STRATEGIZING FOR CLIMATE CORRIDOR CONSERVATION IN THE SOUTH PUGET SOUND, WASHINGTON

by
Christine Ruth Davis

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by

John Withey, PhD
Member of the Faculty

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ABSTRACT

Strategizing for riparian corridor conservation in the South Puget Sound, Washington State

Christine Davis

Low, fertile plateaus in the Pacific Northwest are experiencing rapid population growth and landscape fragmentation as well as extant threats of climate change, yet do not have adequate protections in place to preserve climate refugia and connectivity within riparian areas. Riparian corridors provide ecosystem services and facilitate animal movement. In addition, riparian areas containing high quality habitat are often biodiversity hotspots and potential climate refugia. Despite the high conservation value of riparian areas, and existing protection from the Clean Water Act, The Endangered Species Act and state-level protection laws, riparian areas in the Pacific Northwest are at high risk of disturbance and/or conversion. Strategically identifying conservation suitability within riparian corridors can result in protection of biodiversity and provision of ecosystem services at a landscape level. While previous research has given quality scores to climate refugia areas along riparian zones in the Pacific Northwest, these assessments have not yet been integrated into conservation plans that analyze where habitat quality coincides with climate refugia. Using Marxan, this research identifies high-quality riparian habitat with high-scoring climate refugia and estimates the least cost for future conservation in watersheds of South Puget Sound in Washington State. This planning strategy resulted in good options for enhancing riparian connectivity networks in our study area by identifying areas where increasing conservation areas may support protection of landscape resilience and riparian refugia. This regional climate adaptation strategy can be applied to other Pacific Northwest riparian areas where safeguarding of biodiversity and climate refugia is desired.

CHAPTER 1: INTRODUCTION

Habitat loss, homogenization and fragmentation cause ecosystem and species distribution shifts and often result in irreversible species extinction and landscape changes (Glanzig, 1995; Haddad et al., 2015; Tilman et al., 2017). Land clearing practices, occurring predominantly over the past century in North America, have undermined the habitat quality on which ecological biodiversity evolved (Chapin et al., 2000). It is important to acknowledge that functioning ecosystems often take thousands of years to develop, while abiotic changes from climate fluctuation, pollution, nutrient overloading, and land clearing occur faster than the natural processes which built them (Steffen et al., 2005).

Not all ecosystems are the same; fragility and adaptive capacity of landscapes varies greatly among regions, among the level of landscape disturbances and the amount of protective policies in place (Gunderson et al., 2000; Watson et al., 2013). Major ecosystem alterations from flood plain realignment through diking and rerouting of river channels, unsustainable farming and forestry practices, and urban development contribute to dynamic changes in both riparian and upland vegetation (Gregory et al., 1991). In a continuing era of rapid land transformation, ecosystems that maintain vestiges of connectivity, cover large areas and/or contain species richness and representation have priority for inclusion in protected area networks, particularly where climate change effects can be mitigated (Minor & Lookingbill 2010; Myster et al., 2012).

Structural and functional shifts of landscape disturbance often lead to ecosystem change and biodiversity loss, which in turn deteriorates landscape resiliency to extant threats such as climate change (Hagen & Hodges, 2006; Zavaleta & Heller, 2009). Because global temperatures are expected to rise above the 20th Century average by at least 1.5°C by the year 2030, species distributions and abundance could be fundamentally altered within ecosystems, as landscape resilience deteriorates (IPCC, 2018). As such, conservation planners need to adapt to landscape shifts by integrating strategic planning that considers climate change mitigation and biodiversity protection simultaneously (Pressey et al., 2007; Roberts et al., 2020; Seddon et al., 2020). Climate change is predicted to shift precipitation patterns. For example, high elevations will receive less snow and more rainfall, resulting in high impact flood events in lowland areas instead of a slow and steady release of water from snowpack (Heller & Zavaleta, 2009).

Refugia and resilience

Climate refugia, areas where species can take refuge from effects of climate change, are increasingly important for protection due to the erratic scale and unknown distribution of climate change effects on the landscape (Carroll et al., 2017; Keppel et al., 2012; Zavaleta & Heller, 2009). The Intergovernmental Panel on Climate Change (IPCC) states that ecosystem vulnerability is based on sensitivity, exposure, and adaptive capacity (IPCC, 2018). With climate change, riparian areas will experience ecosystem altering effects such as air and surface water temperature increases, precipitation changes, plant phenology shifts, and plant and animal distribution changes (Groves & Game, 2016). Incorporating riparian climate refugia into strategic land management planning can help to protect important ecological habitat and biodiversity by preserving niche areas for species (Schmitz et al., 2015; Zielinski et al., 2017).

An ecosystem is resilient if it can withstand disturbance to a degree that is supportive to species persistence within it (Walker, 1995). Protecting biodiversity, supports continued resilience in ecosystems despite temporary climate change effects (Isbell et al., 2015). Resilience needs to be considered in strategic conservation planning for riparian areas to protect areas of climate refugia and contribute aspects of ecological robustness to the surrounding landscape (Seavy et al., 2009; Stella et al., 2011). Restoring and conserving riparian areas directly contributes to improved ecological resilience within and around their extent (Hauer et al., 2016; Naiman et al., 1993) and becomes increasingly important as the landscape impacts of climate change accelerate ecological changes (Harris et al., 2006; Seavy et al., 2009).

Riparian areas are already two times more protected than upland sites because riparian areas contain a higher percentage of endangered and threatened species and provide more ecosystem services than upland forests (Fremier et al., 2017; Helfield & Naiman, 2006). Connected land fragments protect species heterogeneity, thus riparian corridors are uniquely suited to connective conservation and adaptive management strategy (Andren, 1997; Haddad et al., 2017). Riparian area resilience can be supported by focusing on adaptation strategy. For example, incorporating reconnecting wetland areas with riparian corridors and an examining riparian buffer contribution to habitat health (Groves & Game, 2016; Heller & Zavaleta, 2008).

This thesis identifies potential new conservation and restoration areas based on biodiversity and climate refugia targets for Thurston County, Washington. The subject of this research is an acceleration of conservation strategy that incorporates climate change issues at local watershed levels and improves on past conservation practices broadening natural set-asides only to out of the way areas. I considered site prioritization as areas between the interface of already protected areas and urban areas where remaining conservation opportunities exist. In this research, I seek to answer the question: How do habitat quality and refugia in riparian corridors contribute to riparian conservation prioritization in the South Puget Sound? At what capacity, if any, should riparian conservation be expanded in watersheds of Thurston County, Washington?

In the Pacific Northwest, the Puget Lowlands also known as the South Puget Sound, have been identified as a critical area for accelerated protection of biodiversity due to rapid population growth and land development combined with extensive areas of high-quality habitat and climate refugia along its rivers (Krosby et al., 2015; 2018). Thurston County, at the interface between the Washington Coast region and the South Puget Sound, is the 6th most populous county in Washington with a rise in population of 13.5% between 2010 and 2018 (US Census, 2018). Yet even before that population increase, satellite imagery from shows large-scale landscape changes occurring, with more than 8000 of the counties' 495,000 acres converted to developed land from 1992-2011 (Thurston Regional Planning Council, 2016).

In Thurston County, state and federal agencies, conservation easement managers and private landowners manage riparian buffer width, unstable slopes, deteriorating roads and insufficient culverts to support healthy aquatic systems in federal and privately owned forests according to the requirements of the Forests and Fish Law passed in Washington in 2006 (WFPA, 2019). The Endangered Species Act and the Clean Water Act work in conjunction with the Forests and Fish Law to support riparian habitats where threatened and endangered species exist within Washington.

Strategic planning

Strategic planning considers biological need for conservation and is the opposite of the ad hoc type of conservation typical of protected areas globally (Klein et al., 2009). Protected area conservation and restoration initiatives can mitigate biodiversity loss when implemented strategically. Often, simply leaving land to function on its own without human interference has restorative benefits (Hobbs et al., 2009). However, strategic conservation planning, while highly practical and iterative, considers multiple conservation features representative of the landscape while maintaining connectivity and reserve size for species range movement and landscape resiliency (Klein et al., 2009; Possingham et al., 2006; Soule & Sanjayan, 1998). For example, strategizing for inclusion of attributes such as varied environments prove crucial to conservation strategy as site heterogeneity is known to support species richness (Stein et al., 2014).

Shifting policy to focus conservation strategy on areas containing movement opportunity for species and ecosystem services for humans such as riparian areas, can contribute exponentially to biodiversity protection in places that are not typically considered as protected areas or as conservation reserves (Pressey et al., 1993, Soule and Terborgh 1999). Ecosystem services, the qualities of an ecosystem that support improved livlihoods of humans, include temperature moderation, air and water purification as well as more tangible effects such as food and drinking water. That these qualities are important to human life, should be obvious enough. However, in order to defend the persistence of ecosystem services in the landscape, a change in conservation planning away from low-cost, low-return conservation areas towards higher-cost, higher-return conservation areas, may be necessary.

The least expensive conservation land acquisitions do not provide the most protection of species (Watson et al., 2014). In a global examination of protected area efficiency, the most inexpensive land acquisitions for conservation were not supportive of vertebrate species protection. In contrast, choosing sites for conservation that had 1.5 times higher cost than the most inexpensive land was found to protect 5 times as many vertebrate species (Venter et al., 2014). This example shows how improving the efficiency of strategic conservation planning can contribute to adequate species protection. Applying a planning objective for biodiversity conservation at the least cost to riparian areas in the Pacific Northwest, focuses on protecting areas that may not be the cheapest for land acquisition and landowner restoration incentives, yet will provide a higher return on biodiversity (Ament et al., 2019; Armstrong et al., 2018).

Protected areas have historically been designated to undesirable or scenic lands that are not representative of regional biodiversity. Lowlands with fertile soil are often left out of land conservation (Soule & Terborgh, 1999; Watts et al., 2017). Rather than aiming only to protect out of the way and scenic areas such as National Parks, strategic conservation planning aims to consider habitat and biodiversity within underrepresented lands. High elevation landscapes are often less expensive to acquire than lowland areas where humans live at higher concentrations. The future resilience of biodiverse landscapes will depend on a shift in land management towards integrating conservation of all lands (Watson et al., 2016).

Past studies have identified riparian corridors in the Pacific Northwest as species dispersal corridors because of their microclimate refugia (Krosby et al., 2018). While other research has found riparian connectivity networks to be important for connecting landscape fragmentation by providing natural corridor systems (Fremier et al., 2017). In Washington State, with the establishment of the Growth Management Act, state land managers have recognized the importance of habitat corridor connectivity between urban areas, yet these habitat corridors have not yet been established nor have remaining opportunities for riparian corridor conservation been identified for Thurston County (Thurston County Resource Stewardship Department, 2015). The Washington Wildlife Habitat Connectivity Working Group produced a climate gradient corridor report and map series showing new pathways for animal movement based on temperature gradients across the Pacific Northwest (WHCWG, 2011). However, these corridor plans do not include environmental variables that influence refugia such as low climate change rates, solarization, topology and environmental diversity (Lawler et al., 2020).

Efforts to incorporate riparian connectivity into regional planning although currently in process, do not have robust climate mitigation adaptive planning strategies. Thurston County

Habitat Conservation Plan, created in 2016, aims to identify high quality habitat for new acquisition and site connectivity across the whole county, but does not include climate refugia data in their habitat quality measurements or a corridor plan. The Conservation Reserve Enhancement Program (CREP) gives farmers incentives for planting vegetation as riparian buffers to protect salmonid species using streams on their property. Although integrative of some biological data, CREP site selection is not based in robust habitat analysis. Similarly, the South Puget Sound Salmon Enhancement Group sponsors projects promoting riparian ecological health in the Puget Sound, but do not incorporate data on biodiversity, riparian refugia and cost of conservation.

This thesis consists of a systematic conservation plan to identify sites for conservation and restoration in the South Puget Sound, Washington by considering habitat quality and riparian refugia data. The major watersheds of three rivers in Thurston County are our case studies: The Black River, Deschutes River and Nisqually River. Using Marxan conservation planning software and GIS, conservation opportunity areas were selected and grouped with least cost for conservation at representative habitat quality parameters and defined by informed targets of biological attributes (Kaim et al., 2017; Watts et al., 2017). This research aims to contribute to localized adaptation strategy for freshwater ecosystems in Thurston County with the objective of biodiversity and refugia protection by way of riparian corridor connection. Land managers can use these methods and adapt their own parameters to achieve similar strategic options for climate refugia conservation in riparian areas where protection of biodiversity is desired.

With a slight change in localized data sets and nuanced examination of project specific objectives, this strategic approach can be applied to conservation action initiatives in other areas of the Pacific Northwest. Identifying site needs such as ‘increase biodiversity’ or ‘mitigate understory heat index' are examples of objectives that land managers can establish to begin incorporating the methods of this strategic planning approach. State and federal agencies can utilize existing data from open source web databases combined with newly collected data as inputs and set targets to support their planning objectives. State, county and city land managers will find that they only need to clip existing WDFW, DNR and County datasets to their own areas of interest in order to run similar tests for conservation prioritization or restoration site selection. Private landowners and easement groups can use results from this study to identify how their property coincides with priority conservation zones that may have important attributes such as climate refugia. Areas of higher protection status based on biological habitat data can be given preference for protection where localized site development occurs. Additionally, federal and state agencies, private landowners and easement managers can use these data to expand their property adjacent to conservation priority areas at least cost for acquisition.

During this thesis I build a case for strategic adaptive management for riparian refugia protection and corridor expansion in the South Puget Sound, using a case study of several watershed area units in Thurston, County Washington. Following *chapter one*, an extensive review of past and current literature builds a framework to set historic, present and future context of systematic riparian conservation planning in the South Puget Sound as *chapter two*. *Chapter three*, the research manuscript, consists of a shorter version of this introduction, the thesis methods, results, and a discussion of the analysis with recommended options for future conservation and restoration in the study areas. *Chapter four* concludes the thesis with appendices and maps to support the strategy and results outlined here.

CHAPTER 2: LITERATURE REVIEW

Introduction

Globally, biodiversity is under attack from land clearing and unprecedented anthropogenic climate shifts (IPCC, 2018). Biodiversity functions as the foundation of ecosystem resilience and species persistence on Earth, but current measures to protect the bare minimum biodiversity are failing. (Isbell et al., 2015; Wilson, 1999). However, the current trajectory of conservation planning has not yet succeeded in protecting the resilience of ecosystems when those habitats are confronted with a myriad of extent threats. Improved strategies for protecting biodiversity include proactive adaptive climate management, understanding genetic processes at site specific levels, habitat connectivity and restoration planning at global scales combined with local implementation (Cowling & Pressey, 2001; Groves & Game, 2016).

Multiple threats against biodiversity necessitate a comprehensive approach to conservation planning for natural areas and the land surrounding them (Stuart et al., 2000). Robust strategic conservation planning incorporates future threats of climate change and landscape development at multiple scales and with many conservation targets to establish management options (Brambilla et al., 2017; Jones et al., 2016). Essentially, planning for and implementing new natural areas as well as incorporating private landowner restoration incentives, can directly reduce biodiversity loss (Carwardine et al., 2010; DiMarco et al., 2019). Additionally, increasing the amount of private land conservation will greatly contribute to local adaptive management successes (Seavy et al., 2009). If we are to depend on this planet to continue to support our livelihoods, we must also work actively to mitigate the biodiversity loss caused by excessive land clearing and climate change. Reassessing the current state of conservation at localized levels can contribute to this work (Seddon et al., 2020).

In their current state, protected areas fall short in their ability to shield species from extinction and ecosystems from collapse (Lawler et al., 2020; Roberts et al., 2020; Watson et al., 2013). A planning approach shaped around incorporating climate change effects on the landscape into conservation strategy brings new challenges and opportunities for conservation management moving forward (Groves et al., 2012; Heller & Zavaleta, 2009). Data gathered from multiple sources for the purpose of habitat quality assessment reflect the complexity of factors influencing habitat quality. Landscape assessments which consider conservation targets, surrounding area land use, historic disturbance, water movement cycles and human perception of conservation management will continue to be important for the protection of high-quality habitats (Dale et al., 2001). However, adding climate velocity and climate refugia data to planning processes supports more resilient habitats and ecosystems.

The success of the conservation movement and protection levels of natural areas remains uncertain (Bookchin, 1987; Geldmann et al., 2013; Sanderson et al., 2006). Driven by laws such as The Endangered Species Act (ESA) and the Clean Water Act in the United States, species protection is still largely inadequate (Gaston et al., 2018; Minor & Lookingbill, 2010). As a result of conservation efforts instigated by the ESA passed in 1973, in the United States, 1661 species are listed as endangered or threatened, while 1169 have ‘active’ recovery plans. This leaves a remaining 491 species without any current plans for their protection (USFWS, retrieved April 2020). Of the 25,780 known terrestrial vertebrates on planet earth, 5,176 are threatened with extinction and only one-fifth of these species have adequate protection for maintaining stable, wild populations (Wilson, 2016). Furthermore, we may never know the breadth of these losses, as a high percentage of these extinctions will be of species not yet discovered (Costello, 2015).

Low flat lands (lowlands) are particularly under-represented in conservation planning and protected area networks, while upland, mountainous areas are often prioritized because they are of less value for urban development (Krosby et al., 2018; Pressey et al., 2017; Soule & Terborgh 1999). Additionally, riparian forests do not have as much marketable value as farms and timber forests (Pressey et al., 1993, Soule & Terborgh 1999, Krosby et al, 2018). Riparian value lies in its contribution to the landscape.

Lowlands such as the Puget Sound Lowlands within the Puget Sound Ecoregion of Washington State have been identified as an area of high importance for protecting river systems in the Pacific Northwest due to a large amount of riparian refugia within yet unprotected areas (Krosby et al., 2018; Wade et al., 2013). Refugia, such as cool climate niches, are areas where higher quality habitats may meet criteria needs for species survival in the event of climate shifts that may otherwise harm their survival chances. However, Puget Lowland riparian areas are threatened by damage from climate change, rapid population growth, future human developments, and resource extraction impacts (Alberti et al., 2006; Hepinstall-Cymerman et al., 2013; Lister et al., 2015; Singleton et al., 2001).

