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TESTING THE UTILITY OF ENVIRONMENTAL CLUSTER ANALYSIS BASED
UPON BIODIVERSITY SURROGATES WITHIN GEOGRAPHIC INFORMATION
SYSTEMS FOR CONSERVATION PLANNING: A CASE STUDY OF INLAND
TEMPERATE RAINFOREST IN THE NORTHERN ROCKY MOUNTAINS

By

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Thesis

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Testing the Utility of Environmental Cluster Analysis Based upon Biodiversity Surrogates within Geographic Information Systems for Conservation Planning: A Case Study of Inland Temperate Rainforest in the Northern Rocky Mountains

Chairperson: David Shively

Abstract:

Environmental surrogates have been proposed as a method for addressing a lack of taxonomic data in biodiversity conservation planning. These surrogates, used as variables in Geographic Information Systems (GIS) analysis, can be used in classification procedures to classify areas that are hypothesized to support or be able to support a targeted species or community. The peripheral range of the inland temperate rainforest's (ITRF) in northwest Montana and northern Idaho was used as a case study for testing the utility of a method known as Environmental Cluster Analysis (ECA) within a GIS using abiotic environmental variables encompassing broad environmental attributes to classify this forest type. The objective was to test if this statistical clustering classification identified sites that contained or could accommodate this forest type and thus contribute to biodiversity planning in the Northern Rocky Mountains. Results indicate that the generalizing nature of ECA is not suitable for meeting the objectives of many conventional biodiversity goals when emphasis is placed on the limited distribution species or communities. The results from this research support the conclusion that ECA is not adequate for formulating a strategy for developing and implementing ITRF conservation planning.

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1. INTRODUCTION

Techniques for selecting priority areas for biodiversity conservation need to be refined and improved (Poiani *et al.* 2000). The design and function of biodiversity conservation reserves should have clear objectives including the maximum representation of diversity in a limited space, facilitating the persistence of that diversity, and successfully representing rare and/or relatively limited species or functional groups (Margules and Pressey 2000). However, the availability of taxonomic and biological data is often insufficient for creating detailed area plans that meet these objectives, and the surveys to complete these datasets may be prohibitively time consuming and costly (Snelder *et al.* 2006). Methods using biological and/or environmental surrogate data to stand in place of these records have been proposed, and there is a need for research to evaluate their utility (Rodrigues and Brooks 2007).

Approaches in conservation biology aimed at protecting biodiversity are undergoing a shift from focusing on perceived static species richness to an expansive view of ecosystem function based on the interacting components of the target area acting as a system. Ecosystem and landscape-level concepts are increasingly being assimilated into conservation frameworks with broader scopes of functionality (Poiani *et al.* 2000). The technique for selecting effective areas, a critical stage in conservation planning, still persists as a limitation. Historically, many areas have been delineated for protection based upon educated guesses and limited expert knowledge of the natural processes and regimes of an area (Humphries *et al.* 2007). The ability to improving prediction of biodiversity in modeling and GIS techniques is an important research priority, using the limited available knowledge and data to provide areal biodiversity assessments to conservation area design practitioners.

There is also a lack of protected land in the northern Rocky Mountains inland temperate rainforest zone, including its contemporary assemblage types and regionally encompassing ecosystem (DellaSalla 2011). Areas need to be clearly identified in relation to biodiversity conservation goals in order to begin addressing conservation plans for protection and maintaining ecosystem functions of the ITRF (Humphries et al. 2007). The technique for selecting conservation areas based on surrogate data and the selection of inland temperate rainforest biodiversity priority areas are both in need of further research to improve efficiency and utility for practical application.

This research, which tests a method for selecting areas based upon biodiversity surrogates, will contribute to the ongoing advancement of conservation area design and selection. Refinement is continually recommended and further research is stressed as a necessity in this field (Hortal et al. 2008). The inland temperate rainforest in the Northern Rocky Mountains has also been identified as a conservation target for maintaining ecosystem function and stability (Craighead & Cross 2004). Multiple conservation initiatives that include this ecosystem have been developed (Stevenson et al. 2011), and refining techniques for site selection will contribute to the advancement of such efforts through the articulation of priority areas and their extent. Such research will provide benefits to conservation planners and any interest involved with land protection and development. Advanced methods to efficiently select representative areas may serve as a way to mitigate conflict be a tool for conservation planners to accurately outline areas (Margules and Pressey 2000).

The purpose of this thesis was to test the utility of using environmental data as variables in a cluster classification with the goal of identifying a network of complementary sites that represent habitat for the inland temperate rainforest (ITRF) association of western hemlock-

western red cedar within the context of conventional biodiversity conservation goals. The objective was to test if a specific statistical clustering classification method was able to identify sites of this forest type that were most represented in a network of sites that will contribute to higher biodiversity and complementarity in the northern Rocky Mountains Physiographic Province. Achieving a network of complimentary sites would result in the maximum representation of environmental types and associated species diversity (Lawler and White 2008).

The primary objective of this research was to test a promising method, as indicated by the literature, for biodiversity site selection. Site selection was based on the use of a multivariate clustering classification, conceptually grounded in a previous approach by Trakhtenbrot and Kadmon (2006). It was outside the scope of this research to evaluate the real application of such reserve areas or perform a policy analysis of the regional contextual framework. Biodiversity, within this study's context, is derived from ecological niche modeling, or potential habitat areas (i.e., environmental site beta diversity). It was in this way that site selection was performed at the community level scale of forest ecosystem diversity. The guiding framework for how to assess sites chosen from the clustering algorithms drew from conventional goals of biodiversity conservation: maximal representation of diversity types, possible facilitation of persistence, and representation of rare or limited species (Margules et al. 2002). This research was guided by the following question: can multivariate cluster classification based on environmental surrogate variables and subsequent analysis of these classes be used to successfully select sites along environmental gradients in the Northern Rocky Mountains Physiographic Province in Montana that satisfy the goals of regional biodiversity representation through complementary networks with a focus on the ITRF association?

2. BACKGROUND

2.1 – Research Addressing the Goals of Regional Biodiversity Representation

Poiani et al. (2000) have presented a framework in that describes how biodiversity conservation is evolving to meet changing demands of conservation scientists and society. This framework includes the notion that the goals of biodiversity conservation plans should incorporate multiple levels of geographic scale, and include a spectrum of goals ranging from local species to ecosystem function. This shifting trend in conservation planning towards conserving broader ecosystem function can be integrated into regional conservation efforts in multiple ways, building different goals that require focus on the components of an ecosystem.

The regional framework for biodiversity conservation was further elaborated and built upon in theoretical work by Margules et al. (2002). The authors stressed the importance for goals to be set in biodiversity conservation, and that these should focus on the prioritization of sites that represent the most biodiversity in limited space and also separating these areas from processes that threaten them. A systematic procedure is needed for meeting these goals, and a critical phase is the integration of appropriate data and using rigorous procedures for identifying priority areas. One of the key concepts to be used in such procedures is complementarity, where each site within the area network contributes to the overall conservation goal, and different areas are assigned values relating to their irreplaceability, flexibility, and possibility for substitution. The goal of a conservation area based on complementarity is overall higher beta diversity throughout the study sites or region of concern, thus hosting a greater amount of species diversity and potential habitat space.

An applied study by Kittel et al. (2011) applied regional ecological conservation planning in the context of these systematic goals. This study outlined the development of a conservation area selection process that focused on putting together different areas that represented all of the biodiversity and ecosystem function in central interior British Columbia. This study went beyond the scope of the thesis research presented here. However, it demonstrated one case study in which the biodiversity conservation goals were assimilated into a regional framework for long term conservation, principally the maximum representation of diversity in the most efficient manner possible.

2.2 – Research on Using Biodiversity Surrogates in Conservation Site Selection

A number of studies have researched the use of different biodiversity surrogate variables to evaluate their utility as inputs for site-selection algorithms. These variables are used to act in place of detailed taxonomic data for the regions of interest. There is an ongoing debate in the literature as to what surrogate data types produce the best results: biological, environmental, or mixed. In the study by Margules et al. (2002), examples of surrogate data were discussed, as was the significance of these data as a way to handle the apparent impossibility of measuring all biodiversity in a region. Each of the three surrogate types has different strengths and weaknesses, and the best choice depends on the specific goals and characteristics of a region. A main point was that although the goal is to represent biodiversity, the actual representation scheme is ultimately that of the surrogate data, and this is presumed at an arbitrary point to actually represent biodiversity (Margules et al. 2002). Success of a produced representation scheme should be evaluated in relation to past classifications of the area and other data to determine if the sites are truly indicative of priority areas that can be further researched for practical conservation.

A case study carried out by Trakhtenbrot and Kadmon (2005) outlined the use of environmental surrogates. In order to compensate for a lack of biological data, and to serve as an exploratory analysis into such methods, the authors tested the use of abiotic environmental variables to represent regional floral diversity in Israel. The main mechanism contributing to the success of environmental surrogates was the focus on site complementarity. Beta diversity between sites showing variation in the environmental types proved to be more efficient in selecting areas than locating individual sites that could host more species. The need for analysis focusing on complementary sites was also addressed in a study by Williams et al. (2006) where multiple relationships between biological and environmental data sets were tested. The effectiveness of surrogate data in these relationships varied depending on how relationships were defined between surrogate data and proposed biological representation. More accurate results were obtained by using the environmental surrogacy method than a randomized test selection of sites, in multiple trials using a host of different variable weights and non-weighted algorithms.

Several other studies have been conducting that test the use of biological, environmental, and mixed surrogate systems (Snelder et al. 2007; Rodrigues and Brooks 2007; Hortal et al. 2009; Grantham et al. 2010). For each case, it becomes apparent that distinct local characteristics determine or drive the effectiveness of each procedure, and there is no apparent uniform method that best represents biodiversity surrogacy. Good results were obtained when mixed surrogates were utilized. However, in order for this to work, community-level data must be relatively proportional between ecosystem units in order for skewed distributions to be avoided. If biological data are not sufficient to this level, environmental surrogacy is the best option.

2.3 – Research on the Use of Statistical Clustering Techniques of Environmental Surrogates for Classification

Multivariate statistical methods have been developed that assimilate the principles of biodiversity conservation and biodiversity surrogate options. Research aimed at classifying floral communities conducted in Israel by Trakhtenbrot and Kadmon (2005) employed cluster classification in their studies which built on the concept of complementarity to select a network of sites that contributed to the overall maximal representation of floral diversity. A statistical cluster analysis was carried out on three abiotic environmental factors (rainfall, temperature, and lithology), which were split into 17 variables based upon their gradients. This method was deemed efficient in classifying and arranging a network of areas that represented floral diversity. In a follow up study to test the accuracy of their procedures, the authors stressed a need for further testing of this promising method in different regions where the representation of groups of species with limited distributions are of concern, and the need for further evaluation of environmental biodiversity surrogate systems (Trakhtenbrot and Kadmon 2006).

Subsequent studies have contributed to the advancement of multivariate statistical modeling of surrogate data for biodiversity area selection (Arponen et al. 2008; Lawler and White 2008; Chen 2008). These studies were primarily concerned with evaluating the extent to which environmental surrogates can be mixed with biological data, and if these can be mixed with other species indices for improved results. In each study, integration of detailed biological data provided improved results for site representativeness. However, the underlying basis for using surrogacy of environmental data is that detailed biological data are unavailable or at an insufficient level of detail for useful integration into the biodiversity surrogacy dataset (Pressey 2004). Although these studies indicate the importance of using biological data, the purpose of this thesis research is to test a method for site selection based upon the lack of such biological

data. According to the literature and the limited data availability in the study area, cluster classification based upon environmental variables was the most promising technique.

For this thesis research, literature was reviewed to specifically inform an unsupervised classification technique. The GIS tools assigned input layers to clusters, and no specific input was used that would guide the algorithm to prioritize certain clusters over others. This is a very simple clustering technique that produces no other output than the image of the clusters themselves in the GIS environment. A simple technique is appropriate in this case study as there is little input data that would require a more computer-intensive technique.

