middens are patchy, since use of a landscape and deposition of materials is not always spatially homogenous (McLaren, 2016, 2015). My best attempt to remedy this was to use spatial polygons of midden extents defined by provincial archaeologists (British Columbia Archaeology Branch, 2019). I sampled within these boundaries using predetermined GPS points and took note of any exposed midden on the shoreline to best orient the sampling locations. My confidence in these site boundaries could have been improved if accompanied by an archaeologist, however this was not within the scope of the project. Another limitation of this study is the variation across habitation sites, since they all vary in size, duration, intensity, and time since last use. In addition, these metrics are complex to capture and it is difficult to glean information regarding continuity and intensity of site use through time. Despite this, these sites were mindfully selected by Fisher et al. (2019) and Trant et al. (2016) with the guidance of archaeologist Dr. Duncan McLaren to minimize these differences, and they are the best data currently available. Lastly, all species respond uniquely to nutrient inputs, and there was difficulty finding direct connections of specific nutrient additions and growth responses for the species in this study. I attempted to make general interpretations for growth responses across a genus, however it is speculative. For example, *Vaccinium sp*. can vary in their responses to nutrient additions (Grelet et al., 2001; Chester & McGraw, 2011). Future research would greatly benefit by measuring plant response (e.g. shrub height, biomass, sugar content of berries) in tandem with nutrient content in order to make direct linkages around growth, productivity, or quality.

For Chapter Three, I acknowledge that models are always a simplification of reality. As helpful as suitability models are, they cannot fully replace the detail provided in ground-based surveys. That being said, the models predict across an area of 3,600 km^2, which would be logistically challenging for ground surveys. I was also limited by the coarseness and quality of data available, which was at best 25m resolution. Some predictor layers were mismatched and did not always overlap, which resulted in Maxent dropping some species presences. Another limitation is the use of presence-only modelling methods, since they cannot offer a true representation of a species distribution without known absences (Yackulic et al., 2013). However, I prioritized Maxent's user-friendly interface to encourage future use for HIRMD, particularly since presence-only data are easier to gather. Not only do these models offer useful data and habitat insights for the five culturally important species, but they act as a blueprint for future modelling applications for HIRMD. The workflow created in ModelBuilder shows the steps required for data preparation, which can be easily mimicked if HIRMD wants to incorporate additional data. Future applications of these models could incorporate other species, either from the 100 Islands dataset or beyond. Additional predictors could be included, like distance to stream, other vegetation indices, solar radiation, or areas logged. The geographic range could also be extended with the incorporation of data from other areas. This habitat suitability modelling framework was crafted to encourage future use for HIRMD beyond the study area and example species.

4.3 Situating this Research

Integrated approaches around eco-cultural research have been increasingly adopted as a resolution to long neglected or misunderstood management practices (Henri et al., 2021).

Archaeological and biological research has a tarnished history of ignorance towards Indigenous cultures and practices, stemming from colonial mindsets in academia (Deur, 2002; Lightfoot et al., 2013). Consequently, historic accounts describe people as passive hunter-gatherers, interpreting passive and nomadic use of the landscape rather than sophisticated management practices (Deur, 2002; Lightfoot et al., 2013; Turner et al., 2013). While these false interpretations are now dispelled as myths, they reveal consistent patterns of bias and oversight that linger in ecological research today (Deur, 2002). Schang et al. (2020) reveal there is still a general lack of acknowledgement, consideration, or inclusion of Indigenous Peoples in ecological research. As a result, many ecological studies may fail to capture ecological legacies associated with past management, and might confound modified sites with 'wild' spaces. Fortunately, integrated and interdisciplinary approaches are increasingly being employed (Henri et al., 2021). This research contributes to this growing body of knowledge that seeks to offer depth of understanding around cultural influences in ecology.

Despite the many challenges facing conservation today, it is clear that Indigenous-led approaches are key to successful initiatives (Gadgil et al., 1993; Garnett et al., 2018; Reyes-García & Benyei, 2019; O'Bryan et al., 2020; Ogar et al., 2020). While acknowledging the damaging legacies of colonialism and dispossession, we are in a hopeful time of Indigenous resurgence and cultural revitalization (Joseph, 2021). In the face of change and uncertainty, traditional management systems have proven to be dynamic and adaptive over thousands of years (Berkes, 1999; Makondo & Thomas, 2018). Globally, areas under Indigenous management are among the most biodiverse (Gadgil et al., 1993; Wilder et al., 2016; Ogar et al., 2020), underlining the need for an equitable shift in conservation and offering a hopeful direction for balanced and harmonious resource management into the future.

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Appendix

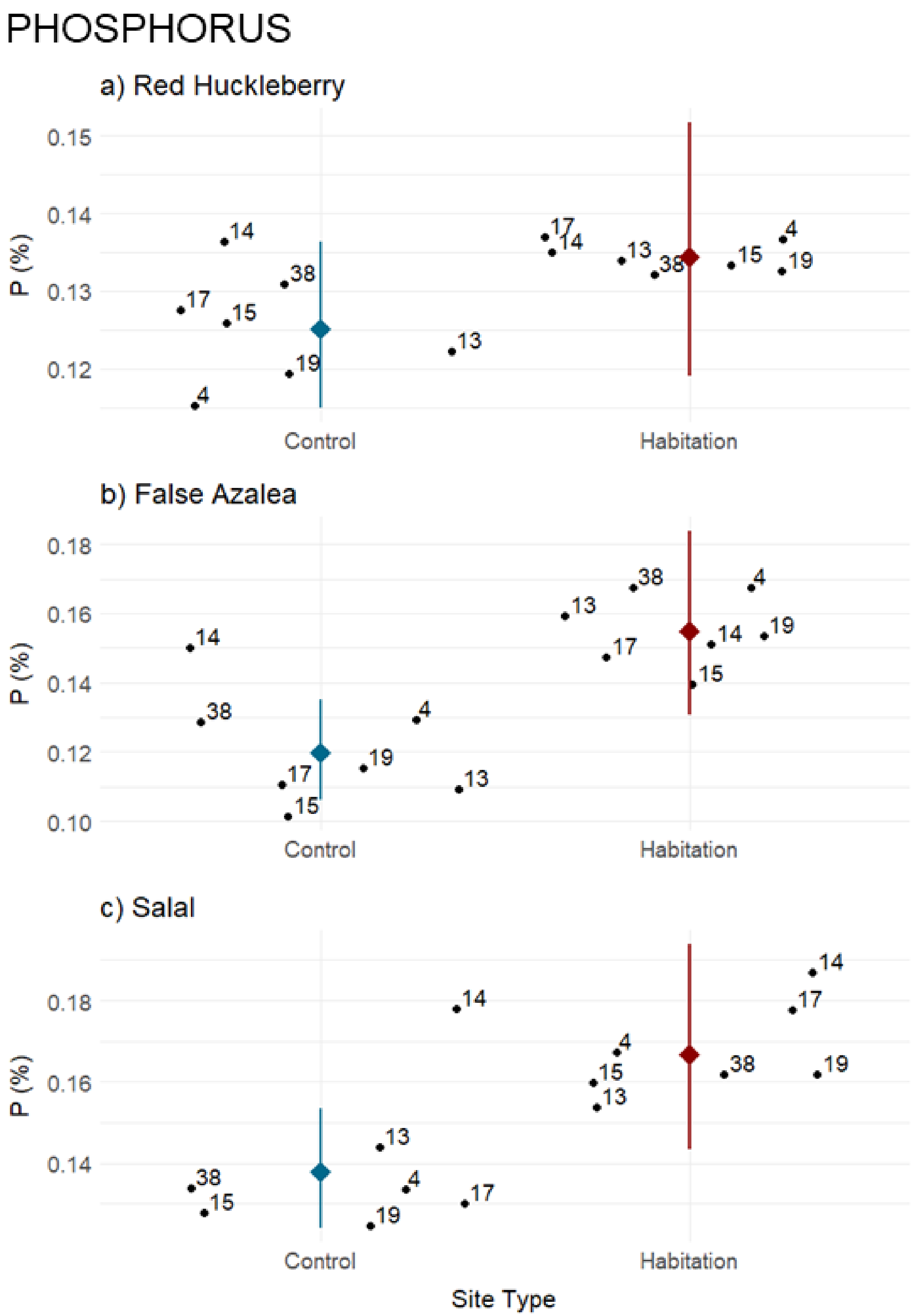


Figure A1. Modelled relationships between phosphorus leaf content and site type (control = blue, habitation = red), with site averages plotted as points. Results are divided by species for a) red huckleberry, b) false azalea, and c) salal. Specific site averages are plotted alongside models, where each number corresponds to the site's name (e.g. EjTa14 = 14; EkTa38 = 38). Control sites are assigned the same number as their paired habitation site. Diamonds are mean values and error bars represent 95% confidence intervals.

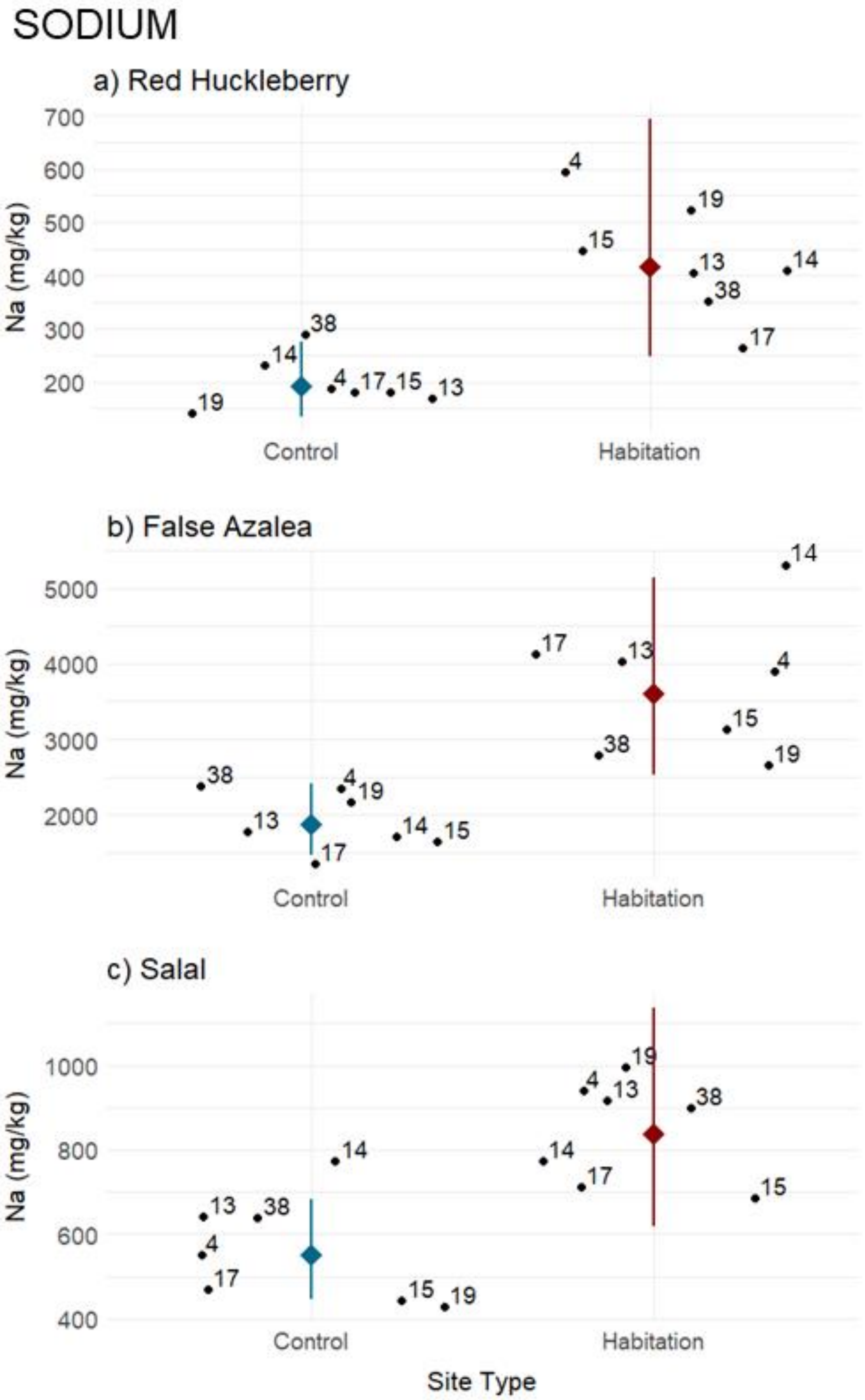


Figure A2. Modelled relationships between sodium leaf content and site type (control = blue, habitation = red), with site averages plotted as points. Results are divided by species for a) red huckleberry, b) false azalea, and c) salal. Specific site averages are plotted alongside models, where each number corresponds to the site's name (e.g. EjTa14 = 14; EkTa38 = 38). Control sites are assigned the same number as their paired habitation site. Diamonds are mean values and error bars represent 95% confidence intervals.