To mitigate cascading effects of fragmentation and habitat loss in riparian areas, strategically identifying new conservation opportunities and reassessing existing protected areas is important for landscape connectivity (Joppa et al., 2016). Because of their susceptibility to degradation, protected areas near fragmented land should be reassessed more often than high quality reserves to ensure they are not being unnecessarily impacted (Margules & Pressey, 2000). The effects of disturbances such as land fragmentation from roads, infrastructure, resource extraction and invasive species are amplified with added stressors of climate change (Bradley et al., 2009; Heller & Zavaleta, 2009). These pressures can push the landscape beyond a recovery threshold, minimizing important climate refugia and microclimate habitat (Beisner et al., 2003; Dunn & Angermeier, 2019; Wade et al., 2013).

This literature review incorporates sources which suggest the need for a paradigm shift in conservation management toward considering all lands as important for protection until proven otherwise. Here, evidence collected shows the need to move away from the *ad hoc* practice of conserving lands set aside only for single attributes such as charismatic fauna, human inaccessibility or resource barrenness and instead promotes analysis of multiple habitat variables into a comprehensive plan for habitat protection at landscape levels (Brambilla et al., 2017; Venter et al., 2014). The following is a comprehensive analysis of the background, practical and theoretical frameworks for analyzing riparian climate-corridor conservation opportunities in the Puget lowlands, while addressing the constraints of conservation in multi-use landscapes.

Climate refugia

Climate refugia are niche areas where species may find refuge from negative impacts of climate change on their habitat. Typically, these are microclimate or otherwise suitable habitat pockets where the air contains such attributes as lower overall temperature, lower solar radiation, and higher tree canopy than the surrounding area. However, climate refugia are not present in most protected areas (Carroll et al., 2017). This lack makes movement of genes among habitat patches less likely during acute and long-term climate effects on the landscape (Pelletier et al., 2014). Climate change is typically included in conservation plans by using climate refugia spatial data (Game et al., 2008). Planning specifically for an inclusion of climate refugia into landscape assessments can contribute to overall landscape resilience when faced with climate change and land development threats (Keppel et al., 2012, 2015; Krosby et al., 2015). In riparian areas, reconnecting riparian corridors to wetlands and groundwater are adaptive mitigation strategies that can promote thermal refugia for amphibians and salmonids (Groves & Game, 2017; McCullough et al., 2009).

Riparian areas have high levels of protection compared to some upland landscapes because they often contain a higher percentage of threatened or endangered species and provide more ecosystem services (Fremier et al., 2017). Riparian areas protect downstream water quality while providing shade, shelter and food to a wide range of animals. Rivers, streams, creeks and their associated forest systems provide not only important resources for humans, plants and animals (Ahearn et al., 2006; Armsworth et al., 2018), but they also provide corridors for plant and animal movement through the landscape (Dale et al., 2001; Detenbeck et al., 1993). Because of these inherent services, protected areas containing water are valuable and common (Naiman et al., 1993; Fremier et al., 2015). Many healthy riparian areas provide microclimates that protect species diversity and climate refugia naturally (Meave & Kellman, 1994; Fremier et al., 2015).

A recent analysis of Pacific Northwest watersheds ranked riparian areas for their climate refugia potential on a climate-corridor index (Krosby et al., 2018). While overall, mountainous areas had higher ranked habitat quality for climate refugia than lowlands; rivers in Thurston County also contained climate refugia. As climate corridors, riparian refugia areas have the potential to contribute to climate range shifts, facilitate movement for both riparian and upland species, and provide shelter from environmental shifts due to climate change (Brambilla et al., 2017; Keppel et al., 2012; Zielinski et al., 2017). Additionally, some abandoned river channels containing no water have been identified as important refugia zones (Stella et al., 2011). The inclusion of refugia measures such as climate-corridor ranking in systematic conservation planning can inform not only conservation options based on the current landscape, but also on the projected effects of climate change on species movement (Heller & Zavaleta, 2009; Monahan & Theobald, 2018).

Krosby et al., (2018) describe riparian corridors as dispersal corridors because of their inherent microclimate refugia. Elements that facilitate these microclimates include temperature gradient, canopy cover, relative width, solar radiation and human interference. Because riparian refugia can exist even where there is no year-round water flow, Krosby et al. (2018) used a potential riparian area model created by Theobald et al. (2013) as a spatial basis for the riparian refugia index. The variables resulted in a ranking system for riparian refugia across the Pacific Northwest on a scale of 1 to 5 with a score of 5 being the most natural state, or 'best' refugia. From their analysis, mountainous regions had the highest scores, while lowland areas such as the Columbia Basin and Puget Lowlands had the lowest scores. Krosby et al. (2018) recommend focusing riparian restoration and conservation strategy in these two lowland areas to provide resource protection while what remains of this refugia is still intact. Because riparian corridors often contain climate refugia, conservation of remaining unprotected riparian areas and adaptive management within watersheds of the South Puget Sound is a proactive strategy that can maximize habitat protection (Seavy et al., 2009).

High quality habitats

High quality habitats are those with the ecological integrity to support many species and provide ecosystem services to humans and animals (Bump et al., 2009; Helfield & Naiman, 2006; Wilby & Perry, 2006). Focusing conservation efforts on high quality habitats keeps conservation maintenance costs low because if protected, there is less need for restoration efforts in those areas (Watts et al., 2017). However, not all habitats "worthy" of protection are of high quality. There are surrounding agricultural or forested areas that may be supportive of adjacent protected area biodiversity (Hobbs, 2001). Results from protected area reporting do not always include the effects of surrounding agriculture and forested areas contributing to connectivity, habitat quality and ecosystem health (Benayas & Bullock, 2012; Kremen & Merenlender, 2018; Tilman et al., 2017; Venter et al., 2014). In contrast, a preference for conserving riparian areas isolates the riparian corridor from high intensity development, thereby creating a network system of protected areas surrounded by encroaching urbanization.

Globally, thirty percent of natural areas are subject to pressure from humans from within (Watts et al., 2018). Additionally, protected areas in proximity to humans require more frequent reassessment than those in remote areas. While it was once thought that ongoing monitoring and management assessments could help ensure that protected areas are not subject to unnecessary impacts (Soule & Terborgh, 1999), the potential for catastrophic effects of climate change has established uncertainty in protected area management (Turner et al., 2020).

Riparian buffers

Riparian areas are high primary production zones which stabilize streams and tree growth (Helfield & Naiman, 2006; Bump et al., 2009). Buffers are important in riparian restoration and landscape planning because intact forests along rivers can retain water sources and reduce flooding (Jiao et al., 2012). Additionally, riparian areas contain more water than upland forests, so they act as heat buffers when high temperatures occur (Naiman, 2000). Buffers around riparian areas are a management practice implemented to protect habitat surrounding streams (Rykken et al., 2007).

The standard riparian buffers in managed forests have been criticized for inadequacy in maintaining the cool microclimates required by species that depend on those specific environments (Olden et al., 2019). Their inadequate size may be to blame rather than the practice itself. Thirty-meter buffers on both sides of the stream were found to be protective of plant communities even with some selective logging within the buffers (Olden et al., 2019). However, another study found that buffer with of fifty meters did not support the same amount of animal species as uncut areas (Marczak et al., 2010). Despite the debate on riparian buffer effectiveness, buffers remain important features for migratory birds and mammals, while providing shade and food to resident animals. Perhaps the most important contributions of healthy riparian buffers come from their function as water filtration systems and their influence on microclimate, and plant diversity, which in turn provide clear water and food sources for endangered and threatened salmonids (Dale et al., 2000).

Floodplain changes

The landscape dynamics of riparian areas are especially impactful as water and sediment work to move and change riparian features. In the Puget lowlands, the constraints of human developments such as agriculture, roads and infrastructure contribute to a reduction of riparian dynamics. This type of influence changes the natural features of the floodplain from a braided system (unaltered and straightened) to a manageable and usable system for humans (Gergel et al., 2002). Yet these changes alter ecosystem functions that are important to other species (Blanton & Marcus, 2009; Glanzig, 1995). In the South Puget Sound the Nisqually River Delta was completely blocked by an artificial dike created by European settlers in the late 1800's. In a large-scale restoration project led by the Nisqually Indian Tribe, the dike was removed in 2009 in order to restore the tidal wetlands for native salmon and bird habitat (Ellings, 2009).

Riparian areas are dynamic systems which are often resilient to threats towards biodiversity such as climate change and land use change. Thus, riparian areas need higher protections to maintain this resiliency (Watson et al., 2013). Yet just as landscapes are dynamic, landscape assessments must have flexibility to adjust to changes brought by new threats. Climate change and its potential negative global feedback loops may contribute to changes in vegetation, species assemblages and human development needs (Heller & Zaveleta, 2009). Negative feedback loops of threats such as changes in urban growth boundaries, local interest rates and demands for land also influence where and when land development occurs (Dale et al., 2001).

Riparian Connectivity

Riparian areas are the resource and movement conduits of protected and unprotected lands, yet they are often fragmented. Riparian forests connect upland areas to larger water bodies such as lakes, estuaries and oceans, and when left unaltered, riparian areas provide a natural corridor system for species movement and nutrient flow (Groves & Game, 2016; Naiman et al., 1993). Riparian connectivity networks can extend existing natural framework strategically (Fremier et al., 2015). Many riparian areas already have some protections in place due to the resources they provide to both animals and humans (Beechie et al., 2009). Even so, freshwater protection has been criticized in the United States as having inadequate management and conservation planning in place to support healthy hydrological processes (Abell et al., 2007).

Along with fragmentation and human development, edge effects – the reduced habitat quality on patch edges, lead to species declines, local extinctions and even species extinction (Andrén, 1997; Prugh et al., 2008; Tilman et al., 2017). Protected areas need buffer areas around their boundaries to protect from edge disturbance (Provan & Maggs, 2011). Edge disturbance or edge effects diminish the habitat quality of an area from the outer edges gradually towards the center of the habitat patch. In a fragmented landscape, the reduction of biodiversity is gradual at first then rapidly increases over time. Revealing the extent of forest fragmentation, Haddad

(2015) found that seventy percent of the world's forests are within one kilometer of a forest edge.

The effects of fragmentation have been studied for many decades. In a case of tropical rainforest fragmentation, over a fifty-year span following complete clearcutting around the 1-kilometer square Bogor Botanical Garden of Indonesia, one-third of its breeding bird species were lost (Diamond et al., 1987). Riparian areas are connected to the greater landscape and yet, they are often protected as isolated features (Gregory et al., 1991). While a strong protected network would include preserves in areas of high biodiversity and habitat quality, many preserves are isolated from the rest of the landscape, limiting gene flow and increasing edge effects (Opdam & Wascher, 2004; Peters & Darling, 1985; Watson et al. 2016).

Gene flow and connectivity

Despite criticisms of fragmented conservation measures, riparian corridors are ideal for adaptive management because when their existing connectivity extends beyond isolated patches, genetic movement for plants and animals improves (Vignieri, 2005). Focusing on protection of certain areas and not others exclude the genetics of many organisms, creating barriers to migration pathways (McRae et al., 2012; Venter, 2014). However, in the age of rapid climate change, a conservation strategy incorporating riparian systems could save time by building on the existing framework of protected riparian areas (Fremier et al., 2015). This strategy could work for river systems that are in or adjacent to areas of increasing anthropogenic disturbance where the threat of fragmentation is accelerated, such as the South Puget Sound in Washington state.

But how much time saved by conservation action is enough? Species currently cannot keep up genetically with climate impacts on habitat (Heller & Zavaleta, 2009; Lemieux & Scott, 2005). Climate velocity, the rate at which climate affects species change and migration movement, will only increase as time goes on (Burrows et al., 2014; Carroll et al., 2017; Loarie et al, 2009). Because of extinction risk, creating larger, more connected preserves stands as the minimum level of climate mitigation that land managers can offer to species with large and small ranges (Heller & Zavaleta, 2009; Provan & Maggs, 2012; Ricketts et al., 2005).

Network theory and strategic conservation

It is often important to preserve ecosystems, not just isolated species (Pelletier, 2014; Wilson, 1999). Network theory, used widely in strategic conservation planning, aims to connect habitats for the protection of multiple species. This theory is based in the idea that habitat connectivity remains the greatest landscape defense against biodiversity loss (Crooks & Sanjen, 2006; Haddad et al., 2015). In sync with network theory, evidence supports the inclusion of multiple factors for conservation plans. Recently, a combination of habitat quality and connectivity parameters for connectivity assessments was found to be an effective measure for achieving the goals of network theory (Alberti et al., 2017). However, only 15% of areas of highest connectivity are within protected areas in the western half of the United States (Theobald et al., 2012).

In the history of conservation planning there remains an evident bias of conservation for charismatic species and species with large ranges (Hagen & Hodges, 2006). Many studies on habitat connectivity have gravitated towards species specific or umbrella species-based conservation (Minor & Lookingbill, 2010). These species-specific conservation efforts have been largely successful in cases where adequate range sizes have been protected (Heindricks et al., 2018; Ripple et al., 2014). However, many umbrella species are not provided with enough protection (Bergstrom et al., 2009; Hagen & Hodges, 2006; Carroll et al., 2018). Conservation strategy may need to shift from species hierarchy planning with land managed for umbrella species to a management practice of preserving overall habitat quality in concentrated areas such as riparian corridors (Cantu-Salazar et al., 2013; Watson et al., 2014). An approach of considering multiple conservation site sizes or groupings within a network that combine needs of both large ranging species and small ranging species may result in more robust protection and higher number of species saved (Armsworth et al., 2018).

Strategic conservation builds on concepts of connectivity and network theory. Some key approaches to conservation strategy are preserving habitat corridors between reserve patches, creating and protecting reserves in proximity to other reserves, setting multiple, informed conservation targets and practicing redundancy in management planning to ensure that species ranges are included in protected habitat (Fremier et al., 2015; Krosby et al., 2018; Monahan & Theobald, 2018; Watts et al., 2017). Strategic conservation planning essentially compares how habitat quality levels and competing land use needs can benefit species persistence when managed effectively (Margules & Pressey, 2000). While strategic conservation planning cannot completely avoid problems such as source-sink and ecological traps, the process of considering multiple habitat and land use scenarios to protect the resilience of the landscape and species persistence produces more robust planning options than landscape studies comparing only one or two conservation features.

Source-sink and ecological trap considerations

Critical habitat assessments are often ineffective because other factors such as habitat quality of the surrounding area may affect the ability of species to survive within the preserve (Battin, 2004; Van Horne, 1983). Source-sink, where species density does not equal persistence and resilience, can be addressed with conservation strategy where multiple habitat quality factors are considered. Larger preserves with connectivity priorities for large and small animals can often address source-sink effects temporarily, but persistence of species diversity over time fails as fragmentation increases around and within the protected area (Di Marco et al., 2019; Haddad et al., 2017; Jones et al., 2018). Similarly, ecological traps where animals show unnatural persistence due to their misperception of available resources, are lacking in most habitat modeling scenarios (Battin, 2004). Often, key research on biodiversity and fragmentation fails to address caveats such as these, instead focusing on simplified versions of landscape protection that may not exist in the Anthropocene.

Landscape patch dynamics, where assemblages of habitat patches support different species to different extents, are more important for species persistence than landscape types for habitat specialists (Hagen & Hodges, 2006). In contrast, Andren et al. (1997) found that species abundance depends on a variety of landscapes. However, they do not consider source-sinks or ecological traps in their analysis. They site an earlier study (Andren, 1992) where findings show hooded crows to use a mosaic of landscapes such as agriculture combined with forest more often than forest or agriculture alone. They do not mention that the crows might be utilizing the human influence on the landscape for resources as a form of ecological trap. For example, those resources would not necessarily be consistent as birds can be attracted to resources provided by excess mowing of agriculture lands and fertilizer impacts on production (Battin, 2004). Furthermore, since humans shifted their subsistence to farming, habitat loss due to land clearing for agriculture has resulted in approximately 80% of the world’s threatened animal species losing their home ranges (Tilman et al., 2017).

Biodiversity targets

In order to build a framework to understand how landscape preservation can be quantified, biodiversity targets are needed to define the parameters for how much of habitat to protect in order to maintain the minimum amount of habitat for species persistence (Ricketts et al., 2005). In systematic conservation planning, targets provide measurable data for habitat analysis (Balmford et al., 2005). Yet these conservation targets are subject to human error and are often guided by belief systems rather than scientific assessments (Albert et al., 2017; Pressey et al., 2017). Additionally, there is often a limit to how many targets can be used in individual habitat assessments (Kaim et al., 2017). To some, assigning value to specific biodiversity targets appears arbitrary (Kaim et al., 2017; Levin et al., 2015). For example, the World Congress on National Parks and Protected Areas and the World Conservation Union established a biodiversity target for 10-30% preservation of historic vegetation (UNEP-WCMC & IUCN, 2016). These targets fail to address actual scientific parameters for biodiversity (Carwardine et al., 2009). However, wherever humans predict landscape change, multiple targets can be built into models to show a variety of conservation possibilities, rather than depending on rigid targets (Doherty et al., 2018; Watts et al., 2017). While still important, the specifics on how biodiversity measures are incorporated into protected area planning has clearly shifted from species richness priorities to strategic mitigation of overall habitat loss (Fahrig, 2001).

Global biodiversity hotspots were first adopted in 1989 by Conservation International to identify core areas for habitat protection (Mittermeier, 2000; Myers, 1990). According to Conservation International's definition of biodiversity hotspots, they must contain 1,500 endemic plant species and at least 30% of its native vegetation must be intact. Since then, tangible conservation targets created by international organizations such as the Paris Agreement, United

Nations's Sustainable Development Goals and the Convention on Biological Diversity's Aichi Targets have brought conservation strategy to the forefront of climate mitigation planning. Yet overall, the targets meant to protect biodiversity and mitigate carbon emissions were set too low during the 2010 to 2020 international convention (Diaz et al., 2020). For example, the Aichi targets of 17% protected land for global conservation by the year 2020 did not produce the desired biodiversity protection.