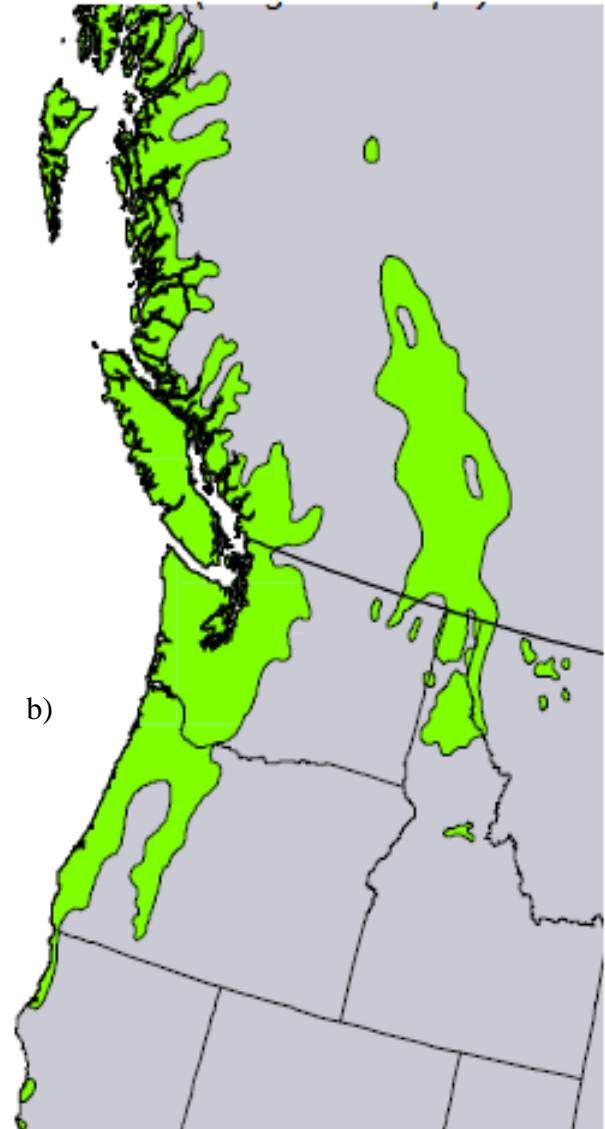
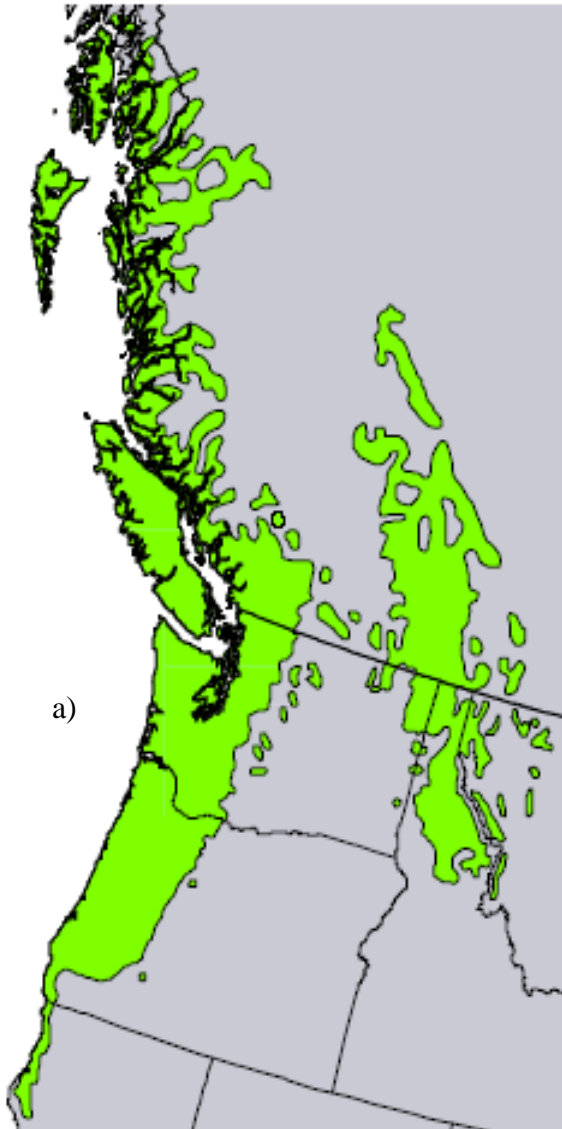
2.4 –Features and History of the Inland Temperate Rainforest

The ITRF of North America extends from northern British Columbia through northeast Washington, northern Idaho, and northwest Montana (Stevenson et al. 2011) (Figure 1). The exposure of north and west-facing northern Rocky Mountain slopes to moist Pacific air masses facilitates the development of these temperate rainforests which are dominated by the *Thuja plicata* (western red cedar) and *Tsuga heterophylla* (western hemlock) association. In a historical biogeographic sense, they are a remnant or refugium system of a broader temperate rainforest biome that extended through these regions before post-Pleistocene climate dynamics and physiographic drivers changed, causing ecological tolerances to permit different forest types to emerge (DellaSala 2011). There are numerous low-lying ITRF valleys in the northern Rocky Mountains that do not cover large areas of land but are a key component of the broad diversity hosted within this mountainous environment.

Species Range Maps

Western Redcedar
(*Thuja plicata*)

Western Hemlock
(*Tsuga heterophylla*)



SCALE 1: 15000000

100 0 100 200 300 400 500 KILOMETERS

A horizontal scale bar with alternating black and white segments, marked with the numbers 100, 0, 100, 200, 300, 400, and 500, representing kilometers.

Figure 1. ITRF dominant tree indicator species range maps for a) western red cedar, and b) western hemlock. The coastal and inland zones are clearly delineated. Large regional areas are broadly identified as species range, with no local detail for ITRF physiographic site conditions. (Reproduced with publicly available images from <http://esp.cr.usgs.gov/data/little/>).

Biological research has not placed a large emphasis on the ITRF, although there is some literature to indicate the recognition of a unique habitat area that can be considered an inland disjunct counterpart to the coastal temperate rainforest of North America. The significance of doing so lies in the nature of the region's climatological specificity. A study by Arsenault and Goward (1999) investigated the ecology and forest dynamics of the ITRF throughout British Columbia compared to its coastal counterpart and sought to identify patterns in lichen and bryophyte diversity that could reflect differing rain forest characteristics. The authors suggest that ITRF areas are at risk because of their preference for unique sites that have historically suited their survival, such as gullies and toe slopes, but will be less conducive as a result of regional climate change.

An early study to relate the ITRF to climate gradients was carried out by Alaback (1990). The author analyzed areas in the Pacific Northwest of North America for their vegetative and environmental characteristics based upon analogous climate gradients, analyzing their regional history and climate patterns, with the goal of coming to a definition for temperate rainforests based on compared climates. The results of the comparisons suggested that the specific climate to which these forests are adapted present unique ecological stressors in which specific vegetation types can be observed. The view of ITRF areas as localized biogeographically unique habitats has been expanded upon by Steward et al. (2010) who view such areas as current refugia for communities of species that share a limited ecological tolerance in a larger region that does not facilitate their establishment. The investigators provide differing interpretations of this refugia theory, stressing that there is a great deal of variation in what might be considered refugia zones, and the nature in which different species are confined to such areas. This reinforced the viewpoints that the ITRF's range and extent is a combination of many ecological factors that,

over a broad temporal period, have contributed to its occurrence in specific isolated areas. These views also suggest that long term isolation of ITRF refugia can result in genetic divergence, as has been observed in a phylogeographical study of this forest (Brunsfeld and Sullivan 2006).

The concepts behind understanding the history of the ITRF and how its species are separated from their main coastal distributions were investigated by Gavin (2009). This investigator studied the distributions of tree and understory species located in inland habitats with an affinity for climates that are more similar to the marine west coast climate regime of the coastal Pacific Northwest, and calculated their species richness to determine patterns of local biodiversity. The purpose was to test the evidence for contrasting hypotheses of how the ITRF became established: either long-term disjunction into a refugium, or recent dispersal from the coast, or a combination of both. Results indicated that there is disequilibrium between ITRF species distributions in refugia areas and local environmental conditions that either facilitate or inhibit ITRF persistence. However, paleoclimate records may suggest that the areas were once more suitable to their establishment. The authors suggest that this indicates a threat from climate change (warmer and drier summer conditions leading to an increase in severe fire risk), as mesic species in the refugia areas will be unlikely to survive.

The environmental congruence between species of Pacific Northwest coastal temperate rainforests and inland counterparts throughout the Northern Rocky Mountains was assessed by Goward and Spribille (2005) by studying populations of epiphytic macrolichens. The authors suggested that a core ITRF area is in the northern extent of its range in British Columbia where the highest oceanic lichen species diversity is observed, with species richness decreasing from the core with latitude. Lichen distribution in this region is closely correlated with summer monthly precipitation, suggesting that changing trends in precipitation patterns and precipitation

timing will cause species' range shifts and localized extinctions. The authors conclude that their observations are consistent with recognizing an ITRF as a unique biologically significant system due to its high biomass accumulation, uniquely high species diversity compared to surrounding forest types, and its vulnerable position to local effects of climate change, and that for these reasons it warrants close observation and careful management practices in resource extraction areas.

Multiple methodologies have been developed and tested for reconstructing ITRF paleoecology for the purpose of understanding its establishment through historical climate change either on millennial scale between glaciations or across millions of years. In a palynological study by Gavin et al. (2009), sediment cores from lakes in the Robson Valley in British Columbia were analyzed to reconstruct the establishment of *Thuja plicata* and *Tsuga heterophylla*. Results found that the species significantly increased in abundance only in the last 2,000 years, possibly suggesting that existing old growth ITRF forests in the ITRF's northernmost extent have been present for just a few forest generations. The possibility for the oldest tree stands to be the first colonizers of an area has implications for the forest's future response to climate change and how best efforts for conservation planning of this forest type should proceed. More research is needed in this area to identify how future generations of this forest type will function if the colonizing individuals established at a time when climatological conditions were significantly different than today.

A separate study by Rosenberg et al. (2003) was carried out to analyze postglacial environmental change in southeastern British Columbia and the migration path of *Tsuga heterophylla* into the region. Palynological data was obtained from subfossil pollen in Eagle Lake, Mount Revelstoke National Park. The analysis indicated that climatic conditions around

the lake were warmer and drier during the earlier Holocene than present day, based upon high amounts of alder pollen. *Tsuga heterophylla* occurs in higher densities first starting 3,500 years ago. The authors conclude that using data from pollen sediment records in lakes is insufficient for fully reconstructing the migration pattern, although evidence does support a northerly migration route as a response to increased precipitation patterns associated with historical climate change during the late Holocene. This study further reinforces the suggested theory that the late Holocene marks a shift to more moist and cool conditions that are more typical of subalpine areas today.

Disturbance regimes associated with the ITRF are of concern for management and conservation interests. Trends in analyzing paleoecology records for ITRF natural disturbance regimes that may pose threats to biodiversity and influence conservation are shifting towards reconstructing fire events. A study by Sanborn et al. (2005) employed radiocarbon dating of charcoal deposits from colluvial and alluvial fans throughout east-central British Columbia to reconstruct ITRF Holocene fire history. With sample dates ranging from 182 to 9,558 YBP, these authors found that fire has been a significant disturbance agent in shaping the ITRF during the Holocene, with recurrence intervals in the range of 800 – 1,200 years. The results also indicated that sediment records from charcoal deposits could be used as proxy data for watershed-scale paleoecological reconstruction where other recorded evidence types, such as tree rings and palynological sediments are not available.

Research in the field of comparative phylogeography is able to contribute extensive analysis and insight with temporal and spatial scales into a region's historical geographical circumstances to explain its biogeography (Carstens et al. 2005; Brunsfeld and Sullivan 2006; O'Connell et al. 2008). This research has strong implications for how the ITRF should be

interpreted as a whole system, and how conservation efforts should view this dynamic forest type. Each of these studies specifically investigated the evolutionary history of an inland counterpart to the mesic forest ecosystem of the Pacific Northwest of North America. Of primary concern for each was determining the timescale of establishment and separation of the region's mesic forest, and identifying what scenario had taken place over a long temporal scale. Carstens et al. (2005) analyzed molecular genetic lineages of four animal and two plant species that are strong indicators of the Pacific Northwest forest ecosystem. Three general hypotheses that are conceptualized throughout the literature were considered:

1. *Ancient Vicariance*: A formerly continuous northwest mesic ecosystem was split by the Cascadian orogeny and subsequent xerification of the Columbia basin ~2.5 m.y.a.