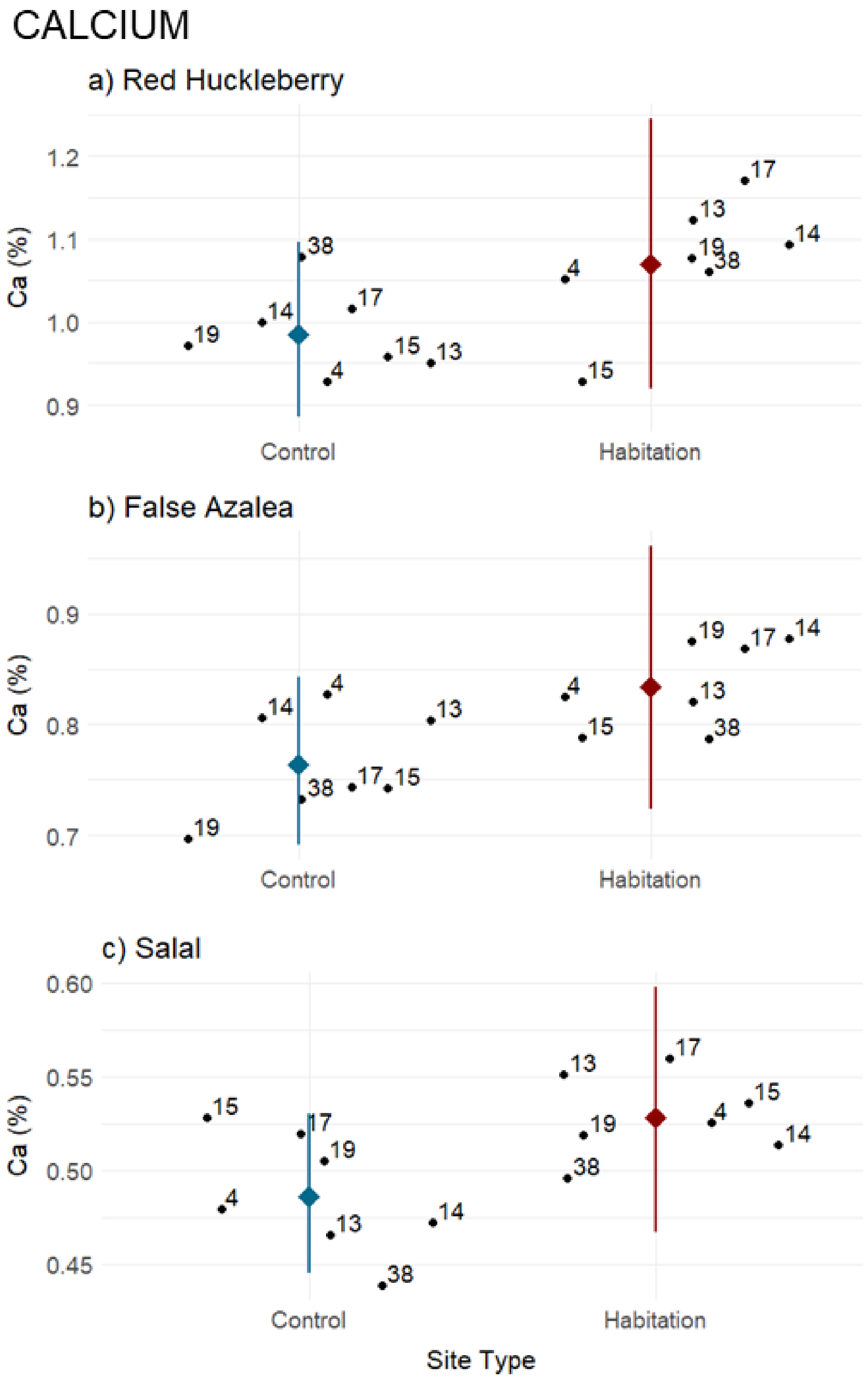


Figure A3. Modelled relationships between calcium leaf content and site type (control = blue, habitation = red), with site averages plotted as points. Results are divided by species for a) red huckleberry, b) false azalea, and c) salal. Specific site averages are plotted alongside models, where each number corresponds to the site's name (e.g. EjTa14 = 14; EkTa38 = 38). Control sites are assigned the same number as their paired habitation site. Diamonds are mean values and error bars represent 95% confidence intervals.

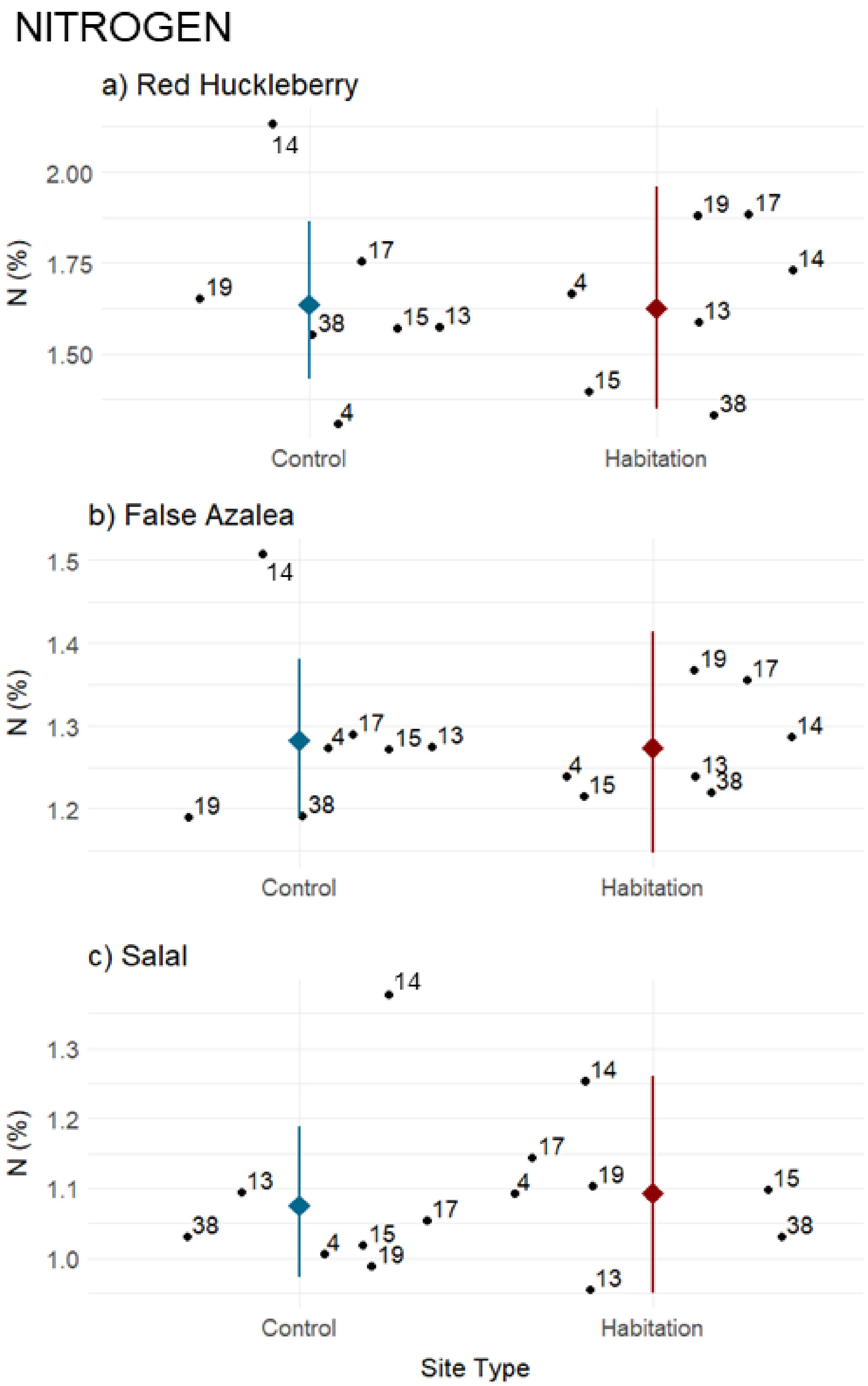


Figure A4. Modelled relationships between nitrogen leaf content and site type (control = blue, habitation = red), with site averages plotted as points. Results are divided by species for a) red huckleberry, b) false azalea, and c) salal. Specific site averages are plotted alongside models, where each number corresponds to the site's name (e.g. EjTa14 = 14; EkTa38 = 38). Control sites are assigned the same number as their paired habitation site. Diamonds are mean values and error bars represent 95% confidence intervals.

Table A1. Description of habitation and control sites (adapted from Trant et al., 2016).

Island	***Site code***	***Site Type***	***Midden depth (cm)***	***Evidence of fire***	***Terminal shell midden age range (1 Sigma Cal AD/BC)***
Calvert	EjTa04	Habitation	800	Yes	AD 1524 - 1643
Hecate	EjTa13	Habitation	400	Yes	AD 196 - 410
Calvert	EjTa14	Habitation	300	Yes	AD 1325 - 1344
Calvert	EjTa15	Habitation	120	Yes	AD 1699 - 1915
Calvert	EjTa17	Habitation	150	NA	AD 1146 - 1027
Hecate	EjTa19	Habitation	120	Yes	AD 1247 - 1274
Starfish	EkTa38	Habitation	250	Yes	BC 1381 - 1413
Calvert	EjTa04C	Control	NA	No	NA
Hecate	EjTa13C	Control	NA	No	NA
Calvert	EjTa14C	Control	NA	No	NA
Calvert	EjTa15C	Control	NA	No	NA
Calvert	EjTa17C	Control	NA	No	NA
Hecate	EjTa19C	Control	NA	No	NA
Starfish	EkTa38C	Control	NA	No	NA

Table A2. Summary of back transformed means and confidence intervals for models. A linear mixed effects model was computed for each species and nutrient, resulting in twelve models.

PHOSPHORUS (%)				
Species	***Site Type***	***Estimate***	***Lower CI***	***Upper CI***
Salal	Control	0.14	0.12	0.15
	Habitation	0.17	0.14	0.19
False Azalea	Control	0.12	0.11	0.14
	Habitation	0.16	0.13	0.18
Red Huckleberry	Control	0.13	0.12	0.14
	Habitation	0.13	0.12	0.15
SODIUM (mg/kg)				
Species	***Site Type***	***Estimate***	***Lower CI***	***Upper CI***
Salal	Control	551	445	683
	Habitation	838	619	1136
False Azalea	Control	1872	1458	2405
	Habitation	3607	2528	5147
Red Huckleberry	Control	193	134	277
	Habitation	416	249	694
CALCIUM (%)				
Species	***Site Type***	***Estimate***	***Lower CI***	***Upper CI***
Salal	Control	0.49	0.45	0.53
	Habitation	0.53	0.47	0.60
False Azalea	Control	0.76	0.69	0.84
	Habitation	0.83	0.72	0.96
Red Huckleberry	Control	0.99	0.89	1.10
	Habitation	1.07	0.92	1.25
NITROGEN (%)				
Species	***Site Type***	***Estimate***	***Lower CI***	***Upper CI***
Salal	Control	1.1	1.0	1.2
	Habitation	1.1	1.0	1.3

False Azalea	Control	1.3	1.2	1.4
	Habitation	1.3	1.1	1.4
Red Huckleberry	Control	1.6	1.4	1.9
	Habitation	1.6	1.4	2.0