Data gaps in assessing biodiversity need to be breached by a global effort in order to protect key habitat with new targets set for 2030 (Joppa et al., 2016). In short, future targets need to include protecting more intact area combined with large-scale restoration efforts and plan for climate mitigation (CBD, 2010; Roberts et al., 2020). Climate mitigation must consider short term effects of local and global feedback loops and catastrophic events such as widespread wildfire.

While target-based conservation planning is the accepted method for creating and meeting conservation goals, improvements can be made on the methodology. Incorporating multiple types of targets into planning may build a robust framework acknowledging different aspects of cause and effect on the landscape. Also, ambitious conservation goals make for resilient landscape (Carwardine et al., 2009). Regarding riparian areas, this view is backed up by Gregory et al. (1991) in their position for assessing riparian forests as whole ecosystems rather than as specific pieces that can be added and subtracted without consequence. Additionally, prioritizing resilience into conservation outcomes has emerged in the past twenty years as paramount to the success of many approaches to conservation management (Chazdon et al., 2016; Fremier et al., 2009; Kremen et al., 2018; Opdam et al., 2006).

Resilience theory and novel landscapes

Not all landscapes have the same amount of flexibility when it comes to setting biodiversity targets. Different soils, water levels and historic use patterns influence the landscape ability to withstand disturbance, even among riparian areas. Resilience theory examines the way ecosystems respond to disturbance. A resilient landscape will maintain its primary functions despite some disturbance (Fremier et al., 2015). Yet every landscape has a changing point. A threshold breach marks the point where ecosystem functions shift away from what they once were, such as a total or partial shift in vegetation (Folke et al., 2004). For example, high nutrient loads can bring invasive, nitrogen loving plants that displace native plant diversity, thereby reducing food sources for animals (Maskell et al., 2010).

The resilience theory is challenged by the idea that landscapes don't just shift from healthy to unhealthy ecosystems, but instead they shift to novel landscapes. Climate change effects on the landscape will not be evenly distributed or exact, so managing for more protected areas and novel landscapes can help protect habitat quality and altered habitats, despite historic ecosystem assemblages (Jackson & Hobbs, 2009; Hobbs et al., 2006). Furthermore, due to negative effects of climate change, measuring restoration and conservation goals with historic baselines of pre-settlement vegetation intactness can no longer provide indication that a site will persist in providing resilient habitat (Choi et al., 2008; Harris et al., 2006; Seavy et al., 2009). Other factors must be integrated to create conservation strategy focusing on restoration and conservation of private lands in addition to federal and state managed lands. To mitigate the effects of climate change, acceleration of conservation strategy at the local watershed level can improve on current practice of primarily conserving remote lands. The future resilience of biodiverse landscapes will depend on a shift in land management towards integrating conservation into all landscapes, not just those with historic species assemblages.

Community change and human perception

Community change results when negative feedback loops of increased nutrients, temperatures and precipitation changes entirely alter ecosystems. This change starts at a global level, eventually impacting the landscape enough to wholly change species assemblages. For example, in some mountainous areas snowpack levels will diminish or shift to rain, altering lowland moisture systems from gradual dispersal of snowpack water, to local flooding. With predictions such as this, landscape management can begin to adjust and adapt to changing features to protect landscape resilience (Zavaleta & Heller, 2009).

Humans need services provided by resilient ecosystems and many animals need movement corridors provided by riparian habitat. These functions will disappear if ecosystems cannot maintain their resilience to external pressures. As an integral part of the landscape, humans have a responsibility to improve conservation efforts to mitigate threats on habitat at multiple levels (Donald & Evans, 2006; Schwartz et al., 2008). However, applicable conservation practices often solely consider ecological factors rather than social acceptance of implementing conservation (Watson, 2015). In addition to services provided by nature, aesthetic appreciation of nature occurs at different levels for different people based on their individual life experiences (Gaston et al., 2018). Human investment in the natural world will shape the future of the planet. Thus, reducing the human need for clearing land is vital to proactive conservation management strategy (Tilman et al., 2017). From human dependence on resources comes a pervasive idea that once an area is protected in some way, the land around it is therefore undeserving of protection (Carwardine et al., 2009). Human perceptions of freshwater habitats must shift towards the idea that freshwater areas should be protected, rather than solely managed for activities such as resource extraction and crop irrigation (Abell et al., 2006).

Conclusion

The preservation of new conservation opportunities that prioritize connectivity of areas with riparian refugia and acceleration of restoration efforts in riparian areas prior to landscape development, will promote resilience and in turn biodiversity protection (Beechie et al., 2009). We must improve on the current trajectory of the pace and breadth of conservation efforts (Watson, 2016; Wilson, 2016). A current lack of actionable, conservation management strategy across riparian corridors in the South Puget Sound may be a product of multiple agency jurisdictions and their varying conservation goals. This research builds on existing science and management practices for riparian conservation by suggesting proactive conservation strategies for the South Puget Sound which can work for any agency or non-governmental organization. The management approach shifts its focus away from upland species-specific strategy and towards overall habitat quality and connectivity for riparian corridors. Approaching conservation strategy proactively and at an ecosystem level, while including multiple options for conservation outcomes improves on previous conservation efforts (Brambilla et al., 2017). Riparian landscape assessment includes analysis of the habitat quality of existing reserves, protected areas and easements within watershed boundaries.

The potential impacts of climate change on habitat require improved assessment and integration of refugia characteristics into riparian resource management. By updating assessment of local riparian areas with climate data such as the riparian climate-corridor ranking, combined with multiple conservation targets, remaining conservation opportunities can be identified. The protection and restoration of high-quality habitat, if implemented, may improve landscape resilience to future threats (Krosby et al., 2018; Lemieux & Scott, 2005).

CHAPTER 3: RESEARCH MANUSCRIPT

Abstract

Low, fertile plateaus in the Pacific Northwest are experiencing rapid population growth and landscape fragmentation, yet do not have adequate protections in place to preserve climate refugia and connectivity within riparian areas. Riparian corridors provide ecosystem services and facilitate animal movement. In addition, riparian areas containing high quality habitat often contain biodiversity hotspots and climate refugia. Despite the high conservation value of riparian areas, and existing protection from the Clean Water Act, The Endangered Species Act and state-level protection laws, riparian areas in the Pacific Northwest are at high risk of disturbance and/or conversion.

Strategically identifying conservation suitability within riparian corridors can result in protection of biodiversity and provision of ecosystem services at a landscape level. While previous research has given quality scores to climate refugia areas along riparian zones in the Pacific Northwest, these assessments have not yet been integrated into conservation plans that analyze where habitat quality coincides with climate refugia, nor have they taken into account costs of conservation. Using Marxan, this research identifies high-quality riparian habitat with high-scoring climate refugia and estimates the least cost for future conservation in watersheds of South Puget Sound in Washington State. This planning strategy resulted in good options for enhancing riparian connectivity networks in our study area by identifying areas where increasing conservation areas may support protection of landscape resilience and riparian refugia. This regional climate adaptation strategy can be applied to other Pacific Northwest riparian areas where safeguarding of biodiversity and climate refugia is desired.

Keywords

Riparian, refugia, biodiversity, connectivity, climate change, corridor, conservation, spatial planning, Washington State, Pacific Northwest

Introduction

Globally, biodiversity is under attack from land clearing and unprecedented anthropogenic climate shifts (IPCC, 2018). Biodiversity functions as the foundation of ecosystem resilience and species persistence on Earth, but current measures to protect the bare minimum biodiversity are failing. (Isbell et al., 2015; Wilson, 1999). Improved strategies for protecting biodiversity include proactive climate adaptive management, understanding genetic processes at site specific levels, landscape connectivity and restoration planning at global and local scales (Cowling & Pressey, 2001; Groves & Game, 2016). Multiple threats against biodiversity necessitate a comprehensive approach to conservation planning for natural areas and the land surrounding them (Stuart et al., 2000). Robust strategic conservation planning incorporates future threats of climate change and landscape development at multiple scales and with many conservation targets to establish management options (Brambilla et al., 2017; Jones et al., 2016). Essentially, planning for and implementing new natural areas as well as incorporating private landowner restoration incentives, can directly reduce biodiversity loss (Carwardine et al., 2010; DiMarco et al., 2019). Additionally, increasing the amount of private land conservation will greatly contribute to adaptive management successes locally (Seavy et al., 2009). If we are to depend on this planet to continue to support us with resources, we must also work actively to mitigate the biodiversity loss caused by excessive land clearing and climate change. Reassessing the current state of conservation at localized levels can contribute to this work (Seddon et al., 2020).

In their current state, protected areas fall short in their ability to shield species from extinction and ecosystems from collapse (Lawler et al., 2020; Roberts et al., 2020; Watson et al., 2013). A planning approach shaped around incorporating climate change effects on the landscape into conservation strategy brings new challenges and opportunities for conservation management moving forward (Groves et al., 2012; Heller & Zavaleta, 2009). Data gathered from multiple sources for the purpose of habitat quality assessment reflect the complexity of factors influencing habitat quality. Landscape assessments which consider conservation targets, surrounding area land use, historic disturbance, water movement cycles and human perception of conservation management will continue been important for the protection of high-quality habitats (Dale et al., 2001). However, adding climate velocity and climate refugia data to planning processes better reflects current and future landscape trajectories.

The success of the conservation movement and protection levels of natural areas remains in debate (Bookchin, 1987; Geldmann et al., 2013; Sanderson et al., 2006). Driven by laws such as The Endangered Species Act (ESA) and the Clean Water Act in the United States, species protection is still largely inadequate (Gaston et al., 2018; Minor & Lookingbill, 2010). As a result of conservation efforts instigated by the ESA passed in 1973, in the United States, 1661 species are listed as endangered or threatened, while 1169 have 'active' recovery plans. This leaves a remaining 491 species without any current plans for their protection (USFWS, retrieved April 2020). Of the 25,780 known terrestrial vertebrates on planet earth, 5,176 are threatened with extinction and only one-fifth of these species has adequate protection for maintaining stabile wild populations (Wilson, 2016).

Low flat lands (lowlands) are particularly under-represented in conservation planning and protected area networks, while upland, mountainous areas are often prioritized because they are of less value for urban development (Krosby et al., 2018; Pressey et al., 2017; Soule & Terborgh 1999). Additionally, riparian forests do not have as much marketable value as farm and timber lands (Pressey et al., 1993, Soule & Terborgh 1999, Krosby et al, 2018). Riparian value lies in its contribution to the landscape. The Puget lowlands in Washington have been identified as an area of high importance for protecting river systems in the Pacific Northwest due to a large amount of riparian refugia within yet unprotected areas (Krosby et al., 2018; Wade et al., 2013). Refugia are areas where higher quality habitats may meet criteria needs for species survival in the event of climate shifts that may otherwise harm their survival chances. However, Puget lowland riparian areas are threatened by climate change, rapid population growth, future human developments, and resource extraction impacts (Alberti et al., 2006; Hepinstall-Cymerman et al., 2013; Lister et al., 2015; Singleton et al., 2001).

Fragmentation, edge effects and human development lead to species declines, local extinctions and even species extinction (Andrén, 1997; Prugh et al., 2008; Tilman et al., 2017). Protected areas need buffer areas around their boundaries to protect from edge disturbance (Provan & Maggs, 2011). Edge disturbance or edge effects diminish the habitat quality of an area from the outer edges gradually towards the center of the habitat patch. In a fragmented landscape, the reduction of biodiversity is gradual at first then rapidly increases over time. Revealing the extent of forest fragmentation, Haddad (2015) found that seventy percent of the world's forests are within one kilometer of a forest edge.

To mitigate cascading effects of fragmentation and habitat loss in riparian areas, strategically identifying new conservation opportunities and reassessing existing protected areas is important for landscape connectivity (Joppa et al., 2016). Because of their susceptibility to degradation, protected areas near fragmented land should be reassessed more often than high quality reserves to ensure they are not being unnecessarily impacted (Margules & Pressey, 2000). The effects of disturbances such as land fragmentation from roads, infrastructure, resource extraction and invasive species are amplified with added stressors of climate change (Bradley et al., 2009; Heller & Zavaleta, 2009). These pressures can push the landscape beyond a recovery threshold, minimizing important climate refugia and microclimate habitat (Beisner et al., 2003; Dunn & Angermeier, 2019; Wade et al., 2013).

North America and other high latitudes have lower climate stability or unstable exposure levels among ecoregions (Watson et al., 2013). The possibility of abrupt changes in ecosystem stability due to climate change bring updated habitat conservation assessment into the forefront of importance and responsibility for natural area managers locally (Ratajczak et al., 2018; Turner et al., 2020). Climate change mitigation and nature conservation require not only higher protected area conservation targets but also integration of methodology for protection (Roberts et al., 2020).

A recent analysis of Pacific Northwest watersheds ranked riparian areas for their climate refugia potential on a climate-corridor index (Krosby et al., 2018). While mountainous areas had higher-ranked habitat quality for climate refugia than lowlands overall, riparian areas in Thurston County also contained climate refugia. As climate corridors, riparian refugia areas have the potential to contribute to climate range shifts, facilitate movement for both riparian and upland species, and provide shelter from environmental shifts due to climate change (Brambilla et al., 2017; Keppel et al., 2012; Zielinski et al., 2017). Additionally, some abandoned river channels containing no water have been identified as important refugia zones (Stella et al., 2011). The inclusion of refugia measures such as climate-corridor ranking in systematic conservation planning can inform not only conservation options based on the current landscape, but also on the projected effects of climate change on species movement (Heller & Zavaleta, 2009; Monahan & Theobald, 2018).

Nature-based solutions such as increasing canopy cover to reduce ground temperatures and integrating wetlands and ground water sources to include carbon sinks into protected areas are becoming more important to climate policy (Duarte et al., 2013; Page et al., 2011). These solutions give validity to the stance that climate change, biodiversity loss and the well-being of humans are interconnected (Seddon et al., 2020). Furthermore, nature-based solutions are intrinsically practical. While conservation and restoration in practice are often not as clear cut as in the planning stages, creating robust conservation objectives and biodiversity targets can result in actions that lead to habitat resilience in the long term.

This strategic conservation plan for the South Puget Sound is both a useable tool for cadastral conservation planning at local scales and a case study for referenceable application to other ecosystems of the Pacific Northwest. By analyzing different conservation target scenarios with multiple habitat data sets, we identify future potential buffer areas around existing natural areas and parcels of high-quality habitat which can be integrated into connectivity planning. However, target representation is not enough for protected area integrity. Habitat quality, size and site clumping and connectivity are just as important in species persistence on a site by site basis (Klein et al., 2009; Possingham et al., 2006, Soule et al., 2004). Thus, we used the annealing algorithm from Marxan conservation planning software to address parcel boundary lengths, aggregation, connectivity, and proximity to existing natural areas in addition to our representative conservation targets.

The approach does not avoid areas that are typically under-represented in conservation planning. On the contrary, high quality habitat within the Urban Growth Boundary are identified as important for riparian connectivity due to the historic preservation of water sources and buffer areas of riparian lands. Potential additions to protected area networks with riparian refugia included in their extent are identified here without bias to their placement on the landscape. Flat, lowland areas act as important connectors to more wild landscapes in the suburban and wilderness interface.

Methods

The objective of our analysis, to maximize riparian climate corridor quality in conservation site selection at the least cost, was conducted using a systematic planning approach. To identify future scenarios for protected area networks in the South Puget Sound, we used the systematic conservation planning software Marxan (Ball & Possingham, 2000), and the ESRI software ArcGIS Pro 2.4.3 and ArcGIS Map 10.7. Marxan uses an algorithm that queries for multiple groups of viable solutions for spatial conservation plans at the least cost based on user identified conservation targets. However, Marxan results are only as good as the user defined data provided along with the ability of the Marxan practitioner to analyze the outputs. Additionally, Marxan does not provide definitive answers, but rather a set of options that can be used as a guide for conservation planning. The resultant solutions are spatial data with selected parcels aggregated into potential new reserve networks.

To build a comprehensive reserve network in a multi-use area such as the South Puget Sound, we considered five major conservation goals for reserve design (Margules & Pressey, 2000 & Watts et al., 2017, pp. 213-214).

1. Representation concerns species biodiversity, conservation features, vegetation types and rare, endangered, or unique species of an area. We achieved representation by

creating quantitative targets for conservation features representative of biodiversity in the entire study area.

2. Complementarity considers the biodiversity features already found within protected areas. We addressed complementarity by asking the question: Are there gaps in biodiversity that can be mitigated by linking new reserve sites to existing protected areas? In order to achieve complementarity, we ran Marxan scenarios with and without "locking in" existing protected areas into our solutions (Ardron et al., 2010). Locking in parcels prioritizes them as the basis for area selection in the solutions.
3. Adequacy pertains to connected, larger reserves and assumes that reserving biodiversity alone is not enough. Considering adequacy of site connectivity and size will contribute to habitat quality persistence over time. We included adequacy by calibrating a Boundary Length Modifier specific to each solution and aggregating parcels with a proximity of 30 meters.
4. Efficiency, refers to the cost to restore or acquire potential new conservation areas? Often, higher habitat quality or smaller parcels cost less to restore or acquire. We plotted the Boundary Length Modifier against the total area (cost) of each solution to maintain clumped solution results at least cost while committing a Species Penalty Factor (SPF) to retain the validity of our conservation feature targets. The SPF works contrary to the BLM with tradeoffs to prioritize maintaining the conservation targets while the BLM selects planning units based on cost characterization. We calibrated the two functions individually for each solution run to work in tandem in a manner that produced parcel selections that met the conservation targets at 100% and at least cost in the solutions.

5. Spatial compactness pertains to site preference where natural areas have a higher level of connectivity and less edge. To address compactness, we set parcel aggregation at 30 meters from each final solution. Because species richness and abundance diminish near area edges, we set boundary parcels at edges measured to their full value, thus reducing edge effects in the selections.