2. *Northern Dispersal*: Disjunct mesic Pacific Northwest forests in the Northern Rockies did not persist through the Pleistocene and reestablished in the region via dispersal from the Northern Cascades in Washington once large ice sheets retreated.

3. *Southern Dispersal*: Similar process to *Northern Dispersal*, although dispersal originated from northwestern Oregon.

Carstens et al. (2005) supports the ancient vicariance hypothesis, primarily with amphibians, and northern dispersal hypothesis to a degree with other species types. The authors posit that the xerification of ancient habitats and the climatologically influenced migration routes for species colonization and establishment had a very significant influence on localized persistence of disjunct zones, and each area where these species have persisted to the present day should be viewed as its own unique system with a distinctive history. In contrast to these conclusions, O'Connell et al. (2008) introduced the concept of a southern refugium in the Northern Rockies for *Thuja plicata*. The authors analyzed genetic variation from microsatellite markers to test for local genetic diversity, inbreeding, bottlenecking and geographic genetic grouping and isolation. Results primarily found that genetic diversity for the inland population

decreased with latitude, coinciding with the theory that they had spread northward from a refugium in the Clearwater River area in Idaho. In addition to the trends in genetic diversity, the authors found that the southern end of the range experienced genetic bottlenecks. Such findings suggest that climate change and past oscillations have had an effect on the genetic diversity of the retreating edge of distribution as overall species range shifts northward. While *Thuja plicata* may exhibit genetic evidence for more recent distribution, other species indicative of an ITRF ecosystem exhibit evidence for ancient vicariance. Brunfeldt and Sullivan (2006) tested the phylogeography of Constance's Bittercress (*Cardamine constancei*), an herbaceous flowering plant endemic to tributaries of the Clearwater and St. Joe Rivers in Idaho, for the ancient vicariance hypothesis. The authors proposed that if the ancient vicariance hypothesis is factual, then populations in a distant and unglaciated location of ancient establishment and origin should exhibit divergent genetic patterns caused by genetic drift and limited gene flow. Results did find this to be the case with *Cardamine constancei*, and support the ancient vicariance hypothesis. The authors did, however, emphasize that this species is rare and specialized, that analyses of other species may find evidence to support other refugial hypotheses, and that multi-kingdom analyses are needed to provide an overall understanding of an ecosystem's history.

These phylogeographic studies both supported viewpoints of an ancient vicariant event and a recent distribution from a mesic refugium originating in the Cascades and Clearwater regions during the last glaciation. The significance of these theories lies in their implications for persistence of these forests and how conservation strategies might approach the ITRF – it is important to understand the different ways ITRF areas have functioned ecologically through past significant climate change events if long term strategies are to be successful.

2.5 - Environmental Change and the Inland Temperate Rainforest

Modeling and predicting environmental change within the ITRF has proven to be extremely complex. Such efforts are needed to help mitigate the negative impacts of climate change in the region, in coordination with conservation area design strategies. DellaSala (2011) provides an overview of how climate change may threaten such areas and what changes in the forest ecosystem may be observed. The primary threat is fire, as much of the remnant refugia habitat for ITRF species are in low lying mesic areas that have escaped historically large fires. A loss of annual winter and spring snowpack with a simultaneous increase in extreme weather events exemplifies ways in which climate change will increase the risk of significant forest fires to threaten the ITRF. In areas where species do survive, it is likely that they will be slowly replaced as the regeneration and establishment of species more tolerant to new hotter, drier conditions increases.

Some more favorable and stable refugia systems may persist however, as discussed by Ashcroft et al. (2009). The authors analyzed how inland warming is modelled with coarse-grained climate surface data and compared this to a more spatially comprehensive data set with climate observation sites. Results of the analysis suggested that models of future climate trends in localized areas with specific climate characteristics for isolated vegetation populations produce less erroneous results when considering regional weather patterns and using elevation-sensitive interpolations to down-scale coarse-grained data. By following such procedures, research using ecological modelling to predict future climate change and its effects on ITRF systems may help to identify specific areas that may be more resistant to adverse effects of climate change, and could be areas for intensely focused conservation efforts. The challenge for modeling vegetation dynamics under future climate change for the purpose of conservation

planning is further elaborated by Svenning and Sandel (2013). The authors discuss vegetation disequilibrium dynamics, in which vegetation range shifts do not respond in predicted ways with their expected climate change. This is a crucial theory for anticipating future species range shifts, developing niche models, and using these models for informing biological conservation planners. The authors suggest that climate change will influence a significant disequilibrium in the leading and trailing edges of vegetation zones, caused by lags in species migration, establishment, and succession in response to climate change. These lags will be associated with a loss in ecosystem components that may be missed or erroneously targeted by conservation efforts. The complexity of such a process is imperative for understanding future climate shifts in the ITRF, and poses a significant challenge to endeavors in conservation planning for the region.

The importance of developing a robust technique for conservation area selection focusing on the ITRF and its broader ecosystem stems from the lack of existing protected areas within this ecosystem and the lack of attention to this regionally rare forest type in conservation biology literature. Overall, the goals should be to develop a conservation network representing the ecosystem's range, maintaining species viability, and sustaining natural processes with acceptable variability. Intrinsic qualities of the ITRF drive its value as an irreplaceable system with components derived from mixed origins through its biogeographic historical development. The limited literature on this topic has identified populations of mountain caribou and coastal lichen species as indicator species to drive conservation priorities (DellaSala 2011). However, it is the sum of the ecosystem components that may or may not be thoroughly known that actually create the ITRF's intrinsic value as a biodiversity region that is in need of conservation efforts. The scope of this research with regard to ITRF biogeography and conservation is to test if environmental cluster analysis has the capability to select areas indicated by environmental

parameters to host such a forest type rather than focusing on an indicator species, potentially providing a biodiversity assessment relating to community composition.

One strategy outlining a biodiversity conservation plan for the ITRF was developed by Craighead and Cross (2004), and focused on the vast portion of this ecosystem type in British Columbia. The basis for the analysis was the identification of key zones that are the most suitable habitat for focal mammal species that are known to take refuge in the ITRF. Habitat models were used as biological surrogates, and land-cover classification was used as means to roughly estimate the extent of temperate rainforest. Although that study is not directly related to statistical analysis of surrogate data, it provides insight into regional conservation planning for the forest type of interest. It also fits into the framework of the previously discussed biodiversity conservation goals insofar as it focused on representing the most overlap of diversity habitat types in the most efficient manner possible.

3. METHODS

3.1 – Study Area

A study area of approximately 8,265,300 acres was selected from the northern border area of Montana and Idaho (Figure 3, page 20). This area was deemed suitable for the testing of environmental cluster analysis using environmental surrogates for the purpose of ITRF conservation because of its known facilitation for ITRF establishment and persistence (Gavin et al. 2009), varying environmental conditions, and variety of mountainous terrain to test the performance of environmental cluster analysis. The majority of the land is comprised of National Forests (NF), including the Clearwater, Lolo, Idaho Panhandle, and Kootenai National Forests. Large portions of the NF land within the study area are designated as roadless areas, and a very

small portion is designated as the Cabinet Mountains Wilderness. Over the past several decades, these factors have underpinned the perception that these lands are suitable for the establishment of larger wilderness preserves in this region (DellaSala 2011).

There is a high level of habitat/ecological diversity in this study area as environmental gradients change in the mountainous terrain facilitate varying species assemblages and niches (Stevenson et al. 2011). Steep mountain slopes dominate the area with local elevations ranging from 731.5 meters and 2663.3 meters. The Cabinet, Clearwater, Bitterroot, and Purcell Mountain Ranges dominate the area, creating a mosaic of diverse habitats and environments with complex mountain climates. Maritime air masses with prevailing westerly winds influence the area's local climate to produce increased precipitation relative to other portions of the Rocky Mountains further to the east (O'Connell et al. 2003). Several large rivers are included in the region, including the Yaak, Clark Fork, Lochsa, and Clearwater Rivers.

Forests in the area are broadly classified as "Northern Rocky Mountain Mesic Montane Mixed Conifer Forest" (Montana Department of Natural Resources and Conservation [MT DNRC] 2014; Washington State Department of Natural Resources [WSDNR] 2011). Movements of mild, wet Pacific air masses across this area produce a highly variable mixture of coniferous tree species and associations. Occurrences of this ecosystem are found on all aspects and slopes in the region of interest, and more broadly in the larger regions that includes the mountains of southeastern British Columbia, eastern Washington, northern Idaho, western Montana, and northeastern Oregon.

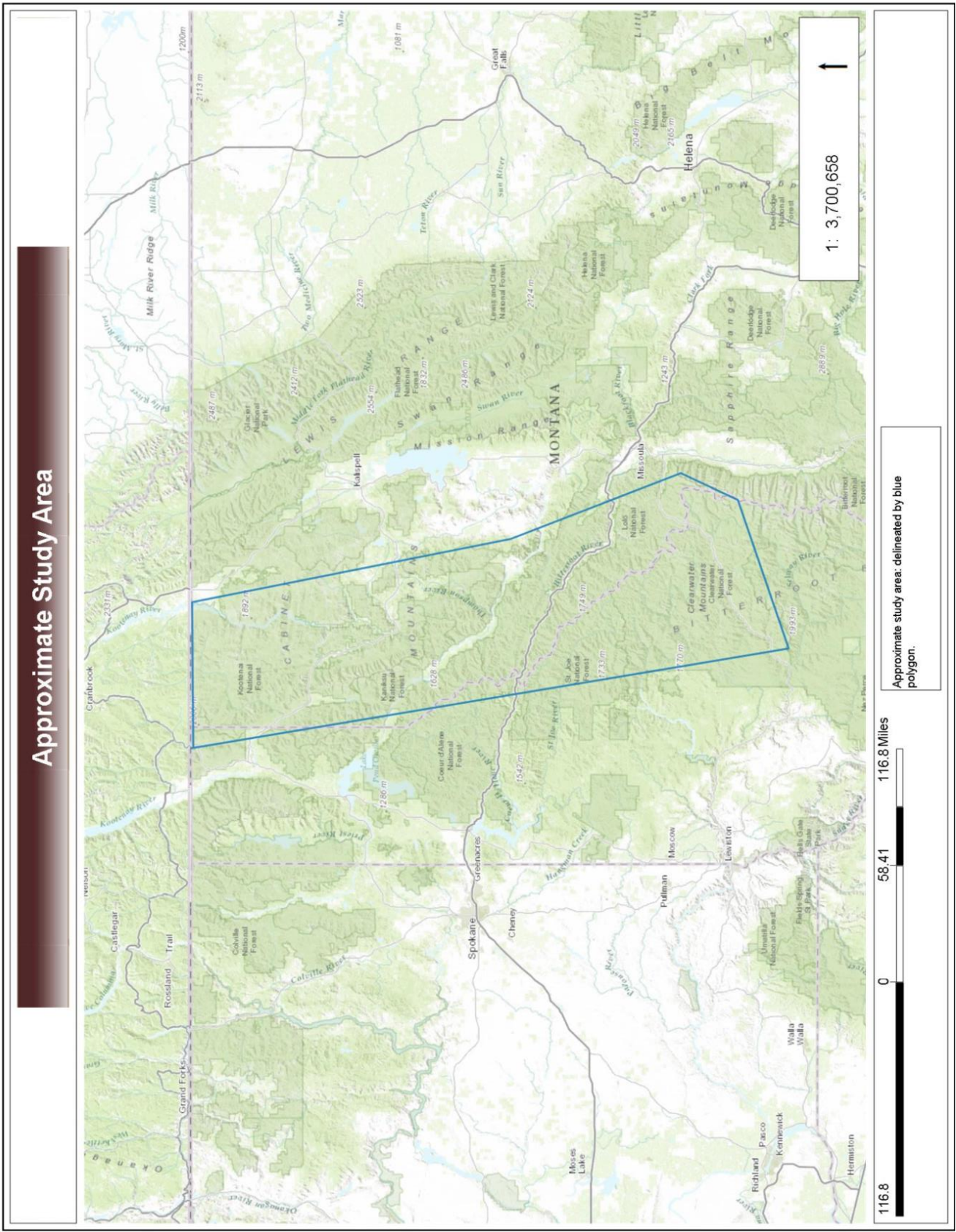


Figure 2. Approximate Study Area

Conditions for the ITRF are most suitable where there is a high level of soil moisture, particularly on toe slopes and the land in lower valleys. *Tsuga heterophylla*, *Thuja plicata*, and *Abies grandis* generally dominate the undisturbed mature forest community, although a host of other species will co-exist and dominate depending on various seral stages and local environmental factors and interactions. Areas between 610-762 meters with an average annual precipitation of 63.5 centimeters facilitate the development of forests dominated by *Tsuga heterophylla* and *Thuja plicata*. These communities are more confined to smaller wet canyons and valleys with cooler temperatures and moister aspects.