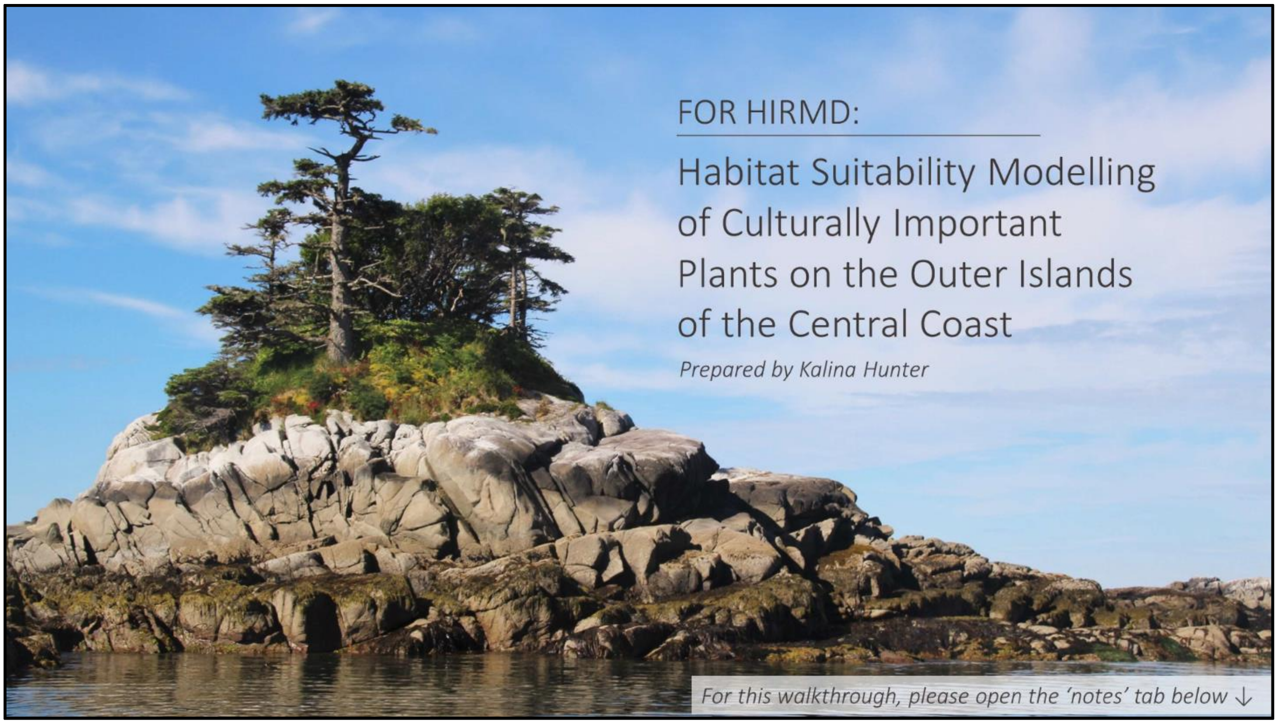
Table A3. Site series and map codes within the CWHvh2 subzone, which are the smallest classification unit in the Biogeoclimatic Ecosystem Classification scheme. Site series (numeric) classes indicate forested ecosystems and describe sites capable of producing the same climax vegetation. Map codes (alphabetic) indicate anthropogenic or natural non-forested units. The Maxent code is an arbitrary number assigned for this analysis.

Site Series or Map Code	**Long name**	**Maxent Code**
01	*Thuja plicata - Tsuga heterophylla - Gaultheria shallon*	1
02	*Pinus contorta - Chamaecyparis nootkatensis - Racomitrium sp.*	2
03	*Thuja plicata - Chamaecyparis nootkatensis - Gaultheria shallon*	3
04	*Tsuga heterophylla - Picea sitchensis - Rhytidiadelphus loreus*	4
05	*Thuja plicata - Picea sitchensis - Polystichum munitum*	5
06	*Thuja plicata - Picea sitchensis - Tiarella trifoliata*	6
07	*Thuja plicata - Picea sitchensis - Oplopanax horridus*	7
08	*Picea sitchensis - Maianthemum dilatatum*	8
09	*Picea sitchensis - Trisetum sp.*	9
10	*Alnus rubra - Maianthemum dilatatum*	10
11	*Thuja plicata - Chamaecyparis nootkatensis - Coptis sp.*	11
12	*Pinus contorta - Chamaecyparis nootkatensis - Sphagnum sp.*	12
13	*Thuja plicata - Picea sitchensis - Lysichiton americanus*	13
14	*Picea sitchensis - Gaultheria shallon*	14
15	*Picea sitchensis - Eurhynchium sp.*	15
16	*Picea sitchensis - Calamagrostis sp.*	16
17	*Picea sitchensis - Polystichum munitum*	17
18	*Picea sitchensis - Carex obnupta*	18
19	*Picea sitchensis - Malus fusca*	19
Wm50	*Carex sitchensis - Conioselinum gmelinii*	20
Wf51	*Carex sitchensis - Sphagnum sp.*	21
Wf52	*Myrica gale - Carex sitchensis*	22
AC	Ba - copperbush	23
AN	NA - metadata not available	-9999
AP	Estuarine marsh	24
BE	Beach	25
BG	Ericaceous shrub - Sphagnum topogenous bog	26
BU	Building	27
CC	Red cedar - Carex swamp	28
CL	Cliff	29
CS	Clubrush - Sphagnum bog	30
ES	Exposed soil	31
FS	Carex fen	32
GB	Gravel bar	33

GP	Gravel pit	34
HP	Hairgrass - plantain estuary	35
LA	Lake	36
MU	Mudflat sediments	37
OW	Shallow open water	38
PC	Pacific crabapple - sedge	39
PD	Pond	40
RD	Red cedar, western hemlock - deer fern	41
RH	Red cedar - Carex swamp	42
RI	River	43
RM	Red cedar - fern bluffs	44
RO	Rock outcrop	45
RU	Rubble	46
RW	Rural	47
RZ	Road surface	48
SA	Sitka alder – Salmonberry	49
SG	Sedge - grounsel avalanche chute	50
TS	Tufted clubbrush - Sphagnum bog	51
UR	Urban/suburban	52
VH	Valerian – Hellebore	53
WF	Wetland fen	54
WI	Willow Swamp	55
WS	Willow swamp	55
YC	Yellow cedar - crowberry scrub	56

Presentation of Chapter 3: Habitat Suitability Modelling for HIRMD

This annotated presentation was sent to William Housty and Kevin Starr of HIMRD in April 2021.



FOR HIRMD:

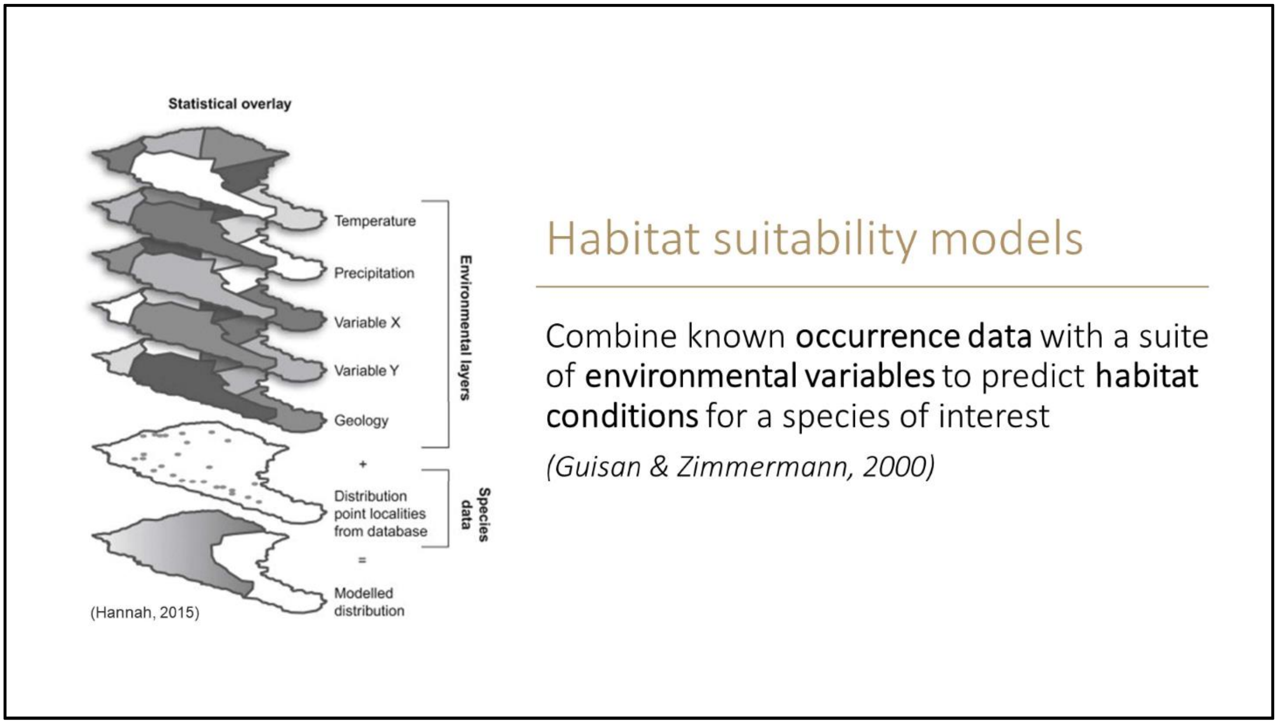
Habitat Suitability Modelling of Culturally Important Plants on the Outer Islands of the Central Coast

Prepared by Kalina Hunter

For this walkthrough, please open the 'notes' tab below ↓

This presentation is offered as a walkthrough for how to use this tool. It is by no means completely comprehensive or finalized, but offers a general guide that hopefully can spark some discussion and feedback on how it can best be suited for HIRMD. For most slides, we offer more information in the notes tab here.

ğiáxsixa for taking the time to go through it!



Habitat suitability models

Combine known **occurrence data** with a suite of **environmental variables** to predict **habitat conditions** for a species of interest

(Guisan & Zimmermann, 2000)

Habitat suitability models (HSMs) go by many different names (i.e. species distribution models, climate envelope models, ecological niche models), but they all do the same thing--they use computer algorithms to predict the distribution of a species across geographic space using layers of environmental data.

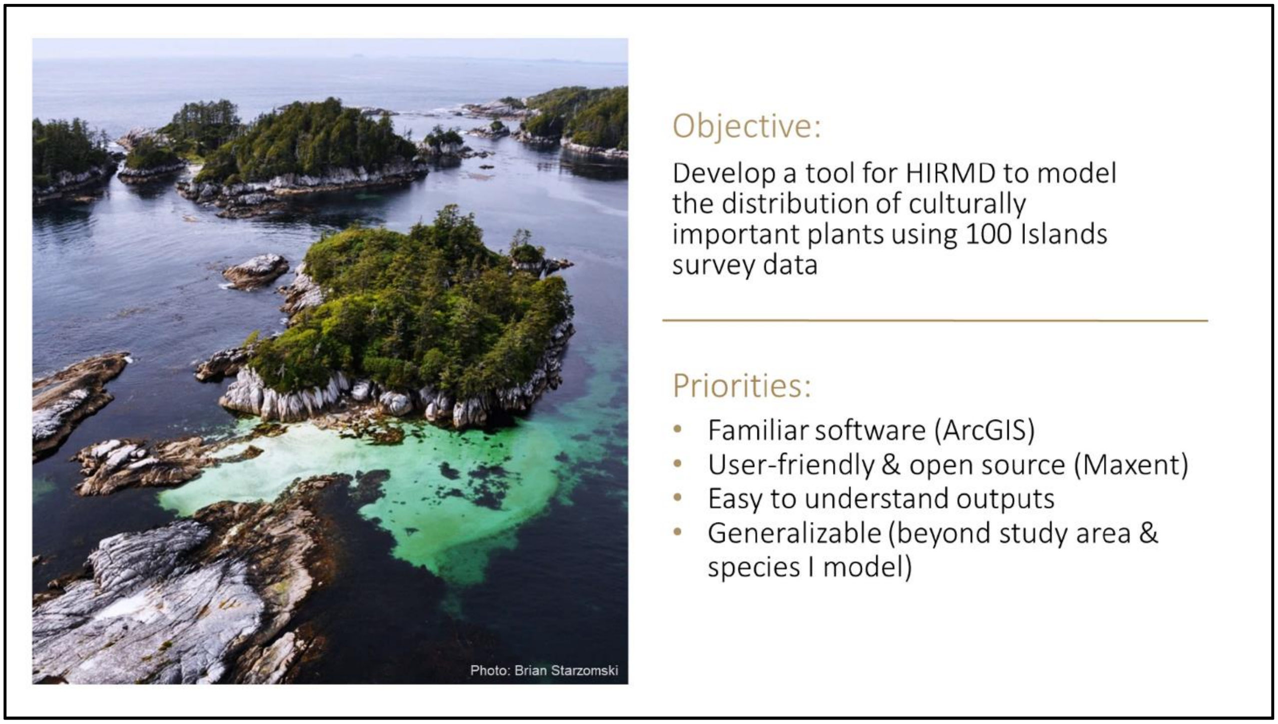


Photo: Brian Starzomski

Objective:

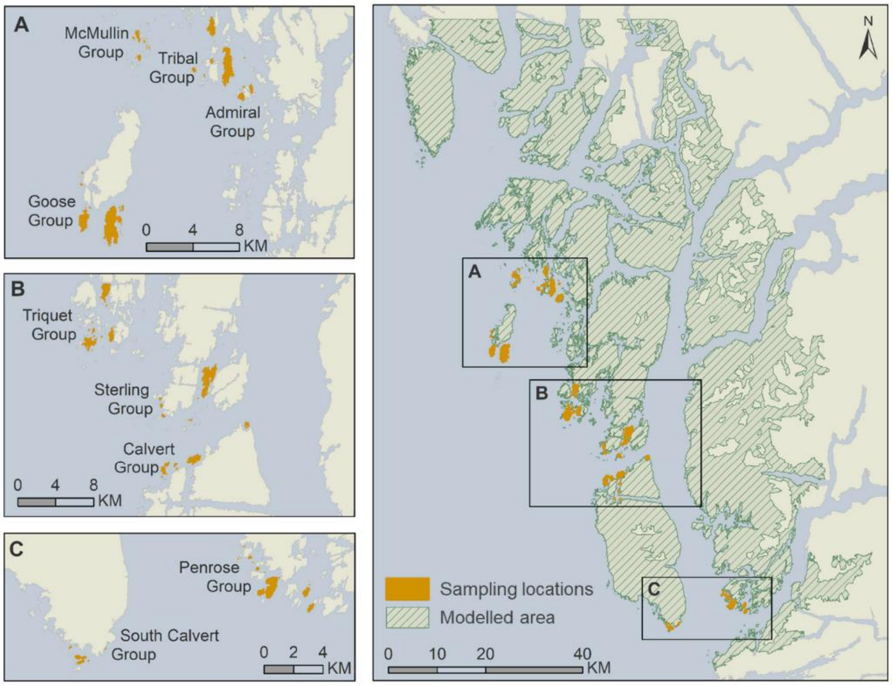
Develop a tool for HIRMD to model the distribution of culturally important plants using 100 Islands survey data

Priorities:

- Familiar software (ArcGIS)
- User-friendly & open source (Maxent)
- Easy to understand outputs
- Generalizable (beyond study area & species I model)

There are many different methods and software you can use to make HSMs. In fact, a huge part of this project was selecting which software to use. We narrowed it down to a combination of ArcGIS (for data preparation) and Maxent (to do the modelling). We wanted to prioritize the familiarity of ArcGIS and something that is user-friendly and free (Maxent). Maxent is very commonly used in resource management and creates relatively easy to understand outputs in an organized way.