Study Area

To provide a strong case study of climate mitigation strategy, the study area focuses on a subsection of the South Puget Sound, an area identified as priority in the Pacific Northwest for riparian refugia protection (Krosby et al., 2018). The area of interest (AOI) surrounding three major rivers, The Black River, The Deschutes River, and the Nisqually River, joins two watersheds within Thurston County in Washington State, USA. Specifically, the Watershed Area Unit (WAU) boundaries for the Black River: McClane Creek, Waddell Creek, Black River; The Deschutes River: Middle Deschutes, Upper Deschutes; and The Nisqually River: McAllister, Yelm Creek, and Powell Creek. These WAU's extend slightly outside of Thurston County boundaries into adjacent counties and are partially divided to the southwest by separation of the Black River units within the Coast Watershed and the Deschutes and Nisqually River units within the Puget Sound watershed. For data continuity, we limited our study area to Thurston County borders. We chose to focus on watersheds as our study area boundaries because they are connected by features intrinsic to riparian connectivity on a landscape level (Figure 1).

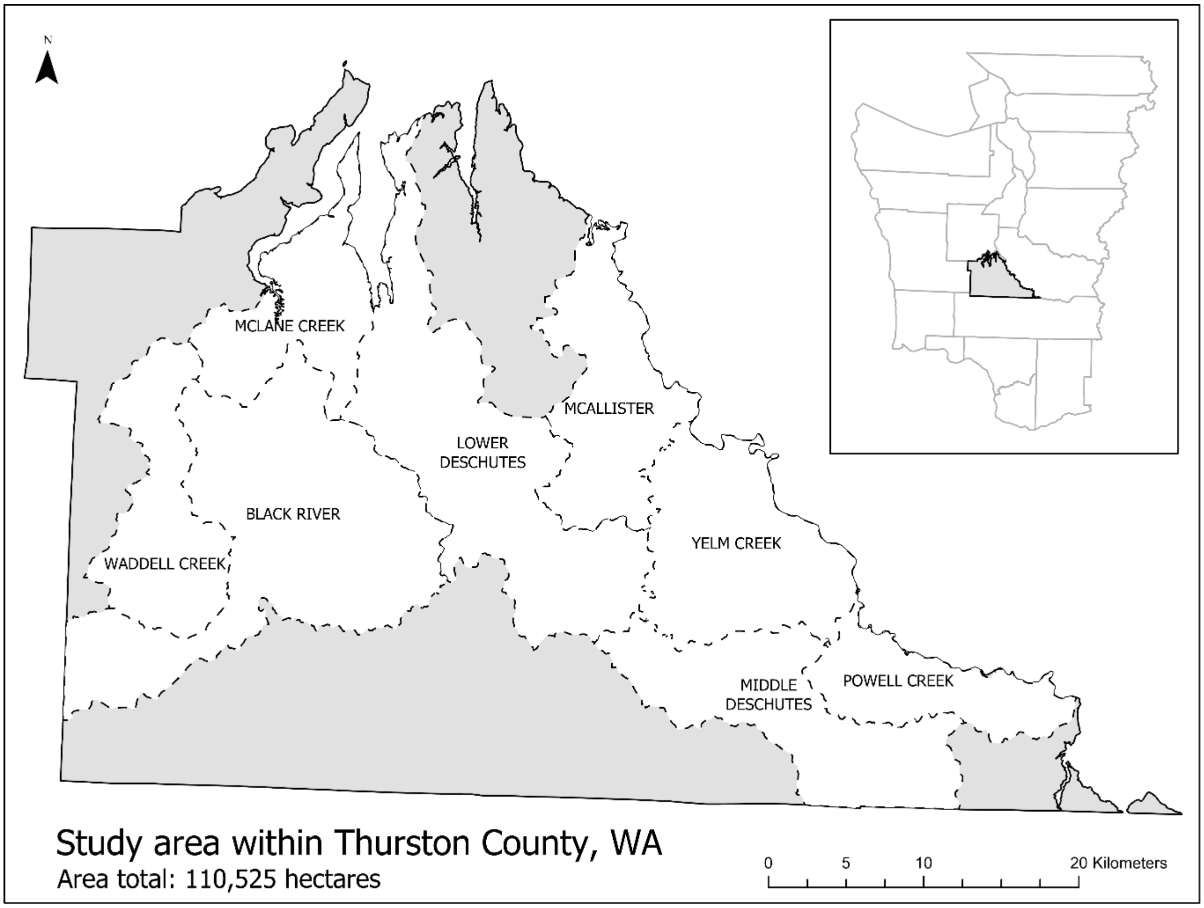


Figure 1. Study Area: watersheds were chosen where they surround The Black River, The Deschutes River and the Nisqually River within Thurston County.

The study area lies at the base of the south Puget Sound Lowlands, straddled between two watersheds and with boundaries meeting densely forested state managed lands. Thurston County, dissected by two larger watersheds, the Oregon-Washington Coastal Watershed to the west and the Puget Sound Watershed to the east, holds weather and ecosystem-level functional differences from west to east. From the outer edges of Thurston County, the watershed boundaries meet with the foothills of the protected regions of Mount Rainier National Park to the Southeast and Olympic National Forest and National Park to the Northwest. This study area is contained with the Washington DNR South Puget Sound Black Hills District, containing Capitol State Forest to the West.

Within these watersheds, county defined land parcels were our planning units (n = 78,122) with a total area of 1066 km^2 within Thurston county. These county parcel units complement availability for state conservation acquisition or private landowner restoration initiatives. Planning units acted as the basis on which to overlay conservation feature data and cost data to produce grouped parcel planning unit outputs. Further in this analysis, parcels were clumped with adjacent connective parcels to form solutions to reserve design objectives for local conservation and restoration.

Ecological datasets

We chose ecological datasets for conservation features which formed the basis for a target -based analysis. The datasets include habitat data from local government agencies, riparian refugia ranking (Krosby et al., 2018) and canopy cover from the National Land Cover Data (NLCD, 2016). Conservation feature targets were selected for estimated biological importance of local biodiversity (Svancara et al., 2005). The conservation features make up the set of target inputs for our analysis with target percentages assigned to each feature. The parcels selected by the model output gave preference to parcels that met the set target amounts within our study area. We used a GIS (ArcGIS Pro 2.4.3) to incorporate conservation features into the analysis. While all the targets were included and achieved in each solution, we emphasized riparian climate refugia data in support of our objective to create good options for riparian corridor conservation networks.

Conservation features were selected based on their contribution to riparian habitat health and thus, the basis for site selection for future conservation and protection. For example, we did not use a generic stream layer as data input. Instead, the water typing data show fish passage ability and the riparian climate refugia index show combined values of ranked habitat quality along rivers and streams, some area in our study site containing rivers or streams may not be selected by the algorithm if they don't allow for fish passage or if they do not have refugia ranking attributed to them.

1. Priority Habitat and Species areas (PHS) and Wildlife Survey Data Management from the Washington Department of Fish and Wildlife (WDFW), obtained February 1, 2020. The data sets contain i.) inventory of priority species use areas based on expert knowledge and field surveys in the form of overlapping polygons in generalized form to township or section and locations for breeding seabirds (Speich, 1989) and ii.) wildlife survey records observations of state and federal listed sensitive, threatened and endangered animal species.
2. Riparian refugia / Riparian Climate – Corridor Index (Krosby et al., 2018)

   The riparian climate – corridor index, based on the mean of 5 variables: mean annual temperature (T), canopy cover (CC), riparian area (A), potential relative radiation (PRR) and landscape condition (LC) was selected at 90m x 90m cells for the Pacific Northwest in ranks of 1-5, with 1 as the worst and 5 as the highest riparian refugia (**Table 1**). To obtain this index, Krosby et al. used hydrologic tools in ArcGIS to gather the mean for each variable by summing values collectively from outlet to headwater of each river. First, they summed each variable for all riparian cells that drained into the potential riparian area. Then, they divided the summed amount for each variable by the number of cells within the raster for each river to obtain the mean. Where the central flow did not have side channel potential riparian area, only the main river channel was counted. The mean of each variable was divided by the highest mean of the variables for each river to give minimal scores for each cell (Krosby et al., 2018).

In our study area, the riparian climate refugia values were only present for values 1-3. The absence of higher, and thus considered better, refugia ranking in the South Puget Sound may be attributed to a lack of elevation. In higher, more mountainous areas, the climate refugia ranking was significantly higher (Krosby et al., 2018). For our analysis, we aggregated the riparian refugia raster data for values within our study area to produce one uniform value showing presence/absence of riparian climate refugia.

3. Water typing data from Department of Natural Resources (DNR) open source data service provided information on fish ability to pass through a stream without barriers. These were retrieved from DNR open source data December 2019.
4. Rare plant data from Washington DNR Natural Heritage Program (NHP). The rare plant occurrence data set contains point and polygon data on endangered, threatened, and endemic flora species' ranges as observed in Washington State. The Natural Heritage Program Data Manager suggested that we query the data to account for only species occurring after the year 1910. This led us to edit out older records of important plant areas not observed since the last century. This data set was retrieved from DNR open source data, November 2019.
5. Tree canopy cover data estimated at > 75% canopy cover within sample areas came from the National Land Cover Database (Coulston et al., 2012; NLCD, 2016).

Land ownership and management data

Using a GIS, we clipped the following jurisdictional dataset boundaries to the study area to extract the percent cover per Marxan solution for each boundary layer (**Table 5**).

1) Conservation Biology International, Protected Area Database for the United States (PAD-US CBI Edition, Version 2). The protected area data set combines state, federal and

private protected areas based on Gap Analysis Project (GAP) status codes 1, 2, 3 and 4. We separated GAP status 1 and 2 protected areas for use as our existing protected area solution runs and gave status 3 and 4 areas the same selection opportunity in our analysis as private land parcels. The data were retrieved from Conservation Biology International in January 2020.

> GAP status 1 and 2: Existing designated protected areas that usually fall under the International Union for the Conservation of Nature (IUCN) categories of Ia - strict nature reserves, Ib – wilderness areas which are minimally modified, and II – National Parks (iucn.org).
>
> GAP status 3 and 4: GAP status 3 lands are managed areas where some resource extraction occurs but are primarily not developed lands. GAP status 4 lands are Federal or state managed lands that are not state or county parks. In Thurston County, these are the military instillations including Joint Base Lewis McChord and other Department of Defense properties, State Forest Lands in trust or managed by the Washington State Department of Natural Resources such as Capitol State Forest and National Forest Lands managed by the US Forest Service.

2) All the parks within Thurston County and clipped to our AOI watersheds including state parks, county open spaces, city parks, and federally managed wildlife refuges. Some of these areas overlap with the GAP status 1 and 2 protected areas used in our Marxan analyses for solutions (d) and (e).
3) Lands of the sovereign Nisqually Indian Tribe (Squalli-Absch) and The Confederated Tribes of the Chehalis Reservation within Thurston County and clipped to our AOI.

4) Urban Growth Boundary: the urban growth boundaries within Thurston County and clipped to our AOI.
5) Private lands: all privately owned land parcels within Thurston County and clipped to our AOI.

Parcel cost and selection frequency

Our analysis considers land acquisition rather than land cover change such as site change from natural to urban, logging, mining, or intensive agricultural practices. We used parcel area as a cost surrogate with the assumption that larger parcel sizes will be more costly to acquire and restore. While not the most precise measure of parcel cost, area is a common surrogate for actual dollar amounts, especially where uniform measures for cost are not available. Planning unit (parcel) cost ranged from low at 798 to high at 27,689,001 square feet (Figure 2).

In addition to identifying viable options for future conservation planning at a local landscape level, we identified parcels with high selection frequency not included in the final solutions for each of the five target scenarios. We identified high selection frequency as those parcels selected more than 75 times within 100 runs per solution (selection frequency of > .75). These high selection frequency parcels were identified by Marxan as having some conservation targets that may have initially been included in the outcome but were outcompeted by other parcels for reasons relating to fragmentation reduction or adjacent parcel quality differences. Nevertheless, high frequency parcels have some features that may be desirable for inclusion by planners.

Frequently selected parcels were those parcels frequently selected by the Marxan algorithm but not included in the final solutions either because they did not fully meet the conservation targets we set, or because there were better, more connective or less expensive optimization of solutions. In our results we have included spatial layer of frequently selected parcels that were chosen by the algorithm >75 times. Parcels can be selected for conservation even if they do not achieve 100% of every target. If a planner needs to make a choice between two parcels with connective qualities, our results provide options for those frequently selected >75% but not included within the 'best' solution.

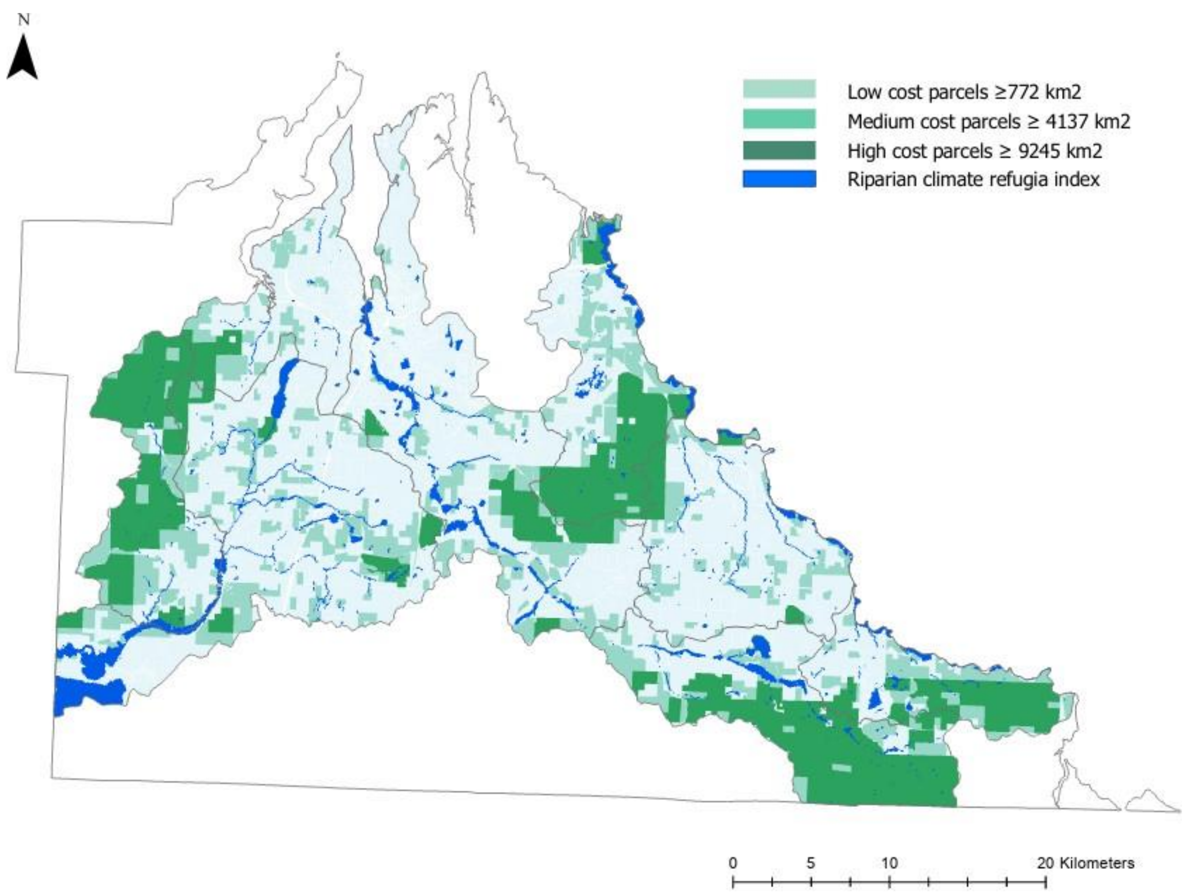


Figure 2. Relative cost of planning units, low to high overlaid with riparian climate refugia index values. Spatial layers of county parcel units show the relative 'cost' of management with parcel size used as a cost surrogate for the Marxan solutions. Cost of parcels within the study area are relative with smaller size parcels assigned lower cost and

larger parcels assigned higher cost. Riparian refugia index data are shown here to display how this conservation feature layer overlaps generally with smaller and thus less expensive parcels.

Targets

To meet expectations of improved biodiversity targets in landscape planning we set targets in Marxan for sensitive species presence, fish passage, high tree canopy cover (> 75%) and ranked riparian climate refugia (Kaim et al., 2017; Roberts et al., 2020). Conservation features were defined with representative targets, where species' distribution coincided with parcels (Venter 2014). We ran multiple scenarios with targets set between 17 – 30% to show a range of options for future conservation parcels. A conservation target range between 10-15% has been a standard for conservation planning through the past three decades. However, as of 2010, Aichi biodiversity targets of 17% were found to be ineffective in protecting the desired amounts of biodiversity. Recent developments in conservation planning have led researchers to suggest a need for higher conservation targets which may be more protective of biological diversity (Diaz et al., 2020; Roberts et al., 2020). This is especially important as increased land fragmentation and climate change effects chip away at landscapes in recovery.

In our study, groups of parcels for conservation that contained at least 30% of each conservation feature at the least cost were identified, producing a prioritization option for that target. We set our lowest conservation feature targets at 17%. A medium target range included a combination of the low and high targets. On the higher end, we used a uniform 30% target. The 30% target is commonly used as a minimum indicator for conserving biodiversity yet does not automatically include planning unit size or proximity to other sites that also meet the target (Carwardine et al., 2009).

Marxan aims to minimize the cost of a reserve system if biodiversity targets are achieved. To provide conservation planning options, we ran Marxan for five sets of options within our study area. We used multiple targets represented for each conservation feature, resulting in slightly different parcel suggestions for conservation. For completely unbiased reference, we first ran analyses of the algorithm without locking in existing protected areas for selection. For these first three runs, we set all conservation features equal at a) 17% and b) 30% and then with all targets at c) 17% except for the riparian refugia target set at 30%. For the final two analyses, targets were set again at 17% except for the prioritized riparian refugia target set at 30% and d) with protected areas 'locked in' with a status of '2' so that they were included in the outcome despite algorithm categorization and e) with protected areas suggested for inclusion but not at the expense of more important areas for connectivity and habitat quality with a status of '1'. We derived the gap status 1 and 2 parcels from the Protected Areas Database built by Conservation Biology International (PAD-US CBI Edition, Version 2).