A key point for the ITRF as it relates to this thesis is that the environmental parameters identified from the literature and used for estimating potential ITRF habitat are meant to be representative of physiographic characteristics that are hypothesized to host the ITRF. The environmental parameters were not intended to predict one particular species, but rather an ecosystem that is described in the literature as being closely associated with lower valley elevations, higher precipitation, and cooler temperatures. Potential ITRF habitat is primarily based on environmental surrogate areas with an elevation range between approximately 730 and 1,300 meters and an optimal mean annual precipitation of 63.5 centimeters. Hypothesized ITRF habitat is also most suitable where there are high levels of soil moisture, where steep mountain slopes converge with the land in lower valleys, canyons, and confined ravines (DellaSala 2011; O'Connell et al. 2003).

3.2 – Data

Table 1. Environmental Variables

<i>Environmental Variable</i>	<i>Native Resolution</i>	<i>Description</i>	<i>Resampling</i>	<i>Source</i>
<i>January Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>February Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>March Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>April Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>May Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>June Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>July Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>August Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>September Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>October Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>November Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>December Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>Annual Mean Precipitation</i>	800×800m	30 yr climate data (1971-2000)	Bi-linear resample	PRISM 2010
<i>Mean Annual Temp. Max.</i>	800×800m	30 yr climate data (1971-2000)	DEM interpolation	PRISM 2010
<i>Mean Annual Temp. Min.</i>	800×800m	30 yr climate data (1971-2000)	DEM interpolation	PRISM 2010
<i>Elevation</i>	30×30m	DEM	90m	USGS 2007
<i>Slope</i>	30×30m	Derived from DEM	90m	USGS 2007
<i>Heat Load Index</i>	30×30m	Derived from DEM	90m	USGS 2007

Variables that were included in the environmental cluster analysis were initially identified and considered according to biogeographical knowledge and theory in the regional context and existing literature on ITRF areas, or mesic coniferous forests of the Northern Rockies (Arsenault 1999; McKenzie et al. 2003; O’Connell et al 2008; Gavin et al. 2009). Basic environmental variables that have been used in earlier environmental cluster analysis efforts were considered (Table 1). These are mean monthly precipitation, temperature, elevation, slope, and heat load index (in place of aspect). Inclusion of very fine-resolution lithological data or

local geomorphology may improve models for refugia habitats of this type (Hortal et al. 2008), however, such data are not available for the study area.

Climate data used in the classification analysis were downloaded from the United States Department of Interior Natural Resources Conservation Service Geospatial Data Gateway. The datasets were created by the PRISM Climate Group at Oregon State University, and consist of 30-year normalized climatological raster layers for monthly mean, annual precipitation and temperature data. The PRISM climate datasets were produced using an algorithm that interpolates values of observed point measurements for temperature, precipitation, and related climatic factors into continuous raster grids for GIS processing at an 800×800 meter resolution (PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>, created 4 Feb 2004). In order to use these datasets in the analysis, the resolution needed to be resampled to a finer resolution determined by the Digital Elevation Model (DEM) data (90 × 90 meters).

A striping error occurred in which the data values contained geometric artifacts that would negatively affect results of the analysis. The cell sizes were resampled from 30 × 30 meters to 90 × 90 meters in order to generalize and smooth the layer, compensating for the artifacts with the consequence of losing some detail but maintaining a dataset that would not contain significant technical error. The temperature data were resampled using the elevation-based interpolation technique of Willmott (1984), which resamples the data using elevation data from the DEM and a temperature lapse rate of 6.5°C per 1000 meters. The precipitation data were resampled to the DEM resolution using a linear interpolation. The end result of this stage in data management was a selection of climate variables to be used as inputs in the environmental cluster analysis that had a consistent resolution for raster analysis. This was necessary as

meaningless results could be produced if resolutions are out of alignment, causing the clustering algorithm to apply arbitrary cell value assignments (Wang et al. 2006).

A 30 × 30 meter DEM dataset was also downloaded from the USDA NRCS Geospatial Data gateway to derive the topographic variables elevation, slope, and heat load index. Slope values were calculated using Environmental Systems Research Institute's (ESRI; Environmental Systems Research Institute, v. 10.1) *ArcMap Spatial Analyst* extension. As an alternative to including aspect in the analysis, a heat load index was derived from the elevation data to indicate the levels of solar radiation. This variable is more conducive to statistical analysis and more closely simulates the heating properties and delineated cool or warm aspects of the region (Beers and Wensel 1966). The raster layer for heat load index was derived by utilizing an *ArcGIS Geomorphometry & Gradient Metrics* tool developed by Jeffrey Evans. The procedure follows a method for obtaining direct incident radiation and heat load index by McCune et al. (2002), in which values for potential annual direct radiation are calculated along a northeast to southwest axis.

To assess how well the environmental cluster analysis can identify or predict ITRF-suitable areas, a selection of nine Research Natural Area (RNA) sites were identified to be used as the best available indicators of ITRF classification accuracy. These data were available as simple shapefiles showing the boundaries of all RNA sites in the Inter-Mountain West as well as other attribute information (e.g., name, area, species assemblages) and were downloaded from the USDA Forest Service Rocky Mountain Research Station (perceval.bio.nau.edu/mpcer_old/RMRS/kml/html). The assessment was carried out by calculating the percentage of raster cells within the boundaries of the RNA areas that were classified as ITRF. Research Natural Areas are administered by the U.S. Forest Service to protect

examples of natural ecosystems and biological diversity so that scientists and educators may access these sites and data (Evenden et al., 2001). Specific RNAs were selected based on the documentation of ITRF representation within them (i.e., documentation indicates or implies ITRF dominance, strong, or less than strong representation). These percentages were evaluated against the site characteristics described in RNA documentation and how they described the floral characteristics of the area.

Because a pixel-by pixel validation was not possible, the RNA sites were used to assess the reasonableness of the ECA results, not to validate them. All data used in the thesis analysis were reprojected to the Universal Transverse Mercator coordinate system (NAD 1983 datum), and clipped to the study area extent. Some of the data included in the analysis fall outside the jurisdiction boundaries of National Forests, but were included as private landowners may be included in conservation strategies.

3.3 – Environmental Cluster Analysis for ITRF Classification

The analysis followed an environmental cluster analysis (ECA) land-cover classification procedure using the *Iso Cluster* tool within *ArcMap 10.1 Spatial Analyst*, with the goal of establishing an ITRF class for further assessment against RNA extents that host species assemblages of this forest type. In order to assess ECA's performance in the study area, cells that were classified into clusters were simply compared to the estimated approximate proportion of cells that would likely be ITRF within each RNA area. Forest Inventory and Analysis plot data were not used for assessment because the RNA areas were deemed to be more appropriate for the purposes of this study since they contain representative samples of plant associations and ecosystem types such as the ITRF. These classified clusters, having spatial expression as discrete

areas, are hypothesized to represent physiographic attributes believed to drive the establishment and distribution of target plant communities, thus having hosted or having the potential to host ITRF. The classified areas were not intended to represent an exact species range or association, but rather a community of plant life that is referred throughout the literature as ITRF.

In order to carry out the ECA, the *Iso Cluster* algorithm tool in ESRI Arcmap 10.1 Spatial Analyst was employed to process the input environmental variables. This procedure used the ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering algorithm, in which pixels are classified according to how they group within multidimensional space (Ball and Hall 1965, Richards 1986). With this method, data iteratively processed until the resulting classified clusters meet the algorithm thresholds. During the initial iteration, all of the sample cells are assigned to a cluster center. In each subsequent iteration, the mean of cluster is recalculated for each class. During this process, the minimum Euclidean distance is iteratively calculated between each individual pixel to the mean of each cluster and its inclusion in each cluster re-evaluated (Richards 1986). The beginning of the process arbitrarily assigns the clusters, which are recalculated in each iteration. Because of this, the number of iterations for this analysis needed to be set high enough to ensure that the clusters were stable and migration of pixels between clusters has stabilized or ceased.

The ISODATA clustering algorithm is a commonly used classification technique for deriving classes from satellite imagery with spectral signatures from multiple wavebands (Belokon 1997). It is also used in studies attempting to derive land-cover classes from environmental or biological data within a region (Wang et al. 2006). The isoclustering technique is generally accepted to find natural breaks within the input variables; however, it does not have a way to include expert knowledge on the relative importance of the input variables (Kent and

Carmel 2011). For each region analyzed, there will undoubtedly be a host of physiographic variables that have an impact on what real-world properties observed but which cannot be included in the statistical models. These factors, known or unknown to researchers, may be highly deterministic or influential. Despite these limitations, isoclustering classification analysis is useful because it is an objective data-driven process and may thus avoid human perception biases (Chen 2008). Applications involving large areal extents, such as in this study, also benefit from using what is considered a relatively simple (and comparatively computationally efficient) classification procedure (Richman 1995).

Input variable selection for the ECA targeting ITRF zones within the study area followed basic ecological and biogeographical principles for community level diversity in the area. Only environmental variables were included, as disturbance data did not fit the project which goal of using just climatological and topographical variable to represent the forest. The classification was not restricted to administrative (i.e., land ownership) boundaries. This was intended to provide to produce a more thorough result of environmental relationships and their classification within the region. Table 1 provides a list of the variables that were used as inputs for the isoclustering procedure.

The cluster analysis procedure analyzed variables according to their full range of values. Entire data layers were used as inputs for the analysis, not a specific range of values. Any specific number of output classes would produce clusters in multidimensional space from all variables. During the isocluster analysis, a series of classifications were performed with 7, 11, and 20 land-cover classes. These three levels were derived from prior forest land-cover classification studies (Wang et al. 2006; Trakhtenbrot and Kadmon 2005). The classifications with 11 and 20 classes produced results with a very high number of diffusely classified pixels.

Given the output maps, 90×90 m cell resolution, and literature regarding the appropriate number of categories and surrogate data extraction techniques, it was decided that the 7 category classification results were most interpretable Wang et al. (2006). Additionally, after visually inspecting the results of 11 and 20 classes compared with the 7 class iteration, it was decided that the 7 class iteration appeared to perform best in relation to the chosen RNA assessment sites and their qualities (i.e., the 7 class iteration produced results that are more inclusive of RNAs that contain ITRF). The procedure classified the individual pixels with values for each surrogate data layer into seven groups after 1,000 iterations with similar combinations of input variable values. Once the procedure was completed, the classified ITRF pixels were examined for display and assessment according to the USDA Research Natural Areas.

4. RESULTS

4.1 – Environmental Cluster Analysis Output

Results from the analysis support the necessity for caution when interpreting output when a good validation data do not exist. For this research, the environmental data were classified into gradients. For the purpose of testing this technique's utility to delineate a very specific forest type (i.e., the ITRF), these environmental zones represent areas that may be able to host these plant communities (Figure 1). The analysis classified mesic riparian areas along with many other areas not consistent with the ITRF environmental requirements. Results were compared to RNA sites that are known to harbor species associations and environmental traits of ITRF. What is presented here suggests that basic environmental cluster analysis is not a reliable method for meeting the goals of biodiversity conservation area prioritization and selection. Many smaller individual factors must be taken into account, as is described in following sections.

The classification contains a large area identified as ITRF. These results are not consistent with known ITRF qualities and extent, or the peripheral nature of this forest type in Montana and Idaho. The ECA did identify pixels throughout valley areas that could be ITRF habitat. These selections, however, imply that ECA did not select core ITRF areas that represent either refugia habitats or specialized zones in which the environment is best suited for this forest type's establishment. Several patterns are apparent, such as classification prevalence along river bottoms, ridges, steep slopes, low elevations, and modeled areas containing higher precipitation and lower temperatures. While these broad categorizations may fit an overarching environmental description of potential ITRF habitat, the output is simply too broad. As noted earlier, the ITRF, in northwestern Montana and northern Idaho, is in the periphery of its range. Based upon information from the previous discussion regarding refugia and paleoecological vegetation migration, a more accurate ITRF classification in this research's study area should exhibit a much more limited extent. These results imply that the ECA method as implemented in this case study produced an overly generalized classification scheme that does not capture the intricate nature of the specific forest type this research targeted.