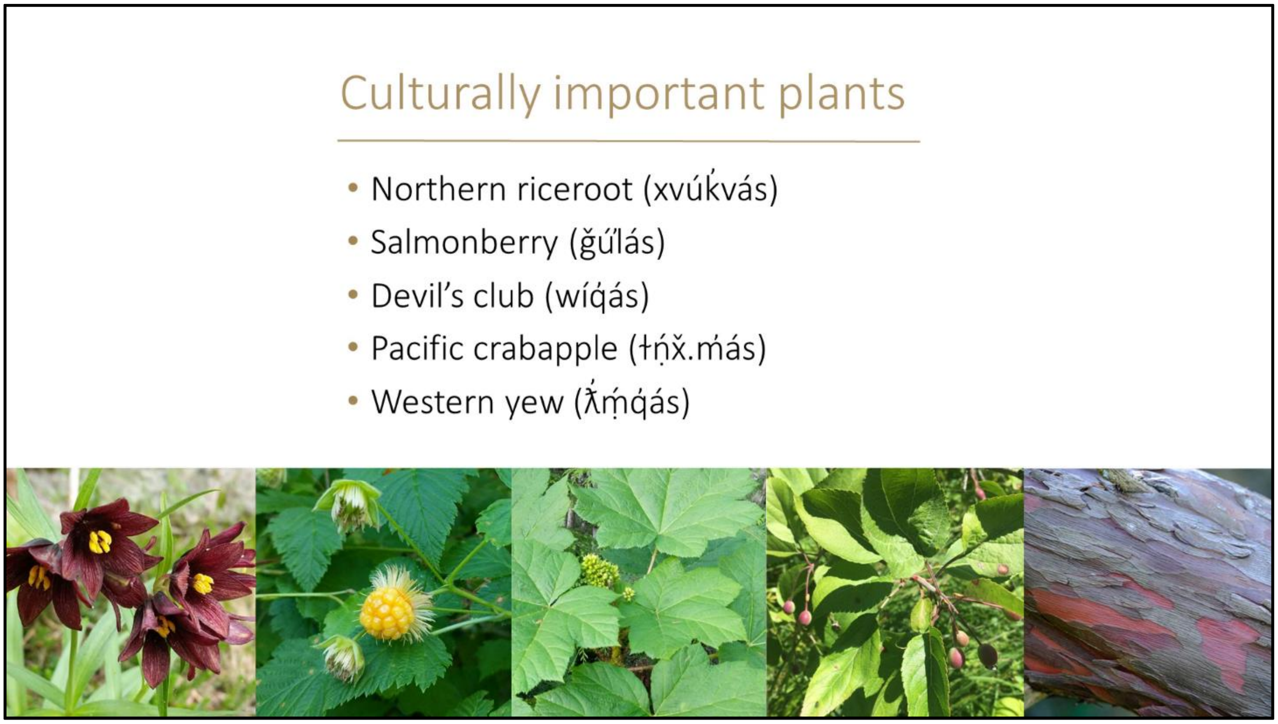
Study Area



The sampled islands (orange) shows where the 100 Islands project (2015-2017) collected the plant data used for this analysis.

The study area for this project (green striped area) was restricted to the Coastal Western Hemlock very wet hypermaritime subzone (CWHvh2). It is best to predict species within the same subzone (alike ecological and environmental conditions) asthe input data.

For future models, this restriction could change depending on the scale of the model and/or the coverage and location of the input data.

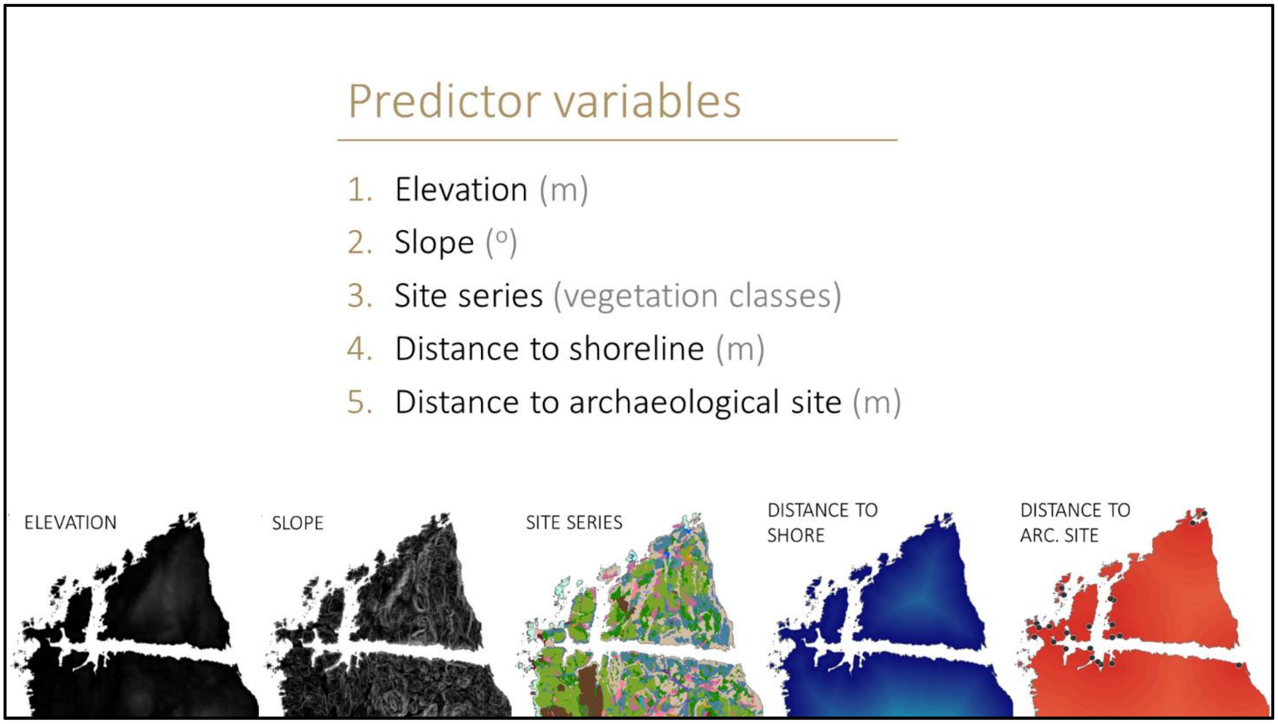


Culturally important plants

- Northern riceroot (xvúk̓vás)
- Salmonberry (ǧú̓lás)
- Devil’s club (wíq̓ás)
- Pacific crabapple (łṇ́x̌.m̓ás)
- Western yew (ƛ̓ṃ́q̓ás)

We selected these five plants from the 100 Islands dataset to model their predicted habitats. It can be easier to model species that have a bit more specialized habitats, so that the model will be more selective. For the scope of this presentation, we walk you through the modelling process for northern rice root.

General rule of thumb is to have at least 30 presences of a species (above 50 is ideal).We included devil’s club even though it only had 22 presences as a test to see how the model would perform.



Predictor variables

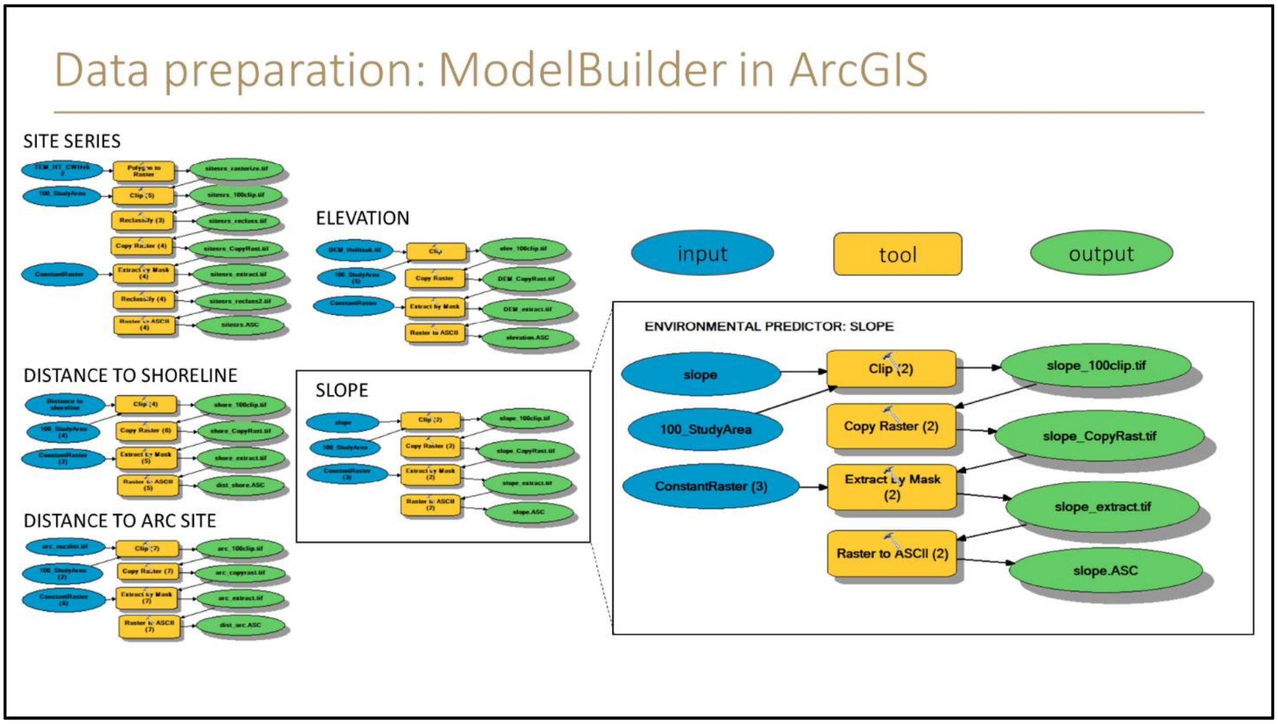
1. Elevation (m)
2. Slope (º)
3. Site series (vegetation classes)
4. Distance to shoreline (m)
5. Distance to archaeological site (m)

Predictor variables are any spatial layers that you think would influence the distribution of a species. In the literature, they are generally environmental (e.g.temperature, precipitation, soil, light), so they often fail to incorporate human influence.

- We added distance to archaeological site* as a proxy for human management of plants (especially translocation!), anticipating that culturally important plants will be more prevalent closer to these sites.
- Elevation and slope are derived from a DEM in ArcGIS.
- Site series is ~50 classes of forested and non-forested land cover. It is the finest scale in BC’s BEC system, and is based on soil moisture and nutrient regimes.
- Distance to shore and archaeological site were derived using the Euclidean distance tool in ArcGIS.

Generally, the rule of thumb is 1 predictor per 10 observations. Exceeding this can‘overfit’ your model, which means its predictions won’t be as reliable.