Analysis

Using Marxan we ran five scenarios with specific, yet different conservation targets. The scenarios were run with 100 solution output options resulting in 500 total solution options. For each of the 500 scenarios, Marxan applied the annealing algorithm to one million calculations. From these multiple iterations, the best solution which most closely fit the conservation targets we set, and the boundary length parameters were identified. The best solutions for each of the five target scenarios, were defined as priority areas that met all the conservation features in the chosen model iteration. The scenarios are similar yet are arranged differently, thus not every solution of the 100 per Marxan run can be considered as a 'good' option for use in planning (Figure 3).

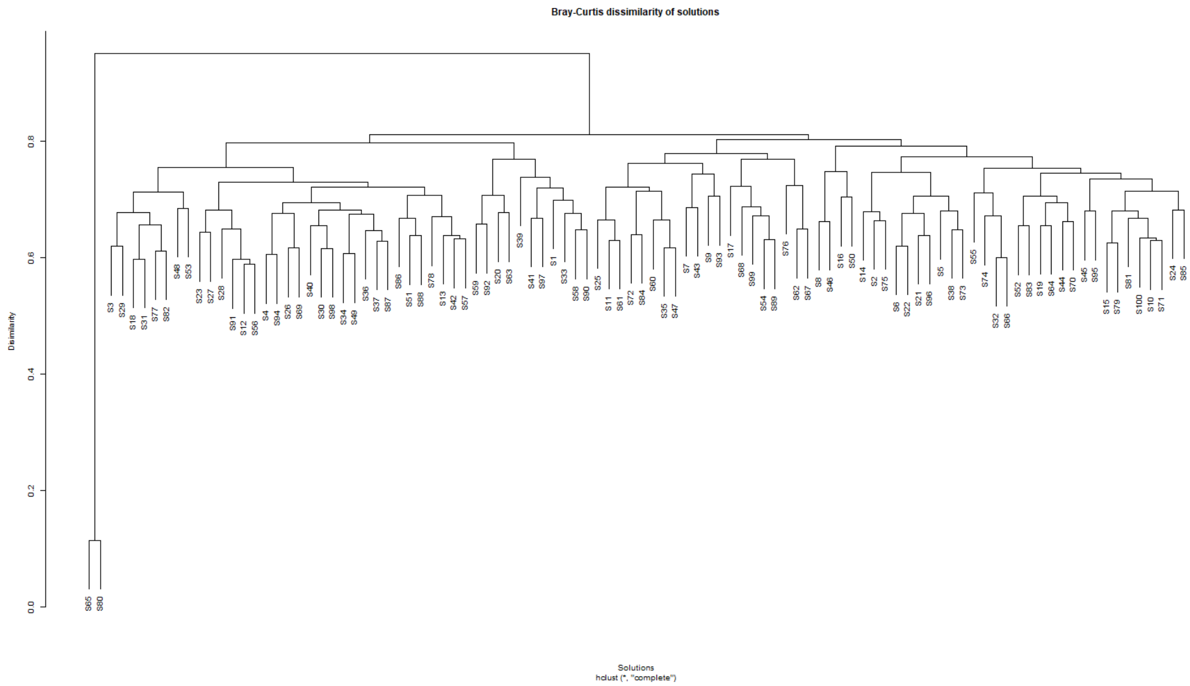


Figure 3. Dendogram of dissimilarity of 100 solutions for Marxan Solution d. Each Marxan algorithm application produces 100 solutions from 1,000,000 iterations of the algorithm. The 'best' solution is the one that best fits the conservation targets set by the user and the planning unit grouping parameters set by the Boundary Length Modifier and the Species Penalty Factors.

The resultant five best options were those areas where parcels contained our set targets or more of a conservation feature at the lowest cost estimate for conservation. Where areas met the targets, Marxan provided clumped sets of areas for best conservation options to consider (Klein et al., 2009). We then analyzed sets of Marxan results providing good estimates of where conservation opportunities remain within our study area (Figure 4).

From the planning units that Marxan identified in each scenario, we used a Boundary Length Modifier (BLM) to clump parcel options and reduce fragmentation. To reduce missed targets, we modified the BLM even further with a Species Penalty Factor (SPF). To calibrate the BLM, we plotted the values against the cost. For the SPF, we plotted the SPF against the missing conservation values. From these analyses, we selected values representative of the highest return on cost and targets met without losing attributes of connectivity.

Marxan solution selections were based on mean area per solution compared with the Boundary Length Modifier (BLM) for each solution run. The BLM modifies the solution run ranging from a values beginning at ‘0’ where reserve compactness is not considered in the solution and site selection is based solely on conservation feature input to values of up to 100,000 where the BLM overrides the conservation feature inputs to create a more expensive yet less fragmented reserve. For this analysis, we calibrated a wide range of BLMs from 0 – 1000 to find trade-off between compactness and conservation feature inputs. Following the Marxan analysis, we used Arc GIS Pro to further aggregate the parcels into clumped connective patches where parcels met at 30 meters or less. Where parcels did not meet at 30 meters or less, they were considered individual patches.

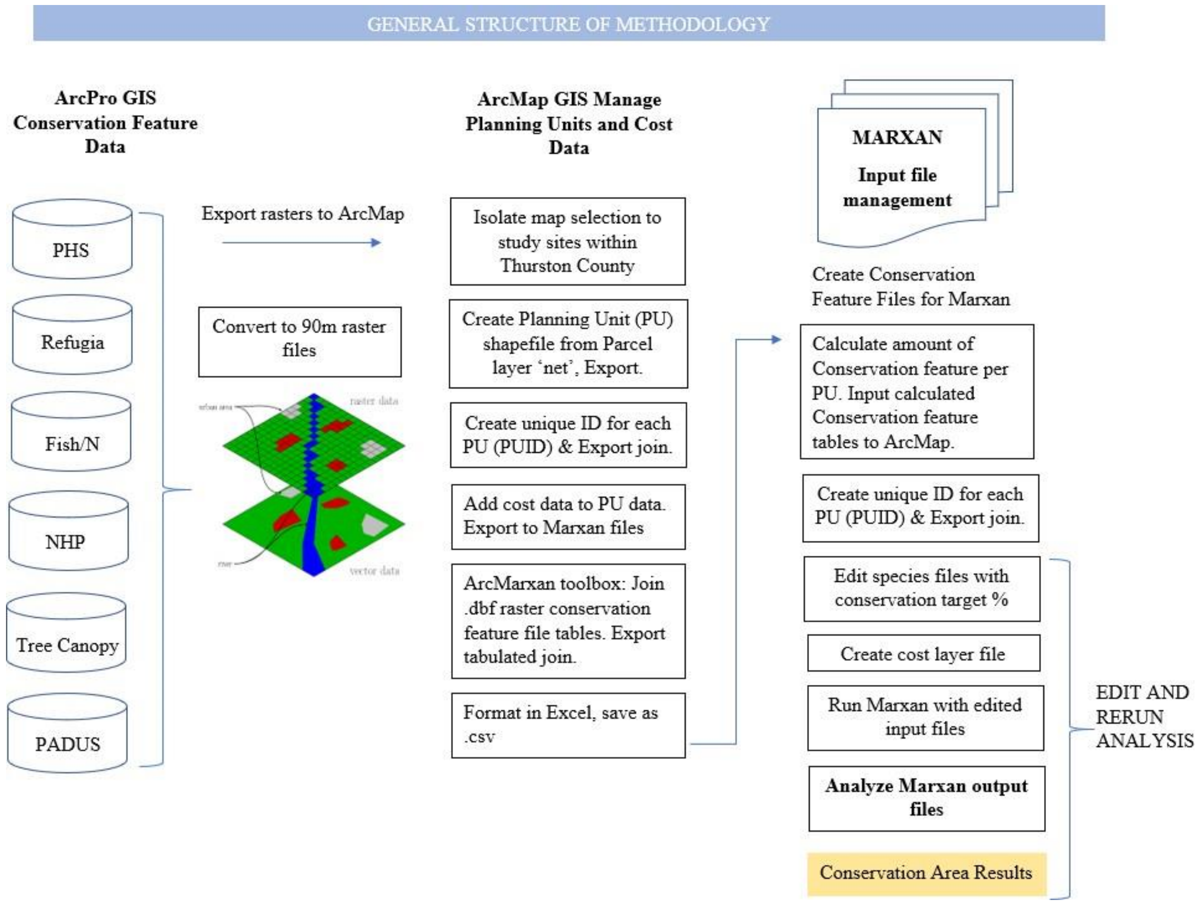


Figure 4. Data management workflow for the Marxan analyses. Conservation feature data are 90 m x 90 m rasters: PHS – Priority Habitat and Species (WDFW), Refugia – riparian refugia index (Krosby et al., 2018), Fish/N – water typing for fish bearing streams (DNR), NHP – Natural Heritage Program sensitive plant data (DNR), Tree Canopy – NLCD canopy cover >75% (NLCD, 2016), PADUS – Protected Area Database US (PADUS, CBI, Version 2, 2016).

Results

In the Marxan solution runs, conservation targets were set to at 17%, 30% and combinations of both with and without existing protected areas locked in. As expected, the uniform 30% conservation target produced a reserve network of approximately twice the amount of total land area than targets set at 17%. The 30% conservation targets resulted in 18.8% of total land area within the reserve network, exceeding the Aichi global biodiversity target of 17% total protected land area. While the Aichi biodiversity targets are intended for larger areas, such as whole countries, looking at subsections and watershed representation with global measurements can inform planning options for maximizing protected areas at the local level (Diaz et al., 2020).

a) Targets set at 17%: This solution is included as an example of a low target percentage solution. The outcome shows high fragmentation among selected parcels. However, the total protected area within the solution remains above 10%. This scenario would be helpful for a conservation plan where there is a need for individual parcels to be identified as somewhat important for inclusion in a conservation network, or for enhancing urban green spaces. The percent of already existing GAP 1 and 2 protected areas within this solution was 19.1%.

b) Targets set at 30%: For this higher percentage solution, the conservation network nearly doubled in total area when the conservation targets were moved from the previous scenario of 17%, to a uniform 30%. The 30% target is generally accepted as a minimum percentage for maintaining the baseline biodiversity targets resulting in 17% area covered by the solution. Consequently, setting our conservation targets to 30% resulted in 18.8% total area within this solution. This scenario may be important for a conservation plan in which the conservation features are considered as a priority and without bias from locking in existing conservation areas as in solutions d and e. Solution b also had the highest calibrated BLM and the largest average patch size, making it a good solution for planning where connectivity and fragmentation reduction are priorities. Percent of already existing GAP 1 and 2 protected areas within this solution was 20.5%.

c) <u>All targets set to 17%, except refugia set to 30%</u>: In this solution, we set the conservation targets to 17% except for the riparian refugia data which was set to 30%. Solution c could be useful for conservation plan with less resources to conserve large parcels or highly connected areas, but where riparian refugia remains a priority in the planning concept. Increasing the riparian refugia target to 30% as opposed to leaving the targets at 17% did not increase the average patch size in the best solutions. At 11390 m^2, the average patch size for solution c was the same as the average patch size for solution a. The percent of already existing GAP 1 and 2 protected areas within this solution was 21.7%.

d) <u>All targets set to 17%, refugia 30%, GAP 1 and 2 protected areas- locked into the solution</u>: We applied the medium level conservation targets from solution c to solution d but locked in GAP 1 and 2 protected areas. Of all our final solutions, scenario d contains the least fragmented solution with the highest average patch size and the most area surrounding existing protected areas for buffers. By locking in the existing protected areas to the solution, the outcome produced a highly connective network where existing protected areas and riparian refugia are prioritized. Percent of already existing GAP 1 and 2 protected areas within this solution 99.4%.

e) <u>All targets set to 17%, refugia 30%, GAP 1 and 2 protected areas- initially in the solution</u>: Including the existing protected areas of GAP 1 and 2 parcels initially included in the selection but without persistence in the final solution, increased overall fragmentation yet produced a solution containing three hectares more riparian refugia. The percent of already existing gap status 1 and 2 protected areas within this solution was 16.5%.

We set conservation targets which resulted in maps with parcels of possible options for future conservation and restoration. Based on minimum recommendations of conservation target amounts, we set Marxan to analyze our conservation targets to represent 17% - 30% of each target in various combinations within our study area to allow for multiple output solutions. Increasing the riparian refugia target to 30% did not increase the solution area percent in solutions c, d, and e. The five-conservation area solutions resulted in percentage of total land cover for each reserve at: a) 10.6%, b) 18.8%, c) 10.6%, d) 13.1% and e) 11.3% (**Table 1**).

Table 1. Results of five Marxan solution options for additional protected area networks.

Solution name	**Target Description**	**# Planning units**	**Solution Km^2**	**Solution area % of AOI**
a	All conservation targets set to 17%	4538	112.8	10.6%
b	All conservation targets set to 30%	4882	200.3	18.8%
c	All 17%, except Refugia set to 30%	4024	112.7	10.6%
d	All 17%, Refugia 30% (GAP 1 and 2 PAs locked in)	3390	139.7	13.1%
e	All 17%, Refugia 30% (GAP 1 and 2 PAs initially in)	4310	120.6	11.3%

Compactness and average patch size

The compactness of parcel clumping was obtained by calibrating the Boundary Length Modifier (BLM) for each solution. In a Marxan analysis, a higher BLM score takes precedence over the importance of conservation feature target inputs, therefore the BLM was calibrated to the lowest possible score to prioritize compactness of the reserve solution without sacrificing minimal cost. Generally, a more clumped or compact reserve design is increasingly expensive as aggregation occurs (Ardron et al., 2010). The effectiveness of each BLM was addressed by aggregating the parcels to a proximity of 30 meters or less and comparing the average patch sizes among each solution relative to the BLM.

Average patch sizes were largest in solution b (209,777 m^2) in which targets were set to 30% and solution d (171,782 m^2) in which PADUS protected areas 1 and 2 were locked into the algorithm solution with targets set at 17% except for refugia set at 30%. In contrast, solution e where PADUS protected areas were included as a suggested basis for protected areas but not necessarily a part of the final best solution, average patch sizes were smaller (100,856 m^2), yet contained three hectares more riparian refugia than solution d (Figure 5).

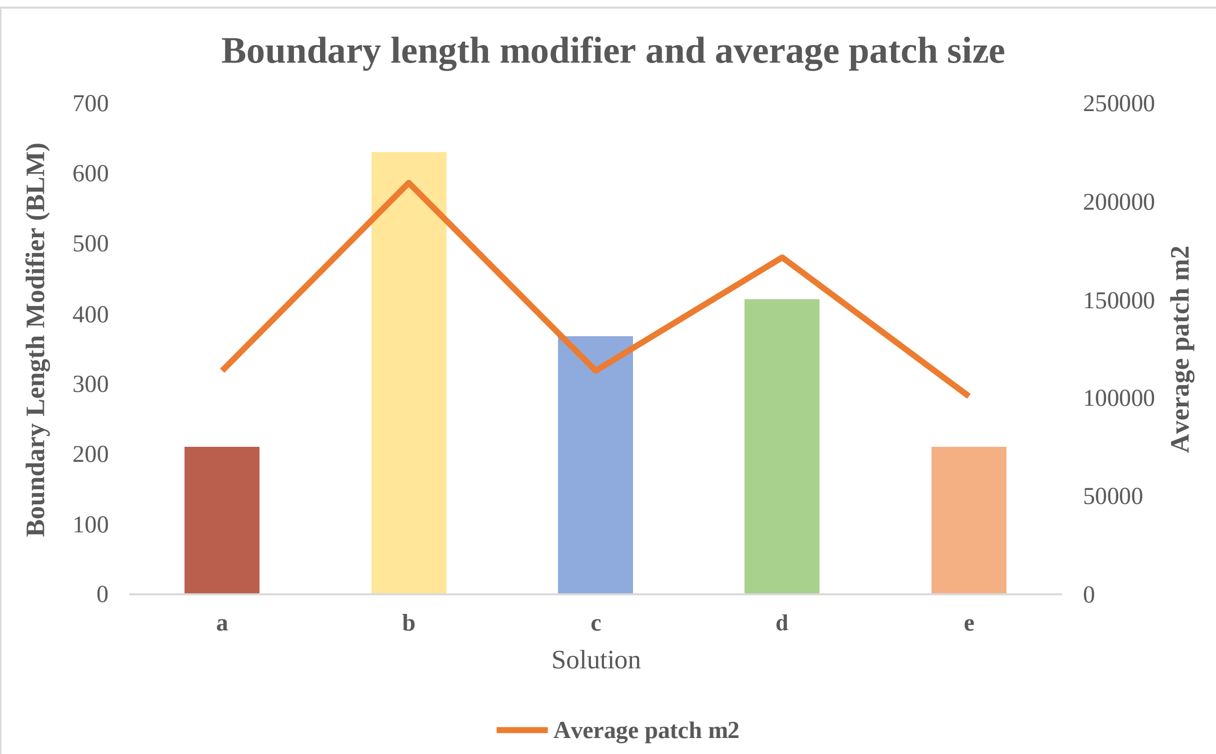
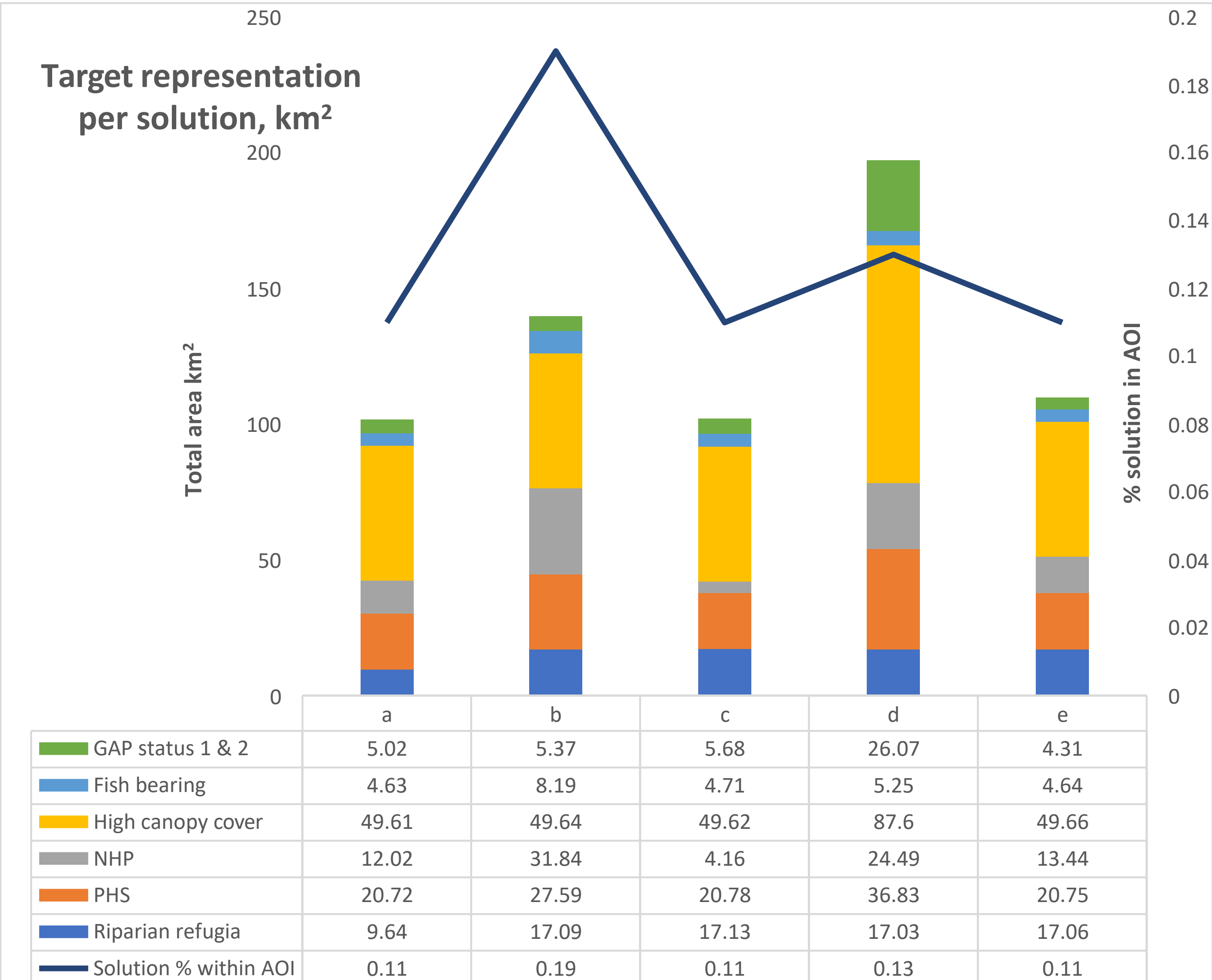