Output clusters presumed to be representative of ITRF cells were selected based on consideration of original environmental parameters identified from the literature. In the GIS environment, particular cluster groups were labeled as being ITRF when they appeared to align with the desired values of the input variables. Classified cells in these ranges were selected to be representative of ITRF environmental surrogates. This broad selection was also visually compared to RNA assessment sites before final selections were made for further assessment.

Inland Temperate Rainforest Classification Study Area Extent

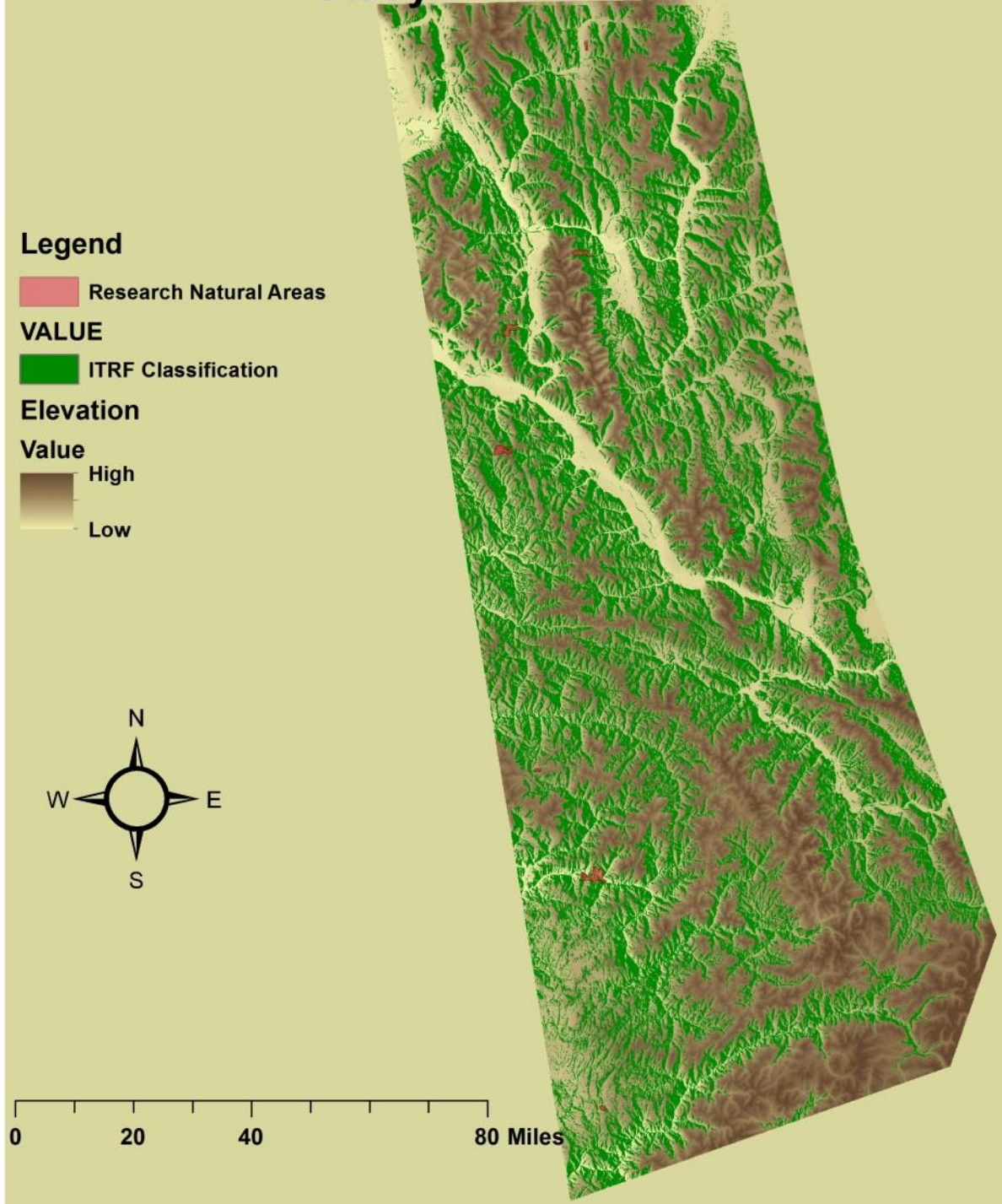


Figure 3. Map of the Isocluster classification for the Inland Temperate Rainforest (ITRF). A large area classified as potential habitat suggests the way the algorithm was applied in this study was unsuccessful.

4.2. – Research Natural Area Assessment of the Classification

Nine RNAs were chosen selected to assess how the classification performed. As will be discussed further, these sites generally demonstrate biotic and/or abiotic properties that are suitable for the presence or potential presence of ITRF species. As discussed previously, the areal percentage of ITRF cells within the boundaries of each RNA was calculated to assess the performance of the classification. To be consistent with common image classification accuracy assessments, 80% of ITRF cell cover within the RNA extent was designated as an expectation of “good performance” (Anderson et al. 1976), and this gauge was compared to documentation describing the individual RNAs (NPS 2010). Table 2 provides the results of the assessments for each of the RNA site and their characteristics.

Table 2. Research Natural Area Assessment. Characteristics of Research Natural Areas used for ITRF classification assessment and the percentage of the area classified in this study as potential ITRF habitat.

RNA	Area (km ²)	Elevation Range (m)	Centroid Coordinates	% Area ITRF
Aquarius	15.8	488– 1218	46°51'17"N, 115°40'9"W	62
Barktable Ridge	1.4	1707 – 1902	47°41'40"N, 115°8'20"W	2
Four-bit Creek	1.6	1073 – 1292	46°17'0"N, 115°39'0"W	45
Hoskins Lake	1.5	969 – 1081	48°53'9"N, 115°38'21"W	9
Lower Ross Creek	7.2	884 – 1582	48°12'15"N, 115°55'8"W	63
Norman Parmenter	5.3	811 – 1881	48°23'8"N, 115°40'37"W	57
Ulm Peak	2.8	128 – 1964	47°54'2"N, 115°57'2"W	13
Upper Fishhook	1.3	1305 – 1487	47°7'9"N, 115°51'32"W	27
Upper Shoshone Creek	5.7	1103 – 1964	47°54'16"N, 115°59'7"W	22

The 3,900 acre Aquarius RNA (Figure 2) in Clearwater National Forest, Idaho, is described as an extraordinary assemblage of disjunct, endemic, and unique vegetation species for the Northern Rocky Mountains,.This is caused by a combination of unusual climate factors for the region, such as higher average annual precipitation and lower temperatures, which facilitate

ITRF vegetation establishment and growth to maturity. It is the best remaining example of river terrace habitats for *Thuja plicata* and a high diversity of ferns, among other rare species of plants and salamanders (Evenden et al. 2011). This RNA is an ideal example of a place having the necessary conditions for ITRF presence or potential (Evenden et al. 2011). The ECA categorized 62% of the cells within it as potential ITRF. The broad environmental envelope that is suitable for ITRF exhibited by this RNA site resulted in the highest percentage of the area being categorized as suitable than any of the other RNAs. However, proportion of classified cells is lower than anticipated for such an area.

Barktable Ridge RNA in Lolo National Forest, Montana, consists of 341 acres spread over the top of a broad ridge (Figure 3). Relatively undisturbed with no major fire activity for several hundred years, the area is dominated by old-growth *Tsuga mertensiana*, *Abies grandis*, and *Abies lasiocarpa*. *Larix occidentalis* and *Pinus contorta* grow adjacent to the hemlock stands as a result of historical fire activity prior to the establishment of the ridge top stands. (Evenden et al. 2011). Only 2% of cells within Barktable Ridge RNA were classified as ITRF. Although a variety of different habitats are present, this result is too low for what the RNA documentation has indicated as dominant vegetation types. This low result implies that the ECA as implemented in this study did not classify enough areas with this a diverse array of habitat types.

Four-Bit Creek RNA in Clearwater National Forest, Idaho, is a 155 acre site representative of the most productive forested land within the Northern Rocky Mountains (Figure 4). Like the Aquarius RNA, it hosts advanced successional stages for *Thuja plicata* and mixed species within its habitat type, although these sites are not in a mature seral stage (Evenden et al. 2011). Areas of shaded riparian vegetation within the area closely follow a meandering stream, its floodplain, and tributaries. Such patterns are consistent with common

features of areas exhibiting ITRF qualities. The ECA results predicted 45% of cells within Four-Bit Creek RNA were ITRF habitat. According to the RNA documentation and the background information for the ITRF, this area should have displayed a higher percentage of classified cells. The result may be caused by the observed classification pattern in which slopes were classified to a greater extent than areas of low relief. The areas of lower relief were underrepresented and should be classified as this forest type.

Hoskins Lake RNA in Kootenai National Forest, Montana, contains 156 acres along a north-south oriented geological fault line (Figure 5). The fault has resulted in a linear trough depression in the land, and has been scoured by glaciers to create a low-lying habitat (Evenden et al. 2011). With a relatively moist and mild climate, the area's forest is dominated by *Thuja plicata*, *Picea engelmannii*, and *Pseudotsuga menziesii*. *Thuja plicata* is identified as a major component of the local forest, facilitated in part by the abundant available soil moisture. Aquatic features of the area are the 33 acre Hoskins Lake, a nine acre pond, and a 12 acre area fen and wet meadow. ECA classified 9% of cells within Hoskins Lake RNA as ITRF. This proportion of cell classification is much lower than anticipated for an area exhibiting the aforementioned environmental qualities. Similarly to Four-Bit Creek RNA, it appears as though a prevalent pattern in the ECA performance for this study region is to classify slopes to a greater extent than valley bottoms or low-relief areas.

Like the Aquarius RNA, Lower Ross Creek RNA in Kootenai National Forest, Montana, serves as a strong indicator for ITRF conditions (Figure 6). It contains 720 acres and a segment of Ross Creek, along with the surrounding slopes, stream terraces, talus slopes and exposed cliffs (Evenden et al. 2011). The terraced area along Ross Creek has facilitated the establishment and persistence of old growth *Thuja plicata*, surrounded by old growth *Tsuga heterophylla*. This old

growth area has historically extended beyond the lower streamside terraces, as evidenced by charred cedar stumps and stems dating to major fires in 1910 or earlier. The ECA results display that 63% of cells within Lower Ross Creek RNA were classified as ITRF. While the cluster algorithm identified a higher number of cells in this portion of the study area as ITRF than other areas it still omitted pixels which should have been included as this is another area that is described as being wholly dominated by the ITRF forest type (Cite the RNA report).

Norman Parmenter RNA in Kootenai National Forest, Montana, contains 1,300 acres situated in a canyon gradually formed by stream erosion and alpine glaciation (Figure 7). A major feature is the seasonal flooding of Parmenter Creek, which has created a habitat favorable to the development of mature *Thuja plicata* and *Tsuga heterophylla* (Evenden *et al.* 2011). The ECA Classified 57% of Norman Parmenter RNA as ITRF. The Norman Parmenter RNA is one of the few selected that seems to have an appropriate level of ITRF classification.

Documentation has indicated that it is not wholly covered and dominated by this forest type, although it is covered to an extent. The emphasis here is on favorable conditions for establishment and persistence to dominance through maturity. Although no biological datasets for particular seral stages or community composition were utilized by ECA, results of the RNA assessments indicate that ECA, as a generalizing procedure, may be better suited for classification procedures in areas hosting a variety of environmental conditions and more diverse communities of plant life, rather than attempting to classify ITRF core areas in a region where its extent is limited.