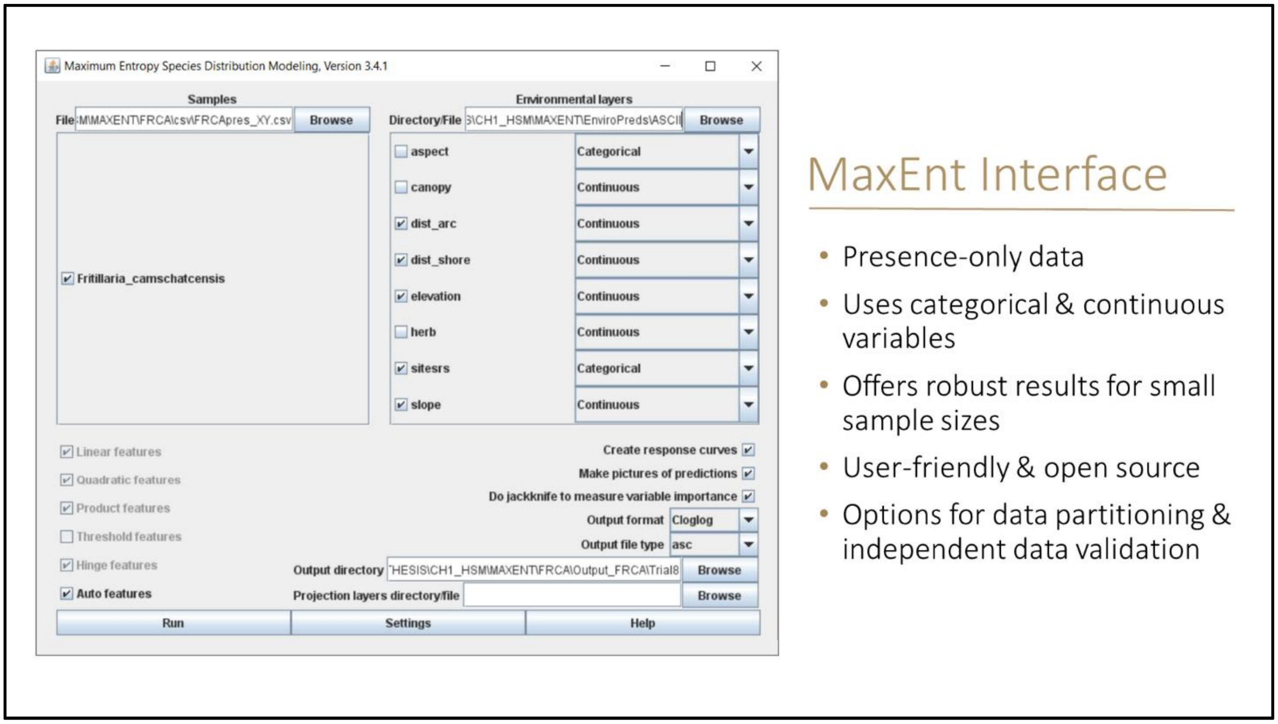
*Archaeological site data is from the BC Gov’s Remote Access to Archaeological Data (accessed through Dr. Darcy Mathews), and includes midden, CMT, clam garden, fish feature, canoe skid, habitation feature, food harvesting, and cultural depression.



Data preparation: ModelBuilder in ArcGIS

We created a workflow using ModelBuilder in ArcGIS for the predictor data preparation, where inputs are blue, tools are yellow, and outputs are green.

Maxent has very specific requirements for data input, so this workflow guides youthrough the necessary steps for preparing predictor data (e.g. 25m resolution, thesame extent and projection). This way, it can be reproducible if you want to incorporate another predictor (e.g. distance to stream, canopy cover).



Maximum Entropy Species Distribution Modeling, Version 3.4.1

Samples

File: M\MAXENT\FRCA\csv\FRCApres_XY.csv

☑ Fritillaria_camschatcensis

Environmental layers

Directory/File: S\CH1_HSM\MAXENT\EnviroPreds\ASCII

☐ aspect	Categorical
☐ canopy	Continuous
☑ dist_arc	Continuous
☑ dist_shore	Continuous
☑ elevation	Continuous
☐ herb	Continuous
☑ sitesrs	Categorical
☑ slope	Continuous

☑ Linear features
☑ Quadratic features
☑ Product features
☐ Threshold features
☑ Hinge features
☑ Auto features

Create response curves ☑
Make pictures of predictions ☑
Do jackknife to measure variable importance ☑
Output format: Cloglog
Output file type: asc
Output directory: HESIS\CH1_HSM\MAXENT\FRCA\Output_FRCA\Trial8
Projection layers directory/file:

MaxEnt Interface

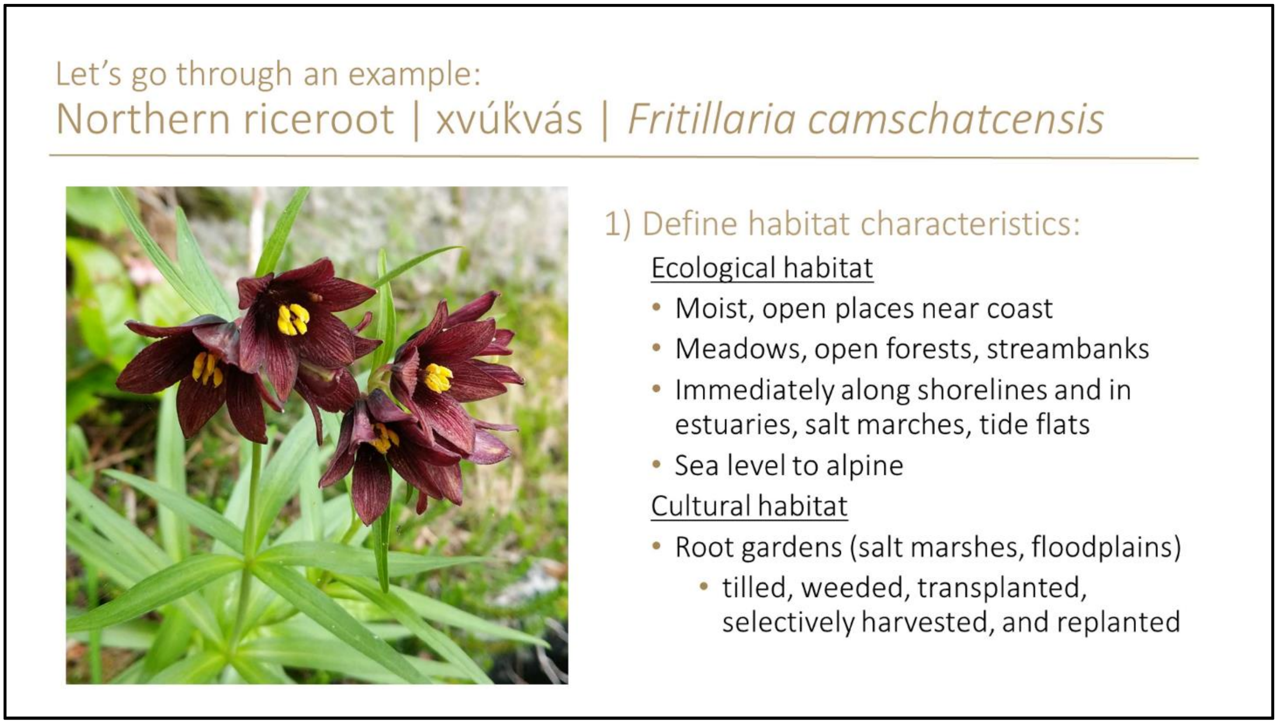
- Presence-only data
- Uses categorical & continuous variables
- Offers robust results for small sample sizes
- User-friendly & open source
- Options for data partitioning & independent data validation

This is a screenshot of Maxent's interface. It's a very simple, one page interface (it can get more complicated if you go into the settings).

The top left is where you import your species location data. The top right is where you import your predictor data (all of which have been formatted and prepared by ModelBuilder on the previous slide). We generally leave the default settings with a few tweaks. In the settings, you can choose your model evaluation strategy: either data partitioning or independent validation. Partitioning means you train the model with 70% of the data, and test it with the remaining 30%. Independent validation means you take a separate dataset of the same species (in this case, I used open-source iNaturalist data as a trial run). This offers a measure of how accurate your model is.

How Maxent works: it takes a list of species presence locations as input, often called presence-only data, as well as a set of environmental predictors (e.g. precipitation, temperature) across a user-defined landscape that is divided into grid cells. From this landscape, Maxent extracts a sample of background locations that it contrasts against the presence locations. Presence is unknown at background locations (Merow et al., 2013).

The math behind Maxent is complicated, and it’s a bit of a black box procedure. The maximum entropy concept is essentially “*the probability distribution that best represents the data is the one with the greatest entropy, i.e. the one which best reproduces the data.”* I use the default ‘cloglog’ output since it’s the easiest to understand, where the output can be interpreted on a 0-1 scale of habitat suitability.



Let’s go through an example:

Northern riceroot | xvúk̓vás | *Fritillaria camschatcensis*

1) Define habitat characteristics:

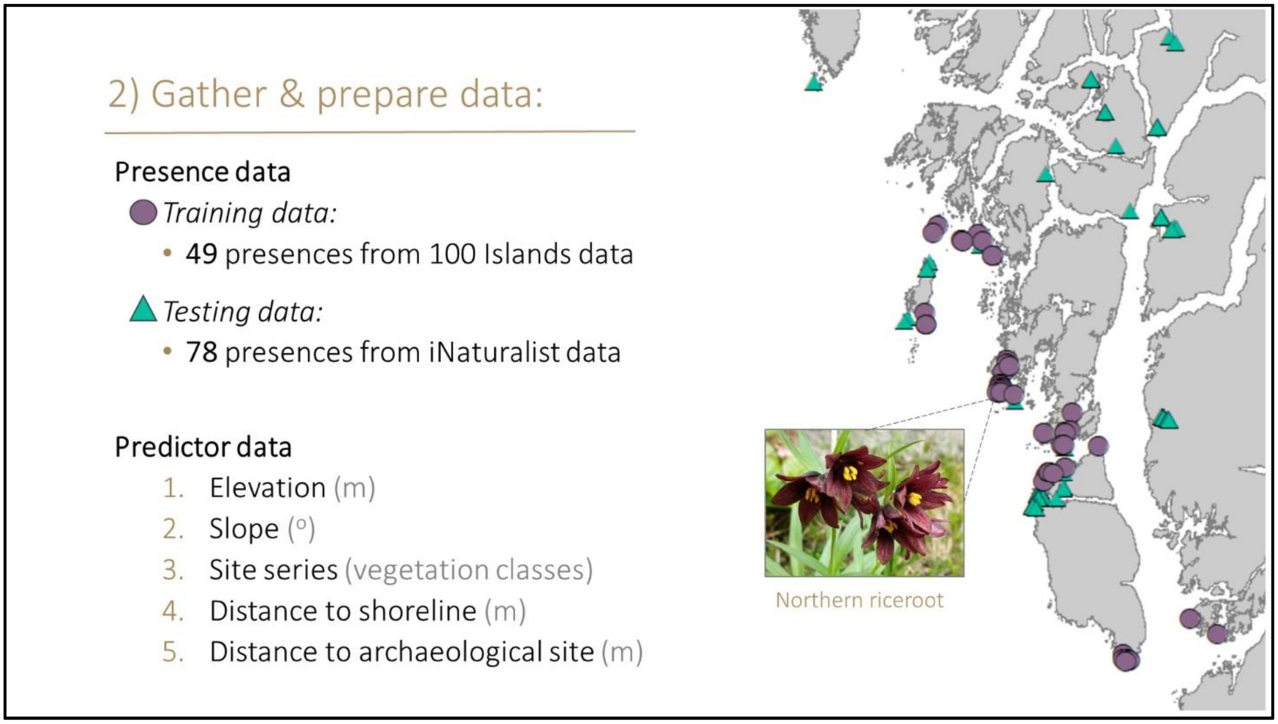
Ecological habitat

- Moist, open places near coast
- Meadows, open forests, streambanks
- Immediately along shorelines and in estuaries, salt marches, tide flats
- Sea level to alpine

Cultural habitat

- Root gardens (salt marshes, floodplains)
  - tilled, weeded, transplanted, selectively harvested, and replanted

Understanding these habitat conditions is the first step and informs your selection of predictor variables.