Figure 5. The average patch size in m^2 for each solution: a) 113,910 m^2, b) 209,777 m^2, c) 113,910 m^2, d) 171782 m^2, e) 100,856 m^2 and calibrated Boundary Length Modifier (BLM): a) 210.5, b) 631, c) 368, d) 421, e) 210.5 show that solution b, with a 30% conservation target scenario, contains the largest average patch size and the highest

BLM. Patch size will be more suitable for connectivity but also more costly due to the higher BLM. Solution d, with 17% targets except for refugia and with existing protected areas locked in, has the second highest average of patch sizes but a lower BLM. Solution **d** has connective patches, but at less cost due to the lower BLM calibration. Because the BLM is calibrated in sync with the Species Penalty Factor (SPF), each scenario achieves the respective conservation targets set for the algorithm.

Conservation feature representation per solution

Among the five selected solutions, conservation feature representation was highest overall within solution d. Solution d, where existing protected areas are locked into the solution, contains the highest proportion of conservation feature (targets) area per total solution area. However, canopy cover had the highest individual representation in each solution. Existing protected areas had the highest representation in d among the solutions because in that scenario, the PADUS gap status 1 and 2 protected areas were locked into the final solution. Solutions b and d contained the most land cover representing Natural Heritage Program sensitive plant data because b had the highest targets set and d contained the PADUS parcels where much of the NHP sites reside. Solution d provides more total area already protected and gives good options for new conservation parcels which can act as buffers around existing protected areas and connectors to other high-quality habitat areas. Solutions c and e had very slight differences except for Natural Heritage Program sensitive plant areas which had a higher representation in solution e. The solution amount within the AOI shows how much land area total is represented for each solution in the study area. Solutions b, and d have the highest total area of the five solutions, while solutions a, c, and e have almost equal amounts of land cover per solution at ~ 11% (Figure 6).



	a	b	c	d	e
GAP status 1 & 2	5.02	5.37	5.68	26.07	4.31
Fish bearing	4.63	8.19	4.71	5.25	4.64
High canopy cover	49.61	49.64	49.62	87.6	49.66
NHP	12.02	31.84	4.16	24.49	13.44
PHS	20.72	27.59	20.78	36.83	20.75
Riparian refugia	9.64	17.09	17.13	17.03	17.06
Solution % within AOI	0.11	0.19	0.11	0.13	0.11

Figure 6. Conservation feature representation per solution in square kilometers on the left Y axis and percent total solution area on the right Y axis within the study area. The solution amount within AOI shows how much land area total is represented for each solution in the study area. Solutions b, and d have the highest total area of the five solutions, while solutions a, c, and e have equal amounts of land cover per solution at 11%. Riparian refugia – riparian climate-refugia index (Krosby et al., 2018), NHP – Natural Heritage Program rare, endangered and threatened plant data (WA DNR), Fish bearing – water typing for fish passage (WA DNR), PHS – Priority Habitat and Species (WDFW), High canopy – NLCD canopy cover >75% (NLCD, 2016), GAP status 1 and 2 – Protected Area Database (PADUS, CBI, Version 2, 2016).

Land management and ownership

We calculated the percent of land ownership and management contained within each solution (Figure 7). With an average of 6%, total solution area within the Urban Growth Boundary was the lowest among the five Marxan solutions while average total solution area was the highest within state park boundaries. Areas within the Protected Areas Database (PADUS 1, 2, 3, 4) also contained high average area totals at 35% and 34% for PADUS 1 / 2 and for PADUS 3 / 4, respectively. A data layer containing all parks (County, state and federal) within our AOI showed a 28% total land area average. Lands of the sovereign Nisqually Indian Tribe and The Confederated Tribes of the Chehalis Reservation averaged at 19%. Private land ownership averaged 34%. Finally, the average land area of each solution averaged 13% within our AOI. Solution b where all conservation targets were set to 30% inclusion within the analysis contained the highest percent of total land area at 19% (Table 2).

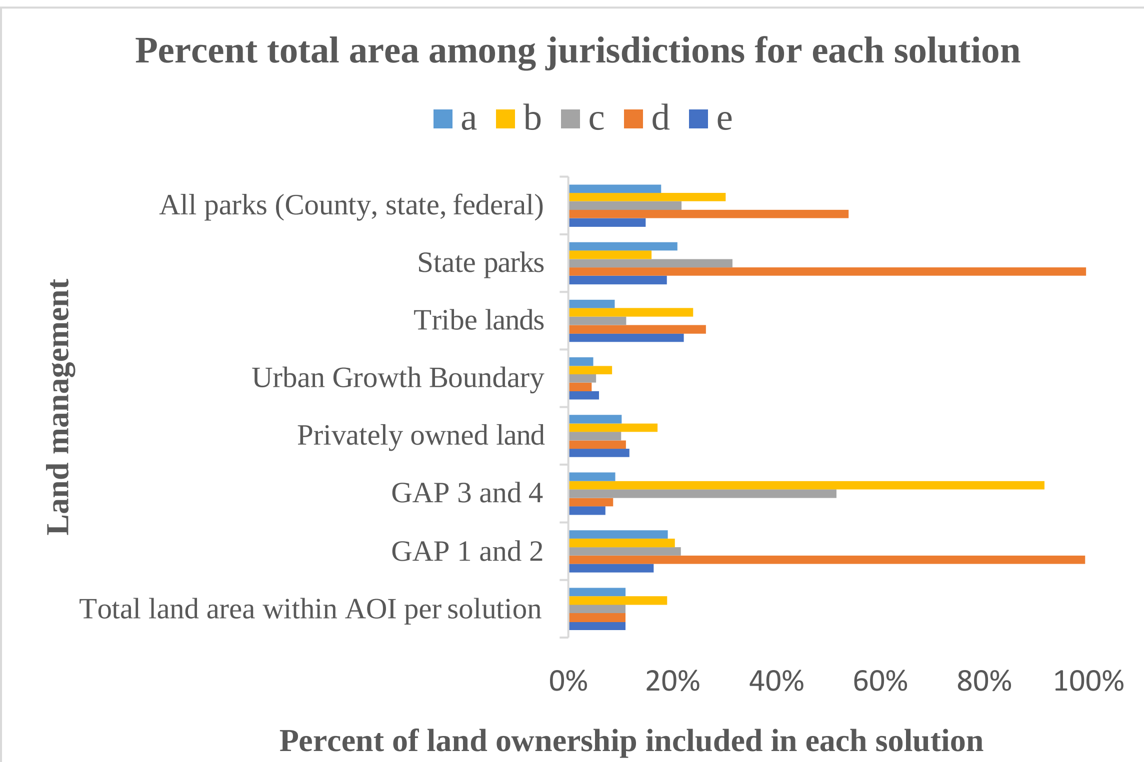


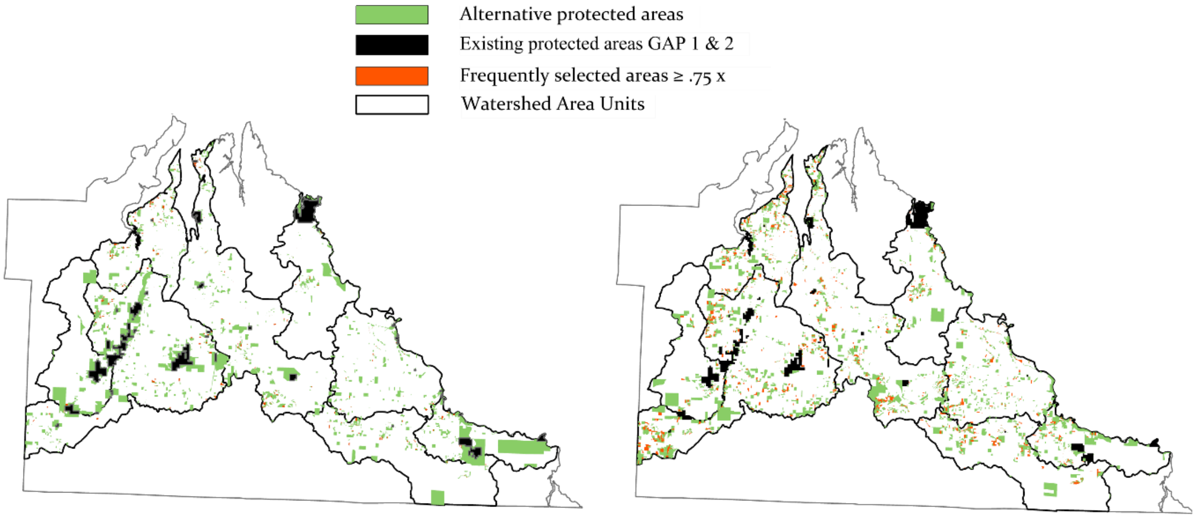
Figure 7. Percent total area within each Marxan conservation solution.

Table 2. Percent land cover of ownership and management among five (a, b, c, d, and e) Marxan spatial conservation solutions within Thurston County, Washington.

Solution	% Total land and within AOI	% Protected areas GAP 1 and 2	% Federal lands GAP 3 and 4	Private lands	Urban Growth Boundary	Tribe lands	State parks	All parks (County, state, federal)
a	11	19.1	9.1	10.3	4.8	8.9	21	17.8
b	19	20.5	91.6	17.2	8.4	24	16	30.3
c	11	21.7	51.6	10.1	5.4	11.2	31.60	21.8
d	11	99.4	8.6	11.1	4.5	26.5	99.7	53.9
e	11	16.5	7.2	11.7	5.9	22.2	18.9	14.9
Average	**13%**	**35%**	**34%**	**12%**	**6%**	**19%**	**37%**	**28%**

Reserve network results

Reserve network results for five Marxan solutions show solutions of conservation options. Solution a at 17% conservation targets to have the least amount of total area in its protected network, solution b at 30% conservation targets contains ~ 50% more total area in its network, solution c with conservation targets at 17% except for riparian refugia which was set to 30%, provides a reserve network that is more tightly grouped near key riparian refugia areas, solution d contains the same conservation targets as c, yet d targets were set to have the existing GAP status 1 and 2 parcels “locked in” to the solution, and solution e with the same conservation targets as solutions c and d, was set to have the GAP status 1 and 2 parcels initially in the solution, but then moved out if the algorithm found better options than those GAP status parcels. Solution e provides a more distributed network than the more clumped results in solution d, showing that there are areas of high quality habitat not currently included in the existing protected area networks of GAP status 1 and 2 areas in our study area (Figure 8).



d) Existing protected areas 'locked in'   e) Existing protected areas initially in

Figure 8. Alternative protected area from Marxan runs shown next to existing protected areas, other frequently selected parcels and riparian refugia index data. Solution **d** with locking in existing protected areas and targets at 17% except for riparian refugia at 30% (13.1% of total study area) and **e** with existing protected areas initially held in the solution with targets at 17% except for riparian refugia at 30% (11.3% of total study area). Frequently selected parcels are those that were selected more than 75x by the algorithm but were not included in the final solution. The frequently selected parcels can be used as possible options for good additions to the protected area network. Including existing protected areas with GAP status of 1 and 2 in the reserve alternative shows good options for where protected area networks could be extended in future conservation efforts.

Discussion

The five solutions here are individual reserve networks designed to maximize connectivity at minimum cost for future conservation scenarios. To maintain a low edge to area ratio resulting in clumped reserves with connective qualities in our solutions, we calibrated a BLM for each set of targets. However, it may be unrealistic to assign large reserve areas across a county with even moderately dense neighborhoods, road networks, and urban growth boundaries. For this reason, we calibrated a low BLM that resulted ultimately in less expensive but more fragmented reserves. This spatial application may be ideal for a multi-use area such as Thurston County where additional protected areas at local and jurisdictional boundaries area desired.

Although important for landscape resilience and species movement, connected protected area networks are not a sure solution to protect the landscape from threats such as climate change and land clearing of adjacent parcels (Caro et al., 2012). This landscape analysis does not claim to provide absolute answers to improving landscape resiliency, yet it does provide options for improving connectivity and habitat protection, which are known to improve resiliency when protected adequately. Our conservation solutions provide estimated areas for increasing land cover of existing protected area networks, linking protected areas for better connectivity and improving protection of riparian refugia in the South Puget Sound. Although, the solutions are estimates, the selection and vetting of the data used was vigorous and based in carefully collected habitat data.

There are many factors supportive of natural area effectiveness in addition to protected area connectivity that are beyond the scope of this landscape analysis. Species range comparison where average patch sizes are set in Marxan to a minimum patch size per species could benefit more precise understanding of a reserve network planned for specific species. Wetland areas and aquifer recharging zones would be valuable data to incorporate to future network designs (Groves & Game, 2016). However, reducing habitat disturbance and prioritizing improved landscape connectivity are more important for species protection than creating new conservation areas without regard to their quality (Fahrig, 2001).

In conservation planning, one approach to make sure that species ranges are supported is to use the average BLM to compare among solutions, which parcel aggregations could potentially support specific species' habitat needs. To understand which species might benefit from riparian refugia connectivity improvements, a planner can compare the required patch size supportive of viable populations to the average patch size in each solution. Estimations of species range vary from small, less than a few feet for many plants, insects, and bacteria, to large, at times hundreds of miles for larger mammals. This study does not attempt to match patch area to specific species, but rather provides the average patch size data for reference. Endangered, threatened, and sensitive species although already within protected areas due to state and federal regulations, could benefit from buffer conservation areas with connectivity to other protected areas and areas of high-quality habitat.

While typically based in good intentions, the conservation of land or water does not always mean that biodiversity is protected or that species meant to benefit from conservation can persist on the landscape. Because habitat fragmentation often results in weak species persistence, conservation targets must incorporate accurate assessments of how this fragmentation affects species ability to maintain their home ranges. Consequently, less fragmented habitats which are further away from urban edges often are more supportive of species diversity and persistence. Riparian areas and the adjacent landscapes they effect contain naturally occurring climate refugia and species movement corridors while supplying important resources for plants, animals, and humans. However, these attributes could be further protected by expanding protected areas around riparian corridors with buffer zones similar in concept to riparian buffers common in forestry planning but with the purpose of supporting long term landscape resiliency and connectivity. Protecting the landscape piece by piece is not necessarily wrong, and overall, this approach will provide some good habitat for some species, but to effectively manage for ecosystem resilience, a more strategic, connective approach is necessary.

From our results, solution d with conservation targets set at 30% shows that the targets are well incorporated into the reserve design and increases land cover available for planning purposes by ~50%. However, the solutions provided in this study facilitate options ranging from low, medium to high conservation target inputs that can be applied to specific conservation goals site by site. A scenario for future planning in the Puget Sound could use the case study of our area of interest and apply these methods to other regions within Pacific Northwest. For example, conservation targets set to 30% and with existing protected areas 'locked in' to act as seeds for the algorithm to build on, produce solutions that may be more protective of riparian refugia and other high quality or less common habitats, than lower target scenarios of 17%.