Adjacent Ulm Peak RNA & Upper Shoshone RNA in Idaho Panhandle National Forest, Idaho, contain 2,097 acres of an undisturbed watershed in the upper Shoshone Creek (Figure 8). The forest consists of diverse old growth hemlock stands of both *Tsuga heterophylla* and *Tsuga*

mertensiana (Evenden et al. 2011). On sites with more abundant soil moisture, *Athyrium filix-femina*, *Oplonanax horridum*, and *Taxus brevifolia* grow in abundance among the hemlock stands. Physiographic features of the upper Shoshone Creek drainage contribute to its diverse aquatic features. Waterfalls and multiple springs occurring along a moderate to steep gradient stream system exemplify the specific topographical features of an ITRF site. The ECA classified 22% of cells within Upper Shoshone Creek RNA as ITRF and 13% of cells within Ulm Peak RNA as ITRF. This RNA exhibits physiographic site characteristics consistent with the high relief sloped areas that ECA typically classified as ITRF. However, only 13% of the cells within the RNA were included and much suitable area was omitted as this area is strongly suitable for ITRF.


Upper Fishhook RNA in Saint Joe National Forest, Idaho, contains 132 acres of irregular topography with active streams and rolling hills in the East Fork Fishhook Creek upper basin (Figure 9). The area contains good examples of extensive, mature *Thuja plicata* facilitated by an unusually moist climate and mild temperatures, a rare occurrence in the St. Joe River drainage in the wake of extensive stand removal (Evenden et al. 2011). Twenty-seven percent of the cells within Upper Fishhook RNA were classified as ITRF. Upper Fishhook RNA, similarly to Norman Parmenter RNA, classified a reasonable proportion of cells as ITRF. It may be that the ECA as applied here performed better in mixed zones with a broader array of forest vegetation types.

Inland Temperate Rainforest Classification Aquarius

Legend


 Research Natural Areas

VALUE

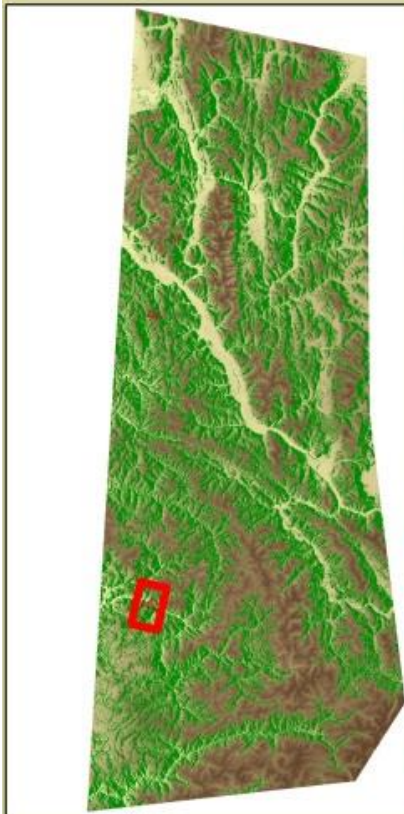
 ITRF Classification

Elevation

Value

 High

 Low




0 1.25 2.5 5 Miles


Figure 4: Aquarius Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Barktable Ridge

Legend


 Research Natural Areas

VALUE

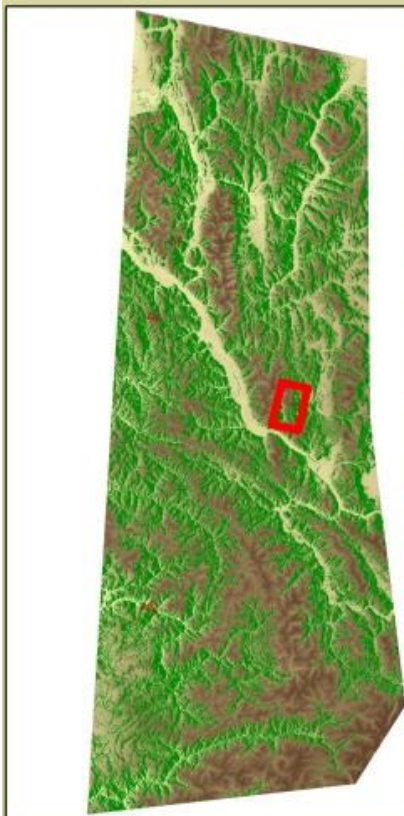
 ITRF Classification

Elevation

Value

 High

 Low



0 1.25 2.5 5 Miles

Figure 5. Barktable Ridge Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Four-Bit Creek

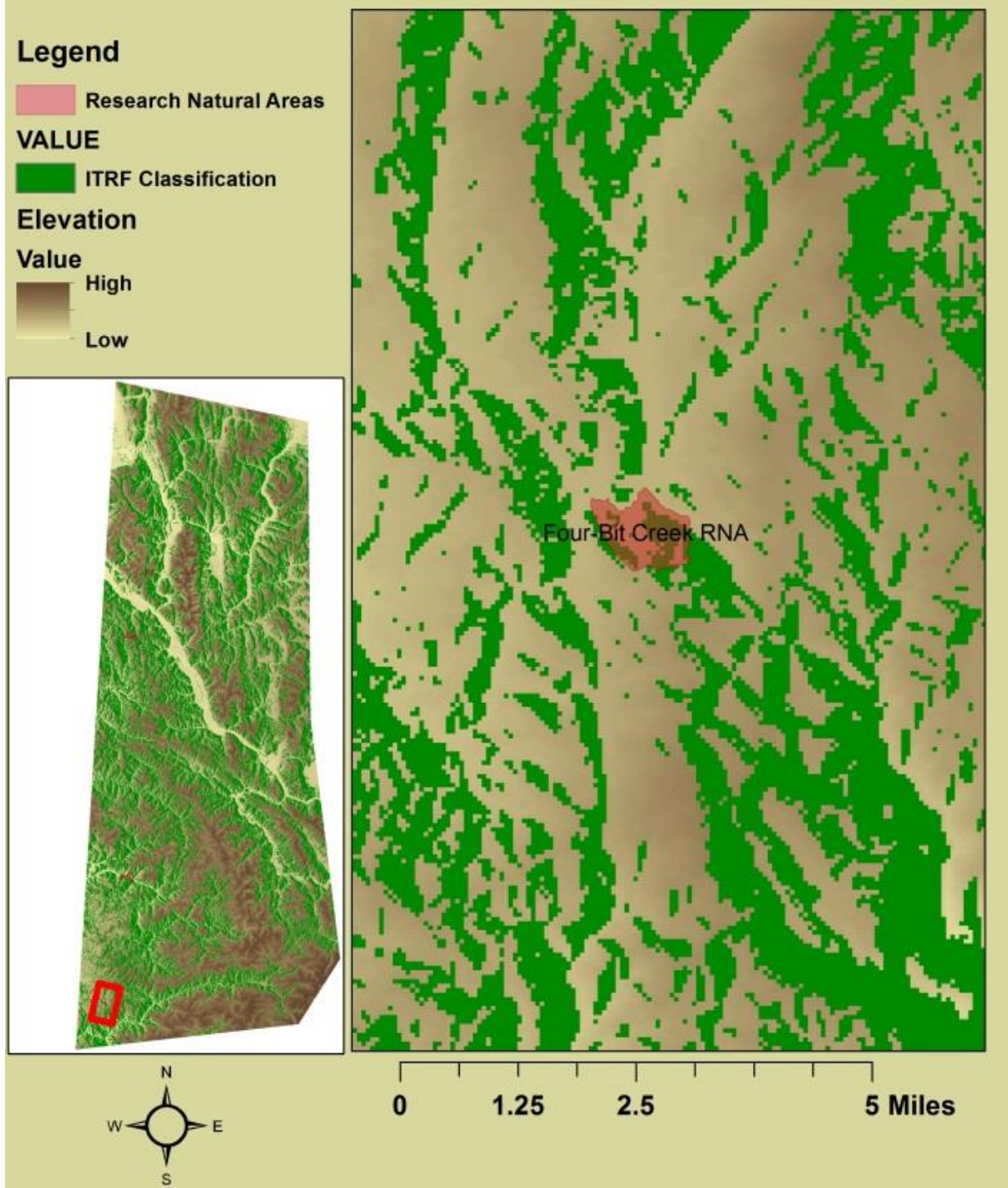


Figure 6. Four-Bit Creek Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Hoskins Lake

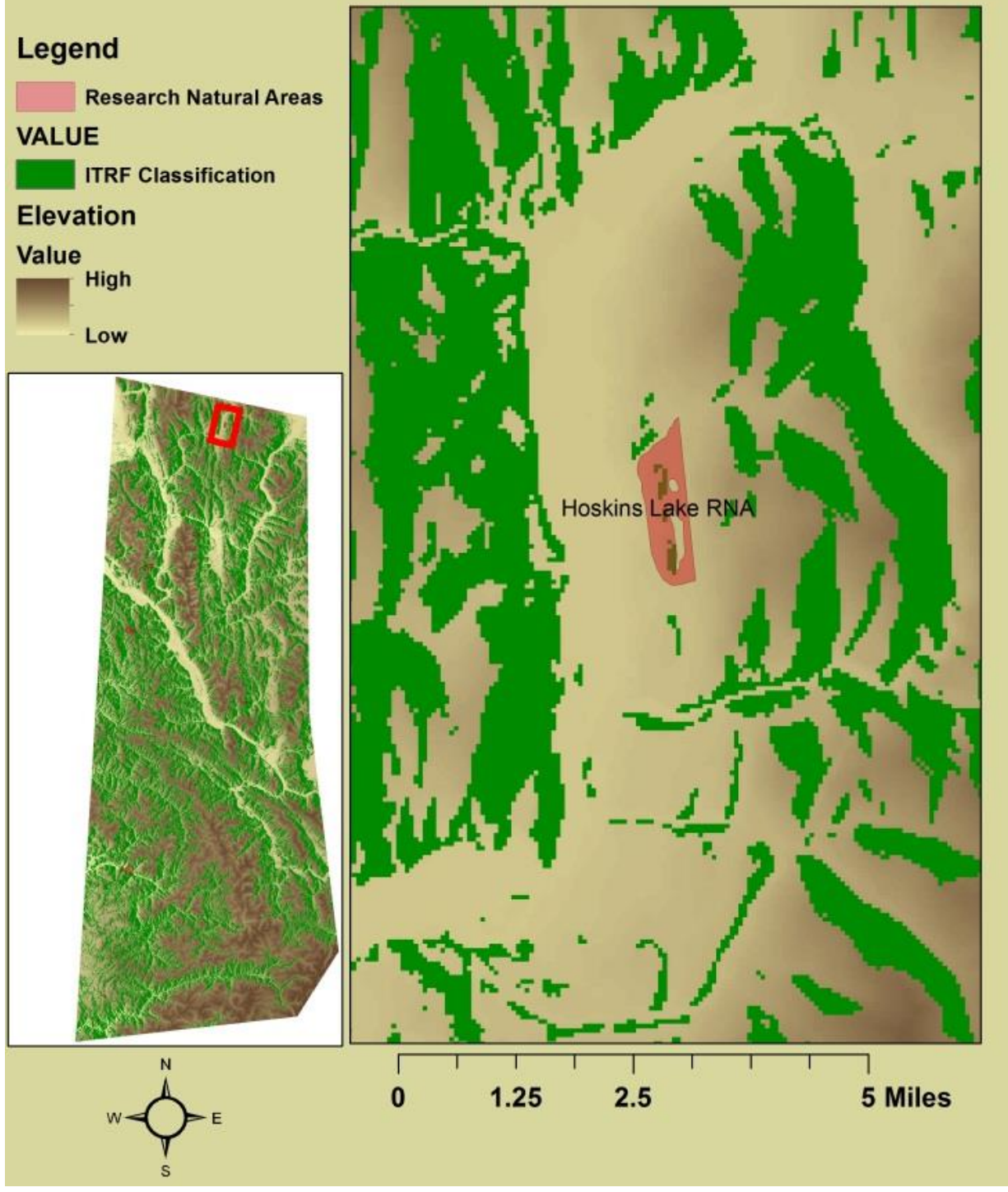


Figure 7. Hoskins Lake Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Lower Ross Creek