2) Gather & prepare data:

Presence data

● *Training data:*

- **49** presences from 100 Islands data

▲ *Testing data:*

- **78** presences from iNaturalist data

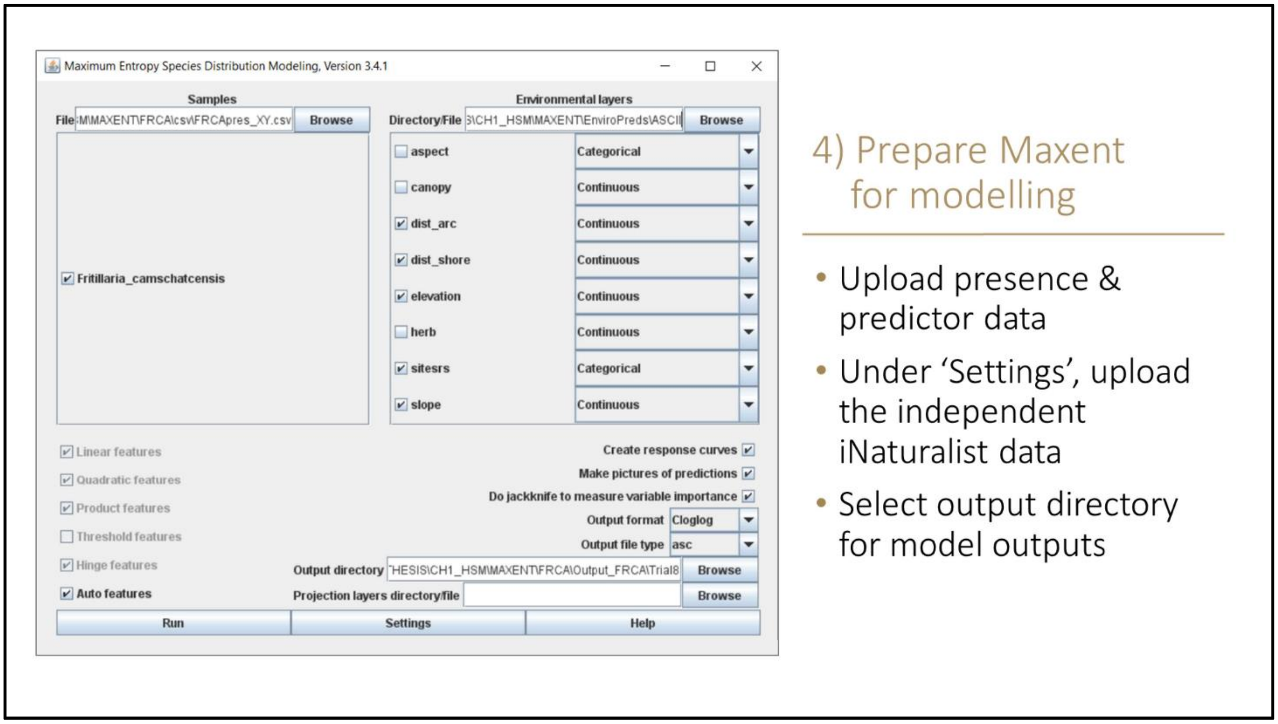
Predictor data

1. Elevation (m)
2. Slope (°)
3. Site series (vegetation classes)
4. Distance to shoreline (m)
5. Distance to archaeological site (m)

This slide outlines the inputs you need for a habitat suitability model using the independent validation method: training/testing data and predictor data.

The data preparation stage is the most time consuming. A lot of work goes into cleaning and preparing the data for use, but we've created a workflow to guide you through the process. The data were resampled so that there is only one presence per25m pixel.

Note that the iNaturalist test data goes outside the bounds of the 100 Islands studyarea, and captures more of riceroot's estuarine habitat. We will discuss these implications at the end.



File: M\MAXENT\FRCA\csv\FRCApres_XY.csv

☑ Fritillaria_camschatcensis

Directory/File: S\CH1_HSM\MAXENT\EnviroPreds\ASCII

☐ aspect — Categorical
☐ canopy — Continuous
☑ dist_arc — Continuous
☑ dist_shore — Continuous
☑ elevation — Continuous
☐ herb — Continuous
☑ sitesrs — Categorical
☑ slope — Continuous

☑ Linear features
☑ Quadratic features
☑ Product features
☐ Threshold features
☑ Hinge features
☑ Auto features

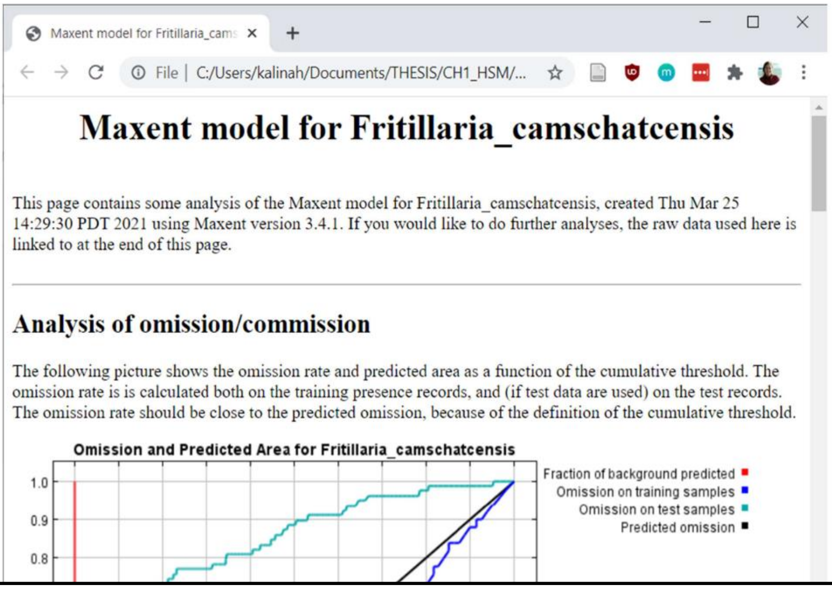
Create response curves ☑
Make pictures of predictions ☑
Do jackknife to measure variable importance ☑
Output format: Cloglog
Output file type: asc
Output directory: HESIS\CH1_HSM\MAXENT\FRCA\Output_FRCA\Trial8
Projection layers directory/file:

4) Prepare Maxent for modelling

- Upload presence & predictor data
- Under 'Settings', upload the independent iNaturalist data
- Select output directory for model outputs

As described above, this is the Maxent interface for preparing your model. This model took under 5 minutes to run.

5) Interpret results



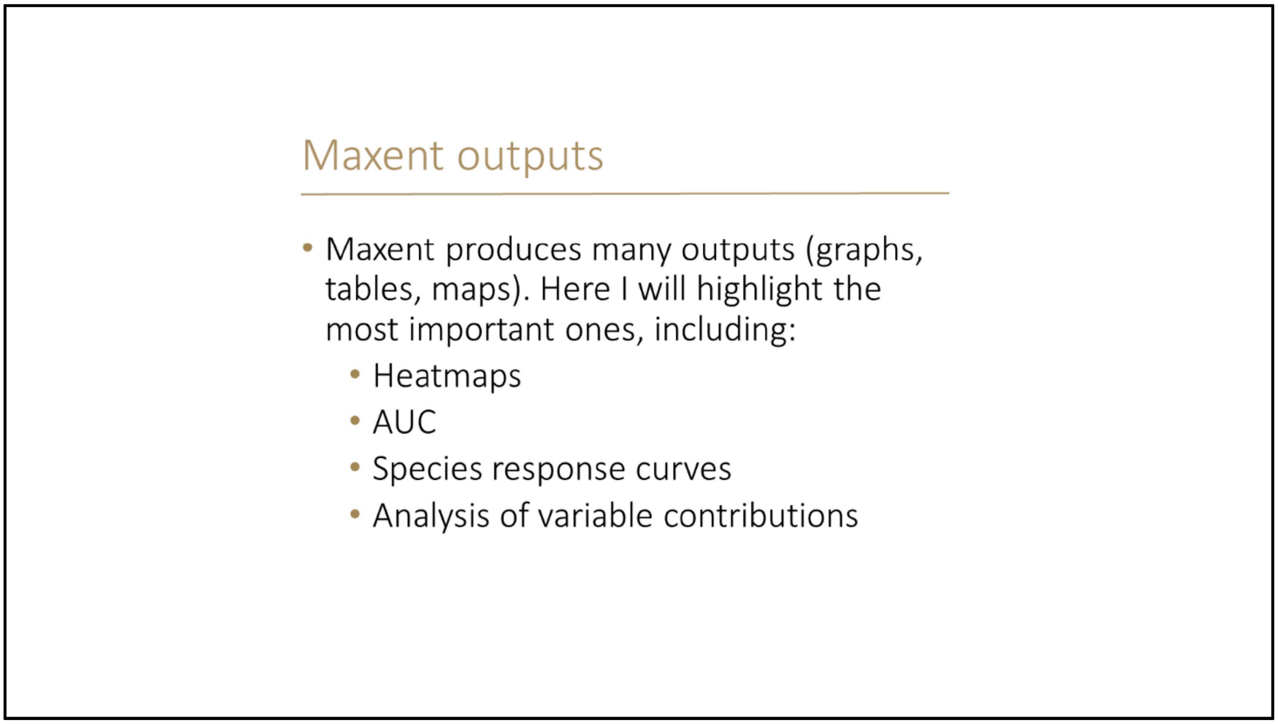
Maxent model for Fritillaria_camschatcensis

This page contains some analysis of the Maxent model for Fritillaria_camschatcensis, created Thu Mar 25 14:29:30 PDT 2021 using Maxent version 3.4.1. If you would like to do further analyses, the raw data used here is linked to at the end of this page.

Analysis of omission/commission

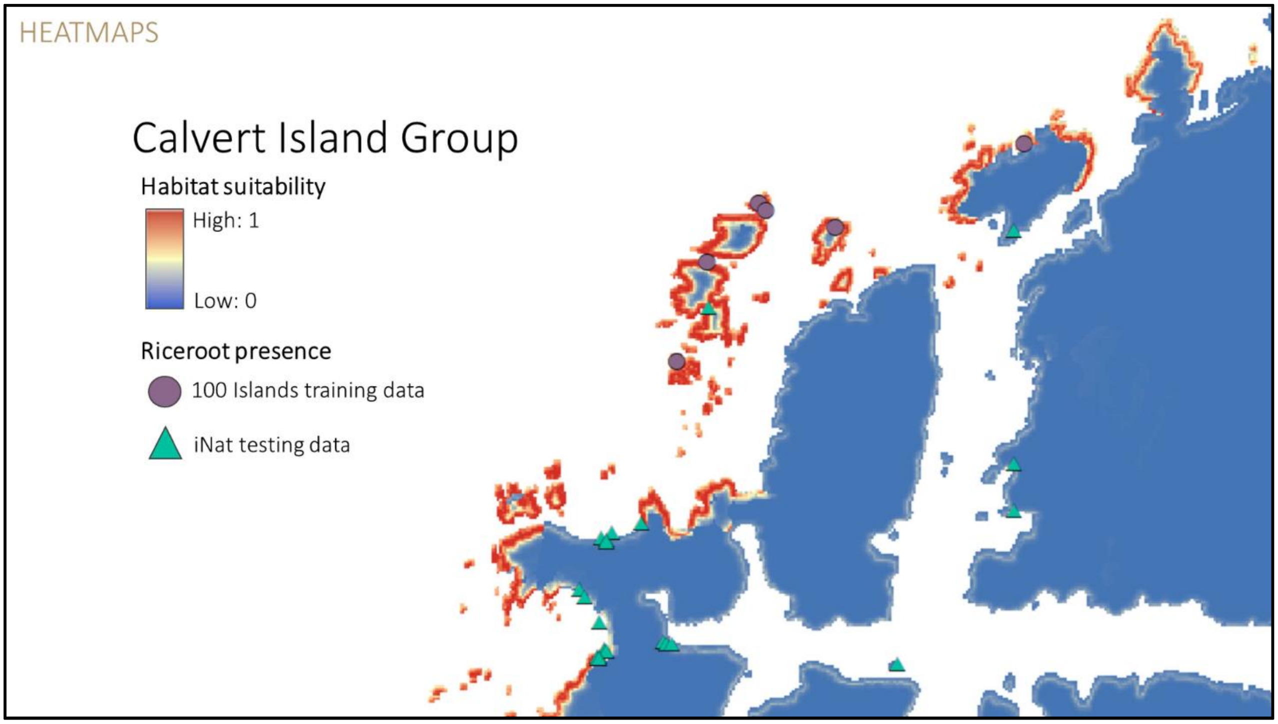
The following picture shows the omission rate and predicted area as a function of the cumulative threshold. The omission rate is is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.