Based on this conservation target analysis, riparian conservation in our AOI may provide exponential returns on surrounding habitat quality and species persistence when fragmented, high quality parcels are connected by future land acquisition or restoration. Expanding riparian corridor protection could result from protecting the parcels we identify here as connective candidates for future acquisition by government or municipal offices and private landholder restoration. For example, planners could focus on sections of public land where acquisition for conservation is more likely and apply our 30% conservation targets to those areas (solution b), while the 17% targets with 30% riparian refugia (solutions, c, d, and e) could be applied to urban riparian areas or areas where there are more obstacles to conservation implementation.

The performance of existing protected areas in our WAUs was tested by our method of running the Marxan algorithm in solutions d and e with the same conservation targets set (17% except for riparian refugia set to 30%) but with solution d having GAP status 1 and 2 protected areas "locked in" to the final solutions and with solution e having those same protected area parcels initially in the solution as a seed for the network but then replaced if the algorithm found better connective or higher quality parcels for the solution. Solution e had a lower amount of GAP status 1 and 2 parcels selected than those that were locked into solution d, showing that high quality habitat exists outside of the existing protected areas as well as within. Thus, focusing conservation efforts on parcels in solution e where GAP status 1 and 2 parcels were not locked in but were prioritized as part of the solution initially, shows where to expand new protected areas near existing protected areas because this solution 'choses' land that may be more connective and less expensive, while also meeting the conservation targets we set for the Marxan algorithm.

A side by side comparison of The Black River and The Deschutes River with solution e parcels overlaid along with current protected areas (GAP status 1 and 2) and other parks (state, county, city) show distinct differences of opportunity for potential new conservation areas. Solution e considered existing protected areas as a part of the initial solution, but then replaced them if there were other parcels that better fit the conservation targets of 17% NHP, PHS, fish bearing, high canopy cover and 30% riparian refugia. Yet along the Black River there are more existing protected areas and other parks than along the Deschutes River, but solution e selected many parcels located outside of the already protected areas. Along the Deschutes River in the Lower Deschutes WAU, there are large amounts of potential new conservation parcels in areas of high habitat quality that are not already under protection status. A comparison of the two areas, shows that there is evidence for considering areas outside of existing protected areas as important for conservation and that additional protection of these lands would satisfy many of the conservation targets close to riparian refugia (Figure 9).

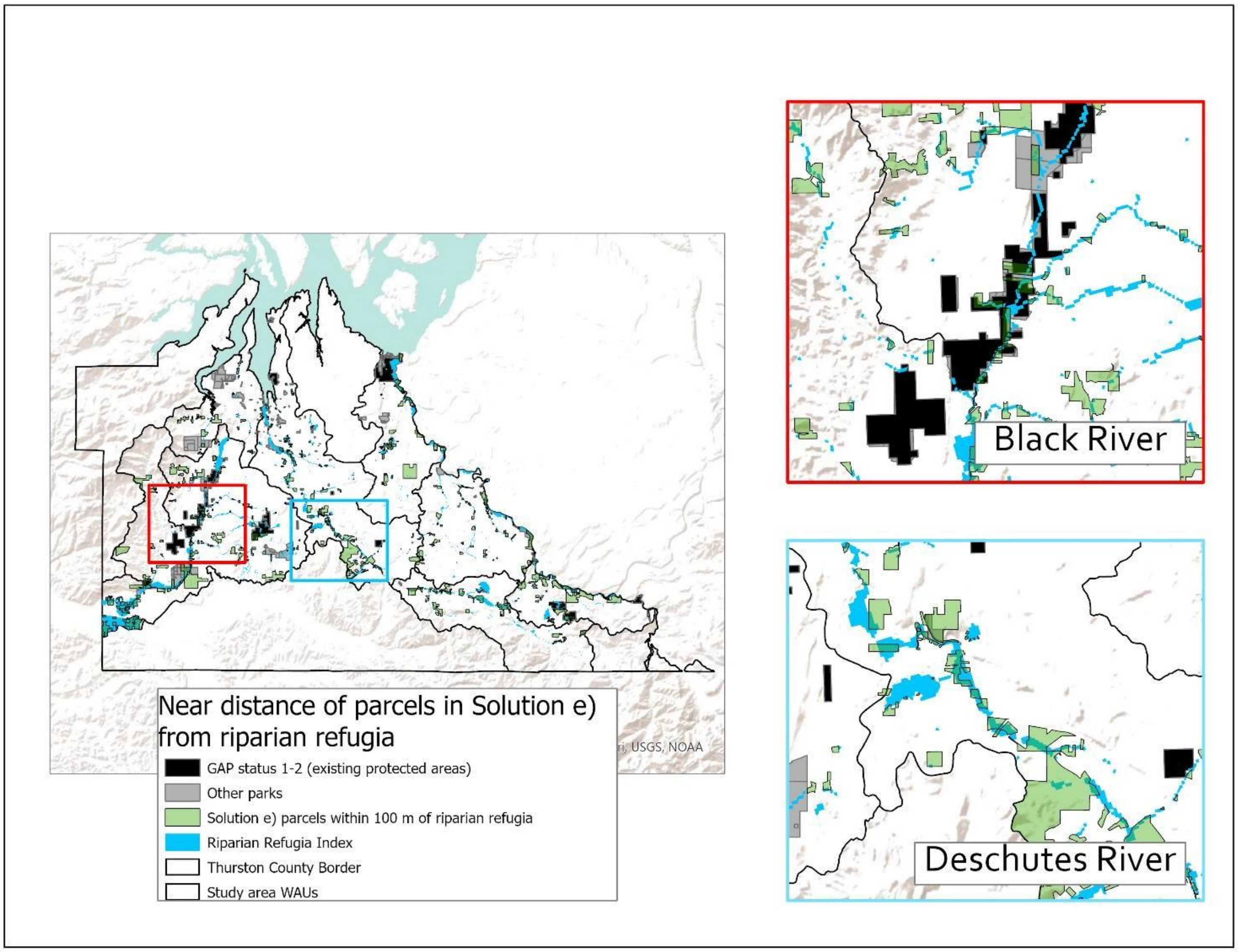


Figure 9. Comparison of solution e parcels near riparian refugia along the Black River and Deschutes River, Washington. The inset maps show parcels in Solution e) within < 100 m of riparian refugia and existing protected areas and parks. A comparison of the Black River and Deschutes River within our AOI shows a higher proportion of unprotected area surrounding riparian refugia and more potential new protected areas along the Deschutes River than along the Black River. The Black River (top inset) contains more existing protected areas and parks within its watershed than does the Deschutes (bottom inset). Between the two watersheds, there is more opportunity for implementing new riparian refugia conservation areas within the Lower Deschutes watershed.

Frequently selected parcels included in our solution maps do not represent planning units in the 'best' solutions because they do not quite reach the selected conservation targets or are not as efficient for the reserve connectivity or cost. Rather, frequently selected parcels, those that occur greater than 75 times within the solution, can be viewed as potential connective parcels where planning may require decision making among parcel areas that are not a part of the solution but where further connectivity within an area is desired. As defined by our conservation targets, proportionally more of the uncommon habitats are represented and protected than common habitats. Where the higher conservation targets might not be achievable across the whole study area, especially where private landowners may have plans for their parcels other than conservation, areas of high conservation value can be augmented by buffering protected areas. For this reason, our solution d where protected areas are ‘locked in’ to the protected area network may be the most useful for city, state, and federal land planners interested in ensuring landscape resilience by buffering existing protected areas.

Cost data

Regional strategic cadastral planning includes both private and government land ownership. Within a relatively small geographic study area, differences among parcels vary greatly, while cost estimates for both private and government owned lands are not consistent. Because of the inherent difficulties of assigning uniform value to private and government parcels, we used parcel area as a surrogate for more specific cost estimates appliable to private land ownership. In a survey of Marxan users, planning unit area was the most used cost factor (Ban, 2006). However, for improved accuracy of estimates, future analysis could include incorporating threats to ecological integrity into cost data such as proximities to urban areas and roads. Also, cost data measurements could be improved by applying actual dollar amounts of parcels sales. (Ardron et al., 2010).

Although using area as a cost surrogate is a relatively common practice with Marxan users, the measurement assumes that larger parcel size equates to higher cost for management and conservation acquisition (Ardron et al., 2010). More detailed and calculated cost estimate data such as the PLACES lab (Nolte et al., 2019) or county-specific costs by land cover (Withey et al., 2012) would be useful to apply to analysis where private land holdings are examined for their conservation contributions.

Conservation targets

Establishing misleading or inadequate biodiversity targets brings well-meaning conservation planning into dangerous territory of losing biodiversity and persistence in the long term. Conservation targets need scientific backing and purpose including endemic and rare species preservation, life-history projections, vegetation heterogeneity and threat vulnerability considerations (Carwardine et al., 2009; Pressey et al., 2003). Higher and more comprehensive conservation targets are often viewed as overly ambitious while undeveloped land surrounding protected areas that may contribute to the protective qualities of protected areas are not included in assessments of protected area effectiveness (Pressey et al., 2003).

The “improved” global biodiversity targets established in 2010 with predictions for achievement by 2020 have unfortunately, failed to succeed in protecting biodiversity at species sustainable levels (CBI, 2010; Lawler et al., 2020). Instead of taking a global approach, conservation and restoration initiatives should be implemented by those associated with the landscape and local jurisdictions. A workable approach to shift from a global goal of 17% of land as protected areas to readdress the issue of conservation at the local or watershed level may improve natural area prioritization methods. If local government and municipalities take initiative to improve on biodiversity by implementing protected area land connectivity, high returns on percentage of protected areas can then be improved on a global scale. Essentially, addressing the issue of biodiversity targets with local and feasible objectives, rather than a ‘top down’, ‘what if’ scenarios can result in more robust and immediate land protection.

To identify areas for future conservation to improve climate corridor refugia, we ran a selection option where data for Riparian Climate Corridor ranking was set above other conservation feature targets. This solution combines recommendations for including refugia targets at 30% and other conservation features at 17% for minimum biodiversity conservation. Much of our study area contains urban and otherwise altered or 'unnatural' landscapes, a target percentage of 30% may not always be a best option for existing biodiversity and connected protected areas. Setting targets for other conservation features lower while keeping riparian refugia targets higher, may reflect a more feasible solution to conservation and restoration within and around urban edges where private land holdings comprise a high percentage of high-quality habitat.

Urban Growth Boundary and habitat connectivity

This analysis does not avoid areas that are typically under-represented in conservation such as land near urban growth boundaries and scenic urban areas. An integrated approach adds elements of responsibility, stewardship, and participation to where we live. Urban areas often contain opportunities for conservation and restoration. However, urban areas are often left out of conservation planning due to their perceived lack of habitat. On the contrary, the use of habitat quality data and parcel modeling within urban areas can show where remaining options for conservation exist. Additionally, urban areas and highways are often choke points where many animals cannot pass from one refuge to the next.

In the early stages of creating Urban Growth Boundaries (UGB), the intention was to limit the impact of urbanization on potential habitat. However, UGBs can instead contribute to increased fragmentation on the landscape. In 2002, the UGB implemented in Thurston County was created to limit urban sprawl. A study aimed at assessing the effectiveness of the UGB found that instead of reducing urban sprawl, the opposite occurred. From 2002-2007, urban and agricultural sprawl increased in Thurston County at a rate of 13%. The authors credit this increase in part to landowners feeling pressured by the new UGB and choosing to develop their land before it could be designated as non-urban (Hepenstall-Cymerman et al., 2013). In Thurston County, open space corridors are beneficial to wildlife and connect protected areas and high-quality habitat to urban areas. The county has a legal responsibility to identify open spaces which provide important habitat for animals; however, these have no formal designation at this time (Thurston County Resource Stewardship Department, 2015).

The UGB in our study area holds some parcels of high-quality habitat that could be important for buffering urban green spaces and improving riparian habitat for animal movement through the landscape. Incorporating habitat conservation into urban areas such as riparian corridor connective zones remains one of the final options for connectivity between urban and rural landscapes. Because stopping overall habitat losses is more important in the long run than creating new conservation areas, the quality of conservation areas and how they contribute to species persistence may be addressed by initiatives such as prioritizing urban habitat corridors into conservation planning (Fahrig, 2001).

Under pressure from rapid climate change, the incorporation of existing conservation frameworks such as river systems into adaptive management for riparian refugia protection and reserve networks may be a more workable and savvy approach to natural area effectiveness than a continuation of the ad hoc, inadequate planning of past conservation management strategies. Approaching riparian area conservation with flexibility and multiple options for conservation outcomes will improve habitat protection, species persistence and ecosystem resilience. At a minimum conservation strategy for the future should include both prioritizing the ongoing protection of existing protected areas with buffers, increasing their extents, and implementing new, connective reserves to shield riparian refugia from further fragmentation.

Conclusion

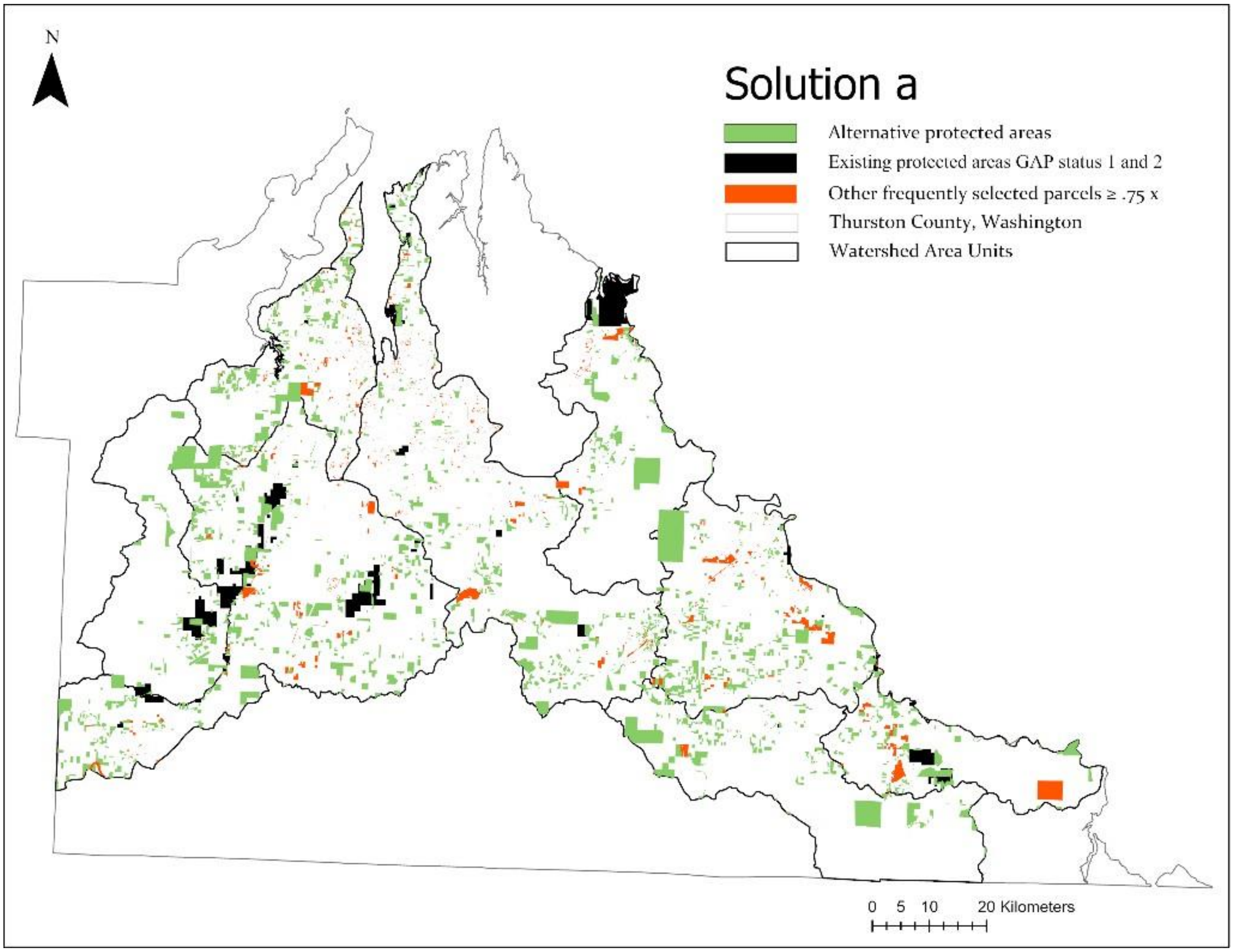
Our results show options to expand conservation lands containing high quality habitat and riparian refugia. In Thurston County, the performance of existing protected areas for buffering riparian refugia needs improvement. In this study area, only 7% (5 km^2 of all solution parcels within 100 meters of riparian refugia are currently protected (70 km^2 total area). The landscape burden of response to disturbance can be further mitigated by prioritizing more high-quality habitat for conservation. There remains great opportunity for creating new riparian conservation networks along the Deschutes River and Nisqually Rivers and buffering existing protected areas along the Black River to include riparian refugia.

We provide a way to use existing habitat data that can be applied to specific conservation needs at the parcel level on a case by case basis. Compared to many wilderness plans, our conservation targets are conservative because while containing much high-quality habitat, Thurston County is not a wilderness preserve. The case we make here, of considering all lands for conservation planning, includes parcels within, around and far outside of urban areas, as well as more remote parcels classically identifiable as wilderness. Therefore, starting with lower, more conservative conservation targets and later adding higher percentages for conservation goals where possible, will greatly contribute to landscape planning that is actionable. In turn, the benefits of conservation implementation will be transferred directly to those plants and animals which remain underrepresented on the margins of protected areas, and indirectly to local feedback loops of improved air and water quality.