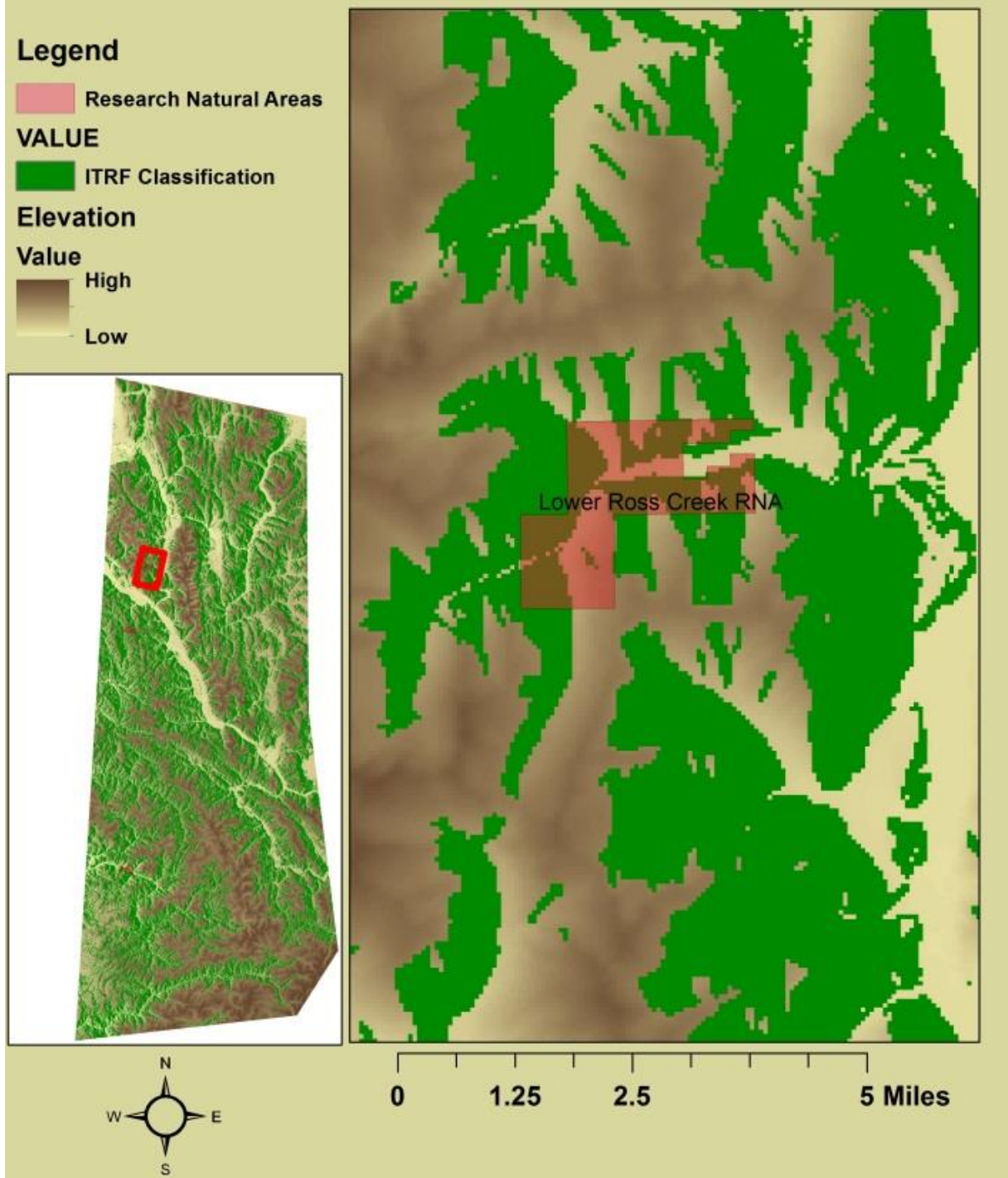


Figure 8. Lower Ross Creek Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Norman-Parmenter

Legend

Research Natural Areas

VALUE

ITRF Classification

Elevation

Value

High

Low

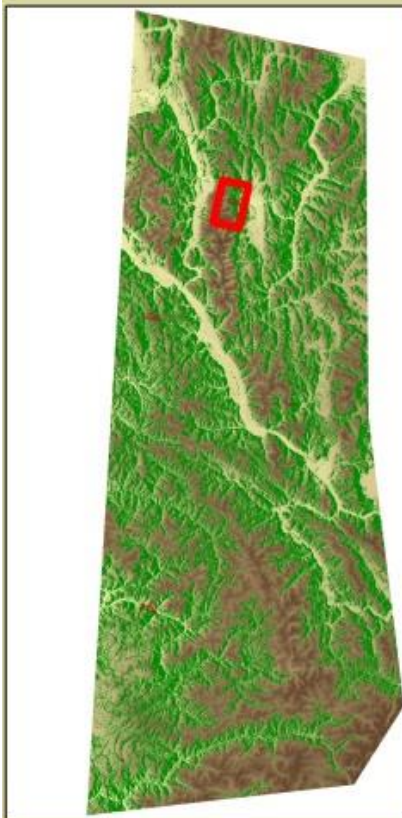



Figure 9. Norman-Parmenter Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Upper Fishhook

Legend


 Research Natural Areas


VALUE

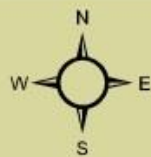
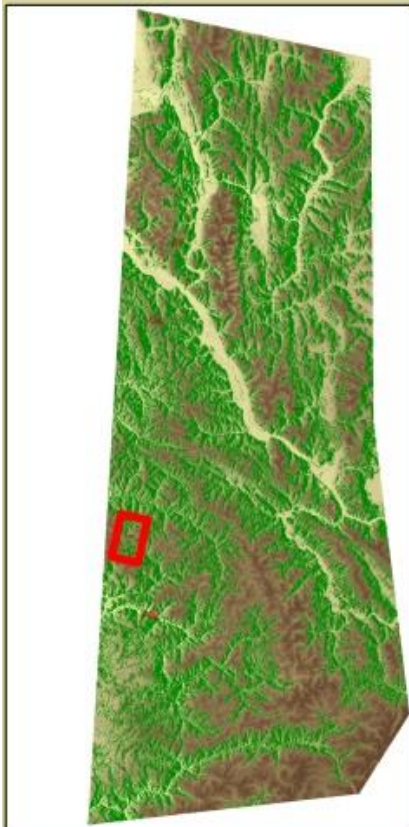
 ITRF Classification

Elevation

Value

 High

 Low



0 1.25 2.5 5 Miles


Figure 10. Upper Fishhook Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

Inland Temperate Rainforest Classification Upper Shoshone Creek & Ulm Peak

Legend


 Research Natural Areas


VALUE

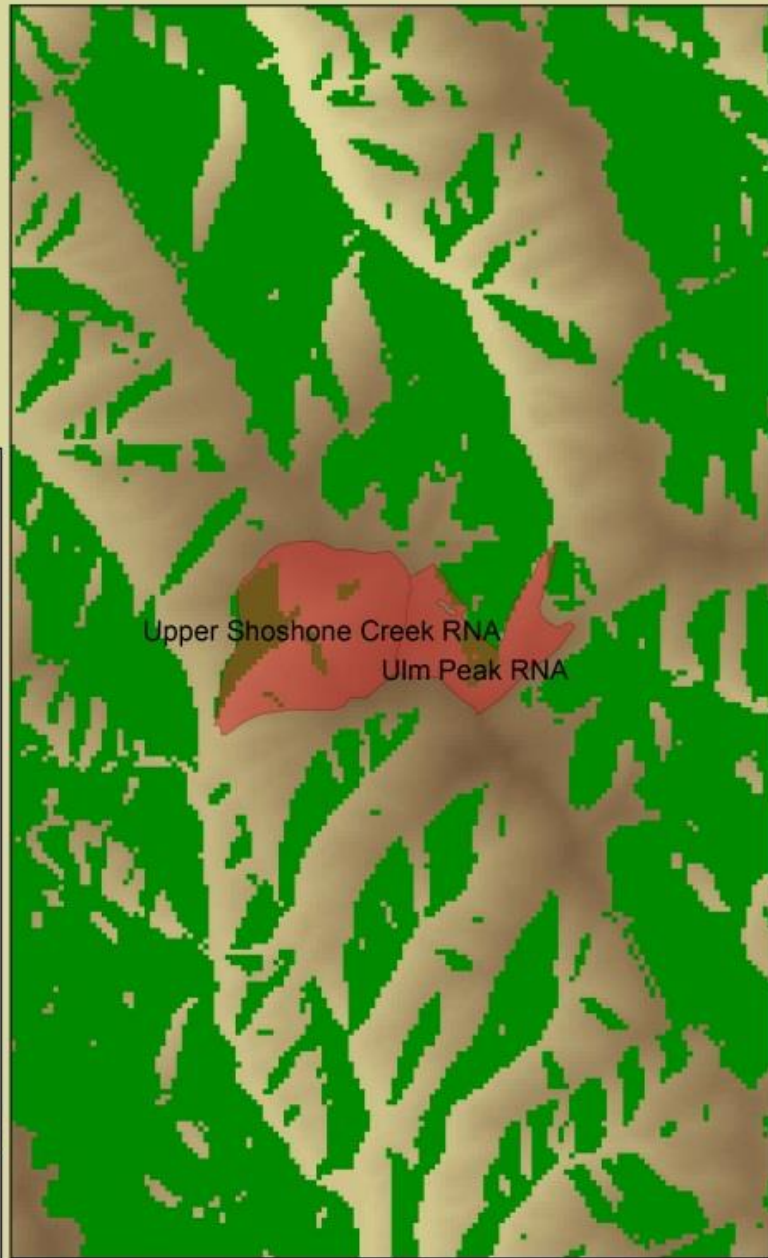
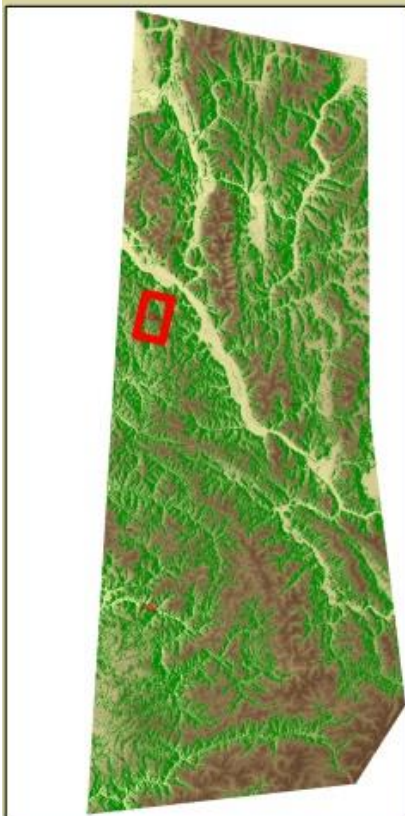
 ITRF Classification

Elevation

Value

 High

 Low



0 1.25 2.5 5 Miles

Figure 11. Upper Shoshone Creek & Ulm Peak Research Natural Area. ITRF Classification is highlighted as green, with the RNA's extent in red.

4.3 Review of Results

Of the ITRF indicator RNA sites, only Aquarius, Lower Ross Creek, and Norman Parmenter showed ECA classified cell percentages near 60 percent. It is critical to stress that the ITRF does not solely constitute of the major dominant tree species listed above. The areas are in a constant forest succession dynamic, and the ITRF, according to conclusions from available literature, describes a greater climatological and physiographic spectrum than dominant species (Evenden et al. 2011). Because the RNA locations that were considered were selected based their display of ITRF features, determined from the best available documentation, larger percentages (75-100 percent) of ITRF classified cells were expected. If the approach to ECA is a strong tool for selecting ITRF areas based on environmental biodiversity surrogates, the classification should have performed better.

5. DISCUSSION

Based on the results and assessment, multivariate cluster classification using the environmental surrogate variables utilized in this study did not produce adequate results from which to select ITRF sites in the Northern Rocky Mountains with the goal of identifying biodiversity representation and establishing conservation networks through regional complementarity. Seven of the nine RNA sites are described in their documentation as being highly suitable for ITRF. The ECA classification results are not consistent with vegetation site conditions for the RNA areas in habitats that were a primary testing goal of this research for the methodology. Areas that were classified as ITRF typically contained higher relief. This physical quality does necessarily match part of the criteria for the habitat in question, although some valley bottoms that should be mature ITRF were left unclassified.