- Maxent creates numerous outputs, all organized into one folder
- Model results are best summarized in the generated .html file (shown on left)
- Each graph/table has an explanation which helps for interpretation



Maxent outputs

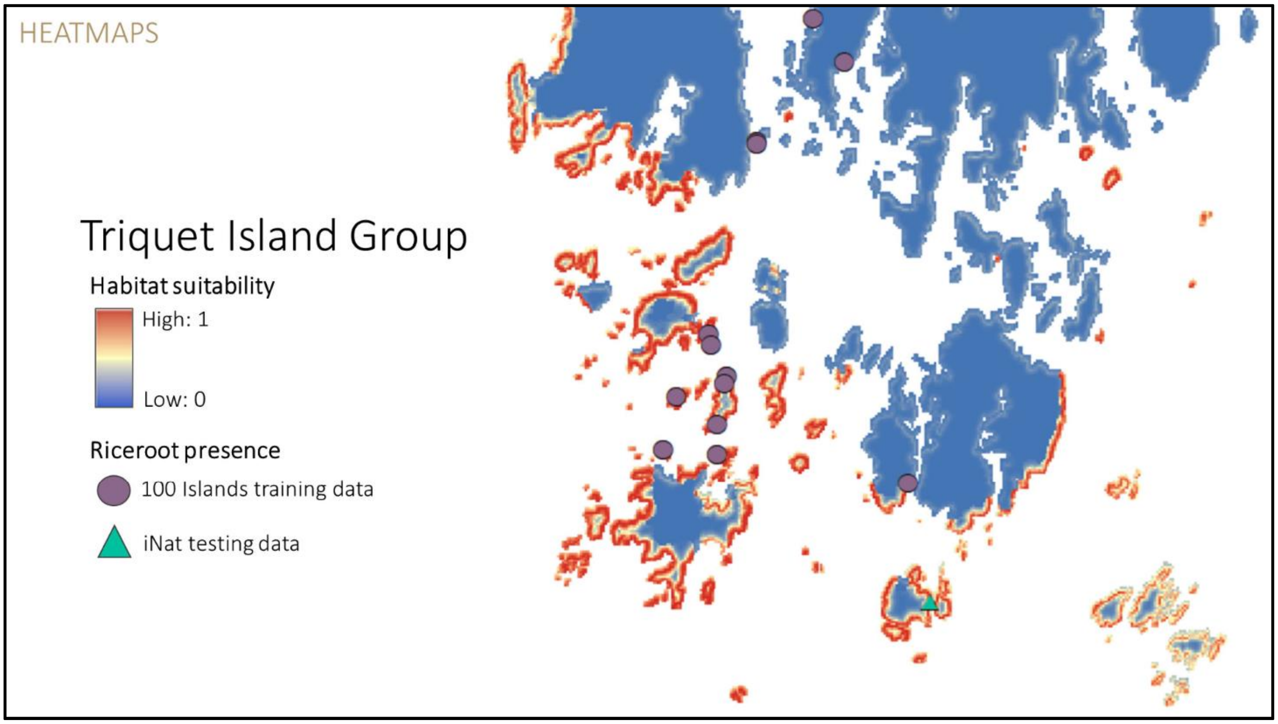
- Maxent produces many outputs (graphs, tables, maps). Here I will highlight the most important ones, including:
    - Heatmaps
    - AUC
    - Species response curves
    - Analysis of variable contributions



HEATMAPS

Maxent provides a map as an .asc file, which you can upload to ArcGIS for a more detailed view. Here are some zoomed in examples of locations of interest, where pixels are at a 25m resolution.

One thing to note: because of the presence-only nature of Maxent and its assumptions, the map scale (0-1) can’t be interpreted as a *probability*, but more of an‘*estimation of occurrence*.’ Because we don’t have true absence data, we can’t be 100% sure where it doesn’t exist. I like to think of it as the red areas being highly suitable habitat, but that doesn’t guarantee that riceroot is in fact there.



HEATMAPS

Triquet Island Group

Habitat suitability

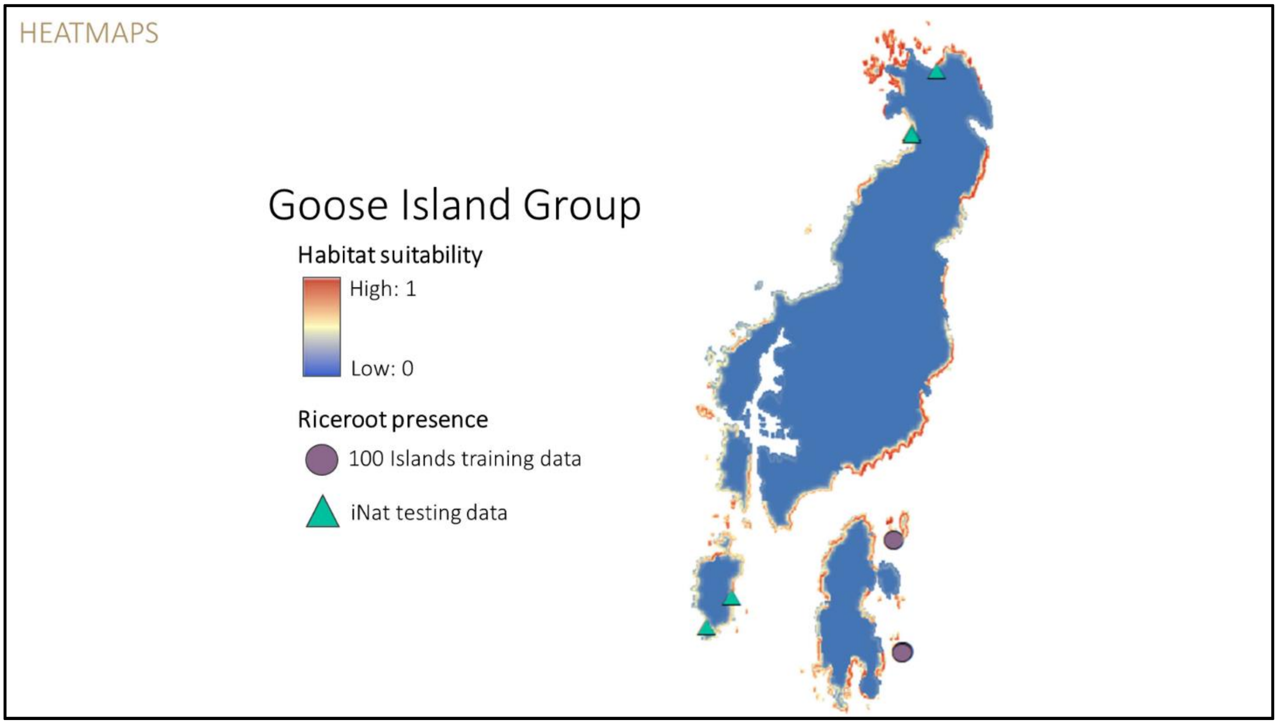
High: 1

Low: 0

Riceroot presence

● 100 Islands training data

▲ iNat testing data



HEATMAPS

Goose Island Group

Habitat suitability

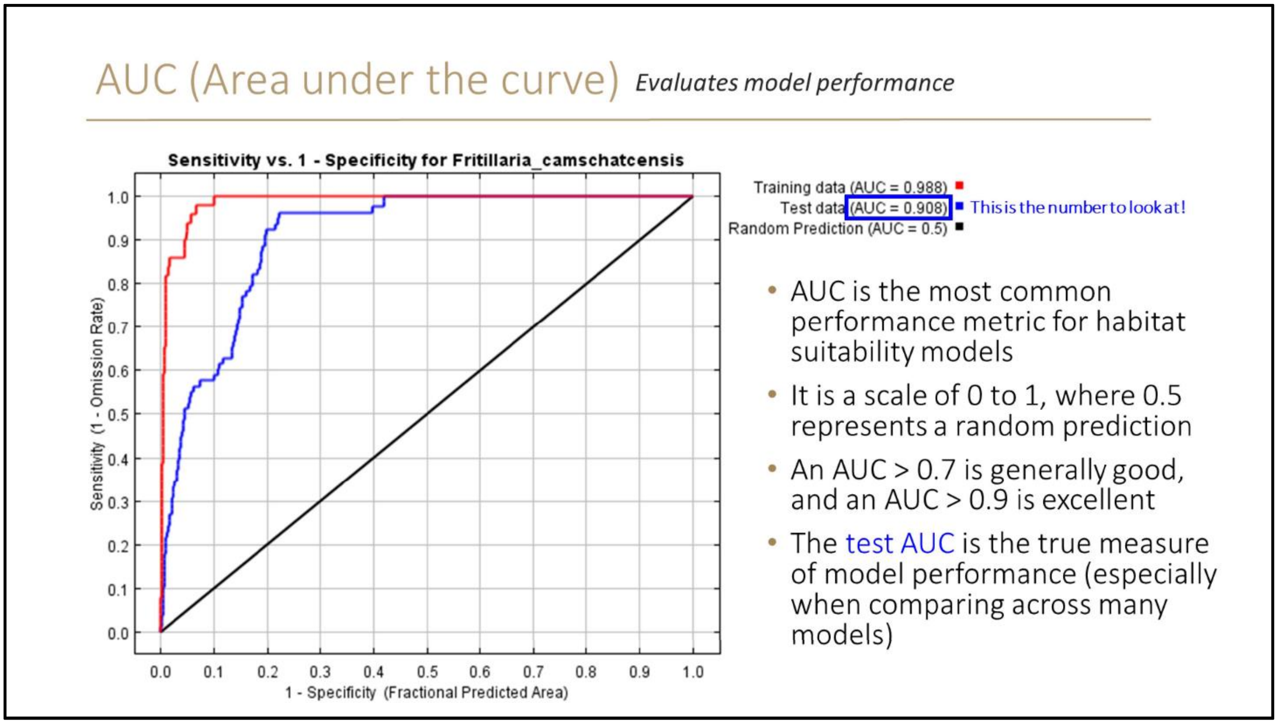
High: 1

Low: 0

Riceroot presence

● 100 Islands training data

▲ iNat testing data



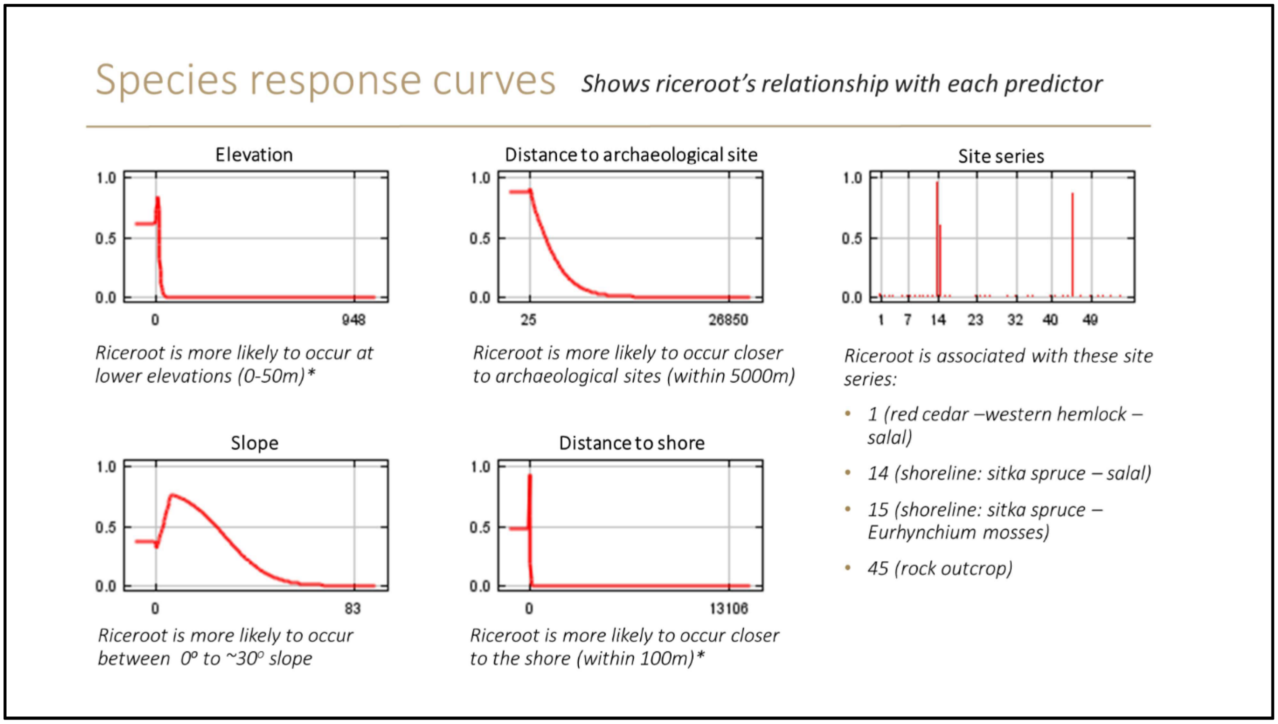
AUC (Area under the curve) *Evaluates model performance*

Training data (AUC = 0.988) 🟥
Test data (AUC = 0.908) ■ This is the number to look at!
Random Prediction (AUC = 0.5) ■

- AUC is the most common performance metric for habitat suitability models
- It is a scale of 0 to 1, where 0.5 represents a random prediction
- An AUC > 0.7 is generally good, and an AUC > 0.9 is excellent
- The test AUC is the true measure of model performance (especially when comparing across many models)

The graph on the left offers a visual for how much area is ‘under the curve’ (0.908 for the test data indicated in blue). However, we can simply use the number to get an idea of model performance on a scale from 0 to 1.