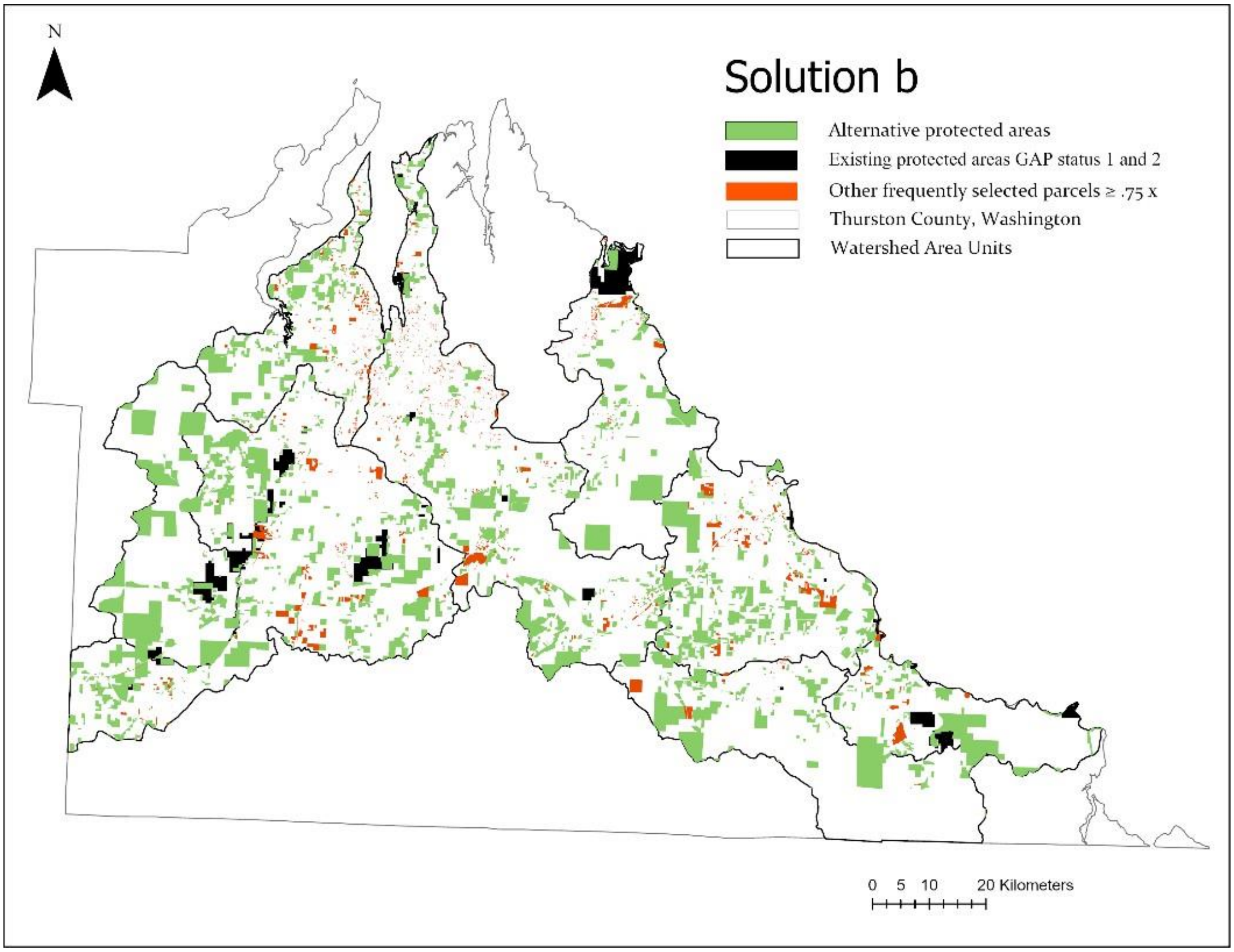
Connectivity combined with habitat quality and conservation targets can contribute to landscape resilience in the long term. Because much of the climate refugia in North America is not within protected areas, increasing parcel connectivity around riparian corridors may improve the persistence and function of riparian climate refugia, thereby sheltering these important habitats from extant threats such as adjacent land clearing and climate change (Carroll et al., 2017). Furthermore, buffering existing protected areas with newly protected, connective conservation parcels is a strategy that may be less costly than protecting new and separate reserve networks, especially when established networks already exist within river systems. A systematic approach to conservation planning along riparian areas with existing protected areas can improve on patchwork preservation of the past to reach future goals of connecting fragmented parcels. The time is now for reassessment of conservation targets at local scales and the incorporation of robust, multi-dimensional approaches to conservation strategy appropriate for multi-dimensional landscape management.

CHAPTER 4: APPENDICES

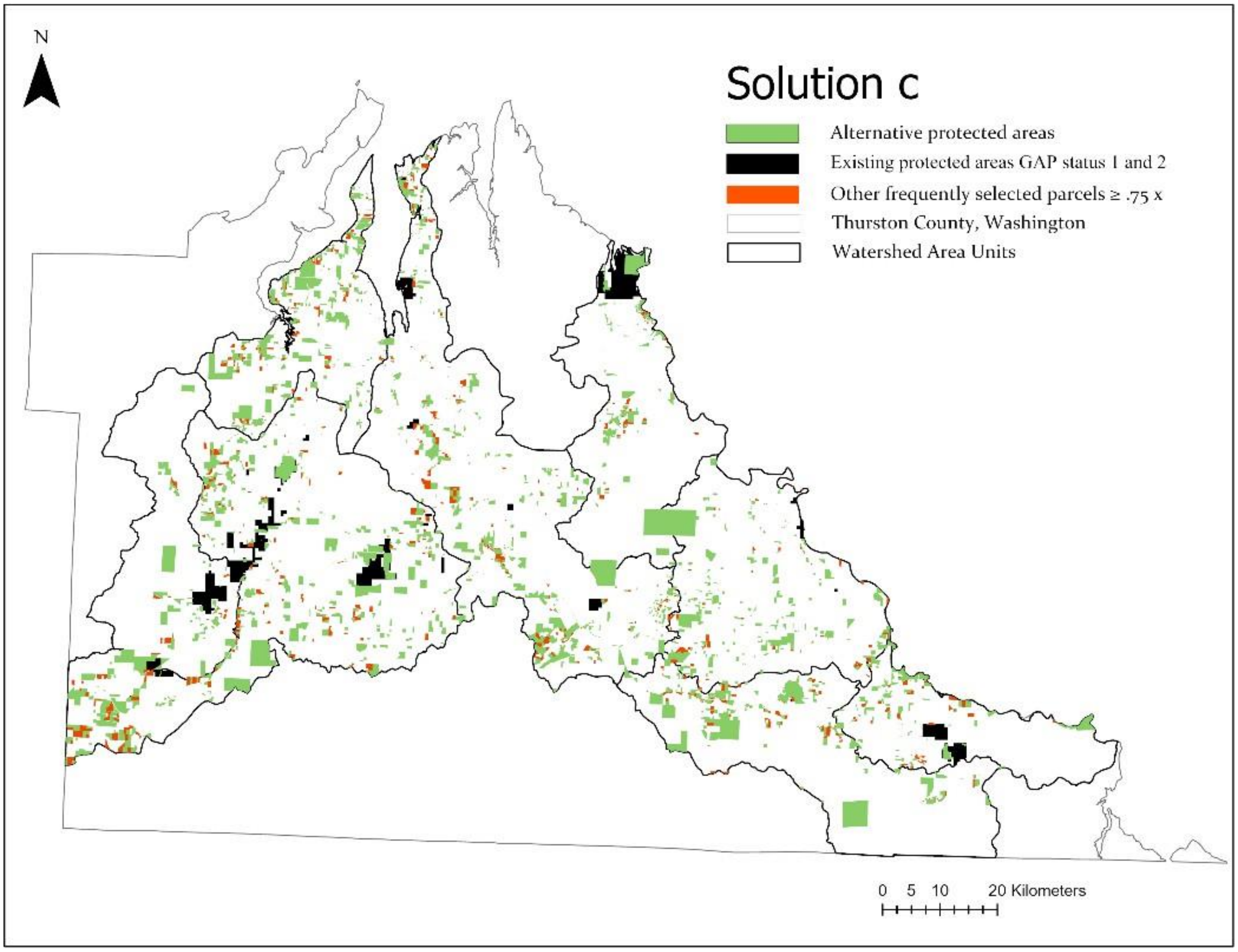
Marxan solutions



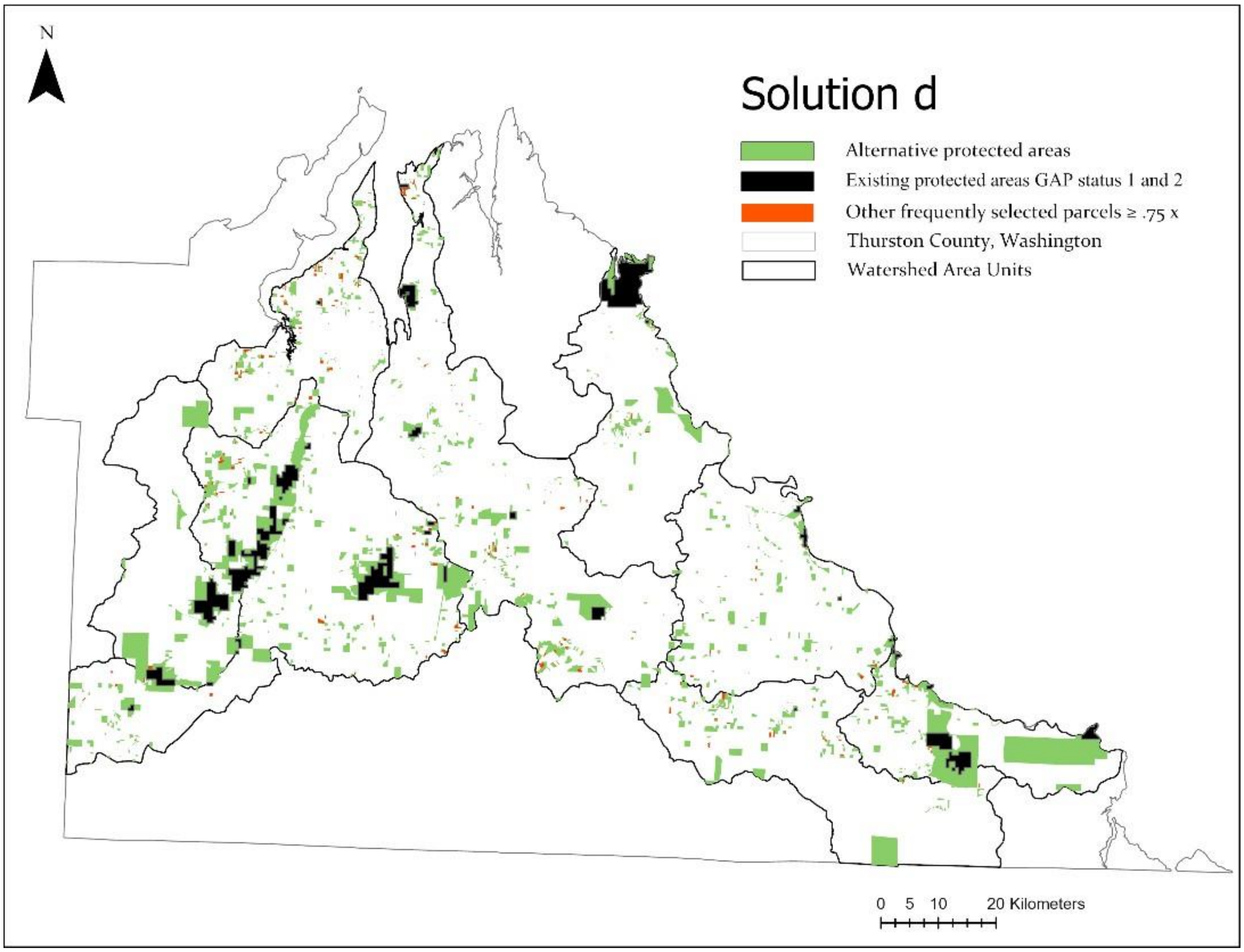
Solution a. Targets set at 17%: This solution is included as an example of a low target percentage solution. The outcome shows high fragmentation among selected parcels. However, the total protected area within the solution remains above 10%. This scenario would be helpful for a conservation plan where there is a need for individual parcels to be identified as somewhat important for inclusion in a conservation network, or for enhancing urban green spaces. The percent of already existing GAP 1 and 2 protected areas within this solution was 19.1%.



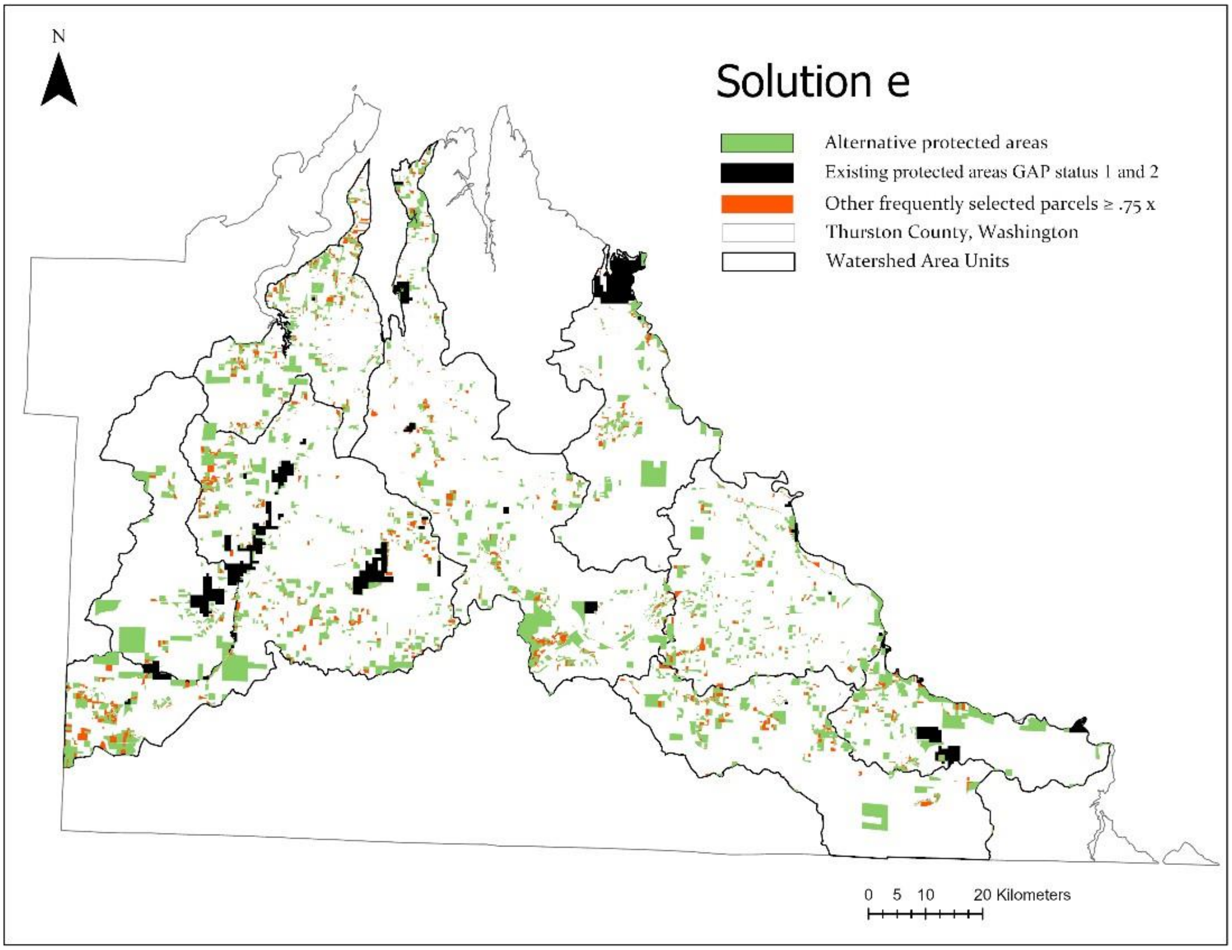
Solution b. <u>Targets set at 30%</u>: For this higher percentage solution, the conservation network nearly doubled in total area when the conservation targets were moved from the previous scenario of 17%, to a uniform 30%. The 30% target is generally accepted as a minimum percentage for maintaining the baseline biodiversity targets resulting in 17% area covered by the solution. Consequently, setting our conservation targets to 30% resulted in 18.8% total area within this solution. This scenario may be important for a conservation plan in which the conservation features are considered as a priority and without bias from locking in existing conservation areas as in solutions d and e. Solution b also had the highest calibrated BLM and the largest average patch size, making it a good solution for planning where connectivity and fragmentation reduction are priorities. Percent of already existing GAP 1 and 2 protected areas within this solution was 20.5%.



Solution c. All targets set to 17%, except refugia set to 30%: In this solution, we set the conservation targets to 17% except for the riparian refugia data which was set to 30%. Solution c could be useful for conservation plan with less resources to conserve large parcels or highly connected areas, but where riparian refugia remains a priority in the planning concept. Increasing the riparian refugia target to 30% as opposed to leaving the targets at 17% did not increase the average patch size in the best solutions. At 11390 m^2, the average patch size for solution c was the same as the average patch size for solution a. The percent of already existing GAP 1 and 2 protected areas within this solution was 21.7%.



Solution d. All targets set to 17%, refugia 30%, GAP 1 and 2 - locked into the solution: We applied the medium level conservation targets from solution c to solution d but locked in GAP 1 and 2 protected areas. Of all our final solutions, scenario d contains the least fragmented solution with the highest average patch size and the most area surrounding existing protected areas for buffers. By locking in the existing protected areas to the solution, the outcome produced a highly connective network where existing protected areas and riparian refugia are prioritized. Percent of already existing GAP 1 and 2 protected areas within this solution 99.4%.



Solution e. <u>All targets set to 17%, refugia 30%, GAP 1 and 2 - initially in the solution</u>: Including the existing protected areas of GAP 1 and 2 parcels initially included in the selection but without persistence in the final solution, increased overall fragmentation yet produced a solution containing three hectares more riparian refugia. The percent of already existing gap status 1 and 2 protected areas within this solution was 16.5%.

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