Utilizing cluster analysis classification based on environmental surrogacy as a means for biodiversity conservation area selection has been presented in the literature with mixed results, with particular uncertainty as to its efficacy with plant communities whose local ranges can be described as ecological refugia or extremely limited and selective (Faith et al. 2003). In this example, ECA was evaluated to determine its practical utility for the ITRF in the Northern Rockies. In response to the proposed needs in research arising from theories of systematic conservation planning, a limited field of research concerned with biodiversity surrogate modeling has emphasized priority in testing GIS techniques for providing area assessments that meet these goals. Results from this research suggest that when refugia, rare, or very selective floral targets are considered, ECA is not suitable or must be integrated into models that go beyond its basic structure. There are various reasons for why this is the case, the first of which being the intricate nature of how the ITRF functions as an ecosystem, both historically and in its ecological dynamics through the present and future. Limitations in this analytical procedure must also be addressed, and significant alterations and additions to ECA may be necessary to establish a classification procedure specifically for the ITRF and other refugia systems. These results and considerations carry implications for biodiversity conservation planning and the concepts that have driven this research. Analyzing a region and planning conservation sites based upon biodiversity surrogates must be evaluated and reconsidered, especially when the target communities or species may be part of a greater system that is not well captured by a simple ECA procedure.

The ITRF was targeted as case study for testing the utility of ECA and general classification based environmental surrogacy. In order to develop a larger conservation strategy focused on diversity of the ITRF and its broader regional extent, multiple goals will need to be met for

identifying and classifying areas for future efforts. One goal among the host of procedures to be completed for an ITRF regional conservation strategy is testing GIS methods for area selection and classification with regard to forest types with specific criteria for establishment and persistence through adverse environmental change and disturbance regimes. The ITRF in northwestern Montana and Northern Idaho is in the periphery of its range, and the objective for testing ECA was to gauge its performance in this type of geographical context.

Future studies in this context would benefit from consideration of different variables to model ITRF. In this research, the variables were simple and based on basic biogeographical assumptions about a region. For such a purpose, these variables, information, and data may not be optimal. Environmental surrogate variables that may be beneficial to explore in future studies would be, but are not limited to, soil moisture content, differences between winter and summer precipitation, and soil type or quality. In addition to the variables, the method itself should be reconsidered for purposes beyond unsupervised classification. More options would be available within a decision tree or support system analysis, rather than a generalized unsupervised classification approach.

5.1 – Inland Temperate Rainforest Complexity

The physical environment in which the ITRF has developed through a rich ecological history has undergone major shifts, and will continue to change under forest dynamics in response to the greater system's progression and feedbacks (Carstens et al. 2005). The physiographic properties in the study area hypothesized to support or be able to support the ITRF have been established in the wake of such major shifts, resulting in the highly variable structure of its host region. The intricacy of ITRF habitats with regard to the limited lands that facilitate the presence of this forest type suggests that simply using ECA with broad environmental surrogate variables

commonly used in past procedures is not highly effective. This approach does not well capture this complex system that is in continuous change, creating localized habitats each with distinct characteristics, as is described in the overview of the ITRF, the general study area, and discussion of the different RNAs' qualities. In addition to the nature of the system itself, there is no clearly understood systematic relationship between ITRF and its greater environmental processes among the literature. Although general conceptual lines have been developed in research, modelling ITRF dynamics will continue to be a difficult task, as regional weather patterns and their effects on localized vegetation distribution and disturbance regimes may prove contrary to modeled trends. If GIS-informed biological conservation efforts for the ITRF are to be successful, they must take the full spectrum of possibilities into account concerning possible range shifts, controlling factors, and small scale patterns that may be unforeseen determining aspects of a local system. Addressing vegetation disequilibrium dynamics in ITRF modeling efforts will also significantly help capture the limited area of such habitats. Integrating concepts of lag-time in this ecosystem may assist in reducing error and selecting more appropriate sites based on how multiple factors culminate on a temporal scale to establish areas that are most likely to persist through the future as data permits (Svenning and Sandel 2013).

5.2 – Limitations of the Study

This study aimed to test a general procedure in terms of both data resolution and spatial extent, and consequently the results were at a coarse regional scale. The subsequent assessment of results among the RNA sites, interpreting these in the context of the habitats the RNA sites represent, and evaluating the overall ECA ITRF results in light of these considerations have provided some insight into the limitations of this study. By using common environmental

variables as inputs for a clustering classification algorithm, an area was generalized into an ITRF class over a broad region. The areas that were classified as such are typically any low-lying valleys and riparian areas. Such an output with generalization does not seem to capture the fine-scale dynamics and refugia characteristics of the ITRF. Different site-specific datasets for areas of interest should be incorporated into ITRF modeling procedures in order to fine tune the analysis to better focus on ITRF refugia.

As the results are considered, it becomes apparent that the underlying nature of ECA may be a limiting factor in ITRF classification in the study area, in the sense that it analyzes broad environmental envelopes to classify a region, with the goal of classifying specific environmental areas that are proposed to host a specialized forest type within the region. Once again, as this is in the periphery of the ITRF range, such an analysis type may be more suitable for core areas in British Columbia. In this study's context, the performance of ECA may be bolstered by the inclusion of real field data for model training that can narrow the range of environmental variables for accuracy and assessment so that the limited nature of the ITRF in this region can be better addressed.

The inclusion of lithological and hydrologic and geomorphological data might also assist in better identifying presence and potential ITRF zones. However, in order to incorporate such data, specific relationships between ITRF and these variable would need to be established when working at a fine scale in order to capture the existing dynamic (Pressey et al. 2004). Intensive environmental surveys in regions that are within a target area should be utilized to establish what variables are significant to particular areas and to gather preliminary datasets. Ultimately, it may be necessary to reevaluate the entire surrogacy approach when the ITRF is of concern. While this approach has provided good results in some conservation efforts around the planet, other locales

have either given mixed or negative results. If good results can be obtained, the relatively simple ECA approach can be a good starting point. However, some priority areas may be non-conducive to such a procedure, and the compromises in output quality may be too substantial to justify its full-scale implementation into a long-term conservation planning strategy. An entirely different procedure, one that does not implement surrogates and instead requires considerably more detailed data, time, and human resources, may be necessary.

It is always necessary to consider the quality of data used in modeling, and those utilized here were limited and perhaps not reflective of what bioclimatic parameters affect ITRF distribution. The unsupervised classification technique on which the ECA is based is likely not the sole cause of the inadequate results. It is a combination of generalized data and a procedure that is not optimal for identifying refugial area based on environmental surrogates. Results reflect what was given to the model algorithm to categorize as potential ITRF habitat, and the data lacked a sufficient level of information to address that forest type. With regard to the method, it is important to state that the fundamental process of ECA is not flawed, but rather this method was not adequate for exploring environmental surrogates in this specific forest type given the input parameters used here. Within the procedure itself, the covariation of environmental surrogate variables predominately based on elevation data and models derived from elevation data may have had a significant impact on results conveying hypothesized ITRF potential habitat. In the results, it is apparent that clusters closely followed elevation. Different specifications for the number of output classes (7, 11, 20) produces a range of clusters along elevation gradients, reflecting the variable covariance. Exploring alternative data sets for climatic and topographic surrogate variables that are not closely derived from elevation may

provide more independent results across class number selection and classification as a whole for the ITRF.

5.3 – Implications of the Study

A major implication of this research is that the accuracy and success of modeling with the use of environmental surrogate variables is dependent on the extent to which a generalized environmental classification system can appropriately describe the region it is applied to. The ITRF is only an application of ECA and environmental surrogacy in this research. As was discussed in the background chapter, multivariate classification methods and biodiversity surrogates have been reviewed with mixed assessments (Arponen et al. 2008; Lawler and White 2008; Chen 2008). Based on the findings of those studies, and the results of this analysis, ECA may be best suited for a preliminary assessment to gain insight into the data needs and specialized nature of the habitats or research targets in question. A benefit of using ECA for analyzing environmental surrogates in the case of the ITRF is that it can provide the researcher with an initial assessment of what areas may be more suitable for hosting this forest type. The limitations, however, possibly outweigh this benefit and should be seen as a major indicator that the larger concepts driving environmental surrogacy and unsupervised classification may need to be reconsidered. The ITRF, at least in this study's context, is not a forest type that can be accurately classified using cluster classification based on environmental surrogate variables.

As conservation scientists work through the current period of ecological change amidst prospects and effects of environmental degradation, conservation planners are developing conceptual tools and methodologies to address problems and provide answers or strategies for species and ecosystems (Kittel et al. 2011). These new concepts and strategies must be tested for

the areas of interest in which they propose implementation. Understanding the utility of hypothesized procedures is necessary and urgent in order to begin working on implementation strategies for complicated and interlinked systems. The negative assessment of ECA in this research is one example of the questions and challenges that must be addressed in biodiversity conservation planning. Such results implicate that biogeographical knowledge and theory must be understood or advanced in a way that further connects biogeography and GIS techniques for area selection. By addressing the specificity and accuracy of data for small zones, such as individual ITRF priority areas, shortfalls in the cumulative understanding can be addressed by refining classification models and improving the way in which these methods draw upon and contribute to disciplines external to geography.

6. CONCLUSIONS

Environmental surrogates can be used to model and classify areas across a broad region to delineate zones in which specific vegetation or other ecological communities might be organized. Through this study's use of ECA, it is clear that there are many factors that must be taken into account when refugia or extremely limited forest types is concerned. Environmental cluster analysis classifies a region based on generalized environmental variables, and with regard to the ITRF considered in this study, it is not the most ideal way to delineate priority areas that host or have the potential to host this forest type. Future ITRF modeling efforts may benefit from localized site focus with more comprehensive datasets of a smaller area.

The use of biodiversity surrogate variables in area selection procedures must be reevaluated. Biological, environmental, or mixed surrogate data types are not, in this application of surrogate methods, adequate for addressing site specific conditions and the unique scenarios that a

conservation target of interest may possess. As surrogate methods have been proposed and employed as a way to represent biodiversity in a region, studies testing their use do not provide conclusive results that such methods are reliable, accurate, or scientifically sound. While each surrogate data type may have strengths and weaknesses, this research and a review of the literature suggest that specific goals and characteristics of a region will dictate the appropriateness of any surrogate data, if such use is justified. Ultimately, the proposed representation scenario produced by the model or procedural output is not of the biological entities of interest. While this fact is inherent in the concept of surrogate data and methods, it must be emphasized that such an output must be used with great scrutiny and only when all other options have been explored under due diligence.

The ITRF habitat may be too broad of a classification for an application of ECA, as it is concerned with multiple species associations combined with ecosystem-level processes and floral communities. The ECA method may be better suited for classifying the potential habitat range of individual dominant floral species, or several very narrow community types and associations that constitute the ITRF, with the intent to evaluate smaller components that cumulatively identify hypothesized habitat cells.

Like surrogate data methods, the multivariate statistical methods that have been developed to develop land-cover classifications have not reached a conclusive level of data adequacy or resulting accuracy to reach a strong conclusion regarding the effectiveness of biodiversity surrogates. Even though the underlying basis for using surrogacy, environmental variables, and ECA is the lack of detailed biological data for site representativeness, it is still not clear if statistical clustering techniques are a sound option. These developing techniques have been studied through case scenarios and have seemed promising. However, the lack of conclusive

results from a majority of studies, and the results of this research support the conclusion that abiotic environmental surrogacy data and ECA are not able to successfully carry out area selection procedures as a necessary step towards meeting conventional goals of biodiversity conservation and systematic conservation planning.

Future research efforts concerned with environmental surrogates for classifying specific forest types should also go beyond ECA to employ further analyses. Additional information could be provided by utilizing models that produce more clusters with specific input parameters, and this may be a way to refine classification results. This may be a way to address the shortcomings of using generalized environmental surrogates in unsupervised classification. Alternative cluster analysis techniques (such as Maximum Likelihood Analysis, decision tree algorithms, etc.) would provide information to help interpret output clusters and how cells were assigned to their respective clusters. By obtaining more statistical information about the clustering procedure, the classes that are representative of ITRF, in this case study, can be individually assessed to better inform researchers.

In this particular research, the ITRF was utilized as a case study for its area, data, and environmental characteristics. While this forest type is of interest to the researcher, the goal of this thesis research was not to establish a conservation plan or identify ITRF sites for future use. Environmental cluster analysis and abiotic environmental surrogates were tested for their utility, and based on the results of this research, the procedure and data methods used here are not of significant utility that warrant their future use. Research and conservation planning projects with similar goals and objectives must explore alternate methods, and although the method used in this study ultimately failed in its procedural objective, these conclusions are a constructive for

the theoretical development of possible area selection and classification methodologies to accomplish the goals of systematic conservation planning.

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