There are some debates in the literature about how reliable the AUC is. While I am cautious to fully deem this result as ‘excellent’, it seems to perform well and is a good concrete measure of performance. It is best used to compare the AUC across multiple models, so you can determine the best one.



Species response curves *Shows riceroot's relationship with each predictor*

Elevation

*Riceroot is more likely to occur at lower elevations (0-50m)**

Distance to archaeological site

Riceroot is more likely to occur closer to archaeological sites (within 5000m)

Site series

Riceroot is associated with these site series:

- *1 (red cedar –western hemlock – salal)*
- *14 (shoreline: sitka spruce – salal)*
- *15 (shoreline: sitka spruce – Eurhynchium mosses)*
- *45 (rock outcrop)*

Slope

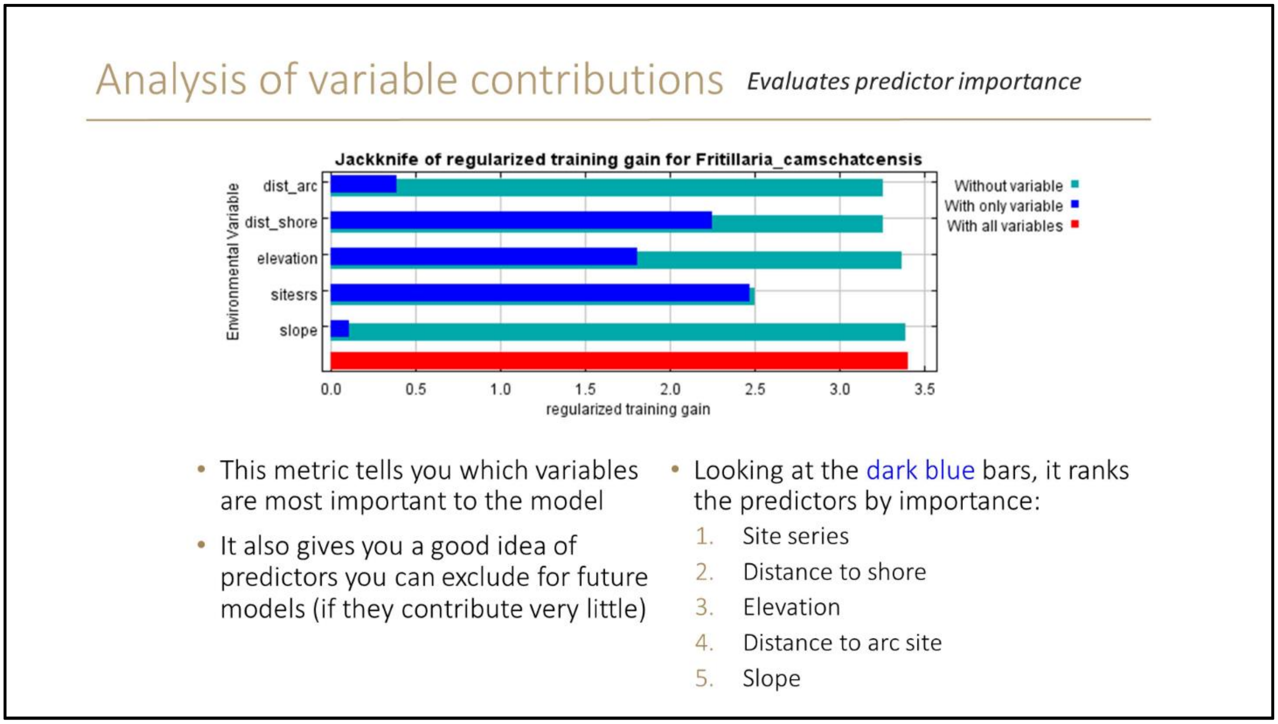
Riceroot is more likely to occur between 0º to ~30º slope

Distance to shore

*Riceroot is more likely to occur closer to the shore (within 100m)**

These species response curves give you an idea of the relationship between riceroot and each predictor. Each of these should make sense ecologically, and should align with your hypotheses about how each predictor might interact with the plant.

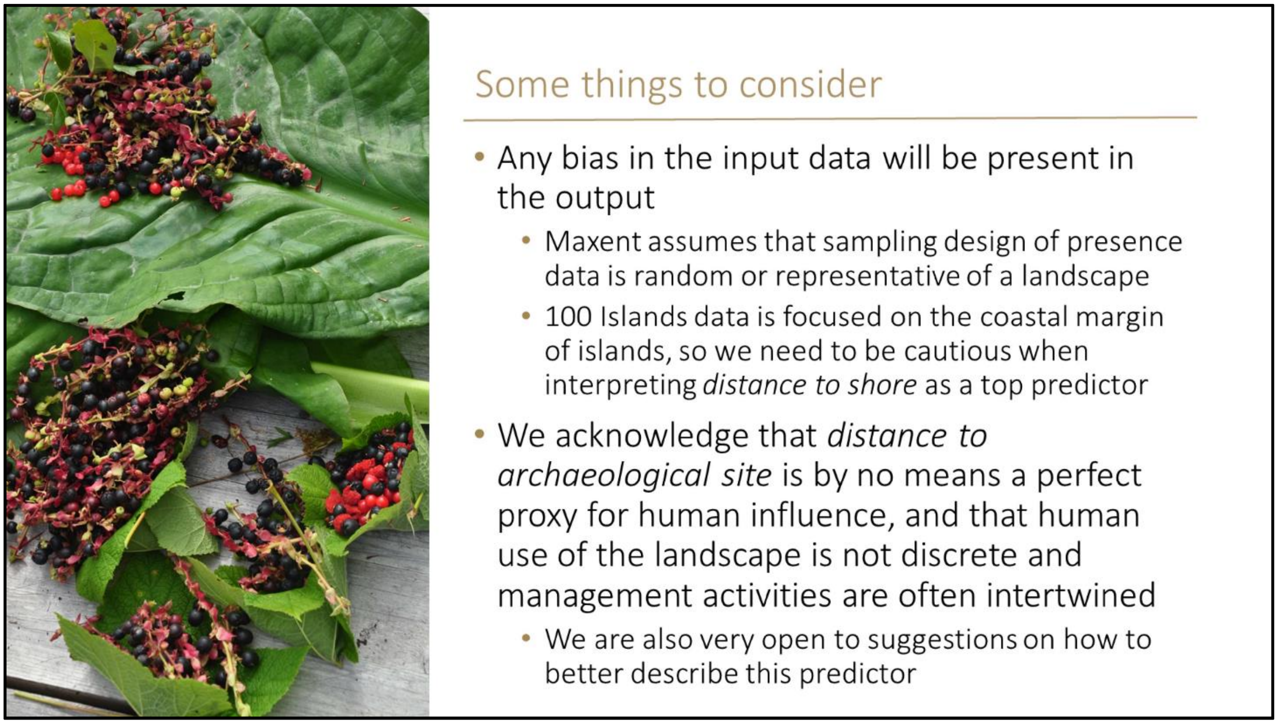
*I looked at the data more closely to get an idea of thresholds (the thumbnails for elevation and distance to shore aren't super useful, since the large values on the rightend of the y axis obscure the details).



Analysis of variable contributions *Evaluates predictor importance*

- This metric tells you which variables are most important to the model
- It also gives you a good idea of predictors you can exclude for future models (if they contribute very little)
- Looking at the dark blue bars, it ranks the predictors by importance:
  1. Site series
  2. Distance to shore
  3. Elevation
  4. Distance to arc site
  5. Slope

This metric shows that site series is the most important predictor, followed closely by distance to shore and elevation.

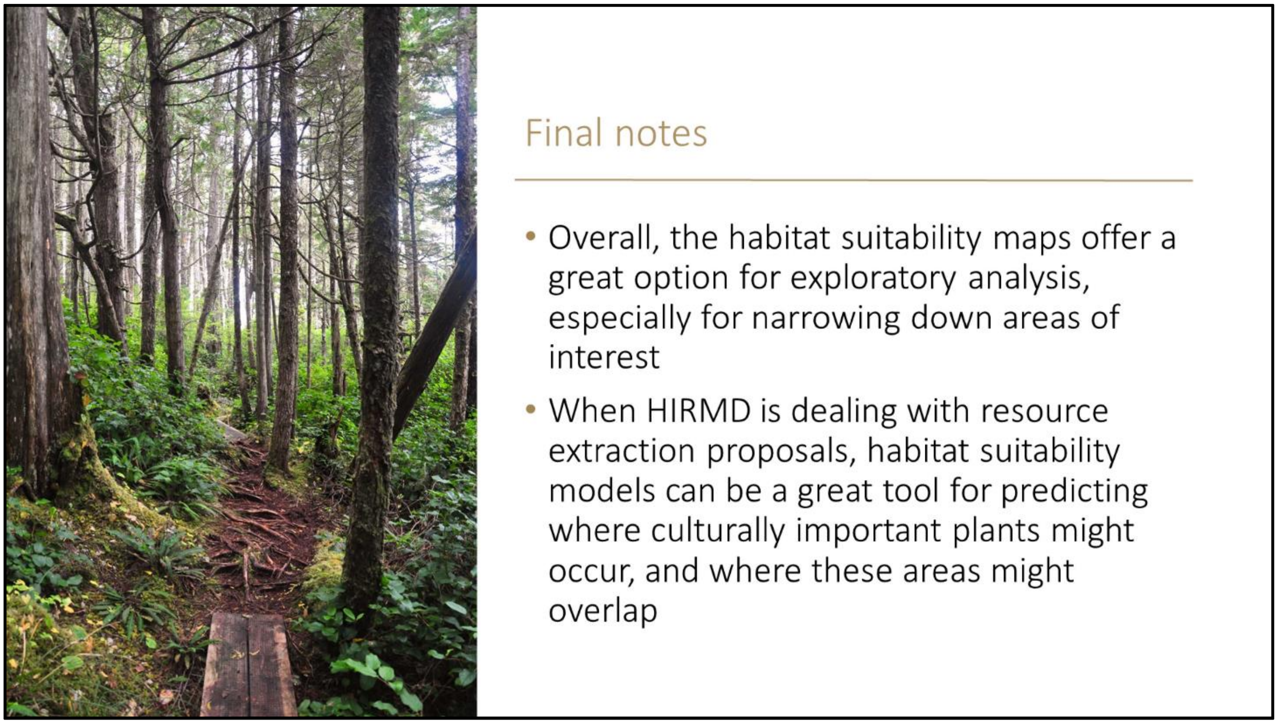


Some things to consider

- Any bias in the input data will be present in the output
  - Maxent assumes that sampling design of presence data is random or representative of a landscape
  - 100 Islands data is focused on the coastal margin of islands, so we need to be cautious when interpreting *distance to shore* as a top predictor
- We acknowledge that *distance to archaeological site* is by no means a perfect proxy for human influence, and that human use of the landscape is not discrete and management activities are often intertwined
  - We are also very open to suggestions on how to better describe this predictor

Even though we used iNaturalist data in this example, using citizen science data has some caveats. To deal with this a bit, we resampled each pixel so only one would occur per 25m. However, data like this is opportunistic and doesn’t always follow rigorous sampling protocols (i.e. random or representative).

Additionally, the iNaturalist data was more representative of riceroot’s estuarine habitat, so it makes sense that it didn’t align perfectly with the training data. Overall, the 100 Islands data does a good job of representing riceroot’s rocky shoreline habitat, since that’s the dominant habitat that sampling was focused on. Knowing the inherent biases in your data is important to keep in mind when interpreting results, as well as when gathering your own presence data in the future!



Final notes

- Overall, the habitat suitability maps offer a great option for exploratory analysis, especially for narrowing down areas of interest
- When HIRMD is dealing with resource extraction proposals, habitat suitability models can be a great tool for predicting where culturally important plants might occur, and where these areas might overlap

It is important to keep in mind that models are a simplification of reality, and that there is still room for error. These models could be improved by ground truthing— going to those areas yourself and seeing if the plant is in fact there! Predictions aresomewhat coarse with a resolution of 25m, but this is excellent compared to most habitat suitability models out there.

It is recommended to use data from within the same predicted area (i.e. using 100 Islands data to model interior landscapes wouldn’t be very accurate). But, it is easy toadd your own presence data with the workflow we developed to customize this model for future needs.

w̓álás ğiáxsix̌a !

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Dr. Brian Starzomski
Project supervisor
starzom@uvic.ca

Thank you for taking the time to go through this presentation, and please let us know how we can best accommodate HIRMD’s needs with this project.

We welcome any questions/comments/concerns/feedback!